TUESDAY EDITION

SPIE. | optics.org | TUESDAY, FEBRUARY 5, 2019

PHOTONICS WEST. SHOW DAILY

The right wavelength

Brittany Speer, II-VI representative, presents the new 405 nm QOMO laser.

Photo: Joey Cobbs

More than just a game. Photo: Adam Resnick

Noise around AR, VR hits new peak

Standing room only at two-day conference on headsets, drones, and smart cars in the future "Photonic City."

As the AR/VR/MR 2019 speakers noted, Sunday's much-augmented Superbowl LIII was a timely case study. Its painted-on lines of scrimmage, first-down lines, replays and ever-present info boxes immersed millions in Augmented Reality.

Earlier, creators and critics of AR, and its cousins Virtual and Mixed Reality, sounded off on successes and misfires at Sunday's second annual Industry Days, one of the best-attended events of Photonics West.

"If you're a Superbowl fan, you came to right place," said Bernard Kress, the event moderator. "We are making the Superbowl more fun, more immersive. We are going to provide the world with this new immersive display to allow millions of people to experience the Superbowl in ways they never have."

But sharp criticism came from Thad Starner, a professor at Georgia Tech, who argued that the industry is ignoring what users actually do, and like. For example, users don't want the widest field of view, don't want to play "head ping pong," moving left and right before a big screen. "Your eyes want to be watching within 30 degrees for the action."

For videos, he said users prefer the small, portable screen in their pocket, like a smart phone, to a giant-size home theater screen. "Portability beats FOV." And users don't opt

continued on page 33

Donna Strickland: Girls just wanna have fun – in the lab

At the BiOS Plenary Session on Sunday, SPIE President Jim Oschmann welcomed Canadian optical physicist Donna Strickland of University of Waterloo to the stage.

Less than two months earlier, in December 2018, Strickland had been led to the podium to speak at the Nobel Prize Award Ceremony in Stockholm, Sweden, and accept the Nobel Prize in Physics – the only women honored with the distinction since Maria Goeppert Mayer in 1963 and Marie Curie in 1903. In her PhD project that eventually led to the Nobel Prize, Strickland had cited Goeppert Mayer's work in multiphoton physics.

In her opening remarks, Strickland noted that she was speaking on behalf of Arthur Ashkin, who was awarded half the prize for the invention of optical tweezers, and her "esteemed colleague" Gérard Mourou, with whom she shared the prize for the development of a chirped-pulse

continued on page 33

Nobel Laureate Donna Strickland at SPIE BiOS. Photo: Joey Cobbs

DON'T MISS THESE EVENTS TODAY.

PLENARY SESSION

NANO/BIOPHOTONICS
10:30-11:30 AM, Rm. 207, So. Level 2

INDUSTRY EVENTS

KEY LEGAL ISSUES FACING THE OPTICS INDUSTRY
8-9:30 AM, Rm. 9, So. Exhibit Level

MARKETING & SALES MODELS FOR SUSTAINABLE GROWTH
8-10 AM, Rm. 10, So. Exhibit Level

ESSENTIAL SKILLS WORKSHOPS
8:30 AM–5:30 PM, Marriott Marquis Hotel, Sierra B, 5th Fl.

SENSORS AND INSTRUMENTATION EXPORT CONTROL MEETING
9 AM-12 PM, Rm. 12, So. Exhibit Level

QUANTUM TECHNOLOGIES: CURRENT AND POTENTIAL APPLICATIONS AND MARKETS
9-9:45 AM, No. Exhibit Level

PHOTONICS WEST EXHIBITION
10 AM-5 PM, North and South Halls

SPIE JOB FAIR
10 AM-5 PM, Hall C, Aisle 1800

STARTUP CHALLENGE SEMI-FINALS
2-4 PM, So. Exhibit Level

SILICON PHOTONICS AND PHOTONIC INTEGRATED CIRCUITS: 2019 INDUSTRY PERSPECTIVE
4:30-5:30 PM, Rm. 21, No. Exhibit Level

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

IN THIS ISSUE.


OptoSigma®
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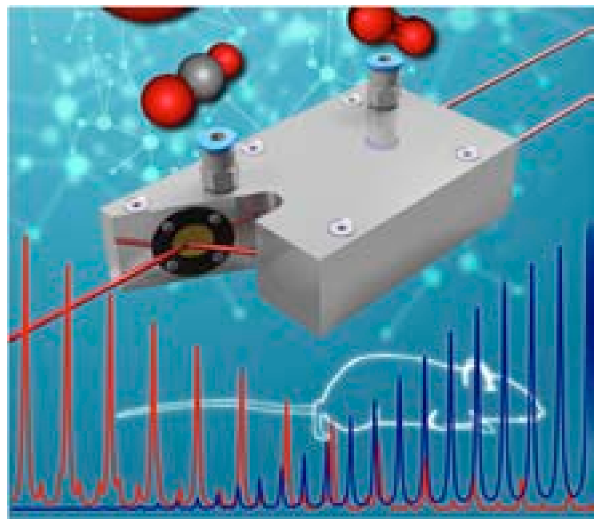
WHAT'S NEW AT OPTOSIGMA
Observe the latest developments in action at the OptoSigma Technology Demonstration Corner
See what we are doing with OptoNano™ Super-Resolution Microscopy System
View innovative solutions in portable power and energy measurement
We're Now Selling Optical Tables. Popular Sizes Stock and Ready to Ship!
Check out our all-new Fiber Optics Product Line Including Fiber Alignment Stages
Stop by our booth for a chance to win great prizes or receive giveaways!
Booth #1427

Analyzing exhaled breath gases streamlines diagnostics

Potentials for diabetes, lung and gastric cancer, even tropical diseases.



The µBreath device, using a substrate integrated hollow wave guide, measures volatile organic compounds in an exhaled breath matrix. Photo: Ulm University

Hundreds of volatile organic compounds in exhaled breath can be monitored by a new device called µBreath, providing non-invasive clues to aid in disease diagnosis, a researcher's keynote talk demonstrated at BiOS on Saturday.

Three prototypes of the µBreath are at work with mouse models. One of them, at the Ulm University Clinics, is continuously analyzing breath of more than 200 mice, said Boris Mizaikoff, director of the Institute of Analytical and Bioanalytical Chemistry at Ulm University in Baden Württemberg, Germany.

These results have been validated with gas chromatography–mass spectrometry, or GC-MS, analysis.

The technique is also used to get at the molecular pattern of rare tropical diseases in exhaled breath, in a European Union-funded project called TROPSENSE, for tropical disease sensing. Other partners include Morocco, Tunisia, and Colombia.

With infrared sensors, the new device can quickly diagnose diseases in humans, in some cases before the disease breaks out. This capability stems from an EU-funded project called Advanced Photonic Sensor Materials, or APOSEMA.

"We anticipate commercialization within the next two years, either via spinning out a start-up we will establish, or licensing to one of our already involved company partners," said Mizaikoff.

Mizaikoff spoke at the Optical Fibers and Sensors for Medical Diagnostics and Treatment Applications conference. His session was called Sensors, Detectors, and Treatment Tools. He described a smart sensor technology that captures disease-specific molecules in volatile organic compounds, called VOCs.

Analysis of volatile biomarkers has great potential for early diagnosis of diabetes and diseases of the lungs, liver, and kidneys, and even breast cancer. The approach offers efficient monitoring of treatment efficacy and identification of altered metabolic signatures.

Exhaled breath analysis in routine clinical practice remains limited, Mizaikoff said, since sophisticated devices are required for the analysis of trace compounds.

But combining highly selective, mid-infrared cascade lasers with innovative miniaturized gas cells enables portable, yet sensitive, exhaled breath analysis devices, Mizaikoff said.

He showed how breath diagnostics in mouse models have achieved direct continuous monitoring of 13CO2/12CO2 isotopic ratio changes, with just a few hundred microliters of the mouse tidal volume – the normal amount displaced by inhalation and exhalation.

Mizaikoff said his research team pioneered use of innovative substrate-integrated hollow waveguides (iHWGs) to detect trace gases in very small sample volumes with the required precision.

A system of exhaled breath sensors makes use of interband cascade lasers enabling real-time breath analysis, and operates as a routine on-line monitoring tool in a mouse intensive care unit with mechanically ventilated and instrumented mice.

Mizaikoff said human-breath technology has long been employed for analysis of biomarkers of human disease stages and progress of therapy targeting gastric cancer. "The 21st century is the century of photonics, and this truly applies in health care," Mizaikoff said, "and it will change way we detect and treat disease."

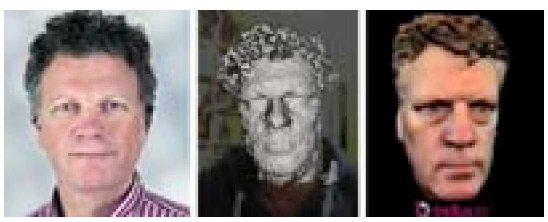
"Photonics is now being used for disease detection, for monitoring treatment, and it is now even used for treating diseases in patients."

The device marks a flurry of activity going on in waveguide-based photonics, Mizaikoff said. "Waveguides have been an enabling technology, always around, but their use in detection and diagnosis has not been so common yet."

FORD BURKHART

iPhoneX scanner enables cheap but effective facial bioimaging

In one of the opening BIOS conference sessions Saturday titled Emerging Technologies, Prof Rudolf Verdaasdonk, of Amsterdam UMC and the University of Twente, Netherlands, described how the Apple iPhone X and tablets can function well as 3D biometric scanners.



Face facts: Rudolf Verdaasdonk and his iPhoneX scans, processed with Scandy Pro (C) and Bellus 3D (R).

These devices that typically cost no more than $1000 (and sometimes much less) enable quantitative photography of human faces yielding high-quality point and mesh surface profiles. These in turn are suitable for diagnosing growth defects, abdominal shapes, and melanomas; for monitoring fitness and diet; and for improving treatments of conditions such as scoliosis or burns and improving prosthetic designs and facial reconstruction.

Prof Verdaasdonk told the conference, "The iPhone X has a face recognition function that can be used as a 3D scanner. In conjunction with the Bellus3D IOS app, it enables face scanning in just 30 seconds.

The iPhone X/Bellus3D performed best for the front view of the face with mesh density around 0.6-0.8 mm compared to the more expensive Artec scanners (<0.2 mm) but similar to the Vectra scanner.

He added, "So we have found that the iPhone X can be used as a practical low-cost 3D scanner to provide absolute measurements of photographic facial features over time. Developers should start to develop apps for diagnostics and automated treatment evaluation."

"3D scanners can greatly improve quantitative measurements of human surfaces and volumes as an objective follow up in clinical studies for various clinical specialisms such as dermatology, aesthetic and reconstructive surgery."

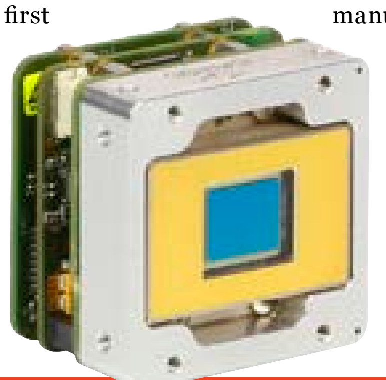
MATTHEW PEACH

XENICS PRESENTS FAST InGaAs CAMERAS FOR HIGH-SPEED APPS

Xenics, Leuven, Belgium, a developer of advanced infrared sensors, cameras and customized imaging solutions across the SWIR to the LWIR realm, is using BIOS and Photonics West to launch its latest high-speed infrared cameras (Booth 735).

While Xenics' established Cheetah series is claimed to be the fastest area-scan SWIR camera commercially available, the company says its new Manx line-scan SWIR series (below) is "the fastest area and line-scan SWIR cameras in the world." Both cameras are on display during Photonics West.

Entering the US market for the first time (having first launched at VISION in Germany in November, 2018), the Manx is a SWIR camera that provides high quality line-scan imaging at speeds of up to 390 kHz line rate.



Xenics states, "This rate outclasses similar cameras by a factor of 2.5, and our breakthrough is provided without compromising other KPIs."

It has a high QE in the 900 to 1700 nm wavelength range. The Manx SQ 2048 variant of the Manx camera is designed for machine vision applications, offering high-resolution square pixels, again with high speed and low noise.

Also on show is the company's established range of infrared imagers, including the Cheetah series and the Xeva cameras with their extended response up to 2.5 µm.

Xenics is a vertically-integrated manufacturer for SWIR imagers, and can respond to customization requirements often required in such projects on multiple levels: from ready-to-use full cameras to camera modules and sensors.

MATTHEW PEACH

AIM Photonics reports 'best-in-class' 300mm silicon photonics MPW wafer performance

The American Institute for Manufacturing Integrated Photonics Monday announced a number of updates leading to "best-in-class" 300mm silicon photonics-based multi-project wafer performance for the Department of Defense-sponsored initiative led by SUNY Polytechnic Institute.

The institute commented that its Si photonics process design kit "continues to advance, enabling industry-leading performance as a result of our library of both active and passive high-performance photonic components, interfaces, schematics, and models for the development of optical modules and systems."

