TUESDAY EDITION
SPIE. | optics.org | TUESDAY JANUARY 30, 2018

PHOTONICS WEST. SHOW DAILY

BiOS Expo news
p.04 and p.33

Virtual experience draws a *real* big crowd

The VR, AR, MR One Day Industry Conference and Demo, the new conference and interactive event at this year's Photonics West, proved irresistible for eager attendees on Monday morning.

Drawn by a diverse program introduced by charismatic conference chair Bernard Kress, who is Partner Optical Architect at Microsoft HoloLens, the crowd discovered that there are many opportunities for new types of photonics solutions to transition alternative reality (AR) technologies from gaming and other niche sectors into the widely-forecast multi-billion dollar mainstream markets.

Kress introduced an A-list of speakers from Silicon Valley companies and beyond, all scrambling to capitalize on the growing opportunity.

"Why are we all here? Why is this room packed now?" he asked. "Perhaps because analyst Gartner has placed virtual, augmented and mixed reality on their blue-chip path to widespread adoption within five years. That means they believe that these technologies will soon become valuable marketplace products, and perhaps it's also because of analysts determining that this will be a $150 billion value market in the next five years. Digi-Capital and Morgan Stanley have both made this same prediction."

SPIE President Maryellen Giger at the VR, AR, MR conference. Photo: SPIE.

Kress added, "This new SPIE event is the largest event in AR-VR-MR hardware planned for 2018, so far, especially for optical architectures, optics, displays and sensors, which together present some of the main challenges for next generation AR-VR headsets."

He likened the pace and unpredictability of these emerging technologies to the early days of the photonics industry, some 40 years ago.

The day-long industry conference comprised 19 invited talks, a panel on the current optical technological challenges and successes for VR, MR and AR, with very popular hands-on — perhaps eyes-on? — demonstrations.

As well as Microsoft's Kress, the morning sessions included inspirational talks from AR and VR specialists from some of the biggest technology companies in the business: Intel, Google, and Oculus Research to name a few.

Ronald Azuma, principal engineer and research manager at Intel Labs, credited with coining the term "augmented reality," identified what he considered to be the four technical challenges facing VR/AR/MR displays — which he said the photonics industry could help to resolve.

Other speakers stressing that the photonics sector is needed to help meet the technology challenges of making VR and AR appear genuinely seamless with "actual" reality were Jerry Carollo, optical architect at Google, and Doug Lanman, director of computational imaging at Oculus Research — already well established as a leading provider of VR and AR technologies.

According to all those speakers, the technical challenges that the photonics community can help to solve include developing more dynamic adaptive optics, transparent displays that enable 90%-plus light transmission, and displays with significantly higher refresh rates of 240Hz and faster.

MATTHEW PEACH

DON'T MISS THESE EVENTS TODAY.

PLENARY SESSION
NANO/BIOPHOTONICS
(10:30-11:30 AM, ROOM 3001, West)
Kishan Dholakia (Univ. of St Andrews)

INDUSTRY EVENTS
BRINGING QUANTUM TECHNOLOGIES TO THE MARKETPLACE
(8:30-9:45 AM, Room 21, North)

IP PROTECTION AND TRADE COMPLIANCE WITH CHINA
(8:30-10 AM, Room 23, North)

SPIE JOB FAIR
(10 AM-5 PM, South Exhibit Hall)

NEXT-GENERATION FIBER TECHNOLOGY PANEL
(1:30-2:30 PM, Room 23, North)

SOLID-STATE LIGHTING PANEL
(1:30-3 PM, Room 21, North)

GRAPHENE – CMOS INTEGRATION TALK
(3-3:45 PM, Room 23, North)

SILICON PHOTONICS AND PICS PANEL
(3:30-4:45 PM, Room 21, North)

See the technical program and exhibition guide for more details on daily events. Conference registration may be required. Industry events are open to all registration categories, except where noted. Read daily news reports from Photonics West online: spie.org/PWnews.

IN THIS ISSUE.

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SOUTH HALL - BOOTH #307

BiOS Hot Topics: what's old is new again and what's new is ... amazing

The old mingled comfortably with the new at the BiOS Hot Topics session Saturday evening. From photodynamic therapy (PDT) and its next-generation cousin photodynamic priming (PDP) to high-resolution imaging tools that are moving us closer to understanding the idiosyncrasies of the brain, the quick-fire presentations provided a high-level, deep dive into the growing optical armamentarium aiding researchers and practitioners at the benchtop and, increasingly, the bedside.

The evening kicked off with the presentation of several awards, including the 2018 SPIE Britton Chance Biomedical Optics Award, which paid homage to Tayyaba Hasan, a professor of dermatology at the Wellman Center for Photomedicine at Massachusetts General Hospital, for her decades of pioneering research in PDT. Hasan then gave an illuminating talk about the current state of PDT research and some of the new directions in which this technology is moving.

"PDT is all about achieving light-activated chemistry to cause the desired alterations in cells and tissues of interest," she said. "There are many approvals for cancer and non-cancer pathologies and new applications emerging; in addition to classical PDT there is PDP.

"I hope there will be a change in perspective, that this technology will serve many purposes," she said, adding that as well as cancer treatment it can also become an enabler and enhancer of existing drugs and modalities at lower concentrations and lower toxicities.

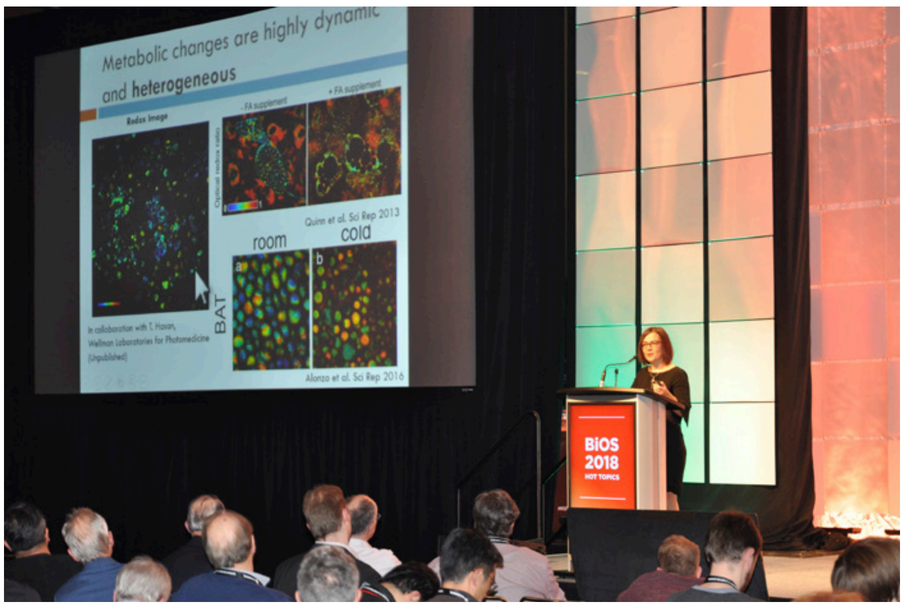
Brian Wilson, a professor at the University of Toronto and head of the Applied Biophotonics group at Princess Margaret Cancer Centre, also discussed new directions in PDT. His talk focused on the intersection of photomedicine and radiation medicine, "an emerging field of great interest that combines the biological advantages of PDT with the physical advantages of ionizing radiation."

His group's research emphasis includes two-photon PDT for melanoma, which has achieved significant efficacy in pigmented melanoma; and the use of PDT in lung transplantation to disinfect the lung tissue prior to surgery and reduce the pathogen load.

"Getting the correct light distribution to the whole lung is challenging, but we could use whole x-rays to achieve distribution to the whole lung," Wilson said. "So, we are looking at the intersection of light-based medicine with x-ray-based medicine."

One of the most anticipated talks of the evening was given by Qingming Luo, a vice president at the Huazhong University of Science and Technology (HUST) in Wuhan, China, and an executive at the Wuhan National Laboratory for Optoelectronics (WNLO). Luo leads a new facility called the HUST-Suzhou Institute for Brainsmatics, which has a 5-year budget of 450 million yuan (US$67 million) and employs some 120 scientists and technicians. Luo, who calls himself a "brainsmatician," also built the institute's high-speed brain-imaging systems, which visualize brain-wide networks using an integrated, systematic approach to measuring, analyzing, managing, and displaying whole brain data.

"My group developed the MOST system, which combines fluorescent labeling, whole brain embedding, big data processing (pre-processing and 3D reconstruction) for neuron morphology, connectome/projectome, vascular networks and cytoarchitecture, and brain mapping," he said.



Irene Georgakoudi at the BiOS Hot Topics session. Photo: SPIE.

Luo showed several examples of the high-resolution detail of neural circuits and single neurons that can be obtained using MOST. This system can also be used to image the brain's vascular network, and his group just reported on a whole brain atlas of certain regions of the brain.

"With our approach, we can achieve brain-wide registration of multiple parameters with high spatial resolution," he said. "We have bridged the gap between electron microscopy and MRI for brain imaging and reconstruction."

Luo's talk was not the only one that focused on brain imaging. Hillel Adesnik of the University of California, Berkeley, gave an overview of his group's work with a new multiphoton microscopy method for controlling neural activity in 3D called 3D-SHOT (scanless holographic optogenetics).

Among other things, Adesnik's approach has been used to study the whisker maps that rodents create in order to navigate their surroundings. "We want to answer the question of how different patterns of neural activity drive different perceptions," Adesnik said.

Other highlights from the BiOS Hot Topics session, facilitated by Tufts University's Sergio Fantini, included:

- Sune and Katarina Svanberg of Lund University and South China Normal University discussed biophotonic applications of GASMAS (gas in scattering media absorption spectroscopy), an optical technique for sensing and analysis of gas located within porous and highly scattering solids that was introduced by Sune Svanberg in 2001. Among the applications they discussed were food monitoring for safety and freshness based on non-intrusive measurement of oxygen levels; and medical diagnostics, such as monitoring tissue degradation following hip replacements, oxygen levels in neonatal and premature infants, and diagnosing ear infections via the gas signals that occur behind the ear drum.
- Keisuke Goda of University of California, Los Angeles, discussed his group's large-scale, single-cell analysis involving high-speed imaging technologies. One focus of this work is to study cellular heterogeneity — the study of different traits of individual cells in populations such as euglena, a genus of single-celled flagellate eukaryotes. The group has been working with three methods: optical time stretch microscopy, frequency division multiplexed microscopy, and stimulated Raman scattering microscopy. "The process of studying cellular heterogeneity takes a long time, so high-speed imaging is a good solution for this," Goda said.
- Irene Georgakoudi of Tufts University described her group's work with two-photon microscopy for assessing cellular metabolism. Because metabolic changes are highly dynamic and can occur in seconds, minutes, days, weeks, months, even years, "many techniques are not great for monitoring metabolic changes," she said. "We are interested in understanding the meaning and impact of metabolic change in our ability to treat things like cancer." Their research into optical metabolic biomarkers takes advantage of two fluorophores that naturally fluoresce: NADH and FAD, which are involved in many metabolic pathways. They are looking at applications in drug discovery, drug safety, and treatment optimization.
- Turgut Durduran of the Institut de Ciencies Fotoniques-ICFO in Spain, is working to bring diffuse correlation spectroscopy to the bedside for non-invasive optical blood flow measurements in deep tissue. His team is currently working to build a less expensive consumer-grade speckle contrast optical spectroscopy (SCOS) custom detector array and has developed a handheld SCOS prototype that allows for scalable, parallel detection of cerebral blood flow.
- Julia Walther of the Technical University of Dresden gave a detailed presentation on the state-of-the-art of hard- and soft-tissue applications for optical coherence tomography (OCT) in the oral cavity. While OCT has been well-established in dentistry, she said, there are still questions about the most effective for diagnostic purposes in a clinical setting. Her group is working with a commercial endoscope for *in vivo* imaging of enamel dentin, gingiva, mineralization defects, epithelium and lamina propria.

Other awards presented at the BiOS Hot Topics session were the SPIE 2018 Technology Innovator Award to Elizabeth Hillman; the inaugural SPIE-Franz Hillenkamp Postdoctoral Fellowship in Problem-Driven Biophotonics and Biomedical Optics to Haley Marks; and a second Hillenkamp award to Jan Philip Kolb with support from the Hillenkamp Fellowship Committee, Thorlabs, and Blossom Innovation (see page 34).

