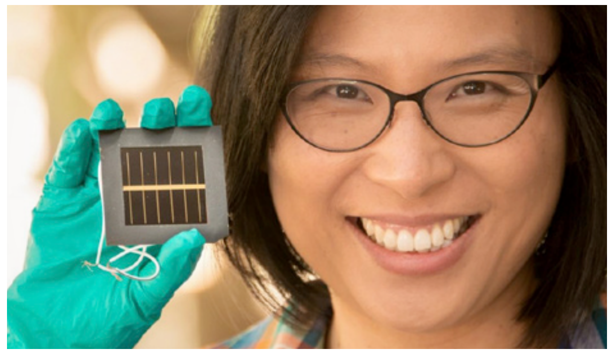
TUESDAY, JANUARY 31, 2017

SPIE. PHOTONICS WEST | optics.org

PHOTONICS WEST. SHOW DAILY

Perovskite progress

Page 25



Trump travel directive disrupts speaker schedules

Restrictions on travel to the US enacted last week in line with a controversial executive order by President Trump have disrupted the Photonics West conference schedule, with at least two speakers denied entry to the country.

Photoacoustic imaging researcher Parsin HajiReza from the University of Alberta in Canada, and PhD student Sahar Mirzaei from the University of Southampton in the UK were both stopped from boarding their flights to the US ahead of the event.

Mirzaei is originally from Iran and moved to the UK to study for a master's degree in 2011 and is now in the final year of her PhD studying metamaterials. She had been due to present a talk on ways to detect and identify DNA on Wednesday afternoon — as part of the OPTO symposium conference on terahertz, RF, millimeter, and submillimeter-wave technology and applications. HajiReza was scheduled to present on photoacoustic remote sensing microscopy in this afternoon's BiOS session on all-optical and laser ultrasound systems.

Mirzaei told *Show Daily* via email that she was due to fly from London's Heathrow airport with British Airways on Saturday, on an Iranian passport and with a business visa. "I asked them if there was going to be any problem for me, as I had heard the news [about the new travel restrictions], but they assured me that as I had a visa there wouldn't be any problem," she reported.

"I checked in my baggage, my visa and passport were checked and I passed through security to the gate. When the time for boarding came, as soon as the lady saw my passport, [she] handed it to an American gentleman, they tore off my boarding pass

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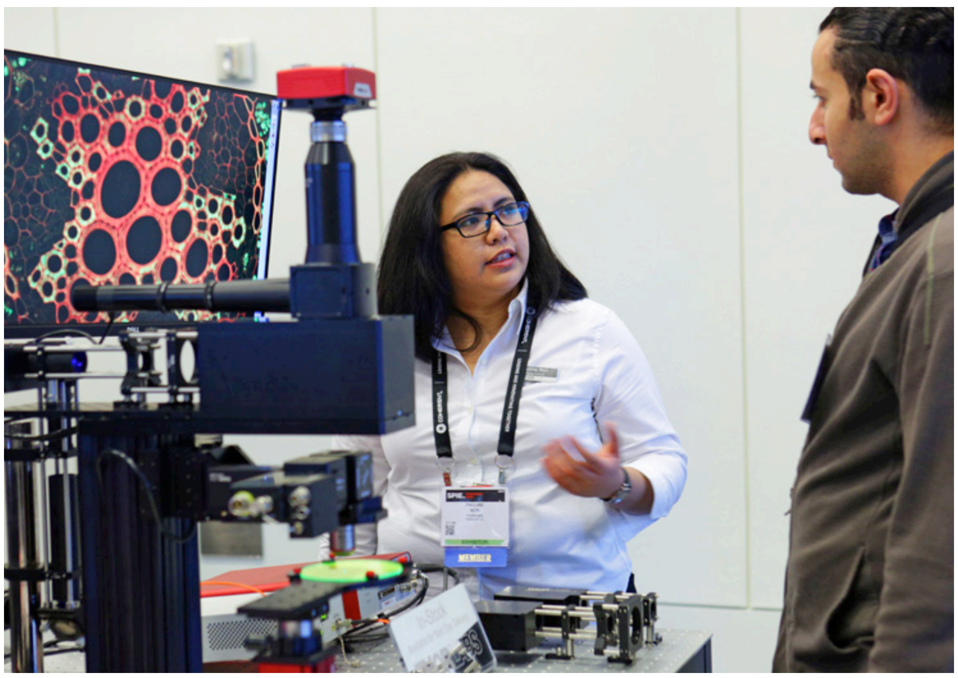

Microscopy advances: under discussion at the BiOS Expo. Photo: Bay Area Event Photography.

MICROSCOPY SHINES AT BIOS HOT TOPICS

In an interview with SPIE last fall, Rafael Yuste, professor of neuroscience at Columbia University and the "brains" behind the US government's BRAIN Initiative, stated, "One of the big challenges I see (in advancing the study of the human brain) is the need to image in 3D, and that calls for the reinvention of the microscope."

If the BiOS Hot Topics session on Saturday is any indication, the research community is well on its way to meeting the challenge. Advances in microscopy dominated the rapid-fire Hot Topics presentations, detailing advances that could dramatically influence molecular research, drug development, and clinical diagnostics.

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DON'T MISS THESE EVENTS TODAY.

PLENARY SESSION

NANO/BIOPHOTONICS
(10:30-11:30 AM, Room 3002, West)
Michael J. Sailor
Univ. of California, San Diego

INDUSTRY EVENTS

BIOPHOTONICS EXECUTIVE FORUM
(7-10 AM, InterContinental Hotel, Ballroom B)

SILICON PHOTOMULTIPLIER WORKSHOP
(8 AM-12 PM, Room 102, South)

SOLID-STATE LIGHTING PANEL
(8:15-9:45 AM, Room 103, South)

SPIE JOB FAIR
(10 AM-5 PM, South exhibit hall)

SILICON PHOTONICS / PIC PANEL
(1:30-3 PM, Room 103, South)

STARTUP CHALLENGE SEMI-FINALS
(2-4 PM, Park Central Hotel)

CHALLENGES IN VR PANEL
(3-4:30 PM, Room 103, South)

GLOBAL TRADE SHOCKS PANEL
(3:30-5 PM, Room 102, South)

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

IN THIS ISSUE.

Hot topics

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Alberto Diaspro of the Istituto Italiano di Tecnologia celebrated the evolution of the microscope in his talk, "The Extra Microscope." From the "microscopiums" and "telescopiums" of the 1600s to the nanoscale optical microscopes ("nanoscopy") of today, "with the microscope we can make visible what is invisible," Diaspro noted. "We are interested not only in the cell, but what is in the cell, the cell interactions. And this is what we can address with the microscope."

Toward this end, Richard Levenson, a medical doctor and professor at the University of California, Davis Medical Center, described a novel technique that uses ultraviolet surface excitation for slide-free tissue microscopy. Dubbed "MUSE," it could have profound implications for global health, Levenson said.

"Pathology is still the gold standard for diagnosis and therapy guidance, and we still use 'state of the art' equipment: a microscope and a slide," he said. "But the pathologist has to go through multiple steps, and it takes hours to go from a 'lump' to a slide. With MUSE, we are proposing to get rid of all those steps and make it a three-minute process."

Based on intellectual property jointly developed at Lawrence Livermore National Lab and UC Davis, the MUSE microscope uses short-wavelength UV light that penetrates only microns-deep into tissue, eliminating the need for precision-cut, thin specimens. The physical setup is simple (the light source, for example, is a single UV LED) — so simple, in fact, that some people are adapting MUSE for use with cell phones. In addition, the single-wavelength, 280-nm LED can excite many fluorescent dyes simultaneously.

"We can also look at very large fields of view, such as a whole brain slice, because we don't have to make thin slices," Levenson said. "So it makes it a very convenient tool for neurophotonics, for looking at very large areas of the brain."

It is also good for imaging the skin and surgical margins, plus a variety of other clinical and pre-clinical applications, he added.

"With MUSE, we see surfaces, not just cut sections," he said. "So we can see what things actually look like. We can see the structure and 'color' (false color) of things more or less in their native format, vs. arbitrarily in sections. With MUSE you get a combination of electron microscopy and fluorescence."

Optical imaging tools

In his talk on "Biomedical Imaging and Spectroscopy with Scattered Light," Lev Perelman of Harvard University Beth Israel Deaconess Medical Center shared his group's research involving CLASS (confocal light absorption and scattering spectroscopic microscopy). This unique combination of confocal microscopy and light-scattering spectroscopy provides new insights into cell structures using the innate light-scattering spectra within each cell as the source of the contrast.

"There are approximately 1,000 different types of cells in the human body, but they are all built from the same set of building blocks: organelles, or membrane-bounded compartments inside the cells," Perelman said. "And different wavelengths of light can be used to look at how light is scattered by these organelles, without the need for any external markers."

His group has used this approach to study cancer progression in live esophageal cells and also to image organs, such as Barrett's esophagus, often a precursor to oral and pharyngeal cancers. "Using endoscopic multispectral scanning light-scattering imaging, it takes only one minute to scan the entire esophagus," he said.

Other talks during the two-hour Hot Topics session covered optical imaging tools and techniques, from noninvasive optical biopsies to cardiac optogenetics, next-generation optical coherence tomography (OCT), molecular transport in live cells, and optical topography. Here are some highlights:

Robert Alfano of the City College of New York/City University of New York and a pioneer in the development of optical biopsy techniques, provided an update on recent advances in this field. Among the notable findings from his lab at CCNY: that tryptophan is a key marker for aggressive cancer. "Cancer cells like to eat tryptophan," he said.

In addition, his research team has demonstrated three short-wave infrared optical windows that appear to offer advantages for optical biopsies: 1100-1350 nm, 1600-1870 nm, and 2100-2300 nm. "Over the years, the 650-950 nm was mainly used to go into tissues via silicon detectors," Alfano said. "But with the advent of InGaAs and InSb CCD/CMOS detectors, we can now go into the infrared. In particular, 1700 nm allows you to go deep into tissue without scattering and with good absorption. So as long as you're not photon-starved, you will get good images."

Christopher Contag (left) receives the 2017 SPIE Britton Chance Biomedical Optics Award from SPIE President Glenn Boreman.
Photo: SPIE

Emilia Entcheva, professor of biomedical engineering at George Washington University, walked the audience through her group's work in cardiac optogenetics, a new framework for the study of cardiac electrophysiology and arrhythmias. Their goal is to use optogenetic sensors and actuators to achieve high-throughput, all-optical cardiac electrophysiology for applications in drug development (cardiotoxicity screen), drug discovery, and patient-specific therapies via the functional characterization of stem-cell derived heart microtissues.

Her group has developed OptoDyCE, a fully automated system for all-optical cardiac electrophysiology. The device is the first high-throughput cardiac optogenetic system that can do this, according to Entcheva, and it has the potential to process 600 independent multi-cellular tissue samples per hour and more than 10,000 compounds per day.

Zhongping Chen of the University of California, Irvine discussed advances in functional OCT, noting that 2016 was the 25th anniversary of OCT, and 2017 is the 20th anniversary of Doppler OCT and OCT angiography. His talk focused primarily on OCT angiography and Doppler OCT. In addition to clinical applications, D-OCT is important for vascular mapping, neuron detection, and for studying neurovascular disease and respiratory cilia function, Chen noted.

"OCT has made a tremendous impact in clinical medicine, particularly ophthalmology," he said. "What is most exciting is that this technology has been translated to the clinic, where it has become the standard of care for studying microvasculature."

Other speakers included Enrico Gratton, also of UC-Irvine, whose work centers on new forms of fluctuation correlation spectroscopy and fluorescence diffusion tensor image analysis to map the diffusion of molecules, and Hideaki Koizumi of Hitachi, who said his dream is to develop a "mindscope" that could be used for diagnosing brain diseases such as depression and schizophrenia.

The Hot Topics session began with a talk by Christopher Contag of Michigan State University, recipient of the 2017 SPIE Britton Chance Biomedical Optics Award. Contag, a pioneer of *in vivo* optical imaging using bioluminescent reporters, discussed on advances in imaging and microscopy technologies, including a tiny snap-together microscope.

KATHY KINCADE

Trump directive

continued from page 01

and let me know I was not able to get on the plane. British Airways would not refund my ticket and I lost some money on my hotel booking too. That's a shame, as I was preparing for months for the conference and visa."

Responding to the disruption, Photonics West organizers SPIE said: "We were surprised and disappointed by the denial of entry to scientific researchers coming to participate in the world's largest optics and photonics conference.

"These people had spent considerable time and money in preparing to come and contribute to the scientific program, where they have always been welcome and had no reason to think this was not the case yet again this year. We wanted to welcome them and their ideas.

"As a scientific society, a core element of our mission is to provide forums where researchers can share advances that benefit people everywhere. At this conference specifically, a major focus is on technology and applications in biomedical imaging that help improve healthcare around the world."

Equity analyst John Dexhemier is hosting a panel session entitled "Brexit, US policy, EU and China: models for managing through global trade shocks" today at 3.30pm, in room 102.

MIKE HATCHER

Sub-retinal prosthetics step up visual resolution

In a dramatic keynote address on Sunday, Daniel Palanker of Stanford University illustrated the promise of devices that restore sight — in ever higher levels of resolution - with photovoltaic arrays placed under the retina.

The implants restore sight lost to retinal degenerative diseases that cause loss of the eye's photoreceptors, while neurons in the "image-processing" inner retinal layers remain intact. Implants convert light into pulsed electric current, stimulating the nearby inner retinal neurons.

Palanker, who works at Stanford's Department of Ophthalmology and Hansen Experimental Physics Laboratory, was speaking during the "stimulation" session of the Optogenetics and Optical Manipulation conference, part of BiOS.

In Palanker's device, images captured by the camera are projected onto the retina by video goggles using pulsed near-infrared (~880nm) light, avoiding the need for bulky electronics and wiring, and reducing the surgical complexity. Wireless and modular implants allow easier implantation and retain the natural connection between eye movements and visual information.