"Our best-in-class MPW offerings reflect our deep bench of experts and collaborators who support our more than 100 signed-up partners and other interested collaborators," commented Dr. Michael Liehr, AIM Photonics CEO and SUNY Polytechnic Institute Executive VP for Innovation and Technology.

Shorter processing times

"Our MPW processing time has decreased from 130 days in 2016 to fewer than 90 days now. AIM Photonics remains focused on achieving impactful, world-class quality and repeatability of the advanced technologies that will shape our world," Liehr added.

This MPW performance is the result of new, ultra-low-loss waveguides, featuring attenuation that is less than 0.25 and 0.10 dB/cm for 220nm silicon and 220nm silicon nitride, respectively, in addition to around 1dB/facet edge coupler for both electric and magnetic polarization.

With only a 90-day fabrication time for full actives to be processed on 300mm silicon-on-insulator wafers, and using the same toolset that produces 14nm and smaller circuits, these capabilities also enable easy transfer to similar high-volume equipped foundries if needed.

As part of AIM Photonics' MPW offering, its passive interposer also features a 100µm-thick Si substrate with a through-silicon-via SiN waveguide with three front-side and one back-side metal wiring levels, in addition to pockets for laser and PIC chips, which can be flip chip soldered in deep trenches for edge or evanescent fiber coupling.

AIM Photonics' PDK now consists of more than 50 photonics components, including passives such as waveguides, edge couplers, and layer transitions, and active devices such as C, C+L, and O Band photodetectors; microdisk switches and modulators; thermo-optic phase shifters and switches; and variable optical attenuators, verified by university and industry experts.

Overcoming challenges

"Companies operating within the integrated photonics space face a number of challenges as they seek to provide cost-effective, high-quality products. With our continually updated PDK, and MPWs that offer a broad component library, we are thrilled to assist the industry with the capabilities they need to meet current technological challenges," said Dr. Douglas Coolbaugh, AIM Photonics' COO and SUNY Polytechnic Institute Associate VP for Photonics Development.

AIM Photonics will also be offering new incentives to parties interested in the MPW runs. These incentives will be available at the AIM Photonics Booth #4425. Contact the MPW team at reservations@aimphotonics.com.

FORD BURKHART

Modulated Imaging to commercialize tissue oxygenation imager with $7 m win

California-based Modulated Imaging, which has developed an optical technique for imaging tissue oxygenation and hemoglobin levels, has closed a $7 million round of venture finance.

The series B round, in which the company aims to raise $10 million overall, will be used to commercialize the UC Irvine spin-out's Clarifi imager, and to support additional work.

Commercialization

Modulated Imaging's technology is based on spatial frequency domain imaging (SFDI), a near-infrared technique that identifies chromophore concentrations in tissue over a wide field of view.

The technique works by shining different patterns of light on the tissue, recording a video of the re-emitted light, and processing the visual information acquired. Mathematical models can then reconstruct the absorption and scattering coefficients of the tissue, yielding quantitative spatial maps of the tissue's optical properties and biochemical composition.

That information can then be used to quantify hemoglobin concentrations in both superficial and sub-surface layers of tissue, enabling diagnosis of circulatory problems and helping doctors identify patients who are at risk of foot ulcers and other vascular complications.

Surefooted: Modulated Imaging can help ensure patient quality of life by identifying trouble before an ulcer develops. Photo: MI

"We expect Modulated Imaging's novel approach to fundamentally change how clinicians diagnose, treat, and deliver care to patients across the healthcare continuum – especially patients with diabetes," said Goulard. "The team is focused on providing a solution for all stakeholders in this space and uniquely equipped to make this happen with their breakthrough technology that is protected by worldwide patents."

FDA clearance

Last year, the US Food & Drug Administration (FDA) awarded the Clarifi imager 510(k) clearance for pre-marketing, and with that and the new funding Modulated Imaging will look to fully commercialize the platform.

The company's CEO and CTO, David Cuccia, said that the support from Pangaea and the continued support of series A investors would accelerate that activity. Hamamatsu and Mitsubishi took part in the $2.9 million series A round, closed in late 2017.

Al Wiegman, who heads up Fresenius Medical Care Ventures, added: "Fresenius Medical Care Ventures' continued investment in Modulated Imaging is based on the disruptive nature of their early data and the impact we believe this technology could have in our mission to decrease life-altering complications in our patients with diabetes, vascular, and kidney diseases."

One application where the Modulated Imaging technology promises to have a huge impact is in diabetic foot ulcers, which often go undiagnosed until they are so advanced that amputation becomes the only option for a patient.

Other potential clinical uses include detailed skin assessment for aesthetic applications and treatment monitoring in dermatology.

MIKE HATCHER

SAFETY TECHNOLOGY HOLDINGS ACQUIRES OPTEK SYSTEMS

Safety Technology Holdings (STH), based in Farmington Hills, Mich., has announced the acquisition of OpTek Systems, headquartered in Oxford, UK, which also operates a processing ITAR-compliant facility in Greenville, SC. OpTek is exhibiting at Photonics West on booth 6025. Financial terms of the deal were not disclosed.

STH is a portfolio company of UK-based private equity firm Bridgepoint and is a holding company with established test and measurement companies including: vehicle safety company Humanetics Innovative Solutions; specialty optical fiber manufacturer Fibercore (on booth 5253); and sensor manufacturer, Hitec Sensor Developments.

Founded in 2000, OpTek's core expertise is in lasers, optics, and laser materials interactions with a high-degree of automation. Its products include laser optical fiber processing and micro-machining equipment. OpTek's founder and CEO, Dr Mike Osborne, will continue in his current role.

MATTHEW PEACH

Visit us at
Booth #1459

TRIOPTICS
See the Difference.

Precise camera module manufacturing and 100% testing technology for ADAS or LiDAR applications - ProCam® and CamTest

An increased demand for complex camera systems used in safety-related and automated object recognition and classification, for instance in the automotive industry (keyword: autonomous driving and driver assistance systems), results in new and higher requirements for the characterization of the image quality and the assembly of camera modules. The entire test chain for optical systems, sensor components and complete camera systems must meet these new requirements.

Here, TRIOPTICS offers the matching technologies and benefits of its many years of experience in optical testing. TRIOPTICS has developed test systems that make it possible to determine the most important measurement parameters in a reproducible way and with the shortest measurement time as an end-of-line (EOL) test integrated in fully automated production lines. Optical characteristics (such as distortion, vignetting and image contrast/ MTF), opto-mechanical characteristics (such as focus position of the image sensor in relation to the lens, the bore sight or the roll angle) and opto-electric characteristics (such as defective pixels, image noise, linearity or color reproduction) are measured with TRIOPTICS CamTest modules. The CamTest modules can be integrated as a modular set up in a fully automated production line for high-volume manufacturing.

In addition, TRIOPTICS has recently developed the extremly compact system CamTest Smart. A 100% testing technology of all essential image quality characteristics of camera modules in just one system. It integrates the three most important test systems CamTest Focus, CamTest Chart and CamTest Spectral. Thus, the system covers besides common optical and optomechanical parameters like MTF, SFR, defocus, image plane tilt and rotation, or distortion additional sensor testing parameters such as OECF, dynamic range, white balance, relative illumination, spectral response and more. Further benefits of the CamTest Smart instrument are: small footprint, flexibility concerning different products and fast changeover times.

TRIOPTICS also offers solutions for the critical challenge of active alignment and series production of high-precision optical sensor systems. Tight mechanical machining tolerances are required to achieve the requested imaging quality. Automated active alignment approaches help to optimize the production. With ProCam® TRIOPTICS offers a complete solution to actively align, assemble and test complex camera modules in order to control and overcome critical issues. The ProCam® Align Smart is a compact system for sampling and small series production and with ProCam® Inline TRIOPTICS provides a fully automated system for 24/7 high-volume manufacturing and testing of precise camera modules.

Experience a wide range of camera module manufacturing options at Photonics West, TRIOPTICS booth #1459.

Highlights at our booth #1459

Alignment Turning of Mounted Lenses
ATS 100

Quality Control of Camera Modules
CamTest Focus

Optical Performance Testing of Waveguides
ImageMaster® Lab AR

Image Quality Testing of VR Lenses
ImageMaster® Lab VR

Rotation-free Centration Measurement
OptiCentric® Linear

MTF Measurement Station
ImageMaster® HR UltraPrecision

Fully Automated Cementing of Doublets
OptiCentric® 100 with LensAlign 2D Standard

Center Thickness Measurement of Single Lenses and Doublets
OptiSurf® LTM

Goniometer for Angle Measurement on Prisms, Polygons and Wedges
PrismMaster®

Electronic Autocollimator for Angle Measurement
TriAngle

Wavefront and Surface Measurement
μPhase® Interferometer

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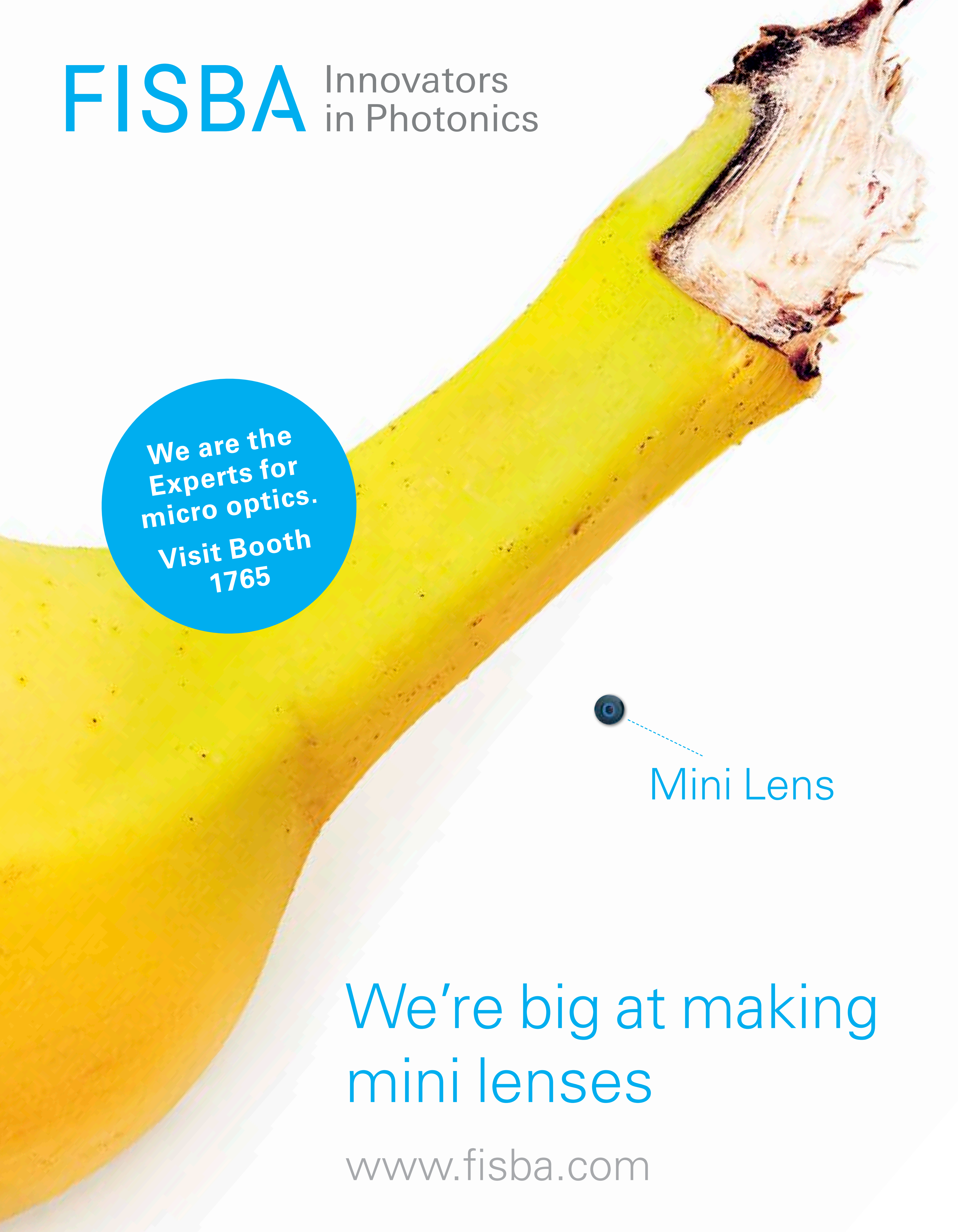
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Back and bigger than ever: it's show time!

SPIE CEO Kent Rochford welcomes delegates to the biggest Photonics West so far, inside a newly refurbished Moscone Center.

From the SPIE leadership, members, and staff, please accept our warm welcome to Photonics West 2019 in the fully renovated Moscone Center. This year's meeting will be the biggest Photonics West ever, and will provide more opportunities to learn, share, and network than a single person can experience, so take advantage of our scheduling tool and mobile app to make full use of the opportunities. Convening our community is an important part of advancing optics and photonics, so thank you for your participation.

SPIE CEO Kent Rochford. Photo: SPIE.

