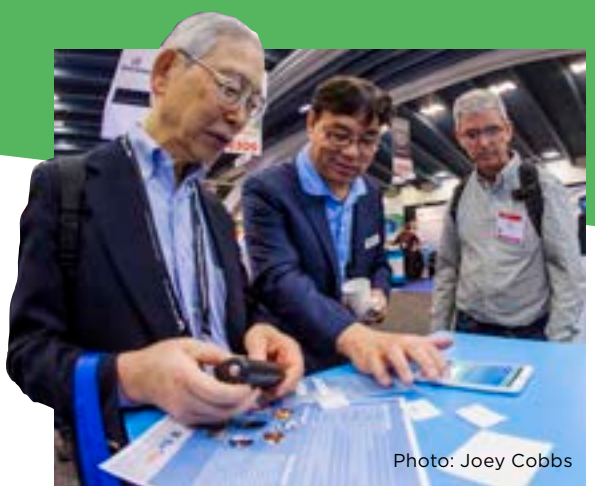
WEDNESDAY EDITION

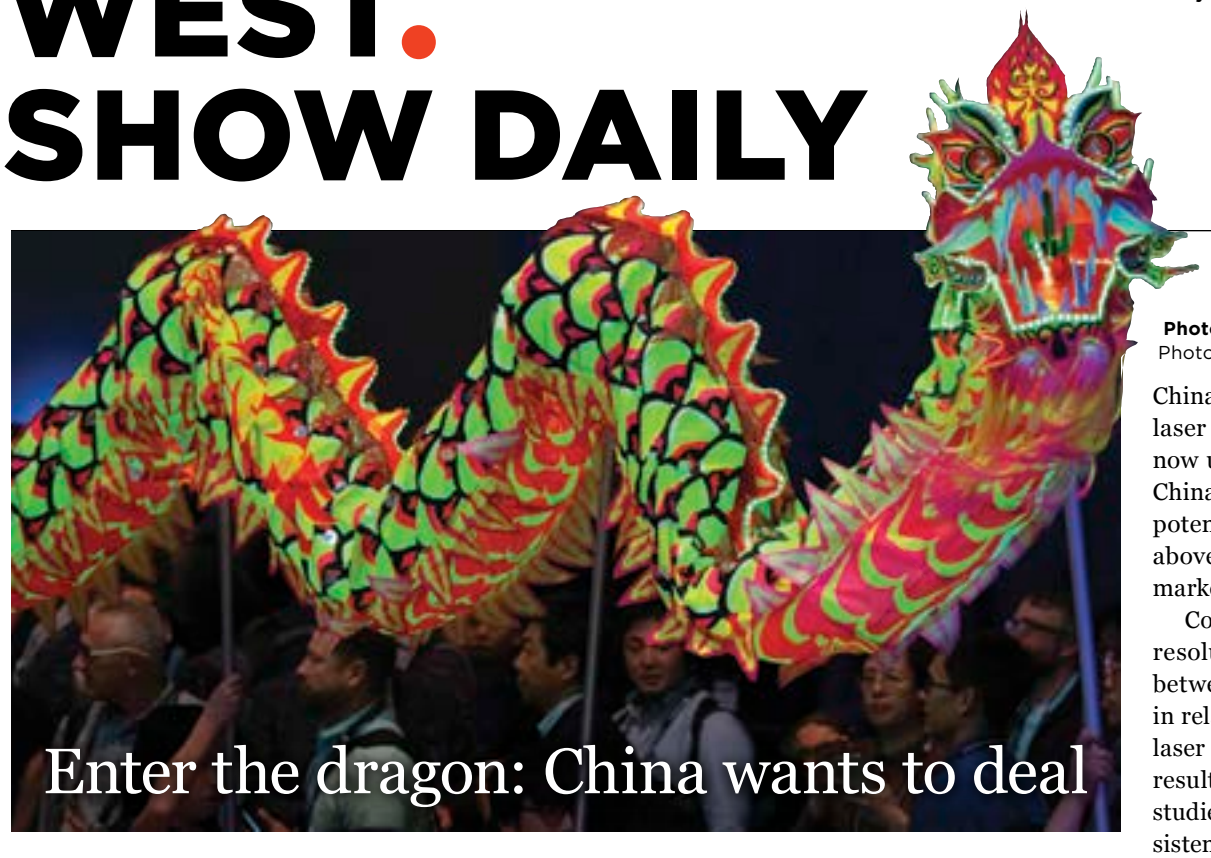
SPIE. | optics.org | WEDNESDAY, FEBRUARY 6, 2019

PHOTONICS WEST. SHOW DAILY



It's a Breeze! Bayspec CEO William Yang (center) presents the Breeze Analyzer.

Photo: Joey Cobbs



Chinese New Year thrills the crowds at Photonics West. Photo: Adam Resnick

Enter the dragon: China wants to deal

The Lasers & Photonics Marketplace Seminar, hosted by Pennwell's *Laser Focus World,* takes place on the Monday between SPIE BiOS and SPIE Photonics West. This year's presentation by China specialist Dr. Bo Gu was of particular interest not merely because it was the eve of Chinese New Year – we have just entered the Year of the Pig: 4717 – but because Sino-US relations have been sorely strained by trade sanctions and increasing mistrust between these two giant trading blocs.

Gu commented, "Political and trade tensions between the US and China are much in the news, often obscuring the deep links and market relationships between China and US and European companies."

He said China's GDP in 2018 was equivalent to $13.5 trillion (or 16% of the world economy), compared to the US figure of $20.5 trillion (24%). But Gu pointed out that China's growth rate was almost 7%, against the US figure of 3.5%, and furthermore that in 2019 the value of China's economy will surpass that of the Eurozone. "So together these big two markets account for 40% of world trade, which is why I think it's so important that these countries learn how to deal with each other," he said.

> Tensions between the US and China often obscure the deep links between these trading blocs.

"Access to finance in China is difficult, which is limiting the potential of Chinese SMEs to purchase laser equipment."

Another trend he noted is that the types of lasers that the Chinese buyers import are going up in power as the capability of the domestic Chinese market to produce higher-power lasers grows. He commented, "The only frontier left for international exports to China is what I call the 2kW laser and above, which are now under development in China. A factor limiting the potential here is still that above the 20kW level, the market is much smaller."

Considering the potential resolution of the tensions between the US and China in relation to high-tech and laser trading, Gu presented results from several recent studies that showed the persistence of what he called a "love-hate relationship – but still an important relationship."

One of Gu's key conclusions from his analysis of the Sino-US business landscape is that even though the Chinese laser industry enjoyed a good 2018, the slow down in the economy and uncertainty due to the trade war "points to a bumpy 2019 – unless there is a resolution soon."

On the upside, he said that successful negotiation between the two countries "will result in a new landscape with more opportunities in China for US companies, and that Chinese companies will in turn be seeking US partners to access the US market."

MATTHEW PEACH

DON'T MISS THESE EVENTS TODAY.

INDUSTRY EVENTS

EXPORT CONTROL WORKING GROUPS
8:30 AM-12:30 PM, So. Exhibit Level

3D PRINTING AND INDUSTRY 4.0: AN INDUSTRY PERSPECTIVE
8-10 AM, No. Exhibit Level

PHOTONICS WEST EXHIBITION
10 AM-5 PM, No. and So. Halls

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

MARKETING TIPS: DESIGNING FOR GROWTH.
1-3 PM, So. Exhibit Level

THE QED-C CONSORTIUM AND ENABLING PHOTONICS TECHNOLOGIES FOR THE EMERGING QUANTUM INDUSTRY
1-2:30 PM, Room 21, No. Exhibit Level

STARTUP CHALLENGE FINALS
3-6 PM, No. Exhibit Level

PRISM AWARDS CEREMONY AND BANQUET
6-10 PM, Marriott Marquis Hotel

***INCREDIBLES 2* FREE VIEWING**
8:00 PM-10:00 PM, No. Lower Lobby, Exhibit Level

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

IN THIS ISSUE.

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WHAT'S NEW AT OPTOSIGMA

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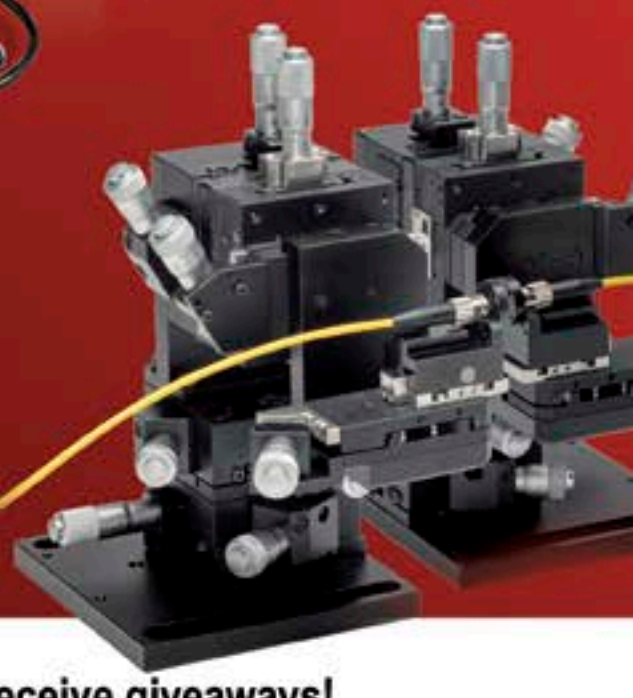

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Booth #1427

Seeking R&D funding? Think way outside the boxes

Leading US NIH and NCI Officers tell a young BiOS audience how to succeed.

Tapping into imaging research funds at the almost $6 billion U.S. National Cancer Institute and the $350 million National Institutes of Health may require some smart moves and knowledge of alternate pathways, top leaders said on Sunday.

A Photonics West workshop for researchers featured insider tips from Behrouz Shabestari, acting director of the Division of Health Informatics at NIH, and Robert J. Nordstrom, chief of image-guided interventions and acting chief of image technology development at the National Cancer Institute.

Nordstrom urged the audience of mostly young researchers to always think beyond the specific offers that are presented.

"Yes, you should read our announcements, but remember that 47 percent of all grants come from your own ideas," Nordstrom said. 'Tell us what you want to do."

He urged the future applicants to attentively 'find out the rules' and then to define what they seek to do, in a list of no more than three aims. "Keep it simple," he said. "This is not the place to show off your extensive knowledge ... and keep controversial comments out of the application." He said applicants should call the listed senior official and "open a communication channel ... start a path for your application."

At the U.S. National Cancer Institute, Nordstrom said, "imaging is central to all of its programs and divisions."

For example, the Division of Cancer Treatment and Diagnosis works in cancer imaging as one of five core programs, "but imaging is done everywhere." He said 41 percent of NCI funding goes to research project grants, or RPGs. Last year 4,700 grants were made.

Imaging, he said, is embedded in all the central areas, biology, technology, clinical projects, informatics, and preclinical efforts. "Imaging encompasses all these different areas," Nordstrom said.

Meanwhile, Behrouz Shabertari, of NIH, said applicants must study the NIH's RePORTer web site. "It tells you everything about all the funded projects with abstracts."

He urged applicants to strongly state their 'new science or technology' in their three aims. "Make reviewers your advocates," he said. And then, he said, "Match the new idea or science to the right place at NIH ... and state what your next steps will be when you succeed."

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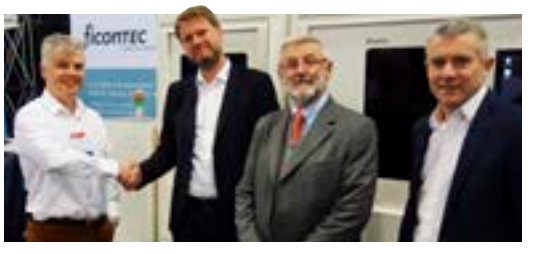

TYNDALL, FICONTEC LAUNCH PILOT LINE IN IRELAND

Ireland's Tyndall National Institute and ficonTEC Service, Germany, along with other industry partners including Eblana Photonics, Faz Technology, mBryonics, and Sanmina, have jointly founded the National Photonics Manufacturing Pilot Line in Cork. This is an integrated photonics manufacturing ecosystem for advancing disruptive photonic technologies to commercialization.

The Pilot Line, located in Tyndall, Cork, with an investment of €6m and a team of 15, will engage with sectors such as medical technology, life sciences, and communications. Tyndall is already the home of the PIXAPP Pilot Line Gateway and the Irish Photonics Integration Centre. (booth 4353).

Above L-R: Peter O'Brien (PIXAPP, UCC), Torsten Vahrenkamp, Ignazio Piacentini, (ficonTEC), Patrick Morrissey (IPIC, Tyndall). Photo: Matthew Peach

BMW stepping up laser headlights for 2020 models

BMW is ramping up its high luminance laser light technology for 2020 to reduce levels of heat from laser radiation, and is adding features that will instantly shape beams to protect drivers from glare.

