PHOTONICS WEST SHOW DAILY

Credit: Adam Resnick

PRISM Awards honor innovative companies

At last night's gala event, these 12 companies took home a coveted PRISM Award honoring the best in photonics innovation. This year's winners included the first back-to-back winner in CloudMinds, and, for the second year in a row, a former Startup Challenge winner turned its large check into a trophy as PhotoniCare took home an award.

Communication: Innolume's CW Datacom Laser is an enabling component for a new generation of data communication equipment. It will substantially reduce laser costs and power consumption – saving energy and the environment one laser at a time.

Energy: Prisma Photonics is the first and only company to offer highly effective, high-fidelity monitoring of electrical transmission lines based on pre-existing optical communication cables. A single PrismaSense system can monitor 100 km of transmission lines without the need to install any sensor on the lines or towers.

Healthcare: PhotoniCare's TOMi Scope uses light to see through the eardrum and directly visualize fluid in the middle ear for the correct diagnosis and treatment. The TOMi Scope uses a proprietary optical coherence tomography engine that meets a significant clinical need at a price point and ease-of-use that enables it to be leveraged in primary care settings.

Life Sciences: TERA-print's TERA-Fab E series is the world's first desktop nanoprinter based on a new, highly scalable and versatile photolithographic technology,

continued on page 03


Credit: Trish Tunney

Startup winners rise to the Challenge

Six companies came out on top at the 10th annual Startup Challenge healthcare and deep tech tracks Wednesday.

First place in the healthcare track went to Odin Technologies, LLC for Lumisense – an optics-based, wearable diagnostic device that assesses extremity hemodynamics – allowing caregivers to identify perfusion injuries and complications.

"We're developing the next generation of intelligent wearable devices to help clinicians to identify non-obvious hemorrhage and compartment syndrome in trauma patients," said Odin founder and CEO Steven Hansen. Through early identification, Lumisense allows patients to get the treatment they need sooner; improving outcomes and reducing costs for hospitals."

Rubitection took second place for the Rubitect Assessment System (RAS) – an optical skin health and wellness tool for diagnosis and monitoring with an initial application for early pressure ulcer (bedsore) prevention. RAS uses applied reflectance spectroscopy to identify redness or changes in the coloration of the skin.

"RAS is a technology that's addressing a global healthcare problem," said Rubitection CEO Sanna Gaspard. "It can reliably measure the properties of the skin on all patients independent of skin color, and it can be used easily by an aid or skilled nurse."

Rachel Kuperman, founder and CEO of Eysz, Inc. came away with third place for her company's Seizure Monitoring Software. "Detecting and responding to seizures is critical to managing epilepsy. Today, accurately detecting seizures outside of a hospital-based setting is like trying to diagnose a fever without a thermometer." The software being developed at Eysz will analyze passive eye movement data including relative eye position and blink frequency, to measure seizures with loss of consciousness.

First place in the deep tech track went to

continued on page 33

DON'T MISS THESE EVENTS TODAY.

INDUSTRY EVENTS

PHOTONICS WEST EXHIBITION
10 AM – 4 PM, Halls A-F

INDUSTRY UPDATE: TRENDS AND OUTLOOK
10:15 – 11:45 AM, Industry Stage, Hall DE (Exhibit Level)

PUBLIC POLICY UPDATE: EXPORT CONTROL, ADVOCACY, AND MORE
10:45 – 11:15 AM, Industry Stage, Hall DE (Exhibit Level)

PRISM AWARDS WINNERS PANEL
11:30 AM - 12:00 PM, Industry Stage, Hall DE (Exhibit Level)

EQUITY, DIVERSITY, AND INCLUSION LUNCH & LEARN: DIVERSITY IN THE WORKPLACE
12:00 – 1:00 PM, Industry Stage, Hall DE (Exhibit Level)

For the full schedule, see the technical program and exhibition guide or download the SPIE Conferences app. Some events require registration. Read daily news reports from Photonics West online: spie.org/PWnews

IN THIS ISSUE.

The rise of the VCSEL

From humble beginnings as an alternative communications source, the VCSEL's applications have mushroomed to embrace laser printing, optical mice, Optical Coherence Tomography (OCT) and now facial recognition. Moreover, this week at Photonics West there are more than 100 VCSEL events and dozens of exhibitors.

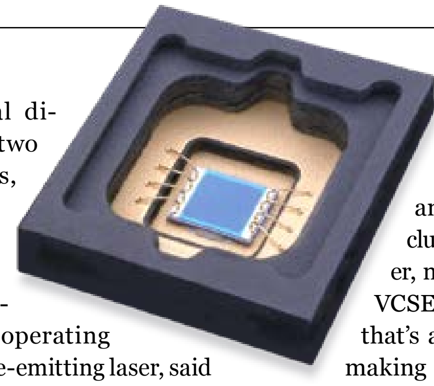
Lightbulb moment: Kenichi Iga visualized a new type of laser in his sleep. Credit: Adam Resnick

The idea came to Kenichi Iga in his sleep. It was 1977, and Iga, now a professor emeritus at the Tokyo Institute of Technology, was trying to design a new type of laser: one that's single mode, with a reproducible wavelength, and could be fabricated using standard semiconductor wafer technology. What he dreamed up was the vertical-cavity surface-emitting laser (VCSEL).

At the time, Iga simply wanted a better laser for optical communication. Today, VCSELs have become a workhorse laser. The global market for them is estimated to grow from $1.8 billion in 2018 to $3.9 billion by 2023, according to one recent market report. He had no idea the VCSEL would become so ubiquitous, said Iga, who delivered one of the LASE plenary talks on Monday.

"They're used everywhere," said Allen Nogee, a laser market analyst and president of Laser Market Research. "They're just a very common, tried-and-true, reliable low-cost laser for a lot of applications."

Unlike other semiconductor lasers, the VCSEL emits a beam perpendicular to its surface. Using standard silicon wafer technology, many VCSELs can be fabricated on a single wafer. The laser can also be tested during the manufacturing process, which makes it easier and cheaper to produce; today, a single VCSEL costs only a couple dollars, Nogee said.



Small but powerful: VCSEL in AIN cavity package. Credit: II-VI

With a typical diameter of about two to three microns, the VCSEL's small size means it requires about 10 times less threshold current and operating power than an edge-emitting laser, said Jack Jewell, one of the VCSEL's early pioneers. "That makes it uniquely enabled for low-power applications."

The precursor to the VCSEL was a longitudinal injection laser that Ivars Melngailis of Lincoln Lab created in 1965. In his device, the beam oscillated between the polished top and bottom surfaces of an indium antimonide diode.

But the modern VCSEL didn't come until the late 1970s with Iga's design, which used reflective mirrors to induce the beam to lase. Two years after his epiphany, in 1979, he and his graduate students created the first VCSEL out of indium phosphide. But, operating at only 77° K, it wasn't practical. Iga and his collaborators would spend the next 10 years developing better crystal growth technology and methods to form reflective mirrors, producing the first room-temperature, continuous-wave VCSEL in 1988.

The following year, a group at Bell Labs and Bell Corp – which included Jewell and Axel Scherer, now at Caltech – created a VCSEL with an active region that's about 100 times thinner, making it more commercially viable. "All previous VCSELs had one-micron thick active regions," Jewell said. "It's just not a practical device. The current density was way too high to be reliable." But, he said, "when we made the active materials thin like edge emitters, that opened the door."

By the end of 1989, a couple of other groups at Bell Corp and Bell Labs showed how to make VCSELs with an ion implantation technique, which was easier to implement and didn't require the etching that was part of previous epitaxial methods. Indeed, the first commercial VCSELs, used for Ethernet, were made with the ion implantation technique.

Over the next decade, Jewell said, several groups – such as Larry Coldren's team at the University of California, Santa Barbara – would work on optimizing power and efficiency, and achieving more stable operation at higher temperatures.

continued on page 34

Awards

continued from page 01

called beam pen lithography, that enables rapid prototyping and fabrication of millimeter-scale nanostructured patterns and devices with a diffraction-unlimited resolution for electronics, photonics, metamaterials, soft robotics, and biomedical applications.

Manufacturing: Inspekto's INSPEKTO S70 is the first plug-and-play system for industrial visual quality inspection, gating, and sorting. The system runs artificial intelligence engines for detection, acquisition and inspection, which optimize the settings to obtain the best image and then analyze it for defects without human intervention.

Quality Control: CloudMinds' Smart MEMS Handheld Raman XI2 is a novel cloud AI handheld Raman device with MEMS scanning mirrors for area sampling. XI2 can measure samples that are normally not possible with a single point measurement with multicomponent analysis at all sampling points to reveal sample heterogeneity. XI2 is important for pharmaceutical companies, food and beverage manufacturing, security and defense detection, and biological applications.

Safety & Security: Pendar Technologies' Pendar X10 is the only handheld, point-and-shoot system that can identify almost any material from up to a meter away without the need for eye protection and is rugged enough for HAZMAT and narcotics applications. Pendar X10 offer new levels of safety, accuracy, and speed in the field: identify materials from a safe distance or through glass or plastic barriers, identify dark materials with minimal risk of explosion, and rapidly identify highly fluorescent materials.

Transportation: Outsight's 3D Semantic Camera is an active 3D multispectral camera that provides point-wise classification including material identification blended into a single 3D stream of data with 3D range and RGB, full vector velocity for each point and SLAM (simultaneous localization and mapping). This new device fuses two hardware and software breakthroughs: a new broadband high-power laser source (SWIR band) with embedded software that provides advanced processing like classification and object detection without requiring machine-learning datasets.

Vision Technology: WaveOptics' waveguide technology transfers the light waves from the light source and projects them into the user's eye, enabling the digital image to be overlaid onto the real world. This technology produces a large eye-box for binocular viewing with a wide field of view that can be customized for augmented reality (AR) smart glasses and wearables.

KEVIN PROBASCO

45 billion cameras by 2022

The number of cameras in the world is set to rise to an extraordinary 45 billion by 2022 – up 60% on this year's total of 28 billion. That's according to Evan Nisselson, general partner and founder at New York City investor LDV Capital.

In a keynote talk at the SPIE Venture Summit this week, Nisselson listed dozens of burgeoning applications and emerging areas where optics and photonics play a critical role.

Gigajot team: Saleh Masoodian, Claire Masoodian, Dakota Starkey, and Jiaju Ma. Credit: Matthew Peach

And it's not all about smart phones, whose total share of the market is set to shrink a little. Although, inevitably, they will continue to represent the single largest application category, Nisselson believes that a proliferation of vision applications inside the home will provide much of the impetus for the rapid rate of growth in the next couple of years.

Outside of the home, Nisselson pointed to ideas ranging from "satellite selfies" to lens-free fluorescent microscopes and chip-scale lidar as new areas that are ripe for growth. Last year, LDV took part in a $4.3 million investment in chip-scale lidar startup Voyant Photonics, a spin-out from Michal Lipson's silicon photonics research group at Columbia University.

Nisselson also name-checked Photonics West exhibitor Gigajot (booth #4157), which is working on single-photon detection for cameras based on what it calls its "Quanta Image Sensor (QIS)" technology platform. Eric Fossum, who was instrumental in the development of the CMOS image sensors, is part of the Gigajot team. Just last week, the company also won a small business innovation research (SBIR) contract with NASA to develop a UV/EUV photon number resolving image sensor.

LDV specializes in investments in "visual technologies," and in February 2018 raised $10 million in its second seed fund.

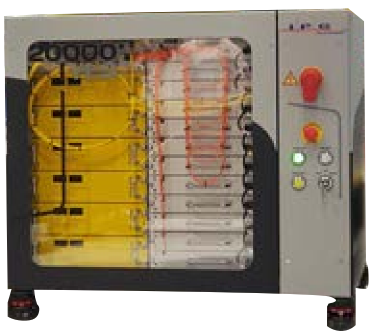
MIKE HATCHER

Fiber lasers primed for 'smart factory' era

Eckard Deichsel from the Swiss machine tool company Bystronic outlined the extent to which high-power fiber lasers have now usurped carbon dioxide sources – and offered some thoughts on how the landscape may further change – in a talk opening the Fiber Lasers conference on Monday.

Bystronic has roughly a $1 billion share of what's believed to be an annual market for laser materials processing systems now worth some $20 billion, and Deichsel illustrated just how dramatically the landscape has changed over the past decade.

Back in 2010, Bystronic had only just launched its first 2kW fiber laser tool for cutting sheet metal. Deichsel said that at that point the company was expecting the market to become split 50-50 between fiber and carbon dioxide sources by 2020. In fact, for Bystronic, that split in terms of new lasers sold already stands at around 90% in favor of high-power fiber lasers. And Deichsel reckons that figure will be similar for most other tool companies.



Superpower: IPG Photonics' new 20kW YLS Ytterbium fiber laser. Credit: Matthew Peach

The reasons why are pretty clear. Deichsel played a video showing just how much faster 10kW and 6kW fiber laser tools were able to cut a complex pattern in 6mm-thick mild steel, compared with a carbon dioxide laser machine. On top of that, the latest fiber tools can now offer a wallplug efficiency close to 50% - three times that of their older rivals, and of huge significance when the annual energy consumption of a typical machine tool is considered.

Bystronic's latest offering provides 12kW of fiber laser power, although Deichsel said he thought that the mass market for metal-cutting tools would not simply adopt more and more powerful lasers to cut faster. The majority of that market will remain below 6kW, alongside significant demand for 6-10kW tools, he predicted.

Remarking on the number of fiber lasers players currently in the market, and the competition coming from some Chinese providers now ramping their power offerings towards 50kW, Deichsel said it would be "interesting" to see how that landscape would look in two or three years time.

The relative proliferation of fiber laser firms in recent years has resulted in significant price erosion. The price of a 6kW fiber laser has roughly halved since 2016, Deichsel pointed out, and Bystronic is now typically paying around $10 per Watt for its lasers – down from $30 per Watt just a few years ago. That trend will inevitably place pressure on some of the fiber laser firms in the market currently, as the industry moves towards the "smart factory" era.

Nikolai Platonov from IPG Photonics, by some distance the market leader in fiber lasers, followed Deichsel's invited presentation with a look at how the Oxford, Massachusetts, company was working to push up the power of its single-mode, diffraction-limited ytterbium-doped all-fiber sources.

Later in the session attention turned to ultrafast fiber sources and their emerging impact in industry. In a separate talk Platonov's IPG colleague Toby Strite told attendees that the company was working to bring the same "virtuous circle" of industrialization that has proved so successful in the high-power sector to bear on the ultrashort-pulse laser scene.

MIKE HATCHER

COHERENT SOLVES 'INSOLUBLE' WELDING PROBLEMS

Coherent, of Santa Clara, California, presented its new laser-based core welding system on the SPIE Photonics West exhibition floor on Tuesday.

Called the Highlight FL-ARM, the device can improve approaches to various difficult industrial welding jobs for products like automobiles or batteries, Coherent said. ARM stands for adjustable ring mode.

J. P. Lavoie of Coherent with the new Highlight FL-ARM laser welding system. Credit: Joey Cobbs

"Coherent's adjustable laser technology was invented to solve some challenges in applications that didn't have a solution, such as welding of high-strength steels, on products like auto bodies," said J. P. Lavoie, North America manager for application laboratories.

"The technology also addresses challenges of welding aluminum alloys that are prone to cracking once the weld is finished."

It's a kilowatt class fiber laser system encompassing several technologies that make it unique to the industry.

With its adjustable ring mode, you can adjust the shape of the welding beam and change where the energy is deposited within the beam "on the fly," Lavoie said.

Its adjustable ring mode will make it particularly useful for microelectronics as well as in automobile body assembly for spot welds or brazing.

The fiber laser technology is being manufactured at sites in Germany and Finland.

FORD BURKHART

'Don't substitute money for creativity'

At the Entrepreneur Program's Venture Summit Tuesday, a panel discussion with investors in the photonics space offered tips, strategies, and even a laugh or two.

Luminate Accelerator managing director Sujatha Ramanujan moderated a panel of industry investors. Frank Levinson, general partner at Phoenix Ventures, Evan Nisselson, general partner at LDV Capital, Jerry Panagrossi, executive director of Renevo Capital Limited, and Laura Smoliar, founding partner of Berkeley Catalyst Fund, fielded questions about how to make photonics companies attractive.

"You should be aware that a professional investor will look for equity, a board seat, a more formalized agreement than friends or family will want," Smoliar opined. "But at every stage you're trying to hit a new value inflection point, to change the value of the company."

Levinson added, "You should come to us because you think we'll be interested. We shouldn't be arguing over valuation at first; we're not just here for the money. "

Then Nisselson gave his thoughts on how to find a lead investor: "You have to talk to 200-300 investors and assume that 99 percent of them will say no. But you just need one. Show that you've done your research. You'll be collaborating with them for 10 to 12 years if it's successful."

"Finding the lead is the hardest thing," added Smoliar. "The lead has to do a lot of heavy lifting. Usually they'll get a board seat. And you want a good lead: they will set the terms of the deal and will help build a syndicate of other investors."

Levinson warned: "We say no a lot, but of the 10 that are left from, for instance, an initial 100, we liked all those 10 people. We still say no to nine of them, but if they come back later on, that's a good sign that they felt the synergy too."

Considering a deep-tech investment opportunity, Smoliar said: "I look for whether the entrepreneur has a good view of what's in front of them. You need to show your investors that you have a credible plan."