Photonics West reflects the state of our industry, and this year's event suggests we're in a good place. The significance of optics and photonics can't be ignored, and is manifest in myriad ways. For example:

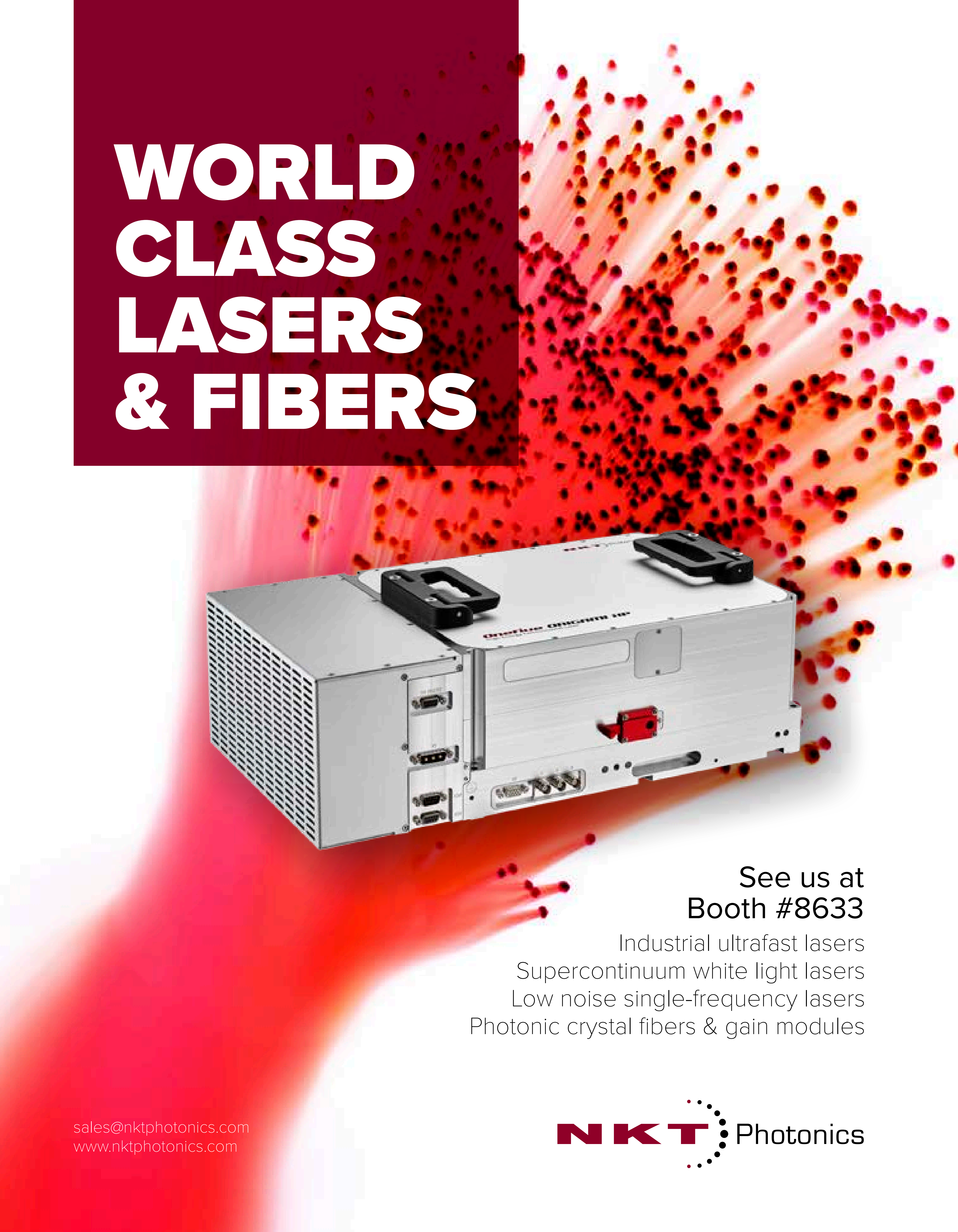
- The most recent Nobel Prize in Physics was awarded for two photonics breakthroughs – optical tweezers, and chirped-pulse amplification that enables high-intensity, ultrashort laser pulses. We heard more about the latter in Nobel laureate Donna Strickland's plenary talk on Sunday evening. Since the invention of the laser, 20% of these prizes have gone to breakthroughs in optics and photonics, or to breakthroughs enabled by optics and photonics. Narrowing to more recent results, 40% of prizes since 2000, and fully 50% in the last decade, either advanced or depended on optics and photonics. A lagging indicator, perhaps, but the collection of prizes certainly points to the importance of our technologies.
- The latest release of our SPIE *Optics and Photonics Industry Report* finds that the value of photonics-enabled products and applications account for more than 10% of the world's economy, or about $7 trillion annually. Considering just the core optics and photonics components business, we count over 3300 companies in over 50 countries that employ more than 950,000 worldwide. Moreover, the industry is projected to have a compound annual growth of 6.6%. You can hear about this report, as well as sessions on industry perspectives, business issues, and commercial applications at our many industry events in the exhibit hall.
- The emergence of 5G means more fiber-optic backhaul – more lasers, components, optics, and test equipment. The steady march of Internet of Things (IoT) – analysts estimate we currently have seven billion active IoT connections, not including smartphones or computers – means more optical sensors and innovative applications. The explosion of lidar – for robotics, autonomous vehicles, wind turbines, surveying, and more – is mainstreaming very sophisticated photonics in a variety of packages and price points. And AR/VR/MR continues to grow – as evidenced at our dedicated conference Sunday and Monday.
- Looking into the future, opportunities in quantum optics and photonics will provide another powerful driver. The US government recently authorized $1.3 billion to add to the billions of dollars in research funding announced by many other countries over the past few years. The National Photonics Initiative, funded by SPIE and OSA, worked with decision-makers to build awareness and support, leading to this encouraging result. Exploitation of quantum effects promises to enable new metrology, sensors, imaging, communications, and computation, and can support unique applications not accessible with classical techniques. The word "quantum" appears over 400 times in our technical program, and we have several conferences devoted to the area, so you'll find many opportunities to learn more.

SPIE is a not-for-profit corporation, as are most professional associations. We have members rather than shareholders to satisfy, and serve a mission to "partner with researchers, educators, and industry to advance light-based research and technologies for the betterment of the human condition." Organizing the conferences and publications that bring together people and knowledge to advance the field is important to our mission, but we do a lot more. In 2018 we provided over $4 million to the community in the form of scholarships, travel grants for students, science fairs, training, and public advocacy. We are very proud to be the leading benefactor for our field, and will do more to reach our Board's directive to increase this support to over $5 million in 2019.

In addition to all of the science, technology, and industry programs, Photonics West is the place to reconnect with colleagues and collaborators, and to meet new ones as well. I hope you enjoyed yesterday's Welcome Reception and were able to attend our *Full Spectrum Photonics* Presentation and Reception, hosted by SPIE Women in Optics and SPIE Diversity & Inclusion, which explored approaches to challenge stereotypes for the benefit of science. Social and networking events continue, and today will include a student networking *Lunch with the Experts,* a Speed Networking social, and an LGBTQ Social.

You have the opportunity to take advantage of all of this at the world's largest photonics technologies event, in this wonderfully eclectic city by the Bay. I hope you got some rest beforehand, because it's show time. Make the most of it!

KENT ROCHFORD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ELI Beamlines now open for business

The various petawatt-class laser systems at the ELI Beamlines facility near Prague bring to fruition the Nobel-winning vision of Gérard Mourou and Donna Strickland.

The Extreme Light Infrastructure (ELI) project, a trio of giant laser facilities across eastern Europe, is officially up and running. Last year saw ELI pass several of its planned objectives on time and on budget as the sites become some of the world's foremost high-power laser user facilities.

The multi-sited endeavor comprises complementary facilities in the Czech Republic, Hungary, and Romania, built to investigate light-matter interactions at the highest of intensities and the shortest of time scales currently possible. At its maximum output, the most powerful of the systems will be more than six orders of magnitude more intense than the prior state-of-the-art.


The "first shot" at ELI Beamlines was officially achieved in July 2018, on the L3-HAPLS system. Photo: ELI Beamlines.

ELI Beamlines, the Czech arm of the project in Dolní Břežany, near the capital Prague, is the first of the three sites to begin real research work. The end of 2018 marked a significant milestone in the implementation of a site that represents the Czech Republic's largest single investment in a research and development facility. It also represents the culmination of work that began in earnest in August 2011, following a preparatory phase coordinated by 2018 physics Nobel laureate Gérard Mourou.

The 2018 prize was of course shared between three laser physicists. Half went to Arthur Ashkin for his work on optical tweezers, with the other half shared by Mourou and Donna Strickland for their method of generating high-intensity, ultrashort laser pulses. While at the University of Rochester in the 1980s, the pair laid the foundations for ELI with their breakthrough innovation: chirped-pulsed amplification (CPA).

As Allen Weeks, ELI's director general, told *Show Daily*: "The Nobel Prize validates the vision Gérard Mourou had more than 15 years ago, [and] his vision is being realized at ELI with our petawatt-scale lasers. This particular development is opening up exotic new fields of science in the sub-atomic and nuclear realms, and exploration for decades to come."

Mourou and Strickland's CPA technique stretches and amplifies low-intensity light, before compressing it back into incredibly short and hugely powerful pulses. Today's petawatt-scale laser systems use the approach to generate pulses with a greater power than the combined output of every power station in the world – albeit for only a billionth of a billionth of one second. And it is the key technology that makes ELI possible.

"Professor Mourou understood the potential of the discovery and has championed the possibilities of advanced laser science for decades," continued Weeks. "That has ultimately led to Europe having some of the most advanced laser systems in the world, as well as [some] leading companies in the field."

Mourou himself first proposed ELI back in 2005, and coordinated the project as a bottom-up initiative of the European laser community. In 2010, he co-authored the ELI "White Book", a blueprint of the key technical proposals and science case behind the project.

2018 proved to be a pivotal year at ELI Beamlines, with the successful installation of three of its four laser systems. Known as "L1-Allegra", "L3-HAPLS", and "L4-Aton", each represents a significant milestone in worldwide laser development. As of January 2019, more than 300 people are employed at the facility, combining their efforts with a broad and growing international collaboration of users.

Collaborations and clients

Those beamlines are now being put to serious research work. One example of the international collaboration is with Italy's National Institute for Nuclear Physics (INFN), demonstrated by the delivery of the "ELIMAIA-ELIMED" system for laser-based ion acceleration, and the launch of a high harmonic generation (HHG) source.

ELIMED is said to represent a key technology at ELI Beamlines, enabling users to carry out pre-clinical research for future applications including cancer therapy. The short bursts of protons and ions accelerated by the L3-HAPLS beamline, which delivers petawatt blasts at an unprecedented rate of 10 Hz, can be used to experiment on biological systems in a way that has simply never been possible previously.

> "At ELI Beamlines we intend to be available 90-100 percent of the time."
>
> ALLEN WEEKS, ELI DIRECTOR GENERAL.

As part of the transition towards user operation, the ELI Beamlines team has delivered 1200 hours of activity to a range of external client users, on four experimental stations. That work has provided the facility with a solid foundation for its first call to the international scientific community.

Weeks joined ELI in November 2017, and is now

continued on page 11

ELI Beamlines continued from page 09

establishing a European Research Infrastructure Consortium (“ERIC”), in order to manage the three different facilities in three different countries as a single legal commercial entity.

“ELI has achieved substantial developments in the past year,” Weeks said. “Notably, we have received $500 million in procurement. Europe, in particular, has really led the world in terms of high-intensity laser developments. We are aiming to reach a research-industry balance to be able to achieve scientific impact.”

Turning to ELI Beamlines, the first active ELI facility, he added: “The Beamlines teams have started operations on time and it is certainly impressive. They have delivered almost exactly what they said they would, when they would, in their development plan six years ago.

The “L3-HAPLS” beamline, which delivers petawatt-scale laser blasts at a rate of 10 Hz, was declared fully integrated and operational in July 2018. It was originally built at Lawrence Livermore National Laboratory (LLNL), before being packed up and shipped to the Czech Republic. Photo: LLNL.

“Current users include French, German, and UK teams, and international groups, mainly from existing laser facilities. The [Beamlines] operations team under Georg Korn is very experienced and enabling the projects of the client groups to make the most of our facilities.”