At a standing-room only conference session on Sunday at the BiOS conference, Julian Carey, director of product marketing at SLD Laser in Santa Barbara, Calif., with plants in the Bay Area and a supplier to BMW, summed up the transition to new high-luminance laser systems with blue laser diodes.

"This is what's going to be inside the new BMW vehicles to be introduced by the end of this year," he said.

Improved safety and visibility are the key elements driving BMW, he said.

He showed an image of a deer illuminated by a BMW laser headlight at a kilometer distance on a dark night.

"By illuminating objects beyond 1,000 meters of range, it will allow more time for stopping distance," he said. "What we expect is that an entirely new headlight architecture will emerge.

"The whole headlight will be able to use one or several sources to enhance safety in the roadway. It offers greater safety because there's no blue laser radiation escaping."

Laser diode efficiency, Carey said, has come a long way, from 15 percent to 40 percent of the electrical energy that is turned into light.

Dynamic lighting is a feature with lasers that can change the shape of the light beam in response to road information, road hazards, or objects. "You can reprogram the whole algorithm of the headlight," Carey said.

"Now that lasers are in the vehicles, that opens up the possibility for dynamic lighting," he said. Using the MEMS scanner, the system activates the phosphor that converts light from blue into white light.

He showed an image of a dynamic Laserlight module, a 50mm (2 inch) cube that can finely shape the beam of light, increasing safety, enhancing visibility, and eliminating glare. "It will let the driver see roadway hazards more clearly," Carey said.

Although Europe has approved laser lights, responding in part to needs of high-speed German autobahns, so far the United States has not. But BMW isn't worried, Carey said. "We expect, since it is so safe, it will be adopted in other regions.

LED headlights are standard on the 2019 BMW X5, but the options list includes BMW Laserlight with adaptive LED Headlights. This technology uses a BMW Laserlight spotlight with Selective Beam, which can project a non-dazzling high beam at a distance of about 500 m. The BMW Laserlight projectors can be identified by the blue X-shaped trim inside the headlight clusters. Photo: BMW

"For now, it's a European product. That market is more innovative," Carey said.

Headlights that used to be huge units with halogen incandescent bulbs now are being replaced by LED lights that reduce the module size but with tradeoffs.

Temperatures can be up to 85°C (185°F) inside the module environment, and inside the headlight can be up to 110°C (230°F). He showed dramatic thermal images showing tons of heat generated by both the combustion engine of the vehicle and the laser lights.

In response, where heat has been a problem, Carey said, "We are using remote architecture to keep these sources cool."

Carey showed the futuristic modules, in the BMW X7, an SUV-type sedan, with headlights that one day may combine several different laser light sources in a single system. It will be able to deliver all the functions of several lights in older modules, like side lights for turns and basic light for road illumination.

The improvements in central light intensity, Carey said, are "really all about luminance."

New products have achieved 10 to 15 times the luminance of previous LED lights and HID lights.

"The previous LED light has come an incredibly long way," Carey said. "They have extreme efficiency, even with lower luminance from the light source."

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Nano/Biophotonic Plenary Session

Kinesin proteins carrying microtubules resemble a mosh pit.

One of the goals of nanotechnology is to treat diseases by sending nanorobots into the body to repair cells and deliver drugs. Optical imaging is helping to make that future a reality, said Henry Hess at this year's Nano/Biophotonics plenary.

"Optical techniques are critical for the development of nanorobots because they're noninvasive and nondestructive," Hess told *Show Daily*.

Using these techniques, researchers like Hess can image, measure, and characterize proteins that act as molecular machines – the motors behind tomorrow's nanorobots. In particular, Hess has focused on a protein called kinesin. One end of the protein binds to a surface while the other end features two appendages that can carry a micron-long molecular tube called a microtubule. Multiple kinesin proteins can "walk" a microtubule along, like how a crowd carries a person in a mosh pit.

The microtubules, roughly 25 nanometers in diameter, can in turn carry cargo. By etching trenches on a surface with photolithography, researchers can pave a delivery route for the cargo.

For example, in earlier work, Hess and colleagues demonstrated how these molecular machines could serve as a smart dust sensor to detect biological or chemical agents. The sensor would be built onto tiny chips, which could then be dropped onto, say, a wet spot in the field. Potentially contaminated water seeps into a chamber in the chip, which is covered with kinesin proteins and filled with microtubules. Attached to the microtubules are antibodies that can bind to a targeted biochemical agent. The kinesin proteins would then deliver the agent-carrying microtubules to a second chamber filled with fluorescent tags, which would bind via a second antibody to the agent on the microtubule and be carried to another area to be detected. The arrival of the fluorescent tags would then indicate the presence of the molecular target.

At the time, Hess noted that biomolecular motors like kinesin can convert chemical energy derived from the hydrolysis of individual ATP molecules into directed, stepwise motion. This enables them to act as fuel-efficient "tractor trailers" within cells, and to actively transport designated cargo, such as vesicles, RNA, or viruses, to predetermined locations within cells.

> Multiple kinesin proteins can "walk" a microtubule along, like how a crowd carries a person in a mosh pit.

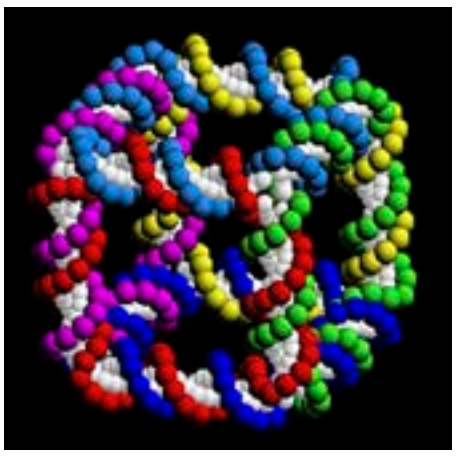
In biological systems, motor-driven active transport complements diffusion and pressure-driven fluid flow, providing close control over cargo movements within extremely restricted spaces. He felt that engineers who observed active transport in biology would be inspired to develop nanofluidic systems for biosensing, active materials capable of rearranging their components, and even molecular conveyor belts for nanoscale manufacturing.

More recently, Hess and colleagues have developed kinesin proteins that only weakly bind to a surface. Previously, the kinesin proteins had to be permanently attached. So for them to carry microtubules everywhere, the proteins had to cover the entire surface.

But in 2018, the researchers showed how weakly binding kinesin proteins could float freely in solution and bind only when they meet a microtubule. After the kinesin meets, binds, and passes the microtubule along, it will release from the surface and return to the solution.

This approach, which more closely mimics biological processes, allows for a more efficient use of the kinesin proteins, said Hess, a professor of biomedical engineering at Columbia University. Furthermore, if a kinesin motor proves defective, a microtubule won't get stuck, as it would if the motors were permanently attached to the surface. Instead, the microtubule can simply shed the defective motor and keep moving.

In recent years, Hess said, his group has focused on how these machines degrade over time. Using advanced optical methods, the researchers have found that the microtubules tend to shrink as they glide along the surface. "It's a little bit like how your car loses rubber from the tires as it moves along," he said. The amount of wear and tear depends on how fast the microtubule moves and the density of kinesin proteins.



Ned Seeman's DNA cube. Source: Seeman Lab

In particular, the wear and tear correlates with the height of the kinesin proteins – which, it turns out, depends on their density. When the proteins are bunched together, like the bristles on a brush (the "brush" regime), they push up against one another and stand taller than if they were alone (the "mushroom" regime). In 2013, the researchers used fluorescence interference contrast microscopy to find that the difference in height corresponds to the rate of wear on the microtubules. Still, the exact reason for how this transition from the mushroom to the brush regimes leads to enhanced shortening of microtubules remains unknown, Hess said.

None of these advances would have been possible without constantly improving optical techniques, he said. The key has been the ability to break the presumed limit in optical resolution of about 200 nanometers – methods that include and derive from the super-resolved fluorescent microscopy approaches that won the 2014 Nobel Prize in Chemistry. Armed with these techniques, he said, researchers could analyze nanorobots down to a sub-nanometer level.

Hess also noted that the microtubules' wear shows a complex dependence on motor density and cannot be readily explained by simple models. The mechanical activity of biomolecular motors can trigger wear at the molecular scale, which requires enhanced self-repair mechanisms. Excessive stress or impaired repair may be the cause of medical pathologies originating from wear at the molecular and subcellular level.

His team's research aims to formulate the rules governing these active self-assembly processes, and to show that the boundaries of self assembly can be greatly expanded by use of biomolecular motors.

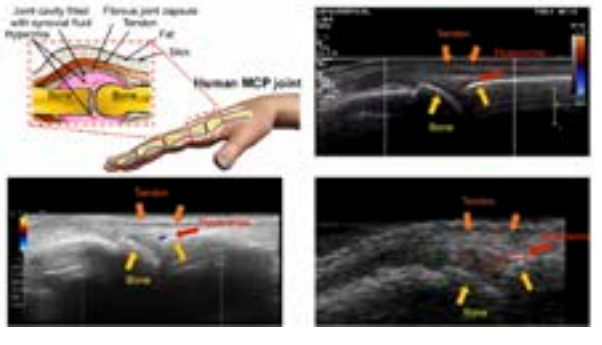
MARCUS WOO & KAREN THOMAS

Cyberdyne's Acoustic X yields 'unique' LED-based photoacoustic Images

A remarkable 3D image of capillary vessels in human fingers, *in vivo,* in real time, illustrated the remarkable imaging accomplishments of the Acoustic X system in an industry talk at Photonics West on Saturday.

Cyberdyne drew a hefty crowd to the BiOS Hall's speaker platform where their Acoustic X system was presented by Dr. Mithun Kuniyil Ajith Singh, research and business development manager.

Cyberdyne, headquartered in Japan with a base in Rotterdam, in The Netherlands, has its Acoustic X in operation at more than a dozen global partner centers like the University of Michigan, where *in vivo* images of rheumatoid arthritis patients were recorded. Images from the University College in London recorded *ex vivo* images of the placenta, and other Acoustic X images were also supplied for the BiOS talk by the Saga University Hospital in Japan.



Arthritis inflammation in human finger. Photo: Cyberdyne

Cyberdyne says its device simultaneously obtains information through light absorption and ultrasound, and the information is then displayed on the monitor of the device.

By combining the two methodologies, Acoustic X displays information that had been seen as too difficult to display, such as capillary vessels and different levels of oxygen saturation, illustrated by photos from the University of Cambridge.

Cyberdyne says it is trying to overcome difficulties of conventional photoacoustic devices, such as high costs and a requirement of vast amounts of electricity supply, by adopting an LED array light source.

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Cementing doublets

A key application of the OptiCentric® systems is the alignment of doublets or triplets when cementing single elements. "With our LensAlign options the exact adjustment of two or more lenses towards each other is possible," highlights Product Manager Dr. Patrik Langehanenberg. "And this in respect to the optical axes." New solutions are constantly introduced allowing not only cementing of doublets but covering the full variety of applications such as lens to arbor or lens to cell alignments.

Measurement technique without rotation for position sensitive samples

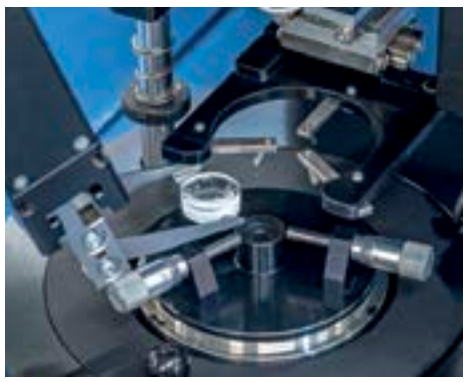
Typically centration measurement requires the rotation of the sample in a vertical measurement arrangement. "These limitations are a challenge for two customer groups," reveals Langehanenberg. "First, those who want to inspect high-quality lenses with floating elements. Second, those who require shortest cycle times for volume production." Faced with this challenge, the engineers at TRIOPTICS have developed a product that measures without rotation – OptiCentric® Linear.

The special feature of this inspection method lies in avoiding the rotation. This new technology allows to measure regardless of the sample orientation, e.g. in a horizontal setup. It also ensures that the required throughput for performing quality inspections in volume production is reached.

Automation to streamline production processes

Another aim of TRIOPTICS' engineers is to increase the efficiency when centering and inspecting lens systems. Langehanenberg explains: "There are a number of reasons for our focus on automation. One reason is that it increases the process reliability of our systems in terms of increased accuracy and shortened process time. Here, robotic processes allow significant improvements."

Thus, automation is taking TRIOPTICS to the next level. "In volume production, operators used to insert every single lens manually and then start the process," reports Langehanenberg. "Now we use robots that load and unload batches of lenses." The alignment process is seamlessly integrated to the handling of lenses.



An alternative solution to OptiCentric® is the alignment turning station ATS. Using the same measurement principle the cell of a mounted lens is turned in such a way that the lens is perfectly centered.