Photovoltaic arrays with 70 micron pixels restored visual acuity to only two times lower than the natural level in rats, Palanker said. "If these results translate to a human retina, such implants could restore visual acuity up to 20/250," he added.

Palanker's system is incorporated in a product called PRIMA, being developed by the French company Pixium Vision. He said his partners are awaiting approval for clinical trials in the UK and in France.

Palanker's lab is now working on even smaller pixels, and has demonstrated that arrays with pixels as small as 40 microns can stimulate the retina at safe levels of illumination. "If successful, they may provide acuity up to 20/130 in human patients," he said. "This would make the system appealing for millions of patients with loss of central vision due to age-related macular degeneration."

Responses from the audience were enthusiastic. "This approach of high-resolution sub-retinal stimulation appears to solve all the problems associated with axonal stimulation and cross-talk of ganglion cells," said one listener, Robert Stirbl, manager of the National Defense Programs Office at the Jet Propulsion Laboratory (JPL) in Pasadena. "The work appears to have promise in restoring vision in people who have advanced macular degeneration."

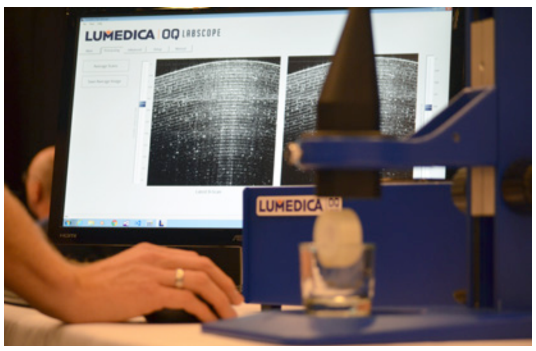
FORD BURKHART

Lumedica makes debut with low-cost OCT scanner

The weekend's BiOS Expo witnessed the unveiling of a new low-cost optical coherence tomography (OCT) scanner that developer Lumedica believes could dramatically extend the impact of the imaging technology for eye health.

Founded in Durham, North Carolina, by an experienced team of engineers including chief scientist Adam Wax from Duke University, Lumedica's debut scanner is priced at $10,000 — in a sector where entry-level equipment typically costs at least $35,000.

Wax explains that the low cost is achieved by using optical components already produced in volume for cell phones, coupled with a streamlined manufacturing process that reduces build time to a few man-hours. "We designed it from the bottom up," Wax said, showing off the shoebox-sized equipment at the Lumedica stand. Off-the-shelf components in the system helping to cut costs include an 840 nm superluminescent light-emitting diode (LED) and a liquid lens.



Low-cost optical coherence tomography (OCT) kit developed by Lumedica at the weekend's BiOS Expo. The company, just out of stealth mode, is taking part in this year's Startup Challenge. Photo: Lumedica.

Originally set up in 2014, but in stealth mode until recently, the company has won small business innovation research (SBIR) funding to aid the development process, but is now engaged in a more significant seed funding round. VP of marketing Scott Whitney said that Lumedica would be aiming to raise around $500,000 to further reduce the size of the scanner equipment so that the "2.0" version would be truly portable.

While OCT has proved itself to be an extremely effective diagnostic tool for ophthalmology, the cost of current systems means that it tends to be restricted to large, regional health centers. If proved to be effective, much cheaper systems could become widely deployed in "red flag" diagnostics — for example by optometrists — to pick up early signs of diseases like glaucoma and diabetic retinopathy.

Wax says that although important regulatory hurdles still need to be cleared, the technology has clear potential to leverage the existing wealth of clinical evidence for OCT built up over the past couple of decades.

He will be representing Lumedica in today's SPIE Startup Challenge semi-finals, taking place this afternoon at the Park Central Hotel. Finalists from three technology tracks will progress to Wednesday afternoon's final, where the winner will walk away with $10,000 in cash from founding sponsor Jenoptik and $5000 in equipment. The Startup Challenge supporting sponsors are Edmund Optics, Open Photonics, Trumpf and the US National Science Foundation.

MIKE HATCHER

EYES RIGHT WITH FEMTOSECOND CATARACT SURGERY

Presenting Saturday morning's Pascal Rol lecture on femtosecond cataract surgery, a BiOS keynote, William Culbertson was already having a great day: "San Francisco is one of my favorite cities and femtosecond laser cataract surgery is my favorite topic."

The professor works at the Bascom Palmer Eye Institute, in the Department of Ophthalmology at the University of Miami, Florida. Recognized as one of the world's most skilled refractive surgeons, specializing in cataracts and LASIK vision correction, he trained partly in San Francisco at the Francis I. Proctor Foundation for Research in Ophthalmology.

"I became a femtosecond maniac when I got my first IntraLase femtosecond laser back in 2004 for LASIK applications," he said. "I was sold on the precision and utility of this instrument."

Paying tribute to pioneers Ron Kurtz and Tibor Juhasz, who first developed ultrafast lasers for ocular surgery when developing the IntraLase system 20 years ago, Culbertson added: "The IntraLase laser makes a corneal flap much more precisely than a surgeon's microkeratome blade. It allows the patient to heal more quickly."

As well as treating hundreds of patients each year, Culbertson has been working to refine the procedures of accessing the eye cavity for surgery, dissecting, emulsifying and aspirating cloudy cataract lenses and replacing them with artificial intraocular lens implants. "I said we could soften the lens by laser and maybe just aspirate the lens instead of using ultrasound, with its side effects."

As laser eye surgery outcomes more predictable, the problem now is that there are many more patients with increased expectations. He showed clips of both Superman and Wonder Woman transforming from their human alter egos - both of whom wore spectacles.

"Everybody wanted perfection in their correction but even in the mid-2000s we knew that there were still many imperfect outcomes: at least 55% of patients did not have a refractive outcome within half a diopter, and 28% within one diopter, of their targets," he said.

The concluding part of his talk covered the need for further improvements in the technology and the availability of the procedures. "I think we can make capsulotomies what we want them to be in terms of quality and safety," he said. "But the problems can still be there: incomplete capsulotomies, incomplete incisions, and there are barriers to the general adoption of femtosecond surgery.

"It is still an expensive procedure, which not every patient can elect to do, but maybe Mr Trump will help us with the problem of funding access to eye surgery. I just wish that these lasers could be made more cheaply and that everybody who needs it could have this treatment."

MATTHEW PEACH


FISBA Innovators in Photonics
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Integrated, circular illumination
Most common application:
Life Sciences
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Political wins; transitional times

Wilkommen, bienvenue, welcome, Huānyíng to the greatest show in photonics. Together we have the opportunity to savor this exciting field and the ferment of photonics from ideas, some older than Einstein, some as new as today. This Photonics West will continue to shape the inexorable advances of the marvelous science and engineering power of light into a growing number of practical uses — practical not just because of advances in understanding but because companies have put affordable products in the hands of clinicians, nurses, dentists, manufacturers, and knowledge-builders. Lead users of today's products are seen by some as the major initiators of new products. Photonics West is a concentration of such people.

This week's convocation of scientists, engineers, inventors, owners, and investors will lead to more advances, and through the product implementers, better health, smarter manufacturing, a more sustainable world, and more enriched lives through photonics.

If I thought that the outlook prospect for my short pieces for the Show Dailies of 2015 and 2016 was cloudy, then I was not counting my blessings. Back then we had in the US a pro-science administration held in check by Congressional fiscal constraints. Federal support for US science continued to decline, fortunately slowly. The inevitability of the photon saw industry invest more in the technology through these years.

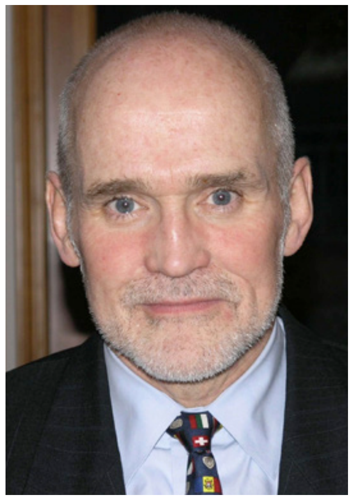
After decades of relying on our technology for the manufacture of the semiconductor products that enabled them, some of the big brand-name technology giants are now having a serious impact on our supply chains, as they diversify into optics-based products. They certainly bring an approach and expectations for performance and innovation rate that will freshen and challenge our industry.

Also, back in early 2016, the European Union was trying to support some of its economies still reeling from the Great Recession, and was solidly supportive of science and technology. Switzerland, one of the leading nations in innovation was then a well-integrated partner of the EU. The EU's public private partnership Photonics21 was a clear commitment to our key enabling technology. Photonics powers in Asia — Japan, Korea, and Taiwan among them — were, and still are, contemplating a future of cooperation and competition with China.

Enough looking back at the "good old days." This year we are trying to discern what a post-Brexit and migration-challenged Europe will be like for science and trade. A week ago we had the inauguration of a new type of president here in the US (at last a good use for the word "disruptive"?). Republicans are in a majority in both houses of Congress. The US National Photonics Initiative (NPI), led by SPIE and the OSA, has been in touch with the Trump transition team to try to discern and influence the priorities, and the wider scientific community has been pleading for continued support for science.

You can hear the latest thinking on some of these global issues at a panel today at 3:30 pm. John Dexheimer will lead this lively session, "Navigating the Tides and Storms of Shifting International Waters." Our exhibitor breakfast on Thursday will feature a talk by Josh Holly and Beth Inadomi from the Podesta Group in Washington, DC. They will have the latest insights of what we might expect from the new administration.

SPIE has not been passive through these historic changes and we had some impressive "political wins" in 2016. Beth and Josh will detail the important bills passed by the outgoing Congress, including a number with, for the first time, "optics and photonics" language. The "CURES Act" sets increased funding for the Cancer Moonshot and the BRAIN Initiative. A five-year extension of the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs was secured. The successor to the COMPETES Act has been a focus of the NPI for years and we are delighted it was passed, even if at the last minute.



SPIE CEO Eugene Arthurs

With the support of industry, we have brought significant changes to the export controls relevant to optics and photonics categories. These changes are relevant not only to products but to workforce issues and will help shape the relevant Wassenaar Arrangement regulations that cover most international trade in sensitive technologies. Search for Jennifer Douris in the Photonics West app to find the time and place for sessions where you can learn more on export controls, and provide input to the US Department of Commerce. Jennifer is SPIE's Director of Government Affairs and also Vice Chair of the Department of Commerce's Sensors and Instrumentation Technical Advisory Committee (SITAC).

Congratulations to the nations and regions who topped the results of the just announced Programme for International Student Assessment (PISA). To my knowledge no one has yet analyzed how PISA results for 15-year-olds in math and science correlate with later economic success. Leadership in technology involves many factors, but certainly Singapore and the others at the top of the PISA rankings are making sure that they are best prepared for a future where STEM skills offer leverage.

I hope the nations that lead in science, but languish in the PISA science and mathematics league, will absorb and apply the lessons on how to have more young people become science savvy. The numbers who go on to careers in science may be small, but everyone's future will be impacted by science and technology and an informed population is in all our interests.

Economists, especially those who are responsible for national or regional innovation, overuse the "valley of death" concept as they try to organize innovation. To me, many of the intense studies on the topic miss completely on "the sense of market," "the smell of the customer." A few days at Photonics West would help them glimpse "a mountain of life," the energy of success. Go for it!

EUGENE ARTHURS


JOIN US!

US BRAIN Initiative continues to boost neurophotonics R&D

The ground-breaking project may have been initiated by the Obama administration, but its future should not be subject to presidential preferences, hears Kathy Kincade.

Despite concerns about the incoming US administration’s intentions on funding science, the US BRAIN Initiative — officially the Brain Research through Advanced Innovative Neurotechnologies Initiative, launched in 2013 by former president Barack Obama — is alive and well and making steady progress toward its decade-long goal of being able to visualize, probe, and understand the human brain to a degree never before possible.

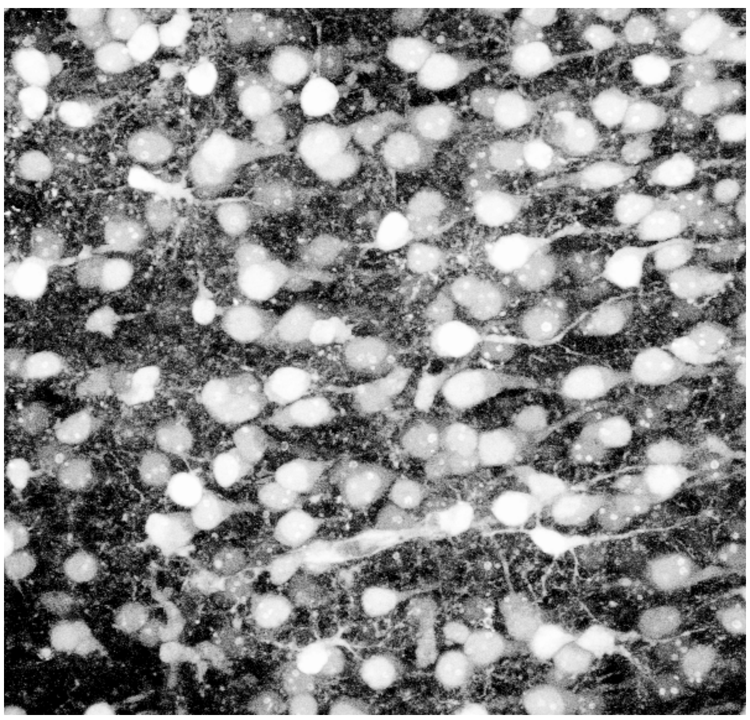
In fact, the 2017 US federal budget proposes to increase government investment in the BRAIN Initiative from $300 million in FY 2016 to more than $434 million in FY 2017. In addition, the 21st century CURES Act that Obama signed in December calls for $1.5 billion for the initiative over ten years (although these funds are not mandatory spending and would have to be allocated by Congress each year).