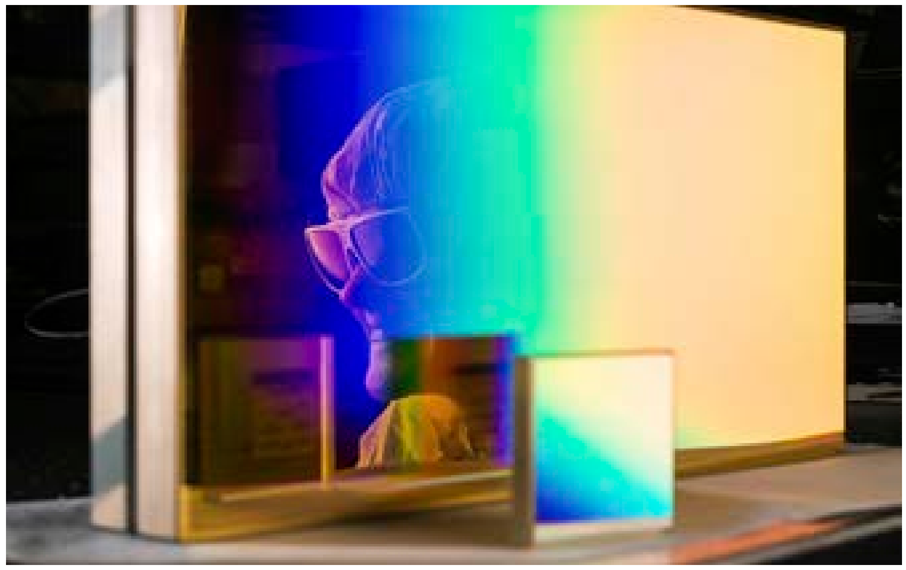
The four different beamlines available at the Czech facility give those users plenty of options. Aspiring to offer the world’s most intense laser system, the L4-Aton line will produce ultra-high peak powers of 10 petawatts and focused intensities up to 10^{24} W/cm^2, at an unprecedented rate of one shot per minute – providing new and unique sources of radiation and particle beams of high utility. Indeed, each of the beamlines is designed to enable groundbreaking research in areas like material science, proton therapy, biomedicine, and laboratory-based astrophysics.

Reliability

Not that simply achieving record-breaking outputs like this is the aim, Weeks stresses. “One of the biggest issues in this field is that while a number of universities have big laser facilities, maintaining and operating these systems ‘on demand’ is very difficult, so availability is generally low – perhaps only half of the time, typically,” he said.

“At ELI Beamlines we intend to be available 90-100 percent of the time, which is very hard to achieve. If a client arrives to conduct an experiment for which they are paying then they will not want to wait for it to begin. We are aiming to guarantee [them] a quick start.”

ELI employs a team of experienced scientists to help with the design of client experiments, and one of the primary missions at the Beamlines site is using lasers to drive other physical systems such as accelerators. But in contrast to more established synchrotron facilities and their associated user programs, which have been in place for more than 20 years, the laser community is still developing new approaches to accelerator experiments.



Inside the University of Rochester’s Laboratory for Laser Energetics, where the CPA technique was invented by Gérard Mourou and Donna Strickland. Here, current LLE student Sara Bucht is reflected in a large grating, shown next to the original, much smaller, grating built by Strickland for CPA while she was a graduate student at the same lab. University of Rochester LLE/Adam Fenster.

The major advantage offered by the powerful laser pulses available at ELI Beamlines is that acceleration can be achieved in a significantly smaller space than a stadium-sized synchrotron. And the arrangement should enable new medical applications, for example proton therapy, where the laser itself acts as the accelerator.

Weeks went on to explain the thinking behind the plan to establish ELI as an ERIC. “This would give us the flexibility to market our activities across Europe, and enable [ELI] to be used by private client companies,” he said. “However, our main aim is to benefit the ambitions of the main ELI group member countries’ national research initiatives.”

“I expect that most of the work to be conducted will be open research for the benefit of all members,” he added. “A typical experiment will run for 2-4 weeks. When up and running, the three ELI facilities in the Czech Republic, Hungary and Romania are together expecting around 1000 researchers to visit and work at the centers over a typical year. We want to continue upgrading over the coming years, so our model will be to develop the ELI technologies and find the partners who want us to help them with their developments. This is exactly what the Czech group is already doing now with our new petawatt lasers.”

Looking at things more broadly, Weeks added: “What a lot of people are saying is, ultimately, we want to consider lasers not so much as a tool of research but as a

continued on page 13

ELI Beamlines continued from page 11

commonplace scientific instrument. One example here would be the laser's capability of driving acceleration."

He also expects to see the ELI approach mimicked elsewhere, and senses an opportunity to drive down the cost of laser-accelerator technology. "I believe we will soon see similar facilities to ELI emerging in the US and in China," Weeks said. "Furthermore, we will see a faster trickle-down benefit." Currently the biggest factor restricting greater proliferation is the sheer cost and limited availability of the key components needed to build such high-power systems.

"Building an accelerator for around $300 million is currently the norm, but if we could achieve it for $5 million or so then it would really make a big difference to the potential of this sector," Weeks said. "At ELI we are aiming to achieve a $5 million source that is effectively an economical, portable accelerator."

Installations done; experiments begin

In October 2018, ELI Beamlines reported the "first light" achievement of high-order harmonic generation (HHG) with the facility's L1-Allegra laser. This represented the successful culmination of a year-long installation process.

ELI Beamlines is working with partners at the Italian National Institute for Nuclear Physics (INFN) on a laser ion accelerator, for applications including medical research. Photo: ELI Beamlines.

In the first integrated test experiment, the Allegra laser's front-end output was propagated through the whole system and compressed in a vacuum by chirped mirrors. The resulting laser output parameters included a pulse energy of 1.4 mJ, pulse duration of 14 femtoseconds, a central wavelength of 830 nm, and a repetition rate of 1 kHz.

The laser pulses were then directed though a vacuum transport and delivered to the HHG beamline. It was characterized and focused into a 20 mm-long gas cell, showing good pointing stability, a crucial feature for pump-probe experiments with tight focusing.

Roman Hvězda, project manager at ELI Beamlines, told *Show Daily*, "We are now completing the second phase of implementation at the facility, and we are moving into our operational phase. So we have now commissioned three lasers out of the planned four. Our main aim is to serve the needs of the client-users by obtaining the radiation and particle sources that they are expecting for a range of experiments – in different areas including physics and astrophysics, chemistry, biology, material science, and medicine."

He continued, "During 2019, four out of the planned nine workstations will become available to external users. The others will be gradually commissioned, along with a complex commissioning scheme using several petawatt-class [lasers], including state-of-the-art ten petawatt lasers and the combination of beamlines delivering X-rays, electrons, and ions.

"Our ten petawatt laser will be used mainly for astrophysics-related research. For example, it will enable researchers to make fundamental observations of ultra-high-intensity interactions, mimicking interactions inside stars.

"Another aim is to develop a compact proton accelerator as the basis for a potential cancer treatment system. With our partners from INFN, we are already working with hospitals to optimize our solution, and to achieve a cost-effective result. We aim to complete this ion beamline in 2019, so that it can be used for medical research or treatment development."

Hvězda added that in mid-2018 he had met Gérard Mourou during the Nobel laureate's visit to ELI Beamlines with his colleagues from École Polytechnique in Paris, to discuss future involvement and development – as well as the opportunities presented by the newly raised profile of the CPA technique and the extraordinarily high-power lasers now becoming available to users.

"We are highlighting his receiving the Nobel prize alongside Donna Strickland to promote our organization, and we hope to attract more government support and activity from across Europe, as well as overseas," Hvězda said.

Mourou has since paid a visit to the Hungarian wing of ELI (ELI-ALPS), where the focus is on attosecond science. While there, he said: "To see the continual progress that is being made here each and every day in laser research and to have a part of the complex commemorated in honor of this year's Nobel Prize is truly rewarding."

MATTHEW PEACH

ELI AT PHOTONICS WEST 2019

At the main Photonics West technology exhibition, ELI Beamlines will be represented on the HiLASE booth (#5074). Members of the scientific team will also discuss their latest progress in a presentation entitled "kJ-10 PW class laser system at one shot a minute". The paper is part of the conference session *High Power Lasers for Fusion Research V: Status of Big Lasers*, which takes place Wednesday morning in Room 211. The talk describes the 10 PW, kilojoule-class laser designed and built by National Energetics for ELI Beamlines, and how the system achieves an unprecedented repetition rate of one shot per minute.

Faster, wider, deeper: imaging advances in focus at Hot Topics session

Leading developers of multiphoton, multispectral, and optical coherence tomography imaging techniques cover the latest technological advances with their cutting-edge hardware.

"Neuroscience has an urgent need for new large-scale neural recording technologies to ensure rapid progress in the understanding of brain function, [and the] diagnosis and treatment of neurological disorders," says Daniel Razansky of University of Zurich and ETH Zurich, one of the scheduled speakers at the BiOS Hot Topics session Saturday evening. The ever-popular gathering featured three speakers working on medical imaging modalities – covering the latest progress at their laboratories, and dropping hints of advances to look forward to.

"This may presently sound like an exaggeration, but I truly believe multispectral optoacoustic tomography (MSOT) and other related methods will soon be routinely used in the clinic, one day becoming as popular as ultrasound," adds Razansky. Looking to integrate rapid biological dynamics with MSOT, he sees applications in the areas of cardiovascular and functional brain imaging, tracking cells and targeted agents to yield early diagnosis.

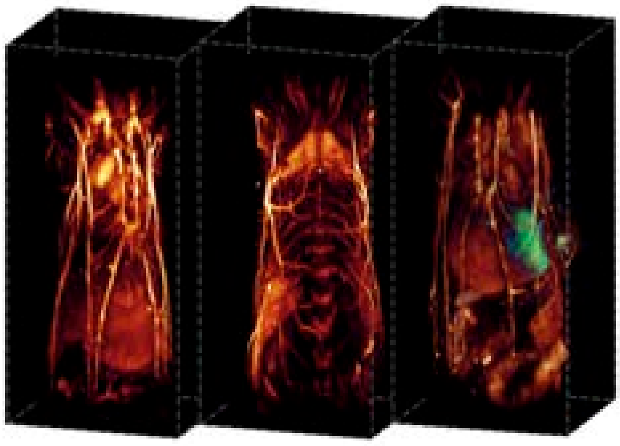
MSOT is based on the optoacoustic effect. And optoacoustic imaging is increasingly attracting the attention of the biomedical research community, thanks to its excellent spatial resolution, deep penetration into living tissues, and its versatile endogenous (internal) and exogenous (external) optical absorption contrast.

The MSOT platforms developed by Razansky's team at ETH have attained exceptional volumetric imaging speeds, enabling new insights into rapid biological processes, and marking an important milestone in terms of clinical translation.

Razansky explains that MSOT is able to image through deep tissues with optical contrast, while avoiding the negative effects of photon scattering. Absorption of short pulses of laser light generates tiny acoustic vibrations, which are detected by sensitive transducers and converted into high-resolution imagery.

"Since light provides rich molecular and functional contrast in biological tissues, it is possible to sense intrinsic biochromes, such as hemoglobin, melanin, or lipids, as well as extrinsic protein-, small-molecule- or nanoparticle-based labels with our method," says Razansky.

MSOT is used in a broad range of biological applications, such as cardiovascular and cancer research, neuroimaging, study of organ function, metabolic research, development of targeted therapies, and treatment monitoring. The realization of real-time, hand-held imaging scanners has seen the technique translate into clinical use, enabling a new level of precision in non-invasive detection of breast cancer and lymph-node metastases, as well as inflammation staging and characterization of skin lesions.



In vivo imaging of rapid biological dynamics in whole mice with spiral volumetric optoacoustic tomography (SVOT).

Razansky feels that although MSOT won't necessarily replace existing imaging equipment, it will complement those tools with exciting new possibilities. "For this vision to become reality, considerable efforts need to be invested into making the technology more robust and affordable, tailor it for specific applications, and develop approaches for accurate image reconstruction, interpretation, and quantification," he says.

His Zurich group is busy devising new approaches to address a broader range of applications, such as spiral volumetric optoacoustic tomography (SVOT), hybrid optoacoustic ultrasound (OPUS), and multimodal combinations with optical microscopy. "These technologies generate lots of enthusiasm among biologists and clinicians, especially when it comes to early disease detection capabilities not available with current modalities," says Razansky.

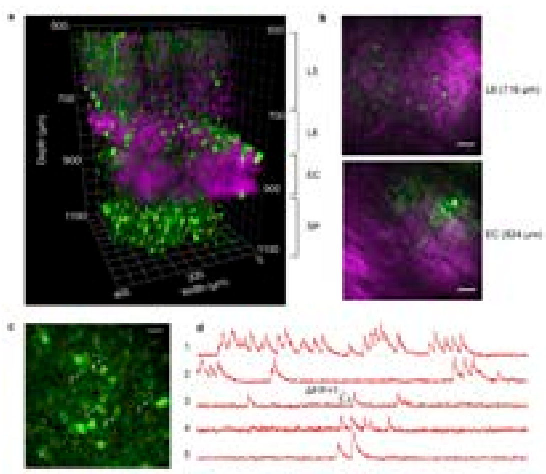
Multiphoton evolution

Also on the Hot Topics agenda was Chris Xu, a professor of applied and engineering physics at Cornell University, to discuss recent advances in multiphoton microscopy (MPM). Speaking before the event, Xu noted that new technology development in the past several years, including lasers and microscopes, has enabled the technique to go deeper, wider, and faster.

"MPM is the go-to technique for high spatial resolution, deep imaging in scattering biological tissue," he says. "The development of long-wavelength MPM has approximately doubled the penetration depth of [the technique] in a living mouse brain."

The combination of long-wavelength and three-photon excitation has resulted in imaging applications that were previously impossible: examples include imaging through highly scattering white matter, an intact mouse skull, and the intact cuticle of an adult fly.