KATHY KINCADE

Hotlight unveils compact multi-photon source

Hotlight Systems says that its prototype optical parametric source could rewrite the nonlinear microscopy rule book. The Australian firm's "MIROPA-fs-M" prototype, seen for the first time at the weekend's BiOS Expo, is suitable for both two-photon and three-photon imaging and, once fully commercialized in around six months, will be aimed at applications in optogenetics and multi-photon microscopy.

Though not yet a trading entity, Hotlight is expected to be spun out of the Australian National University in Canberra within a few months, after a series of MIROPA sources attracted attention from research groups around the world.

Hotlight Systems' compact source for two-photon and three-photon microscopy, unveiled at the weekend's BiOS Expo, is based around crystal technology developed at the Australian National University. Photo: Joey Cobbs.

Thanks to the use of a longer nonlinear PPLN (periodically poled lithium niobate) crystal than is typical in such systems, the multi-photon source is far more compact than rival systems, and needs much less power from a laser driver. Developed by CTO Barry Luther-Davies and colleagues, the technology exploits physics dictating that gain guiding overcomes group velocity dispersion — a concept that Hotlight has protected with intellectual property.

It means a PPLN crystal around 10 mm long can be used, instead of the millimeter-sized nonlinear optic normally employed in such systems, and that translates to much higher gain and much lower source laser power, which can then be provided in a far more compact footprint.

"As a source for two-photon imaging, MIROPA-fs-M can deliver single pulse energies that substantially exceed those available from common Ti:sapphire oscillators," says Hotlight, adding that this means the beam can be sub-divided to simultaneously excite a large number of sites — potentially very useful in optogenetics research.

Offering continuous tuning in the 1300nm and 1600nm three-photon window, as well as a tunable output for two-photon imaging around 800nm, the prototype offers a combination of high pulse energy, and user-selectable repetition rate and wavelength. What's more, Hotlight indicates that, once commercialized, the MIROPA-fs-M will be able to offer users two-photon and three-photon capability at the kind of price normally paid for a standalone two-photon source.

The Australian National University and Hotlight Systems are at booth #4052

Menlo Systems' "YLMO" fiber-based femtosecond laser source, shown here illuminating a glass block on Thorlabs' BiOS Expo booth, is aimed at biophotonics applications in two-photon fluorescence excitation of Green Fluorescent Protein (GFP) and its variants. Said to combine excellent stability with low-noise operation, the YLMO series is engineered for OEM integration and 24/7 operation, and offers more than a watt of average output power centered around the 930 nm wavelength. "Combined with the very compact footprint the YLMO-930 is the perfect choice for applications in life sciences where reliability counts," says Menlo. Photo: Joey Cobbs.

NON-INVASIVE PROBE TRACKS BRAIN BLOOD FLOW

Sports teams increasingly need rapid information about a possible brain injury to a player, and a photonics researcher in Barcelona could provide the answer with a spectroscopy tool to assess blood flow in cases of concussion or for stroke patients.

Turgut Durduran, a physicist at Barcelona's Institut de Ciències Fotòniques (Institute of Photonic Sciences), or ICFO, caused a stir as he introduced his new technology to a crowded hall at Saturday evening's BiOS Hot Topics session.

He showed two versions, one called SCOS — for speckle contrast optical spectroscopy — and SCOT, a tomographic equivalent. They collect blood flow measurements, with claimed advantages in cost, portability and scalability.

"SCOS and SCOT will be building blocks for a new trend in spectroscopy for blood-flow measurement," Durduran said. "We have developed a new detector, bringing costs down by 80%, to a few thousand dollars."

The spectroscopy probe is a user-friendly design, he added, and one that can be made in an industrial setting. Currently too large to be truly portable, the SCOS device will soon be a palm-sized, turnkey product, indicated Durduran.

After signal-to-noise issues are overcome, the envisaged USB-powered technology is expected to collect an image each second. The ICFO researcher showed real results from human subjects, demonstrating the non-invasive measurement potential.

The device is set to be made available through Hemophotonics, a spin-off from Durduran's ICFO laboratory. "I think this brings it from high-end critical care measurement to accessing every physician's office and even to field use by non-medical personnel," Durduran said.

"It shouldn't require any training, that is the goal. We are not there yet [but] I think it's very exciting, opening new applications areas for people who need quantitative diagnosis in the field."

FORD BURKHART

Leukos Systems extends supercontinuum coverage

French startup Leukos Systems, which develops supercontinuum laser sources for applications in spectroscopy, metrology and high-resolution imaging, is presenting what it describes as two significant recent developments at this week's BiOS and Photonics West exhibitions (see booth #4058). They include a watt-level source covering the 700nm-4.8 micron wavelength range, and a "palm-sized" 250mW laser that delivers over the range 320nm-2.4 microns.

CEO Guillaume Huss claims that since NKT's acquisition of Fianium in 2016, he considered Leukos, based in Limoges, to be the global number two supplier of supercontinuum sources.

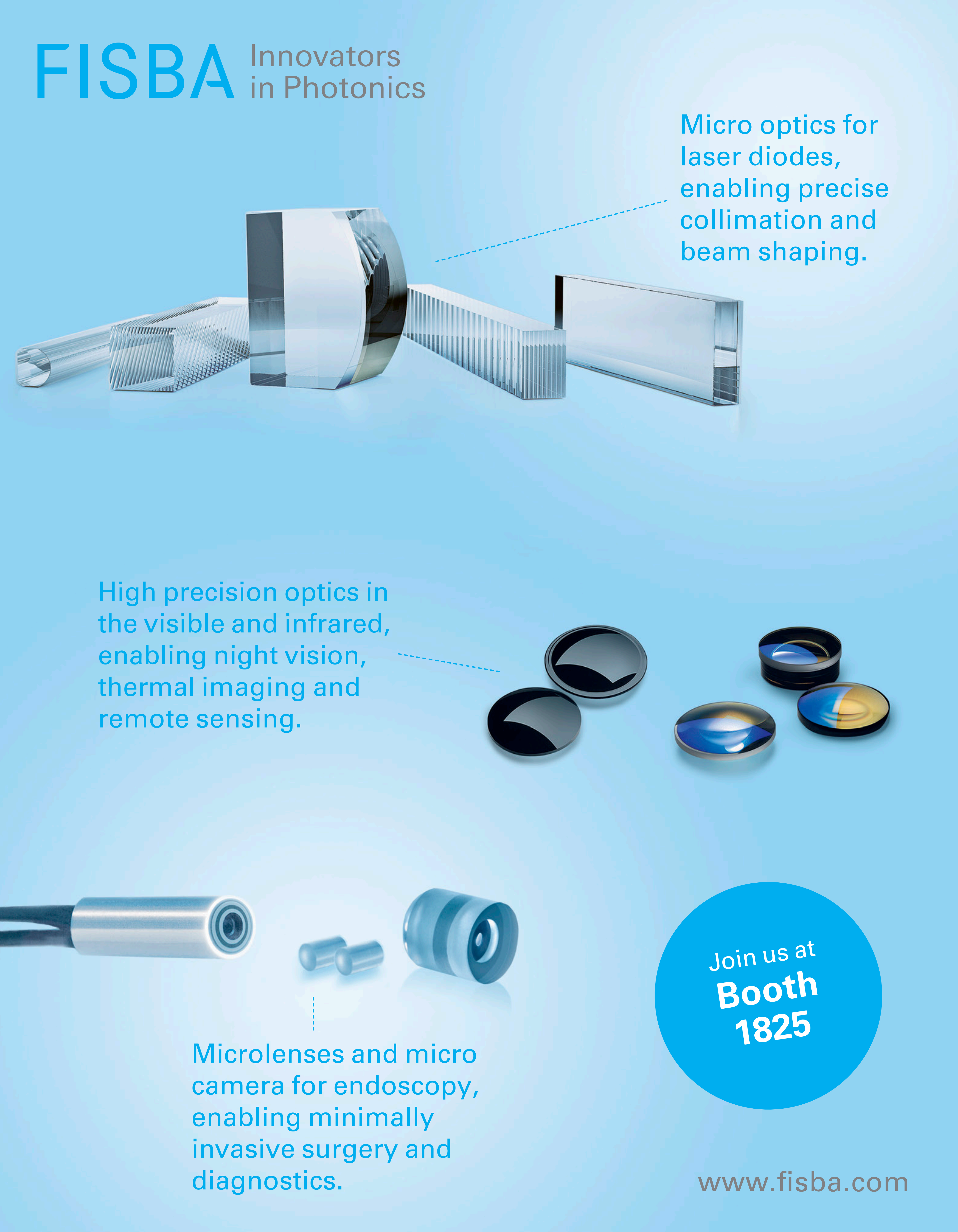
"Our goal is to extend the wavelength range of our supercontinuum sources," he told *Show Daily*. "Typically the industry standard for these lasers extends to around 4.5 microns but we have managed to reach 4.8 microns. This is important because there are many molecules of interest, for chemical analysis and military countermeasures, where the analytical wavelength needs to be much longer."

Leukos has achieved its extended range thanks to a development partnership with Alphanov, the photonics technology research group of the Bordeaux Route des Lasers cluster, and Le Verre Fluoré, Bruz, Brittany, which develops fluoride glass and fiber technologies to deliver the mid-IR wavelengths. It is believed that the French military is interested in supporting such a development.

Huss added that the second, more compact source could be integrated into microscopy and spectroscopy systems, but also that it was of a sealed cavity design and specified to operate over the temperature range -10 to 60°C — so it could be deployed in harsh field environments. This compact supercontinuum source is based on a microchip laser that has also been developed by Leukos.

Huss said, "This laser is ideal for use in field lidar systems such as for environmental monitoring and is currently being evaluated in a Finnish forestry monitoring application."

MATTHEW PEACH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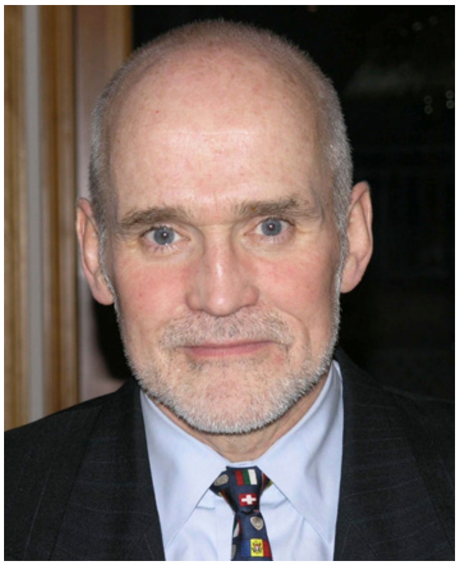
Rational exuberance

SPIE CEO Eugene Arthurs hails the photonics technology behind the magic of the modern world.

With my Gaelic *céad míle fáilte*, a hundred thousand welcomes, to Photonics West 2018, I will only have about four welcomes for each attendee, but these will be warm and heartfelt welcomes from the SPIE leadership and staff. We care that you will have a productive and enjoyable event and that together we will move optics and photonics forward toward a prosperous and generous future.

Photonics West 2018 reflects the welcome and healthy surge in our industry. We had a bigger boom before, back in 2000-2001, but that was built on hype, expectations for the dot-com world getting too far ahead of reality. Some of those dreams for photonics-enabled internet traffic and for e-commerce have been since surpassed without much fanfare. We are now blasé about the supercomputer we have in our pockets, fed by photons and which feeds our eyes with information in glorious imagery — information that was likely called up, or down for those who like the cloud idea, from huge data centers.



SPIE CEO Eugene Arthurs.

The current global output of data is roughly 2.5 quintillion bytes per day. Much of it ends in these myriad data centers, which some claim now add as much data per year as humanity had produced in all the centuries since our origin. This is an expanding frontier of opportunity for photonics. We are already tackling the bandwidth and energy limitations of information processing and storage with photonic pipes. Soon we'll be on the chips with photonic integration, and some of the younger attendees here will eventually have to use virtual museums to recall the era of the all-electronic computer. Quantum photonic computers may be in our future, but certainly photonics will compute.

Photonics West 2018 reflects the welcome and healthy surge in our industry.

SPIE is technically a not-for-profit corporation, as are most professional associations, and so, like many public companies, we have an Annual General Meeting (AGM). We do not have shareholders to satisfy, but at our AGM during SPIE Optics + Photonics in San Diego, we do summarize our accomplishments and try to give a sense of the environment for our 20,000 members. At the 2017 meeting, I was struck by the number of currently exciting areas for our field. Photonics West will showcase the latest in these: lidar for autonomous vehicles, augmented reality, mixed reality, deep learning in imaging, and the ever increasing clinical application of photonics, as well as how SPIE's conferences first fostered these technologies decades ago.