Nisselson added, "I look at who has deep domain expertise and who has the entrepreneurial DNA. You have to show that you're going to make a profitable company."

As for the appropriate time to take an investment, Panagrossi commented, "You want to take the money that lines up with your business plan; be 6-12 months ahead in terms of when you think you'll need the money."

Levinson offered an anecdote about Michael Palin, who said that the Monty Python group had been blessed by not having too much money. If they'd had enough money, Palin said, they'd just have rented real horses for *Monty Python and the Holy Grail,* referring to the scenes in which galloping horses are indicated by the actors banging coconuts together. That, said Frank, would have ruined one of the funniest jokes of the movie. "Don't substitute money for creativity," added Frank. "Being lean is a good thing."

DANEET STEFFENS

(L-R) Frank Levinson, Jerry Panagrossi, Laura Smoliar, Evan Nisselson, Sujatha Ramanujan. Credit: Stacey Crockett

YSL 安扬激光 Photonics

YSL Photonics CO.,Ltd.
+86 27 87204039 Sales@yslphotonics.com
www.yslphotonics.com

20W Supercontinuum Source

APPLICATIONS

- OCT
- Fluorescence Spectroscopy&Microscopy
- STED/Super-Resolution Imaging
- Photocurrent
- Photoacoustic Microscopy
- Nanophotonics

FEATURES

- Total Power >20W
- External Triggerable 1-80MHz
- Wavelength 430-2400nm
- Internal Repetition Rate 0.01-200MHz
- Pulse Energy >1.5uJ
- Single-Mode Output

100W Femtosecond Fiber Laser

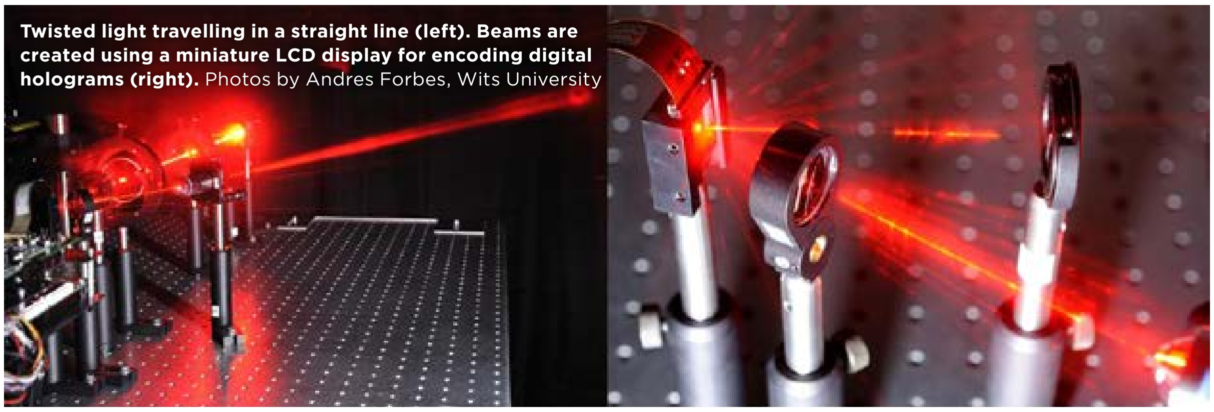
APPLICATIONS

- Femtosecond Laser Material Interaction
- Two/Three Photon Imaging
- OLED Dicing
- Glass/Sapphire Drilling&Dicing
- Thin Metal Drilling&Dicing
- OPO/OPA/OPCPA Pumping

FEATURES

- Average Power 100W
- Pulse Duration ~300fs-10ps
- Peak Power >500MW
- Repetition Rate 25-5000KHz
- Pulse Energy >200uJ
- 515nm/343nm Available


FISBA Innovators in Photonics
Visit Booth 763 South Hall
READY for the FUTURE
Think SMARTER
Think FASTER
Think EASIER
Think READYBeam™
FISBA
READYBeam ™
FISBA
READYBeam™
fisba.com/readybeam



Twisted light travelling in a straight line (left). Beams are created using a miniature LCD display for encoding digital holograms (right). Photos by Andres Forbes, Wits University

Optical communications and sensing extended with a twist

Exploiting orbital angular momentum photonics, or "twisted light," is offering great promise for data traffic and sensing – but many challenges remain.

By passing information at rates of a 200Gbit/s via a drone, US researchers have pushed the limits of "twisted light" communications. Alan Willner's University of Southern California (USC) team achieved this bandwidth by encoding data into light using orbital angular momentum (OAM). This powerful technique lets the scientists combine beams with different OAM modes, each of which can carry data.

This work built on the team's first 2Tbit/s demonstration using 16 OAM beams with the same wavelength in 2012. From this the USC team moved to 42 wavelengths, each combining 24 OAM beams. "We had around 1000 different beams that were all orthogonal," Willner says. "We had 100Tbit/s in the lab." More recently, they have communicated at 400Gbit/s between transmit and receive stations 120 meters apart outdoors. In 2019 they published their work sending data by reflecting the beams off a drone, and separately published an experiment demonstrating a 40Gbit/s link transmitting beams through water. These impressive results suggest great promise in communications and beyond, which scientists are discussing at Photonics West 2020.

Willner explains that OAM relies on more complex electromagnetic wave properties of light than optical communication does conventionally. In conventional circular Gaussian beams, photons are all "oscillating up and down together," he explains. "With OAM, the relative phases around your circle are changing, oscillating out of phase with each other." OAM can be used in communications through the combination of beams so that they form orthogonal channels. "One twists fast, one twists slower, one clockwise, one counterclockwise," Willner says. "You put them all together and you multiply your capacity."

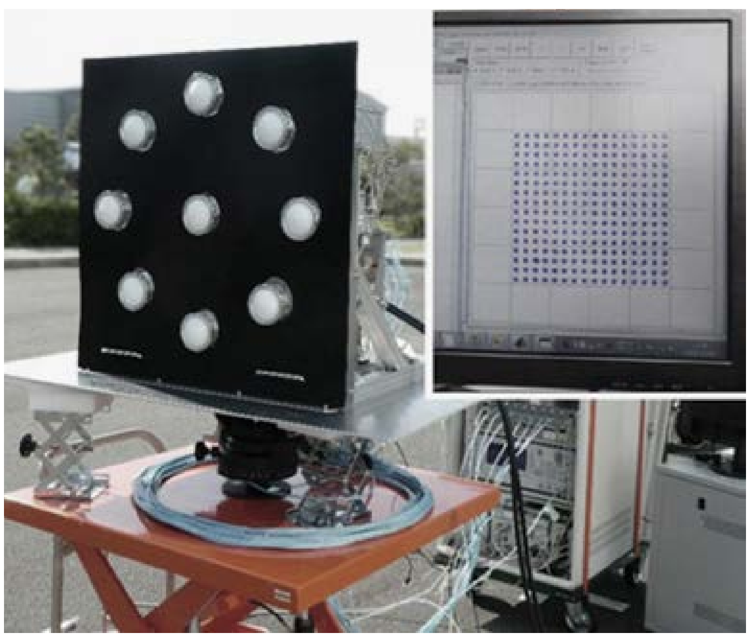
That contrasts from how existing optical communication techniques exploit the on-off signalling of time division multiplexing, and divide information into frequency channels. "We're starting to max out both of those in terms of the amount of information we can include," explains Martin Lavery from the University of Glasgow, UK. Normally, a laser produces a Gaussian beam – a beam whose magnetic and electric field amplitude profiles look like a bell curve, Lavery says. OAM exploits light in the forms known as Laguerre-Gaussian modes.

"These have almost donut-shaped structures," Lavery says. "They have dark centers and an annulus of bright light." Lavery then switches metaphors to a spiral staircase, with an empty space running down the middle. In OAM beams, light twists around this empty 'vortex point' with orbital momentum, he explains, which changes in discrete amounts, like electronic energy levels. "These things you can use as orthogonal channels because they're completely separate in terms of the information you want to encode," Lavery stresses.

Giovanni Milione from NEC Labs in Princeton, US, puts this mathematically. "Predominantly, we exploit light's OAM modes," he explains, which comprise a set of solutions to the wave equation in cylindrical coordinates, with cylindrical symmetry. "What makes OAM modes so interesting are the striking physical analogies that naturally follow due to that symmetry," Milione says.

The approach has clear potential in optical fiber

continued on page 09



Dot to dot: NEC has demonstrated real-time digital OAM mode multiplexing transmission in the 80GHz RF band to meet the increasing demand for 5G networks. Image credit: NEC

Twisted light continued from page 07

communication, where OAM modes are typically used for mode division multiplexing. This approach is analogous to other well-known multiplexing techniques, such as wavelength division multiplexing. However, Milione stresses that any spatial mode can be used for mode division multiplexing. He explains that the approach uses each spatial mode of a few- or multi-mode optical fiber to transmit an independent data signal. "As compared to the use of a single mode optical fiber, mode division multiplexing can multiply the data speed of optical fiber communication by the number of spatial modes used," he says.

Commercial breakthrough

"A major challenge of mode division multiplexing is that spatial modes can unavoidably experience mode coupling in optical fibers," adds Milione. Mode coupling is the transfer of power from one spatial mode to another, which results in data errors when the spatial modes are detected, he explains. There are two major trends to resolve this challenge. "The first trend is the use of a digital signal processing (DSP) technique referred to as multiple-input-multiple-output (MIMO)," Milione says. "This is effectively a digital uncoupling of the spatial modes' data signals after detection. The second trend is the attempt to avoid mode coupling as much as possible."

To avoid mode coupling, researchers are also studying optical fiber design. "If using OAM modes, the design of an optical fiber with a ring-core can significantly reduce mode coupling over kilometer-scale distances," Milione says. At Photonics West, he presents a talk entitled *Mode-division multiplexing using few-mode elliptical-core optical fibers,* on Wednesday, in *Optical Communications, Session 2*. "It is possible to reduce mode coupling in elliptical core optical fibers to such an extent that only a fraction of a fraction of the power from one spatial mode is transferred to another spatial mode even when the optical fiber is bent into small loops," Milione says. NEC's mode division multiplexing products may be useful in data centers, he adds, which require high speed links between nodes.

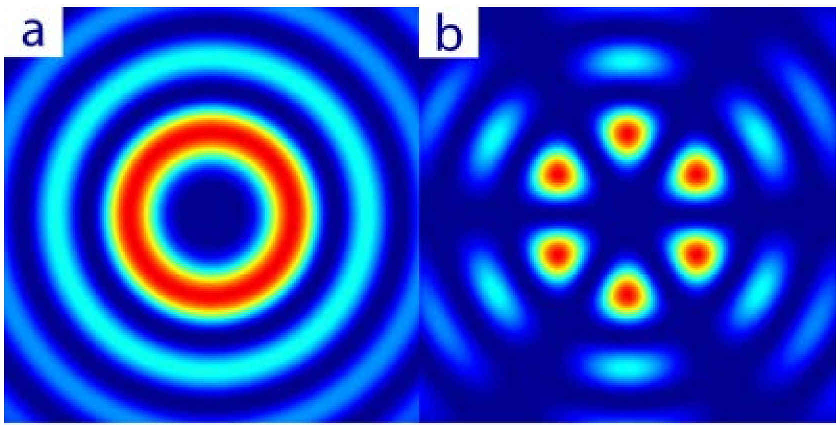
"The push towards communication seems to be getting bigger," Lavery adds. He believes the area where this technology would initially get deployed would be "long-distance communication channels between continents." In this context, undersea cables are replaced roughly every 20 years, so "there is a possibility in the next upgrade to have OAM fibers or some other form of spatial division multiplexing (SDM) integrated," Lavery says. He notes that Nokia Bell Labs is "really pushing SDM in fiber as a way of solving overstretched capacity issues with subsea optical communications cables."

Researchers are also exploring OAM outside of the fiber medium, for example in free-space communications. Lavery's research group is therefore currently working with British Telecom on free-space communication technologies. However there remain challenges regarding atmospheric turbulence, he explains. Consequently, researchers are also trying to apply DSP and MIMO techniques to resolve this – although without complete success, according to Lavery. "A couple of hundred meters is not so bad," he says. "But when you start getting to a couple of kilometers, the technology we have is still not quite mature enough." Early spatial light modulators were also "quite big devices," Lavery adds.

"If you want to make some of these schemes commercially viable you need chip-scale ways of controlling and generating beams," he says. Lavery and his collaborators have therefore been developing both OAM generators and detectors at the chip scale.

Another way that avoids the use of spatial light modulators will be presented by Milione in a paper titled, *Machine Learning Orbital Angular Momentum Spectra,* on Wednesday morning, February 5th in *Complex Light and Optical Forces XIV,* session 6. "Using only a conventional camera and deep learning via an artificial neural network, OAM modes can be detected with great accuracy," Milione says.

NEC is also working on radio-frequency (RF) OAM for high-capacity wireless connections for 5G networks. "Many mode-division multiplexing techniques used for optical fiber communication originate from RF communication," Milione says. "NEC's use of OAM in the RF domain originates from optical communication." In that regard, NEC designed an RF antenna array and digital signal processing circuit that transmitted, separated, and demodulated multiple OAM modes in real-time. "This may be applicable in connecting ultra-dense urban areas and data centers, where it is difficult to achieve sufficient transmission capacity via conventional methods," Milione says.



By combining two structured light fields in the form of Bessel beams (a), the resulting beam of "petals" (b) spins as it travels. The spin can be made to speed up or slow down. Photos by Andrew Forbes.

Defeating distortion

Willner is pleased by the involvement of companies in OAM. "It's less blue sky than it used to be," he says. Yet Willner also recognises that industry involvement is the exception rather than the rule. Prior to the recent excitement, issues like distortion of the wavefronts of the OAM signal by water or air turbulence meant that there had been "a lot of naysayers" about the technology, he concedes. "Turbulence can distort the phase of different parts of the beam," Willner explains. "Some of the photons are now going to be in different modes. So you get crosstalk to other modes." Going beyond DSP and MIMO, his team has exploited adaptive optics to apply an inverse phase function at OAM receivers that "undoes" the phase change, he says.

Those advances have resolved the turbulence issue sufficiently to enable Willner's team to publish work on quantum communication with Robert Boyd's team at the University of Rochester, NY. Willner notes that OAM is well suited to this application because quantum bits,

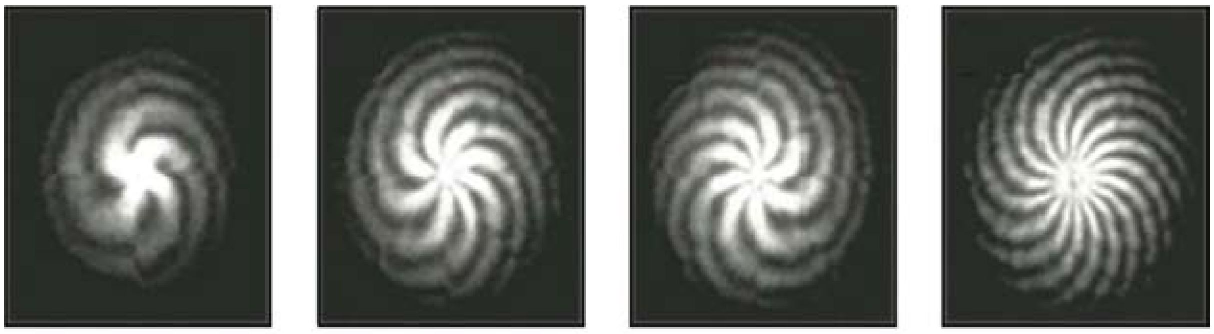
continued on page 11

Twisted light continued from page 09

called qubits, encode both a zero and a one state orthogonally. The many orthogonal beams OAM combines orthogonally enable researchers to transport many more such combined quantum states. Jiapeng Zhao from the University of Rochester presented this work in a poster at *Free-Space Laser Communications XXXII* on Tuesday, February 4. Meanwhile, on Monday, February 3, in *Optical, Opto-Atomic, and Entanglement-Enhanced Precision Metrology II* Willner talked about the next steps that will lead to more practical OAM systems.

some microscopy or metrology experiment. They just want to press a button and have what they need."

This will help enable one of the major trends that Forbes sees: using "structured light" in metrology and quantum control. "You can tailor the light with OAM, and then you can measure rotations more accurately," he explains. "A quantum experiment traditionally would be done with polarisation, and you'd get two levels. But OAM has got an infinite number of levels. So you can do lots of cool quantum mechanics with structured light." As such, Forbes notes that OAM is already being used in such non-communications applications, but it is hidden "inside the box."



OAM value = +4 | OAM value = +8 | OAM value = −8 | OAM value = +16

Interferograms produced from optical interference between OAM beams with orders +4, +8, -8, +16 and a Gaussian beam reference. The number and direction of petals in the interferogram indicates the absolute value and sign of OAM order, respectively. Image credit: Alan Willner/USC.

Andrew at the Forbes University of Witswaterand, Johannesburg, South Africa, emphasizes that mixing quantum with classical encoding using approaches like OAM, means information is not only transmitted faster, but more securely. His team's work includes quantum self-healing beams for through-space communication. "Using Bessel beams to carry OAM, we can pass through obstacles, and still keep the communication link intact," Forbes explains. "That makes it robust to any perturbations. And then that would be a scheme to improve the speed by using different patterns to get the robustness up."