Long-wavelength, deep-tissue MPM relies on ultrafast lasers, particularly the new generations of optical parametric amplifiers that deliver high pulse energies alongside a flexible repetition rate, and broad wavelength coverage. "Further improvement in laser technology will immediately translate to better imaging performance, and open new opportunities for biological applications," says Xu.



Three-photon microscopy showing spontaneous activity in labeled neurons inside a mouse brain.

Imaging over a large field of view (FOV) without sacrificing spatial resolution requires new optical engineering, adds the Cornell researcher, highlighting some remarkable new developments in recent years. Those include an imaging FOV of around 5 mm, with 1 micrometer spatial resolution. "Something one could only dream of about a decade ago is now available for deployment in biology labs, and the approaches are robust and relatively cost-effective for practical applications," Xu says. "Along with imaging large FOVs, there are also exciting developments in imaging multiple axial planes."

Xu points out that imaging speed has proved a bottleneck for MPM, because of the requirement for point scanning. A critical concern in rapid imaging is the photon budget: a certain number of signal photons are needed per pixel to obtain the desired signal-to-noise ratio. This means that merely scanning quickly is not enough on its own to ensure genuine fast imaging.

One way to improve that speed is to leverage what's already known about a given sample. "Random access" scanning, for example, using acousto-optic deflectors or adaptive excitation lasers, has developed as a photon-efficient approach for fast imaging. Parallel imaging acquisitions, using either multi-foci excitation or extended-depth focus, can also be used if the sample is sparsely labeled. With these new developments, says Xu, multiphoton imaging at the equivalent of hundreds of frames or volumes per second is within reach.

Extending OCT

Continuing the theme, Yoshiaki Yasuno from the University of Tsukuba in Japan was due to follow Xu with a talk on extending optical coherence tomography (OCT) toward multiple-contrast imaging.

Yasuno notes that although several such extensions, like Doppler OCT, OCT angiography, and polarization-sensitive OCT, have been investigated for several years, image interpretation is often complicated, so the clinical value of the techniques has only been recognized recently.

The Tsukuba group studies various forms of OCT and their applications in ophthalmology and dermatology. Work being presented at Photonics West 2019 included compression-based, polarization-sensitive optical coherence elastography (PS-OCE), developed for simultaneous analysis of birefringence and biomechanical properties of tissues; a method for pixel-by-pixel tissue classification using multiple contrasts of Jones matrix OCT (JM-OCT); and a high-resolution, motion-free, multi-contrast OCT method for imaging the posterior segment of the eye.

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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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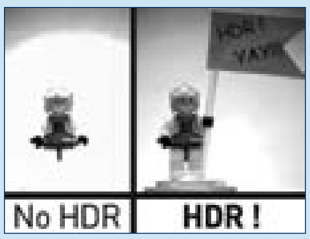

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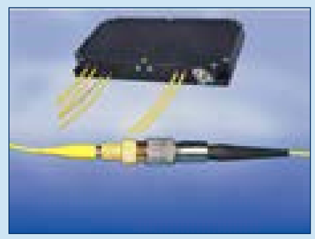

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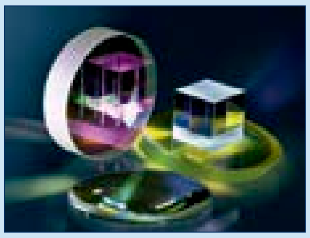

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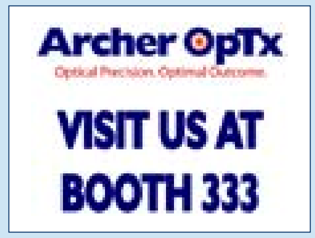

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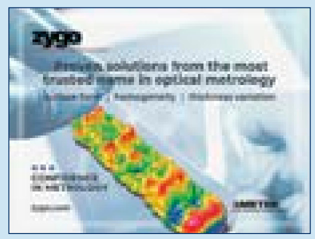

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WaveOptics sees bright future for diffractive waveguides as AR takes off

With augmented reality a key focus of discussion at Photonics West, components from a UK developer could bring new versatility to the technology.

The ability of augmented reality (AR) technology to enhance the real-world environment by overlaying additional visual information within a user's field of view makes it a potentially valuable and disruptive technology for several areas of science and commerce. It also represents a tempting and substantial business opportunity.

Several different approaches to AR systems and the associated wearable glasses that are required have been developed, but optics and photonics technologies remain the key challenge in delivering a convincing and comfortable AR experience to users.

Designs in which a glass waveguide carries the AR overlay from a side-mounted light engine to a position in front of the user's eye offer the most promising route to keeping the view of the outside world as unobstructed as possible, while still allowing the added AR information to be visible. But to work effectively, the waveguide has to meet multiple design and performance requirements, and compromises in image quality can be inevitable.

WaveOptics, established in 2014 and located close to Oxford, UK, has developed new diffractive waveguide technology that tackles this challenge in a novel way. Several recent manufacturing and supply deals signed by the company suggest that the sector is now taking note of a breakthrough that could offer substantial advantages over current competitor designs.

"There are many factors which influence the ideal AR system, but if there's one key aspect that's imperative in practice, then it's the overall size of the AR glasses that users are required to wear," said Phil Greenhalgh, the WaveOptics CTO. "The glasses must have as small a form factor as possible."

In that regard, the waveguides themselves are not necessarily the limiting factor, as the size of the light engines which pump light into those waveguides have more of an influence over the total size and weight of the wearable device. But WaveOptics says its waveguide technology effectively allows a smaller light engine to be employed, reducing the overall size of the glasses.

The company's devices employ two distinct diffraction regions: an input grating where light from the light engine is first coupled into the waveguide; and an output structure comprising a two-dimensional array of nanostructures, designed with a particular periodicity and symmetry according to WaveOptics' proprietary designs.

This layout differs from more conventional approaches, which have typically needed to accommodate not two but three gratings: input, output, and a third to direct the light from the former into the latter. The WaveOptics design allows its single output structure to occupy a larger area than a conventional output grating, with obvious benefits for the image viewed by the wearer.

"Our nanostructures redirect a portion of the light out to the eye, but also distribute some of the remainder diffractively back into the waveguide, where it continues to propagate until it hits the next diffractive structure," explained Greenhalgh. "Repetitions of this cycle as light propagates onward through the entire array effectively expands the guided wavefront in both the 'x' and 'y' dimensions simultaneously."

This expansion and the increased area over which it takes place means that the so-called "eye-box" — the spatial region in front of the eye within which a viewable image is formed — is also made larger, up to 19 x 15 mm in the WaveOptics system. This in turn greatly simplifies the challenge of designing AR glasses able to suit subtly different individual eye spacings and facial characteristics. The result, says the firm, is an improved AR experience to all wearers, who can perceive an expanded field of view without moving the eye. For its system, WaveOptics quotes a possible 40-degree field of view, measured diagonally.

Augmented, virtual and mixed reality (AR/VR/MR) technologies were a major attraction at January's Consumer Electronics Show (CES) in Las Vegas. WaveOptics announced two key manufacturing partnerships at the event, deals that should enable the firm to meet demand from both enterprise and large-scale consumer applications. Photo: CES.

"When conventional AR waveguides perform a similar expansion it requires two separate gratings, but I am not aware of any other technology that achieves a simultaneous expansion in two dimensions solely in the output grating," said Greenhalgh. "This design approach also enhances our adaptability to meet customers' specific requirements for different AR systems. WaveOptics has developed simulation software able to predict the optical behavior of our nanostructures under different design parameters, allowing us to change those parameters and meet customers' differing needs for field of view and other characteristics."

Disruptive technology… for the right end-users

Towards the end of 2018 WaveOptics made a number of significant business moves, including an exclusive waveguide production partnership with Chinese electronics ODM company Goertek, and a long-term supply agreement with glass giant Corning for the ultra-flat, high-index glass wafers used to make the waveguides. It also raised $26 million in a first stage of series C venture funding, which will be used to scale the business and support international expansion. More business deals followed at the start of this year, as the company signed manufacturing partnerships with Taipei-based Compal and Wistron.

These moves reflect a period characterized by WaveOptics as a key inflection point for the company, and for its progress towards delivering proprietary waveguide technology to customers as a component supplier.

"Our agreement with Corning is significant, since naturally the quality of the glass used to produce the waveguides — its flatness, refractive index, and the parallelism of its surfaces — has to be rigorously controlled," Greenhalgh said. "We have also partnered with Corning with a view towards the future products we envisage, where even thinner waveguides are combined with smaller and lighter light engines for more compact devices, with no loss of brightness."

Several large technology companies are now very active in the AR sector, a fact demonstrated by the list of high-profile speakers in the dedicated AR/VR/MR conference stream at Photonics West, and reflecting the belief within multiple industries that the technology can meet their particular needs.

From his perspective, Greenhalgh expects AR to be particularly valuable in areas such as fire safety, where thermal imaging overlays could become a vital and potentially life-saving aid to firefighters. Other fields as diverse as medical training and warehouse logistics are also an obvious fit with AR concepts.

"AR is such a promising technology that there can be a tendency to believe it can do anything," Greenhalgh noted. "It can certainly do many things extremely well, but there are others for which it is less well suited. And there are several applications for which AR is now being promoted, that could realistically be done just as well with modern high-resolution mobile technologies or tablets. There are more than enough really beneficial areas for AR, without trying to squeeze it into areas where only marginal benefits may be found, or which could be done better by other means."

TIM HAYES

SPIE offers assistance in reporting harassment

The problem of harassment in the workplace isn't new, but high-profile cases lately have been making headlines and sparking national discussion.

A recent report from the National Academies of Sciences, Engineering, and Medicine (NASEM) examined sexual harassment of women in science, engineering, and medicine. The report concludes that the cumulative result of sexual harassment causes significant damage to research integrity and results in a costly loss of talent in these fields.

SPIE is committed to providing a harassment- and discrimination-free experience for everyone at its events, an experience that embraces the richness of diversity where participants may exchange ideas, learn, network, and socialize in the company of colleagues in an environment of mutual respect.

2018 SPIE President Maryellen Giger says, "I am glad that SPIE is engaging in not only bringing awareness to this issue, but in helping to fight against harassment in both the workplace and conference setting, which ultimately hurts optics and photonics research and industry."

The NASEM report recommends that professional societies "provide support and guidance for members who have been targets of sexual harassment," and "use their influence to address sexual harassment in the scientific, medical, and engineering communities they represent and promote a professional culture of civility and respect."

Anita Mahadevan-Jansen, chair of the SPIE Diversity + Inclusion Committee, says: "I was just having a discussion with my team about this issue and one of the things that came up was how to report instances of harassment and prejudice, as well as knowing what the consequences could be at large conferences.

"During this conversation, I learned just how blatant apparently gender harassment (not necessarily sexual harassment – so meaning inappropriate comments, etc.) can be in some areas of a conference. This was news to me, as we had not discussed such things before."

SPIE has established a confidential reporting system for staff and all meetings participants to raise concerns about possible unethical or inappropriate behavior within our community (see box). Complaints may be made anonymously.

"Providing a professional and safe conference environment, plus raising awareness of harassing behaviors, are critical priorities to SPIE and OSA," adds SPIE CEO Kent Rochford. "Working together, we have surveyed our members to learn if they have experienced or observed harassment or bullying as an attendee at our conferences and events that either society organizes.

"We are now in the process of analyzing that data and will be sharing the results with our members and the community to help us all better understand the magnitude of these problems, and work within our community to develop solutions and create change."