One might note that for another "hot area" for SPIE, quantum technologies, the revolutionary and strange ideas about quantum behaviors are around 100 years old. The panel today on "How Global Investment is Bringing Quantum Technologies to the Marketplace" will give you a sense of the developing momentum for the exploitation of the quantum world. Many of the advances are based on work with our familiar quantum, the photon.

And who, even in the irrational exuberance of 2000, would have forecast that we would be able, or could afford, to have information about our genome to perhaps surprise us about our heritage — or more importantly, provide information on our predisposition to illness and to allow us to optimize personalized treatment. Maybe science and medicine are now so overwhelming that we who work to advance both are among the many who see all of this as some kind of magic. We should recall that we are behind the sorcery. Most genome readers and cytometers are packed with lasers and sensors, which matured on the exhibit floor at SPIE events. The processors and memory that are key to genomics were produced by deep-UV excimer lasers using the old microscopy "trick" of immersion.

Tomorrow you will have the occasion to assess another opportunity. The role of photonics in Industry 4.0 will be immense. 3D printing is taking hold in the demanding aerospace industry. Robot vision, 3D imaging, and optical metrology will all be integral in this fourth industrial revolution. Catch the developing opportunities at the session on "3D printing and Industry 4.0: An industry perspective."

2017 was a year of strong growth for our industry. The stock prices for many of the exhibitors on the floor here in the Moscone Center shot up. To me, this was long overdue recognition, and our industry has strong tail winds. I mentioned some of the potential above. The Internet of Things is also upon us, and if you don't believe me, ask Siri, Bixby, or Alexa. The semiconductor chip and equipment sectors popped in 2017 and look to at least hold close to these rhapsodic levels for 2018. Europe has finally shook off the Great Recession, and the tipping of the US tax laws to favor corporations (known to some as tax reform) is also underpinning what I hope this time is rational exuberance. Heady days, indeed. You have the opportunity to take advantage of them here at Photonics West in this wonderfully eclectic city by the Bay. My recommendation is a quote from Gandhi, "*The future depends on what you do today.*" Make the most of it!

EUGENE ARTHURS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Faces light up over VCSEL prospects

Newly-emerged sensing applications like facial identification in smartphones and the chance to help autonomous vehicles "see" are transforming a mature laser technology, finds Andy Extance.

Until 2017, trying to sell a product that relied on shining lasers at customers' faces might have been expected to alarm those customers, and bring on commercial failure. But, as it has often done, Apple has defied that expectation with its latest iPhone, and its face identification functionality.

With that technology, Apple has given top-emitting vertical-cavity surface-emitting lasers (VCSELs) a launchpad into consumer markets. Gaining momentum both from smartphones and from potential use in intelligent and autonomous vehicles, VCSEL companies are therefore upgrading their fabrication capabilities, as they position themselves to benefit.

More traditional needs for VCSELs as light sources to carry data communications over optical fiber are also growing, explains Mark Lourie, director of corporate communications at Saxonburg, Pennsylvania-headquartered VCSEL producer II-VI. "Rapid growth of services such as cloud computing and video streaming is driving very strong demand for server-to-server communications within large data centers," Lourie says. These servers communicate via active optical cables using VCSEL arrays over up to 300 meters. And even this VCSEL technology is now finding an application in consumer electronics, in optical HDMI cables. II-VI has recently invested in additional manufacturing capacity to ramp up production lines serving these markets and meet growing demand, Lourie notes.

The bar along the top of the front of the iPhone X contains the VCSEL-based dot illuminator, time-of-flight sensor and other components that form its True Depth camera. Credit: Apple.

VCSELs' use as a light source in sensors monitoring their surroundings, for example in combination with detectors that measure reflected or scattered light, isn't new either. II-VI has a long track record supplying them for sensing in computer mice and other devices, Lourie stresses, and foresaw the need to scale up to compete in this area. In 2016, II-VI acquired epitaxial growth and device fabrication capabilities on 6-inch gallium arsenide (GaAs) wafer platforms, transferring, developing, scaling and qualifying VCSEL manufacturing processes and products in these new manufacturing lines. "As a result, II-VI is today the only vertically integrated 6-inch [wafer] VCSEL manufacturer," Lourie says. "In the second half of 2017, II-VI significantly ramped up manufacturing of VCSELs for 3D sensing using these 6-inch manufacturing lines."

Late 2017 also saw three-dimensional sensing — as deployed in the iPhone X — introduced to consumer electronics for the first time. Currently it's thought that to detect whether there's something in front of the iPhone X, it uses a "time-of-flight" (TOF) sensor, powered by an LED-based infrared illuminator. TOF itself isn't new, having first been used in smartphones as a rangefinder in the "laser autofocus" of LG's G3 model in 2014. This method illuminates an object repeatedly at a very fast rate, often using VCSELS, and measures the time taken for light to reflect or scatter back to a detector. It is especially useful for measuring distances and speeds.

If the TOF sensor detects an object, it triggers the iPhone X's True Depth camera to take a picture. If that reveals a face, the phone activates its dot projector, shining a single infrared VCSEL through an optical system to create 30,000 spots, while its infrared camera captures an image. It sends both regular and spottily illuminated infrared face images to an application processing unit (APU) that can recognize the owner and therefore unlock the phone.

Because the system senses depth, you can't hack it with photographs, says Manuel Tagliavini, principal analyst for MEMS and sensors at London, UK-headquartered research firm IHS Markit. It may be hackable with three-dimensional face reproductions, but previous fingerprint recognition technology could be fooled more easily, Tagliavini says.

Coming soon: to your pocket

IHS Markit has seen differing origins for the iPhone X's "structured light" dot projector. Tagliavini had suggested that the primary supplier was Unterpremstätten, Austria, headquartered ams, through its sensing subsidiary Heptagon, which is based in Santa Clara and can produce its own VCSELs. However, the late-2017 news that Apple had placed guaranteed orders enabling Sunnyvale-based Finisar to scale its VCSEL production confirmed the Californian company's key position in the supply chain.

Tagliavini says that Ulm, Germany, headquartered Philips Photonics may also have a small share of the iPhone X market, while he thinks that Milpitas, California, headquartered Lumentum, despite persistent links with Apple, seemed not to be involved in the iPhone X.

The analyst notes that Finisar didn't report significant earnings from high-power VCSEL arrays for sensing in the quarter ended July 2017, due to a change in its processes expected to drive production of next-generation sensors. The December announcement that Apple would spend $390 million on Finisar's VCSELs clarified the relationship, and as a result Finisar will refit a former

continued on page 11

VCSEL prospects continued from page 09
Texas Instruments silicon semiconductor fab in Sherman to GaAs wafer processing.

While Philips Photonics' general manager Joseph Pankert was unable to comment on any direct involvement with Apple, he emphasizes that the firm supplies VCSELs both for sensing and data communications. Philips Photonics also covers a broad spectrum of industrial applications, including sensors, but also combining many VCSELs to produce lasers for materials processing. Nevertheless, Pankert foresees that the iPhone X's trendsetting will prove especially fruitful. "I expect that all smartphones in the world will eventually adopt sensor technologies based on VCSELs," he predicts. The technology will then spread to tablet computers and wearable devices, consuming a large quantity of VCSELs, Pankert asserts.

Consequently Philips Photonics has also been expanding, having added a second, much larger, cleanroom into which it was recently moving production equipment. "We can double or even treble our capacity by 2018," Pankert says, adding that further scale-up could be achieved with foundry services, if needed.

The company is also hiring more engineers to build up its technical capabilities, which Pankert believes will be just as important. "We can accommodate quite different wavelengths, product designs and different chip sizes," he says. "That level of flexibility is necessary as I believe that VCSELs will become more sophisticated. We really have to think about how to integrate VCSELs with a driver, although not necessarily on the same chip. It's very much about design capabilities, and working with customers to make a full system that works optimally."

Every existing commercial device stays "well below" the laser power limit needed for safety, in particular to avoid damaging people's eyes, Pankert stresses. For mobile devices, optimal function includes minimising VCSEL power consumption and heat production, he points out.

Yet that's quite a change from VCSEL technology that originated in telecommunications, notes Chuni Ghosh, general manager at Princeton Optronics, based in Mercerville, New Jersey. For that application, devices didn't need to be optimized for high efficiency. By contrast, Princeton Optronics' technology originates from ten years of development, funded by the US military, specifically to optimize this parameter. "We have the highest efficiency and highest power density," Ghosh claims. "No one even comes close." As a consequence, ams snapped up Princeton in March 2017, complementing related capabilities the Austrian firm is cultivating.

Workers in Finisar's wafer testing area. Apple has committed to buy $390 million of VCSELs from the California-headquartered photonics company. Credit: Finisar/Apple.

Long-awaited overnight success

Unlike Finisar, Lumentum, and Philips Photonics, Princeton Optronics operates on a fabless basis, manufacturing its device using semiconductor foundries and device packaging companies in Taiwan. "We're able to deliver many thousands of 6-inch wafers per month," Ghosh says, equating to the hundreds of millions of pieces per year required by cell phone OEMs and taking advantage of existing GaAs wafer capacity to provide power amplifier components in their billions.

Other parameters are also important, depending on the application, and Ghosh cites examples in TOF sensing and lidar. Getting the best depth resolution in both means producing the shortest pulse possible. That in turn means minimizing the time it takes for VCSELs to rise to and fall from their peak output. Ghosh stresses that Princeton Optronics' devices can produce pulses of 50 picoseconds or less.

Similarly, with structured light, depth resolution requires bringing spots as close together as possible, without them overlapping. That demands a very narrow divergence to provide optimal resolution, where Ghosh again claims Princeton Optronics excels.

This year will mark the rise of a major market for VCSELS in smart phones, with Ghosh expecting handsets to include eight or more devices. "Other people think it came up suddenly," he says. "But we've been working with customers now for more than five years. It's not that sudden."

Some companies will also be buying VCSELs from Princeton Optronics for self-driving cars in 2018, Ghosh adds. He suggests autonomous vehicles will become a high-volume market from 2020 onwards. By then as many as 20 million cars could be equipped with lidar facing in all directions, he predicts, adding: "The market could be pretty big, but not as big as cell phones."

If lidar does penetrate the automotive sector in a big way, systems will eventually cost only a few hundred dollars, says Philips Photonics' Pankert, although they're currently much more expensive. VCSEL costs would be only a tiny part of the total, he adds. Yet switching from smart phones to cars would involve extra considerations, Pankert underlines. Devices need to work in a specified range of temperatures from -40°C to 125°C. Also, in order to provide sensors for self-driving cars, lidar needs a range of at least 200 meters, which Pankert concedes is "pretty challenging" for VCSEL technology.

The market for automotive lidar systems will grow from $290 million in 2016 to $2.7 billion by 2026, according to another IHS market analyst, Akhilesh

continued on page 13

VCSEL prospects

continued from page 11

Kona. Emitter devices will be crucial in enabling this technology, and the most commonly used devices are currently edge-emitting laser diodes, not VCSELs.

Kona says that XenomatiX in Leuven, Belgium, is currently the only lidar system producer that he knows of using VCSELs, although Canada's LeddarTech is also working on it. "The real challenge for VCSELs is that it's a state-of-the-art technology, something being developed right now," said the analyst. In contrast to the three- or four-year lifetimes demanded in smart phones, automotive-grade devices have to last for more than a decade. In addition, getting enough power out of 800-900nm wavelength VCSELs to reach the 200 meter-plus ranges demanded raises eye-safety concerns.

One advantage is that it's easier to create a two-dimensional array of devices with VCSELs than with edge-emitters, Kona says. Another is that thousands of VCSELs can be integrated into a single, two-dimensional package. That could help address the eye-safety concerns, as energy can be spread among them, rather than being concentrated in a single beam.

Gesture recognition

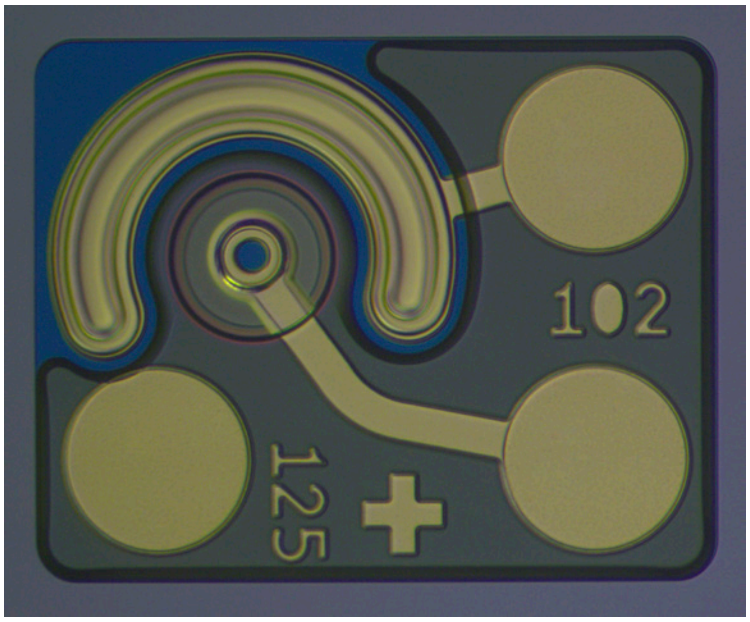
VCSELs may also find use in cars before lidar or autonomous vehicles become commonplace, Kona adds. Examples could include recognizing facial expressions or gestures within the car, an application being worked on by the Albuquerque, New Mexico, firm TriLumina.