Rafael Yuste, a neuroscience professor at Columbia University and a pioneer in optical methods for brain research. Photo: Columbia University

However, at this point it is unclear whether Congress and the new president will approve the proposed budget or make other significant funding changes. Rafael Yuste, the professor of neuroscience at Columbia University in New York who was instrumental in launching the Brain Activity map project, which became the BRAIN Initiative, told *Show Daily*:

“With the new president being elected and the BRAIN Initiative being an Obama initiative, it is natural to question whether it is going to be maintained or dropped.

“It has only been going on two years, but so far has had bipartisan support from the Senate and the House,” added Yuste, a world leader in optical methods for brain research. “So we hope that this continues because this initiative is much larger than a single president and is something that should continue to keep us at the forefront of science and technology in the world. It is a US initiative, not Obama’s initiative.”



Cortex slice, close up: Neuronal activity in a mouse hippocampus, captured by two-photon microscopy imaging using calcium fluorophores. Image: Yuste Lab

The BRAIN Initiative is currently funded primarily by five federal agencies: the Defense Advanced Research Projects Agency (DARPA), the National Institutes of Health (NIH), the National Science Foundation (NSF), Intelligence Advanced Research Projects Activity (IARPA) and the Food and Drug Administration (FDA). The 2017 budget proposed by Obama also calls for the Department of Energy (DOE) to join.

In addition some major foundations, private research institutions, patient advocacy organizations, universities, and companies, including the Howard Hughes Medical Institute, Allen Institute for Brain Science, the Kavli Foundation, the Simons Foundation, GE, GlaxoSmithKline, have committed more than $500 million to the BRAIN Initiative.

The overarching goal of the BRAIN Initiative is to equip researchers with the tools and technology necessary to better comprehend how neural circuits work and use this knowledge to treat brain disorders, among them Alzheimer’s, schizophrenia, autism, epilepsy, and traumatic brain injury. Thus, much of the early focus of research projects funded by the BRAIN Initiative has been on building new methods for measuring and mapping neuronal activity.

“There has been a tremendous push and rapid advances in simultaneously measuring thousands, tens of thousands and more, neurons acting in concert at the microscopic level so we can better understand network activity and relate network neuronal activity to behavior,” said David Boas of Massachusetts General Hospital and Harvard Medical School and editor-in-chief of *Neurophotonics*, an SPIE journal. Boas is part of a team that has received NIH funding through the BRAIN Initiative to support their work in better understanding the BOLD (blood-oxygen-level-depen-

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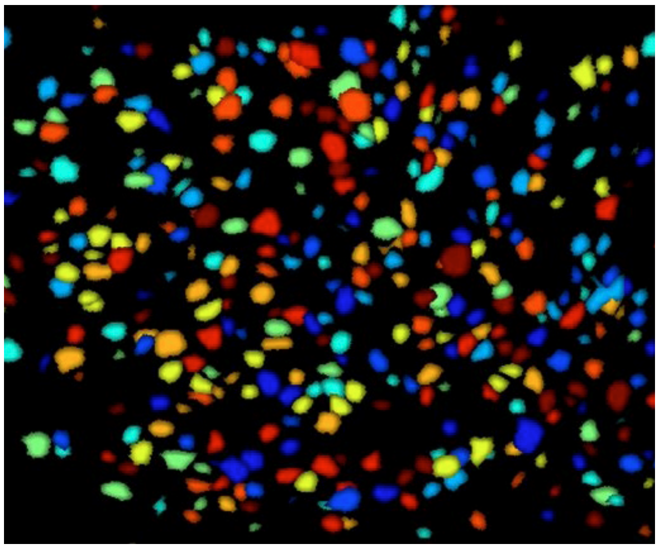
Brain Initiative continued from page 09

dent) fMRI signal and better relating it to the underlying neuronal activity.

Emergence of neurophotonics

This is where neurophotonics comes in. Much of the current research in neuronal activity is being enabled by photonics technologies, including sensors, lasers, and imaging devices. Thus the US photonics industry has been active in the BRAIN Initiative as well.

In 2014, several companies, including Accumetra, Agilent, Applied Scientific Instrumentation, Coherent, Hamamatsu, Inscopix, Spectra-Physics, and Thorlabs, pledged to invest upwards of $30 million in existing and future research and development spending over three years to advance optics and photonics technology in support of the BRAIN Initiative. As part of the National Photonics Initiative's (NPI) Photonics Industry Neuroscience Group, many of these companies were invited to participate in key meetings and workshops alongside administration and agency officials.



Individual neurons: Researchers from UCLA are using a three-year, $2.3 million grant from the BRAIN Initiative to build a new generation of miniature fluorescent microscopes to image and manipulate the activity of large numbers of brain cells in mice. The microscopes will visualize individual neurons expressing calcium-triggered fluorophores, which light up when specific wavelengths of light are shined on them. Image: Daniel Aharoni/UCLA Health

"Part of what the NPI has done is get all these agencies to sit down at the table together and with the academic communities and industry," said Tom Baer, former chair of the NPI and past chair of the Photonics Industry Neuroscience Group who remains involved with the NPI on several life-science topics. "We work directly with the private sector and companies to help facilitate interaction with users of the technology and also to communicate their messages to the government."

One of the key achievements to emerge from the NPI's efforts was a technology roadmap specific to the BRAIN Initiative. The final roadmap, presented to the White House Office of Science and Technology Policy in May 2015, detailed recommendations derived from in-depth discussions and information gathered from optics and photonics industry leaders, prominent researchers, and agency program managers who attended several NPI Photonics Industry Neuroscience Group meetings.

The roadmap is intended to spur public/private collaborations, provide insight from a consortium of industry partners on areas of technology development they are actively pursuing, and illuminate potential areas for economic growth within the US.

"One of the primary messages we have been taking to Washington is the idea that we need to identify programs and funds to support the development of key technologies, such as wearable microscopes and protein fluorophores that are essential for imaging neural activity in animals," Baer said.

continued on page 13

FUNDING SOURCES FOR BRAIN INITIATIVE

A breakdown of key agency funding for the BRAIN Initiative under the proposed 2017 federal budget:

- **NIH:** The FY2017 budget calls for NIH to provide an estimated $190 million for the BRAIN Initiative. This investment will support a diverse set of projects, including efforts to create a complete accounting of the cellular components of brain circuits in various vertebrate species; create tools and infrastructure to address big data from these cell census projects; develop breakthrough neuroimaging technologies to study human brain function; and support broad research teams to understand how patterns of neural activity at multiple spatial and temporal scales give rise to mental experience and behavior.
- **DARPA:** DARPA plans to invest an estimated $118 million to support the BRAIN Initiative in FY2017. DARPA's support aims to leverage nervous system research to alleviate the burden of illness and injury and provide novel, neurotechnology-based capabilities for military personnel and civilians alike. In addition, DARPA is fostering advances in neural interfaces, data handling, imaging and advanced analytics to improve researchers' understanding of interactions across the entire nervous system.
- **NSF:** In FY 2017, NSF plans to invest $74 million to support the BRAIN Initiative. To attain a fundamental scientific understanding of the complexity of the brain, NSF investments in the BRAIN Initiative will generate an array of physical and conceptual tools needed to determine how healthy brains function across the lifespan. NSF will also focus on the development and use of these tools to produce a comprehensive understanding of how thoughts, memories, and actions emerge from the dynamic actions of the brain.
- **IARPA:** In FY 2017, IARPA is proposing $43 million to continue investing in applied neuroscience research programs focused in three areas: advancing understanding of cognition and computation in the brain, developing non-invasive neural interventions that have the potential to significantly improve adaptive reasoning and problem solving, and building novel computing systems that employ neurally inspired components and architectures.

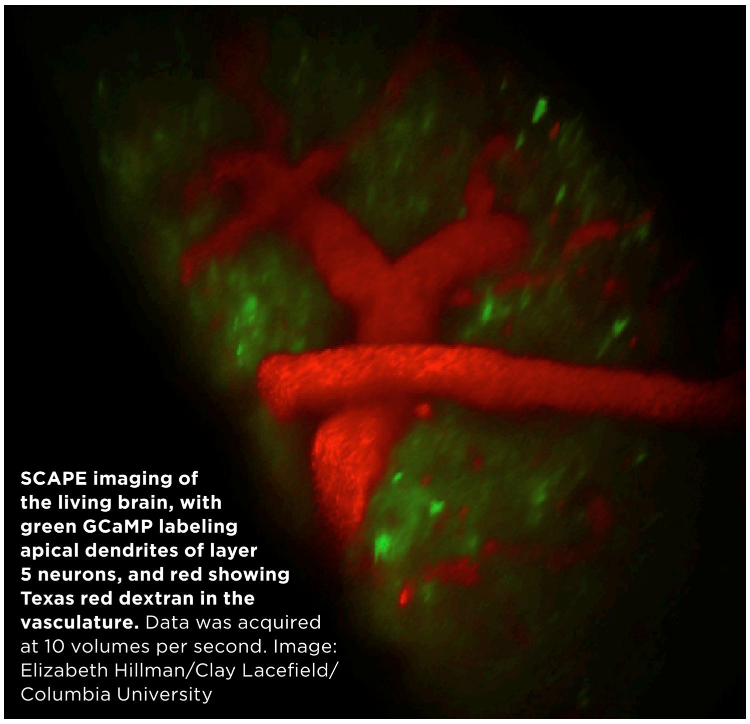
Brain Initiative continued from page 11

"The work the BRAIN Initiative and NPI have been doing has really helped establish the direct links between leading groups and companies that are using the technology roadmap to determine the technology fields to invest in. Much of this technology really didn't exist until the BRAIN Initiative defined what was needed."

Toward 3D microscopy

Despite these successes challenges remain, particularly in the development of imaging optics, laser sources, automated scanning technology, and high-resolution cameras that can provide up to a 100-fold increase in the ability to image groups of thousands of active neurons. Other technology needs identified by the NPI include miniature, implantable microscopes for therapeutic screening based on neural activity signatures; new fluorescent indicators of neural activity with tenfold improvements in efficiency and temporal response; and automated software for detailed mapping of the 3D datasets generated by MRI, CT, and microscopic imaging.

"Conceptually, we need methods to write and read brain activity," Yuste said. "We need to read what the neuron is doing and change what the neuron is doing. In our original proposal we had four types of methods: optical, electrical, electrochemical, and computational. And the BRAIN Initiative is pushing for these four methods for experiments in both animals and humans."



SCAPE imaging of the living brain, with green GCaMP labeling apical dendrites of layer 5 neurons, and red showing Texas red dextran in the vasculature. Data was acquired at 10 volumes per second. Image: Elizabeth Hillman/Clay Lacefield/Columbia University

At this point, two-photon microscopy remains the workhorse in neurophotonics research, according to Yuste, who, along with Boas, is co-chairing the SPIE Brain applications track at Photonics West and hosted the neurotechnologies plenary session on Sunday.

While advances in two-photon microscopy optics have been made — making it possible to access larger volumes of tissue — a fundamental challenge remains, explains Boas: this technique is largely constrained to head-fixed animals.

"It is tremendously exciting to follow the various responses and increases in the number of neurons that can be monitored simultaneously," Boas said. "But it would be nice to extend these advances to freely behaving animals to try and understand what is going on in the brain during natural activity."

This is the goal of a number of novel microscopy and related imaging projects, such as three-photon microscopy, acoustic and photoacoustic imaging, and fMR, being funded by the BRAIN Initiative. Some of these include:

In November 2015, five scientists from University of California, Los Angeles (UCLA) received a three-year, $2.3 million grant from the NIH to develop methods for recording the activity of intact neural networks in living animals. The investigators aim to build a new generation of miniature fluorescent microscopes to image and manipulate the activity of large numbers of brain cells in mice. The tiny, head-mounted microscopes will monitor brain cell activity in real time while the mice are moving freely in their natural environments.

In December 2015, Columbia University professor Elizabeth Hillman received a $1.83 million, three-year grant from the NIH to support her work on SCAPE, a high-speed 3D microscope used for imaging the living brain. Whereas most modern microscopes can only image a single plane at up to 20 frames per second, SCAPE (swept, confocally aligned planar excitation microscopy) can image over 100 planes within a 3D volume in the same amount of time, enabling researchers to image neurons as they talk to each other within a large volume of the brain.

