PHOTONICS WEST. SHOW DAILY

Extreme Light Infrastructure

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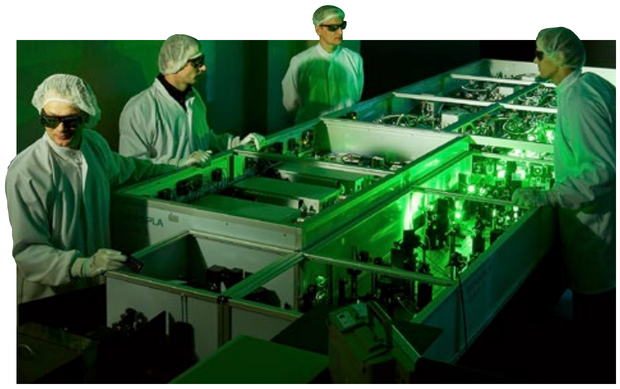
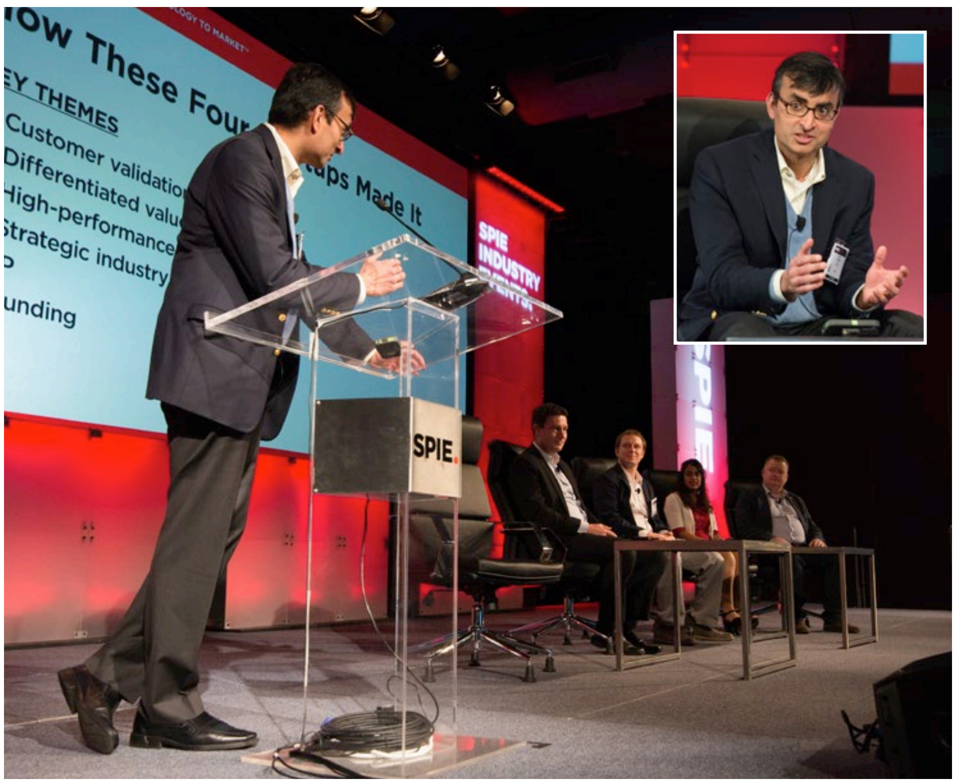


How four startups made it: founders are resilient and know their customers

The first time Supriya Jaiswal paid payroll tax for her new company, the state of California slapped her with a $1000 penalty — for not paying. She had a receipt, but the state insisted she still owed the fee. She later enlisted the help of a tax advocate. But after a year of headaches, hassles, and fighting, it turned out that the penalty was issued because Jaiswal didn't pay the tax during the right time of day, violating a relatively trivial rule.

For Jaiswal, CEO of Astrileux Corp., a semiconductor company that she launched in 2015, that was just one of many mistakes, challenges, and setbacks she encountered while building her startup. She was one of four startup founders who urged entrepreneurs to listen to customers and to be resilient, answering audience questions during a panel discussion at Photonics West on Monday.



Arun Chhabra (inset) of 8tree moderated the startup panel of founders from Optotune, Optofluidics, Astrileux, and M Squared Lasers. Photo: Adam Resnick

The four panelists represented rare success stories. According to the common refrain, nine out of 10 startups fail.

"The first word of caution is that doing a startup is sexy, but it does come with quite a few lashes," said Bernardo Cordovez, president and founder of Optofluidics, a particle analysis company that he started in 2010. "In these six years, I probably made every mistake in the book."

Indeed, one of the main messages from the discussion is that mistakes are inevitable. But you must learn from them. For example, when Manuel Aschwanden was starting his company, Optotune, which makes focus-tunable lenses, he misjudged the market. He was trying to use his technology for lighting applications, an industry with a billion-dollar market. But he discovered that companies didn't think the technology was worth the money.

"Our mistake was we talked more with technologists of the companies," Aschwanden said.

The lesson was repeated throughout the discussion: talk to customers. Only potential customers will know whether your technology or product is really worthwhile.

"If everyone says it's a great thing, but no one puts money on the table, then maybe it's not so great," Aschwanden said.

That's one main challenge especially for academics considering a startup. Just

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DON'T MISS THESE EVENTS TODAY.

LASE PLENARY SESSION
(10:20-12:30 AM, Room 103, South)
Karsten Danzmann, Max-Planck Institute
Alberto Piqué, US Naval Research Lab
Hakaru Mizoguchi, Gigaphoton

INDUSTRY EVENTS

3D PRINTING PANEL
(8-10 AM, Room 103, South)

SITAC OPEN MEETING
(9:30-11:30 AM, Room 102, South)

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

EXECUTIVE CHALLENGES PANEL
(1:30-2:30 PM, Room 103, South)

LASER MATERIAL PROCESSING WORKSHOP
(1:30-3 PM, Room 102, South)

EXPORT LAWS WORKSHOP
(3-4 PM, Room 102, South)

SPIE STARTUP CHALLENGE FINALS
(3:30-6 PM, Room 103, South)

PRISM AWARDS CEREMONY
(6-10 PM, Marriott. Tickets required)

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

IN THIS ISSUE.

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Startups continued from page 01

because your idea is garnering a lot of intellectual interest, that doesn't mean it can be translated into something marketable — or even useful beyond your immediate group of specialists. We live in bubbles, Cordovez noted.

The right approach isn't to simply find an application for your expertise, Jaiswal said. You have to learn the market and understand the problems that people have and what kind of technology could offer solutions.

"In my mind, there's only one person that you need to advise you," she said. "And that is the customer." Customers are the ones who can take your idea to the market and be your champion.

Then you have to sell. "As scientists we think we need to have a proof-of-principle first," she said. "Honestly, I tell you that's not true. You just have to have the ability to sell your product."

Building a startup team

But as you're developing your idea, the other crucial question is how to build your early team. For Jaiswal, that depends on what you're selling.

If you're selling technology, as she does, you want the experienced and brilliant scientist or engineer. It's your job as the CEO to sell and publicize. But if you're selling software, for example, then she recommends you target someone who can pitch.

In those early days, though, sometimes you just need partners who share your vision. After all, those who like what they're doing tend to be really good at it.