II-VI sounds a note of caution about the prospects offered by lidar for autonomous driving. "We believe that the market potential is still not adequately sized," says Mark Lourie. "It will depend on the laser technology selected if any, [as well as] cost targets, whether autonomous hail riding services may have the effect of reducing the total number of cars sold, and whether there will be applications in autonomous vehicles other than autonomous cars."

Instead, VCSELs are an important part of his company's growth strategy in communications and elsewhere in sensing. "II-VI believes that 3D sensing in particular will become a very large market that will eventually be served by a reliable base of suppliers with vertically integrated and scalable manufacturing capabilities," Lourie asserts.

"In principle, as long as VCSELs from different vendors meet a specified form, fit and function, they should be interchangeable for that specification. Often times, the challenge is in translating the full set of requirements into specification parameters that can be measured accurately enough or guaranteed by design. Beyond these requirements, II-VI's VCSELs are often differentiated in terms of conversion efficiency and reliability."

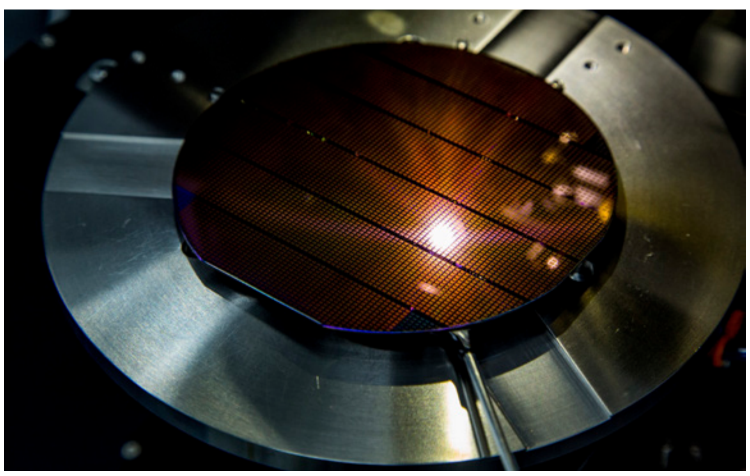
The promised growth relies on the ongoing convergence of computing, communications and consumer



As well as growing demand in sensing, cloud computing and video streaming are improving the prospects for devices like this datacom VCSEL from II-VI. Credit II-VI.

electronics, Lourie adds, bringing together big data analytics, cloud computing, broadband wireless, artificial intelligence and sensing. "This convergence will continue to enable new disruptive applications," he says. "We believe that semiconductor lasers, including VCSELs and edge-emitting lasers, will continue to play an important role both in communications and sensing."

IHS Markit's Manuel Tagliavini has a more specific vision: one where VCSELs could transform applications related to security, access and augmented and virtual reality, where an interface between humans and machines is needed. "This is transforming the user interface, since you don't need to touch buttons or screens, or to talk with a microphone," he says. Machines can "read" your intentions simply by observing your eyes, or reading your lips as they move. "It's really changing your interactions with appliances and devices," adds the analyst.



A Finisar wafer on which VCSEL devices are fabricated. The company will dramatically scale up production this year at its reconfigured Sherman, Texas, wafer fab, thanks to purchase commitments by Apple. Credit: Finisar/Apple.

Pankert says this answers an often-asked question about why the VCSEL market is exploding now, even though the basic device was invented nearly four decades ago. "It feels a little bit like LEDs 10 or 15 years ago," he explains. "LEDs had also been around for many years, and it was only after certain applications had matured that they really took off. The applications that drive VCSEL consumption are only ready now. All the sensors that are being built into either mobile devices or cars? Well, they haven't been around for the last 10 years. The same may be true for other applications where there hasn't been time to adopt this technology. It's all changing."

ANDY EXTANCE

Silicon photonics: is bigger better?

Rockley Photonics CEO and OPTO plenary speaker Andrew Rickman argues that the desire for smaller devices negatively impacts manufacturability, efficiency and performance. Hence the provocative title of his talk.

With the vast majority of technological innovations, the orthodoxy suggests that new generations of OEM products and systems must be smaller, lighter and consume less energy than their predecessors. So why might developers possibly want a bigger component to do the same job than a smaller, older model? Intriguingly, this is the latest idea for silicon photonics chips proposed by Andrew Rickman, the founder of Rockley Photonics (and before that, of Bookham Technology).

Rickman, who kicked off yesterday's OPTO plenary session with a presentation on the topic, told *Show Daily* before the event: "Over the past 30 years silicon photonics has evolved into a volume technology supporting mainstream commercial applications. Although we have seen a proliferation of new approaches, the attributes required for commercial success remain the same as they were three decades ago: volume manufacturability, optical power efficiency, and high signalling bandwidth.

"Compared with the evolution of the silicon microelectronics industry several decades earlier, in the history of silicon photonics we see one key difference: for electronic integrated circuit design, reductions in process node geometry have generally always contributed to advancing the goals of the product, leading to a conclusion that smaller is better."

He is somewhat unimpressed with the silicon photonics devices to have emerged over the past few years — often integrated into transceivers for communications, but now starting to find more roles. "It's always the case that the silicon photonics community has its axes to grind, but it's a tricky area," he says. "The point I [made] in my OPTO talk is that it was around 1986 that silicon photonics was first proposed [by Richard Soref], but 30 years on it has made a lot less progress than the mainstream semiconductor industry. I started working in this field two years later. There have been a lot of good ideas over three decades but, then again, when you look at silicon photonics in relation to the wider semiconductor industry, it is talked up too much but its potential has not been fulfilled."

Rickman explained how his view of the need for an alternative approach to silicon photonics structures was born out of years of experience of researching and working in this field: "When I started working with Graham Reed at the University of Surrey (Reed is now at Southampton), and then when I formed Bookham, one of the things that I did was build a silicon process that was completely optimized for photonics. That manufacturing process was licensed and adapted by Kotura, which has been going for years, and also deployed at Bookham, subsequently Oclaro."

Rickman notes that after the dotcom and optical telecoms crash of the early 2000s, the likes of Intel — a major investor in Bookham — and others focused on the idea that sub-micron, CMOS-type processing could be used to make silicon photonics. "It was technology that already existed," he said. "It was possible to see the integration of electronics and photonics; it would be like a foundry process that could enable lots of derivative processes, people thought."

This is where Rickman believes there is a structural problem; literally. He contends that the approach is flawed, noting that there has not been the same convergence for CMOS processing of radio-frequency components. "With microelectronics and CMOS, of course the industry generally wants to make things smaller. But with photonics most of these structures need to be a hundred times bigger -at the micron level rather than at the finer hundreds of nanometers. A design works better for photonics if the structures are about the same size as the optical wavelengths."

It's not just an issue of size. Rickman added, "For photonics devices to work optimally the precision of the parts is critical. It's the ability to create structures that are the most accurate geometries and purity that you can think of — at the atom level of roughness. It's these sort of parameters that we can leverage from the semiconductor fabrication industry to achieve the features we need for optical purposes. Not as small as you can make it, but as accurate as you can make it."

In today's silicon photonics, Rickman sees a series of partial structures that do not solve issues such as the need for achieving optical polarization, or the power deficit problem.

"I would call them halfway houses," he said. "In all cases the developers are solving some problems, but not all of them. What we need is to integrate these devices into a single process flow. Essentially, current silicon photonics systems are still inferior to established non-silicon devices. If we are going to fulfill the new, revised vision of silicon photonics then we need to integrate the whole lot, and not compromise on manufacturing and performance."

Announced shortly before Photonics West, the joint venture between Rockley and Hengtong aims to launch three 100G silicon photonics modules this year. Photo: Rockley Photonics.

And what is Rockley Photonics going to do differently? Rickman says his company has a well-funded global team of more than 80 people, based in Pasadena and San Jose, California, Oxford, UK, and Helsinki in Finland, where the Finnish government has committed to support silicon photonics volume manufacturing. On top of that are close links with the UK Photonics Hub, established across the universities of Southampton and Sheffield.

"We are developing a state-of-the-art, low-loss, 3-micron silicon photonics-based platform: essentially a polarization-independent waveguide platform, designed for high-density WDM [wavelength division multiplexed] routing," he explained. "The devices will be monolithically integrated, high-speed, low-power modulators with integrated photodiodes." Besides the technical specification designed for high-density interconnect applications in data centers, these modulators are expected to have high manufacturing tolerances and excellent yields in fabrication.

Earlier this month, Rickman and Rockley revealed details of a joint venture deal with China's Hengtong Optic-Electric to manufacture silicon photonics transceiver modules. Valued at $42 million, the Hengtong-led co-investment will commercialize Rockley's particular take on silicon photonics.

The modules that result are intended to meet the burgeoning market for high-speed data communication, including carrier networks, data centers, and high-performance computing. Rickman said, "Demand for high-speed optical interconnects is increasing at an unprecedented rate, and technology providers must demonstrate capacity to deliver solutions at high volume scale. Hengtong is a recognized manufacturing leader for fiber-optic technologies, and we are excited to partner with them."

According to one analyst, the global market for optical network hardware will grow at double-digit rates and be worth nearly $25 billion by 2021. Mushrooming mobile data traffic, high demand for data centers and new 5G networks are just some of the drivers of that predicted boom. Rickman observed: "This is a growing market but it's an under-supplied sector and a lot of people have a lot of problems manufacturing these products."

Rockley's transceivers are slated to appear later this year, with initial plans for three 100G models offering different distance capabilities. "They will be made to industry standard specifications but better than the competition by being less expensive to produce and with a smaller energy demand," Rickman said. And those products will provide the first chance to test his thesis: is bigger better?

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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.

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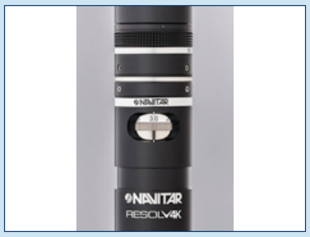

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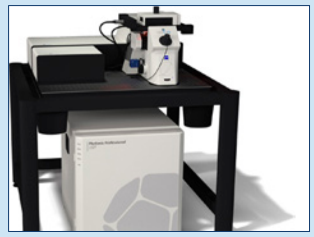

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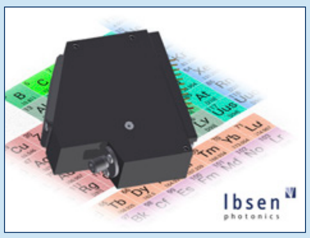

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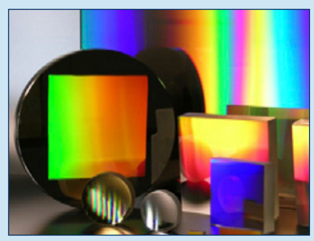

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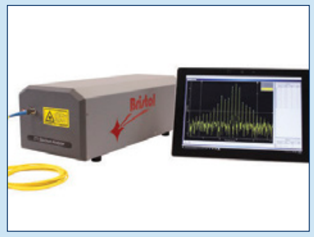

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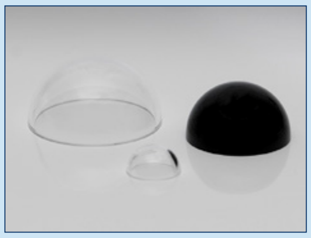

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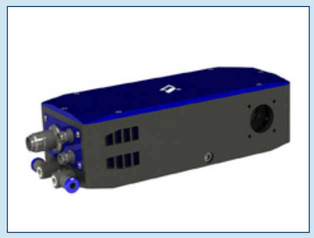

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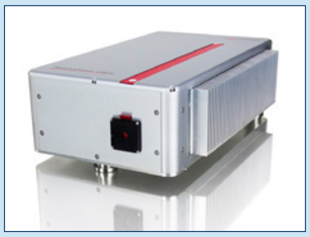

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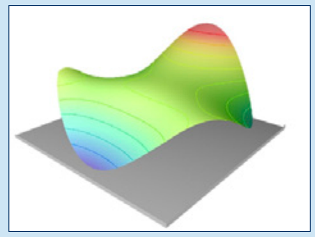

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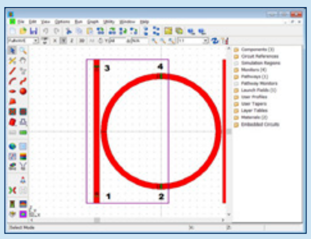

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Femtoprint gets fast and furious

From precision components in breathtaking timepieces to micro-needles for vein cannulation, breakthrough laser writing from Photonics West exhibitor Femtoprint is reshaping microdevice fabrication.