In this approach, light that passes around small obstacles re-interferes and creates the beam that existed before, enabling the communication link to remain intact. While this approach has been around for a decade, Forbes' team seeks to "blend in the quantum, so that we can make the link fundamentally secure. We're really pushing the boundary in terms of how many dimensions we can use with quantum and structured OAM light," Forbes says.

Forbes gives the keynote presentation in session 6 of *Complex Light and Optical Forces XIV* on Wednesday, February 5. In the keynote, Forbes gives an overview of the concepts behind structured light and lasers, and his group's recent work. Forbes and Lavery are also leading a workshop on methods of complex light during *Complex Light and Optical Forces XIV* on the same day. Meanwhile Forbes' collaborators will give several other presentations throughout Photonics West, using quantum and classical methods to create and detect structured light, and self-healing beams – and also discussing OAM toolkits they're creating.

Beyond communication

Such toolkits are needed because rather than offering everyday practical use, "OAM still sits very much in the labs" Forbes admits. "It's because the kits to create, detect and manipulate it are still too sophisticated." Forbes' team is therefore trying to develop toolkits to enable practical applications. "You can't expect the user to be an expert in OAM," Forbes says. "Let's say they're doing

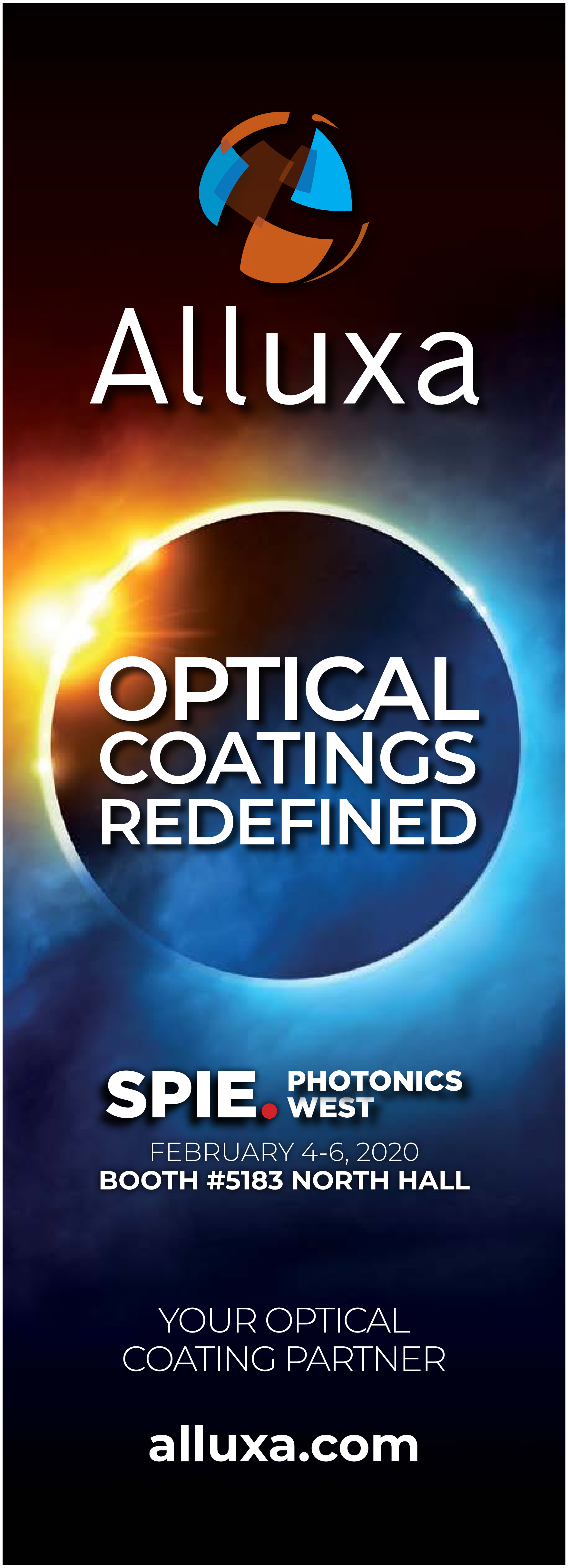
At Photonics West, in session 7 of *Complex Light and Optical Forces XIV,* Lavery presents one such measurement application of OAM, this time in environmental sensing. In this case, the approach considers photons travelling through a medium that scatters them, known as ballistic light. When light shines through muddy water, a lot of light bounces off the particles in the water, Lavery explains. A sensor detecting ballistic light travelling through such water could provide real-time monitoring.

"We wanted to see if you could have a laser beam going across the River Thames and detect if someone's dumping something illicit further up the river," Lavery says. Light beams in an OAM mode physically interact with the particles and become distorted, which Lavery's team use to infer particle size. "If you think of an OAM mode as a spinning top, when you go through a channel full of particles it gets knocked around," he says. "We are analyzing how that movement is changing, and using that as a way to detect particle size."

This is a good example of how Forbes sees the promise of OAM evolving, beginning from non-communications applications. Microscopy and imaging are OAM's starting points, he says, although they may not explicitly mention they use it. For OAM to proceed from here to communication, Forbes sees three key considerations. The first is efficiently creating twisted light beams at high enough power. The second is how to detect those beams. The third is how to deliver them from one place to another.

"In communications, the creation and detection steps have been completed," Forbes says. But for communications "further work is needed on the channel," he adds. When the channel is fiber, more work is needed to fix modal crosstalk. When the channel is free space, more work is needed to fix distortion caused by rain, fog, dust, and atmospheric turbulence. "How do you unravel this messy channel?" Forbes asks. "That's the final hurdle."

ANDY EXTANCE


Alluxa
OPTICAL
COATINGS
REDEFINED
SPIE. PHOTONICS WEST
FEBRUARY 4-6, 2020
BOOTH #5183 NORTH HALL
YOUR OPTICAL
COATING PARTNER
alluxa.com


Modulation
solutions for
challenging
applications.
LiNbO3 Phase and Amplitude Modulators
• Bare, lensed, pigtailed, packaged chips
• Drivers and MBC matching components
• Qualified products for Space & harsh environments
ModBox
• Reference transmitter
• Pulse Generation & Shaper, Pulse Picker
iXblue
PHOTONICS
www.photonics.ixblue.com
Meet with us at Photonics West, booth #5548

A new pair of hands on the steering wheel at the Fraunhofer ILT

Show Daily interviews Prof. Constantin Häfner, as he succeeds Prof. Reinhart Poprawe, in charge of the groundbreaking laser research center in Aachen, Germany.

In November, 2019, renowned laser physicist Dr. Constantin Häfner took on the Directorship of the prestigious Fraunhofer Institute for Laser Technology (ILT) in Aachen, Germany. He has moved back to his home country after working 15 years in the USA, first at the Nevada Terawatt Facility, at the University of Nevada, Reno, and subsequently, from 2006, at the Lawrence Livermore National Laboratory in Livermore, California.

As Program Director for Advanced Photon Technologies, he headed up the development of the world's most powerful laser systems and pioneered key technologies for next-generation, high-average-power petawatt laser systems enabling a new arena of real-world applications. At the ILT, Dr Häfner succeeds Prof. Reinhart Poprawe, the outgoing previous chairholder and director, credited with having led technological progress in laser photonics on the global stage as well as building up the next generation of young talent for the industry.

To discover how he plans to keep the ILT at the forefront of laser innovation, Show Daily interviewed Dr Häfner.

Show Daily: As a career choice, what is the great attraction of lasers?

Constantin Häfner: Lasers have always had a magic attraction to me; from building light shows as a teenager to later making disposed indsutrial lasers work again, then to using pulsed lasers for probing and manipulating magnetic properties in solid state matter in my research studies at the University of Konstanz. Then after receiving my PhD from the University of Heidelberg in 2003 I moved to the USA, and led the development of high-peak-power lasers for high energy density experiments as Chief Laser Scientist at the Nevada Terawatt Facility (NTF). In 2006, I moved to California and joined Lawrence Livermore National Laboratory to work on developing the world's most powerful, high-intensity laser systems.

As director of the Fraunhofer ILT, what will be your main aims?

The Fraunhofer Institute for Laser Technology is one of the most important contract research and development institutes in the field of laser development and laser applications. I see the following objectives for me as the ILT's new director: to maintain and extend a diverse, inspiring and creative environment for our more than 550 employees so that they can come up with new ideas to solve challenging problems; to expand our capabilities and in-house expertise; and to underpin the competitiveness of the ILT's clients by solving their real-world problems.

The ILT provides laser and laser production systems engineering expertise. We will surely continue to work on topics such as laser system technology, process monitoring and control, modeling as well as the entire system technology.

New direction: Laser physicist Dr. Constantin Häfner is now head of the Fraunhofer Institute for Laser Technology. Photo credit: Fraunhofer ILT.

How is Fraunhofer addressing the laser market in 2020 and onwards?

The laser market is undergoing radical change: lasers for welding and cutting have now become commodities and mass products. Automotive production engineering is seeing radical change with electric vehicles on the rise. The development of beam sources is moving towards even more compact systems with high beam quality, short pulses, high power and precise modulation for process control. To exploit their full potential, industry needs sophisticated beam shaping and guidance systems to unlock new applications for high-power ultra-short pulse lasers. The Fraunhofer has concentrated their expertise in a cluster of expert institutes to develop multi-kilowatt ultrafast machining lasers and their applications. By parallelizing the new beam sources, we can now structure or functionalize large surface areas with extremely high precision and most important: economically. The laser is and remains an unprecedented precision tool and is one of the main pillars of Industry 4.0.

Therefore, we must continue systematically coupling laser technology with

continued on page 27


PHOTONIC SCIENCE
Specialist Camera Solutions
X-Ray | sCMOS | SWIR | ICCD
PHOTONIC
NEW HDR SWIR Camera
with in-camera corrections, 300 fps
Visit us at Photonics West, Booth 4686
www.photonicscience.com


visit us at booth 4545-53
son x
ultrasonic precision
Leading Edge Ultra Precision Manufacturing
Ultrasonic Tooling System UTS2
→ Direct diamond machining of difficult to cut materials
→ Materials: Steel, Invar, Glass, others
→ Optical quality Ra < 5 nm and PV < 300 nm
→ 100 kHz of vibration frequency
Contract Manufacturing
→ From 1 piece to large series
→ Mirrors up to 1000 mm (Space, lasers, semicon...)
→ Optical mould inserts (LED, camera lenses...)
→ Infrared lenses (Thermal imaging, defense, sensors...)
→ Plastic lenses (Imaging, illumination...)
Always pushing the boundaries in ultra precision technology.
www.son-x.com


zygo®
PRODUCTION TESTING OF SPHERICAL OPTICS
VERIFIRE™ VTS WORKSTATION
• Automated & reliable ROC measurements
• Robust & stable for production environments
• Ergonomic design with simple functionality
• Flexible upward-looking interferometer
NEW!
SEE IT IN ACTION | BOOTH #1048
www.zygo.com
AMETEK®
ULTRA PRECISION TECHNOLOGIES

Artificial intelligence set to assist doctors in low-resource settings

David Levitz of MobileODT believes AI will provide the next step forward for optical diagnosis of multiple conditions using cell phones.

Korea opportunity: MobileODT has initially targeted its AI platform at Korea, Poland and India.

The ability of biomedical optics technologies to make an impact in places where resources are limited continues to improve, not least thanks to the research themes highlighted in the sixth Optics and Biophotonics in Low-Resource Settings conference at SPIE Photonics West.

Reduced cost and robust instrumentation are the constant driving forces, along with designs intended to make devices more portable, suitable for use in locations that may be a long way from the nearest hospital.

The availability of cell phones and the relatively sophisticated optics they now contain has been another factor. Research by groups such as the one led by Aydogan Ozcan at UCLA has shown how cell phones can form the core of handheld devices able to examine samples of blood cells and tissue, potentially allowing diagnosis of disease to be made on the spot.

David Levitz, co-chair of the BIOS conference alongside Ozcan, is co-founder of MobileODT, an Israeli developer of hand-held platforms for colposcopy procedures. The company's goal is to allow any health provider to carry out meaningful examinations of a patient's cervix, and help tackle the high levels of cervical cancer found worldwide.

From Levitz's perspective, the deployment of artificial intelligence algorithms able to carry out efficient analysis of the image data is now the route to wider use of such devices.

The EVA system is lightweight and portable.

"MobileODT was founded in 2012 to build small visual diagnostic tools, empowering less-trained providers and increasing the reach of health systems," said Levitz. "Our product, the Enhanced Visual Assessment (EVA) System, is an FDA-cleared internet-connected mobile colposcope for examination of the cervix."

The system includes the EVA 3 Plus colposcope itself, a hand-held module built around a Samsung Galaxy J5 Pro cell phone with its Android operating system, and incorporating an added high-magnification lens to boost the handset's on-board optics. Images of the cervix are viewed directly on the embedded phone's HD-resolution screen, while a bespoke app and web portal from MobileODT allows patient data to be stored or accessed by other healthcare professionals as required.

Now available in several territories, the MobileODT platform indicates the potential impact that can still be made by relatively traditional microscopy and optical hardware in sectors such as healthcare, according to David Levitz, even while it is discussed alongside the more technologically groundbreaking research highlighted at SPIE Photonics West.

"We investigated the use of more optically advanced technologies, such as scattering absorption, to carry out tissue assessments of the cervix, but it proved too difficult to achieve commercially," he commented. "The challenges involved in commercializing a spectral energy device are, of course, immense. But I am very optimistic about 'old school' optics having an impact, and allowing us to take technologies that work in the developed world and make them available elsewhere at lower cost."

Transforming cervical diagnosis

The next leap forward that Levitz foresees is in the incorporation of artificial intelligence capability and dedicated image analysis algorithms, able to receive the images of a cervix from the colposcope and determine whether evidence of cervical cancer is present.

This process is now underway, with MobileODT developing its own AI component, termed an Automated Visual Evaluation (AVE) algorithm, as part of an image analysis platform called Visual Pap. In trials, AVE has proven more reliable than a human in identifying abnormal tissue that might indicate a pre-cancerous condition, according to the company.

In MobileODT's view, its algorithms have the potential to transform cervical diagnosis, especially in low-resource settings. "Visual Pap will reduce the marginal cost of each test, and enable clinicians receiving the screening result on EVA to immediately conduct a colposcopy or refer to a remote gynecologist," Levitz said.

The potential appeal of the AI approach is clear, but as MobileODT brings the technology to more markets it will inevitably meet both commercial and institutional challenges.

One immediate factor is the regular release of updated or redesigned models from the cell phone companies, often on an annual basis. Each tweak potentially impacts the ability of external optical modules to function properly, as well as presenting fresh regulatory hurdles to be negotiated.

Another is the attitude of the doctors and clinicians in the field, since the way that doctors think about AI and how that thinking evolves will be a major driver behind its adoption, according to Levitz.

Clear and simple: EVA operator's view.

"It will take time for clinicians to get used to the idea of pressing a button and receiving a diagnosis, accustomed as they naturally are to Pap smears and biopsies, and to a certain time delay," he commented. "We carried out a six-month clinical trial in Korea involving ten users, [pictured, left], some of the first commercial users of AI for this application, and after the trial concluded half of those users carried on using the product—but equally, half did not."

Acceptance by patients and their peace of mind receiving a cervical examination through a new instrument based around a cell phone, and potentially receiving a diagnosis on the spot, is another factor.

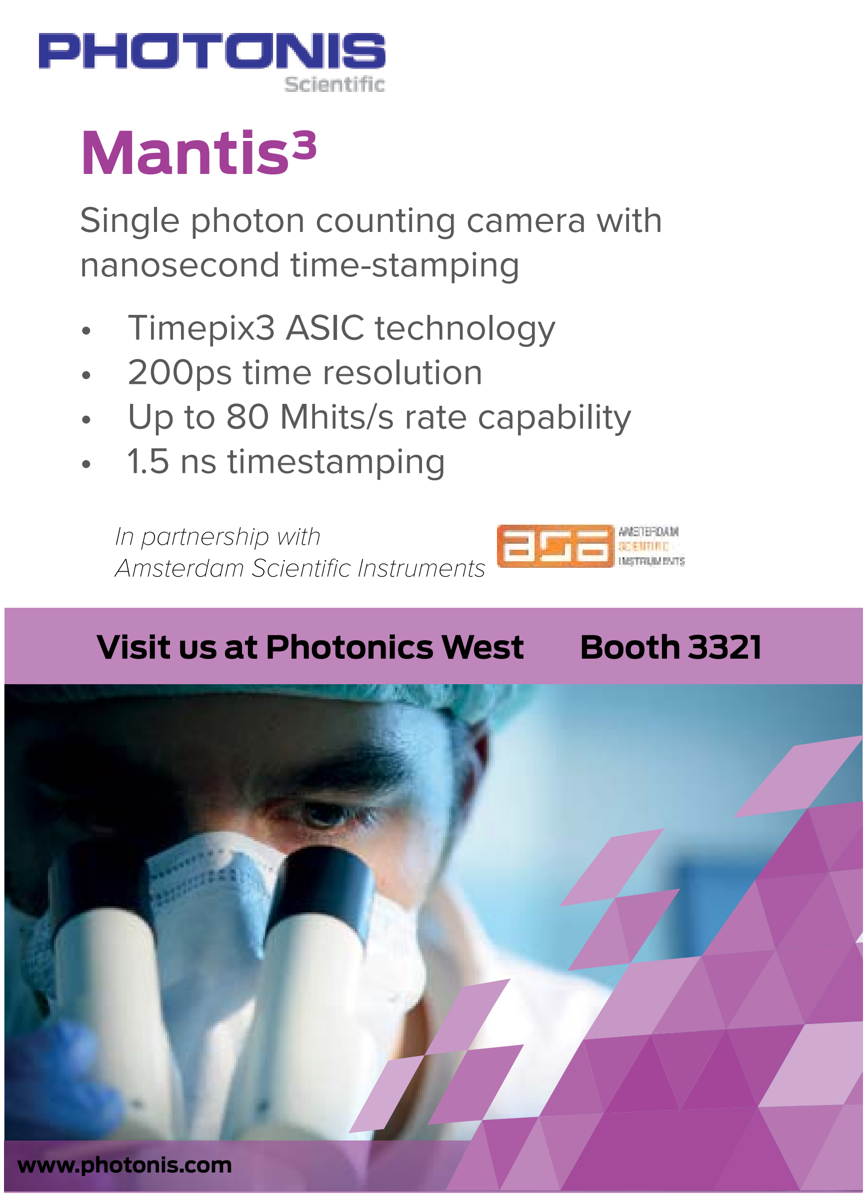
Cultural and financial differences between regional healthcare systems will also play a part, as with any new biomedical technology. MobileODT has initially targeted its AI platform at Korea, Poland and India, with an emphasis on low-resource settings in those territories. But the three regions have distinct healthcare landscapes, according to Levitz, who notes that the India market is particularly price sensitive compared to Korea, with Poland presenting a different picture again.