"You've got to find people at the start who are very passionate over what you're going to do," said Graeme Malcolm, CEO and founder of M Squared Lasers, his second startup. "It's going to be a long, bumpy journey."

Cordovez agrees. "The last thing you want from the beginning is a disgruntled founder. That's very toxic," he said. "Everyone has to be on the same page."

VC and other funding

Then, of course, there's funding. Aschwanden opted for the bootstrap approach. But Jaiswal suggests you consider non-dilutive funding sources, such as crowdfunding or grants. These sources give you cash without forcing you to sacrifice equity.

Supriya Jaiswal of Astrileux (left) and Graeme Malcolm of M Squared Lasers answer audience questions. Photo: Adam Resnick

Especially during the first couple of years, which are the most critical and uncertain, you don't want to give away too much of your company to venture capitalists, Jaiswal said.

Manuel Aschwanden (left) of Optotune with Bernardo Cordovez of Optofluidics. Photo: Adam Resnick

But while you may not want to take venture capital too early, research grants have pitfalls, too, Aschwanden said. They may distract you from your goal, occupying your time with tasks like writing reports rather than building a product you can sell.

"One way to think about venture capital is that it's scale-up capital," Cordovez said. Non-dilutive funding helps you develop your idea and understand your customers. Once you have that set, you can seek venture capital to scale up your technology or product.

Being the best you can be

The ultimate message was, as in life, be resilient.

"You're going to be wrong and people will say no," Cordovez said. "And it's OK." You have to keep reinventing yourself, and at every point in the process, get feedback and act on it.

There's no end to the difficulties and the times when you're going to be burying your head and wondering why you're doing this, Jaiswal said. "At the end of the day, you have to be brave," she said. You have to push your limits in every way, in financial innovation, recruitment, and commercialization strategy. Pursuing a startup, she said, "helps you know what you are truly capable of. It helps you be the best you can be."

Despite the rough road, none of the panelists expressed regrets. "It's an incredible thing to do, to build a business," said Malcolm, who also started Microlase Optical Systems before M Squared Lasers. You can work with great people, follow your own course, and craft and build things. And in the increasingly globalized technology industry, you can make friends from around the world.

A startup could be your opportunity to contribute to society. Life is short, Jaiswal said. "With that time I want to do something really useful. I just want to advance the state of civilization in a way that really takes us toward the future."

MARCUS WOO

Problems and paradoxes: optics and lung disease

During Saturday's BiOS program, lung disease experts made a strong and concerted plea for better non-invasive optical biopsy techniques to aid in earlier diagnosis of pulmonary fibrosis.

The disease, which strikes about a million people worldwide every year and an estimated 100,000 in the US alone, took center stage in a well-attended session and panel session.

Under the title "Joining Forces," medical and optics experts illustrated the complexity of research and diagnosis of such a large and intricate human organ. All five speakers were united in appealing for rapid work on optical techniques to offset risky surgical biopsies.

Melissa Suter, an optical engineer at Massachusetts General Hospital (MGH), said, "It's clear from the session today that a collaborative effort is needed by the clinical side and optical engineers to develop new tools to make an impact on early diagnosis in pulmonary medicine." With an illustrated account of a pilot clinical study using optical coherence tomography with a mouse model to examine lung disease, she drove home the advantages of looking at the lung with non-invasive techniques that work. "Yes, we can do this," Suter said.

Her colleague, Lida Hariri, a medical doctor specializing in pulmonary pathology but also an optical engineer at MGH, added, "There's a clear clinical need for new diagnostic and monitoring methods for lung diseases such as pulmonary fibrosis. We think there's a real potential for optical imaging modalities to meet this critical need, and to provide patients with lower-risk methods for diagnosis and disease monitoring."

Anthony Lee, a staff scientist at the British Columbia Cancer Agency Research Centre in Vancouver, Canada, added: "Optical technology is great for looking at the lung, and we are just at the beginning of exploring what possibilities these technologies can be applied to."

All the panelists, Lee said, "are trying to minimize risks for diagnostic procedures, with less invasive methods, ones that do not require surgery."

However, a note of caution was sounded by Harold Collard, of the University of California, San Francisco. "Our current approach to diagnosis in pulmonary fibrosis remains limited," he said, "and we need better, less invasive, possibly optical diagnostic approaches to improve patient care and to get a more accurate diagnosis. It's a challenge. Getting tissue is risky. But our diagnostic options are limited and all have risks. We need better, safer approaches. Optical diagnostics is worth looking at more vigorously and comprehensively."

David Sampson, from the University of Western Australia in Perth, expanded those options to include optical elastography. "Elastography is fertile ground for the future of lung and airway basic research," he said. He described "problems and paradoxes" in the imaging required to make a diagnosis. "We need both high resolution and contrast in a very large organ," he said. "It's like needing to see the whole football field, and not just one stripe; and doing that in high resolution."

However, Hariri, of MGH, responded: "A biopsy is not diagnosed in a vacuum. We need to know what is going on from a clinical perspective. You don't just stick a probe in and hope for the best. You go over the areas that look a little funny. You don't have to image every airway to get good reliable data."

She said physicians always struggle with the risks, asking: "How can we minimize the amount of tissue we are taking out, and not just look at the tissue but look at the *in vivo* information as well?"

FORD BURKHART

‘Big lasers’ near completion as NIF ramps shot rate

Two of the largest laser projects in Europe are nearing completion, heard a Photonics West conference on Monday. At the Laser Megajoule (LMJ) facility in France, where a petawatt-scale beamline is under construction, the latest laser bundle has just been commissioned, while all the main structures in the laser bays have now been assembled.

Representing the giant laser fusion project, Marc Nicolaizeau told the High Power Lasers for Fusion Research conference that three new tools for target diagnostics were now in service, and that although there is a lot more assembly work to do, LMJ performance was so far meeting requirements and matching simulations well.

Over the past two years, with its first laser bundles in place, the facility has completed 90 shots. The shot-to-shot cycle time and shift patterns at the LMJ site mean that one shot per day is now possible. By the end of this year, the two laser bundles currently operating should be extended to five, providing lots more energy to fire at the gold hohlraum target.

Meanwhile at the 192-beam National Ignition Facility (NIF) in California, the dedicated “campaign” to generate fusion with ignition may be over, but the annual shot rate at the giant facility has jumped from just under 200 shots in 2014 to more than 400 currently.

Mark Bowers from Lawrence Livermore National Laboratory (LLNL), which houses NIF, told delegates that the rate at which useful science is being done with the laser has increased significantly, with the NIF team making a successful transition to becoming a user facility, rather than one focused on its own science projects.

The laser pulses produced by the highly energetic NIF beam typically deliver around 1.8 MJ to the target chamber, enabling some unprecedented physics research to be carried out. Meanwhile, the NIF team has installed its own optical fiber drawing tower to make custom fibers, and added a new petawatt-class beam in the form of the Advanced Radiographic Capability (ARC) that is able to probe cold materials at extraordinarily high pressures.

Another team at LLNL is busy completing the high-repetition-rate advanced petawatt laser system (HAPLS), which is due to be shipped to the first of the Extreme light Infrastructure (ELI) projects – “ELI Beamlines” near Prague – later this year. Georg Korn from ELI Beamlines said that the first experiments at the new facility, built with European structural funding usually reserved for roads and bridges, will begin at the start of 2018.