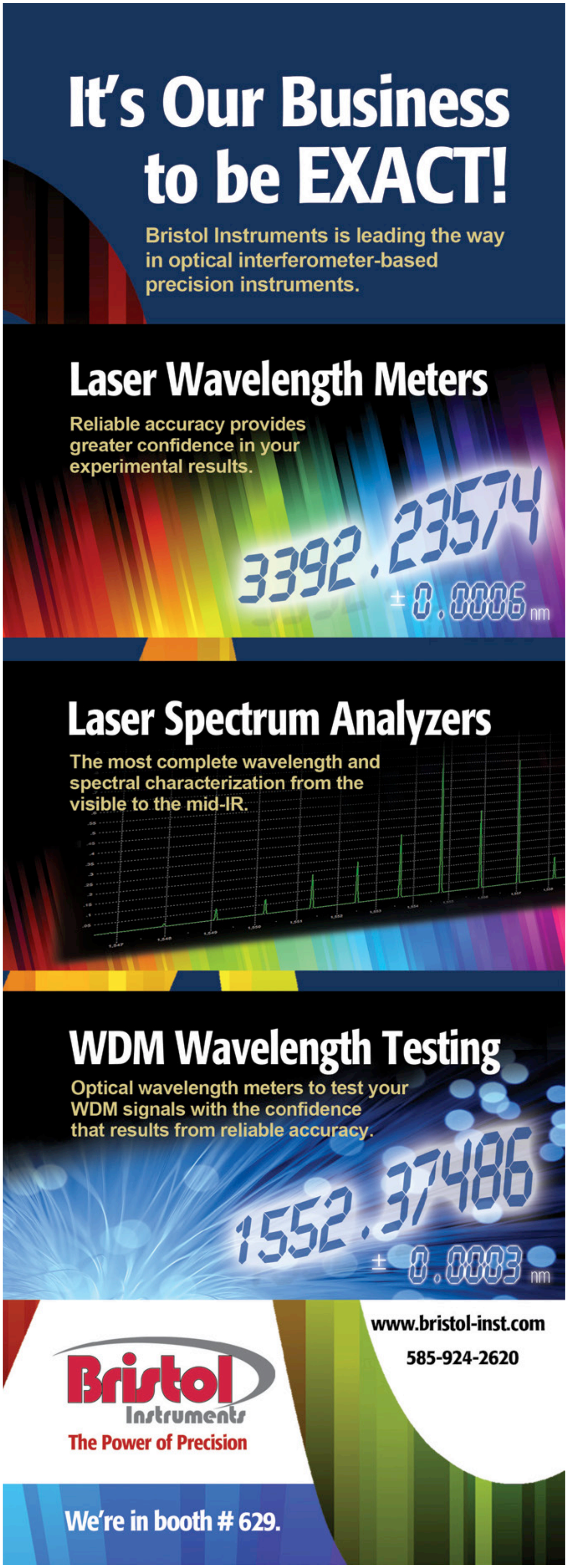
In October 2016, four University of California, Berkeley research teams were awarded a total of $1.7 million from the BRAIN Initiative for projects that included wireless sensors, dubbed "neural dust," to record activity in the central nervous system. The projects will also employ compressive light field microscopy to optogenetically track neural activity; magnetic resonance corticography to study the organization and neuronal circuitry in the brain; and high-speed volumetric multiphoton microscopy to study developing neural circuits in the retina.

In October 2016, Cornell University's Chris Xu and Yi Wang received funding to continue their work combining MRI and multiphoton imaging to study the relationship between neural activity at the cellular and network level and map neuronal function at multiple spatial scales, from synapses to the whole brain. Xu has been developing deep-brain, high-resolution multiphoton microscopy with the help of two previous BRAIN awards.

These projects represent just the tip of the iceberg: more than 200 projects are being funded by the BRAIN Initiative, and microscopy is just one of many imaging modalities used to study the brain. But in the long run, Yuste believes that 3D microscopy will be one of the key technologies for achieving the initiative's long-term goals.

"One of the big challenges I see is the need to image in 3D, and that calls for the reinvention of the microscope," he said. "From the beginning, microscopes were designed as 2D imaging devices that focused light at the focal plane of a tissue and collect the light from there. So collectively, we need to redesign the microscope to be able to simultaneously excite cells in 3D and collect the information together."

KATHY KINCADE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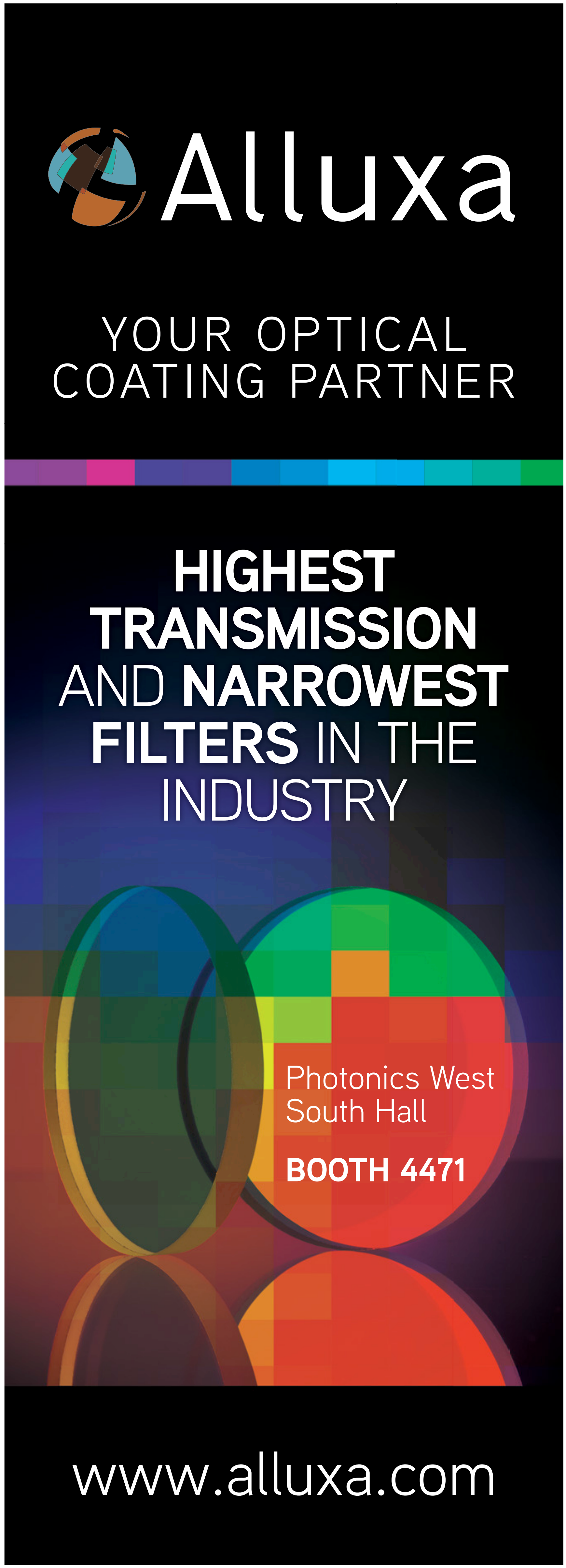
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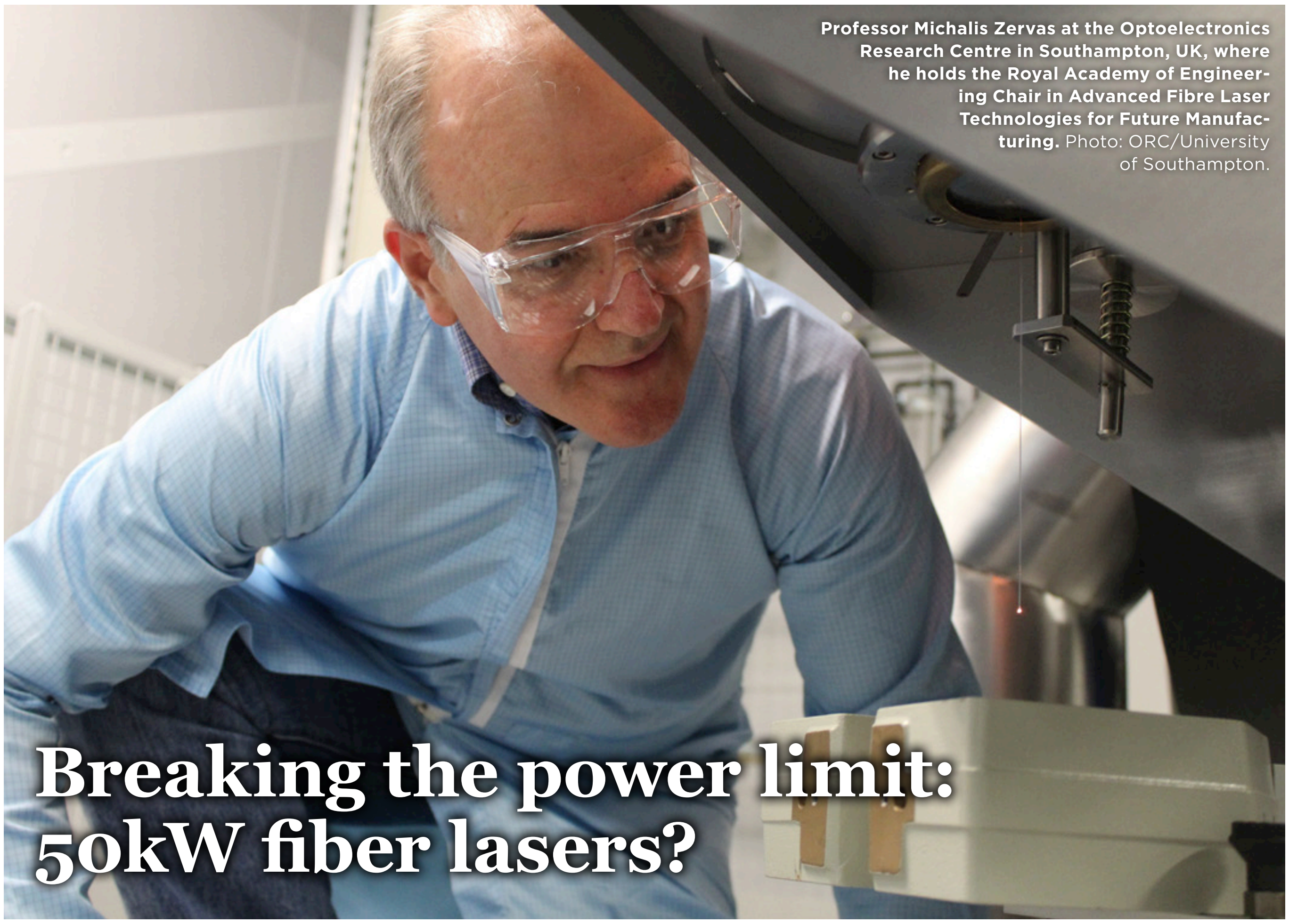

Professor Michalis Zervas at the Optoelectronics Research Centre in Southampton, UK, where he holds the Royal Academy of Engineering Chair in Advanced Fibre Laser Technologies for Future Manufacturing. Photo: ORC/University of Southampton.

Breaking the power limit: 50kW fiber lasers?

Invited paper by Michalis Zervas from the University of Southampton's Optoelectronics Research Centre (ORC) suggests current 25kW power limit can be overcome.

Doubling the current limit on the output of a high-power fiber laser to 50 kW is possible, according to a new understanding of the factors that cause the technology to suffer from a phenomenon known as "TMI" — transverse mode instability.

Professor Michalis Zervas from the University of Southampton's renowned Optoelectronics Research Centre (ORC) in the UK, who also works at Trumpf-owned SPI Lasers, is scheduled to present an invited paper on the topic at 8am today. In it, he explains how TMI is a consequence of both thermal *and* inversion effects in the laser cavity — not solely the former, as has been the orthodox view thus far.

Ahead of the conference, Zervas told *Show Daily* how the work could transform the future of fiber lasers:

"The question facing the fiber laser sector is how can we make more powerful fiber lasers — I am talking about multiple tens of kilowatts — stable and efficient, with a high yield," he said. "This TMI problem was a bit of a surprise. Until it was first observed by Jens Limpert's group in Jena in 2010, everybody across the industry thought that fiber lasers would have no problem in power scaling due to thermal issues." That is because the high surface-area-to-volume ratio of fiber is excellent at removing heat. However, in contrast with other nonlinear effects the TMI problem actually becomes more severe when you try to increase the core area of the fiber in order to accommodate higher peak powers, Zervas explained.

His key observation is that TMI is not just caused by a failure to remove excessive thermal energy from the lasing medium as power rises. There is in fact a second critical factor, which is related to population inversion in the laser cavity, especially at lower powers.

Dual nature

His conclusion neatly unites the two ideas: "Mode instabilities in fiber amplifiers are analyzed by a new approach, considering the stability of the steady-state FM (fundamental mode) amplification in the presence of transverse amplitude and/or phase perturbations, taking into account the effects of population inversion and thermal loading due to quantum-defect heating."

The population inversion contribution is shown to dominate at low powers and high inversion, in line with experimental evidence from Oleg Antipov's group at the Russian Academy of Sciences, Zervas says. "Under high powers and low inversion (high amplifier saturation) the thermal effects dominate the instability behavior," he adds. "A simple and easy-to-interpret TMI power threshold formula is derived for the first time."

In related work at the ORC and SPI Lasers, Zervas recognized and then sought to explain TMI's dual nature. "This is a particularly acute problem as soon as you try to increase core size of a fiber laser," he observes. "This effect had been widely observed in many labs around the world."

Zervas continues: "The root cause of TMI was widely expected to be of a thermal nature, but what my work shows is that its origin depends on how the laser is operated and what is happening in the cavity of the laser. In fiber lasers you have different levels of signal intensities in different places, so the problem can be either a thermal effect or an inversion effect inside the fiber cavity — or a combination of both of these. This is new."

Although there had been experimental evidence of this phenomenon previously, Zervas was first to recognize the combination of factors. He explained, "I identified the thermal and the inversion effects and I have combined them into a single theory. This was established around the start of 2016."

Implications for manufacturers

Zervas believes the new perspective has significant implications for the wider fiber laser community. Although not yet offering a solution to the problem, the work already has significant IP protection and the researcher noted: "I have provided new physical insight into this TMI problem and I believe that the solution will follow once fiber laser developers understand the nature of the problem."

He added, "For me, what is important is that the wider laser community recognizes this effect following the LASE Program Committee inviting my paper. I believe this will shed some new light onto this problem." Previously the approach has been to cool a high-power fiber laser to minimize thermal effects, and while Zervas says that what is now needed is to make the entire laser cavity and gain process more efficient, he warns: "When we are talking about a practical high-power fiber laser then there are a lot of things that can go wrong in this area."

Considering possible future developments, Zervas added: "I want to answer the question, what is the absolute output power limit of what a fiber laser can deliver when TMI is also taken into account?" He says that for a diode-pumped single fiber laser designed on the current model, impacted by TMI and Stimulated Raman Scattering (SRS), that limit is about 25kW. For reference, IPG Photonics has already achieved an output of about 20kW.