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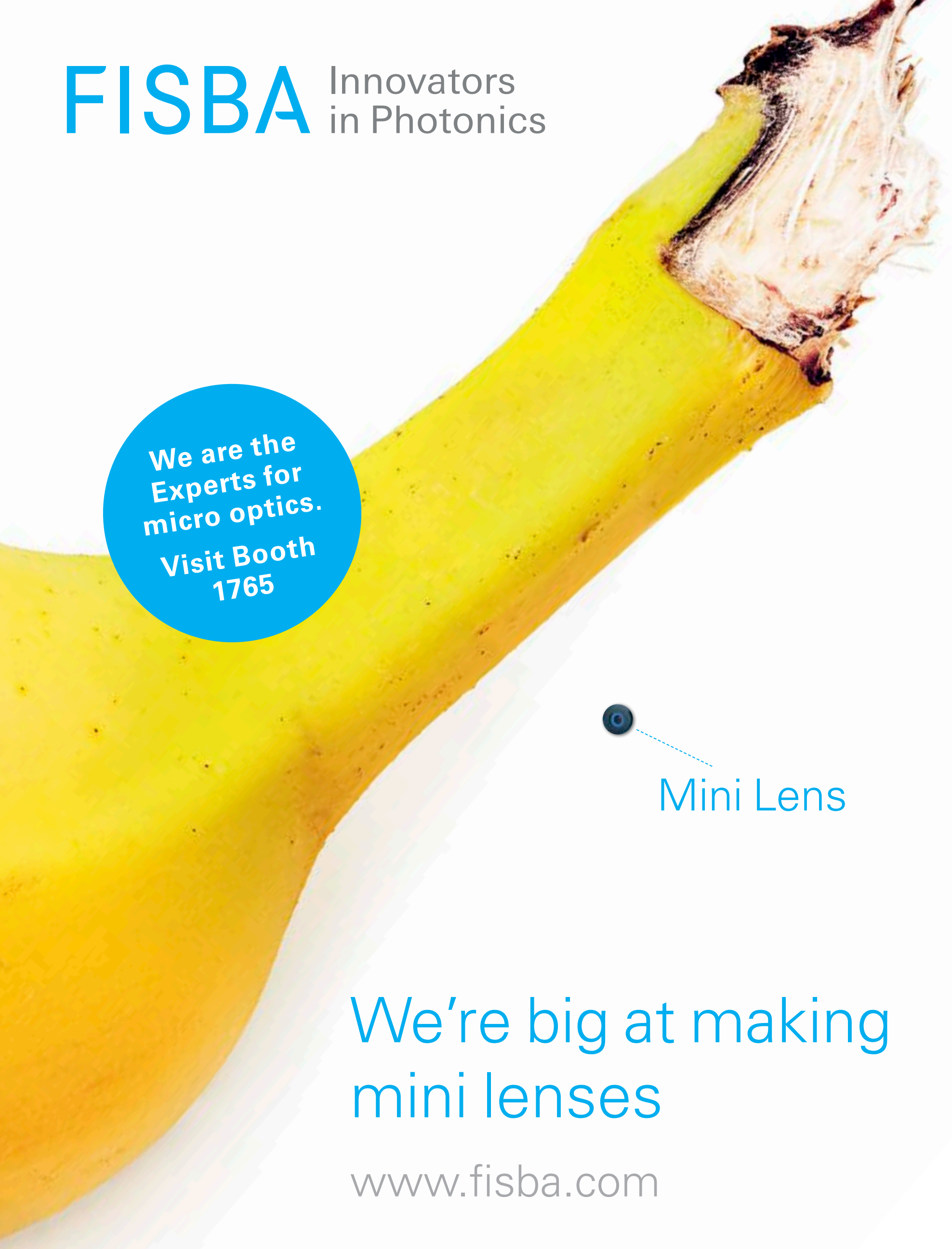

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Facebook focuses on optics integration

Photonics West 2019 plenary speaker Katharine Schmidtke decides which photonics technology is best for Facebook data centers. But how did the one-time UK university researcher become a strategist at the world's largest social networking site?

Facebook technologist Katharine Schmidtke never set out to make waves in industry. With a PhD in non-linear optics from the UK's University of Southampton, followed by post-doctoral research into epitaxial growth of non-linear optical materials at Stanford University in the US, her first foray into business was meant to be research-focused.

Working at San Jose photonics equipment manufacturer New Focus, Schmidtke was tasked with developing acousto-optic tunable filters and spent a lot of time defining waveguides within crystals.

As she puts it: "I had left Stanford feeling very comfortable that this was all going to be pretty similar, and it was a practical, useful implementation of many things I had been doing during my research."

But photonics entrepreneur Milton Chang, at the time the New Focus CEO, had also hired Schmidtke to head up a product line, and the young researcher's career swiftly shifted paths.

"Of all the people to have this first exposure to industry with," laughs Schmidtke. "Milton Chang had such energy, enthusiasm and passion for entrepreneurship that I instantly caught the bug. This was a huge revelation."

Schmidtke discovered quickly that business demanded the same problem-solving skills as academia, but that the results flew in much faster. "As a physicist it had been fascinating to understand how things work and then to control them," she says. "Yet in business, if you are running a well-oiled machine, you understand how it works, what the controls are, and then you optimize the controls. This was what was unexpected about my job at New Focus."

Dot-com boom

After spending three years at New Focus, in 1998 Schmidtke moved to telecoms-focused heavyweight Uniphase, again to head up a product line. It was the heady days of the dot-com boom, the company was merging with JDS Fitel in a deal valued at $3.3 billion, and would soon acquire a handful of California-based optics businesses for the spectacular sum of $66 billion.

> "I realized I could have more impact on the industry from within Facebook than working for a supplier."

Schmidtke describes her short time at JDS Uniphase as 'interesting and innovating', as well as 'a wild ride' and 'chaos'. So three years later, as stock prices were crashing, she moved to Germany to grow the EMEA (Europe, Middle East and Asia) business for another California-headquartered manufacturer of optical communication components and subsystems, Finisar.

From the word go, Finisar had focused on building high-speed networks for enterprise customers, and so was somewhat protected from the dot-com crash. As

Photonics West 2019 OPTO plenary speaker Katharine Schmidtke, seen here presenting at the Prism Awards in 2017. Photo: SPIE/Bay Area Events Photography.

Schmidtke points out: "Finisar wasn't primarily a telecoms player. [It] had a good technology mix, and after looking at their management team and technology I was very impressed."

At the time, the company had little to no presence in Europe, but Schmidtke was able to change this from the ground up. In 2002, the company formed Finisar Europe and acquired Germany-based telecoms optical subsystems supplier, AIFOtec, for $2.3 million. In 2004 Infineon's 10 Gb/s fiber-optics arm was bought for $263 million, with the Norwegian optics supplier Ignis following later, in 2011.

That global expansion by acquisition was very much part of Finisar's culture. During her 12-year stint at the company, Schmidtke saw the firm's optical communications market share mushroom from 2% to nearly 15%, making it the market leader in transceivers prior to its pending acquisition by II-VI, announced in late 2018.

"The company put out good technology at a very good price, but I think what was really good about my time at Finisar was the team of people," she says. "We were a

continued on page 09

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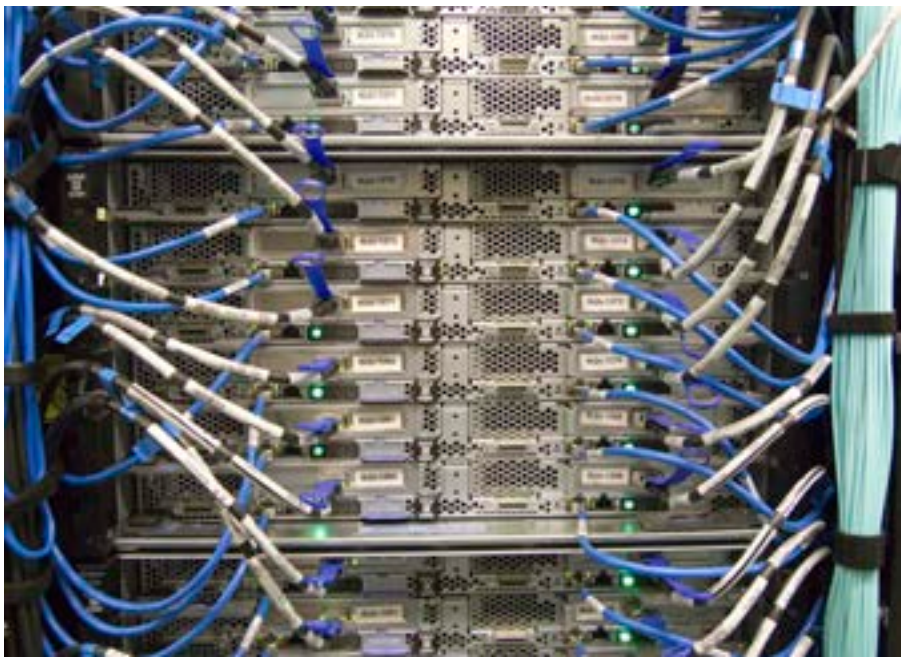
Facebook continued from page 07

cohesive group and had a very close-knit team. Most of the people I hired with around 2002 were still at Finisar when I left in 2014, and many remain there now."

From Finisar to Facebook

Next up was the move to Facebook, to lead optical technology strategy in the role of sourcing manager. In her own words, this wasn't an obvious move, but Schmidtke wanted to make an impact, and Facebook ticked the right boxes.

"I realized I could have more impact on the industry from within Facebook than working for a supplier, even the world's number-one supplier of optical transceivers," she says. "Finisar was trying to guess what customers were going to buy next, and then make it, but at Facebook I work out what technology we need next – and then try to get the supply base to do that."



Facebook's data centers face the challenge of handling ever-growing demand for bandwidth. A key question now is which optical technology platform to deploy as augmented and virtual reality applications apply an additional strain on capacity. Photo: Facebook.

Schmidtke arrived at Facebook just as the social media giant was starting to roll out its next-generation "fabric" data center architecture.

Up to this point, Facebook's data centers had been built using a cluster architecture, in which hundreds of server cabinets and top-of-rack switches were aggregated on a set of massive cluster switches. But to accommodate its exponentially growing machine-to-machine traffic, the company was moving from this hierarchical system of clusters to a more homogeneous, building-wide, fabric network topology. This architecture consists of many more 'micro-clusters' of servers and switches, and, crucially, is scalable to 100 Gb/s and beyond.

As part of this, Schmidtke was responsible for deploying 100G optical links to connect the switch fabric at ever higher data rates. She made the bold decision to abandon multi-mode fiber, which suffers dispersion and signal losses at data rates beyond 40 Gb/s, and embrace single-mode fiber.

> "Milton Chang had such energy, enthusiasm and passion for entrepreneurship that I instantly caught the bug."

"Many people were still pushing for multi-mode optics as it was cheaper, but I could see that the higher price of single-mode optics was more to do with the way the parts had been specified for telecommunications markets, what the yield was, and also the [relatively low] manufacturing volumes," she points out. "So we altered the specifications to fit our data center requirements, including reducing the temperature range and the link budget, and then by driving Facebook volumes on this platform, brought the price down really quickly."

AR/VR challenge

Clearly Schmidtke has already made a significant impact at Facebook and beyond. When asked why she thinks she was employed by the social media giant, her answer is straightforward; the organization needed to make a decision on what optics to deploy next.

"Back then there weren't many people at Facebook that knew about photonics and they didn't have an expert to help them make that decision; so that's why I was brought in," she says. "I understood this kind of optoelectronics and the market, and knew that solutions are sometimes presented to maintain a market niche for a type of product, rather than what the technology can actually do. I could cut through this and find the optimum solution for Facebook, which wasn't necessarily what the supply chain wanted to sell."

So where next for Facebook and optoelectronics? According to Schmidtke, rolling out infrastructure to accommodate the company's ever-growing data traffic will continue. The advent of video sharing was a particular challenge, and now the prospect of using massive augmented and virtual reality (AR/VR) video files is set to bring another huge leap in scale.

But for the Facebook technologist, the future is integration. "This isn't just putting together the functions that we use today, but it's putting optics together and integrating these with other functions," she says. "Integrating the optics with the switch is one example; it's going to be a while before this happens but that's certainly moving in."

Schmidtke highlights how Facebook is technology-agnostic and won't be drawn on which optical innovations will play a role in the future – although silicon photonics is clearly a compelling candidate. "There are pros and cons with all technologies, even silicon photonics, which right now has a higher loss penalty compared to other technologies," she says. "But we really are agnostic, as we can use any of these technologies."

REBECCA POOL

Quantum race intensifies amid global competition

With Europe's ten-year flagship research program now officially under way, and plans for a similar US effort passed by Congress, the global race to develop quantum technology has moved up a gear.

As one of the key technologies underpinning quantum coherence – what Einstein called "spooky action at a distance" – photonics is enabling a potentially vast new set of future applications. Around the world, and with ever greater financial support, researchers are working to move those technologies out of the laboratory and into truly commercial settings like encrypted telecommunications networks, high-precision navigation, and even construction sites.