SPIE's Safe Meeting Policy can be found here: **http://spie.org/conferences-and-exhibitions/photonics-west/spie-safe-meeting-policy**

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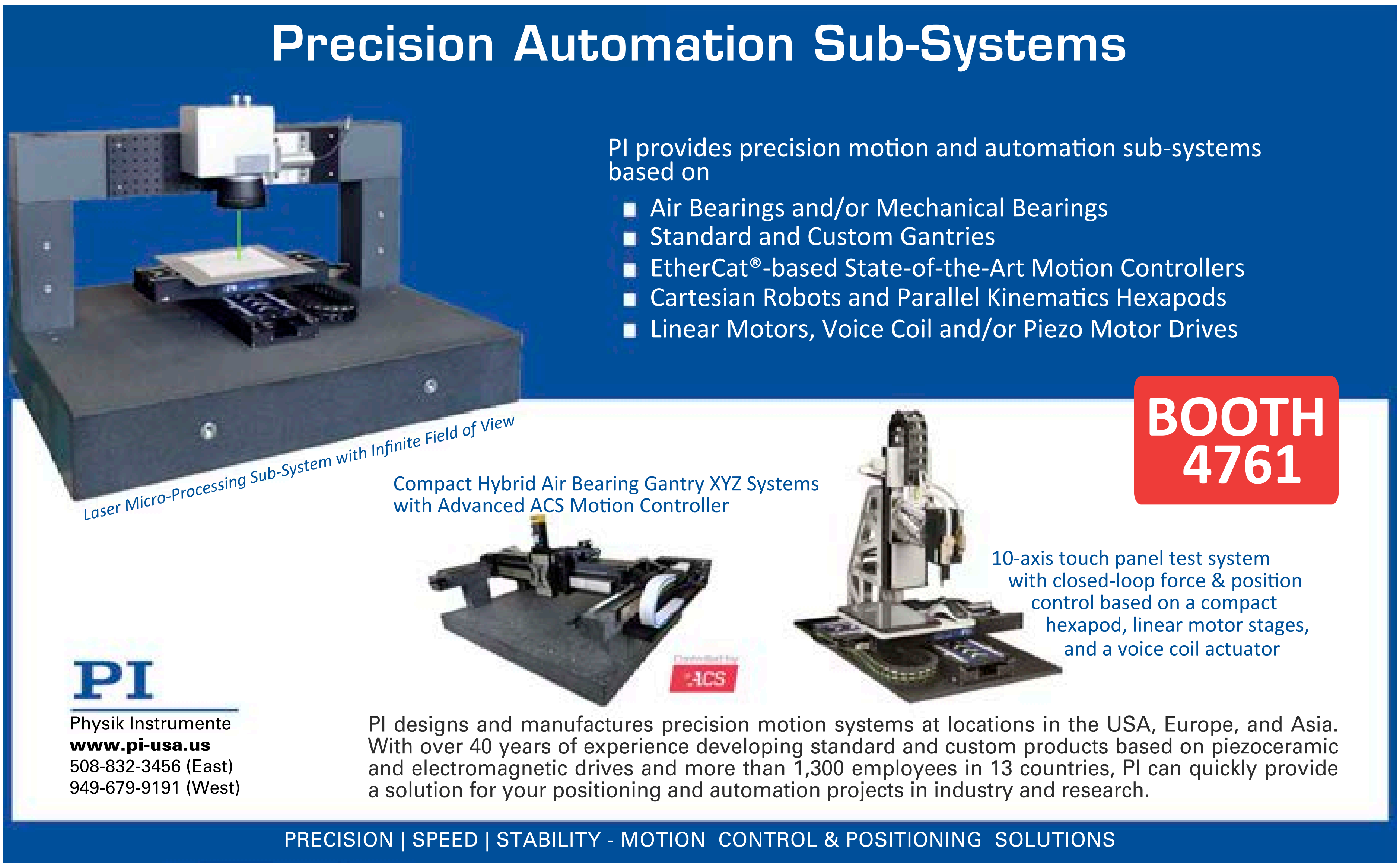
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Photons plus ultrasound: 25 years at Photonics West

Blood vessels, tumors, organs: photoacoustic imaging can visualize all manner of structures deep within tissue. As the “Photons plus Ultrasound” conference marks its 25th anniversary at Photonics West, the technology is on the verge of a clinical breakthrough.

In 2003, Lihong Wang, then at Texas A&M University, US, delivered images of brains in living rats that well and truly moved the field of photoacoustic imaging into the fast lane. Revealing intricate networks of blood vessels in the rat cerebral cortex – acquired with the skin and skull intact – the tomograms represented a massive leap forward for functional imaging using photoacoustics, also known as optoacoustics, and stunned researchers worldwide.

“This was a real breakthrough, and Wang had even induced changes in blood flow by stimulating the rats’ whiskers,” says Paul Beard, founder of the Photoacoustic Imaging Group at University College, London (UCL), UK. “I saw his images and thought, well, this is the standard we have to meet from now on.”

Fellow optoacoustic imaging pioneer and CEO of US-based TomoWave Laboratories, Alexander Oraevsky, was equally impressed. “The worldwide community looked at these images and said, ‘they’re just so beautiful’, and everyone finally realized this was something very real,” he recalls. “We could see functional information that just wasn’t available from any other technology; it was the key milestone and made everybody notice.”

In fact, the effect of sound generation by light was first reported in 1880 – only for the phenomenon to disappear again quickly, and for a very long time. Alexander Graham Bell had discovered that shining rapidly modulated sunlight on an optically absorbing medium induced an acoustic wave, and proposed a ‘photophone’ based on this effect. But his results were crude, the idea shelved, and photoacoustics slid into oblivion for almost a century, while technology caught up.

> “We can study microvasculature to see the onset of these diseases, and potentially prevent a stroke or a heart attack.”
>
> ALEXANDER ORAEVSKY, CEO TOMOWAVE LABORATORIES.

By the 1980s, sensitive acoustic receivers and intense laser light sources were available. As a result, optoacoustic sensing and photoacoustic spectroscopy applications were proliferating. At the same time, physicist and radiologist Theodore Bowen from the University of Arizona was using ionizing radiation and microwaves to excite acoustic waves in materials, in an attempt to retrieve depth-resolved spatial information.

As UCL’s Beard points out, Bowen wasn’t using light, but his results have been important to the field of photoacoustic imaging. “He didn’t really produce an image, and his results were some way from the real genesis of the technique that came in the 1990s,” he says. “But this was one of the starting points of photoacoustic imaging, and shouldn’t be forgotten.”

By the early 1990s, the field of photoacoustic imaging was taking shape. Oraevsky, who by now had been working on laser-induced acoustic waves for several years, was on the cusp of unveiling results that would demonstrate the effect’s potential.

“It hadn’t been clear to us how deep into real tissue you could actually see,” he remembers. “So we started to perform experiments using many stacks of chicken breasts with a little piece of liver underneath.”

Using his then-new technique based on time-resolved detection of laser-induced stress transients, he could visualize the depth distribution of absorbed optical energy in the tissue layers. In 1994 Oraevsky reported his results in the SPIE Proceedings journal, and his technology was catapulted towards practical laser optoacoustic imaging systems for pre-clinical research and breast imaging. As he highlights: “We had clearly seen the signal, and at this ‘aha’ moment realized that yes, it was possible to see deep into the tissue.”

The same year Robert Kruger, then at the Indiana University Medical Center and also CEO of Optosonics, published similar experimental results in the same SPIE Proceedings. And only two years later, Beard – as part of his doctoral studies

3D optoacoustic tomography showing an entire mouse body, including blood vessels and organs. Image: Alexander Oraevsky.

– was using photoacoustic methods to characterize arterial tissue for detecting atherosclerosis. “In the course of this work we ‘accidentally’ obtained a photoacoustic waveform that we later realized represented the structure of the tissue specimen in the depth direction,” Beard highlights.

Following these early demonstrations the field expanded, with more and more researchers joining the field. By 1999, Kruger had developed the world’s first RF-induced thermoacoustic computed tomography scanner for detecting breast cancer, equipment that could differentiate soft tissue with 2-5 mm resolution, up to a depth of 40 mm. At the same time, Wang published the first microwave-induced thermoacoustic tomography based on scanning a focused ultrasonic transducer.

By 2001, Oraevsky had unveiled his prototype of a clinical laser optoacoustic imaging system (LOIS), again, for detecting breast cancer. The system used a single optical fiber to deliver laser pulses and an arc-shaped array of piezoelectric transducers to detect the acoustic signal. Crucially, later clinical trials of the equipment on breast cancer patients showed enhanced contrast between normal tissues and cancerous tumors when compared with X-ray mammography, plus the ability to differentiate cancer from benign masses more accurately, with image resolution on par with regular ultrasound.

Indeed, in 2005, researchers from the

continued on page 27

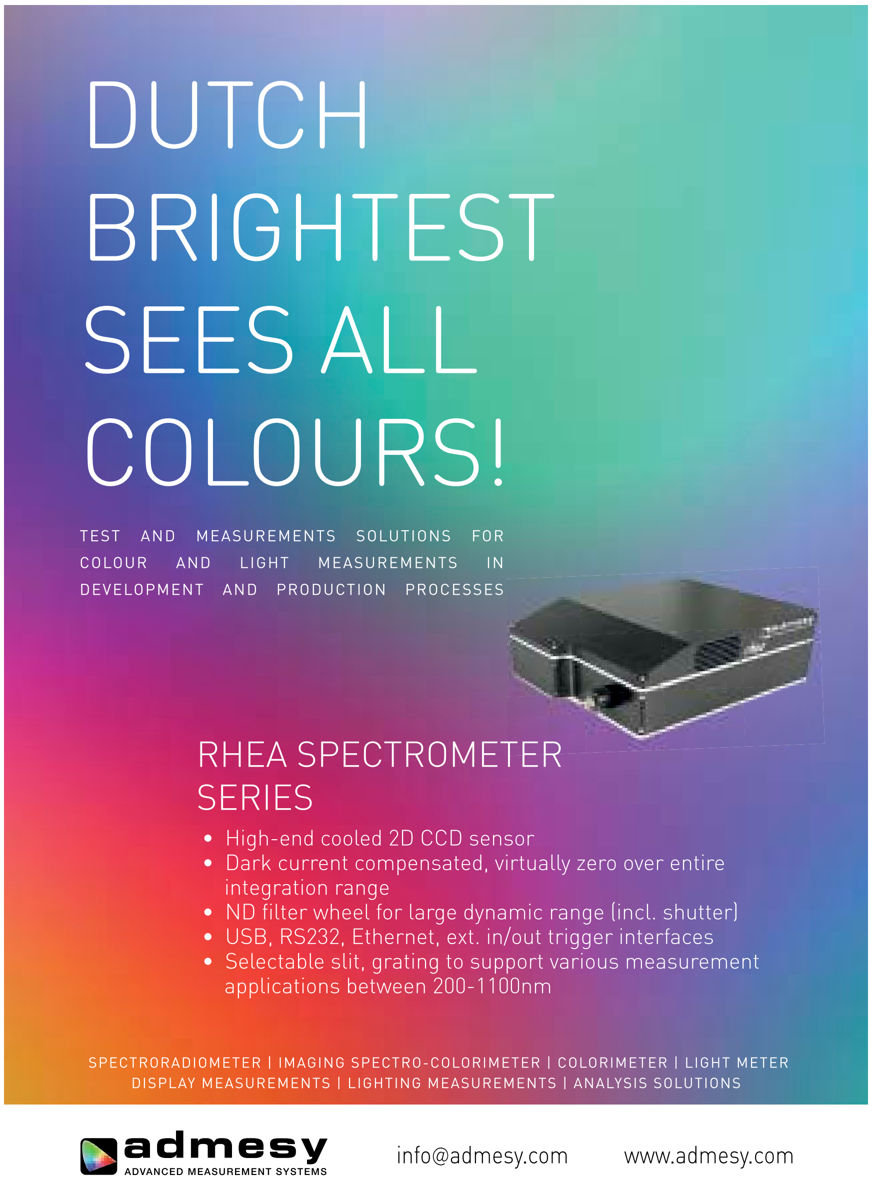
SEEING WITH SOUND: 25 YEARS AT PHOTONICS WEST

Also known as optoacoustic imaging, the photoacoustic technique uses a low-energy, short-pulsed, red or near-infrared laser to produce ultrasound in tissue. When the laser hits the tissue it heats up, expands, and generates a pulse of ultrasound that travels back to the tissue’s surface. These acoustic signals can then be recorded using ultrasonic receivers, and a 3D image based on laser absorption can be reconstructed.

But why does the prospect of photoacoustic imaging excite so many? Simply put, this imaging modality combines the high contrast of optical imaging with the high spatial resolution and penetration depths of ultrasound, without the need for ionizing radiation or toxic contrast agents.

Ultrasound waves are also scattered less than light waves, so optoacoustics overcomes the optical diffusion limit that hinders high-resolution optical-contrast imaging. Meanwhile, both scattered and unscattered photons trigger photoacoustic signals, so acoustic waves can be generated deep within the target tissue.

It means that the technique can image tissues at depths of several centimeters, much deeper than conventional optical imaging, while the light-absorbing structures within that tissue can be resolved at high resolution and with rich contrast. This ‘double-whammy’ of effects has held the attention of the technology’s early pioneers and drawn researchers into the field worldwide. That high level of interest has been reflected in the Photonics West schedule, where the “Photons Plus Ultrasound” conference is this week celebrating its 25th year. Now the largest single conference of the entire symposium, it extends to 16 oral sessions this year and runs through Wednesday in Room 301. A panel session this lunchtime will discuss international standards in photoacoustic imaging.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Photoacoustics continued from page 25

University of Twente, The Netherlands, unveiled the 'Twente Photoacoustic Mammoscope'. At the same time, US-based Seno Medical Instruments bought Oraevsky's intellectual property to commercialize optoacoustic imaging for breast cancer diagnosis.

Tipping point

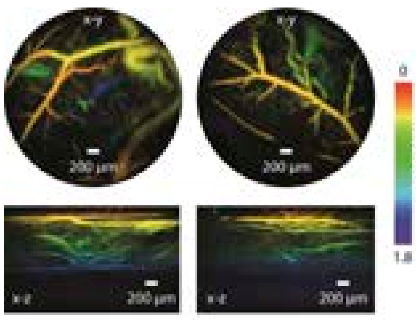
Like many other researchers in the field, Wang and colleagues had been devising image reconstruction algorithms, and by 2001 had developed an algorithm that delivered, in Wang's words, 'beautiful images'.

Next, they set out to demonstrate *in vivo* functional imaging of small animal brains, using laser-induced photoacoustic tomography, and in 2003 made imaging history with the seminal results published in *Nature Biotechnology*. The team had mapped brain structures in rats, as well as functional changes in blood vessels as the rats responded to whisker stimulation.

"This advance was so exciting," Wang says. "The paper is now the most cited in the field, and we have experienced exponential growth since this publication."