The HAPLS beamline will become the “workhorse” of the user facility, providing petawatt-level pulses at an unprecedented repetition rate. Although some screed material on the top floor of the ELI Beamlines building has had to be replaced due to problems with vibrations, user workshops are already underway ahead of those first experiments, which will take place in what Korn described as an “excellent building.”

See feature on ELI-ALPS page 7.

MIKE HATCHER

ARIZONA TEAM HAS OPTICAL COMPUTER IN THE WORKS

A new, powerful world of photonics-based computing – with as many as a million wavelength channels – lies in a distant future.

And the groundwork, including fabrication and imagination, is under way at the University of Arizona, said Nasser Peyghambarian in a keynote address on Tuesday for the Quantum Sensing and Nano Electronics and Photonics conference.

Peyghambarian, from Arizona’s College of Optical Sciences, described what’s new and what’s ahead with high-performance computers based on photonic chips that are able to move data much faster than electronic ones.

He collaborates with Mark Neifeld, of the UA, and the US Office of Naval Research scientist Ravi Athalie on ways to use lasers to eventually replace conventional electronics.

Going beyond the 10 nanometer semiconductor industry “node” is essential, Peyghambarian said, to keep increasing computational power. “Everything is becoming saturated,and we need new technology. One approach is to ‘go optical.’ You can bring in 1 million wavelengths, each with a different channel. Just think about a million wavelengths for multiplexing.”

While current state-of-the-art designs feature multi-core fibers with 144 cores, he thinks that in the distant future there could be as many as 10,000 cores in a single fiber.

The multi-core fiber fabrication is taking place in labs at the University of Arizona. “Our experiments are still under way,” he said, “We are getting close but we are not there yet.”

FORD BURKHART

US Army ready for 60 kW laser weapon

High-energy laser weapon systems of the order of tens and even hundreds of kilowatts power are rapidly moving from prototype demonstrations into fully-fielded systems for military environments.

Mark Neice, executive director of the US Directed Energy Professional Society and a former US Air Force Colonel, Monday told the several-hundred-strong crowd at Pennwell’s Lasers & Photonics Marketplace event, “The Department of Defense is interested in the opportunities presented by high-power directed energy systems, whether they are high-energy lasers or high-power RF systems. The DoD is always interested in kilowatt-class lasers.”

At a conference when the emphasis is more typically on civilian applications, Neice joked, “the defense sector’s aims are not that different from that of industry: we are looking at high-precision materials processing – in the area of cutting and welding – but at a distance of several kilometers rather than millimeters.

“Operational issues are similar: beam control, power quality, efficiency. But the differences are that the military must compensate for the atmosphere, targets are usually very dynamic, and they tend not to be cooperative.”

Neice’s talk followed a forecast saying that the cost of obtaining power from laser diodes may be going down to a couple of dollars per watt. “As that will benefit industry it is also of great interest to the defense industry,” he said.

Neice described the latest military-focused, high-energy laser projects: the Joint High Power Solid-State Laser, a 100 kW-class diode-pumped development with Northrop Grumman that has actually achieved 105 kW output; the Robust Electric Laser Initiative, resulting in “TRL5” laser sources with military size, weight and power; and Advanced Beam Control for Locating & Engagement, which achieved effective beam control subsystems for military platforms.

The US Army is set to take delivery of a 60 kW laser for its High Energy Laser Mobile Test Truck next week. Photo: US Army.

He also revealed that in just a week or so the US Army will take delivery of the first 60 kW laser source, following the High Energy Laser Mobile Test Truck (HELMTT) project. This source, developed by Lockheed Martin, will be mounted on a truck.

“HELMTT is an outgrowth of their Robust Electric Laser system. It’s currently undergoing its final testing and will be delivered to the Army, next week, in Huntsville, Alabama,” he said.

“Previously the Army has demonstrated a 10 kW mobile laser weapon system and 60 kW is not the ultimate goal,” Neice added. “It’s designed to counter UAS (unmanned aerial systems). The laser system is designed for defensive rather than aggressive purposes. The power source will be the truck’s own engine, with a super-charging capability for firing in burst mode.”

MATTHEW PEACH

ELI: the blazing ambition lighting up eastern Europe

Europe's Extreme Light Infrastructure is poised to unleash laser pulses with unprecedented scientific utility. Is the world ready, asks Rebecca Pool.

Ever wanted to follow charge migration through molecules with absolute clarity? Struggling to understand how radiation damages DNA causing mutation in next-generation cells? Maybe you're desperate to discover how the universe's most complex polyaromatic hydrocarbons break, release energy and ultimately form life? These and many more mind-blowing mysteries are set to be solved when a new attosecond laser facility in Hungary comes online.

In 2005, the European Strategy Forum on Scientific Research Infrastructures gave the go-ahead for what is widely considered to be the most ambitious laser project in years. The various Extreme Light Infrastructure (ELI) sites will investigate light-matter interactions at the highest laser intensities and on ultrashort timescales, via four massive laser facilities.

The ELI Beamlines facility, in the Czech Republic, is poised to provide trains of ultrashort laser pulses of a few femtoseconds duration, up to 10 PW, while the site in Romania will focus on nuclear physics, hosting two 10 PW ultrashort pulse lasers delivering intensities to 10^{24} W cm^{-2} and an intense, brilliant, tunable gamma-ray beam.

A third, ambitious, Ultrahigh Field facility will astound physicists with its 100 PW laser that provides intensities beyond 10^{25} W cm^{-2} on par with power received by the Earth from the sun focused onto a pin tip.

Attosecond science

But for attosecond scientists around the world, it is the ELI-ALPS (Attosecond Light Pulse Source) facility in Hungary, with its myriad ultrafast, powerful light pulses, that holds the most excitement. First experiments will commence in 2017, and Dr Franck Lépine, leader of the Attosecond and Strong Field Science group at ELI-ALPS and researcher at the CNRS Institut Lumière Matière, Lyon, can barely wait.

"Attosecond science is one of the most important research fields in photophysics today, as using these pulses we can observe electron dynamics in real-time on attosecond- and Angstrom lengthscales," he says. "Yes, several labs around the world already have attosecond sources but we will have light source parameters and properties which are beyond what already exists in most laboratories."

As Lépine points out, existing sources usually provide extreme ultraviolet light at repetition rates of around 1 kHz, but ELI will deliver blisteringly high 100 kHz repetition rates. "We will be able to carry out much faster and more sophisticated experiments," he says. "And researchers will be able to perform experiments they cannot even think about in their own laboratory."

Attosecond molecular dynamics is a growing field of research, with the prompt ionization of molecules by an attosecond pulse inducing charge migration across a molecular structure on attosecond to few-femtosecond timescales.

Observing such charge dynamics helps researchers to understand how electronic behavior determines molecular pathways and, ultimately, the chemical reactions that lead to more complex structures. But as Lépine asserts: "While we can do this in our laboratories right now, laser stability, repetition rates and photon numbers are limited, so we can only work with simple molecules."

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Florian Just and Steffen Hädrich, from Jena's Active Fiber Systems, with an ultrafast laser that will be used as one of the sources at the ELI-ALPS facility in Hungary. © Walter Oppel, Fraunhofer IOF

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Aerial view of the ELI-ALPS site in Szeged, Hungary. Photo: ELI.