Last year the Swiss watchmaker Ulysse Nardin released its extraordinary concept watch, the "InnoVision2". Replete with intricate mechanisms precisely controlling gold, silicon and sapphire parts, the timepiece stunned the world while re-plotting the future of mechanical watch making.

Nestled within the watch's innovations lie two glass components; a minute hand and a balance wheel bridge. Each was fabricated by Switzerland-based laser microsystems company Femtoprint, and each follows years of painstaking research to perfect the art of rapid laser writing for watchmaking, and much more.

Femtoprint was established in 2014, following a €3.4 million, three-year European Union project, also called Femtoprint. Here, a pan-European team, including laser vendor Amplitude Systemes, microelectronics supplier Quintenz Hybridtechnik, precision mechanics developer Mecartex, plus research teams at the universities of Eindhoven and Southampton, had set out to create a cost-effective tool that could convert a solid material into a microdevice without the need for a cleanroom.

As Femtoprint chief executive Nicoletta Casanova puts it: "The team wanted to create a system that would spark real innovation and rapid prototyping in universities and small companies."

"Any kind of miniaturization process typically needs a cleanroom, but this is expensive, consumes large amounts of energy and many organizations just can't afford it," she says. "The idea was to develop a new tool that could convert a piece of glass into a microsystem with optical, mechanical and fluidic functionalities, without the cleanroom environment and subsequent assembly process."

At the time, many researchers had been using femtosecond lasers to micromachine 3D microstructures, writing, for example, waveguides into fused silica and borosilicate glasses. In traditional industrial laser machining, based on ablation, the smallest feature size is driven by the optical diffraction limit. But the nonlinear interactions generated by ultrafast lasers dictate that feature sizes below the diffraction limit can be delivered.

Still, the Femtoprint researchers wanted to build on this and produce a versatile, compact machining platform that used a lower-energy femtosecond laser and was only tabletop-sized. And this is exactly what they did.

By the end of the project, the team had built a 1030 nm laser with an output below 60 mW that was smaller than a shoe box and could write microstructures within glass at sub-micron resolution and an aspect ratio better than 1:200. The laser source delivered a pulse energy of up to a microjoule, with a 600 kHz repetition rate and 300 femtosecond pulse duration. During laser exposure, that translates to instantaneous powers of a terawatt per square centimeter, but an average power of only a few hundred milliwatts: comparable to that of a bright LED.

This laser was integrated into a desktop-sized "printer", alongside piezoelectric motor-driven stages and high-accuracy beam positioning to manipulate glass sheets of different thicknesses. Software also converted 3D computer aided design files into executable machine code, ready for writing the necessary structures.

Writing with a laser

As part of the Femtoprint 3D printing process, tightly focused, low-energy femtosecond pulses below the ablation threshold are used to pattern the glass matrix. Densification within the focal point of the laser changes the properties of the glass with both the refractive index and etching rate of the material increasing.

By moving the material relative to the laser focus, microstructures are scribed into the glass and then etched with hydrofluoric acid to remove the written parts and form the 3D structure.

"We actually work with the laser inside the volume of the glass, printing what we want and then removing this drawing with a selective etching solution, which in effect sets the device free from the glass," notes Casanova. "In this way we get the real 3D structure with, say, the necessary microfluidics and mechanics in a monolith."

Indeed, as early as 2004, members of the Femtoprint team had used femtosecond laser writing to fabricate fluidic channels and tunnels of virtually any shape within fused silica. But as the Femtoprint project progressed, increasingly novel and complex components were being rapidly prototyped. They included the first transparent actuator as well as a biochip with integrated channels and waveguides, for monitoring algae populations.

And by the end of the project, the team of researchers at the University of Southampton had showcased what was dubbed "Superman memory". The five-dimensional optical data storage format — which uses birefringence as an extra degree of freedom — comprised laser-induced nano-gratings in fused silica, and promises virtually limitless data storage.

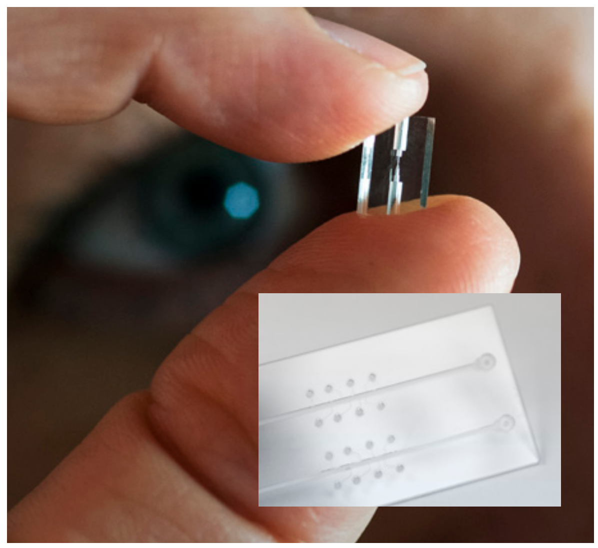
With the compact 3D printer developed, system costs reduced, and myriad components demonstrated, the project's final objective was achieved: Femtoprint was launched as a commercial entity.

Commercial progress

With company in tow, Casanova soon realized the platform's untapped potential. "I would meet with clients and they would say, 'I don't actually need this technology to make rapid prototypes, I need it to create devices that I just can't make with standard technologies'."

From day one, Femtoprint has been doing this and more. Recent examples include the delivery of challenging fiber alignment systems for the telecoms industry and a 3D electrode implant, while micro-tools for vein cannulation have also been developed for medical applications.

In a more unusual move, the company produced novel glass targets suspended within microfluidic chips, to investigate the effect of a swimming microbot's morphology on complex fluid flows within the chip. But in terms of sheer beauty, the best was yet to come.



Femtoprint is fabricating 3D microfluidic channel devices for microbiology research. Inset: a device for blood analysis. Photo: Femtoprint.

In 2017, Ulysse Nardin released the second version of what can only be described as a breathtaking concept watch, the InnoVision2. Intent on driving watch manufacturing to its limits, the Swiss firm had already become the first to use silicon in a wristwatch, and in 2007 stunned the industry with its InnoVision1. History repeated itself with last year's innovation-packed update.

Crucially for Femtoprint, the company wanted two

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Femtoprint continued from page 21

critical 3D fused silica sculptures: a cage-shaped 3D glass minute hand, and a glass balance bridge. "[Ulysse Nardin] came to us and said, 'we would like you to fabricate these two pieces and if you can do this all in less than a month, you have authorization to disclose them later on'," explains Casanova.

She describes the Innovision2 minute hand as "beautiful and unique", highlighting how her team laser-sculpted the delicate part and placed it on a thin metal backing to make it flexible and able to bear extreme shock. The glass balance wheel bridge, based on a monolith of fused silica, was produced in a single piece without masks, ablation, assembling, or other traditional manufacturing, and showcases exactly what the company's 3D printing process is capable of.

As part of the design, silica glass is used as the balance cock, holding and

This glass bridge of the Innovision2 watch provides integrated balance shock protection, partly thanks to laser-sculpted flexures. Photo: Ulysse Nardin.

providing integrated shock protection for the balance wheel. The component contains precisely written fluidic channels, which are filled with a photoluminescent compound that exhibits a blue glow when mixed with an oxidizing agent.

The center of the bridge integrates other intricate flexures to provide additional shock resistance, while the brand letters "U" and "N" within the silica body provide a fine demonstration of 5D optical writing.

"We created the flexures to absorb shock, and removing the glass to leave these perfect flexures was a challenge," admits Casanova. "And then we altered the polarization of the material to make sure you could see the company brand.

"This project wasn't just about uploading a drawing into the system, hitting enter and getting the part," she adds. "We really had to make many iterations and push our limits, but in the end you can design any component you want inside glass, and we are now adding even more challenging components to our portfolio."

So where next for Femtoprint? While the company continues to add to its ever-swelling collection of components and devices, it is also offering two versions of its latest 3D printer. They work with a range of transparent materials, including borosilicates and alkali-free glasses, as well as fused silica.

As Casanova points out: "Fused silica is still used in 99% of our applications, but we alter the laser power according to the type of material we are using."

The latest printers are more compact, and reach a resolution down to 0.5 microns in all three spatial directions. Thanks to ongoing software and control developments, they are ten times faster than the original project prototype and reach writing speeds of more than 140 mm/s, while still ensuring high surface quality and accuracy of the microdevices.

"Now we really are moving from rapid prototyping to serial production," Casanova says. "We have produced thousands of pieces for some of our customers.

"We have developed some key components internally, such as the stages, but we are always encouraging collaborations." she says. "We have also spent a lot of time on our software and control, but I always stress that if you can, you should work closely with experts, such as the laser manufacturers, while keeping the focus on our process; this is the path to excellence."

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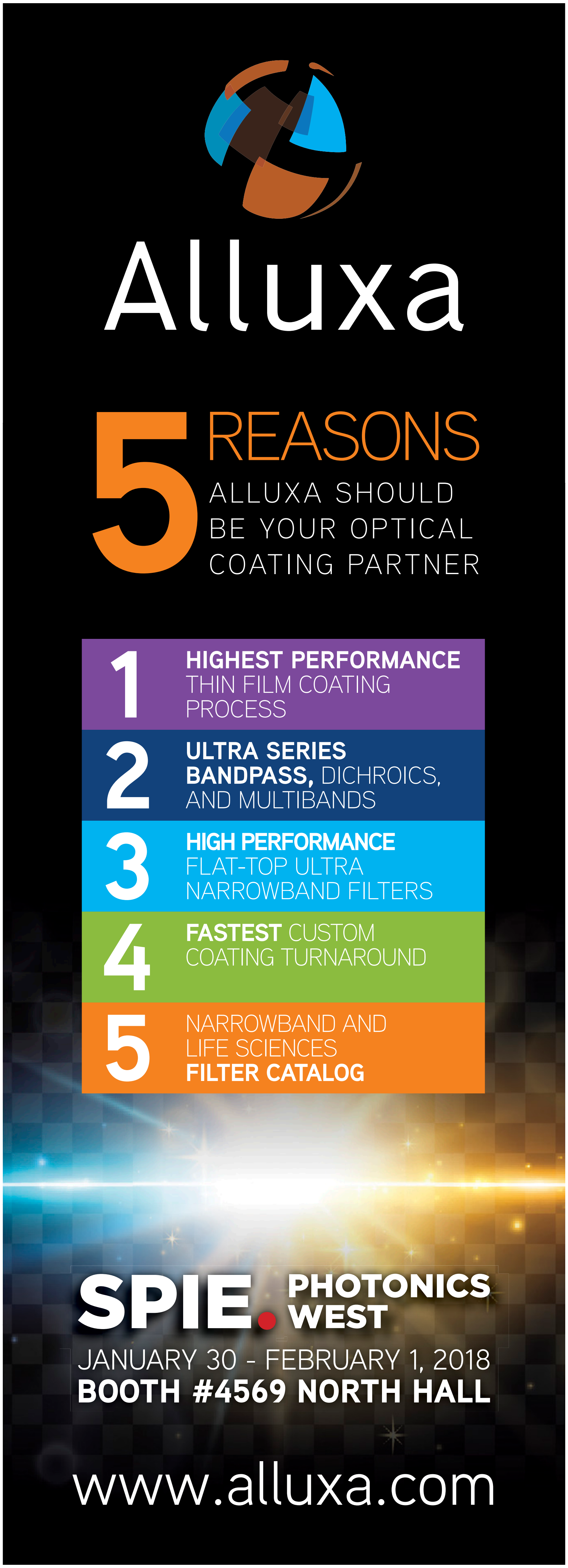

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Optics the key challenge for AR, VR and mixed reality evolution

A new conference incorporating interactive experience at Photonics West reveals the rapid growth of augmented and virtual realities. Its chair, Bernard Kress of Microsoft's Hololens division, tells Matthew Peach that optics remains the key challenge in developing the ultimate virtual experience.