Some suppliers of lasers and other photonic components have already benefitted greatly from the more science-led efforts. But that market will be small-fry compared with the anticipated future opportunity, and in recognition of recent developments in the US this year's Photonics West features a panel session dedicated to the topic.

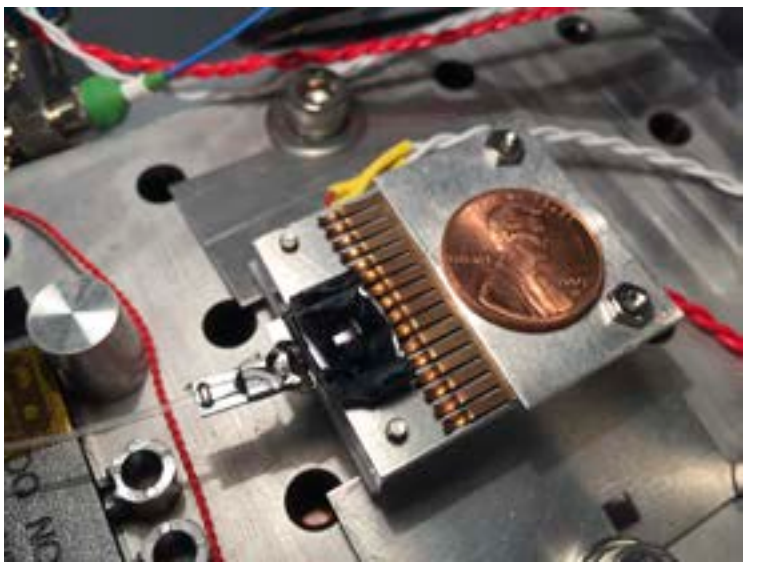
In a rare recent example of bipartisan action, last summer the US House of Representatives unanimously approved plans for a decadal investment intended to help create a domestic "quantum industry." Just before the end of 2018 and the subsequent political impasse, the Senate passed the National Quantum Initiative (NQI) Act. SPIE, The Optical Society, and the National Photonics Initiative all applauded that action immediately, with SPIE's CEO Kent Rochford saying: "The passage of this landmark bill delivers the exciting promise of a future-focused, technology-smart world. The bill establishes the collaborative framework that is needed to produce research breakthroughs that will ultimately lead to fully enabled quantum applications."

But even before the NQI legislation was signed into law, the wheels were in motion. The establishment of the Quantum Economic Development Consortium (QED-C) – its mission to "help accelerate the quantum industry by fostering a robust supply chain" – was already being overseen by the US National Institute of Standards and Technology (NIST) and the independent, non-profit research laboratory SRI International.

Joseph Broz, VP of SRI's Advanced Technology and Systems Division (ATSD), is moderating Wednesday lunchtime's panel session on the quantum topic at Photonics West, focusing on the enabling photonics technologies that will underpin the emerging quantum industry.

According to an October 2018 presentation for NIST's Visiting Committee on Advanced Technology (VCAT), SRI's plans to establish the QED-C will target technology readiness levels (TRLs) 3-5, from first-of-a-kind device prototypes through to efficient purpose-designed components and subsystems.

One of the key elements of that will be to highlight use cases and grand challenges to help accelerate development efforts. One possible idea for such a grand challenge is to build a prototype "few-node" quantum network incorporating devices like quantum repeaters, memories, and processors.



This NIST-developed chip squeezes a tiny cloud of atoms and structures for guiding light waves into an area of less than a single square centimeter. The square window seen on top of the chip here is a vapor cell containing the atom cloud, and is surrounded by black epoxy holding a fiber-optic array. Photo: Matthew Hummon/NIST.

Noting the level of fragmentation in the nascent quantum industry in the US, a key goal for the QED-C will be to foster effective industry collaboration and coordination, and build a stronger supply chain – of which photonics technologies will be a critical element.

A proposed organizational structure for the QED-C includes a technical advisory council with the job of identifying technical gaps and defining enabling technologies, alongside a governing board comprising three representatives of large industrial members, two SMEs, and two federal partners. As of October, 25 companies had signed letters of intent – ranging from major players like Google, IBM, Intel, Boeing, AT&T, and GE, to Photonics West exhibitor Toptica.

Global efforts

The global investment in quantum technology research and development is partly a response to the strides that have already been made in China. As well as establishing the world's first quantum-encrypted trans-continental satellite link, it is reported to be spending heavily on a huge research center devoted to quantum computing. The prospect of one country establishing a competitive advantage in computing and encryption can clearly be

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read as motivating the recent spending decisions elsewhere.

One of those locations is Europe, where a €1 billion, ten-year research program is now officially under way. In a blog post late last year Roberto Viola, director of the European Commission's DG Connect section (the part of the commission responsible for managing its digital agenda), wrote that the flagship program showed how Europe was "serious about turning its world-leading research into practical applications."

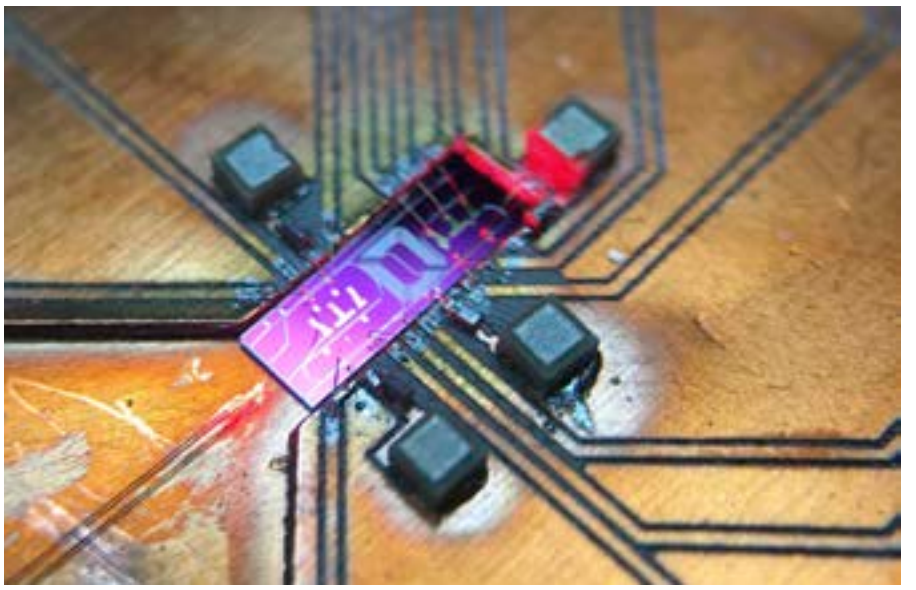
It's not quite clear that this was the message received by those applying for funding under the new scheme, however. At the program's official launch just a few weeks earlier, in the sumptuous surroundings of the Hofburg Palace in Vienna, it was revealed that of 90 proposals made under the "fundamental science" stream of funding, only seven were successful. In contrast, and seemingly underlining the applied focus, four out of ten proposals received under the "quantum communication" pillar won support.

According to reports at the time, that stark disparity in success rates manifested itself with some grumbles in Vienna. After nearly two decades supporting more fundamental quantum research – at a cost of €550 million, according to Viola's post – perhaps the EC's message about a new direction of travel had not been made sufficiently evident.

But Viola himself seems clear enough in stating the flagship project's aims. "Now we are taking quantum research to another level," he wrote in his post. "The focus is very much on practical applications of quantum technologies, with more than a third of participants coming from industry, half of which are SMEs."

As in the US, Viola described the need for Europe to become home to a world-class quantum *industry*, to make the fullest use of quantum technologies, accelerate their development, and to bring them to the market.

"With investment of €1 billion over a decade, the initiative will turn Europe's already excellent quantum research results into real market leadership," he stated. "Quantum is no longer a curiosity; it is becoming mainstream. There are many practical applications of quantum technology, which could eventually replace many of the current technologies used in everyday life."



The UK-based startup KETS Quantum Security, a spin-out from the University of Bristol, won venture backing to support its development of chip-scale quantum key distribution (QKD) hardware in December 2018. Photo: KETS Quantum Security.

Probably the best-known quantum applications right now are atomic clocks, already used in time standards and high-precision navigation systems. But Viola says that the latest advances in quantum technologies will open the door to miniaturized and ultra-precise clocks with a multitude of uses including smart energy grids, and time-stamping of financial transactions.

Another area where quantum technologies will play a major role in the future is in communications. Viola describes data as the "lifeblood" of the European Union's digital economy, and that ensuring it is safe and secure is vital. "Using quantum technologies will mean more secure telecommunication networks, ensuring the long-term secrecy of our digital data," he wrote.

And after spending more than half a billion euros on the more fundamental work, the plan now is to exploit quantum phenomena in computing and simulation, metrology, sensing, and communications. "If Europe truly wants to lead this technological revolution, we must set common objectives and coordinate our efforts," stated Viola. "The flagship initiative is the first example of a truly coherent pan-European strategy for quantum technologies."

UK showcase

Those envisaged areas of application align strongly with the UK's standalone effort, whose second major tranche of funding was confirmed in the UK government's November 2018 budget statement. With £315 million to support developments over the next five years, the UK's *per capita* spending on quantum technologies is among the highest globally, and following the initial five-year developmental period the focus is now very much on commercial activity.

At the fourth UK Quantum Technology Showcase, held in Westminster, London, just before the budget announcement, around 800 attendees were able to view some of the latest prototype equipment in action. With the UK's scheme now looking to raise the TRL level further, four new efforts were announced. Two of those projects are devoted to quantum key distribution (QKD) for secure communications, a third will develop a gravity "imager" for use in construction, and a fourth is focused on miniature atomic clocks. Crucially, the expectation is to realize full working prototype systems within the 29-month duration of these projects.

That commercial focus is equally evident in the latest report on quantum activity from the House of Commons Select Committee on Science and Technology. It recommended establishing a new executive board in early 2019 to oversee the second phase of the national quantum effort. "[The board] should have a clearly

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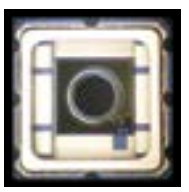

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Quantum race

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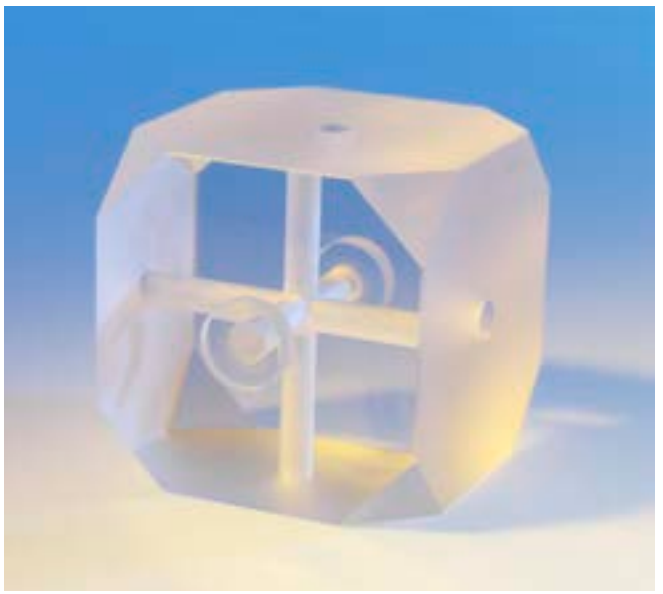
defined mission statement and be held accountable for delivering on it," wrote the Members of Parliament on the committee.

It's clear that this is not just about funding more science – even though that element is still regarded as important. "The mission statement should include an overall aim to support the development of a UK quantum technologies industry that delivers the maximum economic, national security, and societal benefit for the UK public as a whole," states the report.

One of the first jobs for a new executive board will be to produce a detailed roadmap, or series of roadmaps, detailing the future markets that quantum technologies in the UK would be expected to serve. The committee wants that roadmap to extend 20 years into the future, with annual updates planned. It should be publicly available, and identify future markets and any obstacles to commercialization of quantum technologies in the UK, as well as a strategy to overcome them. "The strategy should be published and updated alongside the roadmap and include clear, measurable milestones, to be reviewed annually."



Engineers at the UK's National Physical Laboratory (NPL) have developed this optical stabilizing reference cavity cube. Measuring 5 cm along each side, it is made from low-expansion glass and has mirrors placed precisely at each end of the drilled cavity for use in optical atomic clocks. Photo: NPL.

Another outcome should be the establishment of dedicated, application-focused "innovation centers", to sit alongside the four established, but more science-focused, quantum hubs that were set up in the first phase of the UK effort.

Modelled on the UK's existing "Catapult" centers for applied technologies, the new innovation centers would be expected to provide access to facilities for developing, manufacturing, testing and validating quantum prototypes, and should become focal points around which collaboration and supply chains can consolidate. This suggests real physical centers rather than "virtual networks", with a focus on the development of commercial products for specific market sectors – rather than simply reflecting the different types of quantum technologies under development.