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However, when the first ELI-ALPS lasers are switched on during 2017, researchers at the facility will begin tracking electron and proton dynamics in more complex molecules.

Life, the universe and everything

Indeed, working with NASA astrochemists, Lépine recently used a laboratory-based compact attosecond beamline to resolve femtosecond and attosecond dynamics in naphthalene, a polycyclic aromatic hydrocarbon that has been detected in space. The compound is considered a complex molecule to study by today's attosecond laser standards, but will be small-fry for ELI-ALPS.

"Polycyclic aromatic hydrocarbons such as naphthalene become more complex and eventually lead to the appearance of life in the universe, but right now we don't have the means to understand how," says Lépine. "But we will with ELI-ALPS."

"We'll be able to study much larger systems, composed of, say, 50 carbon atoms, find out how these molecules absorb XUV radiation, release energy and evolve into biomolecules and eventually into DNA, cells and so on," he adds. "It is essential to understand what's happening on an ultrafast timescale to understand what happened in the universe over hundreds of millions of years."

But ELI-ALPS isn't just about the attosecond. As Lépine points out, the dazzling array of light sources will also provide terahertz pulses, mid-infrared pulses, electron and proton bunches, and more. "This is a unique facility in the sense that it will provide so many different light sources with short pulses," he says.

According to the researcher, the first experiments will include investigating how high harmonics can be created from solid materials. "Researchers are interested in how we convert infrared photons into extreme UV, or soft X-ray photons, using solid materials, so you can build such a system in your laboratory," he says.

Then within two years, with all the lasers in place, the facility will be welcoming researchers from outside of ELI-ALPS, and a broad range of research will start. Fundamental research activities will range from atomic, molecular and optical physics to relativistic laser plasma interactions and surface/condensed matter science. For example, the wavelength structure of the ELI-ALPS light source is set to allow researchers to develop new ways to probe valence dynamics that go beyond today's femtochemistry methods.

Electrons in motion

The combination of light sources at the facility will also drive attosecond imaging in 4D forward. Currently, 4D

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HIGH REPETITION RATE LASER PROGRESS

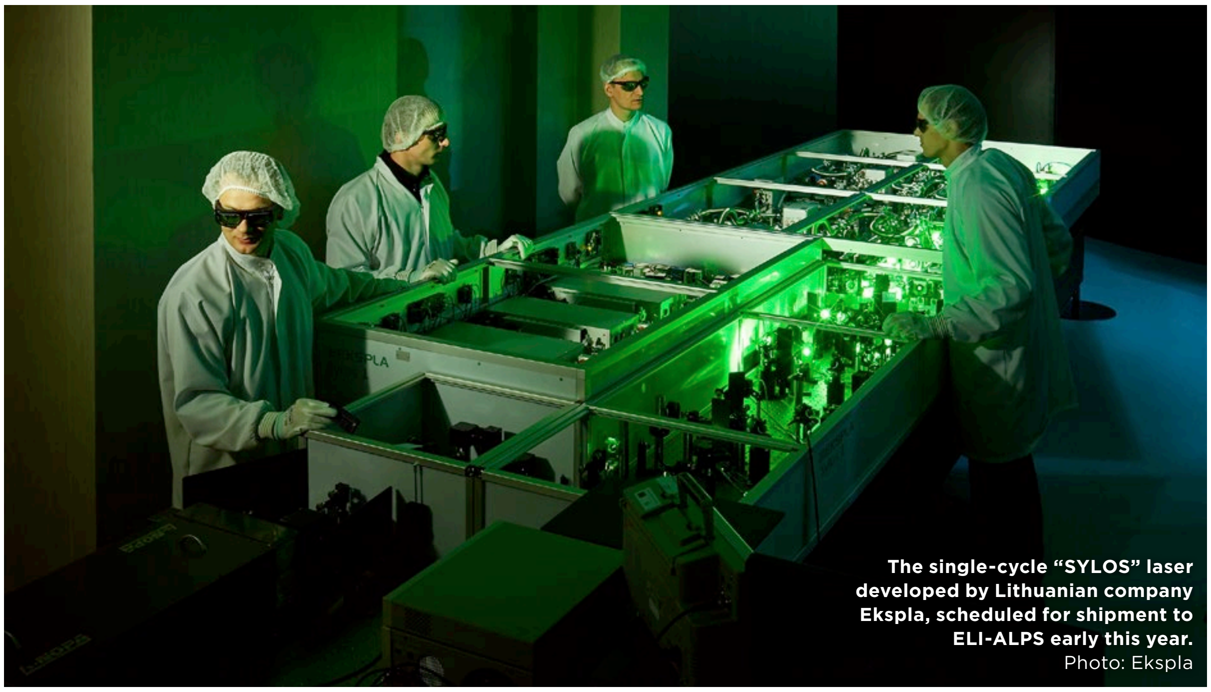
The high repetition rate laser system — HR1 — is based on a femtosecond fiber laser with two non-linear compression stages. The pump source incorporates a fiber chirped-pulse amplification system with up to eight main amplifier channels.

For this first phase laser, target specifications are 1mJ energy at a 100 kHz repetition rate with a pulse length of around 6 fs. As of late 2016, the Active Fiber Systems team had hit 75% of this performance.

"We've really been working towards achieving a higher laser pulse energy and have reached 0.75 mJ and 75W performance," says Steffen Hädrich from the company. "The laser system is already running at full specifications so we're now setting up our analysis, optimizing parameters and will continue to increase its energy step by step."

The team has also been working to ensure that the laser's carrier-envelope phase — a critical feature of any few-cycle laser pulse — is stable so that each laser shot has an identical electrical field. And with this in place, installation at ELI-ALPS is scheduled for early 2017.

Hädrich believes researchers interested in atomic and molecular dynamics will be the primary users of the laser system. As he also highlights, ELI-ALPS has already issued the tender for the second phase of the high-repetition-rate laser system, aiming for 5 mJ, 500 W performance. "The remaining laser parameters are the same, so hopefully our team will work on this system as well," he says.



The single-cycle "SYLOS" laser developed by Lithuanian company Ekspla, scheduled for shipment to ELI-ALPS early this year.
Photo: Ekspla

ELI continued from page 09

imaging is possible with femtosecond time resolution and atomic-scale spatial resolution but ELI-ALPS will enable researchers to visualize ultrafast electronic motion with attosecond temporal and atomic spatial resolution.

Opportunities for biological imaging abound. Light sources at ELI-ALPS will provide nanometer-scale imaging of living cells and sub-Angstrom spatially resolved structural investigations of macromolecules as well as single-molecule imaging and serial femtosecond X-ray crystallography. What's more, the facility's ultrafast, high-energy, high repetition rate lasers could also lead to revolutionary approaches in radiation oncology.

"This is a very nice opportunity for the entire research community to carry out experiments they just wouldn't do 'at home'," says Lépine. "And the facility will also provide light sources to researchers that haven't traditionally been interested in ultrafast science."

At the same time, laser plasma research is expected to thrive. The interaction of high power — TW to PW — laser pulses with any form of matter triggers a host of processes that take place at femto- or attosecond timescales. Such studies demand a high power laser system equipped with a synchronized femto- or attosecond pulse, which ELI-ALPS can provide.