Bernard Kress, Partner Optical Architect at Microsoft HoloLens and chair of the inaugural VR, AR, MR one-day industry conference at Photonics West this week. Photo: Microsoft.

New types of optical and photonics technologies need to be implemented in next-generation virtual reality and augmented reality (VR/AR) systems in order to provide greater visual comfort for prolonged usage, and to achieve a better sense of display immersion for the user.

That is one of the main conclusions drawn by Bernard Kress, Partner Optical Architect at Microsoft HoloLens and chair of the inaugural VR, AR, MR (the hybrid "mixed reality") one-day industry conference and headset demonstrations event that took place in the Moscone yesterday. The new event featured no fewer than 18 invited talks from key systems developers, academics and industrialists, as well as a panel covering the latest optical challenges and successes for VR, AR and MR technologies.

Hot topics that this diverse community is currently addressing include some familiar and some not-so-familiar terminology: optical foveation, vergence, accommodation conflict mitigation, pixel occlusion, high dynamic range and peripheral displays.

Foveation is a digital image processing technique in which image resolution is varied across the field of view according to so-called "fixation points" determined by the position of the user's fovea, at the center of the retina.

Vergence is the simultaneous movement of a user's pupils towards or away from one another during focusing. As AR, VR, MR have rapidly taken off, these issues have become real challenges for the optical engineers, who also have to consider size, weight, center of gravity, and thermal management of the equipment to provide true, wearable comfort.

Microsoft's Hololens VR hardware assisting Ford's car designers. Photo: Microsoft/Ford.

Kress told *Show Daily*, "This conference at Photonics West is the first time we have in a single location all the major developers of VR, AR and MR headsets. These include large corporations such as Microsoft, Google, Facebook, Amazon, Intel and Huawei, but also exciting smaller start-ups such as DigiLens, Avegant, Meta, ODG, Lumus, and Leia, as well as renowned universities that have strong research programs in these fields such as University of Arizona, Berkeley University and Stanford University."

This week's conference follows a demonstration at last year's Laser World of Photonics event in Munich, part of SPIE's Digital Optical Technologies conference, which Kress also chaired. That event featured demonstrations of headsets from Microsoft, Oculus, HTC, and Sony. Attendees had the opportunity to learn about and try on the headsets to experience a range of head-spinning entertainments like virtual rollercoaster rides, deep-sea diving, and car racing.

"With this new full-day conference, we are particularly glad to have hosted 18 exciting invited talks focussing on specific optical hardware from such companies and start-ups, 12 amazing headset demonstrations in the largest such session assembled to date, and a panel discussion of leading industry figures," says Kress.

These included world-renowned VR and AR pioneers such as Jaron Lanier (the so-called "inventor of VR" as well as an author, musician and composer), Ronald Azuma (who defined the term "augmented reality"), Thad Starner (Professor at Georgia Tech and one of the first smart glasses pioneers) and Mark Bolas (Professor at USC, founder of Fakespace and mentor of Palmer Luckey, founder of Oculus).

Kress described his own personal highlights of the day: "I really enjoyed the various novel solutions described by the participants to solve main visual discomfits in AR systems, such as how to resolve Vergence Accommodation Conflict, and how to enable more comfortable arm's length display interaction in MR immersive display systems, now a key feature for enterprise-driven MR applications."

With at least 500 attendees expected to take part — many very actively — this was definitely an interactive experience. In April, Kress will continue the series of AR and VR events at Photonics Europe, with a conference entitled Digital Optics for Immersive Displays (DOID18). The Strasbourg, France, event will feature a student-focused optical design challenge dedicated solely to designing novel optics and optical architectures for imaging, optical combiners and sensing for AR and VR. "We have been pleased to receive around 70 submissions to be shortlisted," says Kress.

Emergence of "MR" hybrid

Virtual reality started to take off in the early 1990s, involving some of the pioneers that have been speaking at this week's panel sessions (notably Lanier and Bolas). AR and smart glasses also experienced an initial boom in the 1990s, thanks to the early work of Azuma and Starner.

Kress told *Show Daily* that he believes these rapidly evolving technologies will interact over the coming years. "Market analysts agree that the AR market will overtake the VR market as early as this year, 2018," he said. "The main revenues today and in previous years have come solely from VR systems, but revenues in the coming years will be ever-increasing for AR.

"Now we have MR, which combines the concepts of VR and AR in an architecture that is more flexible, capable of delivering to the user both experiences, through high-performance imaging, and combiner optics capable of producing a quasi-lightfield over large fields of view. MR is supported by a battery of sensor technologies providing eye tracking, gesture sensing, depth map sensing, head tracking and iris authentication — all in a low-power and compact format."

One key issue to address in order to solve the ultimate MR hardware challenge is to better understand the limitations and specifics of the human visual system, which is very different to traditional imaging systems based on cameras and sensors. Combining efforts through collaboration between optical engineers and optometrists is key to achieving these goals. An example is what we call "high resolution": for a camera just a simple, high-pixel-count image, but an entire sensory experience for the human visual system.

Kress commented, "This is why we involved renowned optometrists on our panel, such as Marty Banks from Berkeley University, who gives unique insights on the human visual system and how to take advantage of them in order to decrease the burden on optical design, while increasing the comfort for the user."

Equipment trends

What might be termed the "ultimate MR headsets" are now demanding new developments in all aspects of hardware. That ranges from battery technology, thermal management, material engineering, and custom silicon for display and sensor fusion, to custom mechanical design and novel optical elements and optical architectures, including micro and nano-optics operating both in free space and waveguide mode.

Kress contends that the associated electronics will continue to follow Moore's law, providing smaller and less power-hungry circuits. Optical sensors will also be reduced in size, but classical

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Coherence Matters.

AV, VR evolution continued from page 25

optics will have a hard time adapting to the size, weight and efficiency requirements. Unlike electronics, optics does not follow Moore's law, and is proving to be one of the hardest challenges to solve in AR/VR hardware.

"However, the optical engineer's toolbox is ever growing, with new and very exciting tools such as surface gratings, volume holograms, sub-wavelength relief structures, surface plasmons, photonic crystals and metamaterials," Kress points out. "The task is not to replicate traditional optical functions with novel technologies but to use novel technologies to provide optical functionalities that [it has not been possible to] integrate with classical optics."

> "One thing is for sure. We have not yet found the killer app for VR, AR, MR or smart glasses."
>
> BERNARD KRESS, MICROSOFT HOLOLENS.

Application areas

Market analysts had predicted impressive growth for VR and AR in 2017, but the reality was a slower ramp than had been anticipated. However, Kress predicts that the scope of the VR/AR market by 2022 will cross the "$100 billion line" in terms of revenues. He added:

"The pace of discovery in optics today is faster than any time in my own career in optics, even faster than through the glorified optical telecom boom of the late 1990s and early 2000s. Such technological revolutions — for example, optical metasurfaces — will feed the need for smaller, lighter, cheaper optics delivering functionality that was out of reach for traditional optics, including diffractive and holographic [elements]."

From VR to AR to smart glasses and MR, application fields vary significantly. VR tends to appeal to gaming and virtual presence and virtual experience purposes. Aside from games, examples include virtual home visits for the real estate sector, along with virtual travel, sports, art, and communications applications such as virtual conferences and meetings. There is also telepresence (the use of virtual reality technology, especially for remote control of machinery or for apparent participation in remote events), and Microsoft's own "Holoportation" application.

That Holoportation technology boasts of enabling users to "jump into someone else's reality". At its heart is a new 3D image capture system developed by Microsoft Research. A series of cameras are set up around a room, tracking shapes and movement for the observer and stitching together a 3D model in real time.

AR seems to have more appeal in professional and enterprise sectors, potentially boosting productivity and decreasing human errors in complex processes (such as in automotive or avionic assembly, on oil rig platforms, or for complex machinery support), but the technology is also finding markets in architecture, surgery, and industrial design. In gaming, fewer opportunities have emerged than with VR.

AR also allows for arm's-length interaction of the real world, notably hands, and the display. Kress says this is only possible with light fields or holography (as provided with Avegant or Magic Leap hardware). Interaction between a user's hands and the virtual objects in holograms could become essential for designers, surgeons, and many other enterprise application examples.

The relatively established technology

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of smart glasses tends to appeal more to consumers. Such spectacles can provide a minimalistic AR approach, exemplified by the "Pokemon Go" game, including contextual display of features such as traffic conditions, food outlets.

Despite all of this apparent commercial and info-tainment sector progress, Kress says that the full potential of mixed reality technology has not yet been realized: "One thing is for sure," he told *Show Daily*, "We have not yet found the killer app for VR, AR, MR or smart glasses."

By way of explanation, he added, "The companies represented at this Photonics West conference are attempting to provide the ultimate MR user experience in terms of wearable comfort, visual comfort and immersion, as well as the best development platform so that developers can figure out and develop the killer apps.

"It's a chicken-and-egg situation: hardware functionality entices developers to develop new, exciting apps, and then the apps entice hardware developers to develop new hardware functionality to enable them."

Right now, the key developmental challenges range from increasing the FOV without decreasing the so-called eye box (violating the etendue conservation principle), mitigating the vergence accommodation conflict (VAC) to allow arm's-length display interactions, including pixel occlusion to make holograms more realistic, and including optical foveation. Most of these developments will rely on accurate eye tracking.

For image generation, traditional technologies such as HTPS LCD, LCOS, micro-OLED, DLP, laser MEMS or fiber scanners are used, while novel technologies capable of high-brightness, high-contrast emissive displays, are emerging. New challenges such as VAC mitigation call for additional optics such as tunable lenses either in reflection or transmission modes and/or liquid crystal or MEMS phase panels for holographic displays.

On the optics side, there are many sensor challenges. An MR device is only as good as its sensors, followed by the quality of its display — in that order. Options include head-tracking (requiring six degrees of freedom), but also depth mapping provided by time-of-flight sensors for 3D scanning, allowing for "world locking" of holograms.

Another rapidly emerging technology, artificial intelligence (AI), will also likely be used to recognize scanned objects such as tables, chairs, or people, and categorize them as such. To this end, Monday's conference featured Sense: a San Jose company specializing in optical sensors for AR and MR.

Other issues include the usual technological difficulties: improving batteries, thermal dissipation, and optimizing ergonomics. But Kress says that optics remains the main challenge.

DigiLens is working with BMW on a near-to-eye technology for motorcycle helmets. Photo: DigiLens.

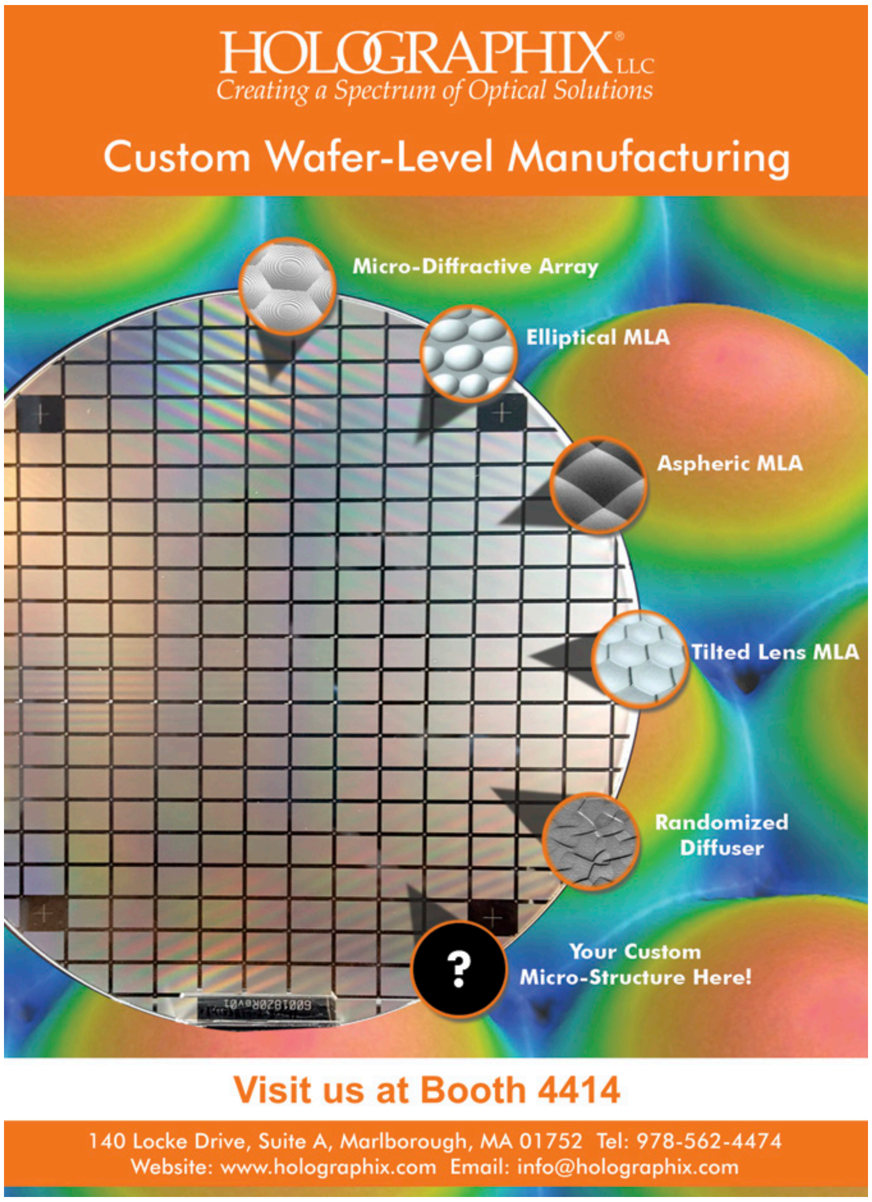
Considering the geography of the AR/VR/MR business, the key companies are mainly still based in the US. However, the key AR/VR market will be in Asia and the center of gravity could be starting to shift. Kress said, "Today, most of the investment in AR and VR startups is coming from China. Emerging startups in AR and VR are multiplying in China thanks to huge government investments in this very exciting field."