"Following the presentation of my work, I expect that there will be consequences in the manufacturing of the next fiber lasers," Zervas predicts. "If you can successfully employ in-band pumping or tandem pumping then the upper limit can be doubled to about 50kW stable output — based on a laser pumped by another laser."

Realization

Recalling his realization that TMI must result from a combination of factors, the ORC professor explained: "I was looking at TMI, and how it manifested itself, for some years. At the time, all of the models in the literature seemed to show a gradual change of power. But to my mind [this was] not happening experimentally, where there was more of a threshold-like, sudden 'breaking-up' of the fundamental mode."

That sudden onset of instability reminded him of comparable effects, for example modulation instability in single mode fiber, the impact of beam filamentation in semiconductor lasers, and even the 'thermal blooming' and deterioration in the quality of a Gaussian beam propagating in absorbing free space. "I saw a discrepancy between theory and what was observed — and then I made a connection between this effect and what I observed with the problems seen in these other laser types."

MATTHEW PEACH

Michalis Zervas presents his invited paper "Transverse mode instability analysis in fiber amplifiers" at 8am today in Room 131, North Exhibit Level.

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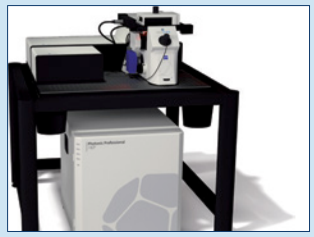

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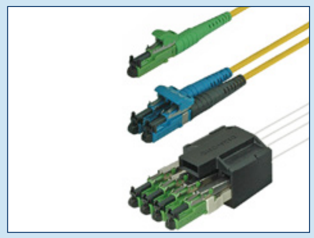

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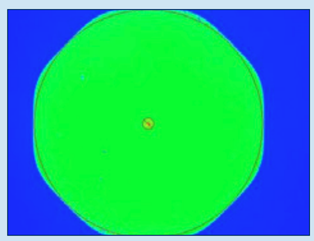

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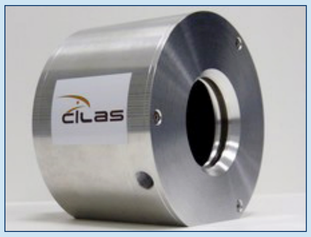

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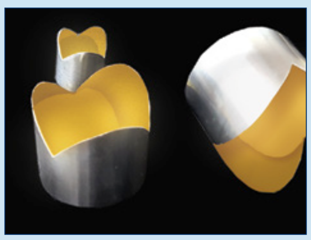

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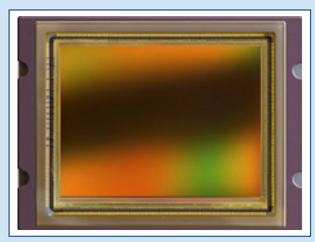

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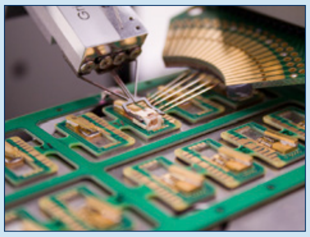

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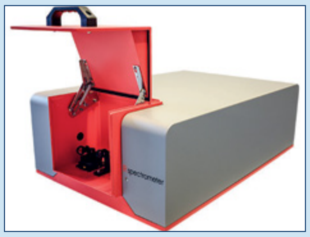

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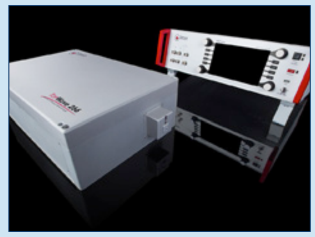

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LiFi: the future of wireless Internet access?

With the promise of blisteringly fast Internet speeds across an empty spectrum, is the world ready for LiFi?

It's been more than five years since Professor Harald Haas first wowed an audience by showing how a simple LED could be used to stream data to a computer.

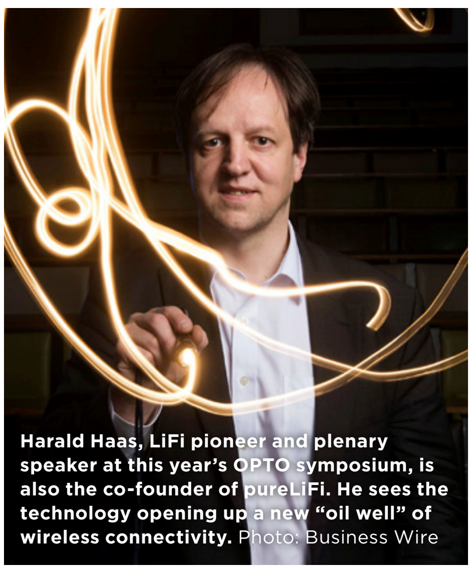
As part of that seminal *TED Talk,* the Scotland-based researcher and founder of tech startup pureLiFi used an LED lamp fitted with a transmitter driver chipset to modulate the light, encode and then transmit data to a desktop. High-definition video was transmitted through the light beam and 'LiFi' was born.

Half a decade on, and Haas' technology is less about wow and more about how. LiFi installations are proliferating across the globe as Haas, and many industry players, jostle to prove its viability.

As Haas puts it: "Commercial activity is increasing all the time, and the more pilot projects we have, the more we can show that this technology improves our lives."

To this end, pureLifi recently joined forces with France-based lighting supplier, Lucibel, to supply LED lighting luminaires, fitted with its LiFi technology to a 3500 m² office at the Paris headquarters of real estate developer Sogeprom.

To access the Internet, employees plug a USB LiFi dongle into their devices that receives and transmits data via the LiFi luminaire. A photoreceiver on the dongle receives data from the modulated visible light while an embedded infrared transmitter provides the uplink from the dongle back to the luminaire.



Harald Haas, LiFi pioneer and plenary speaker at this year's OPTO symposium, is also the co-founder of pureLiFi. He sees the technology opening up a new "oil well" of wireless connectivity. Photo: Business Wire

Bi-directional data rates reach up to 42 Mbps, similar to current WiFi data rates. And as Haas explains: "Sogeprom wanted secure communications. Wifi's radio waves penetrate walls and can spread everywhere, but LiFi remains in the room and this was important."

Help for the blind on Paris Metro

Similarly, France-based LiFi pioneer Oledcomm is trialing its LiFi services at several museums, supermarkets, hospitals, and Charles de Gaulle airport. The University of Versailles spin-out has developed LiFi chipsets equipped with indoor positioning systems that can also provide up to 5 Mbps data rates for bi-directional communications, Internet access and Internet of Things (IoT) applications.

In a recent move, the company signed an ambitious contract with Paris Metro to provide LiFi services across 66 stations by integrating its chipsets with more than 250,000 LED luminaires. "We will send location-based information to people's phones so they don't waste time looking for information and we can also guide blind people around the Metro," says Oledcomm's chief executive, Professor Suat Topsu. "We have lots of these installations now and are adapting our supply chain to deliver accordingly."

Like Haas, Topsu has been working on LiFi for some ten years, developing systems for an impressive line-up of blue-chip clients including car manufacturer Renault, the energy giant EDF, aerospace and defense group Thales, and the state-owned rail company SNCF. He launched Oledcomm in 2012, which from the very outset has targeted lower-bandwidth markets than pureLiFi.

"To ensure quick market deployment, we have been focusing on systems that can work with any kind of LED," says Topsu.

Right now, your everyday LED comprises a blue LED with a phosphor coat to produce white light. However, the phosphor impedes the light's response to intensity modulation. As a result, modulation rates are limited to a fairly modest 2 MHz, slowing data rates to around 0.1 Gbps.

Haas and others have taken LiFi data rates to 5 Gbps by using more advanced red-green-blue LED systems. Clearly the communications industry needs speed, but as Topsu asserts: "I want to first develop systems that work with any LED to ensure a quick network roll-out. Then I believe we can work with LED manufacturers to increase the quality of LEDs to reach the higher bandwidths."

Topsu is also intent on reducing the size and cost of his LiFi chipsets. Oledcomm routers currently cost tens of euros but he soon hopes to deliver a €1 router, to, as he says: 'start the mass market'.

"The marketplace for LiFi is huge right now and many companies are looking for different segments," he asserts. "It is good for the industry to have these different approaches."

"LiFi-X," the latest LiFi system from Haas' startup venture pureLiFi, offers a 40 Mbps uplink and downlink, is USB compatible and inherently secure. Photo: pureLiFi

Indeed, PureLiFi and Oledcomm are hardly alone. Dubai-based Zero.1 recently signed a deal to equip the city's streetlights with LiFi. Meanwhile India-based Velmenni has added LiFi to streetlights in Estonia and is now working with aircraft manufacturer Airbus to provide in-cabin LiFi Internet access as well as secure cockpit communications. Factor in developments from Russia-based StinsComan, Sisoft of Mexico as well as interest from Airbus, Cisco, Apple, Toshiba and more, and the future for LiFi certainly looks buoyant around the globe.

Clearly Haas agrees and, as he highlights: "Industry interest is growing and many now understand that the misconceptions that have existed around LiFi are just not true. We're in the process of seeing real acceptability now."

From line-of-sight to sunlight

That said, adoption of LiFi has doubtless been, and in fact still is, fraught with concerns. Many have assumed that LiFi must be a 'line-of-sight' technology, but as Haas has iterated time and time again, using a certain type of light modulation, data rates scale with signal-to-noise ratios and data can still be transmitted at ratios as low as -6 dB.

What's more, LiFi receivers will also receive 'residual' light reflected from the ground, ceiling, surrounding walls and objects. "A good photodetector on the receiver will still detect the weakest of signals," he explains. Sunlight has been another key issue, but according to Haas sunlight interference falls outside typical data modulation bandwidths and can be filtered out easily. Topsu concurs, saying: "Sunlight isn't a problem. We can optically and digitally filter... and data speeds may be slower but we can manage sunlight."

"We have equipped some street lights in Paris, and even in sunlight you can switch the street lights on from your smartphone and receive the LiFi data," he adds.

Haas and Topsu are both now adamant that although the benefits of the technology are accepted, education is still a critical issue. "We no longer need to provide so much effort to convince users that LiFi works, but we do need to let them know how to use it," says Topsu.

According to the chief executive, Oledcomm's chipsets are integrated into LED drivers that are then sent to LED manufacturers for installation into the LED luminaires. Given this, Oledcomm is ramping up its 'after-sales services' to bring together the two disparate camps of lighting professionals and IT engineers.

"IT services [at a facility] need to know how to install our systems [into luminaires] and then, how to manage these lights," he says. "So we are acting as the middleman between the lighting companies and IT software providers."

PureLiFi has tackled this conundrum head on by collaborating with lighting supplier Lucibel. And while Haas sees this as a signal that the lighting industry embraces the business opportunities that LiFi will enable, other industry players believe LiFi system integration could still prove to be a barrier to more widespread technology adoption.

Mark Bünger, research director at Lux Research, reckons industry integration is a sticking point. "The [engineers] that work with data and communications know nothing about lighting, which is an important function too," he says. "So perhaps the biggest hurdle right now is integrating these industries, rather than technology issues."

Indeed, in accordance with Haas and Topsu, Bünger doesn't believe issues over sunlight and line-of-sight are the show-stoppers for LiFi. "When it comes to WiFi, everyone has dead zones in their home, but use repeaters [and range extenders] to improve coverage," he says. "Likewise, line-of-site doesn't have to be

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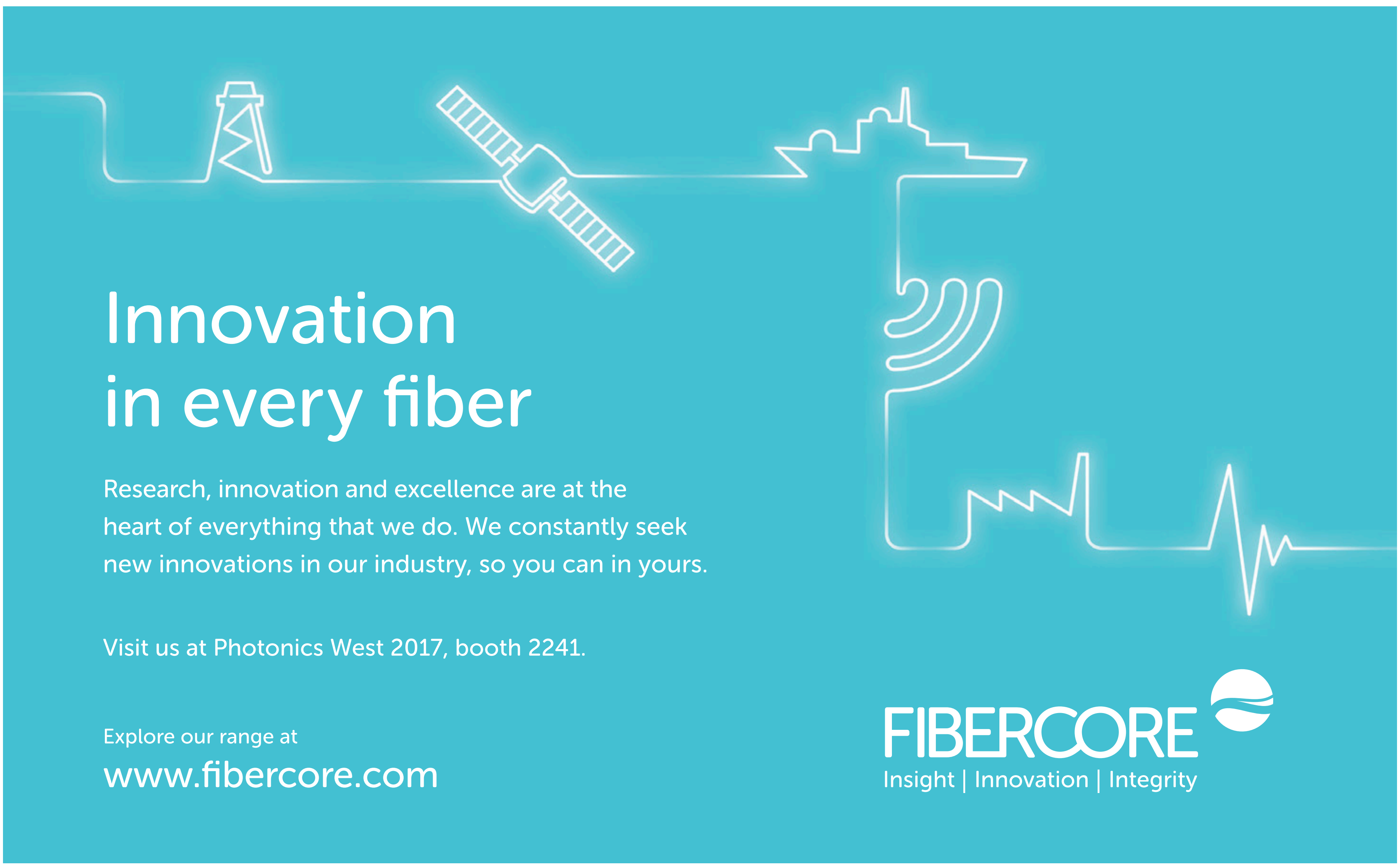
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Li-Fi continued from page 21

an issue with repeaters. There are always these ‘workarounds’ for such issues.”