What might those commercial products be? The Photonics West exhibitor M-Squared Lasers, which has been heavily involved in the UK program, gave a clear indication in London, where it unveiled its new quantum accelerometer, developed with researchers at Imperial College, London.

The current system is designed for navigation of large vehicles, but could also aid the search for dark energy and gravitational waves, which the Imperial team is also working on. Ed Hinds, a professor at Imperial's Centre for Cold Matter, said: "I think it's tremendously exciting that this quantum technology is now moving out of the basic science lab and being applied to problems in the wider world, all from the fantastic sensitivity and reliability that you can only get from these quantum systems."

At the London showcase a panel session chaired by M-Squared CEO Graeme Malcolm was asked to estimate when commercial quantum systems would be available to buy as products. As Andrew Shields from Toshiba Research Europe noted, that's already possible now – though only if you are prepared to spend in the region of £100,000 on a QKD encryption system. But Shields predicted that with the availability of mass-produced photonic integrated circuits (PICs), that cost ought to fall dramatically.

The same panel session heard that a UK project to develop gravity sensors based on laser-cooled atoms could result in a real-world product in just a couple of years. Engineering consultancy RSK is coordinating the "Gravity Pioneer" effort, which will use photonics technology from the likes of UnikLasers, OptoCap, and Teledyne e2v to image beneath high-value construction sites, to avoid hitting otherwise invisible buried pipes, or other hazards. It may seem a rather prosaic application – but as George Tuckwell, RSK's director of geoscience and engineering, noted, the sheer scale of the construction industry in the UK ought to realize a substantial market opportunity. "As soon as we have something that works, we can sell it," he said, adding that some of the prototype developments shown in London were getting close to what he called the "interesting" performance levels required to capture new kinds of data.

For each of the panellists involved, proof of success would mean seeing real systems at future editions of the UK's quantum showcase event – something that is not yet evident, M-Squared's accelerometer aside.

Shortly after the London showcase one of its exhibitors provided a different signal indicating commercial progress. KETS Quantum Security, a University of Bristol spin-out working on chip-scale QKD hardware and involved in one of the newly funded prototyping projects, revealed that it had attracted seed investment from Paris-based specialist venture firm Quantonation. The investor, which describes itself as dedicated to supporting "deep physics" and quantum technologies, previously invested in Bordeaux-based Photonics West exhibitor and Prism Award finalist Spark Lasers.

Commenting on the KETS funding, Quantonation's CEO Christophe Jurczak added: "After years of ground-breaking research, now is the time for the unique properties of quantum physics to be harnessed and exploited."

The global competition doesn't stop there. With Germany investing in a large number of projects to develop quantum repeaters for extending the reach of QKD, plus substantial efforts also under way in Canada and The Netherlands, the overall message is clear: the global quantum race is on.

MIKE HATCHER

NEW BUSINESS OPPORTUNITIES AND THE QED-C: PHOTONICS WEST PANEL SESSION

Led by a group of visionaries, the National Quantum Initiative (NQI) ensures that the US remains a global leader in quantum research and development. The Quantum Economic Development Consortium (QED-C) is a public-private partnership supported by NIST to inform the NQI with respect to private-sector needs, and to facilitate a robust commercial quantum ecosystem across the quantum computing, communications, and sensing domains.

The QED-C's mandate is to coordinate industry, academia, and the US government in enabling the future quantum economy and its supply chain. During a special Photonics West session today Joseph Broz, executive director and chair of the QED-C, will provide an overview of the consortium, its scope and goals, and will update the audience on the status of its technical sub-committees.

Following the QED-C briefing, Broz will moderate a panel discussion on key photonics technologies that are enabling the emerging quantum industry. There are still many gaps regarding the array of photonic technologies available to serve its needs, and hence many new business opportunities for manufacturers and vendors.

The five industry panelists assembled (representing Honeywell, Raytheon, Photodigm, Toptica, and Corning) are experts in sources, quantum optics, nanophotonics, integrated photonics, and the application of photonics to quantum information and sensing systems. They will discuss the critical role that the photonics industry will play in the emerging quantum sector, including examples such as compact, reliable and tunable lasers; critical fiber-optic components outside the telecom band; optical waveguide phase modulators; amplitude modulators; frequency doublers; frequency combs; and sum/difference generation with extended wavelength ranges for neutral atom experiments or ion trap quantum devices. The panel will also touch on the need for dedicated fabrication facilities for ultra-low-loss photonic devices, as well as standardized packaging and interfaces.

Industry end-users, manufacturers, vendors, and system integrators will all find the emerging quantum industry an increasingly important driver of revenue growth. Gaining an early understanding of the unmet needs in this industry will benefit attendees in the development of their strategic plans, and orient the audience to the important role photonic devices are likely to play in the emerging quantum economy.

The QED-C Consortium and Enabling Photonics Technologies for the Emerging Quantum Industry panel session takes place Wednesday at 1-2.30pm in Room 21, North Exhibit Level.

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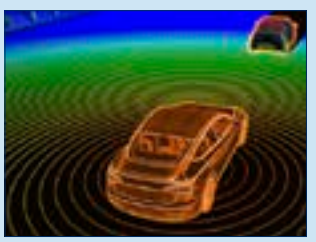

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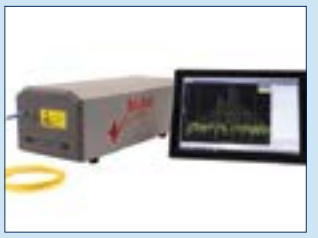

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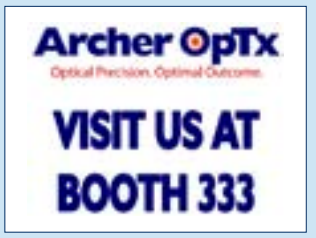

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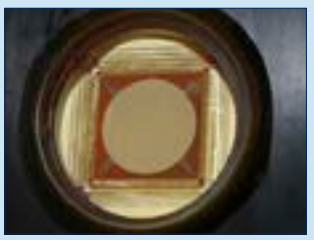

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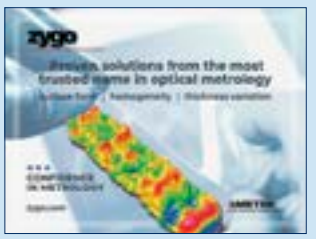

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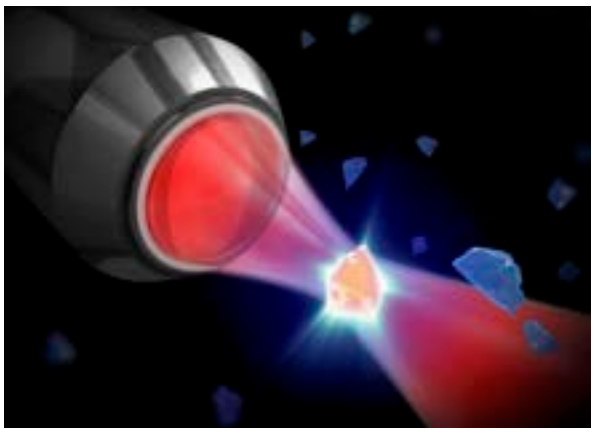
Photonics ecosystem takes Nobel-winning technologies to market

Optical tweezers and high-power lasers that rely on advances by the 2018 laureates feature widely at the Photonics West exhibition.

When revealing the 2018 Nobel Prize in Physics winners last October, the Royal Swedish Academy of Sciences announced, "This year's prize is about tools made from light." Awarded to three laser physicists, the decision marked the second consecutive year that photonics-related work was recognized by the Nobel committee, after the 2017 Nobel went to three of the key scientists involved in the first direct observation of gravitational waves.

Arthur Ashkin, a former Bell Laboratories researcher, was honored with half of the 2018 prize, for his work on optical tweezers and their application to biological systems, with Gérard Mourou of École Polytechnique in France and Donna Strickland from the University of Waterloo, Canada, sharing the other half for their method of generating high-intensity, ultrashort laser pulses.



An artist's conception of cavity optomechanical cooling of a silica nanocrystal, using a non-planar ring oscillator (NPRO) in the form of Coherent's "Mephisto" laser. Credit: Peter Barker, UCL.

Following the news, SPIE's CEO Kent Rochford noted that, since the invention of the laser, there were now a dozen physics Nobel prizes that either advanced, or were enabled by, optics and photonics. But that's not where the story ends: those light-based technologies are continually being developed and improved to enable and enhance life. Photonics West features components, devices, and systems based on Nobel-winning technologies for applications across biomedical diagnostics and therapies, nanophotonics, optical communications, and laser manufacturing. Many of the companies at both the main Photonics West exhibition and the weekend's BiOS Expo already sell products enabled by the 2018 winners, with optical tweezers becoming a critical technology for research in fundamental physics, biological studies, and cold-atom trapping.

The virtuous cycle

"You can think of photonics as a large ecosystem where today's bright ideas beget tomorrow's great ideas, and then the pattern repeats itself in a cycle," says Alex Cable, CEO and founder of Photonics West exhibitor Thorlabs. "Virtuous cycle," Cable explains, refers to the connection between basic research and technology development. Research gives high-level understanding of new ideas – which technologists then use to improve the tools that help push the researchers onward to their next invention. "Thorlabs is certainly part of this cycle as we contribute to the improved instruments and related technologies that are integral to driving the cycle," says Cable.

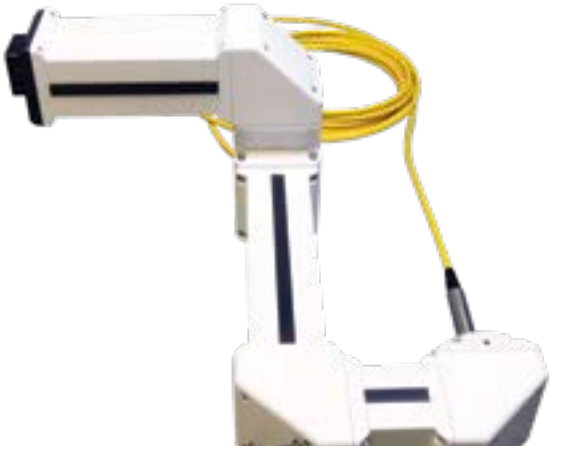
In the mid- to late-1980s, Cable worked with Ashkin and other collaborators at Bell Laboratories on the project that ultimately earned Steven Chu, Claude Cohen-Tannoudji, and William Phillips the 1997 Nobel Prize in Physics for their development of methods to cool and trap atoms with laser light. In fact, the work with Ashkin and colleagues at Bell inspired Cable to start Thorlabs. The company, named after his golden retriever, seeks to increase the speed of scientific discovery. "We're having a profound effect on society," notes Cable, "both indirectly through the technological advances enabled by the products we sell, as well as directly through our own internally sponsored research."

Published in 1986, Ashkin's seminal paper, "Observation of a single-beam gradient force optical trap for dielectric particles," outlined a technique for trapping micrometer-sized dielectric particles using a focused laser beam – an approach now widely known as "optical tweezers."

"Without the early work of Ashkin, we would never have been able to develop the systems we have today," says Mike Elliot, chairman of Elliot Scientific, another exhibitor at the Moscone Center this week.

He explains that the first optical trapping systems were single-beam, open-architecture laboratory experiments. Researchers later developed more complex single, double, and multiple trap systems. In 2003, Elliot Scientific and Kishan Dholakia from St Andrews University in the UK started a collaboration to develop "off the shelf" fully integrated optical tweezers – meaning that for the first time it did not require a PhD researcher to build and operate such a system. Elliot Scientific and Dholakia developed a unit that worked straight out of the box, rather than taking months to build and install.

They started with single-trap units, moving to dual-beam traps, and later computer-controlled multiple trap systems including force measurement and particle trapping. These integrated microscope systems comprise lasers, an imaging system, optional force measurement, specialist software, and superior opto-mechanical design. They are designed to allow biologists and microscopy researchers to start their relevant optical trapping experiments on day one.



Part of Elliot Scientific's optical tweezer system, this add-on arm can be retrofitted to an existing microscope. Photo: Elliot Scientific.

"Ashkin's work revolutionized single-molecule biophysics and new studies of Brownian dynamics, statistical mechanics, cell-cell interactions, and the use of optical tweezers with other forms of microscopy such as confocal and Raman," says Dholakia. "In single-molecule biophysics, optical tweezers act as a calibrated force transducer and a miscible version of a Hookean spring. They can be used to look at the actin-myosin system, for unravelling DNA, and observing kinesin 'walking' on microtubules.

"For example, transcription is the initial step for the expression of genetic information, and is performed by macromolecular enzymes called RNA polymerases. [Optical] tweezers have helped study this fundamental tenet of biology in ways never before imagined."

Into the real world

Holographic optical tweezers take things further, using a liquid crystal spatial light modulator (SLM) to create a volume of optical focal points that can be used to manipulate the position of objects in three dimensions. Objects with a higher refractive index than the surrounding media are pulled toward the center of the focal points, enabling manipulation of objects by moving the position of the focal points.