Of his own particular brand, Microsoft's Hololens project, Kress commented, "I cannot say much about our own internal development plans, of course, but we have a very aggressive and challenging MR hardware roadmap which reaches well in the 2020s. HoloLens V1 is only the tip of the iceberg."

In addition to MR hardware and an apps development platform, Microsoft is also actively pursuing various AI aspects dedicated to MR, especially in the image processing realm and optical sensors for MR — including continuous 3D world scanning for realistic hologram world locking and interaction.

Kress concluded, "We have one of the strongest optics teams on the planet, which continues to amaze me every day with its vision, inventiveness, excitement and productivity."

MATTHEW PEACH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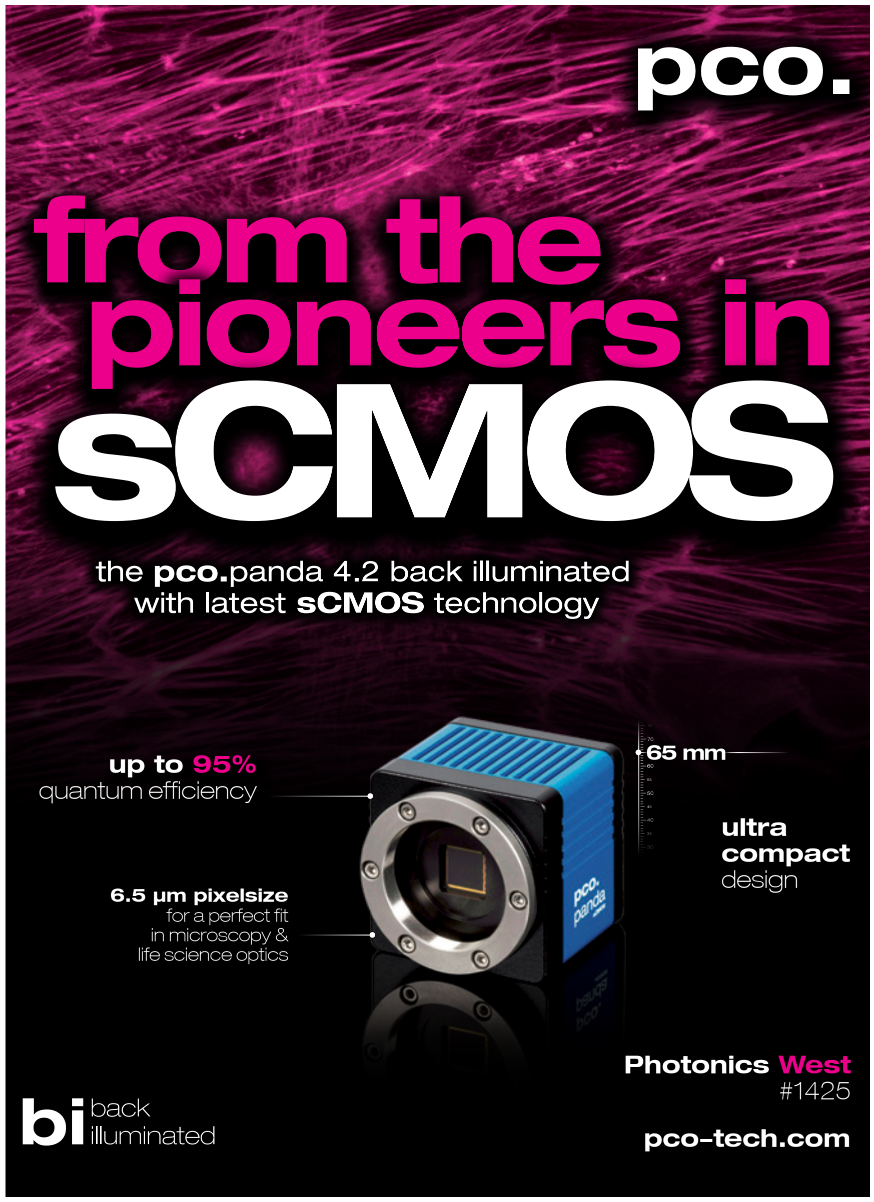
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New Onefive industrial ultrafast lasers from NKT Photonics

Looking for industrial ultrafast lasers that can handle 24/7 operation in a manufacturing environment? The new Onefive range from NKT photonics is for you!

Known for their supercontinuum and single-frequency fiber lasers as well as their unique photonic crystal fiber technology, NKT Photonics has long been a trusted brand in the photonics industry. With their new range of Onefive ultrafast lasers, the company is now moving into the market for industrial and medical ultrafast lasers.

Leading the industry trend of shorter pulses in more rugged form factors, the new ultrafast lasers offer a wide range of pulse lengths from femtosecond to picosecond and output power up to 100 W. The pulses can be controlled accurately with variable repetition rates from single shot to MHz and burst mode.

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Manufactured at their ISO 9000 and 13485 certified facility in Switzerland, the Onefive lasers offer unparalleled reliability, beam quality, and power in a compact form factor ready for 20/7 operation. Moreover, NKT Photonics have thousands of lasers installed worldwide and offer local service and support in Asia, Europe, and US to make sure your lines stay up.

See all the new Onefive ultrafast lasers at booth #1336 and talk to our product specialists or visit www.nktphotonics.com for more details on models and specifications.

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OptoSigma offers a high quality portfolio of Objective lenses for imaging, laser processing and water immersion applications. Available wavelengths range from Ultra-Violet and Visible to near Infra-Red. Standard products are infinity corrected, designed for use with coaxial illumination and are parfocal at the design wavelengths and visible to allow for monitoring during processing.

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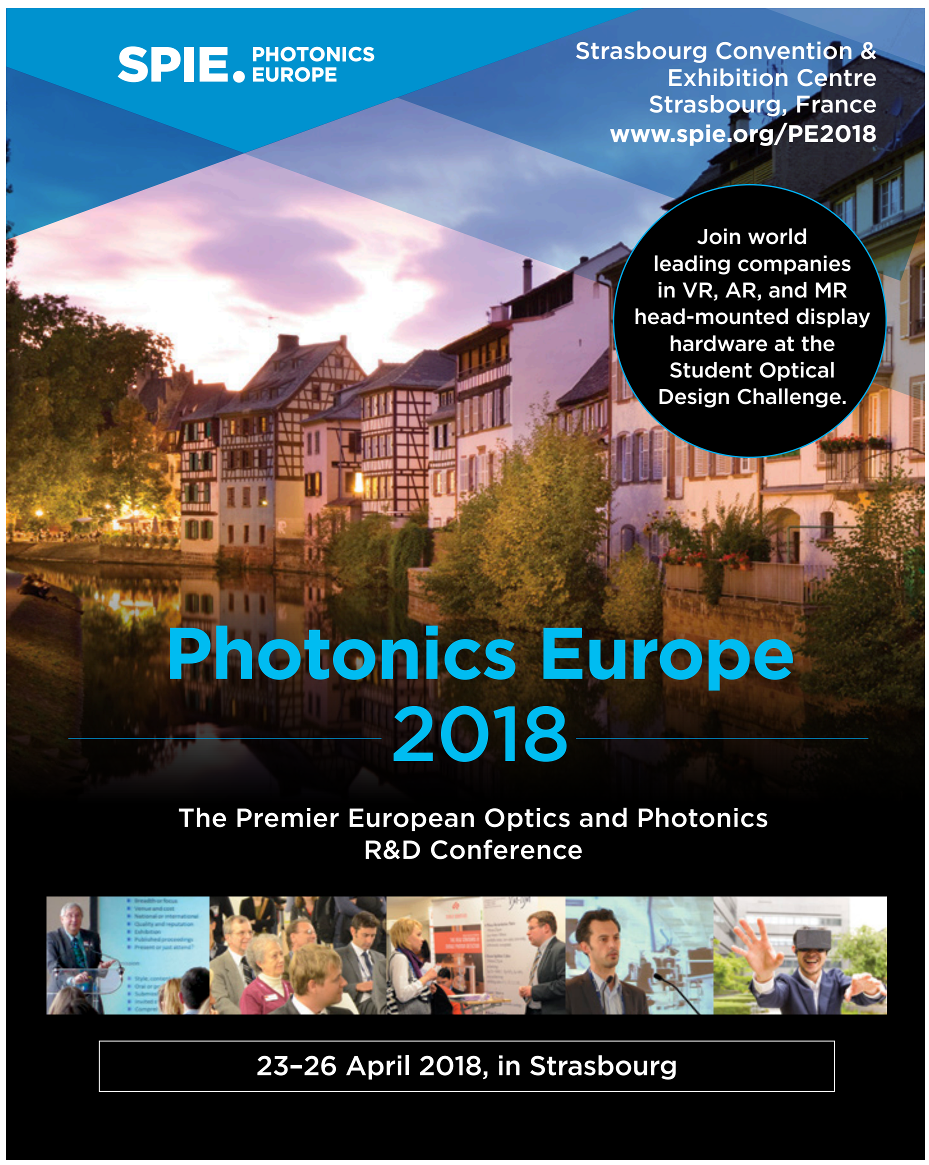


Pix4Life offers economical route to silicon PICs

BiOS exhibitor Pix4Life — the photonic integrated chip development consortium led by IMEC in Leuven, Belgium — says it intends to make the technology more accessible, to become an enabler for a broad range of medical device and industrial applications.

The European Commission-funded project has built a state-of-the-art silicon nitride photonics pilot line for life science applications working in the 400-850nm wavelength range.

That facility is now available on a shared "multi-project wafer" (MPW) basis to all-comers worldwide, but companies or groups from European Union member states are entitled to a significant cost reduction of almost 50%. Hilde Jans is the new co-ordinator of the project, having succeeded Liesbet Lagae last year.

Jans told *Show Daily*, "We are here at BiOS to show off our capabilities and we are hopeful that some new clients will sign up to use our services. The sort of applications we support include medical and health-related sensing technologies, including ground-breaking developments such as optogenetics."

Pix4Life chip fabrication is conducted either through dedicated wafer runs — if an order is significant enough — or more usually by MPW runs, meaning a lower fabrication cost for individual users. Additional services including photonic integration consultancy, circuit design, chip testing and packaging are all offered.

Pix4Life project co-ordinator Hilde Jans at the weekend's BiOS Expo. Photo: Matthew Peach.

The first early-access MPW, led by LioniX International, ran in mid-2017, based on LioniX's "TriPleX" platform. This was followed in late 2017 by a run using IMEC's own "BioPIX" approach.

To ease the design of the circuits by external users, project partner PhoeniX has developed the "TripleX Process Design Kit (PDK)", which is available to external users. Full circuit design services are offered by VLC Photonics. Interested parties should email info@pix4life.eu.

A notable new player in the application of lens-free biomedical analysis is Belgium-based life science venture Mi Diagnostics. Launched in 2015, the startup is developing tests that require only drops of blood for on-chip detection of cells, proteins, nucleic acids, and/or small molecules.