With results in hand, the next challenge was to improve spatial resolution. By 2004 the Wang team had developed the first photoacoustic microscope for *in vivo* imaging. They used it to image angiogenesis – the formation of new blood vessels that feed tumor growth – as well as melanoma and hemoglobin oxygen saturation of single blood vessels, another hallmark of cancer, in small animals. They also imaged total hemoglobin concentration in humans, reporting the results in 2006. "With these and our 2003 results, we were the first to take 3D photoacoustic imaging to *in vivo* and the micron-level," points out Wang. "This 2006 paper is the second most cited paper in photoacoustic imaging, so maybe it helped to accelerate growth as well."

Another breakthrough followed in 2009, when Wang unveiled the first photoacoustic endoscope, based on a miniaturized imaging probe. Integrating an optical fiber, ultrasound sensor, and mechanical scanning unit at the end of the endoscope, it enabled high-resolution imaging of soft tissue at depths that even photoacoustic microscopy couldn't reach. Key results included imaging the gastrointestinal tract of a rat.



Photoacoustic images of abdominal skin microvasculature in a mouse. Image: Paul Beard/UCL.

Importantly, in the same year Oraevsky and colleagues also unveiled a 3D optoacoustic tomography system capable of imaging an entire mouse body, for applications in pre-clinical research. The system included a motor to rotate the mouse within an array of ultrasound transducers, as well as an optical module to illuminate tissues of the entire mouse body evenly.

Oraevsky's results, and his images of mouse blood vessels, kidneys, liver and spleen – with 0.5 mm spatial resolution – caught the attention of many researchers.

Beard describes those images as 'just amazing'. Oraevsky adds: "This was so important to pre-clinical research as you could, for example, image cancer progression from onset to metastatic activity for months and months, as well as study what happens when you introduce a therapeutic drug."

The road to clinical applications

In the years that have followed, Oraevsky has developed his 3D photoacoustic tomography system to support clinical breast imaging. The equipment combines ultrasound with optoacoustic imaging to provide both anatomical and morphological information, adding molecular detail on blood.

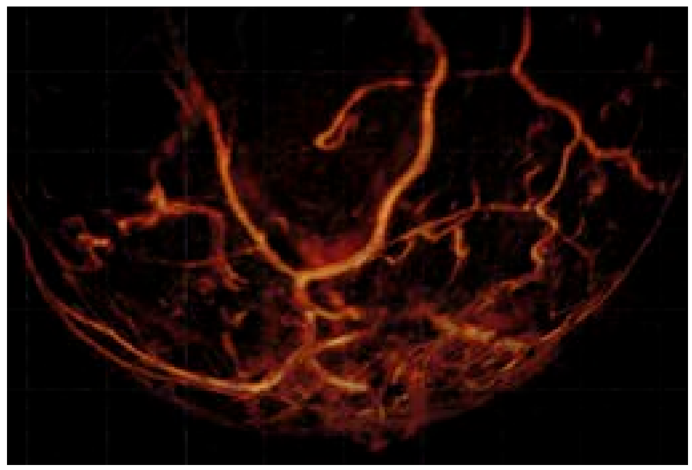
From the outset, Oraevsky has been confident of the impact that optoacoustic imaging could have on cancer detection and diagnosis. Crucially, optoacoustics can estimate oxygen saturation in hemoglobin, which correlates with hypermetabolism, a key characteristic of cancer. As Oraevsky explains: "Aggressively growing cancer also requires an increased blood supply, and creates its own microvasculature network. "Optoacoustic imaging, based on the difference in optical contrast of blood hemoglobin and oxyhemoglobin, is uniquely suited to detect breast vasculature and tumor microvasculature."

Indeed, a host of companies now offer pre-clinical and/or clinical systems that can directly detect such microvascular hallmarks of cancer to a depth of around 4 cm, *in vivo*, a capability previously only available through contrast-enhanced MRI.

Key companies involved in the sector include Oraevsky's Tomowave Laboratories as well as Seno Medical, the Canada-based FujiFilm subsidiary VisualSonics, Germany's iThera Medical, US-based Endra Life Sciences, and Canon Medical Systems in Japan – most of whom are presenting papers at this year's Photonics West. US-based CalPACT has also licensed technology from the Caltech Optical Imaging Laboratory where Wang is now a professor. Oraevsky says that while pre-clinical systems have already reached the market, the first clinical systems are currently undergoing regulatory approvals – and should be diagnosing patients soon.

"I believe we will see the first system from Seno Medical reach the market in 2019," he predicts. "Our technology is not in clinical [settings] yet, but we are

continued on page 28



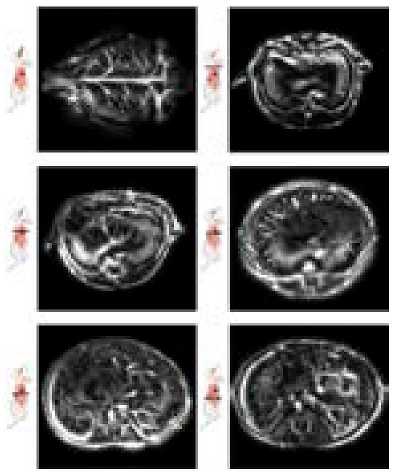
Optoacoustic image of human breast vasculature, captured using TomoWave's "LOISA3D" clinical imaging system. Image: TomoWave Laboratories.

Photoacoustics continued from page 27

getting there, and the next breakthrough will come when systems reach clinical markets and hospitals start to use them."

The technology can also be used to detect blood vessel damage associated with diabetes and cardiovascular disease. "We can study microvasculature to see the onset of these diseases, and potentially prevent a stroke or a heart attack," Oraevsky says. "There are so many applications of this technology where doctors need to detect the properties of blood and circulation."

Wang agrees. Thanks to faster imaging speeds, he and colleagues have developed a single-breath-hold photoacoustic computed tomography system that reveals detailed angiographic structures in human breasts – without any imaging artifacts caused by breathing motion. Recently they also unveiled a photoacoustic flow cytography method to detect single circulating tumor cells in mice. And as Wang highlights, the technique can also be applied to melanoma detection, as well as prostate, gastrointestinal tract and colon cancer screening, plus neonatal brain imaging.



***In-vivo* photoacoustic tomographic images of a mouse.** Image: Lihong V. Wang/Caltech.

"Adult brain imaging is probably one of the most challenging areas in photoacoustic tomography, so we'd like to start with neonatal brain imaging – as the cranial bones are still soft and the fontanelle may be open," Wang explains.

Real-time 3D image acquisition

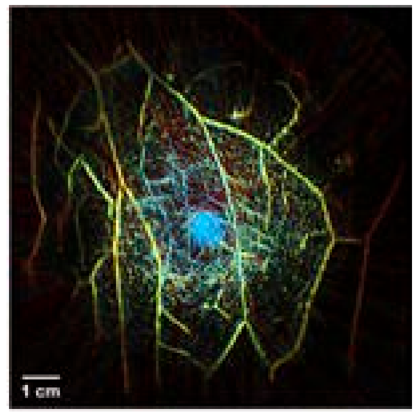
Alongside these extensive developments, Beard has been pioneering the use of ultra-high-sensitivity, wideband Fabry-Perot (FP) ultrasound sensors. Serving as an alternative to traditional, narrowband piezoelectric transducers, these offer higher-resolution images of structures, whatever their size.

> "Adult brain imaging is probably one of the most challenging areas in photoacoustic tomography, so we'd like to start with neonatal brain imaging."
>
> LIHONG WANG, CALTECH.

Crucially, Beard's UCL team has also slashed the time it takes for these sensors to acquire a 3D image – from a lengthy five minutes to less than one second, thus matching the acquisition times of piezoelectric sensors, but with improved image quality.

"We increased image acquisition speeds by parallelizing detection and using higher repetition rate excitation lasers," he says. "With these faster image acquisition rates, we now hope to present an imaging system that will give real-time 3D images, bringing us into the realm of clinical imaging."

Using a similar technology platform, Beard and colleagues have also developed endoscopic probes, and combined the technology with a mobile arm for bedside patient imaging. "We've just started our first clinical studies," he says. "It is very rewarding to have seen the technology develop from first principles to pre-clinical and now clinical imaging. I never thought we'd reach the image acquisition speeds necessary for this."



***In-vivo* 3D photoacoustic tomographic image of a human breast.** Image: Lihong V. Wang/Caltech.

So what next for the world of optoacoustic/photoacoustic imaging? Determined to continue driving the technology further into the molecular realm, and working with Martin Pule at UCL's Cancer Institute, Beard recently imaged a genetically encoded probe – tyrosinase – for tagging specific cells in photoacoustic imaging. Tyrosinase is an enzyme that generates the pigment eumelanin, which provides good contrast when imaging cells *in vivo* – as Wang first demonstrated back in 2011.

With colleagues at his California Institute of Technology (Caltech) laboratory, he has now developed a technique called "single-impulse panoramic photoacoustic computed tomography". Remarkably, it can acquire a cross-sectional image through the entire body of a small animal within tens of microseconds, at high resolution. "I have seen a lot of interest [from the pharmaceutical industry] in this technology for drug discovery," Wang reports.

Meanwhile, Oraevsky is pursuing temperature imaging, and has shown his first images in live animals. "If we collect a series of optoacoustic images under conditions of changing tissue temperature and constant optical properties, we can observe that the brightness of the image is proportional to temperature," he points out. "So, we can guide doctors performing thermal therapy of cancer ... by generating 3D images of temperature distribution in and around tumors."

These are just a few of the recent breakthroughs, and a look at this year's "Photons Plus Ultrasound: Imaging and Sensing" conference sessions confirms that the field is expanding as fast as ever. From assessing the aggressiveness of prostate cancer, to super-resolution photoacoustic imaging, laparoscopic surgery, and guiding injections of stem cells into spinal cords, the wide-ranging nature of the applications offers a glimpse of what lies ahead.

As Wang, who co-chairs the popular conference with Oraevsky, says: "I have always believed that to fully understand biology you've got to have information across all the relevant length-scales, from organelles to organisms. It has taken us a long time to get this far, but photoacoustic imaging provides this multi-scale continuum, and I know from here we will continue to grow."

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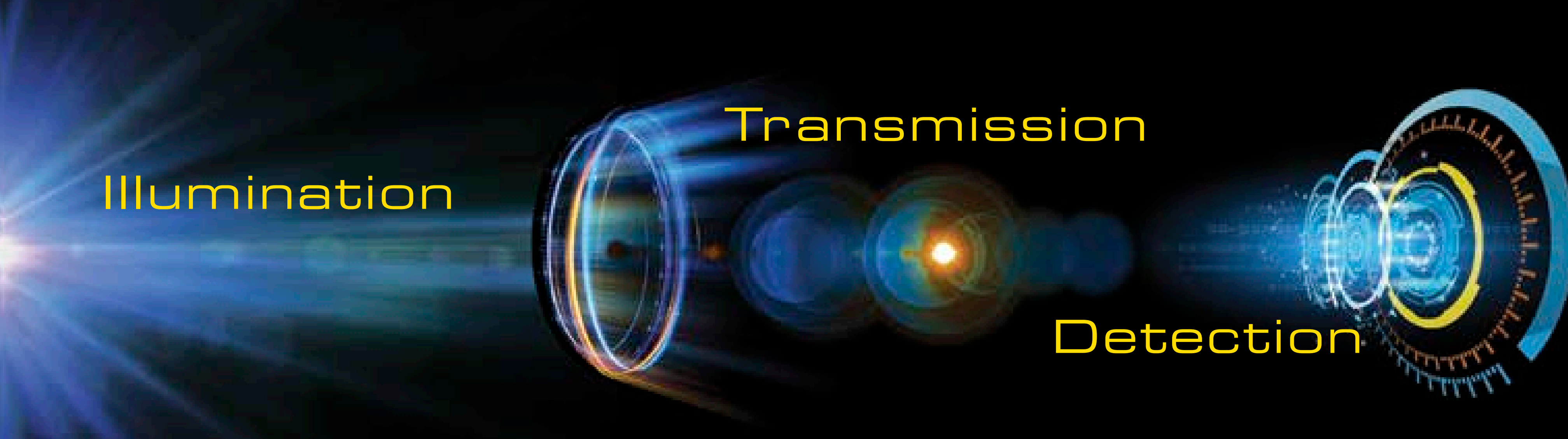

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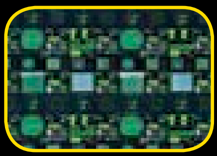
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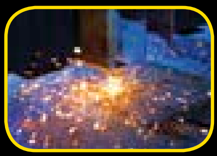
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Donna Strickland continued from page 01

amplitude (CPA) laser.

"Not everyone thinks physics is fun, but I do," Strickland told the Stockholm audience. A self-described "laser jock," she referred to Cyndi Lauper's hit song, 'Girls Just Wanna Have Fun,' which was getting a lot of airplay when she was a graduate student in Mourou's group in the Laboratory for Laser Energetics (LLE) at University of Rochester. "They wanted to wait until the workday is done, but I wanna have fun while I'm working."