In 1979, Tom Baur, then a researcher at the National Center for Atmospheric Research, launched Meadowlark Optics – initially as an after-hours venture in a spare bedroom of his Colorado home. Meadowlark has since become known for its innovative, ultra-high-quality polarization optics, offering a range of products for customers interested in optical tweezing.

"Meadowlark Optics has been offering SLMs for phase control for over 25 years," says Baur. "We are pleased to see the broad adoption of this liquid crystal technology for optical tweezing, and to contribute to the ease of use of this tool in microscopy and elsewhere."

For customers interested in a turnkey solution, Meadowlark offers the "CUBE", a compact holographic optical tweezing microscope developed by Miles Padgett and his team at the University of Glasgow and transferred to Meadowlark for commercialization.

"Working with the Meadowlark team was a fantastic experience for us and really gave us an insight into how new products make it from the university into the real world," says Padgett. "Their expertise in SLMs is what makes the CUBE possible." He adds that optical tweezers brought a revolution to both the physical and life sciences, and was glad to see the technology recognized with the "long overdue" award of the Nobel to Ashkin.

Pushing the limits

Mourou and Strickland's work helped pioneer the field of ultrafast lasers and their applications. They developed chirped-pulse amplification (CPA), which achieves very high optical powers when an ultrashort laser pulse is stretched out temporally and spectrally prior to amplification. CPA opened a whole new branch of science called relativistic optics, one of the most

continued on page 23

Nobel winners continued from page 21

active fields in physics today.

"The work of Mourou and Strickland is geared towards generating high-power lasers for a variety of applications," says Dholakia. "The method of stretching and then re-amplifying pulses is elegant, and has widespread uses such as laser machining and corrective laser eye surgery."

Janis Valdmanis, general manager at Thorlabs' Ann Arbor division, was part of Mourou's team of graduate students – which included Strickland – at the University of Rochester in the early 1980s. While attending the 2018 Nobel awards ceremony in Stockholm, he was approached by Allen Weeks, director general of Europe's Extreme Light Infrastructure (ELI) project, who commented on the success and camaraderie of Mourou's student team. "ELI is now the world's largest set of lasers that use the CPA technique," says Valdmanis. "These high-intensity lasers are pushing the limits for both lasers and the high-field science they enable. None of this would have been possible without CPA."

"We've taken the Nobel-winning technologies, optical tweezers and CPA, worked to commercialize them and drive their adoption in the marketplace," says Herman Chui, senior director of product marketing at Spectra-Physics, the world's first laser company and now part of MKS Instruments. "CPA has interesting uses in medical applications, micro-machining, and scientific research. For those applications, we'll be showing the latest innovations in ultrashort pulse lasers based on CPA technology, including high-power femtosecond lasers for high-throughput, highest quality micro-machining."

Particle-trapping mechanisms need a stable and narrow-linewidth laser that provides tight control of the output frequency. The most stable type of commercial continuous-wave source is based on the non-planar ring oscillator design, and one example is the Mephisto laser from exhibitor Coherent that acts as the master laser oscillator in all today's gravitational wave interferometers. Amplified versions of this 1064 nm source are widely used for trapping cold atoms in optical dipole or optical lattice geometries.

A team of researchers led by Peter Barker at University College, London is using a Mephisto laser in novel techniques for trapping and cooling nanoparticles. This includes using optical tweezers, but also a special optical cavity. Barker explains: "This is called levitated cavity optomechanics, where our high-finesse cavity is tuned so that blue-shifted scattered light escapes and takes away mechanical energy, but red-shifted light does not. Repeated scattering of the 1064 nm non-resonant light in this way systematically drains center-of-mass kinetic energy from the particle. So far, we've reached the millikelvin regime, and we are hoping to reach 10 μK soon."

As optics and photonics technologies continue to develop and advance, the Photonics West Exhibition and BiOS Expo will continue to showcase the newest tools, applications, and innovations within the laser and photonics industry.

KAREN THOMAS

Meadowlark Optics' "CUBE" is a compact holographic optical tweezing microscope, initially developed at the University of Glasgow, UK. Photo: Meadowlark Optics.

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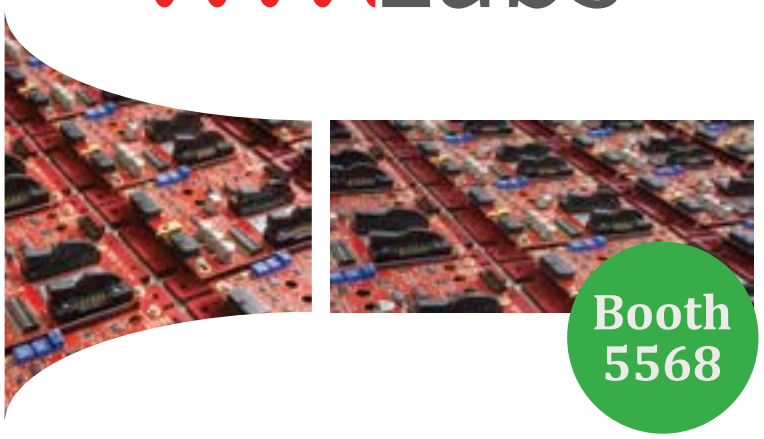

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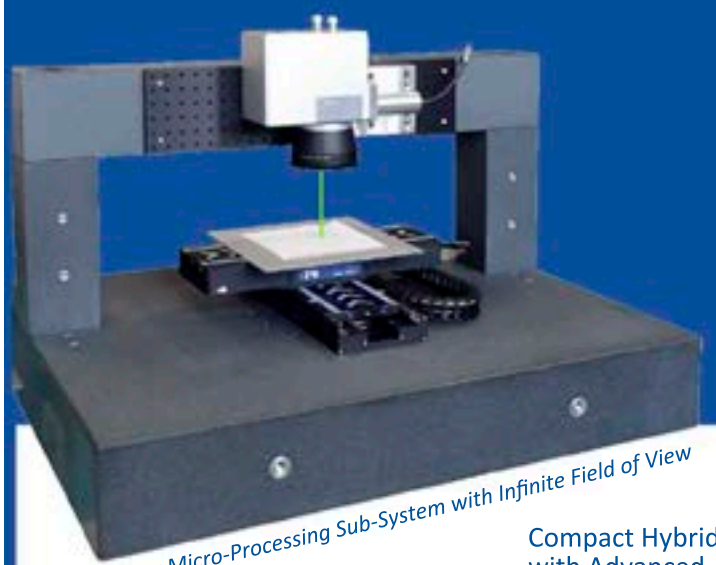

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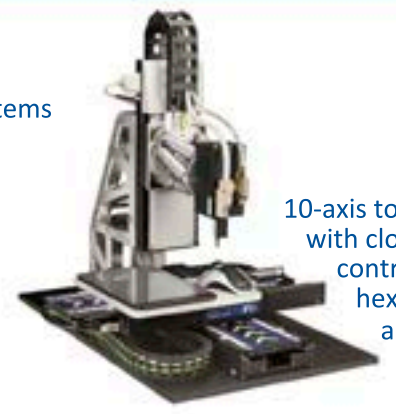

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US clusters thrive on regional expertise

From Arizona to New York, and Florida to Colorado, photonics communities continue to grow in influence across the country.

In 1992, *Business Week* magazine bestowed the name "Optics Valley" on Tucson, Arizona, recognizing the area's growing optics industry with a nod to Silicon Valley. And the moniker has stuck, serving as the long-time nickname for the Arizona Optics Industry Association. In 2016, when the organization became part of the Arizona Technology Council, it adopted Optics Valley as its official name.

Optics Valley is one of the oldest such groupings scattered across the US. These clusters are regional organizations that aim to promote photonics and foster partnerships between industry, academia, research labs, and other institutions. Members include companies and universities, and dozens of similar efforts can be found in Canada, Europe, and the Asia-Pacific region. The clusters' functions and goals to promote businesses and innovation are similar, yet they maintain some of their own characteristics representative of their local industries, resources, and environment.

In Tucson, the engine behind Optics Valley is the College of Optical Sciences at the University of Arizona, one of the pre-eminent optical science institutions in the world, says Jack Schumann, the cluster's co-chair. As a hub of education and research, the college trains a skilled workforce and helps develop new technology. "We have a lot of inventors," he said. "We foster a lot of startup companies."

Perhaps the most visible part of Arizona's optics industry is astronomy, as the state boasts the most astronomical telescopes in the country. The region is seeing growth in companies developing autonomous vehicles, camera technology, and lasers, Schumann says. Just prior to Photonics West, Optics Valley and the BIO5 Institute at the University of Arizona hosted an Arizona Photonics Day – actually a two-day event to further strengthen relationships between industry and academia.

Fiber lasers in Florida

Like Optics Valley, the Florida Photonics Cluster is centered around a highly regarded educational institution: CREOL, the College of Optics and Photonics at the University of Central Florida (UCF), the largest university in the nation. "We have a very strong educational pipeline that prepares good photonics specialists, and it starts from magnet school programs in high schools," said cluster president Alexei Glebov.

The organization has helped build UCF's Business Incubation Program, a pipeline to turn technology developed at the university into startup companies. One of the program's success stories is OptiGrate, where Glebov is CEO and president, a company that in 2017 was acquired by the fiber laser firm (and major Photonics West exhibitor) IPG Photonics.

When it comes to photonics, the region is booming. "Florida is doing pretty good, that's for sure," Glebov said. What's driving the growth, he thinks, is the constant supply of an educated workforce from UCF, plus state and local government incentives for businesses, relatively inexpensive land, and, perhaps unsurprisingly, the warm weather.

Lidar firm Luminar Technologies recently set up R&D and manufacturing operations in central Florida. Photo: Luminar Technologies.

The region is now becoming a hub for smart optical sensors, Glebov added. Recently it became home to the "BRIDG" research facility for making and developing such devices. And Luminar Technologies, which builds lidar sensors for self-driving cars, has opened a manufacturing and R&D facility in Orlando.

The defense industry is also flourishing. L3 Technologies and Harris, who have just joined forces through the largest-ever merger in the US defense industry, are headquartered in Melbourne.

New York: nurturing the industry

Also thriving is New York Photonics, whose optics industry even predates the American Civil War – according to Tom Battley, the organization's executive director. He's referring to the time that experts from Europe brought their expertise in glasses and telescopes for the war effort. Since then, institutions like the University of Rochester and the Rochester Institute of Technology, and companies like Kodak, Xerox, and Bausch and Lomb have helped build a robust community that is now driven by a new generation of startups and companies.

> "We have a very strong educational pipeline that prepares good photonics specialists, and it starts from magnet school programs in high schools."
>
> ALEXEI GLEBOV, CEO, OPTIGRATE

"Everybody takes ownership in nurturing the industry and filling in the gaps," Battley said. "That's what we're really good at. That's why companies like to come here."

The latest highlight is the American Institute for Manufacturing Integrated Photonics (AIM Photonics), the public-private partnership that's leading the nation in developing integrated photonics, Battley said. AIM's test, assembly, and packaging (TAP) facility is now ready to start ramping up production, and a long list of customers is already in the pipeline.

Half of New York Photonics' member companies are involved with the defense industry, he said. But plenty of other fields are growing too, among them laser technology and biomedical research. Vuzix and Six15 Technologies are leading the way in augmented and virtual reality. And in more traditional areas, the likes of Optipro, Optimax, and Rochester Precision Optics are still expanding.

To foster entrepreneurship the state hosts Luminate, the largest optics and photonics startup competition in the world. The final round will take place in June at the Rochester International Jazz Festival, with the winner from the latest cohort of short-listed startups set to win $1 million.

Education at all levels is a priority, too, with SPIE's local student chapter providing outreach in middle schools. Over 200 high school students are taking dual credits in optics at the community college, while for 40 years, Rochester's Monroe Community College has been home to the country's only optical systems design program in a two-year college.

"The community college in Rochester is getting calls from other countries asking if they can hire students," Battley said. The program at Monroe is so successful that others are starting to emulate it.

Colorado's shining stars

In Colorado, Research Electro Optics, now a part of Excelitas Technologies, has helped create a new year-long optics certification program at Front Range Community College, as part of the institution's Center for Integrated Manufacturing.

The rest of Colorado is said to be flourishing too. One of the country's biggest aerospace industries, an educated workforce, a relatively low cost of living, and a good quality of life for those who love the outdoors are all attracting business and driving industry growth, said Damon Lenski, a board member of the Colorado Photonics Industry Association (CPIA). "I hear about it again and again – it's lifestyle."

Thanks to the presence of companies like Seagate, the region is a center for data storage, while many telecommunications companies are headquartered in the state. To promote the biotech industry, the organization is working with the state to fund grants, nurture startups, and support internships, while several federal laboratories are located nearby.

Last fall, CPIA selected scientific instrument maker High Precision Devices as Colorado's "photonics company of the year", with other nominees including Cold Quanta, MBio Diagnostics, and past Luminate winner Double Helix Optics.