And for materials scientists, ELI-ALPS is set to expand the frontiers of knowledge of ultrafast activity at the nanoscale and in complex materials. For example, the light sources could shed new light on phenomena such as photo-induced magnetic phase switching, instrumental to encoding information on hard drives, magnetic random access memory, and other computing devices.

Clearly 'ultrafast science' impacts modern physics, chemistry, biology, materials science, engineering and more. As Lépine points out: "Using ultrafast pulses we can see so many processes in real-time and in all research fields we now understand that to make progress we have to understand what is going on, on these very, very short timescales."

"Researchers will want to irradiate samples with accelerated protons, bombard materials with terahertz pulses and they will be able to carry out much more sophisticated experiments that just aren't possible [yet]," he adds.

Crucially, the researcher also hopes the facility will promote collaboration amongst researchers from different disciplines from around the world. "We will have laser scientists, physicists, chemists, biologists, materials scientists and theoreticians all in the same institute," he says. "This is going to be a fully-integrated facility; researchers and non-specialists will come to ELI-ALPS to collaborate and do experiments they cannot even think of in their own lab."

Building the vision

So what infrastructure will lie within the vast facility of ELI-ALPS? Primary, femtosecond, near-infrared lasers, with an unprecedented array of pulse characteristics, will soon drive a host of secondary sources resulting in terahertz, mid-infrared, ultraviolet, extreme ultraviolet and X-ray radiation.

These secondary sources will then provide a range of wavelength-dependent pulse durations ranging from picoseconds, femtoseconds and, of course, down to attoseconds. And crucially, these pulses will feed into end-user chambers so researchers' experiments and measurements can begin.

According to Professor Karoly Osvay, previously research technology director at ELI-HU, the primary laser sources will comprise five all-important lasers; a high-repetition-rate laser, a single-cycle laser, a high-field laser, a mid-infrared laser and a terahertz pump laser.

"We have devoted money and person power to develop these very reliable lasers with outstanding specifications," he says. "All the sources are so stable, and so well made and engineered that they will run for up to twenty four hours without interruption. This feature is a very important aspect of our facility."

ELI-ALPS awarded all its laser contracts between October 2014 and May 2015. A Lithuania-based consortium comprising laser manufacturer Ekspla and femtosecond laser developer Light Conversion won the first contract, developing 'SYLOS'. In its first implementation stage, this single-cycle, robust system is set to provide 45 mJ pulses with sub-10 fs duration, forming the backbone of research at the facility.

"The system will deliver extremely short pulses with high pulse power and a pulse repetition of 1 kHz," explains Zenonas Kuprionis from Ekspla, which is exhibiting this week at booth #1133. "The laser will be used to

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generate high harmonics, extreme UV light, X-rays and general attosecond pulses, so we think this high power will be used for real life X-ray applications in bioscience and biomedicine."

"To the best of our knowledge, SYLOS provides at least four times the peak power of any system with a 1 kHz repetition rate in the world," he adds.

For Kuprionis and colleagues, work on the laser is almost complete and trials at Ekspla are coming to an end. The system will be ready to ship to Hungary in early 2017, and the team is now interested in securing a contract for SYLOS's second and third implementation stages that will take pulse energies to an ambitious 100 mJ and pulse duration to less than two optical cycles.

Following SYLOS, a second contract was swiftly awarded to France-based Amplitude Technologies, to develop a massive high-field laser for delivering optical pulses with 2 PW peak power.

Unique wavelength

As ELI-ALPS' Osvay highlights: "Trials on this laser will take place in late 2017 and then dismantling and shipping of this huge system is going to take several months. We expect installation to be complete by December 2018."

Another French source developer, Fastlite, won a third contract to develop a mid-infrared primary laser system, which according to Osvay, is also nearing completion. "This laser operates at a wavelength of around 3.1 microns, where water absorption decreases significantly," he says. "So, with its 100 kHz repetition rate, it is an excellent tool to carry out ultrafast spectroscopic experiments on samples containing water, such as tissues and cells."

"A few-cycle laser system operating at this unique wavelength also provides us with the opportunity to generate X-ray photons," he adds.

And in a fourth contract, a German consortium comprising researchers from Active Fiber Systems, Friedrich Schiller University, and the Fraunhofer Institute for Applied Optics and Precision Engineering has been designing, developing and building the high repetition rate laser system, "HR 1". This laser will also be synchronized with the mid-infrared system, enabling joint experiments. Osvay says that synchronization of these two 100 kHz laser systems is of the highest priority and importance.

In its initial phase, target specifications are 1mJ energy at a 100 kHz repetition rate with a pulse length of around 6 fs. The Active Fiber Systems-led team is on target to hit performance requirements, and Osvay expects the system to be up and running at ELI-ALPS by July 2017 (see box 'High repetition rate laser progress').

With these laser systems approaching completion, and the final one — a terahertz pump laser — under contract, Osvay reckons all five primary lasers will be installed by the end of 2018. Given this, work on the secondary source beamlines is now gathering momentum.

These laser-driven sources will include gas and solid-state high harmonic generation and attosecond pulses, as well as new concepts for high harmonic and attosecond pulse generation. Particle acceleration sources will also be driven by the SYLOS and HF laser systems, while high-intensity pulsed terahertz sources with extremely high peak intensities will be available. If all proceeds to plan, the secondary sources will be in operation at ELI-ALPS by the beginning of 2020.

Beyond the laser-related facilities, ELI-ALPS is also set to provide optical preparation laboratories, electron beam lithography and plasma etching equipment, as well as microscopy suites with atomic force microscopes, scanning electron microscopes, and more.

As Franck Lépine puts it: "We will have absolutely everything for the user to come here and experiment in one place."