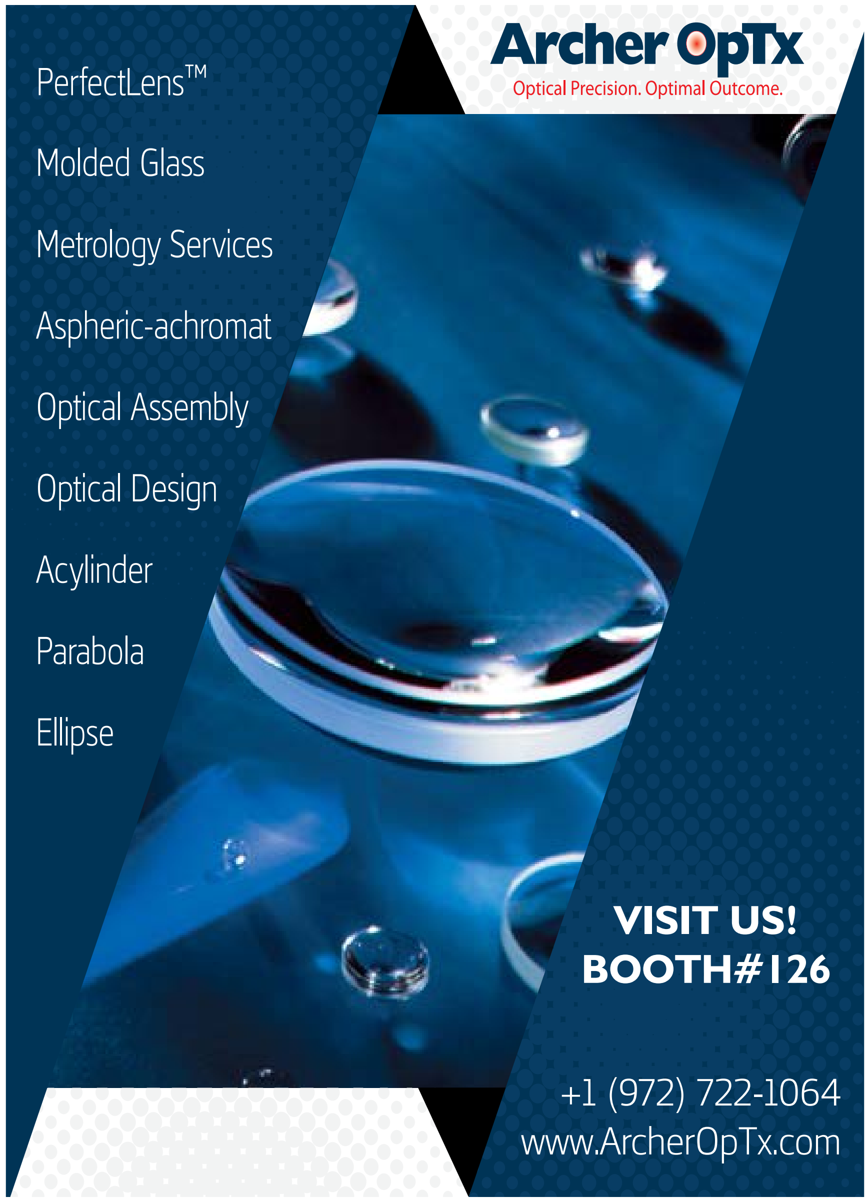
"Our wish list for the future impact of this technology inevitably revolves around money," Levitz commented. "We are effectively a company moving from hardware to the incorporation of bespoke software, and which could be in clinics very shortly—perhaps not the norm for biophotonics developers or for companies at Photonics West. We are also currently working with our AI platform in markets outside the US, and ultimately few medical advances make their fullest impact without addressing the US market. All of this can put us somewhat outside or investors' comfort zones."

But Levitz is confident that the adoption of AI is the biggest change coming in healthcare over the next few years, a process that will not be stopped once it commences.

"AI is going to become increasingly common in almost every aspect of medicine," said Levitz. "We are going to see a lot more microscopes where the optics are combined with an AI function, and people are going to be developing their own low-cost hardware and adding AI to it."

TIM HAYES


PHOTONIS
Scientific
Mantis³
Single photon counting camera with nanosecond time-stamping
• Timepix3 ASIC technology
• 200ps time resolution
• Up to 80 Mhits/s rate capability
• 1.5 ns timestamping
In partnership with Amsterdam Scientific Instruments
Visit us at Photonics West Booth 3321
www.photonis.com


Archer OpTx
Optical Precision. Optimal Outcome.
PerfectLens™
Molded Glass
Metrology Services
Aspheric-achromat
Optical Assembly
Optical Design
Acylinder
Parabola
Ellipse
VISIT US!
BOOTH#126
+1 (972) 722-1064
www.ArcherOpTx.com


Next-generation
ASSEMBLYLINE
New features and system layout.
Made for industry, for FAB and HVM.
PHOTONICS AUTOMATED ASSEMBLY AND TESTING
FROM LAB TO FAB
Visit #5269
Live Demos
ficonTEC
photonics assembly & testing
www.ficontec.com

the business of photonics

optics.org

celebrating 24 YEARS online excellence

Photonics West is the premier photonics and laser event. With more than 1,250 companies, this exhibition continues to be the flagship event to find the latest products, tools, and applications for your research or business needs.

SPIE. PHOTONICS WEST

product focus

The Moscone Center, Moscone North and South
San Francisco, California, United States
4th - 6th February 2020

Welcome to the optics.org Product Focus which we have published specifically for Photonics West 2020 in partnership with SPIE and the Photonics West Show Daily.

Here you will find an effective at-a-glance guide to some of the latest products available on the market with booth numbers if available making it easy for you to check out the products for yourself.

All this information and more can be found on the optics.org website. Simply go to **www.optics.org** for all the latest product and application news.

Alternatively, why not sign up to our **free weekly newsletter (www.optics.org/newsletter)** and get the information delivered direct.

Diamond USA, Inc.

Visit us at Booth #2248

DIAMOND DM4 Multipurpose Connector Insert

The versatile DIAMOND DM4 connector insert provides the unparalled fiber core concentricity and superior optical performance found in all DIAMOND products, along with the ability to be combined with electrical termini.

The DM4 insert is well-suited for Harsh Environment applications and is the core of the DIAMOND HE-2000, MIL-38999 and MIL-83526 connectors.

In addition, the DM4 is designed to handle standard and specialty fibers and is available with the new DIAMOND Expanded Beam ferrule for applications where mating-cycles, dust insensitivity, reliability and low losses are required.

Contact Details

Diamond USA Inc.
85 Rangeway Road, Bldg. 3
North Billerica, MA 01862
www.diausa.com
sales@diausa.com
Tel: +1 978 256 6544

Diverse Optics Inc.

Visit us at Booth #2262

Custom Polymer Optics

Diverse Optics specializes in precision injection molding and single-point diamond turning of custom polymer optics.

We do it all; prototyping to series production of free-forms, spheres, micro-optics, aspheres, domes, convex/concave, plano/convex, bi-convex, diffractives, Fresnels, prisms, light-pipes, lens arrays, collimators, combiners, toroids, CPC's, TIR's, parabolics, off-axis, ellipticals, and more.

Reduce cost, trim weight, improve performance, and simplify your product design by implementing precision polymer optics. Whether its thousands of molded optics or a few diamond turned prototypes, we'll show you how polymer optics are perfected!

Contact Details

Letty Trevino, Sales Engineer
Diverse Optics Inc., 10310 Regis Court, Rancho Cucamonga, CA 91730
www.diverseoptics.com
info@diverseoptics.com
Tel: +1 (909) 593-9330
Fax: +1 (909) 596-1452

EKSMA OPTICS

Visit us at Booth #748

High Reflectivity Laser Mirrors for High Power Picosecond Applications with LIDT >3 J/cm2

New advanced ion-beam-sputtered coatings by EKSMA Optics feature extremely high picosecond laser induced damage threshold, allowing to increase laser power limits and to extend the lifetime of optical components.

EKSMA Optics offers laser mirror coatings with R>99.9% and guaranteed damage threshold value of >3 J/cm2 at 1030 nm or >2.5 J/cm2 at 515 nm.

Laser induced damage threshold measurements were performed according to ISO 21254 standard procedures 1000-on-1 with high power lasers operating at 20 kHz repetition rate and 10 ps pulse duration.

Contact Details

EKSMA OPTICS
Mokslininkų str. 11
LT-08412 Vilnius
Lithuania
www.eksmaoptics.com
info@eksmaoptics.com

First Light Imaging

Visit us at Booth #957D

C-RED 3 – A smart compact camera for FSO and industry

C-RED 3 is a 640x512 InGaAs camera running at 600 FPS full frame while offering a <30 electrons RON, with optimized SWaP and low cost adapted for FSO, industrial or surveillance applications.

C-RED 3 supports a unique high dynamic range mode (HDR) providing 93dB dynamic range and true 16 bits linear response.

Available in USB3 and Camera Link Full, C-RED 3 also offers OEM and custom features for easy integration in every system.

(SPIE 11272-14 - C-RED 3: a SWIR camera for FSO applications)

Contact Details

First Light Imaging
Europarc Sainte Victoire, Bat 6
Route de Valbrillant, Le Canet
13590 Meyreuil, FRANCE
www.first-light-imaging.com
contact@first-light.fr
Tel : +33 (0) 4 42 61 29 20

ID Quantique SA

Visit us at Booth #4356

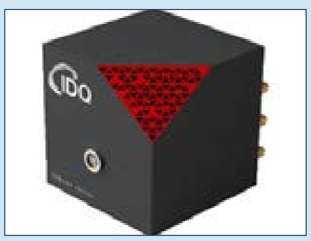
ID Quantique launches the ID Qube Series

The ID Qube series is a range of very compact and cost-effective modules for single-photon detection.

It offers the possibility to receive external pulses for fast and slow gating operations depending on the model.

A first module is optimised for fast-gated (up to 100 MHz) operations at telecom wavelengths, specially suited for quantum communication protocol while a second module offers ultra-low noise free-running operation mainly required for photon correlation and Time of Flight measurement.

More info : **www.idquantique.com/IDQube-series**



Contact Details

ID Quantique SA, Ch, de la Marbrerie, 3
1227 Carouge/Geneva, Suisse/Switzerland
www.idquantique.com
info@idquantique.com
Tel: +41 22 301 83 71

Oz Optics Ltd

Visit us at Booth #4445

OCT components

OZ Optics is introducing a new line of Fiber Optic Components for OCT Applications:

High Speed Polarization Controller/Scrambler, 330ps Electrically/Manual Controlled Optical Delay Line, Collimators/Focusers, Electrical Controlled Variable Attenuators, Faraday Rotators/Mirrors, Isolators, Fiber Pigtailed Ultra Stable Laser Module, Fused Coupler, Polarizers, Reflectors, Directional Fiber Optic Power Monitors (Taps/Photodiodes), Miniature Inline Polarization Maintaining Splitters/Taps/Combiners, Polarization Maintaining Fused Fiber Couplers/Splitters, Optical Circulator, Voltage Controlled Tunable Filter, Inline Fabry-Perot Tunable Filters.

Contact Details

OZ Optics Ltd
219 Westbrook Road, Ottawa, Ontario, K0A 1L0
www.ozoptics.com
sales@ozoptics.com
Tel: +1 613-831-0981
Fax: +1 613-836-5089

Suruga Seiki Co., Ltd.

Visit us at Booth #4186

Suruga Seiki New Laser Autocollimator: Ultra-compact Sensor Head with Easy-to-use Processing Unit

We are announcing new version of Laser Autocollimator (H410 Series) designed to fit for alignment and inspection of various miniature devices.

It consists of ultra-compact sensor head (W40 x D40 x H64mm) and easy-to-use Image Processing Unit (IPU), and is capable of measuring +/- 1.75 degree with 650nm class-1 laser beam (Infrared-option will be available soon).

Please drop by at our booth and have a look at the brand new product, as well as our range of optoelectronic components.

Contact Details
Suruga Seiki Co., Ltd.
https://eng.surugaseiki.com
e-ost@suruga-g.co.jp
Tel: +1 408-435-2974 *(San Jose office)*

Radiant Vision Systems, LLC

Visit us at Booth #4282

Evaluate Displays as Seen from the Headset: All-In-One AR/VR Display Test System

No costly equipment or advanced programming required – Radiant's compact AR/VR display test solution is designed to simplify visual performance evaluation within augmented & virtual reality headsets and glasses.

The system captures up to 120° horizontal field of view from the eye position in a single measurement for quick and comprehensive analysis.

Combining a high-resolution imaging photometer or colorimeter, specially engineered lens system, and AR/VR display measurement software, the solution evaluates virtual projections for accurate brightness, color, contrast, distortion, sharpness (MTF), uniformity, and more.

Contact Details
Radiant Vision Systems, LLC
18640 NE 67th Court
Redmond, WA 98052 USA
www.RadiantVisionSystems.com
Info@RadiantVS.com
Tel: +1 (425) 844-0152

Navitar

Visit us at Booth #238

Tunable Lens Focus Module for Zoom 6000 System

Gain greater working distance and faster focus by integrating a tunable lens focus module with the Navitar Zoom 6000 digital imaging system.

Key Features

- Fast and accurate fine focus adjustment in a compact design
- Extends working distance range of the 6X lens attachments
- Increases depth of field when coupled with infinity corrected microscope objectives
- Maintains image resolution with the integrated Optotune EL 16-40 tunable lens
- Long cycle life of the tunable lens unit and motorized Zoom 6000 system
- Easy to install USB electrical lens driver with software to control the tunable lens

Contact Details
Navitar
200 Commerce Drive
Rochester, NY 14623
www.navitar.com
info@navitar.com
Tel: +1 585.359.4000

Duma Optronics Ltd.

Visit us at Booth #2621

BeamOn U3 – High Resolution Innovative beam profiler

Duma Optronics offers an innovative beam profiler system (1/1.2") with integrated filter wheel. The device is based on a high resolution 2.3 MegaPixel camera with 12 bit dynamic range.

Measurements include: Beam Profile, position and power. The spectral range covered is 190-1600nm. Sensor area 11.34X7.13mm, with USB3.0 interface. Optional accessory for high power attenuation up to a few KWatts.

New software module for testing multiple beams in parallel. The most cost effective solution for beam profiling tasks!

Contact Details
Duma Optronics Ltd.
www.dumaoptronics.com
sales@duma.co.il

Iridian Spectral Technologies

Visit us at Booth #3241

Wavelength Selective Custom Optical Filter for Satcom Applications

Iridian designs and manufactures custom wavelength selective optical filters including solar rejection windows (SRW) and dichroic beam-steering filters to improve the signal to noise and enable wavelength multiplexing for optical inter-satellite links (OISL) and ground to satellite links.

Iridian has over 20 years of experience producing industry leading optical telecom filters for terrestrial systems.

This communications filter expertise is combined with a space heritage providing filters flown in satellite applications such as earth observation and is supported by our dedicated Aerospace and Specialty Optics team.

Contact Details
Iridian Spectral Technologies
2700 Swansea Crescent, Ottawa,
ON, Canada K1G6R8
www.iridian.ca
sales@iridian.ca
Tel: +1 (613) 741 4513 (x240)

Photon etc.

Booth #4455

IR VIVO™ NIR-II preclinical imaging system

Photon etc
info@photonetc.com

IR VIVO™ combines Photon etc.'s ultra-low noise InGaAs camera (ZephIR™ 1.7) with novel illumination and powerful analytical software to provide an unprecedented combination of fast, high resolution optical imaging at depths up to 3 cm.