"These are great examples of what we consider to be the shining stars in the photonics world," Lenski said.

MARCUS WOO

Medical imaging and artificial intelligence: naturally compatible

Elizabeth Krupinski tells the SPIE Fellow Member Luncheon that machines should do the tedious, monotonous, and time-consuming tasks, so that humans can take healthcare to the next level.

"As an experimental psychologist, I have always been interested in trying to discover why images are viewed and interpreted differently by different people," says Elizabeth Krupinski, professor and vice chair for research in the Department of Radiology and Imaging Sciences at Emory University in Atlanta, Georgia. Her work is designed to better understand the perceptual and cognitive mechanisms underlying the interpretation of medical images. The goal: to improve patient care and outcomes through better training, reduction in errors, and optimization of the reading environment.

Krupinski notes that interpretation in medical imaging is particularly important, since differences in interpretation can lead to errors and directly impact patient care. Throughout her career in radiology, she has conducted numerous studies assessing the impact of how image data are presented to the radiologist, and how the addition or change in data format or content can impact diagnostic efficacy and efficiency. This has included everything from the actual display medium – whether film, monitor, or smart device – to how images are processed, and how "decision-support" outputs are incorporated into the interpretation process. Decision-support tools originally took the form of computer-aided detection and/or diagnosis (CAD) prompts, and that has steadily evolved into artificial intelligence (AI) applications in radiology, says Krupinski.

On Monday this week, Krupinski addressed the SPIE Fellow Member Luncheon with a talk entitled "Medical Imaging: The Need for Human-Artificial Intelligence Synergy." She pointed out how AI is changing the field of medicine, particularly in clinical imaging. Instead of eliminating the role of radiologists, pathologists, and other image-based specialists, Krupinski explained how AI will help increase efficacy and efficiency. However, she warned that optimizing the integration of AI into medical imaging would demand careful consideration of the human user.

With colleagues at Emory, Krupinski is currently working on collaborative research involving imaging sciences, biomedical informatics, and other medical specialties. Projects include not only the more traditional use of AI to detect lesions, and segment and measure images, but also exploring ways to use AI to go beyond detection and provide more diagnostic information by combining imaging with related data from the electronic medical record; addressing workflow issues; analyzing report quality; and many other potential applications. Other image-based specialties such as pathology, dermatology, and ophthalmology are also looking to radiology for guidance in ways to incorporate AI pipelines into their research and clinical workflows.

Elizabeth Krupinski demonstrates the eye-tracking device used in her fatigue studies.

The potential of pigeons

In a 2016 *SPIE Proceedings* article, "The potential of pigeons as surrogate observers in medical image perception studies," Krupinski writes about using pigeon models "as a surrogate for the human observer." Part of her conclusion is: "These early results suggest a novel method or tool that has the potential to help us better understand the mechanisms underlying medical image perception."

Despite the intriguing title, the goal of the study wasn't to use pigeons to diagnose images clinically, but rather to gain an understanding of how visual learning takes place, and which types of visually learned tasks generalize well to some applications, but not to others. Working with the pigeons could also narrow down experimentally the specific types of image manipulations (e.g. compression) that are more or less likely to impact the detection and discrimination performance of humans – so that human resources would be better expended on the most clinically relevant tasks.

Krupinski explains that the insight this study provides to those developing or using AI in medical imaging is two-fold: "On the one hand, it speaks to the fact that each image interpreter – human, computer, or animal – 'sees' the image data in a different way, and thus performs differently at a given task," she says. "Understanding these differences can lead to insights into how we can improve any of these systems, including AI and humans.

"On the other hand, it reinforces the idea that the goal should not be to replicate exactly what the human eye-brain system does, since we are limited in what we see by our own physiology. Pigeons see features in their

continued on page 28

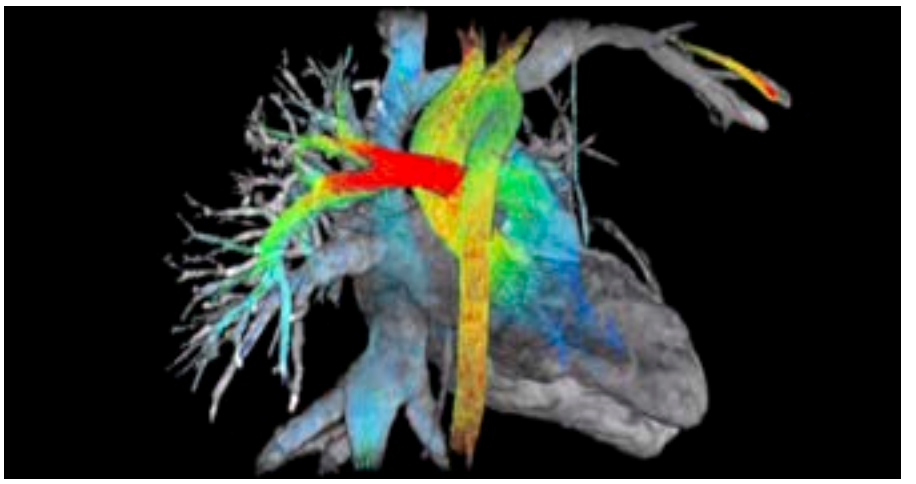
Medical imaging

continued from page 27

environment that humans don't see, and *vice versa*. The same applies to AI."

One aspect of the human user that has influenced Krupinski's work in AI for medical imaging is fatigue. Over the past few years, with colleagues at Emory, the University of Arizona, and the University of Iowa, she has investigated the role of fatigue and its impact on radiologists and radiology residents.

A typical workday for a radiologist can be 10-12 hours long, and often those hours are spent poring over images at a workstation. Tiredness and difficulty in focusing can affect diagnostic accuracy. Krupinski and her co-workers have found evidence that visual search patterns are impacted by fatigue, potentially reducing search efficiency and extending the time it takes to interpret individual cases. "All of this evidence points towards one inescapable conclusion: radiologists, especially residents, are often experiencing significant fatigue, reducing their ability to focus, and hence their diagnostic accuracy," she says.



Data-driven medicine: blood flow in the heart, captured using a combination of magnetic resonance imaging and artificial intelligence software. Image: GE/Arterys.

Krupinski also argues that CAD and other analysis tools can assist radiologists, by optimizing images and detecting features that the radiologist may be less sensitive to, or even unable to perceive in the same way that a computer can. She adds that such tools need to be properly integrated into the clinical reading workflow, and not be an impediment to efficiency and accuracy.

Bright future, with a caveat

Krupinski notes that although the future of technologies like AI, AR/VR, and robotics in medicine is bright, the physician is still the ultimate decision-maker, and will remain so for the foreseeable future. "AI will be making some decisions and enabling radiologists' decision-making as well," she predicts. "One of the reasons for variability in radiologists' interpretation of images is the huge variability in the images themselves – both in terms of 'normal' features and lesions."

> "Pigeons see features in their environment that humans don't see, and *vice versa*. The same applies to AI."
>
> ELIZABETH KRUPINSKI, EMORY UNIVERSITY.

In her opinion, this is also why AI will never be 100% accurate either. The medical imaging community should be proactive in deciding which tasks (and why) are most appropriate for AI to carry out, and which tasks are best suited to the human radiologist, assisted by additional information/intelligence, either human or artificial.

When asked if she thinks the issue of doctors becoming isolated from patients will be exacerbated by the use of AI, her answer is "not at all."

"I think AI opens paths for better and more informative communication between physicians and patients," says Krupinski. "If AI can relieve clinicians of redundant, time-consuming tasks (such as measuring size changes in lesions over time with treatment), that are readily and often more accurately and consistently done by computers, clinicians will have more time to dedicate to the actual decision-making process and to interact with patients."

Last year, in a live Point/Counterpoint debate in the AAPM Virtual Library entitled "Artificial Intelligence will soon change the landscape of medical physics research and practice," Krupinski seems to take the opposing side of the for-or-against AI discussion. She noted that while AI will definitely revolutionize healthcare and thereby medical physics, it's imperative to understand that it will not (or perhaps should not) do what many are afraid it will – take over the roles and responsibilities of the doctor, radiologist, or other medical professionals.

A key role for many medical professionals is education and training of junior-level healthcare colleagues. Krupinski points out that while AI can certainly be used to develop and provide a variety of training tools, it cannot sit down with a trainee, listen to their problems, explain subtle concepts and the "art" of medical physics, or provide them with the mentorship and guidance and support required to foster their success as independent professionals.

"Deep learning and AI are still a long way from being creative and this has been the case from the very beginning of AI implementations," said Krupinski in the debate. "As [professor of cognitive science at the University of Sussex, UK] Margarita Boden pointed out in 1998, the two major bottlenecks to AI creativity are domain expertise and evaluation of results (i.e. critical judgment of one's own original ideas)."

Krupinski notes that a significant portion of a medical professional's job – whether solving a complicated clinical problem, developing a new line of research investigation, or communicating and collaborating with colleagues and patients – involves creativity and ingenuity. So far, AI has not been able to master these activities and display true creativity.

"Let the computers take over the tedious, monotonous, and time-consuming tasks," suggests Krupinski. "Humans will have more time to create, discover, and lead healthcare to the next level."

KAREN THOMAS

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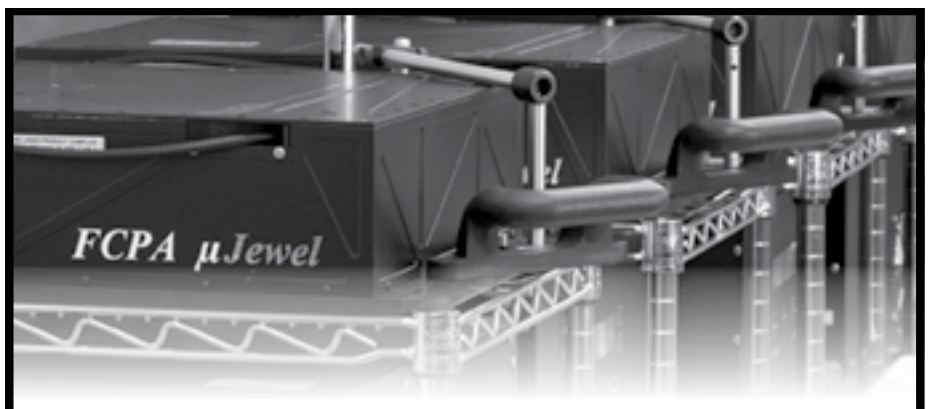

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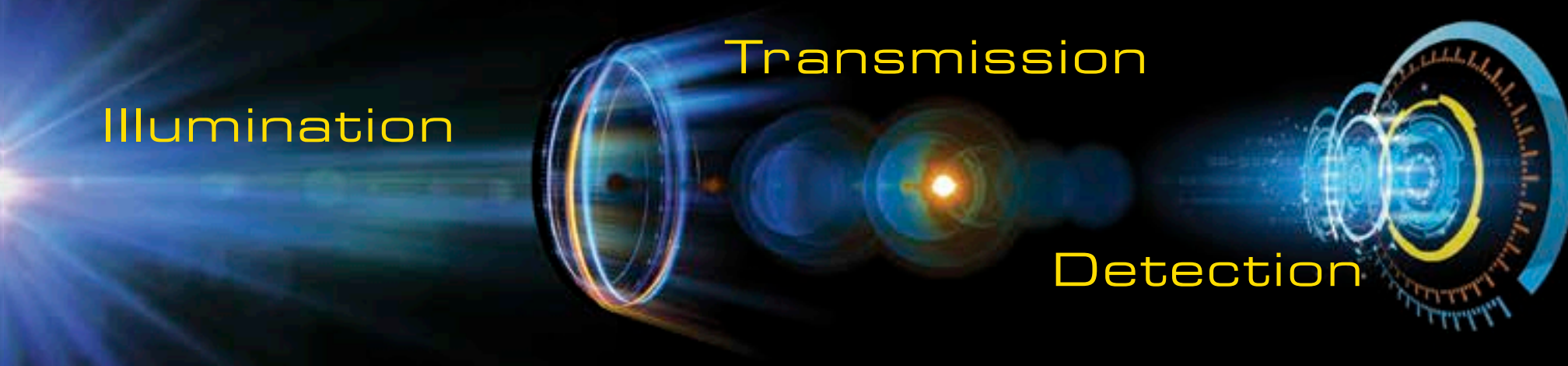

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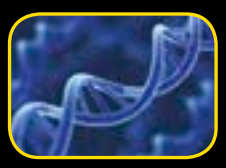
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OPTO Plenary likes Facebook's Schmidtke ...

Monday's OPTO plenary session highlighted the emerging power of deep learning in microscopy and imaging, the advent and continued promise of photonic crystals, and the need for new photonics technology to handle increasingly large-scale data networks.