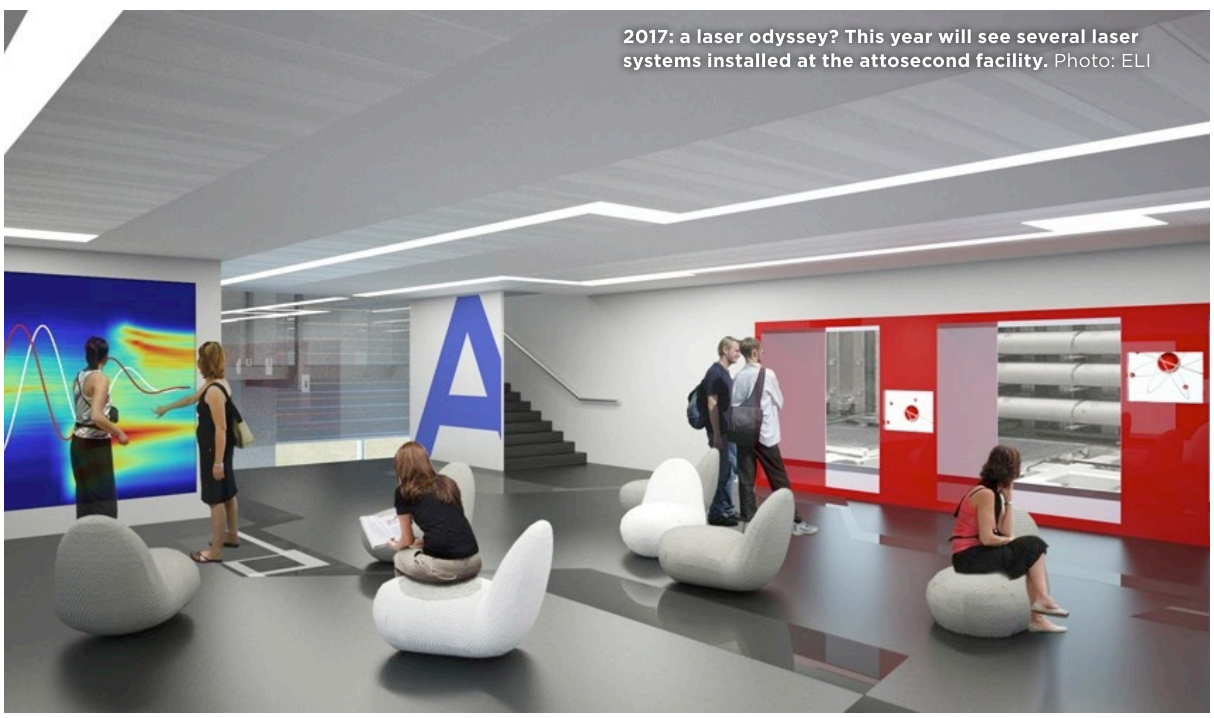
Osvay concurs, saying: "I want ELI-ALPS to become a unifying place where communities from all fields can meet. We are providing so many different resources, when in the past it has been difficult to collect these in a single national facility."

At the time of writing, Osvay was thrilled that the ELI-ALPS building was ready to open. Necessary infrastructure such as lighting, heating and cooling systems, and cleanroom facilities had been tested, ready for integration of the primary lasers in early 2017.

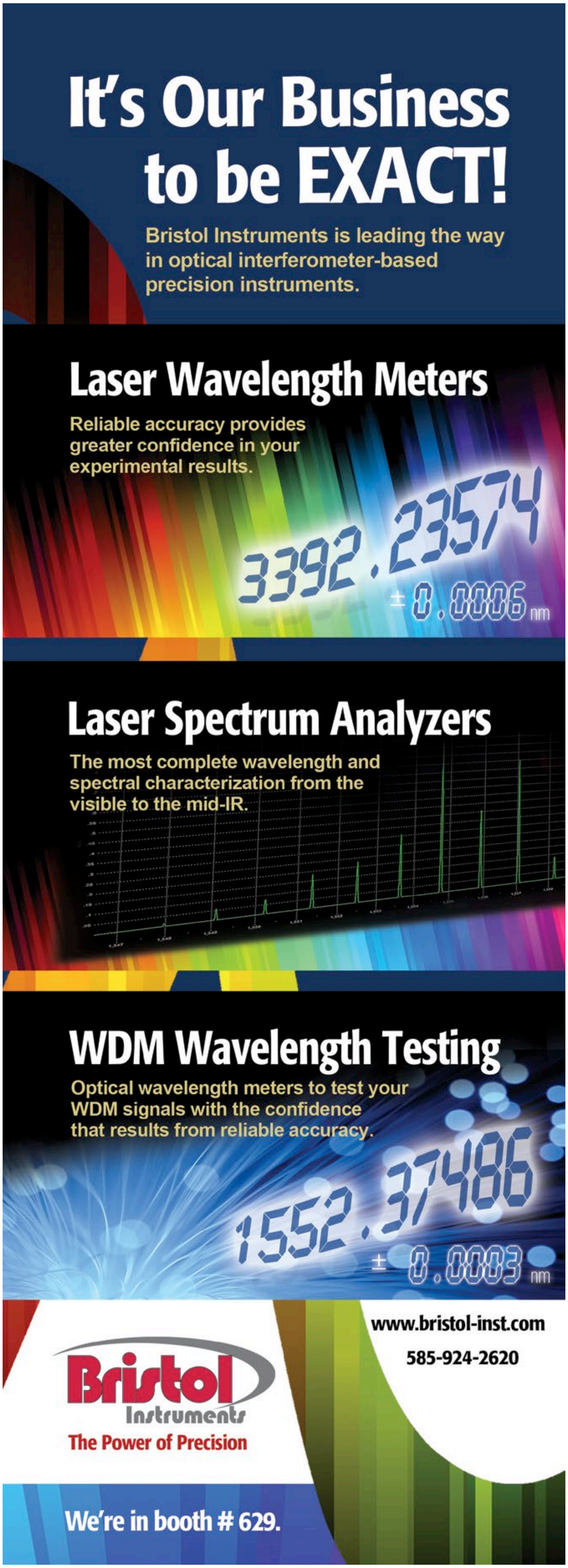
"Our first attosecond beamline will be fully-operational in roughly one year from now," he predicted in late 2016. "This will initially be offered to ELI-ALPS [employees] but in only a few years all sources will be ready for outside users, worldwide."

REBECCA POOL

Rebecca Pool is a freelance writer based in Boston, UK.



2017: a laser odyssey? This year will see several laser systems installed at the attosecond facility. Photo: ELI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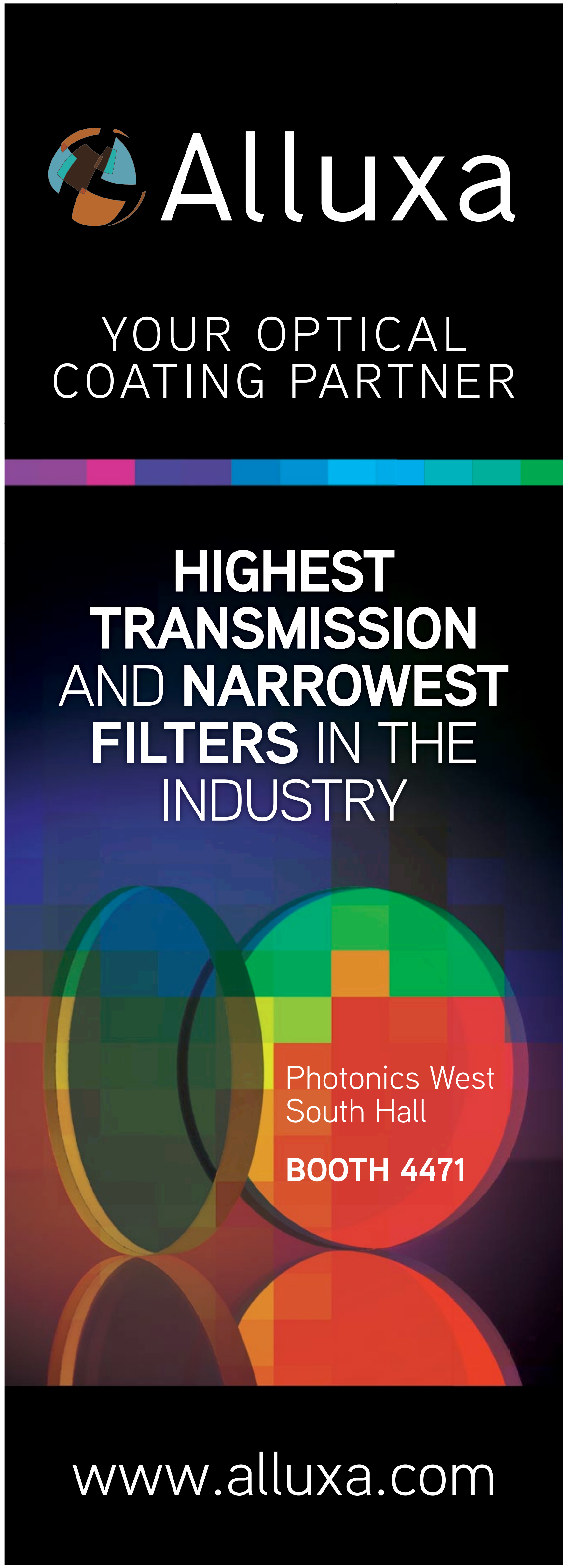
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“Develop the dialogue”

For Zeev Zalevsky, who combines a broad program of research with a track record of successfully moving products towards market, Photonics West’s cross-disciplinary nature is crucial for entrepreneurial academics.