- » Penetration depth up to 3 cm
- » High resolution imaging with 5 by 4 cm FOV
- » Capabable of generating monochromatic fluorescent images
- » Fluorescent imaging in NIR II window from 900 nm to 1620 nm

Boston Electronics Corp (BEC)

Visit us at Booth #3401

High-Performance, High Speed Infrared Detectors and QCL

Boston Electronics offers fast, high-performance infrared detectors from the leader, Vigo System. Detectors (MCT or III-V) are room-temperature or TE-cooled and have nanosecond time constants.

Detectors are available with preamplifiers, controllers and software providing you with turn-key capability for your most important measurements.

New products include >1 GHz sensors, linear arrays and affordable chip-on-board modules. We also provide OEM modules specially designed to your volume application and packaging requirements.

We also supply infrared quantum cascade lasers (QCL) from Alpes Lasers to complement your infrared detectors.

Contact Details

Boston Electronics Corp (BEC)
91 Boylston St.
Brookline, MA 025445 USA
www.boselec.com
shop.boselec.com
boselec@boselec.com
Tel: ++1 617-566-3821

ADIT Electron Tubes

Visit us at Booth #1461

ADIT Electron Tubes introduces a complete range of Photodetector Modules:

Photodetector modules are available in cylindrical and rectangular format for photon counting and analog signal detection using 25mm and 30mm diameter photomultiplier tubes.

- Spectral range 170nm to 850nm available
- Signal output – analog, TTL, USB
- Dual TTL and USB available
- Operates from +5 volts
- Dynamic range up to 100 Mcps
- Choice of 3 software configurable counting modes
- HV and data retrieval controlled by dedicated application software

We welcome your inquiry for custom modules.

Contact Details

ADIT Electron Tubes, 300 Crane Street
Sweetwater, TX 79556
www.electrontubes.com
paul@electrontubes.com
Tel: +1 325-235 1418
Toll free: 800-399 4557
Fax: 325-235 2872
Cell: 862-209 0653

GPD Optoelectronics Corp.

Visit us at Booth #3135

GPD Optoelectronics Corp. announces availability of 1cm InGaAs pin Photodetector

We are pleased to announce the availability of 1 cm diameter InGaAs Photodetectors in die form, on ceramic submount or in TO-9 package.

Ge photodetectors are available in diameters up to 13 mm.

GPD Optoelectronics Corp. manufactures germanium PN, PIN, APD and InGaAs PIN high-speed, large-area and extended wavelength photodetectors and APDs for near-infrared applications (800-2600 nm.) Custom submounts and packages including fiber pitgailed and cooled applications are a GPD specialty.

Contact Details

GPD Optoelectronics Corp.
7 Manor Parkway
Salem, NH 03079
www.gpd-ir.com
sales@gpd-ir.com
Tel: +1 603 894 6865
Fax: +1 603 894 6866

Headwall Photonics Inc.

Visit us at Booth #5552

New Hyperspectral Camera with Onboard Processing & Industry-Leading OEM Holographic Gratings, Sensors

Headwall's new hyperspectral camera features on-board processing in an industry-first IP-67 enclosure.

Come to the leader with decades of experience creating high-performance, economical solutions, putting our customers ahead of the competition. Our award-winning products are used every day in the field, in the lab, under water, in the air, and in space.

Master-quality holographic gratings are made in house for your instrumentation, custom spectrographs, or as part of an integrated solution. We work with you to design the best solution for your application.

Contact Details

Headwall Photonics, Inc.
580 Main St, Bolton, MA 01740
www.headwallphotonics.com
sales@headwallphotonics.com
Tel: +1 978 - 353 - 4100

Bristol Instruments, Inc.

Visit us at Booth #229

NEW Pulsed MIR Laser Spectrum Analyzer

Bristol Instruments now offers a spectrum analyzer for pulsed lasers that operate from 1 to 12 µm.

The model 772B-MIR measures wavelength to an accuracy of ± 1 part per million, and bandwidth and longitudinal mode structure to a resolution of 4 GHz.

It is the ideal solution for scientists and engineers who need to know the spectral properties of their pulsed mid-IR lasers.

Contact Details

Bristol Instruments, Inc.
770 Canning Parkway
Victor, New York 14564
www.bristol-inst.com
info@bristol-inst.com
Tel: +1 (585) 924-2620
Fax: +1 (585) 924-2623

Pixelink a Navitar Company

Visit us at Booth #238

USB 3.0 Industrial Cameras

Pixelink's extensive USB 3.0 Vision compliant camera lines are ideal for OEMs and organizations seeking reliable, high-quality industrial cameras with fast data transfer speeds.

Our USB cameras are ideal for new or existing customers looking to upgrade to USB 3.0 while maintaining existing frame rates and resolutions.

All industrial USB cameras are used in both off-the-shelf and custom industrial vision solutions.

Pixelink autofocus cameras feature various frame rates, lens formats, and sensor types in addition to global and rolling shutters to meet your application requirements.

https://pixelink.com/products/industrial-cameras/usb-30/

Contact Details

Pixelink
1900 City Park Drive, Suite 410
Ottawa, ON, K1J 1A3, Canada
www.pixelink.com
Sales@pixelink.com
Tel: +1 833-247-1211

Bristol Instruments, Inc.

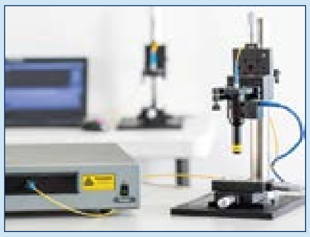
Visit us at Booth #229

Non-Contact Thickness Measurement

Bristol Instruments offers a family of thickness gauge products that employ proven optical technology to provide the most precise and reliable thickness measurement available.

What's more, this level of performance is achieved with an unprecedented level of versatility and convenience.

These systems are ideal to measure the thickness of optical components and lens assemblies, contact and intraocular lenses, OLED, AMOLED, and LCD displays, and medical tubing.



Contact Details

Bristol Instruments, Inc.
770 Canning Parkway
Victor, New York 14564
www.bristol-inst.com
info@bristol-inst.com
Tel: +1 (585) 924-2620
Fax: +1 (585) 924-2623

Optikos

Visit us at Booth #1827

New TM-1050 Thermal Module for LensCheck™ Systems

Lenses that are subject to extreme temperatures, such as those in automotive cameras, need to meet stringent performance and athermalization requirements for vehicle safety.

Now you can ensure top performance by testing in those extreme conditions using the LensCheck with new Thermal Module.

The TM-1050 provides a flexible and powerful tool to characterize the performance of smaller lenses up to 50mm including image quality and flange focal length, over temperatures of -25°C to 105°C.

Learn more at Booth #1827.

Contact Details

Optikos Corporation
107 Audubon Rd., Bldg. 3
Wakefield, MA 01880 USA
www.optikos.com
sales@optikos.com
Tel: +1 617 354 7557

Special Optics a Navitar Company

Visit us at Booth #238

Special Optics is a leading designer and manufacturer of high N.A. microscope objective lenses.

These precision optics are used within the life science, quantum physics, ultra cold atom and physics research arenas, as well as industrial applications.

Our designs span working distances of 0.3mm to 55mm, cover wavelengths from visible (390-750nm) to near infrared (700-1400nm) and can be modified for aqueous, oil and vacuum environments with housings of stainless, ultem and titanium.

https://specialoptics.com/products/microscope-objectives/objectives/

Contact Details

Special Optics
3 Stewart Court
Denville, New Jersey 07834
USA
www.specialoptics.com
Craig.fitzgerald@navitar.com
Tel: +1 973.366.7289

Presco Engineering

Visit us at Booth #3137 Hall D

Presco Engineering, a product design and contract manufacturing company, has expanded its services.

Known for solving challenging electrical engineering problems for over 40 years, they have added staff and facilities to offer complete instrument design and manufacturing.

Expert at designing ultra-low noise front end DAQs, amplifiers, high-speed A/D switching circuits, power and thermal management solutions, Presco is steeped in spectroscopy knowledge and uniquely qualified to service the medical, life sciences and defense industries.

Multi-disciplinary teams include electrical, software, mechanical and optical engineers, as well as, industrial designers and technicians.

ITAR Registered and ISO 9001:2015 Certified.

Contact Details

Presco Engineering
8 Lunar Drive
New Haven, CT 06525
www.prescoinc.com
info@prescoinc.com
Tel: +1 203 397 8722

iXblue Photonics

Visit us at Booth #5548

EY fibers for High Temperature Environment

Based on intensive qualifications from laboratory to field trials with major fiber-based LIDAR manufacturers, iXblue launches new double clad Erbium Ytterbium co-doped fibers compatible with long term 125°C operation.

This new capability, a real gap from the classic 85°C, arises from iXblue's cumulated experience in fiber coating for harsh environment: space qualified, temperature sensing and gyroscope optical fibers.

Test results show no trade-off on long term reliability as well as on optical performances; fiber exhibits record 1.5 µm efficiency and low 1 µm ASE emission.

Contact Details

iXblue Photonics
34, Rue de la Croix de Fer
78100 Saint Germain-en-Laye - France
www.photonics.ixblue.com
contact.photonics@ixblue.com
Tel: +33 (0)1 30 08 88 88

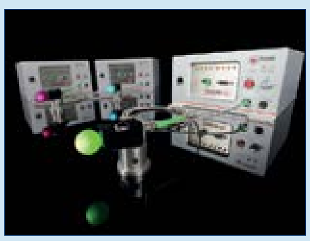
TOPTICA Photonics AG

Visit us at Booth #3209

Complete-off and crosstalk-free: Four-color Laser Combiner for Biophotonics & Microscopy

TOPTICA's iChrome CLE is a compact laser engine that combines four laser lines in one box. All integrated colors are provided via one polarization-maintaining single-mode fiber. It is available with 405, 488, 561 and 640 nm and more than 50 mW guaranteed output power after the fiber each.

With its auto-alignment the laser combiner system is ready-to-use after one simple button click. Each laser line, including the 561nm FDDL, can be directly modulated up to a frequency of 1 MHz and TOPTICA's "Complete OFF" mechanism guarantees zero photons in the "off"-state.



Contact Details

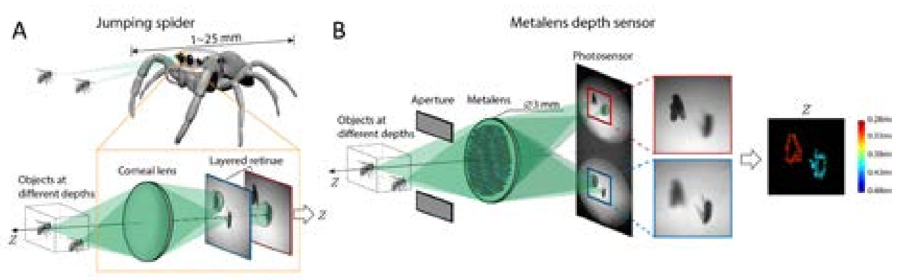
TOPTICA Photonics AG
Lochhamer Schlag 19
82166 Graefelfing (Munich)
Germany
www.toptica.com
sales@toptica.com
Tel: +49 89 85837-0

Metamaterials tackle real-world challenges

Development of a metalens depth sensor and research into hyperbolic metamaterials indicate the diversity of potential applications.

Metamaterials are once again a focus of discussion at this year's SPIE Photonics West, thanks to the range of real-world applications that might benefit from their novel optical properties, and the current technical challenges that they could solve.

A forecast published in late 2019 indicated that the overall market for metamaterials could exceed $10 billion by 2030, stimulated initially by demand for antenna technologies from 5G wireless networks. A widening applications base should then follow, with the proliferation of autonomous systems and platforms likely to spur growth in metamaterial-based sensing devices.



1. Above: "Spiders" Compact single-shot metalens depth sensor inspired by eyes of jumping spiders. (Abstract notes: Jumping spiders (Salticidae) rely on accurate depth perception for predation and navigation. They accomplish depth perception, despite their tiny brains, by using specialized optics. Each principal eye includes a multi-tiered retina that simultaneously receives multiple images with different amounts of defocus, and from these images, distance is decoded with relatively little computation. We introduce a compact depth sensor that is inspired by the jumping spider. It combines novel metalens optics, which modifies the phase of incident light at a subwavelength scale, with efficient computations to measure depth from image defocus.)

2. Right: Artistic visualizations of the metalens.Nature provides diverse solutions to passive visual depth sensing. Evolution has produced vision systems that are highly specialized and efficient, delivering depth perception capabilities that often surpass those of existing artificial depth sensors. Here, we learn from the eyes of jumping spiders and demonstrate a metalens depth sensor that shares the compactness and high computational efficiency of its biological counterpart. Our device combines multifunctional metalenses, ultrathin nanophotonic components that control light at a sub-wavelength scale, and efficient computations to measure depth from image defocus. Compared with previous passive artificial depth sensors, our bioinspired design is lightweight, single-shot and requires a small amount of computation. The integration of nano-photonics and efficient computation establishes a new paradigm for design in computational sensing. Credit: All images courtesy of Capasso Group, Harvard University.

The Harvard University group of Federico Capasso has been a hub of activity in the metamaterials field, and is presenting research into one such sensing device here, this week. This novel technology could significantly improve the performance of microrobots and microsensor networks, addressing the shortcomings of the conventional visual depth sensors that form a vital part of many autonomous platforms.

Depth sensing has traditionally involved a combination of cameras, algorithms and light sources to determine the 3D shapes of surrounding objects, whether through Lidar, time-of-flight cameras or other methods. But these techniques are often inherently unsuited to low-power mobile platforms, where size, weight and power consumption are critical considerations.

Harvard's new device employs a design inspired by the eyes of jumping spiders, a species where each principal eye includes a multitiered retina that simultaneously receives multiple images with different amounts of defocus. From these defocused images, distance is decoded by the animal's tiny brain with relatively little computation.

Building from this basic principle, the Harvard group employed a metalens to split incoming light into two differently defocused images, falling on distinct regions of a planar photosensor.

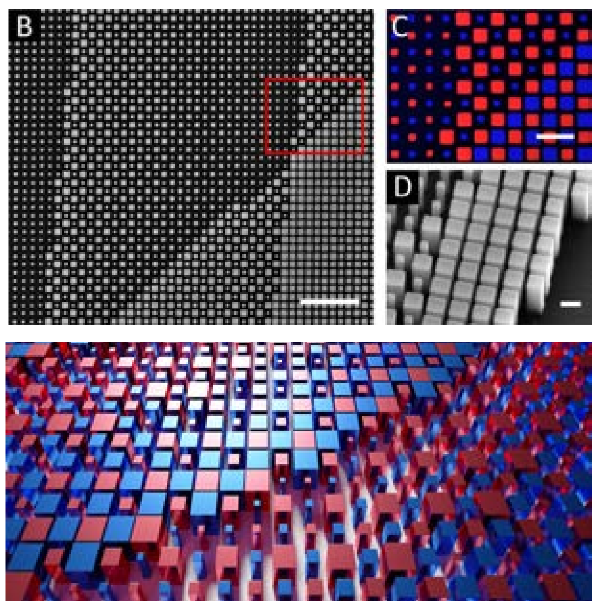
"Defocus is the essential concept here," commented Zhujun Shi of Harvard's John A. Paulson School of Engineering and Applied Sciences. "Previous implementations of similar algorithms have required mechanical adjustment of the sensors, either using an electrically tunable liquid lens or a tunable aperture. This not only makes the hardware and control mechanisms complicated, but also limits the temporal resolution, as well as introducing unwanted artifacts such as motion blur."

Using a metamaterial instead allowed the team to get rid of those moving parts. A single metasurface, consisting of patterned subwavelength-spaced nanostructures of titanium dioxide on a glass substrate, can function as two off-axis lenses in a single structure, encoding two complementary lens phase profiles with distinct focal lengths and lateral offsets. This allows the depth sensor to become compact, single-shot and completely passive; according to the Harvard project, its device is the first demonstration of a depth sensor that demonstrates all those qualities.

Microrobots and microsensor networks

The sensor is also intended to be computationally efficient. Alongside the metalens and its desired focal lengths, the team developed a depth-reconstruction algorithm allowing accurate depth maps to be computed from the two simultaneous images, with calculations that are spatially localized and few in number. The goal was to allow the depth computations for each specific image pixel to involve only a small spatial neighborhood, and require no additional correspondence search after initial calibration.

As a result, the project believes that it has reduced the amount of computation



involved in a depth sensing operation by a factor of ten, compared to previous traditional implementations. In trials, a device using a 3 mm-diameter metalens proved able to calculate depth over a distance range of 10 cm, and did so using fewer than 700 floating point operations per output pixel.

Future iterations of the device could reduce the computation burden further and make the depth sensor still more efficient. The current design predominantly uses established metalens design principles, and in the future the team intends to develop an end-to-end optimization pipeline that co-optimizes both the metalens and the algorithm. This could lead to a paradigm shift in metalens design and computational sensing.

"This integration of nanophotonics and efficient computation brings artificial depth sensing closer to being feasible on millimeter-scale, microwatt platforms such as microrobots and microsensor networks," said Zhujun Shi. "Currently, the biggest challenge is the operating bandwidth. Our proof-of-principle demo device works only for green light, and to extend the bandwidth and realize broadband white light operation, we will utilize the dispersion engineering method to design an achromatic metalens. Our group has already published several papers on dispersion engineering of metasurfaces for a different application."

The potential applications for such a depth sensor could ultimately be broad, especially as autonomous systems intended to operate in real-world environments become more sophisticated.