But as LiFi players race to educate industries while rolling out new installations, Bünger warns of competition from alternative, more advanced wireless technologies like Bluetooth, LoRa and SigFox. “These technologies have a head-start on LiFi and are ready to integrate with the other types of devices and technologies that are being used in data communications,” he says.

Still, Haas isn’t fazed, highlighting how these alternatives are point-to-point technologies with lower data rates than LiFi. And perhaps more importantly, the LiFi pioneer is adamant that it can, and should, co-exist with alternative wireless front-runners.

“LiFi is complementary to RF and adds substantial wireless networking capability,” he says. “It is a fact that the RF spectrum is limited to 300 GHz, yet wireless

In France, University of Versailles spin-out Oledcomm is trialing its LiFi services at several museums, supermarkets, hospitals, and Charles de Gaulle airport. Photo: Oledcomm

data transmission demands increase exponentially.”

“There will be billions of IoT devices which need wireless transmission capabilities and we need more spectrum; visible light provides this by opening up a new ‘wireless oil well’ which is 1000 times larger than the entire RF spectrum,” he adds.

Records and standards

As LiFi companies emerging around the world navigate the road to market success, back in the lab LiFi speeds are as blisteringly fast as ever. Topsu, for one, has developed a chipset that reaches 5 Gbps data rates. Meanwhile Haas and fellow researchers at the University of Strathclyde and the University of Glasgow have claimed a world record with a 10 Gbps system that uses a single, gallium nitride micro-LED.

Digital modulation methods are critical to LiFi data rates. The first Visible Light Communications standard, IEEE 802.15.7, used so-called variable pulse position modulation to encode data, but Haas and his team have pioneered a novel orthogonal frequency division multiplexing (OFDM) technique, enhanced unipolar OFDM, which he claims doubles LiFi data rates.

Right now, he is optimizing the optical front ends of the setup to boost light input and extend its 20 cm communications range. “We have not yet reached the data rate and coverage limits of LiFi, but the advances we make in research will ultimately pull through to commercial products,” he says.

In the interim, more action can be expected. Last year, Apple was rumored to be testing LiFi for its upcoming devices after recent versions of its iOS were found to reference “Li-Fi capability.” For Haas, this is heartening, given just five years ago colleagues in the wireless communications industry reacted with ‘smiles’ when he presented LiFi at conferences. And crucially, he believes Apple’s interest is a clear signal that the ‘commercial explosion’ has started.

Topsu is equally confident on LiFi’s future. “We are working with phone and tablet manufacturers to integrate the [LiFi] receiver into devices,” he says. “I expect by 2018, we will have the first LiFi smartphones and tablets on the market, and our chipset will be inside.”

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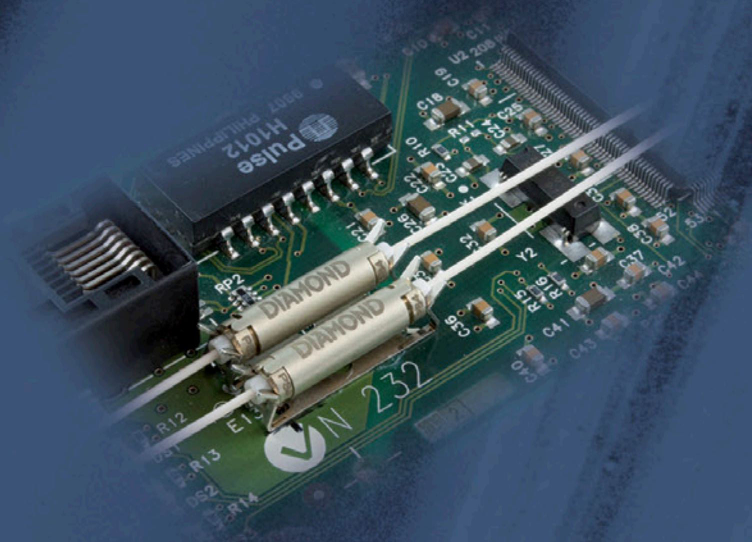

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Commercial dawn approaches for perovskite solar cells

Easy to make, and with desirable semiconductor properties, perovskites are attracting scientific attention that's resolving their outstanding issues, finds Andy Extance.

"Global warming is a huge risk for the world, and we need photovoltaics." So says Chris Case, chief technology officer at UK-based Oxford Photovoltaics. His company is pioneering the commercialization of perovskite materials, widely considered today's hottest photovoltaic (PV) technology prospect. "This is the way to deploy PV at the global scale faster and better than the 10% that it represents in energy production today," Case asserts.

Such a strong claim requires strong evidence — and perovskites' meteoric progress is a powerful 'exhibit A'. The first solar cell using perovskites was reported in 2009 by Tsutomu Miyasaka's team at Toin University of Yokohama, Japan, delivering an efficiency of 3.8%. At first it seems an unremarkable device, until you register how easily its inventors made it. Simply mix two components, coat them onto the device, remove the solvent, and crystals rapidly form. Other thin-film photovoltaic materials are also simple to produce, but amorphous in structure and therefore riddled with defects that handicap their performance relative to slow-to-make crystalline silicon PV cells. Thin-film perovskites, by contrast, can be relatively highly crystalline.

That combination of properties attracted the attention of a handful of researchers who quickly pushed efficiencies beyond 10%. Those scientists included Nam-Gyu Park from Sungkyunkwan University, South Korea, dye-sensitised solar cell (DSSC) co-inventor Michael Grätzel from EPFL in Lausanne, Switzerland, and Oxford PV founder Henry Snaith, from the University of Oxford. Today, less than eight years since their invention, more than 2,000 papers have been published on perovskite PV, and the best research cell efficiency has now reached 22.1%. Research on silicon PV started in 1953, and currently the record for a practical size crystalline silicon cell is 26.3%

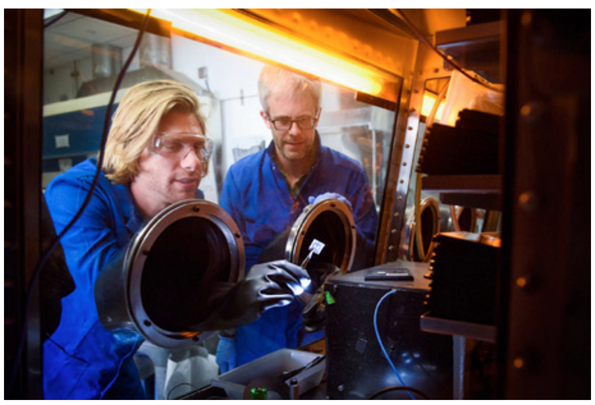
And recent announcements, from Oxford PV in particular, have certainly put the technology on the path towards becoming more than a laboratory marvel. Yet concern remains over several apparent weaknesses, including limited evidence that cells can be made sufficiently large, and issues like water sensitivity that could seriously hamper their commercial potential. A wide community of scientists and engineers, enabled by simple fabrication, has therefore emerged to harness the perovskites' benefits, and overcome their weaknesses, taking the technology in many directions.

Better solutions

The term perovskite originally referred to one specific calcium titanate mineral, which gave its name to all other materials sharing its crystal structure. For photovoltaic applications, the perovskites used are typically methylammonium lead halides. The Japanese scientists who first used them adopted them only as a tunable light-absorbing and electron generating semiconductor material in their DSSCs. They spin-coated the material onto a titanium dioxide (TiO_2) paste which helped collect the electrons generated as current passed to the cell's electrodes through an organic electrolyte solution.

Scaling up: Oxford PV employees working on perovskite solar cells. Photo: Oxford PV

From there, two collaborations — one between Snaith and Miyasaka's team, the other between Park and Grätzel's — replaced the electrolyte solution, which was difficult to contain, with solid materials. Since then, the perovskite absorber has typically been sandwiched between an electron transport material like TiO_2, and a solid-state organic hole conductor like spiro-OMeTAD.



In the lab: Stanford scientists Tomas Leijtens and Mike McGehee, who collaborate with University of Oxford perovskite pioneer Henry Snaith, examine their research-scale cells. Photo: L.A. Cicero

Yet those early cells were less than $1cm^2$ in area, whereas commercial solar modules typically string together 60 or 72 15.6cm x 15.6cm solar cells. They also suffered from hysteresis, which can cause a 'burn-in' effect, where efficiency falls under initial exposure to sunlight. In addition, they were sensitive to moisture from the atmosphere dissolving the perovskite material — clearly something of a problem if water was able to enter a perovskite solar module.

Grätzel's team showed in June 2016 that subtleties in solution-based perovskite deposition can address all three of these issues. The common 'anti-solvent' deposition approach adds a chemical specifically to precipitate perovskite crystals from their solvent, but causes defects in the film that's formed. The EPFL team developed a vacuum-assisted method that enables the sudden and well-controlled removal of solvent, producing high quality crystals that performed far better than earlier examples. The approach enabled 19.6%-efficient cells measuring $1cm^2$, which were stable in air for up to 39 days and did not suffer from hysteresis.

Researchers at the University of New South Wales (UNSW) in Sydney, Australia have likewise improved solution phase methods to produce a $16cm^2$, 12.1% efficient cell. Their device is the largest certified-efficiency single perovskite photovoltaic cell yet. UNSW's Anita Ho-Baillie emphasizes that spraying, dipping, printing, evaporation, and sputtering can all be used to apply perovskite and transport layers and cell electrodes. "Challenges during up-scaling from lab scale to pilot line, and from pilot line to production will include film uniformity, temperature uniformity as volume and mass increase," Ho-Baillie says. "Thermal and mechanical stress in the films and glass will need to be managed as size increases. Other things to consider are the throughput and yield of the process."

UNSW, as part of the Australian Centre for Advanced Photovoltaics (ACAP), is also aiming to lift perovskite solar cell efficiency and improve durability. For the perovskite research program, ACAP has AUD\$2.7 million (US\$2 million) in Australian Renewable Energy Agency funding, and participants include Chinese silicon solar giants Suntech Power and Trina Solar. To reach high efficiencies, the performance difference between bulk perovskite crystals and thin films has to be reduced, Ho-Baillie says. That's because, beyond their easy fabrication, methylammonium lead halide perovskites work well. Electrons moving through their crystals have a relatively long 'lifetime' in which to reach a cell's electrodes. However, that lifetime falls from tens of microseconds in bulk crystals to hundreds of nanoseconds in thin films. "We are also working on perovskites that have higher temperature tolerance," Ho-Baillie adds.

Another perceived problem for perovskite cells is the toxicity risk the lead they contain poses if it escapes into the environment. However the risk is lower than it might seem, Ho-Baillie suggests. "The content of lead in perovskite layers is an order of magnitude lower than the lead content in solder in silicon PV panels," she explains. "However, lead percentage by weight can become an issue for lightweight modules. It is therefore a good idea to look at ways of taking lead out of perovskites without sacrificing performance and durability. This is a challenge."

Non-disruptive technology

Meanwhile, Oxford PV's commercialization is currently focused on tandem cells, laying perovskite on top of silicon, using its tunable semiconductor properties to ensure it only absorbs the light that silicon cells cannot. In 2015, the company produced prototype tandem structures on 10cm-diameter silicon cells, and glass mini-modules containing one tandem cell each. Monolithically combining a 17% efficient silicon cell with a 15% efficient perovskite cell produced a 21.3% efficient combined device. That has since increased to 23%, Case says.

Yet the company wasn't satisfied with its products' long-term reliability, according to the CTO. "Much of the focus for 2016 was enhancing the materials to offer both improved performance and reliability," Case says. "Hysteresis is behind us, even if it's not accurately understood why. Thermal stability has been improved and moisture sensitivity has been reduced." Some of Snaith's recent research has focused on the kind of material advances needed in this regard. In one study, his

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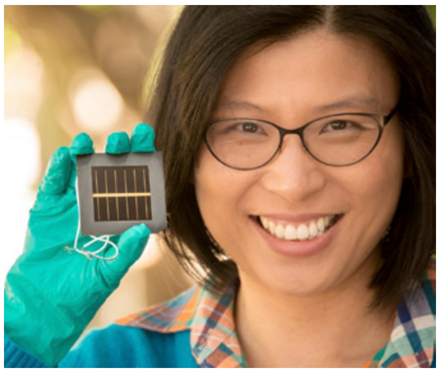
team collaborated with Grätzel's to produce neodymium-doped TiO_2 electrodes that enhance perovskite cell stability and efficiency. In another, Snaith's team used water-repellent organic hole transporter materials to improve moisture resistance.