From a position heading the electro-optics program at Israel’s Bar-Ilan University, Zeev Zalevsky has assembled a diverse range of photonics research projects and shepherded several of them towards commercialization.

The variety of his applied research portfolio owes something to the economic support available to Israel’s researchers and venture capitalists, intended to encourage entrepreneurship and smooth the path to market. But it also derives from Zalevsky’s personal inclination towards broad and inclusive science.

“The range of my research doesn’t stem from any official policy, but is I think connected to my own character,” Zalevsky commented. “Some researchers prefer to be more focused on a small number of areas, while some prefer to venture more widely. Personally I have an active curiosity about photonics, and the reason I came to this university rather than go into industry was because of the freedom it gave me to think of new things.”

Zalevsky divides the research underway in his lab into two broad categories — special optics, and electro-optical devices — with the common thread between them being an emphasis on applied and potentially exploitable technology.

The special optics category includes work on super-resolution microscopy, where Zalevsky has been involved in the development of carefully designed nanoparticles able to change the diffraction-limited point spread function and achieve sub-wavelength resolution.

Remote sensing technology also comes under this heading, such as an optical platform to detect various biometric parameters with a single sensor. “This could allow continuous sensing of vital bio-signs such as respiration or blood composition,” Zalevsky said. “But the technology may also be able to authenticate a person’s identity according to their heartbeat, or possibly to detect what an individual within a crowd is saying in a very directional manner.”

Technology transfer

The second stream of research covers electro-optical devices, and a spectrum of potentially disruptive technologies from the nano-scale up to the millimeter regime. As examples, Zalevsky pointed to research on nanodevices, covering both silicon photonics and plasmonic technologies, potentially allowing rapid wireless transmission of data between the sub-processors of a functioning CPU via nano-antennas.

On the micro-scale, Zalevsky has developed a multifunctional endoscope suitable both for minimally invasive *in vivo* imaging and monitoring of bio-parameters such as hemoglobin concentration. Careful design of the optical fiber in this device restricts propagation of those modes most sensitive to fiber bending, helping to improve both image quality and the versatility of the device.

A technology to restore some perception to patients suffering from forms of vision loss is also under investigation, using a specialized form of contact lens to deliver patterns of tactile sensation to the cornea — analogous to the physical interaction with raised Braille patterns used when reading from paper, according to Zalevsky.

His portfolio duly encompasses projects at various stages of commercialization, with some already well advanced along the path.

“The remote bio-sensing technology has been commercialized via a startup called ContinUse Biometrics,” he said. “The company now has an alpha prototype, and the goal is to bring a first product to market during the first quarter of 2017. Our endoscope design is moving towards market through another spin-out, Z-square, which received initial funding from a specialist biomedical incubator and is now raising investment for commercial exploitation of the technology.”

Earlier-stage projects brewing within the group and still preparing to seek funding include a design for in-fiber optical neural networks with “neurons” and “synapses” formed from individual silica cores in a multi-core fiber, and an all-optical means to encrypt digital information at a level below the nominal noise level of the optical fiber carrying the signal.

“A lack of communication across different disciplines is problematic for progress in engineering and technology in general, but it can be particularly difficult in biomedicine to speak the same technical language as other participants.”

Dialogue: as important as the science

Marshaling such a varied research program for successful real-world impact needs careful husbandry, but Israel has put in place systems intended to make the technology transfer operation as effective as possible.

“A lot of scientific research in Israel is applied by nature, although commercialization is still not automatically an easy process here or in any country,” commented Zalevsky. “But every university in Israel has a technology transfer company, under the national umbrella of the Israel Tech Transfer Organization, which encourages researchers at each institution to focus on research that is capable of eventually being commercialized, and which has the potential to lead to products that the market may desire.”

At Bar-Ilan this structure has seen the Bar-Ilan Research and Development Company (BIRAD) become involved in the spin-out of both ContinUse Biometrics and Z-square from Zalevsky’s lab.

On top of this local support, the Israeli government has recognized the funding gap that can hinder translation at the critical point where the step into commercialization is at its most fragile — the much-trod “valley of death.” It has allocated central funds targeted at projects that may not be ready for outright venture capital, but which have progressed far enough to be beyond the comfortable support of an academic institution.

However, this support for entrepreneurial researchers can only be properly effective if the researchers themselves are able to visualize the opportunities available — a perspective that cross-disciplinary networking at events like SPIE Photonics West helps to develop.

“A lack of communication across different disciplines is problematic for progress in engineering and technology in general, but it can be particularly difficult in biomedicine to speak the same technical language as other participants,” commented Zalevsky. “It may be hard for a photonics engineer to readily exchange views with a medical doctor about the areas of common interest, so developing a dialogue is important.”

Zeev Zalevsky, who heads up the electro-optics program at Israel’s Bar-Ilan University. The final of the SPIE Startup Challenge, which Zalevsky entered this year with the company “IC Touch”, takes place this afternoon in room 103. Photo: Bar-Ilan University.

Zalevsky himself was a semi-finalist in the 2016 SPIE Photonics West Startup Challenge with FabriXense, a novel approach for biomedical monitoring of vital signs such as heartbeat, blood oxygenation and blood pressure, utilizing an optical fiber-based sensor incorporated into smart clothing. The design is intended to remove the need for full contact between the clothing and the wearer’s skin, by analyzing light emitted by the fiber and reflected back from the skin, as well as providing an interferometry function to detect movements and deformations caused by the wearer’s movements.

“The Startup Challenge was not my first competition, and my philosophy is to learn from all such meetings and opportunities, whether you win a prize or not,” said Zalevsky. “My experience was very positive, and I am glad SPIE realizes that activities like the Startup Challenge and the Prism Awards are as important as the pure science being discussed at the conference.”

TIM HAYES

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product focus

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31 January - 2 February 2017

Welcome to the optics.org Product Focus which we have published specifically for Photonics West 2017 in partnership with SPIE and the Photonics West Show Daily.