"Compared to conventional approaches, our device does not require active lighting as time-of-flight sensors do, or the heavy computational load that a learning-based method involves," Zhujun Shi noted. "The ultra-lightweight and compact architecture could make it particularly suitable for small platforms that have a limited power budget, such as microrobots and wearable devices, where conventional approaches do not work. Many companies have expressed interest in our research, and we definitely believe that these principles are going to have a real-world impact in the future."

Hyperbolic metamaterials: extreme anisotropy put to good use

Another form of metamaterial under discussion at SPIE Photonics West for its novel optical properties is the class termed hyperbolic metamaterials (HMMs), now becoming attractive candidates for applications in imaging, waveguiding and sensing.

The label of "hyperbolic" derives from plots of the propagating wave vectors, or k-vectors, allowed by the materials. When drawn as isofrequency contours, the k-vectors allowed naturally by a conventional isotropic material form a simple closed sphere, but for HMMs the same plot becomes an open hyperboloid shape.

continued on page 23


QUARTUS
ENGINEERING
GOT AN OPTICAL SYSTEMS CHALLENGE?
STOP BY BOOTH #3438
AND REGISTER TO WIN A DJI OSMO CAMERA
FOR MORE INFORMATION:
quartus.com • (858) 875-6000


MCL
MAD CITY LABS INC.
Piezo Nanopositioning Systems
Modular Motion Control
Microscope Stages
Single Molecule Microscopes
Atomic Force Microscopes and NSOM
Vacuum Compatible and Custom Solutions
sales@madcitylabs.com
www.madcitylabs.com
SPIE BiOS #8340 — SPIE Photonics West #4974
USA: +1 608 298-0855
EU: +41 (0)44 803 98 18


Measuring colour in a world of light!
test and measurement devices for colour and light measurements in development and production processes
ADMESY
colorimeters | spectroradiometers | lightmeters
PHOTONICS WEST
SAN FRANCISCO
4-5-6 February 2020
BOOTH # 2359
COLORIMETERS
SPECTRORADIOMETERS
LIGHTMETERS
2D IMAGING
contact us!
-
info@admesy.com
admesy.com

Metamaterials continued from page 21

In real-world practice, this means that HMMs demonstrate extreme anisotropy in their electromagnetic properties, and can effectively act as a dielectric in one direction and a metal in another.

"In many ways, the HMM platform is an alternate design approach to the traditional way of designing a metamaterial structure for effective media properties, which is to construct it from individual 'meta-atom' cells," commented Augustine Urbas of the Air Force Research Laboratory, chair of a Photonics West conference session on hyperbolic metamaterials. "In that aspect they parallel other metamaterial approaches, but with some distinct characteristics. They can be made to exhibit many of the properties that other metamaterials systems show, but the geometries are very distinct."

While approaches based on meta-atom cells usually rely on sub-wavelength and typically resonant unit cells, this need not be the case for HMMs, which instead only require that the material be effectively both conductive and nonconductive in different directions. Pioneers in the HMM field realized that a simple multilayer of metal and dielectric could achieve this, and early work on these systems indicated their many unique properties.

"The building block materials can be the same as typical metamaterials and plasmonic metamaterials, but the geometries are simpler and, in many cases, non-resonant," said Urbas. "Typically, HMMs are multilayers or arrays of parallel wires, for example, to achieve the anisotropic metallic behavior. I am not sure I would call it a radical departure from other metamaterials, but the simplicity of fabrication and the flexibility of the single platform make it distinct."

That ability to tune and change the properties of HMMs will be a factor in their ultimate real-world usage, with one focus of discussion at Photonics West being how changes in their effective properties can either trigger a non-linear response, or switch and tune a linear response.

Dynamic optical systems

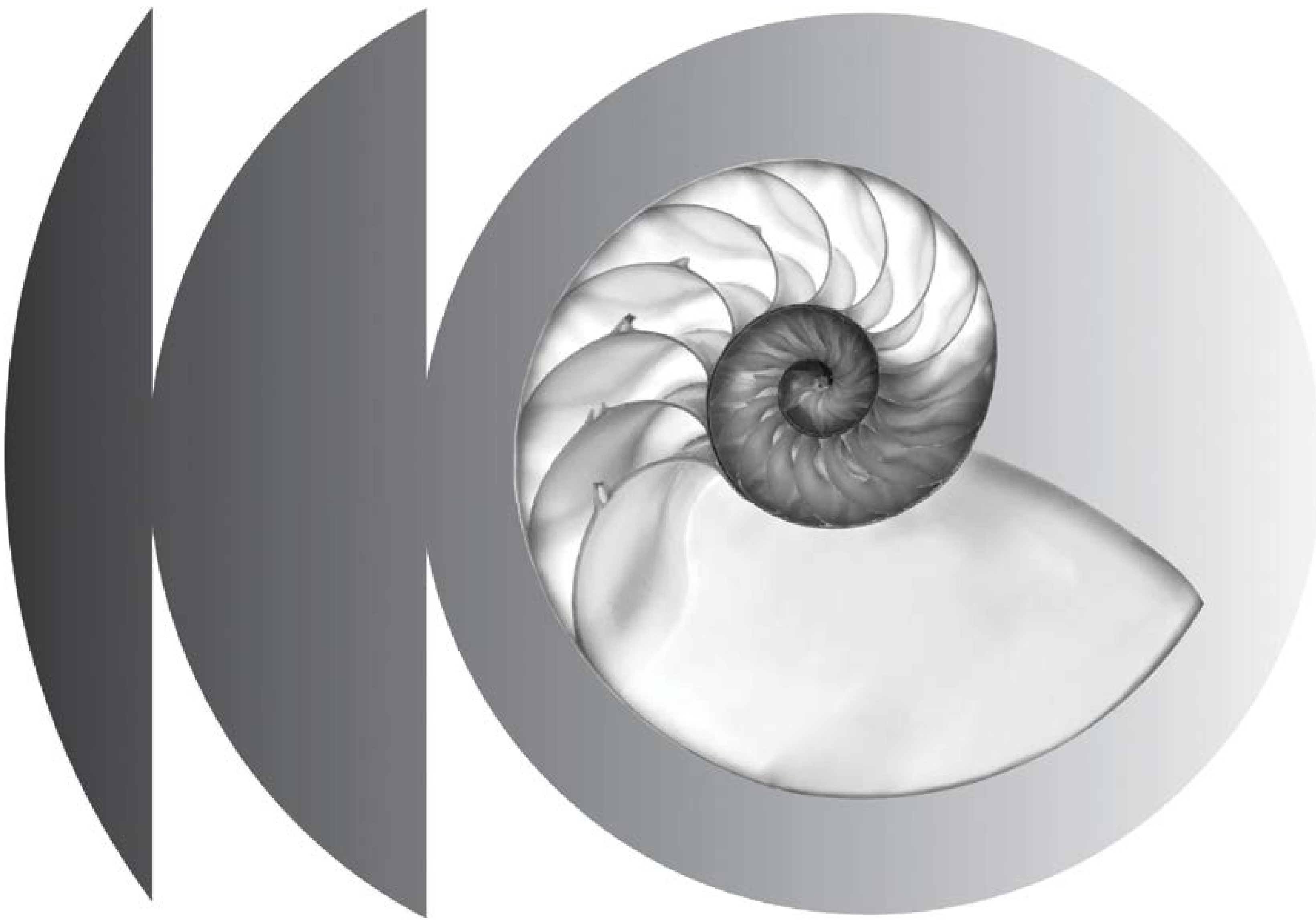
Urbas believes that the possibility of integrating HMMs into photonic systems and their subsequent use in real-world applications is one of the most appealing aspects of these materials.

"Their simple geometries, and fact that HMM properties have been observed in nanostructured and natural materials as well, offer direct ways to integrate them into technological platforms where more traditional meta-atom systems may be difficult or costly," he noted. "Explorations on using them in dynamic optical systems and photonics are ongoing and the initial steps toward this will be among the reports at this Photonics West. There may not be an individual property or effect that HMMs uniquely exhibit that other meta systems do not, but I think they offer some technological integration potential that may lead to early applications."

Some challenges on this path still remain, however. One is how to describe the behavior of dynamic and nonlinear HMM systems in terms of their effective properties, and identifying whether this homogenization is useful for engineering these systems, or for capturing their interactions and effects. Experimental and theoretical studies are currently exploring this question, alongside other HMM hot topics such as whether there is a role for the materials in quantum effects.

"Since the properties are broadband, it is possible that these materials can influence and mediate interactions between quantum systems," said Urbas. "Coupled with their tunable properties, this may prove enabling. Some initial reports have suggested these effects, and this is an area of future study."

TIM HAYES



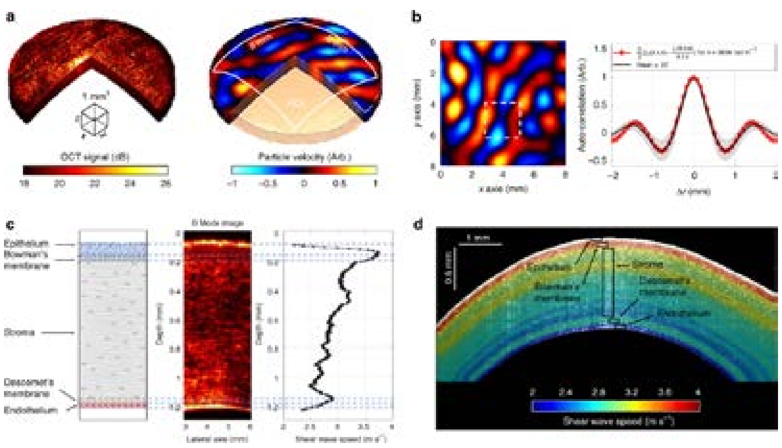
Biomechanics of tissue adds essential information to optical imaging

Kirill Larin explains how techniques such as optical coherence elastography use optical and mechanical data to assist diagnosis of disease and treatment of injuries.

A family of techniques combining optical examination of biological tissues with measurements of their mechanical properties is set to assist with a number of current medical challenges, including recovery from heart attacks and treatment of corneal disease.

The potential impact of these technologies is recognized this week at SPIE Photonics West by the holding of the seventh Optical Elastography and Tissue Biomechanics conference, co-chaired by Kirill Larin of the University of Houston's Department of Biomedical Engineering, and Giuliano Scarcelli from the University of Maryland.

"This conference was inaugurated in 2014, at a time when the field of biomechanics was starting to grow and research into combining biomechanical measurements with optical imaging was expanding," said Kirill Larin.



OCE combines optical and mechanical data to assist with diagnoses. Image courtesy of Kirill Larin.

"Today there is an established body of published research and regular breakthroughs in this field, as people start to recognize that biomechanics can reveal more information about tissues than optical examination alone, and bring additional contrast to images obtained by optical techniques."

The motivation behind this growth is the increased understanding of ways in which biomechanical properties, such as tissue stiffness, can play a significant role in both the development of disease and subsequent recovery from treatment. Those properties could also ultimately be a predictive marker for a number of diseases and degenerative conditions, including cancer.

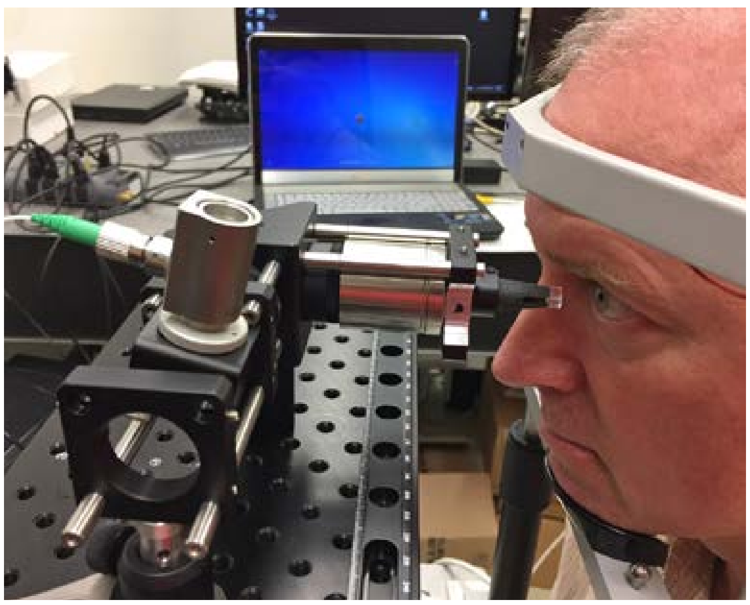
One example would be the ways in which myocardial infarctions—heart attacks—leave the damaged areas of the heart as scarred tissue, with distinctly different biomechanical properties from those of healthy cells. Restoring the original attributes and healing the tissues is one route to treatment and therapy, but ways to accurately assess the tissue mechanics are an essential part of the process.

"The only way we can monitor the success of such therapies is by measuring the mechanical properties and seeing how they change as the heart heals," commented Larin.

Additional contrast

The technique being brought to bear on myocardial infarction is optical coherence elastography (OCE), in which optical coherence tomography (OCT) is used to image tissue while it is under some form of transient local mechanical deformation and subsequent recovery. This exploits the basic difference between image contrast created by mechanical action, and intrinsic optical contrast: an OCT scan assesses differences in scattering from a target area, while mechanical contrast requires only scattering above a basic OCT threshold, and without it necessarily varying over a sample.

"OCT plus some additional contrast mechanism is an inherently powerful approach, and one beauty of OCE is that OCT is already well established in clinics," said Larin. "OCE can fill a gap in non-destructive imaging techniques, combining field-of-view in the millimeter or centimeter range with spatial resolution from microns to millimeters."



OCE can be used to treat corneal disease. Image courtesy of Kirill Larin.

The applied external force needed in OCE can be delivered by different excitation methods, both contact and non-contact. Each has its advantages, and Kirill Larin's lab at Houston is working on non-contact and completely non-invasive stimulation techniques, which are likely to be best suited for eventual translation into clinics and reducing patient discomfort.

Given OCT's existing wide acceptance in ophthalmology, an OCE platform using a non-contact excitation source could be a versatile way to assess the properties of the cornea in cases of keratoconus, where the cornea has become deformed, and to monitor the corneal cross-linking treatments used to address the disease.

It may even be possible to assess corneal biomechanics without any external stimulation at all, using instead the tiny physical changes caused by the natural heartbeat of a patient, and the pulsed blood flow in the cornea it creates.

Other techniques showing promise include shear wave elastography (SWE), the topic of an invited keynote during the BIOS conference from Mathias Fink of France's Langevin Institute. SWE uses external stimulation to create shear waves propagating through the tissue, and an ultrasound pulse has been the traditional way to create these waves. Larin's project group aims to develop alternative methods, and learn from the more established ultrasound approach.

"SWE measures mechanical waves produced on the tissue surface or inside the tissue, and allows you to see straightforward relationships between different properties," he said. "In my lab we use a tiny puff of air to produce shear waves of sub-micron amplitude in the cornea, so small that patients do not feel it; but OCT is sensitive enough to detect and image the contrast that those waves produce."

Also on the BIOS agenda is Brillouin elastography, a label- and contact-free method which exploits inelastic scattering of light by acoustic waves in a medium, when those waves are induced by thermal or other excitation. Current areas of research in this technique include ways to address the inherent weakness of the measured scattered signal, which can lead to long data acquisition times and photodamage to the tissues.

Some profitable synergies are expected to develop between these different biomechanical techniques, according to Larin. A combination of OCE and Brillouin spectroscopy could potentially be used to measure the physical properties of the lens of the eye, by incorporating the quantitative nature of OCE with the ability of Brillouin spectroscopy to produce 3D data from deeper layers of target tissues. Directing focused acoustic radiation to the lens of the eye could allow quantitative elastography of the lens in 3D, assisting studies of ubiquitous conditions such as presbyopia.