Mini modules containing Oxford PV's tandem cells have now passed IET61646 thin-film reliability tests in challenging temperature and humidity conditions. "That's the validation people have been seeking out of perovskite," Case asserts. However, he concedes that the company is yet to test its products outdoors. Varying real-world illumination conditions could bring new problems, the executive admits, but adds that "there's no hint of that." "Confidence will build once these things are out in the field with years behind them," he predicts.



Scaling up: Anita Ho-Baillie from the Australian Centre for Advanced Photovoltaics at UNSW, with a 'large' perovskite cell. Photo: Rob Largent/UNSW.

Another new way to improve reliability, while simultaneously boosting efficiency to 21.7%, was published in November 2016 by a team led by Alex Zettl at the University of California, Berkeley. The group's 'graded bandgap perovskite solar cells' incorporate two perovskite layers, each consisting of distinct compounds absorbing light from a different part of the solar spectrum. They also use transparent gallium nitride (GaN) electrodes, monolayer hexagonal boron nitride (h-BN) to stop the different perovskite materials mixing, and graphene aerogel.

"Our new perovskite PV structure provides a robust, hysteresis-free and time-stable graded band gap perovskite cell with record performance," says Zettl. "Notably, using h-BN as a cationic diffusion barrier is a new and unorthodox approach to material synthesis. It opens up a new experimental dimension, leading to as of yet unexplored physics and engineering. The graphene aerogel acts as a barrier to moisture ingress and improves the stability against water."

Zettl believes that producing large versions of these devices should be 'perfectly possible'. "All the materials we used are facile, scalable, and ultimately inexpensive, except GaN," he says. "However, there has been a tremendous effort and continuous progress in developing cheap and scalable GaN. Moreover, we recently developed a very cost effective method to directly grow GaN on h-BN. The research is still in progress but there is great promise to adapt it into our technology." His team is exploring bringing the approach to practical use through either a spin-off company or partnership with existing PV companies.

The overall solution to making robust perovskite cells and modules will involve a combination of approaches, according to Thomas Brown from the University of Rome Tor Vergata, Italy. These will include stable materials and their combination, stable device architectures, and effective encapsulation.

As one component of this, his recent research has shown the importance of TiO_2 layers for improved stability. In one study, cells with electron transport layers made of TiO_2 nanorods actually increased in efficiency after 2,500 hours operation. And in collaboration Technical University of Eindhoven his team deposited high

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quality thin TiO_2 electron transport perovskite layers by atomic layer deposition (ALD). "We were very recently able to show remarkable efficiencies, up to 25%, of solar cells under indoor lighting," Brown says. "These findings can be transferred to large area devices with rotary ALD and with solution processing/evaporation and laser processing of all the other layers."

Building excitement

Oxford PV has also been able to adopt vapor-phase approaches similar to ALD. Its focus was originally on solution-phase processing for perovskite and carrier extraction materials, because it's cheap, says Case. But vapor phase can also meet its potential customers' cost targets. "PECVD and sputtering tools are large and relatively costly from a capital standpoint, but they do the job," he stresses.

A variety of manufacturing approaches is needed because, rather than making and producing its own cells, Oxford PV is intending to licence its technology for companies to add to theirs. In December 2016 the firm therefore signed a joint development agreement with a 'major solar panel manufacturer'. And to support that strategy, in November it bought a 30MW annual capacity former Bosch Solar CISTech thin-film solar panel development line near Berlin, Germany. These moves have been enabled in part by a £16.8 million ($21 million) funding round closed in late 2016, with investors including the Norwegian oil and gas giant Statoil.

"We believe that this represents an excellent route to introduce this technology without disrupting existing mainstream silicon manufacturing, which still represents 92% of PV," Case explains. "Instead of competitors, we're going to be partners that can help produce higher efficiency solar cells." By the end of this year, Oxford PV is aiming to produce hundreds of prototype cells per day at the German plant, coating perovskite onto potential customers' products. It will benefit from well-qualified staff as well as many of the tools already in place at the facility.

"We'll assemble modules so that we can evaluate fully functional products," Case explains. "Otherwise customers would have to invest in capital upgrades to their factory before they've seen operating panels on their cells. One facility can do this on behalf of multiple customers." At the new site, Oxford PV is looking to scale up to 15.6cm x 15.6cm solar cells. It also needs to attain acceptable fabrication yields, and expects the final tandem cells will show 25% efficiency.

Brown, meanwhile, highlights another promising perovskite possibility: truly flexible cells. "Although research efforts have started more recently, strides have been made in this arena with efficiencies reaching 16% over small areas," Brown says. "Perovskite solar cell manufacturing has been demonstrated with roll-to-roll techniques." The only company currently active in flexible perovskite cells is Poland's Saule Technologies.

Flexible cells also bring new challenges, Brown highlights. "Due to the nature of the plastic substrates, problems include deformation at temperatures above 150°C and permeability to ingress of moisture and oxygen," he admits. "There is still a lot of research and development to carry out in order to guarantee high efficiency and stability at the module level. However, the resulting bendable, lightweight, easy-to-integrate photovoltaic devices make this an exciting arena to be in."

Case, meanwhile, still finds the entire perovskite solar industry exciting. "I started in copper sulfide/selenide decades ago, and it took 20 years to get into some sort of commercialization," the CTO reflects. "If perovskite delivers in what we're hoping to be the next couple of years, it'll be a record. The fact that it's moved so fast in efficiency has shaved nearly ten years off the typical development. I don't think you expect the progress that we're making."

ANDY EXTANCE

Andy Extance is a freelance science and technology journalist based in Exeter, UK.

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NKT Photonics on the hunt for talent

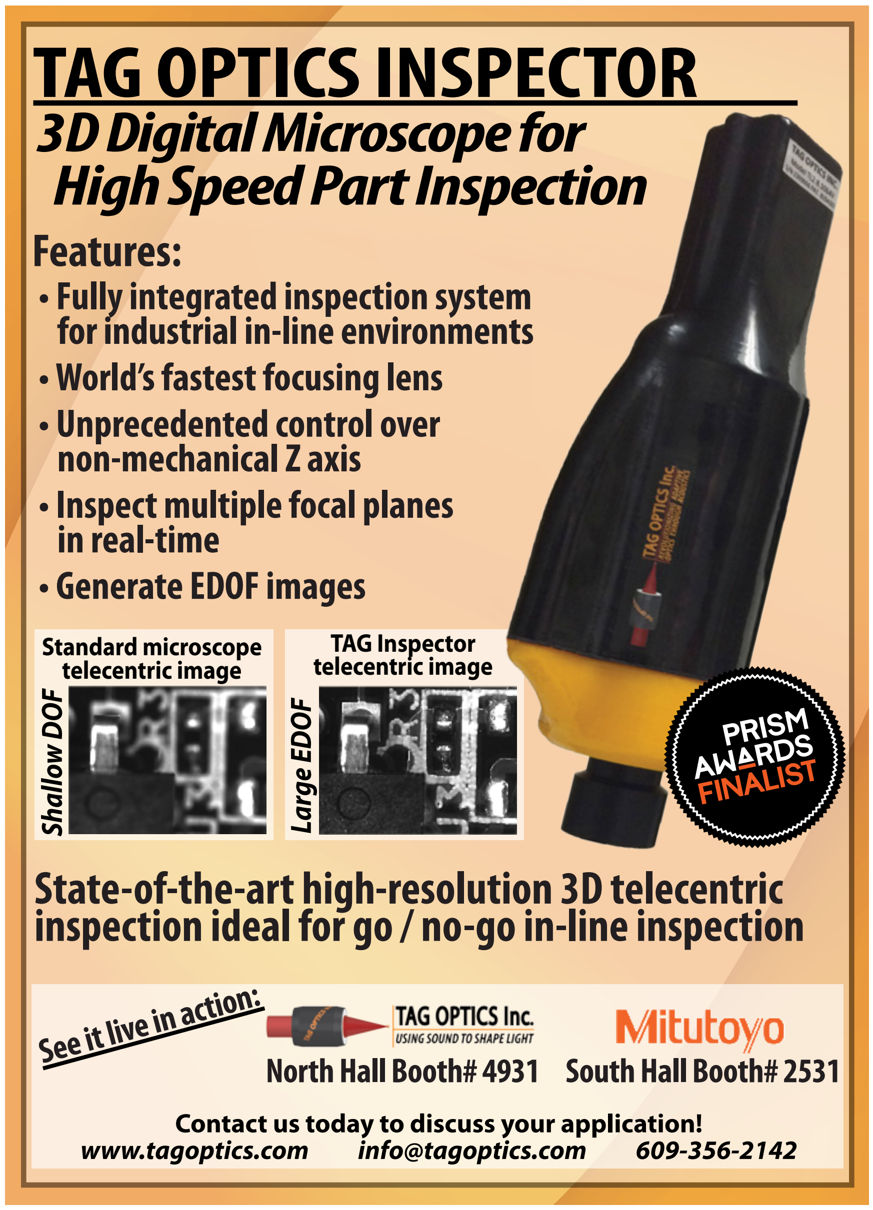
In the laser industry, the switch to fiber technology has been a hot topic for years and at the forefront of the wave we find photonics crystal fiber pioneers NKT Photonics. With a comprehensive product line spanning everything from supercontinuum lasers, ultrafast- and single-frequency lasers, to distributed temperature sensing systems, the company is the leading fiber laser manufacturer outside macro-material processing.

NKT Photonics is growing fast, and with the inclusion of UK-based Fianium and German LIOS Technology in 2016, the company now employs over 240 people globally, and more is needed. To man the many new projects that flow through organization, NKT plans to significantly ramp up their recruitment activities in 2017.

Like their more famous cousins LEGO and B&O, NKT Photonics is a Danish company with an international outlook. Walk the corridors of any of their sites, and you will notice the international atmosphere with employees from all corners of the globe. English might be the official way of communication, but you are likely to hear most of the World's major languages at the coffee machine.

Right now, NKT Photonics has a number of open positions within optics, software, electronics, mechanics, sales and service, quality management, and many more are to follow later this year.

Give your career a boost and visit NKT Photonics at their booth #823 where you can meet representatives from Engineering, Sales, and most of the Management team - including Global HR Director Nicola Davies – and see all the open positions at **www.nktphotonics.com/careers**



Photoacoustics tipped for new role in brain imaging

An early-morning start the day after Chinese New Year celebrations did nothing to put off delegates at the opening session of this year's Photons Plus Ultrasound conference at BiOS, as a standing-room-only crowd heard about new applications in brain imaging.

Chaired by Edmund Talley from the US National Institute of Health (NIH), who is closely involved with the high-profile Brain Research through Advancing Innovative Neurotechnologies (BRAIN) Initiative, the session opened with photoacoustics (PA) pioneer Lihong Wang outlining a number of recent efforts. They included imaging brain tumors in mice, mapping cerebral oxygen saturation in response to electrical stimulation, and even a whole-body PA computed tomography scan of a mouse.

Opotek's laser setup for photoacoustic imaging, as seen at the weekend's BiOS Expo. Photo: Bay Area Event Photography.

"The next big goal is to see the brainwaves," Wang said, which means mapping of calcium ions or voltage changes as neurotransmitters "fire."

Wang's group, which as usual accounts for a large number of speakers in this year's conference line-up, is in the process of moving from Washington University in St Louis to the Department of Medical Engineering at the California Institute of Technology — with Wang saying that the group's trucks were "on their way" to Pasadena, where they will set up as the Caltech Optical Imaging Laboratory.

Lei Li from the same research team told delegates about work to image electrical activity in an *ex vivo* mouse brain, where "live" slices of brain tissue still respond to stimuli. Using a fluorescent marker protein called GCaMP6 as a calcium ion sensor, Lei and colleagues were able to map activity with a PA system based around a pulsed 488 nm laser. The team has also carried out *in vivo* experiments on a live mouse brain where bloodflow can complicate matters, with Li saying that paw stimulation yielded PA signals, although they were much more challenging to distinguish from background noise.

Later in the same session, Lin Li from the Wang group showed how it was possible to generate PA computed tomography images from deep in a rat's brain, using a single-impulse light source. Imaging in the coronal plane maximizes depth penetration (to 11 mm) and minimizes acoustic distortion, the researcher added.

IRsweep launches mid-IR comb spectrometer

Switzerland-based IRsweep, a spin-off company set up by researchers at two federal institutes in Zurich, chose the weekend's BiOS Expo to launch what they expect to be a breakthrough mid-infrared spectrometer for the industry.

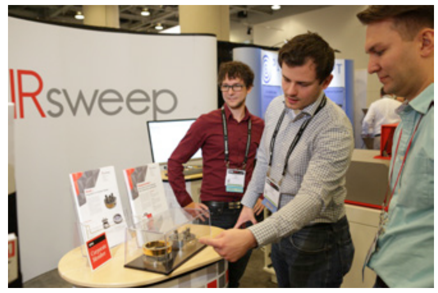
Based around a quantum cascade laser (QCL), the "IRspectrometer" is described as the first commercial table-top frequency comb spectrometer to combine microsecond time resolution with a wide bandwidth and high spectral resolution.

The equipment offers center wavelengths between 6 microns and 9.5 microns, with an extension to 12 microns now under development. The mid-infrared spectrum, often referred to as the molecular "fingerprint" region for spectroscopy, is expected to become a critical new area for chemical and biological analysis, with likely applications in medicine and security.

"IRspectrometer excels where fast time resolution, or high throughput and superior brightness, is required — including applications involving a complex background matrix or where multiple similar molecules must be simultaneously quantified," claims the firm.

New applications with the kit could include time-resolved bio-spectroscopy, with the possibility of monitoring protein folding on the microsecond scale, and analysis of enzyme activity. Protein folding is a critical process in the development of debilitating diseases like Alzheimer's and Parkinson's.