In its procedures, test data are collected, processed and displayed as structured results on a smartphone, tablet or laptop within minutes, enabling rapid medical decisions. Mi Diagnostics combines the know-how and technical expertise of researchers at IMEC and Johns Hopkins University.

MATTHEW PEACH

IRSWEEP SPECTROMETER GETS DUAL QCL UPGRADE

After making its debut at the BiOS Expo in 2017, this year Swiss startup IRSweep chose the event to reveal a new version of its dual-comb mid-infrared frequency comb spectrometer.

Now featuring two exchangeable quantum cascade laser (QCL) modules in place of a single source, the equipment is said by managing director Andreas Hugi to be much more versatile, meeting the requirements of university-based clients for biomolecular spectroscopy applications such as monitoring protein reactions.

With the two exchangeable QCL modules in place of a single, fixed source, the new instrument can provide an even wider spectral coverage than its predecessor. Compared with conventional Fourier transform infrared (FTIR) equipment, the frequency comb approach provides much better time resolution, and is said to be ideal for studying rapid, non-repeatable biochemical processes.

Following recent investment by an unspecified but major Swiss maker of technology instrumentation, IRSweep's headcount has grown to ten, with dedicated sales and applications engineer personnel in place to provide greater customer focus.

The ETH Zurich spin-off's "IRisF1" second-generation spectrometer with modular design is said to be available "imminently", although unfortunately the system intended to be on show at the Moscone West exhibition was held up in US customs.

MIKE HATCHER

Optics aids malaria diagnosis in Rwanda

In Rwanda, a US student-designed photonics technology will soon lead to instant, on-the-spot malaria diagnosis, and treatment as needed — helping authorities cope with the proliferation of drug-resistant strains of the disease.

Gerard Coté described the work, at a new center called "PATHS-UP", short for Precise Advanced Technologies and Health Systems for Underserved Populations, during the BiOS conference on Optics and Biophotonics in Low-Resource Settings. At Texas A&M University, home to the NSF-funded PATHS-UP center, Coté is director of the Center for Remote Health Technologies and Systems.

The students and Coté visited Rwanda last year with support from Engineering World Health, a non-profit organization based in North Carolina. They designed a malaria detection system based around two optical methods: fluorescence and polarized light. The data will stay in Rwanda as local doctors make their own diagnoses.

The project illustrates the goals of the PATHS-UP center, which is one of 20 such engineering locations in the US. "Our vision is to change paradigms," Coté said, "and to develop revolutionary solutions [with] lower costs."

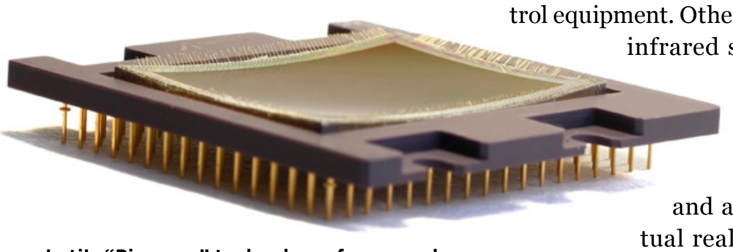
Coté leads a consortium of researchers from industry, government agencies and universities developing optical technologies and systems, including representatives from UCLA, Rice, and Florida International and Texas A&M.

FORD BURKHART

Leti gets flexible with 'Pixcurve' concept

French technology institute Leti's new curved optical component technology is making its global debut in the Moscone Center this week, with the developers of 'Pixcurve' claiming that the state-of-the-art approach improves optical performance by enhancing the field of view and compensating for optical aberrations.

Appearing at booth 431, it can be used to curve components such as CMOS and CCD imagers for mobile phones, cameras, medical equipment and industrial-control equipment. Other uses could include infrared sensors for astronomy, defense, and drones. Microdisplays for automotive applications, and augmented and virtual reality (AR/VR) could also benefit.


Leti's "Pixcurve" technology, for curved optical components, is on display at booth #431. Photo: Leti.

"Pixcurve is a proof of concept, introducing Leti's latest curving technology for various optical components, such as visible imagers, microdisplays, bolometers and infrared detectors," says the Grenoble team behind the work. "This technology addresses companies' growing interest in a range of curved optical components that will help them achieve higher levels of performance and compensation for optical aberrations, while minimizing the vignetting effect and enhancing field of view. It makes cameras, imagers or microdisplays even more compact and easy to assemble."

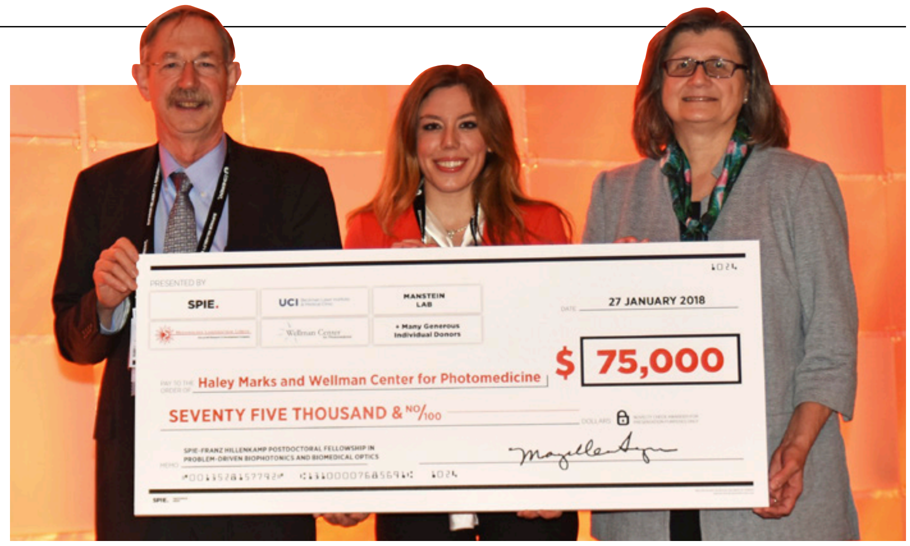
Alexis Rochas, Leti's business developer for visible imaging, added: "Leti's advances in miniaturization and integration technologies for photonics will help make the digital world visible for key uses in multiple sectors."

The research and development organization has been working on an "aggressive" reduction in curvature radius and spherical and cylindrical curvature, and says that it is still looking to improve a collective curvature technology for high-volume market applications, as well as tunable curvature for more high-end optical deployments.

Leti is also partnering with companies to help establish a supply chain capable of manufacturing products exploiting the Pixcurve approach.

MIKE HATCHER

Inaugural Hillenkamp fellowships awarded



SPIE President Maryellen Giger (right) and SPIE-Franz Hillenkamp Fellowship Committee Chair R. Rox Anderson (left) award the 2018 SPIE-Franz Hillenkamp Fellowship to Haley Marks. Photo: SPIE.

At the BiOS Hot Topics session on Saturday, Haley Marks of the Wellman Center for Photomedicine at Massachusetts General Hospital (MGH) received the inaugural $75,000 SPIE-Franz Hillenkamp Postdoctoral Fellowship in Problem-Driven Biophotonics and Biomedical Optics.

Marks, an SPIE member and postdoctoral researcher in Conor Evans' lab at the Wellman Center, was recognized for her work on a luminescent oxygen-sensing, drug-releasing bandage that provides quantitative visual feedback for clinical treatment guidance.

Honoring the career of medical laser pioneer Franz Hillenkamp, the fellowship was created in partnership with four international biomedical laboratories — the Wellman Center, the Manstein Lab in the Cutaneous Biology Research Center at MGH, Medical Laser Center Lübeck, and the Beckman Laser Institute at University of California, Irvine — and the Hillenkamp family. The annual award supports interdisciplinary problem-driven research and provides opportunities for translating new technologies into clinical practice for improving human health. This fellowship is supported by contributions from the biophotonics and biomedical optics community and matching funds from SPIE.

Jan Philip Kolb

The Hillenkamp Fellowship Committee, comprising representatives from 12 top biomedical optics research and medical laboratories and chaired by SPIE Fellow R. Rox Anderson, director of the Wellman Center, had a difficult job choosing a recipient. In this inaugural year, the committee wished to demonstrate the importance of this novel type of fellowship combining research and translational sciences, and to inspire the next generations of scientists in biophotonics and biomedical optics.

The committee, with additional support from Thorlabs and Blossom Innovations, sponsored a second fellow, Jan Philip Kolb of the Medical Laser Center Lübeck, for his work on fiber-based nanosecond two-photon microscopy (nsTPM), which can be translated to clinical applications, such as pathology and endoscopy. Kolb also received his $75,000 award at the BiOS Hot Topics session.

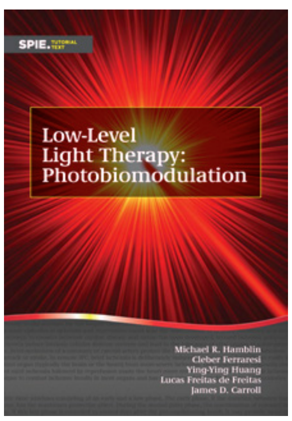
For more information on the fellowship, see spie.org/hillenkamp.

NEW YAVER SCHOLARSHIP

SPIE has established the Joe and Agnete Yaver Scholarship for SPIE members and staff seeking an advanced degree that provides business knowledge to facilitate the advancement and application of optics and photonics research and technology. Application deadline is 15 March. For more information, see spie.org/yaverscholarship.

Book sheds light on photobiomodulation

While optics and photonics are at the cutting edge of computing, communications, and advanced laser technologies, light technologies are also being used to protect, heal and regenerate tissue. SPIE Fellow Michael Hamblin, principal investigator at the Wellman Center for Photomedicine in the US, along with four co-authors, has written a new book, *Low-Level Light Therapy: Photobiomodulation*," that aims to introduce the topic of photobiomodulation (PBM) to the wider SPIE community.



Hamblin gave a talk on PBM and the brain at the Photonics West neurotechnologies plenary session on Sunday and discussed translational research applications of blue light for diagnosis and treatment of infections at the Translational Research forum, also on Sunday.

Discovered in 1967 by Endre Mester in Hungary, PBM, also known as low-level laser therapy, remains somewhat controversial and only recently has it begun to become somewhat accepted by the medical profession, the scientific community, and the public at large.

Mester found that red lasers could regrow hair and stimulate wound healing in rat models. For many years, it was thought that this property was associated with coherent laser light that interacted with cells or tissues in a specific manner, Hamblin says. This led to the rise of "laser therapists" who built practices applying various lasers (often red or near-IR with powers up to a few hundred mW) to a range of medical and orthopedic problems.

When LEDs came along, scientists and clinicians rapidly discovered that non-coherent light was just as effective, if not better, than laser light, especially with LED arrays that could illuminate large areas of the body. Moreover, Hamblin notes that the relatively inexpensive nature of LED arrays suggests that LED therapy will become much more widespread in the future. "LED arrays can be used at home as a wellness device to improve the function of many different parts of the body," Hamblin says.

The new SPIE Press Tutorial Text includes original and previously published research and focuses on a critical analysis of diseases and disorders of human and animal tissue and organ systems that PBM therapy can potentially treat. The book discusses how PBM therapy works, including how mitochondria (the powerhouses of the cell) are deeply involved in the basic mechanisms.

Chapters in the book explain possible emerging applications for PBM, including for treatment of painful conditions such as arthritis, back problems, neck pain, tendinitis or non-healing wounds as well as the wide range of side effects that afflict patients receiving conventional cancer therapy, chemotherapy or radiotherapy. Side effects such as oral mucositis, dermatitis, neuropathy, and loss of taste, smell, hearing, or vision can be so severe they cause the patient to stop the treatment, with possible dire consequences.

Hamblin and his clinical collaborators also discuss potential applications of PBM to the brain. If LEDs are applied to the head (possibly as an easy-to-wear helmet), the near-IR light can penetrate into the brain, where the mitochondria-rich tissue responds very well to the light. For instance, Hamblin says sudden causes of brain damage (stroke, head injury or heart attack) may be improved either in the acute phase or the chronic phase. Neurodegenerative diseases (Alzheimer's or Parkinson's) might be treated by shining a light on the head. Psychiatric disorders (depression anxiety and insomnia) may also respond to transcranial PBM.

One of the commercially successful areas of PBM is the rapidly growing application for general wellness and cosmetic applications, such as LEDs applied to the muscles to dramatically improve athletic performance.

For more information, visit the on-site SPIE bookstore.

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PUBLISHED BY
SPIE, 1000 20th Street
Bellingham WA 98225 USA
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