Niche applications

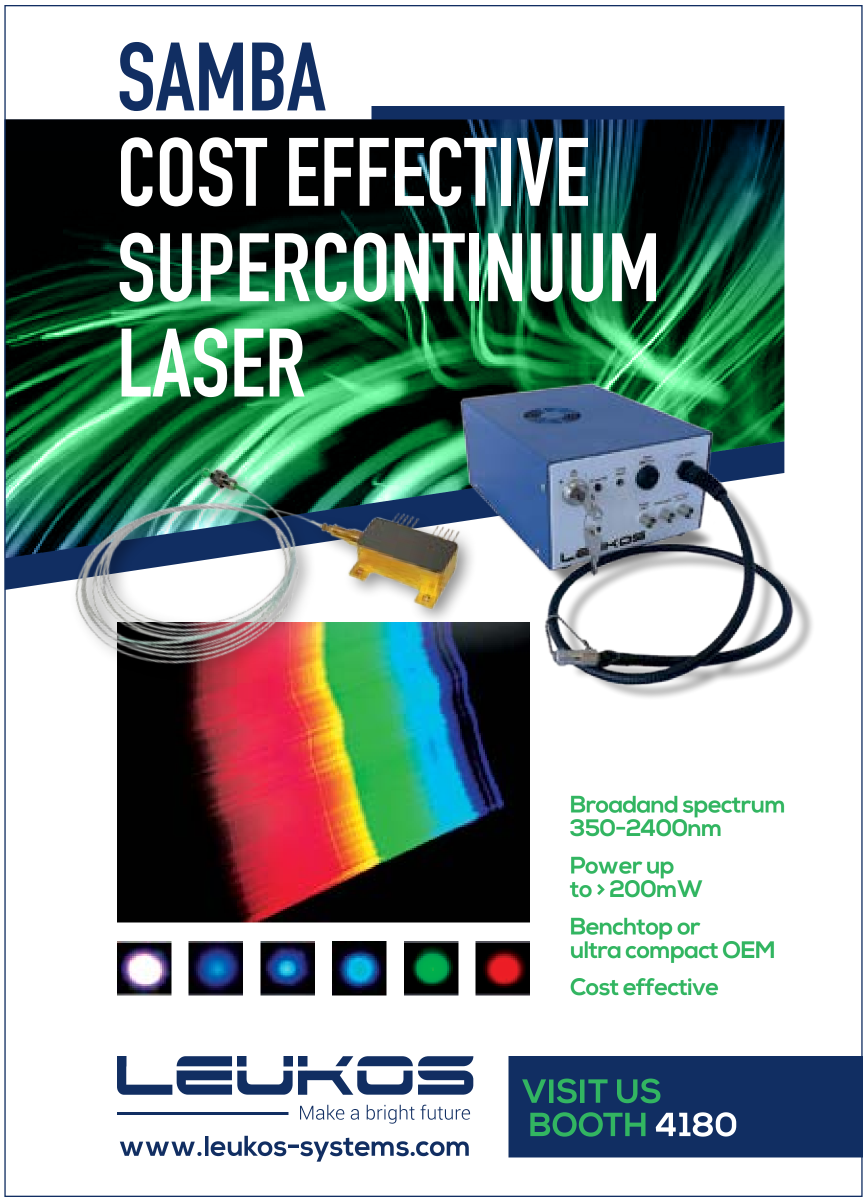
All these techniques are now gearing up for clinical translation, a process expected to be relatively smooth for a method such as OCE, where the underlying optical instrumentation is already tried and tested.

"Each technique has different applications and will take a slightly different route to market," said Kirill Larin. "Most clinics already employ OCT, for example, and simple modifications can enable the use of OCE and imaging of mechanical contrast, rather than just structural images."

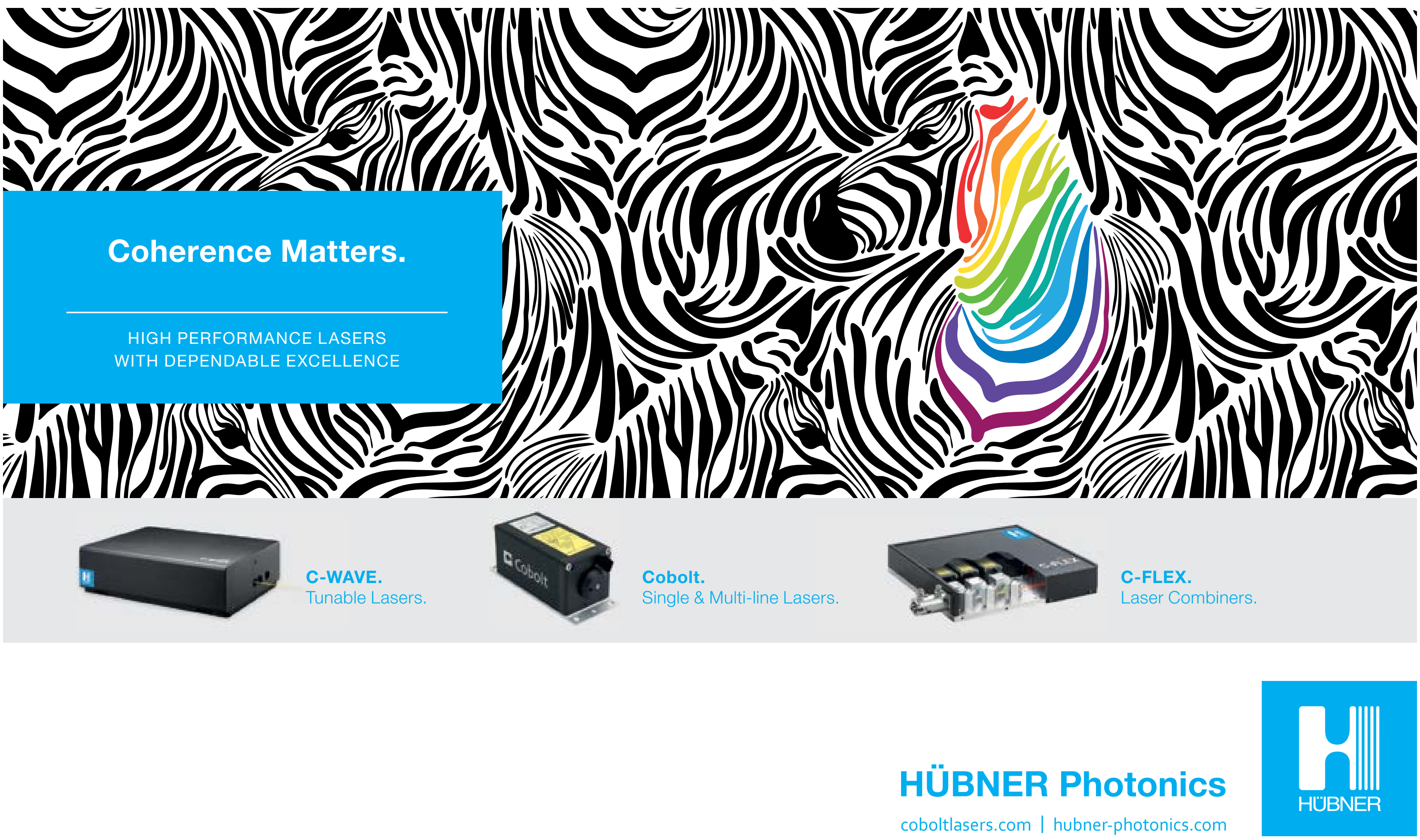
Although no commercial platforms based on tissue biomechanics have come to market as yet, the translation process will soon be bearing fruit. Larin currently has a clinical system being trialed in a hospital, while studies on keratoconus patients are bringing the techniques into the ophthalmology space.

"This field is evolving fast, and with the patents now in place commercialization is very close," he commented. "I am sure that in five years these biomechanical platforms will be in commercial use. With so many potential applications, it is only a matter of time."

TIM HAYES


SAMBA
COST EFFECTIVE
SUPERCONTINUUM
LASER
Broadand spectrum
350-2400nm
Power up
to > 200mW
Benchtop or
ultra compact OEM
Cost effective
LEUKOS
Make a bright future
www.leukos-systems.com
VISIT US
BOOTH 4180


SPIE. PHOTONICS WEST
Booth
5475
RedWave
Labs
Specialists in custom development
Laser controllers and power supplies
Digital laser and temperature controllers
Embedded control and OEM integration
Amplifiers and detectors
ISO 9001 Registered
Quality Management
UKAS MANAGEMENT SYSTEMS
TEXAS INSTRUMENTS
Design Network
PC/104
Consortium Member
www.redwavelabs.com


Coherence Matters.
HIGH PERFORMANCE LASERS
WITH DEPENDABLE EXCELLENCE
C-WAVE.
Tunable Lasers.
Cobolt.
Single & Multi-line Lasers.
C-FLEX.
Laser Combiners.
HÜBNER Photonics
coboltlasers.com | hubner-photonics.com
HÜBNER

Constantin Häfner continued from page 13

digitization. One aspect we have already initiated in Aachen – digital photonic production – can be raised to a new level by underpinning computational methods with machine learning and artificial intelligence. Applying these methods will lead to higher flexibility in production, better results, lower costs and reduce time-to-market.

Furthermore, we are working on the photonic aspects of quantum technology 2.0. The idea is to transition cutting edge R&D results into real world applications. There is a plethora of ideas but we as a community are just at the beginning to exploit the world of quantum effects commercially. For example, we are looking into how quantum information can be transmitted via existing telecommunications networks using suitable lasers. Our role is to bridge between the hardcore research physics world and industry.

We are also pushing forward into medical technology or provide solutions for aerospace applications; both require tailored laser sources. The laser parameter space is only partially explored yet; we will test new wavelengths, higher powers and tailored laser beams. Last but not least, laser-driven secondary sources are gaining interest with high peak-power lasers becoming affordable and opening up another arena of opportunities. This is where Fraunhofer ILT team plays to its strengths.

What is the Fraunhofer approach to photonics R&D?

The special feature of the Fraunhofer model is its comprehensive funding model, which includes contract research for industry, publicly-funded projects and base block funding from the Fraunhofer-Gesellschaft. The latter is a major key to the success of Fraunhofer: without losing sight of our main duties it allows us to direct research in areas that lead us into the future, conduct basic science research to better understand the underlying challenges, and conduct proof-of-principle demos.

This is of particular benefit to SMEs, which only have limited research capacities of their own. In addition, basic research builds expertise, skills, knowledge and new abilities in our workforce that spark new ideas and which we then develop into marketable innovations with in-depth expert know-how.

Nevertheless, at Fraunhofer our aim is to transfer knowledge from cutting-edge research to industry and bridge the well-known "valley of death." We pursue and couple basic research with industry-driven contract research. In Aachen, we work hand-in-hand with the RWTH Aachen University, one of the premier engineering universities in Europe, the other Fraunhofer Institutes and the Helmholtz-Association's Research Center Jülich in our neighborhood.

One of these expert networks is the Fraunhofer Cluster of Excellence Advanced Photon Sources CAPS, where we are developing ultrahigh power, ultra-short pulse (USP) laser sources and process technology. With our partners, the Fraunhofer Institute for Applied Optics and Precision Engineering (IOF) in Jena, and other Fraunhofer institutes, our goal is to achieve average powers up to 20 kW and develop processes and applications for these new laser capabilities. With this cluster we take an open innovation approach to fast-track new solutions and tailor our solutions to the real needs of our customers.

Dr Häfner: "We aim to bridge the valley of death." Credit: ILT.

The Fraunhofer has just celebrated its 70th birthday, so how has this model been successful for so long?

The German Fraunhofer model builds a direct bridge between science and industry. This applies not only to developing new technologies and transferring processes and systems to the industrial world; it also applies to training of new talents and their transfer to industry. We provide training not only in the technical world but also in competencies such as project management, team leadership, business development or strategic planning.

Many former Fraunhofer employees conducted applied research in a Fraunhofer institute after completing their university degrees. While pursuing their PhD at Fraunhofer they learn both sides: industrial contracted project work combined with solving fundamental questions in parallel. This is accomplished through the links between the ILT and the university: four full professorships hold both responsibility at Fraunhofer ILT and for their institutes at the technical university, among several other colleagues that are adjunct professors at RWTH and teach photonics classes. I must stress that technology transfer happens through people, not through manuals.

Like every Fraunhofer institute, we are closely linked to the local technical university, RWTH Aachen University. In the summer of 2019, RWTH was recognized for the second time as one of eleven "Universities of Excellence" in Germany and will receive corresponding funding from the Federal Ministry of Research and Education for the next seven years. Of course, our four associated professorial chairs are part of this. This is a big attractor for excellent people and we have several projects in which we work in integrated university-ILT teams. We can thus incorporate valuable impulses from

continued on page 28

Constantin Häfner continued from page 27

contract R&D into the knowledge that RWTH passes on to its students.

Other countries are warming up to the successful Fraunhofer approach. At LLNL we saw an increasing interest by industry in partnering with us: despite the high cost of a national lab the return of investment for the industrial partners is enormous as they can tap into the broad knowledge of subject matter experts. For industry time-to-market and the winning margin matter. However, many factors play into the success of Fraunhofer in Germany including the structure of Germany's science funding and the political support in investing into research and development. And, last but not least, the success is also rooted in the mutual trust of industry and us. This culture is deeply rooted in Germany's R&D triad of the academic world, industry, and public funding support.

> The photonics field – or should I say world – offers a great chance to develop your personal and professional skills and start an exciting career path with many growth opportunities.

How will you build on the work of Prof. Poprawe?

The success of Fraunhofer ILT rests to a large extent on the shoulders of Prof. Reinhart Poprawe, and I am grateful for the trust he and his colleagues have placed in me during the change of directorship. My goal is to maintain and expand an environment that fosters initiative and the creative power of our staff, promotes dedication and inspires passion! What unites us all is the fascination for the laser. My mission is to listen, understand needs, bring people together, build partnerships, support innovation and actively shape the future together with all stakeholders.

What are your views on international photonics business and current threats and opportunities?

Our world is rapidly changing and we must stay constantly alert to recognize new trends. So in that sense the only threat I see is us not recognizing opportunities in a timely fashion. Lasers are now in almost every product cycle. Let's not forget that is also only a tool, one of many that is needed in production. Over the past 20 years, we have seen rapid growth in laser manufacturing – specifically in cutting, welding, drilling, structuring and so on. In these areas we are getting closer to the end of the S-curve; in other words improvements are marginal unless we leap-frog with new approaches.

However, effective solutions and technologies are in demand for current mega-trends such as mobility, energy, communication, climate protection, safety and health. Photonics not only offers unique opportunities, it is also an enabler. In climate research and environmental protection, photonics can be used to lower greenhouse gas emissions and achieve the goals of the Paris Agreement; for example, with lasers we can improve LEDs and reduce their electricity consumption; or we can reduce CO_2 emissions or conserve materials through new recycling processes and technologies for environmental protection.

With the help of laser-assisted 3D printing, individualized components can be produced on demand for the end customer. This digitization process could be the enabler for a virtual spare parts warehouse thus saving resources in storage and transport. And finally, fusion energy as a clean and carbon-neutral energy source with quasi-limitless fuel supply remains one of the most important challenges for mankind. Laser-driven ICF has certainly gone the furthest in achieving ignition, but whatever solution will finally succeed, lasers will play a significant role in the path to fusion energy.

Why would you recommend a young scientist to consider working in photonics?

Photonics and specifically lasers are cool! We live in the century of the photon, maybe the millennium. It is still a young field and we have seen mindboggling inventions that have disrupted our world so many times. Photonics is everywhere in our today's life but by no means have we exhausted its potential yet – there is a plethora of opportunities that we are thinking about today, and of course all the stuff we haven't yet thought of.

Photonics and specifically lasers are a key pillar of the next revolution in production – Industry 4.0. Photonics and the laser are becoming smart! It is a fast-moving field, and what was considered a wild idea a few years ago is already reality today. This is particularly evident in life sciences. A few examples: bespoke dentures, artificial hip joints and bone replacements can be produced with laser light using 3D printing on the basis of data specific to each patient.

Photonics touches almost every field today – including computation and software development. The nice thing is that we are actually making stuff. A haptic experience of what you have done through the day is a nice reward. The photonics field – or should I say world – offers a great chance to develop your personal and professional skills and start an exciting career path with many growth opportunities.

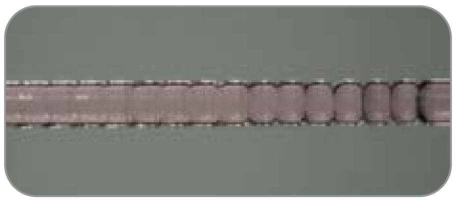
How does Photonics West support this industry?

Photonics West has emerged to become one of the most important meetings in the photonics world with increasing participation of academia. That's good news as it reflect the interest on both sides to enter into a dialogue and work together in advancing our field. An academic audience depreciates product-marketing talks and an industrial audience depreciates complex and reality-detached talks that remain speculative at the end. Program committees can steer a route through invited talks and a stronger emphasis on peer reviewing contributed papers. Promoting a workshop-like character that offers time and space for discussions that will certainly benefit the most attendees.

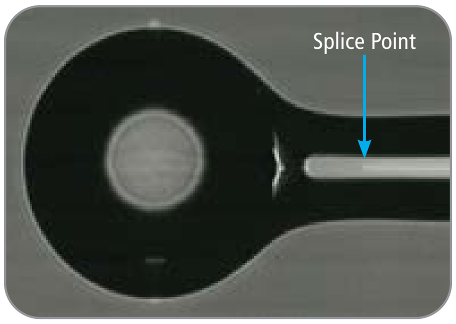
More information: German Pavilion, North Hall EF, Booth 4545-19

MATTHEW PEACH

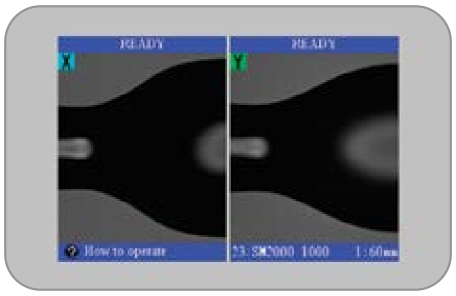
SMART TECHNOLOGY



Laser Ablated Cladding Mode Stripper



Coreless Ball Lens to
Collimate SMF Fiber Output



1 mm to 2 mm X-LDF Splice

LZM-120A+
Laser Splicing System

Photonics West Booth #3019

Introducing the new LazerMaster™ 120A+

The LZM-120A+ is an optical fiber processor / splicer using a CO_2 laser as its heating source. This machine performs laser based fiber shaping functions such as, homogenous fiber splicing, dissimilar fiber splicing, tapering, end-capping, ball lensing, and component fabrication. This new addition to the LZM-120 family now offers fiber ablation.