Targeting the market for laboratory instruments, with a view to entering the pharmaceutical sector in the future, IRsweep was set up by co-founders Andreas Hugi, Markus Geiser and Markus Mangold in 2014. Bootstrapped by the co-founders, it has since won financial backing from the US Defense Advanced Research Projects Agency (DARPA) and the European Commission, with a round of investment likely later this year.



The IRsweep team at the weekend's BiOS Expo. The company is also exhibiting the new IRspectrometer during Photonics West, at booth #4160. Photo: Bay Area Event Photography.

The company, which spun out from the Swiss Federal Institute of Technology (ETZ Zurich) and Laboratories for Materials Science and Technology (EMPA) has a number of well-known names from the photonics industry on board. IRsweep's advisory team includes Jérôme Faist, part of the Bell Laboratories research team that originally developed QCLs, and Timothy Day, co-founder of the Californian QCL specialist Daylight Solutions. Christoph Harder is also a member of the start-up's advisory board.

BRAIN PRESSURE MONITOR WINS TRANSLATIONAL AWARD

A non-invasive optical device for measurement of intracranial blood pressure (ICP), potentially replacing the risky, slower measures using a drill to pierce the skull, won SPIE's Translation Research Award during Sunday's BiOS sessions.

Parisa Farzam, a research fellow at Harvard Medical School and Massachusetts General Hospital (MGH), won the $500 prize, in a competition with some 250 other applications.

Farzam is part of the Athinoula Martinos Center for Biomedical Imaging at MGH, and previously studied medical optics at The Institute of Photonic Sciences (ICFO) in Barcelona, Spain.

Her innovation, using a soft, 3 cm-long optical probe on the cranial surface, won high praise from Yama Akbari, a medical doctor at the departments of neurology and neurological surgery at the University of California, Irvine, who said: "I think that a device to non-invasively measure ICP accurately would be a paradigm shift within the field of neurology and neurosurgery. It would change medical practice."

The award, which looks for the new approach with the highest clinical potential, was announced during a lunchtime forum at the Moscone Center.

Farzam said some advantages in her approach include the ability to carry out the procedure on more patients — potentially all patients, in fact — possibly saving lives, and avoiding the more aggressive older technique when a patient arrives in an intensive care unit (ICU) with a traumatic brain injury or a tumor, or after a stroke.

Currently, such patients face an ordeal. Akbari illustrated the rigors with a close-up video of a physician drilling into a skull to put a sensor inside the brain and measure pressure. "It's nice to have that," said Farzam, "but it would be much better to have a non-invasive method, without the risks of a hole in the brain, hemorrhage, infection, sedation."

Farzam's approach, developed with a team led by Maria Angela Franceschini and with the lab of David Boas, both of the Martinos Center, uses diffuse correlation spectroscopy (DCS), a method in use for about 15 years in research settings to measure blood flow.

She explained that if the measured blood flow changes within a heartbeat, during that one beat it can provide a measure of ICP. The key measure is called the "critical closing pressure."

The breakthrough is speed. If you can measure it fast enough, you get a good ICP measurement, in real time, she said. In this case, Farzam's device records the arrival time of each detected photon, before autocorrelation and image processing. "The device is new," Farzam said, "but we have it ready for research use, in the clinic for tests."

Currently, that includes patients undergoing the old invasive procedure, with DCS used in tandem for comparison. Animal studies have shown that it works, while the first human patients have now been monitored and the data captured is being analyzed.

The innovation has already received three patents, and Farzam concluded: "We want to measure many patients, and learn how to improve the device, see what the challenges are, and validate it against the standard methods."

FORD BURKHART

OPTO talks explore quantum dots, LiFi

The OPTO plenary talks on Monday explored the promise of technology from controlling thermal radiation, quantum dots, and LiFi — wireless communication using visible light.

Everything, from your body to the universe itself, emits thermal radiation. “If we can control thermal radiation, we open new possibilities for technological applications,” said Shanhui Fan of Stanford University.

One example is a passive cooling system. Almost any black material, surrounded by an insulator, radiates heat. By putting such a setup on a rooftop, you can passively cool buildings at night by as much as 15 degrees C below the ambient temperature.

Recently, though, Fan and his colleagues have devised a way to cool a building even during the day. The researchers fabricated a structure made of multiple layers of dielectric materials, which reflect sunlight but still strongly emit infrared radiation in the 8 to 13 micron range.

Using this structure, they built a module that cools running water to below ambient temperature. The water feeds into a condenser, resulting in an air-conditioning unit that doesn’t require electricity.

This method uses the ambient environment as a heat sink, so, in principle, if you use the universe itself as a heat sink, you could cool something down to 3 degrees kelvin, the temperature of the cosmos. “If you think about it, the sky is really the limit,” Fan said. His group has already reached temperatures below the freezing point of water.

Controlling thermal radiation

These approaches, however, reflect visible light — which isn’t always desired. By layering a silica photonic crystal on top of an absorber, the researchers created a material that emits heat and is transparent to the solar spectrum. Such a device could be used to cool photovoltaic cells even while they bake in the sun. For every 10-degree increase in temperature, solar cells drop in efficiency by 1%, so cooling is paramount.

Such passive cooling can also generate electricity. If you place a diode next to a cooler object, photons will flow out from the diode via thermal radiation, generating electricity. Placing a fan-like optical chopper in front of the diode periodically blocks the thermal radiation, allowing the ability to encode signals into the electric current.

Fan also described his work developing textiles for clothes that keep you as cool as if you’re wearing nothing. Working with Yi Cui’s group at Stanford, the researchers developed a material made of polyethylene, which is typically clear and nearly 100% transparent in the infrared.

But by embedding holes ranging in size from 500 nm to 10 microns in the material, they produced a nanoporous polyethylene that’s as opaque as cotton, yet transparent to infrared.

QDs for encryption

OPTO plenary speaker Dieter Bimberg of Technische University in Berlin described the benefits and potential of quantum dots in a variety of applications — and how they are vital for quantum cryptography and energy-efficient nanophotonics.

Quantum dots can be fabricated via self-organizing processes. For example, indium arsenide dots are grown on and embedded in gallium arsenide. The dots act like individual atoms, with completely quantized energy levels. This allows them to emit light at discrete wavelengths. By embedding quantum dots in a waveguide, for example, you can create a nanophotonic device, like a laser or amplifier.

> “We really have to work on energy-efficient devices. Quantum-dot-based lasers and amplifiers are absolutely essential.”
> DIETER BIMBERG
> TECHNISCHE UNIVERSITY, BERLIN

A single quantum dot, Bimberg explained, can have important uses in quantum cryptography and communication. Within a quantum dot, a hole and an electron, bound together as a quasiparticle called an exciton, can recombine and emit one or at most two polarized photons. One photon can serve as a qubit for sending encrypted signals; two are useful for entanglement.

Unlike in classical encryption, quantum encryption enables the sender and receiver to know immediately if an interloper has broken the coded signal. Quantum dot technology, Bimberg said, is also relatively simple and inexpensive, since it is based on classical semiconductor technology. A single qubit emitter is just a LED with one single quantum dot inside.

In a large assembly of quantum dots — say, several million in a semiconductor device — their discrete properties are hidden. But that’s what makes them advantageous for creating or transmitting optical signals through communication networks.

A laser based on a large collection of quantum dots has a broad emission. Such lasers also allow for quantum techniques to suppress the slight fluctuations in arrival times of signals called jitter, down to as little as 200 femtoseconds, which would otherwise be very difficult with conventional lasers.

Using quantum-dot technology for other network devices like amplifiers will reduce energy consumption and cost, he said. For instance, devices like an erbium-doped fiber amplifier (EDFA) compensate for the intensity loss of a signal that travels through kilometers of fiber-optic cables. But these amplifiers are complex and expensive and do not operate in the O-band around 1310 nm, which is the range where local and metropolitan area networks operate. Instead, amplifiers based on quantum-dot technology are a cheaper and simpler solution.

Quantum-dot amplifiers have several other advantages. A single device can amplify multiple signals with different wavelengths and does this wavelength division multiplexing without crosstalk. These devices can even change the wavelength of signals, which is sometimes necessary in a network because signals of the same wavelength can interfere.

In general, quantum-dot technology is more energy efficient, which is important given the rising energy demands of the internet. “We really have to work on energy-efficient devices,” Bimberg said. “Quantum-dot-based lasers and amplifiers are absolutely essential.”

A quantum-dot laser has a threshold current density three to four times lower than that of a conventional quantum well laser, which means it requires much less electricity. Such a device is also more thermally stable, not changing its threshold current density up to 70-80 degrees C, and thus doesn’t need an energy-consuming cooling system.

Because a quantum-dot amplifier works for both upstream and downstream signals, a network can cut the number of devices — and thus energy demand — by half. Conventional technology would require a separate amplifier for upstream and downstream signals.

Concluding the plenary session, Harald Haas of the University of Edinburgh discussed the possibilities of LiFi. This technology could potentially be revolutionary, playing a role in everything from driverless cars and industrial robots to delivering the internet to remote areas and the Internet of Things. See page 21 for more.

MARCUS WOO

NEW FELLOWSHIP HONORS HILLENKAMP

Biophotonics community members are working to estabish an annual fellowship to honor the late Franz Hillenkamp, developer of the laser microprobe mass spectrometer.

BiOS co-chair R. Rox Anderson of the Wellman Center for Photomedicine (US) announced the Hillenkamp fellowship at the BiOS Hot Topics session Saturday. The fellowship will be funded by donations from individuals and organizations in the biomedical optics community.

Anderson said the fellowship would fund $75,000 a year for a researcher at one of four biomedical optics centers. Participating organizations are the Wellman Center, the Medical Laser Center in Lübeck (Germany), the Beckman Laser Institute at the University of California in Irvine (US), and the Manstein Lab at the Cutaneous Biology Research Center (US).

Anderson said the Hillenkamp Foundation Fund Committee is delighted to have the opportunity to collaborate with SPIE on this project and participate in the SPIE 100% charitable matching program.

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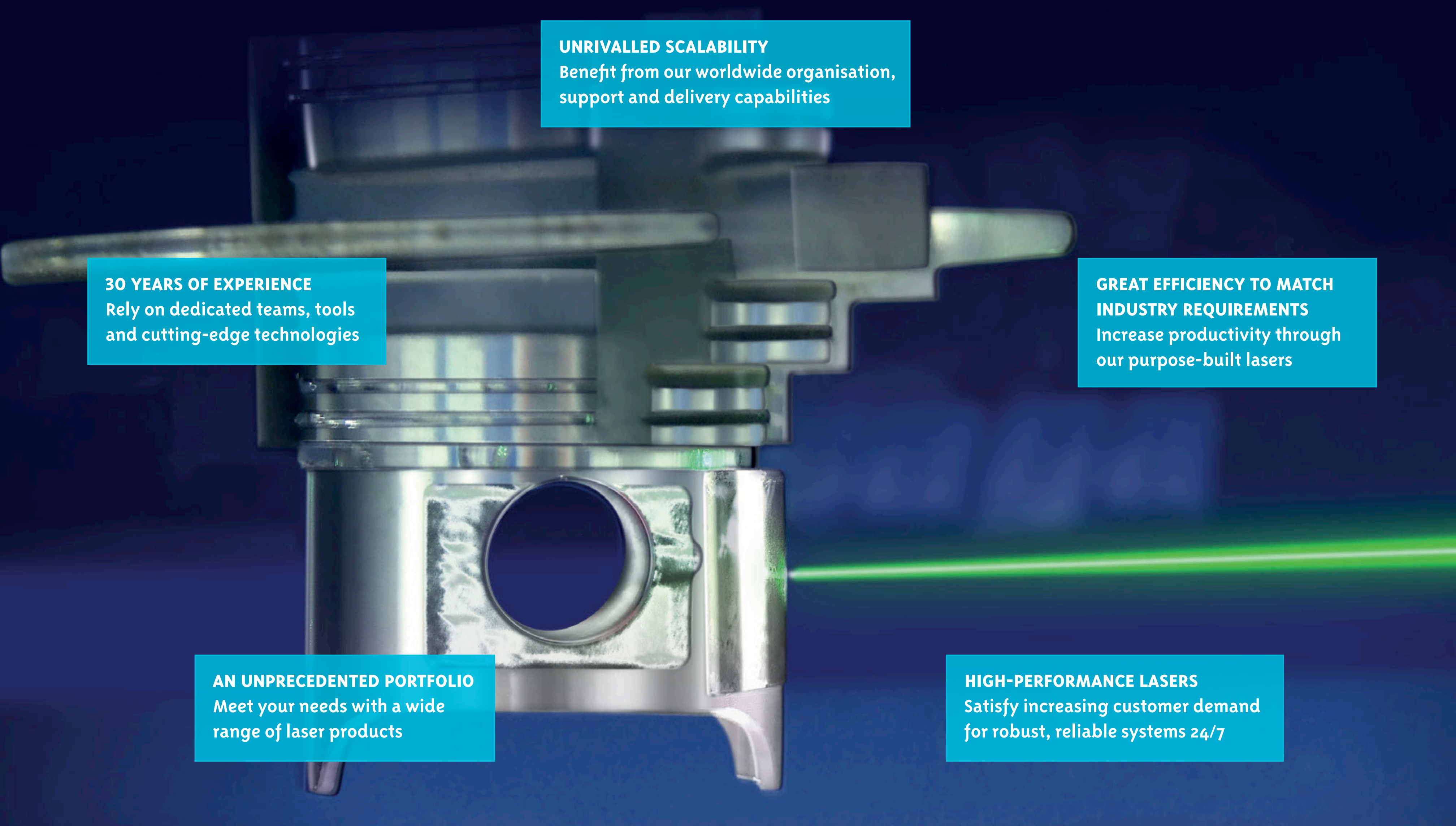

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