For companies like Facebook, which has submarine and long-haul networks, the demand on their data infrastructure is putting stress on available technology. "The amount of data we have at the data center and the speed at which we need to move it around has developed so quickly it's outpaced the rate of innovation in the rest of the market," Katharine Schmidtke, who leads optical technology strategy at Facebook, told the *Show Daily*. (see page 07)

Susumu Noda, Kyoto University. Photo: Adam Resnick

While internet traffic is always growing, machine-to-machine traffic is exploding even faster, due to the need to back up data, and for optimization.

The data centers themselves are enormous, she said. Facebook's Altoona data center in Iowa, for example, is equivalent in size to the Empire State Building on its side. As much optical fiber is inside these centers – tens of thousands of kilometers in total length – as there are outside, connecting the centers.

To handle rising data demand, these hyperscale data centers require new photonic technology, Schmidtke said. For its part, Facebook is trying to influence and inspire what comes next.

There is a particular need to accelerate the rate of data transmission while maintaining power efficiency. For example, data centers will need integrated switch ASICs, the hubs that control the networks connecting the servers. Such devices now consist of separate modules, but if they were integrated into a co-packaged unit, they would allow for higher data rates and save power.

Another need is to incorporate more automation in manufacturing. She envisions that one day, photonic circuits can be printed using methods similar to CMOS technology.

Reviewing 20 years of development, Susumu Noda of Kyoto University highlighted the promise of photonic crystals, which have potential applications in areas such as quantum information processing, laser technology, and the new field of topological photonics.

"Photonic crystals could be one of the most important materials in the 21st century," Noda told *Show Daily*.

In 1999, Noda and his colleagues used a water fusion technique to develop the first complete 3D photonic crystal that worked in optical wavelengths. By stacking crisscrossing bars of gallium arsenide on top of each other, they built a nanoscale 3D photonic crystal that bottles up photons of a certain frequency – a so-called complete photonic crystal.

In 2000, Noda and colleagues developed the first 2D photonic crystals, thin semiconductor sheets covered with holes. Depending on the hole pattern, the sheets can trap and channel light. A small area without holes can form a nanocavity that traps photons. Such nanocavities can be embedded with quantum dots to serve as quantum bits and a platform for quantum information processing.

Shifting the spacing between the holes by just a few to tens of nanometers prevents these cavities from leaking photons, thus increasing the Q factor by as much as 10 million times, Noda said.

One of the most important applications of photonic crystals is in semiconductor lasers, he said. While their compactness remains an advantage, today's semiconductor laser beams can degrade rapidly, limiting their power output to just a tenth of carbon dioxide, disk, or fiber lasers.

But as Noda has shown, 2D photonic crystals can enable semiconductor lasers that are bright and narrow without the need for collimating lenses. These lasers would be useful for manufacturing and processing materials and for LiDAR technology, which are crucial for technologies like autonomous vehicles.

Using photonic crystals, Noda has also demonstrated how to control thermal emission, converting a broad spectrum into a narrow one without the loss of energy. The researchers can also switch the emission on and off, creating an efficient infrared light source for environmental and biological sensors.

These types of technologies will be essential for a future society in which cyberspace is integrated with physical space, he said.

Katharine Schmidtke, Facebook. Photo: Adam Resnick

Concluding the session was Aydogan Ozcan of the University of California, Los Angeles, who described how deep learning techniques are changing imaging and microscopy.

"Deep learning and neural networks are helping us create new types of imaging and sensing systems that are fundamentally more powerful and work differently from traditional, physics-based solutions," he told *Show Daily*.

The idea is to apply these computational techniques to process the image as it's being taken in real-time. Such techniques, for example, can be used to identify objects immediately, as they are being imaged.

With conventional image-recognition methods, a system takes an image and then processes it after the fact. Ozcan's group has built a device consisting of several layers of polymer wafers that diffract the light coming from an object. Using a so-called diffractive neural network, the system can identify the object – handwritten numbers and clothing, in their experiment – by measuring where most of the light leaves the wafers.

The researchers have also used deep learning techniques to reconstruct holograms out of 2D images – a much faster and powerful process than conventional holographic techniques. They used their method to make holograms of Pap smears, but it would be powerful in all areas of medicine.

Most recently, the researchers used deep learning techniques to effectively turn a low-resolution microscope into a super-resolution one. They previously did similar work to enhance cell-phone images of biological samples to match those taken with laboratory microscopes.

By incorporating computational analysis and statistical learning into the front-end of an imaging technique, the researchers are creating an approach to imaging that doesn't just passively collect light. "We can essentially create thinking microscopes," Ozcan said.

MARCUS WOO

... as Uber joins the Job Fair

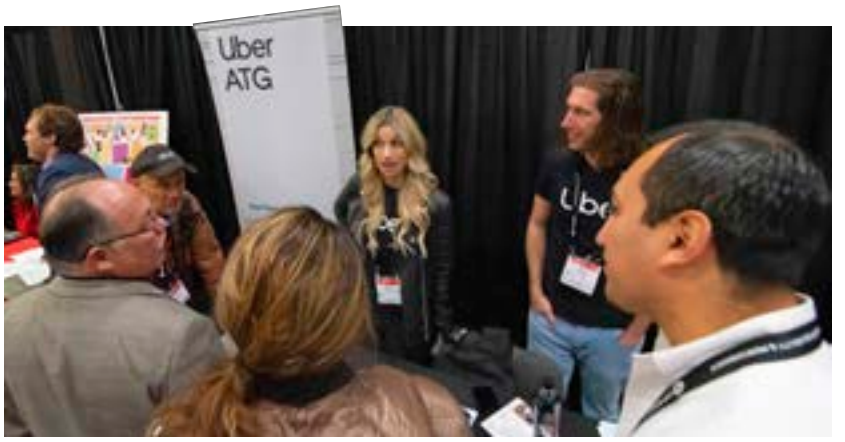
This year's job fair experienced record success. Besides logging 46 hiring exhibitors with a healthy stream of eligible candidates, this year's sell-out fair has attracted employers from beyond photonics, hinting towards a new era of photonics in application.

Joining familiar faces, such as KLA and Thorlabs, influential and significant players in commercial technology are here canvassing for talented optical engineers. Big names such as Uber, Waymo, Magic Leap, and Facebook have joined the early-year hiring frenzy in a bid to develop photonics technologies in house.

This development provides further evidence that Photonics West remains at the forefront of market trends. Lance Azzatto, Senior Hardware Recruiter for Uber ATG, commented, "our hardware engineering managers suggested that Photonics West is the premier conference to attend to find applicants in the optics industry.

Visit the Job Fair on Wednesday 10am-5pm, in the 1800 aisle of Hall C.

KANE WALPOLE & LACEY BARNETT

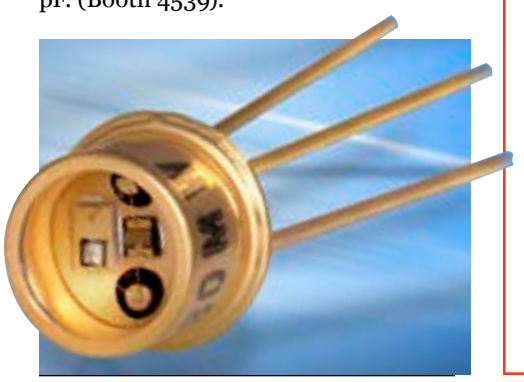


UV LEDS FOR DISINFECTION

Opto Diode is premiering a new addition to its range of narrow-spectral-output UVLEDs. This ITW subsidiary company is showing the OD-280-001, which provides disinfection-friendly peak emission wavelengths from 275 nm to 285 nm.

The LED is housed in TO-46 package and output power ranges from 0.9mW to 1.2mW. The company says the device is ideal for fitting into new or existing systems.

The spectral bandwidth at 50% is typically 12 nm. It features a half-intensity beam angle of 70 degrees, forward voltage of 6.5 V to 7.5 V, and capacitance of 350 pF. (Booth 4539).



LUMIBIRD UNVEILS MERION FOR DPSS LASER RANGE

Lumibird Group, a Lannion, France-based developer of diverse laser technologies, is presenting MERION, its new diode-pumped solid-state laser platform, developed jointly by its French and US teams, at Photonics West (view its pulsed and CW fiber lasers and amplifiers and pulsed diode-pumped solid-state lasers at booth 1159).

The company commented that its product ranges are "transitioning to an industrial platform model, as seen in the auto industry, in order to meet the laser market's diverse needs."

MERION is a modular platform designed to enable the Lumibird Group to extend its business in various sectors, from environmental LiDAR to medical equipment and industrial instrumentation.

Built around a core foundation that includes the electronics, software, pumping module, internal QCW diodes, and wavelength conversion modules, Lumibird produces a range of lasers with different power levels (from 100 mJ to 1J), different frequencies (from a few dozen to 500 Hz), and variable wavelengths.

Marc Le Flohic, Chairman & CEO, told *Show Daily* about the introduction of this new product range: "The release of our MERION lasers is in line with the Group's revised strategy to develop modular multi-application platforms that will enable us to respond quickly to clients' changing needs. Initial feedback has been extremely positive, and we are very optimistic about the potential of this new range of lasers."

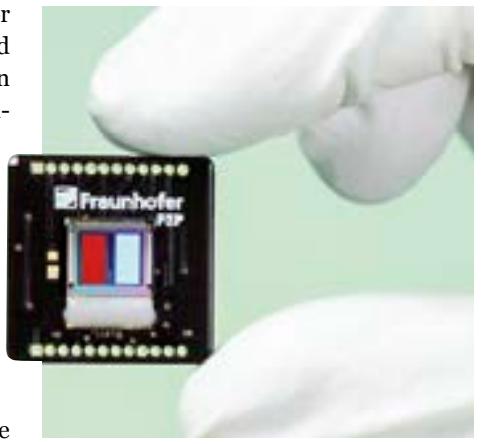
Lumibird was established in October 2017 from the combination of Keopsys Group with Quantel. The new company has more than 500 employees and over €100 million of revenues, and is present in Europe, America, and Asia.

MATTHEW PEACH

Cordell Maines, Lumibird, with the MERION platform. Photo: Matthew Peach

BLUE OLED ON SILICON SENSOR DETECTS PHOSPHORESCENCE

Researchers at the Fraunhofer Institute for Organic Electronics, Electron Beam and Plasma Technology FEP have long been involved in development of OLED-on-silicon sensors. Now they have developed a miniaturized phosphorescence sensor that combines a marker and sensor.



Considering oxygen sensors, there are many current-based sensors available to cover large temperature ranges, but FEP comments that these can be difficult to miniaturize and restricted to certain measurement points: "Optical sensors, such as phosphorescence sensors, overcome these hurdles. They are popular alternatives due to their ease of handling and capability of being integrated into existing systems," says the Dresden, Germany-based institute.

Its blue OLED release statement says, "Highly integrated OLED-on-silicon electro-optical devices have become standard for realizing high-resolution microdisplays in augmented- and virtual-reality glasses, and this technology is now increasingly under development for optical sensor solutions."

"Optical fingerprint" sensors have already been created by merging the display and image sensor into a so-called a bi-directional OLED microdisplay. In addition to the display function, the display pixels serve as smart illumination of the finger on the surface, whose features are then detected by the embedded photodiodes.

Now the researchers have taken another step and developed a miniaturized phosphorescence sensor. In this sensor, a chemical marker is excited by modulated blue OLED light. The phosphorescent response of the marker is then detected directly inside the sensor chip. The marker determines the substance to be measured; a typical application is measurement of an oxygen concentration.

To achieve the design of an extremely small sensor that combines all the required functionalities and which could be manufactured cost-effectively, the OLED control and the sensor front-end are integrated into the silicon chip. The FEP team then investigated different configurations of the excitation and detection areas.

LASER WHITE LIGHT FIBER MODULE FOR ILLUMINATION

Laser Components USA is presenting the Albalux FM, said to be the first ever laser white light module. The device delivers a highly-directional fiber optic output for precise illumination, such as for medical and machine vision applications.

The distributor says the Albalux FM is set to "spark a new innovation wave in illumination solutions for medical endoscopy, surgical headlights, manufacturing, and 3D machine vision."

A key component of this module is the LaserLight technology from SLD Laser. Based on GaN semi-polar blue laser diodes, LaserLight generates brilliant white light that is more than 10 times higher in luminance than today's brightest LEDs, yet with minimal power consumption and long lifetime.

To maximize light transmission and beam directivity, optical fibers are incorporated that drive >150 lumen CW output with sharp edges and a narrow beam. Laser Components comments, "This design results in enhanced vision that provides faster processing times and more reliable monitoring on the manufacturing floor, and improved diagnostics and patient outcome in medicine." (Booth #1751).

MATTHEW PEACH

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PUBLISHED BY
SPIE, 1000 20th Street
Bellingham WA 98225 USA
Tel: +1 360 676 3290
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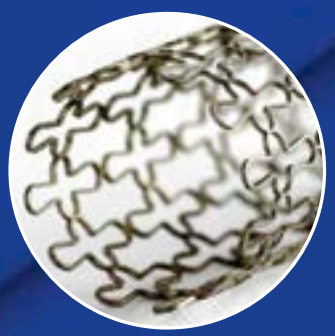

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