With the new fiber ablation capability, the LZM 120A+ can:

- Create clad mode strippers
- Cleave large-diameter fibers
- Produce sensor arrays
- Punch holes with desired shapes on glass capillaries

AFL

www.AFLglobal.com/SPIE
864.433.0333

sponsored advertorial

New tunable white light laser for characterization of nanostructures and bioimaging

For their scientific users, NKT Photonics just launched the new SuperK FIANIUM range of pulsed supercontinuum lasers.

Build on the World's best-selling supercontinuum laser, the SuperK EXTREME, the new FIANIUM has upgraded electronics and new fiber technology giving you improved performance and reliability. And it is even easier to use.

NKT Photonics' new SuperK FIANIUM pulsed supercontinuum laser

Working with bioimaging or nanostructures, you know the importance of supercontinuum lasers to give you high brightness light over a wide spectrum. The SuperK FIANIUM covers the UV, VIS, and nIR wavelength ranges from 390 to 2400 nm. Get broadband output or tune to the line you need using NKT Photonics tunable filters. Or expand further into the UV with their spectral extension unit.

The monolithic all-fiber architecture of the SuperKs makes them inherently stable and robust. This ensures a lifetime of thousands of hours with high reliability, so nothing stops your work.

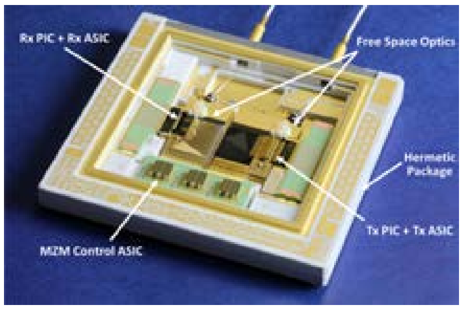
You don't need to be a laser expert to operate the SuperK FIANIUM. It is easy and intuitive to use, and you can operate it either from the front panel or via a graphical interface on your PC.

The SuperK FIANIUM is a cost-effective and user-friendly alternative to Ti:Sapphire solutions. Try it out at booth #3201.

AIM Photonics points with pride to giant steps

AIM Photonics, the huge $600 million public-private US optics consortium, based in New York state, is upbeat as it heads into its fifth year.

The consortium, known as the American Institute for Manufacturing Integrated Photonics, received an initial award of $110 million from the Department of Defense. Now, it has its sights set on not only future federal defense funding beyond 2020 but also self-sustainability through partnerships with big industry players, now that its test, asssembly, and packaging (TAP) facility is active in Rochester, New York.



MPW integrated photonic chips, ready for shipping. Credit: Peter Goetz.

"A lot is happening," said Frank Tolic, the chief marketing officer of AIM, in a major understatement. "We are working toward approval of new funding with the DoD, but we are also working to be sustainable with less government funds, now that we have an established ecosystem that provides the entire solution from design to final product all under one institute."

A new CEO will be named in early 2020, replacing Michael Liehr, who retired at the end of 2019 from his post at AIM and as the SUNY Polytechnic Institute's executive VP for technology and innovation. Show Daily asked Liehr to discuss his achievements and his future plans.

What has AIM Photonics accomplished so far?

In just four years, we have established an entire photonic integrated circuit (PIC) manufacturing ecosystem. This is a major accomplishment, considering we started with a blank sheet of paper. There were many pieces missing including design enablement standards, HVP (high volume production) manufacturing methods, advanced technology directives, and the most difficult and most expensive part—test, assembly and packaging. We leveraged the prior learning from the PIC baseline we developed at the Albany Nanotech facility, and grew from there. Now users have access to an established development and final product program not available elsewhere.

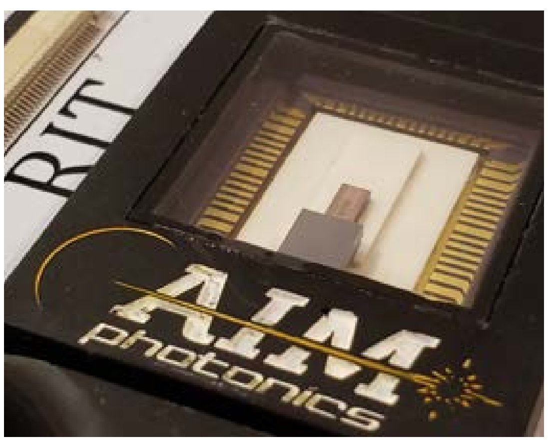
What were some of the challenges and successes?

Our first goal was establishing a team of industrial, academic and government partner/members that understood the needs for future HVP PIC manufacturing, and focusing on those needs. I would say some of the successes our partners have achieved are with advanced PIC datacom transceivers; bio and chemical sensors, and RF (radio frequency) over fiber research are great examples, not to mention the one-of-its kind 300 mm TAP facility now up and running, which houses some of the most advanced PIC packaging tooling in the world. This would not have been possible without the support of the DoD, New York state, and all of the AIM Photonics Members.

What is the structure of AIM?

Acting CEO is Doug Grose, who is also the president of NY CREATES, short for the New York Center for Research, Economic Advancement, Technology, Engineering and Science. That nonprofit, based in Albany, oversees SUNY Polytechnic's vast holdings across New York State.

AIM's Integrated Photonics Wafer Development Engineering team is located at labs in Albany. Its TAP development and operations team is housed at the AIM facility in Rochester, New York. Since it opened in 2015, the consortium has become the world's only open research foundry producing photonic integrated circuit (PIC) devices on a 300 mm diameter wafer.



Packaged AIM Photonic chip with a fiber array attached. The chip was packaged by the RIT Integrated Photonics group led by Professor Stefan Preble. Credit: Frank Tolic.

Replacing heavy wiring in jets

As an AIM Photonics member, Lockheed Martin has been working on a radio frequency over fiber solution for future warfighters. Current platforms communicate via electrical cabling, wiring and electronic signals. Replacing these structures with fiber optics and integrated photonics significantly reduces weight of the fighter and reduces power consumption.

"Integrated photonics is going to give us the opportunity to be more compact in how photonics fits onto our platforms, saving size, weight and power. And then we also get the inherent benefit of photonics which is the bandwidth capability, and the scalability we need in our platforms," said Rick Stevens, a Lockheed Martin Fellow.

AIM Photonics' TAP Facility Metrology Lab dual beam spectroscopic ellipsometer. Credit: Frank Tolic

Hundreds of wafer runs

From its start in 2015, AIM's experts have achieved success in helping with wafer design and with moving them to speeded-up multiproject wafer (MPW) runs, for companies of all sizes.

Last year, AIM reported that it had cut the timetable for MPWs from 130 days to fewer than 80 days, while adding new mask levels and functionality. The MPW program has provided benefits to small to medium enterprise (SME) companies that are producing lower-cost crucial PIC components.

AIM Photonics TAP Facility Metrology Lab scanning electron microscope integrated with secondary ion mass spectrometry. Credit: Frank Tolic.

Biomedical sensor breakthroughs

In one project, AIM has partnered with industry, university talent and startups in Rochester, New York, to advance diagnostics equipment for blood testing, and on a new generation of film sensors involving microfluidics. The sensors will monitor tiny amounts of fluid, at a sub-millimeter scale, to enable high-throughput screening, which in turn allows millions of chemical tests in a short time. "We have produced working samples of these microfluidic devices to check blood samples," Tolic said.

"The advanced node microelectronic chip facility, where AIM Photonics PIC research takes place, has provided significant capabilities and access at very reasonable costs," said Benjamin Miller, of the University of Rochester Medical School, a professor in three departments – dermatology, biomedical engineering and the Institute for Optics.

FORD BURKHART

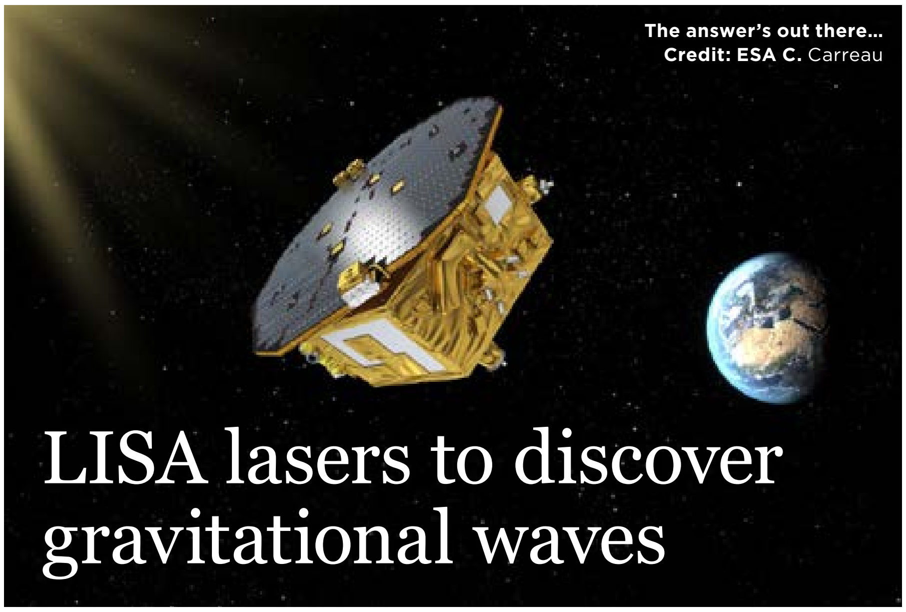
Startup winners continued from page 01

Senorics GmbH for its VIS/NIR spectroscopic sensor on chip level. "Spectroscopy can easily provide reliable data to enable robust and fact-based decision making," said CEO Ronny Timmrick. "Our mission is creating the spectroscopic tools necessary to facilitate this process."

Labby Inc. took second place with its farm-efficient milk analyzer technology. "Current milk testing is costly and time consuming," said founder and CEO Anshuman Das. "Our milk analyzer technology instantly provides quality data to farmers and informs them about individual and herd health. This crucial data lets them be proactive and take preventive measures to ensure maximum profitability."

Third place went to Circle Optics for the Hydra – a stitch-less, 360-degree camera. "The Hydra is setting a new standard for 360-degree content capture by making it as easy as a regular point-and-shoot camera," said director of operations Ian Gauger. "Our breakthrough came from realizing polygonal fields of view – not just circular – are possible."

KAREN THOMAS



The answer's out there... Credit: ESA C. Carreau

LISA lasers to discover gravitational waves

Physicists detected the first gravitational wave, produced in a collision of faraway black holes, in 2015. Now, almost five years later, the observatories have become so consistent at detecting these spacetime ripples that researchers announce candidate detections just about every week. Some experts are now looking to build the next generation of these detectors.

On Tuesday, Julia Majors of Avo Photonics in Pennsylvania described a compact prototype laser for LISA, a space-based gravitational wave observatory led by the European Space Agency (ESA) scheduled to launch in 2034.

The concept of LISA is based on three satellites, in an equilateral triangle of sides about 2.5 million kilometers long, that all orbit the sun. "Each satellite has a laser system," Majors explained. The satellites beam their lasers back and forth to each other to form an interferometer. If a gravitational wave passes through, it will ever so slightly change the distances between the satellites. By analyzing the interference patterns in the laser signals between the satellites, LISA researchers should be able to identify gravitational waves.

NASA, collaborating with ESA, charged Majors' company to build prototypes of some of the lasers that would go in each of the satellites. Majors' team has now built a prototype laser, weighing about two pounds, that can sit in the palm of your hand. The laser is based on a non-planar ring oscillator (NPRO) model. The lasing medium, a crystal, is cut such that the pump light internally reflects without a mirror. The crystal serves as both the lasing medium and the cavity, says Majors. The laser outputs 200mW, which would be further amplified to 2W in operation.

Julia Majors. Credit: Adam Resnick

Avo Photonics developed this laser to meet LISA's specific space-based constraints, said Majors. The prototype is designed to be hermetically sealed. In addition, the laser produces very little frequency noise, a particular constraint of LISA's, since the observatory is designed to sense slow gravitational wave frequencies ranging from 100 microhertz to about a hertz. Eventually, Majors' team will develop the prototype such that all the connections are solder, as opposed to epoxy, which releases gas over time.

Gravitational waves give astronomers another probe to study distant objects. These observatories serve as an "ear" on the universe to accompany optical telescopes. LISA should be sensitive to a lower frequency range than those detectable by LIGO, the observatory where researchers discovered the first gravitational wave, which is sensitive to the hertz and kilohertz range. This sensitivity should allow LISA to probe binary stars in the Milky Way, as well as supermassive binary black holes in other galaxies.

SOPHIA CHEN

Cyclists gear up with NIRS muscle monitoring tool

An ongoing study in Canada is attempting to establish whether portable near-infrared spectroscopy (NIRS) devices could be used by elite cyclists as a new pacing tool.

Optimum pacing: Assaf Yogev. Credit: Tammy Brimner

During Saturday's sessions on wearable biophotonics devices, Assaf Yogev from the University of British Columbia (UBC) described a collaboration with local Vancouver company Photonix Innovation to monitor tissue oxygenation in different muscle groups.

The tests involved 11 trained male cyclists, who each completed two pacing programs designed to take them from warm-up to exhaustion in different ways. Initial results were complicated by issues with proprietary software, but since then a similar follow-up study using four NIRS sensors made by US firm Moxy has been completed.

Yogev and colleagues placed the sensors on the cyclists' glute and deltoid (shoulder) muscles, as well as their left and right vastus lateralis – the largest quadricep muscle, and one that generates much of the power in cycling.

Results showed how tissue oxygenation decreased in the glute and quad muscles as the cyclists were ramped to exhaustion, matching up well with other physiological changes in heart rate and pulse oximetry as the cyclists became tired, although little change was observed in the deltoid.

While it's too early to say whether or not NIRS sensors will prove to be as useful to elite cycling teams as the introduction of heart-rate monitors and power meters in the past, the UBC group is now looking to check the repeatability of the laboratory tests, before extending them to in-the-field measurements with cyclists on road bikes.

MIKE HATCHER

VCSELs

continued from page 03

In 1994, a team at the University of Texas, Austin, led by Diana Huffaker and Dennis Deppe, developed the first oxide VCSEL. Fabricating a VCSEL via oxidation methods results in lower threshold currents, higher efficiencies, and better reliability, Jewell said. Kent Chouquette and Kevin Lear of Sandia National Laboratories later demonstrated even better efficiency and reliability. Today, Jewell said, oxide VCSELs are by far the most common.

In the mid-1990s, researchers had a number of applications in mind, including laser printers, bar code scanning, and CD-ROMs. But commercial VCSELs didn't take off until the end of the decade, with the rise of the internet. VCSELs turned out to be a perfect fit for short-distance communication, and in particular Gigabit Ethernet used in local area networks.

And now the commercial potential for VCSELs has skyrocketed, after Apple's release of the iPhone X in 2017.

The iPhone X is equipped with several VCSELs that enable its facial recognition technology, which is based on structured light. The phone recognizes a face by analyzing the distortion of reflected beams. "The excitement starts when you get a billion phones and a few lasers in each one," Nogee said. "You multiply that out and you get a lot of revenue quickly."

For the last two years, Android phone makers have been playing catch up, he said. "Once Android phones get them, we're talking about an even bigger market than Apple alone."

Companies are ramping up production. In 2018, Finisar—which provides Apple with VCSELs and was acquired for $3.2 billion last year by rival optoelectronics firm II-VI—opened a new plant to manufacture the lasers in Sherman, Texas.

Smart phone applications will likely constitute the lion's share of the VCSEL market. But VCSELs have other uses, too. The 3D-sensing market for lidar in self-driving cars, while smaller, is forecasted to grow by 57%, according to Nogee. VCSELs can also be used for atomic clocks and a variety of sensors that detect motion, gestures, and even how many people are in an elevator.

"The sensing application is really interesting and a big one," Nogee said.

Retired for 20 years, Iga is no longer active in VCSEL research. But, he said, "I am pleased to see a lot of people joining the research and development of VCSELs, and developing newer technology and applications." Seeing how far his idea has gone, he said, brings him satisfaction.

MARCUS WOO

VISIT NOVANTA AT BOOTH #1133

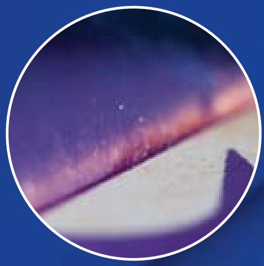
We deliver innovations **that matter**

Rely on our engineering expertise for your most complex technical challenges. At Novanta, we develop lasers, beam steering sub-systems, and precision motion and machine vision solutions for applications that require extreme precision and accuracy.

When you need to develop innovations that achieve breakthrough performance and enhance people's lives, turn to Novanta, your trusted technology partner.

Micromachining

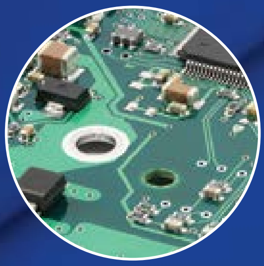
Digital Converting



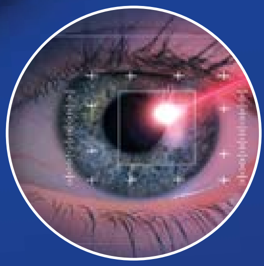
Marking & Coding

Laser Additive Manufacturing

Metrology



Drilling & Perforating



Microscopy & OCT

Robotics & Automation

Novanta

ARGES • Cambridge Technology • Celera Motion
JADAK • Laser Quantum • Synrad
ARE ALL PART OF NOVANTA