While in Stockholm, Strickland participated in the tradition of touring the Nobel Museum and autographing a chair on the museum café. That chair had also been signed in 2013 by the Canadian author Alice Munro, who had won the prize for literature. Another honored tradition is for Laureates to donate an artifact to the museum. Strickland donated an Nd:glass laser rod from the original CPA laser she and Mourou developed.

"It's hard to believe," said Strickland, but my former colleague, Bill Donaldson, who still works at LLE in Rochester, found it in a drawer. It was in its original box, with handwriting stating it was for the 7mm Quantel Laser."

In her talk Sunday night, Strickland shared the story of finally measuring the compressed pulse width of the amplified pulses with a colleague who had wheeled a streak camera into her lab one evening.

"I will never forget that night," she said. "It is truly an amazing feeling when you know that you have built something that no one else ever has and it actually works. There really is no excitement quite like it — except for maybe getting woken up at 5 in the morning because the Royal Swedish Academy of Sciences and the Nobel Foundation also think it was an exciting moment for the field of laser physics."

Among her slides, Strickland shared an image from the ceremony of her with 2013 SPIE President Bill Arnold and his sister Frances Arnold of Cal Tech who was awarded the Nobel Prize in Chemistry for "the directed evolution of enzymes." Arnold was the fifth woman in history to win the prize for chemistry – not a bad day in Stockholm for women in science.

> Strickland first saw the red and green lasers and thought, "it's like working around a Christmas tree all the time. How fabulous is that?"

Hooked from the start

In the acknowledgments section of her PhD thesis, "Development of an Ultra-Bright Laser and an Application to Multi-Photon Ionization," Strickland credited her father, an electrical engineer; her mother, an English teacher; and her siblings who "continually supported and encouraged me through all my years of education."

When she was about five years old, Strickland's father took her to the Ontario Science Centre, where he showed her the museum's laser exhibit. "You'll want to see this, he said. "Lasers are the way of the future." Strickland barely remembers seeing that laser, but her curiosity and interest were captured. Later, as an undergraduate student at McMaster University, she was torn between electrical engineering, which offered more jobs, and physics, which offered more fun. Strickland chose fun.

"I think experimental physics is especially fun," said Strickland, "because not only do you get to solve puzzles about the universe or on Earth, there are really cool toys in the lab. In my case, I get to play with high-intensity lasers that can do magical things like take one color of laser light and turn it into a rainbow of colors. That's just one of the amazing things we get to see in our laser labs."

While working toward her graduate degree at University of Rochester, a fellow Canadian took Strickland to Mourou's lab where she first saw the red and green lasers and thought, "it's like working around a Christmas tree all the time. How fabulous is that?"

Mourou became her PhD supervisor and it was he who dreamed up the idea of increasing laser intensity by orders of magnitude. It was Strickland's job to "take Gérard's beautiful idea and make it a reality." During that process, she built a pulse stretcher, then a laser amplifier, and finally a pulse compressor. To do all this, she had to learn such things as how to cleave optical fiber, machine various parts, and do a lot of plumbing.

She then had to measure the pulse durations and the frequency spectrum. "Not all the measurements showed what we expected," she said. "We had to figure out the problems and then a way around them. That was the fun part. "We scientists like to puzzle as to why something is or isn't working."

Working together, Strickland and Mourou paved the way toward the most intense laser pulses ever created. Their research has several applications today in industry and medicine — including cutting the cornea in laser eye surgery and machining small glass parts for use in cell phones.

Open fields: no barriers

Since winning the Nobel Prize, Strickland has had several speaking engagements and has been through several interviews where she has been asked every question in the universe – including "what did you donate to the Nobel Museum?"

Her message often turns to young people, especially girls, pursuing careers in science. When she learned she was only the third woman to win the Nobel Prize in Physics, her reaction was, "Is that all? I thought there might have been more. Obviously, we need to celebrate women physicists, because we're out there."

Strickland says she never encountered blatant sexism in her career; that she's "always been treated like an equal among male scientists." As she discusses her experiences in the lab and in academia, she simply ignored any prejudices.

"I always went through with blinders on," said Strickland in a talk at University of Waterloo. "I don't think I purposely put the blinders on, but if I want something, I just see what I want, and if people say no, I think they're wrong. So, that's my advice – if someone says something you don't believe in, just think they're wrong and you're right and keep going. That's just pretty much the way I always think." She added that she doesn't think there should be barriers for anybody to do what they're good at, "because that's how the world works best, if we're all out there doing our best."

Strickland ended her plenary talk with pictures of the Nobel winners seated with the Swedish royal family at a long, well decked-out dinner table in the palace. The rule is everyone sits boy-girl-boy, so Strickland was seated between the King and one of the princes.

"Somehow I went from being a student just trying to finish a PhD to landing in the middle of a fairytale," she said.

KAREN THOMAS

Noise around AR, VR continued from p. 01

for 3D features. With a choice of 3D and 2D, Starner said, 'Most users set the device to 2D mode. In this industry, that's heresy."

Headsets are too heavy on the nose to wear them more than a short time, he said. Starner wears his own all day, he said, because "I believe in wearing them.' But he asked his audience of 400 or so, and no one else was wearing one. "Wear one all day every day for six weeks. See how usable it is," he challenged them.

Meanwhile, he said, there are cases for using heavy AR/VR headsets – fixing complex equipment, maintenance and repair work, and yes, entertainment.

Otherwise, he said, design of many sets "is based on science fiction and aspiration, rather than achievable goals and real experiences."

Tish Shute, of the Chinese company Huawei, said spatial computing – for example, in automobiles – was a key AR/VR ingredient, but it's too early to predict its future. "It's 9 a.m. in the age of light," she said, as we are moving from an electronic to a multi-user photonic society. "You change what It means to be human when you change the nature of communication.

"Personal drones can see and hear you. Your house becomes your health monitor. A dialogue without words is unfolding between driver and vehicle."

The future of computing, she said, goes well beyond screens. She predicted that "the photonic city" will merge light, data, and communications. Other speakers included Jerry Carrollo of Google and Ted Selker of Selker Design Research.

FORD BURKHART

AR and VR in the palm of your hand in the interactive demonstration area. Photo: Joey Cobbs

Photonics techniques key to unraveling the mysteries of the brain

BiOS neurotechnologies plenary talks reveal cheaper, simpler techniques to boost access to life-enhancing treatments.

The human brain is a notoriously enigmatic subject. The occurrence and cost of brain disorders has increased in recent years because of higher population and ageing – yet researchers still lack a detailed understanding of the organ's structure and function. Disease detection is difficult; clinical trials for treating brain disorders fail at high rates. To improve these prospects, experts are developing new methods to image and study the brain, which they presented at Sunday's neurotechnologies plenary session.

One technical challenge is imaging large brain sample-slabs that are centimeters thick, for example, says Raju Tomer of Columbia University. He presented his group's microscopy method that can image deeper and faster than conventional light sheet microscopy (LSM). Like LSM, their method uses light sheets to illuminate a sample. However, they rotate the plane of the light sheet so that it hits the sample at an angle. Then, after scanning the illuminated part of the sample, they move the light sheet and repeat the process. This enables them to image an entire brain sample quickly. The goal is to create a "Google maps" of the brain, Tomer explains. Vermont-based company MBF Biosciences is developing a commercial version of the technique.

Denise Cai, a neuroscientist at the Mt. Sinai Health System, presented on the Miniscope, a do-it-yourself miniature microscope whose designs and instructions are all open-source. Cai's team has used the Miniscope to study live mice. Weighing 3 grams, the instrument comes in several different versions, including a wireless battery-operated design that attaches to a mouse's head.

The Miniscope is based on a design by Stanford researchers, first published in 2011. Stanford's original scope is commercially available, but for a hefty price, says Cai. So over the past four years, she and her collaborators developed this more affordable version. The materials to build the miniscope amount to about 1000 dollars, she says.

To teach people – largely neuroscientists – how to build the Miniscope, Cai's team has led workshops in countries around the world including New Zealand, Germany, and France. "After two days, everyone will have built their own miniature microscope system," she says. To Cai, open-source technology provides more people with the opportunity to pursue important scientific questions. "I really think it's the future of neuroscience," she says.

Emily Gibson of the University of Colorado at Denver discussed her team's lightweight microscope, used to image neurons in moving mice with two-photon microscopy, a technique that can also penetrate the brain relatively deeply. They aim to use the microscope to study how groups of neurons reflect animal behavior, says Diego Restrepo, Gibson's colleague at CU Denver. The group is also working with Denver-based company 3i to commercialize the instrument.

Researchers have been able to perform two-photon microscopy in mice only recently, and it usually requires bulky machines, says Gibson. Their two-gram microscope affixes to a mouse's head and consists of a liquid droplet lens shaped electrically. It can achieve a 2µm resolution laterally and a 10µm resolution axially. One challenge of two-photon microscopy is the quality of the light source. Her group compresses the light into an intense pulse shorter than 100 femtoseconds.

Lin Tian of the University of California, Davis, presented on a new fluorescence-based sensor for imaging dopamine activity inside live mice. Studying the dynamics of dopamine, a molecule involved in motor control and pleasure, can shed light on many types of diseases including depression and addiction. To image dopamine, they modify the dopamine receptor, a protein on a neuron that binds to dopamine, by attaching it to a green fluorescent protein.

This method improves on other dopamine imaging methods by achieving good temporal and spatial resolution simultaneously – a resolution of about 2 µm at ten frames per second. In addition, the method could be easily adapted to sense other types of neurotransmitters, such as serotonin, says Tian.

Blood flow

Vivek Srinivasan, also from the University of California, Davis, presented a noninvasive technique for monitoring blood flow inside the human brain. This work improves upon a state-of-the-art technique known as diffuse correlation spectroscopy (DCS), in which near-infrared laser light is beamed into a person's head at a particular point (NIRS). Fluctuations in the intensity of the detected light indicate the rate of blood flow in a region of the brain several cubic centimeters in volume.

However, because this signal is so faint, DCS requires expensive detectors for counting single photons. Srinivasan's group devised a potentially cheaper and more scalable alternative – by using interference. They split the laser light into two different beams: a reference beam, which is not directed at the person's head, and the sample beam, which is.

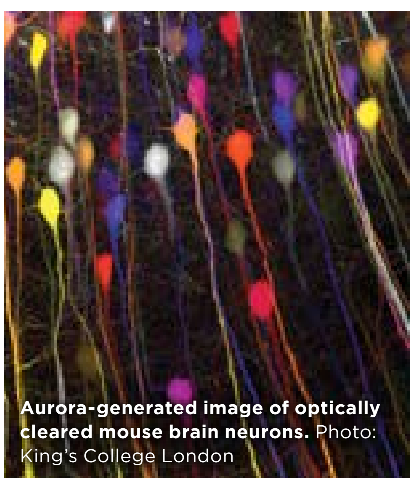
The photons emerging from the head are recombined with the reference beam. The resulting interference fringes produce a larger signal compared to that of DCS. This means they can capture the signal using cheap CMOS cameras. Now that they've demonstrated the technique on human subjects, Srinivasan wants to develop a clinical prototype based on this technique.

Measuring brain signals can also be used as a teaching aide, said Xavier Intes of Rensselaer Polytechnic Institute. Intes's team has used functional near-infrared spectroscopy (fNIRS) to observe brain activity in surgeons and medical residents as they performed practice tasks relevant to laparoscopic surgery.

The process involves beaming near-infrared light into a person's head and measuring an emerging signal from another point on the head. This signal indicates the relative amounts of oxygenated blood, and thus the level of activity in that part of the brain. Intes's team found that the less experienced residents displayed more activity in the front part of the brain involved in planning, while more experienced surgeons had more activity in parts of their brain that involve fine motor control.

These interdisciplinary projects that combine neuroscience and photonics have increased in recent years, session co-chair David Boas of Boston University pointed out. The goal, he said, is to get more neuroscientists and photonics researchers to talk to each other.

SOPHIA CHEN



Aurora-generated image of optically cleared mouse brain neurons. Photo: King's College London

Brain power

Maximizing the performance of bio-imaging systems is achieved with the combination of improving resolution and field of view while minimizing photo-toxicity. Photonics company M Squared, based in Glasgow, UK, has improved this performance with its Aurora Imaging System, which creates a sheet of light in a technique known as Airy Beam Light Sheet Microscopy. This leads to amplitude and phase spread of a light beam, ultimately revealing more information about the subject cells.

M Squared CEO Graeme Malcolm told *Show Daily,* "This technique creates a large field of view with comparable resolution, a 600µm field of view 20 times larger than a conventional Gaussian light sheet.

"The Aurora imaging system enables deeper penetration with a lower photon dose for longer imaging times. The wider field of view allows more of a specimen to be imaged while maintaining a high 3D resolution, which is unique to this market." (Booth 657).

MATTHEW PEACH

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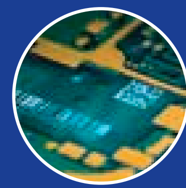

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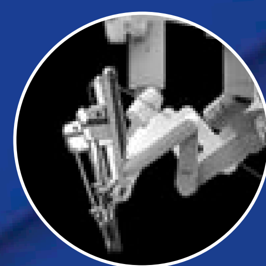

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