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

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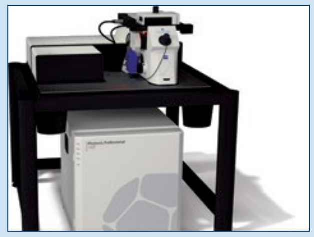

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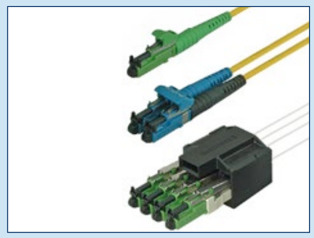

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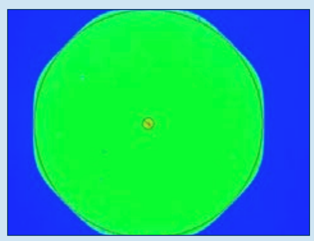

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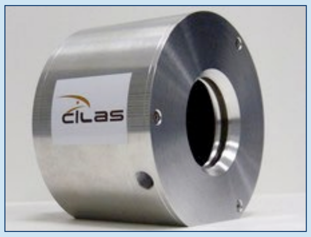

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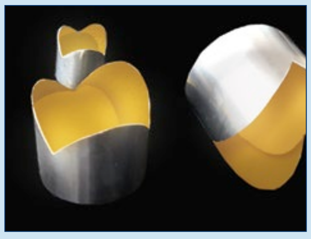

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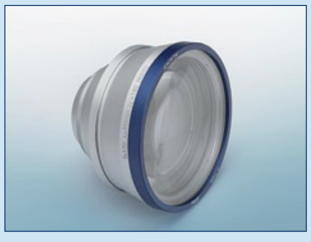

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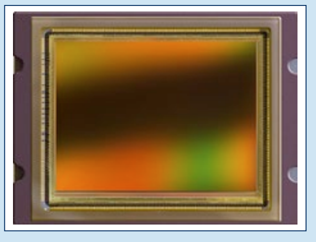

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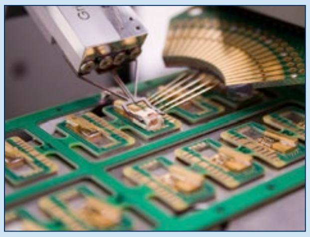

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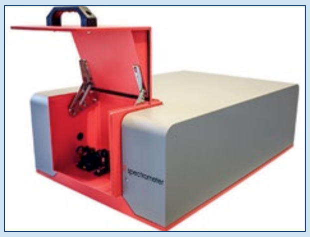

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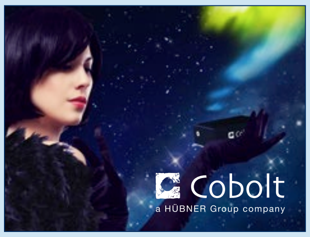

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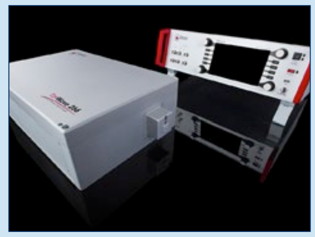

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ALPHA-RLH showcases innovations from nine cluster members at Photonics West

ALPHA-RLH (Route des Lasers & des Hyperfréquences®), a newly merged technology cluster specializing in photonics, lasers, microwave and digital technologies, will host the innovations of its cluster members **Neta, Irisiome, ALPhANOV, Spark Lasers, ISP System, First Light Imaging, Kylia, Femto Easy, Azur Light Systems**, as well as unveil new products, at Photonics West.

Novel devices improving imagery, laser accuracy and speed will also be unveiled at ALPHA-RLH stand #1823 during the event.

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Amplitude: on the crest of a wave

Eric Mottay, CEO at the French ultrafast laser specialist, talks company growth, Prism Awards, and politics.

Eric Mottay, co-founder and CEO at Amplitude, has overseen significant expansion in the past couple of years, with the acquisition of US-based Continuum, a new site in Seoul, and investment in the company's Bordeaux production facility. Photo: Amplitude Laser

Based near Bordeaux, France, the Amplitude Laser Group develops and manufactures ultrafast lasers for a range of scientific and industrial applications, and thanks in no small way to its distinctive, brightly colored products, has become a familiar sight on the Photonics West exhibition floor.

The company, led by co-founder and CEO Eric Mottay, has been particularly expansive in the past few years: buying San Jose's Continuum Lasers in 2014; opening a glass research lab at L'Institut d'Optique in Bordeaux; and, following a deal with Samsung's venture wing in late 2015, a subsidiary in Seoul with an eye to market opportunities in Asia.

After all that, the Amplitude group of companies now employs more than 300 people. It means that Mottay is unsure whether to consider Amplitude large or small: "We can actually be both because, although we employ several hundred staff, we are challenging much larger players such as Coherent and Trumpf, which employ thousands," he said. "However, I believe we have strong differentiators because Amplitude is focused on ultrafast lasers only, whereas the others do all sorts of lasers and systems."

In fact, the CEO claims that Amplitude is the only company to offer the complete range of ultrafast laser technologies currently available, from industrial fiber lasers through to high-energy, petawatt-class Ti:sapphire sources — with the company's rate of growth propelled by a similarly wide range of applications.

"Generally, our markets are growing — in the sense that the range and volume of applications are increasing," he observed. "Our technology is mature but still developing so that new applications can be developed on an industrial scale. The increase in average laser power, of which the Tangor (Amplitude's Prism-nominated ultrafast fiber laser) is an example, has led to the development of new applications."

Alongside the product development work, Mottay highlights continuing structural growth: "We have been reinforcing our operations in Korea and China, especially. And in France in the past few years, we have almost doubled the size of our facility in Bordeaux."

For Amplitude, Asia now generates a strong pull. "A couple of years ago demand centered on systems from integrators based in the US or Europe, but now in Asia there is a good network of local systems integrators working locally," the CEO said.

"By the second quarter of 2017 we will significantly increase our production capability for the international market, and also the scientific capabilities of our ytterbium lasers," he says, pointing out collaborations with the European Extreme Light Infrastructure project (see feature page 7), as well as growing applications in LASIK and cataract eye surgeries and the microelectronics sector.

Amplitude's new "Yuja" ultrafast laser, which is making its world debut in San Francisco this week, is designed for cutting and drilling delicate materials. Photo: Amplitude Laser

Asked about business growth in the past year specifically, Mottay would not reveal precise figures (Amplitude is privately owned) but commented, "Overall, Amplitude has seen sales growth at a double-digit percentage level in 2016, which is comparable with the global rate of our part of the laser market, which I would say has been 10 to 15 percent, per year."

So what is behind the period of sustained growth and product development? "We are now seeing more convergence between our constituents than when we started the company," Mottay observes. "We divided the business into two distinct parts: Amplitude Technologies, where we develop applications for big science, and Amplitude Systèmes, where we focus on the smaller lasers."

With the market for ultrafast lasers seemingly growing in all directions, Mottay cautions that this also creates some challenges: "There's a strong demand for process development such as in new surface treatments, glass drilling and materials processing."

But, crucially, it appears that the laser is no longer the bottleneck it once was. "We have technologies that can handle the beam and manage the processes," he says. "Beam engineering, shaping and handling represent active fields of development."

He added: "We have seen the performances of our ytterbium laser technologies increase and we see industry taking more and more of these, as they replace Ti:sapphire sources. However, Ti:sapphire still has a role in the very-high-energy sector, [generating] petawatt powers, where there is still no other technology that can do that job."

Mottay also believes that the more mature laser type is holding on in spectroscopy. "The Ti:sapphire laser has a short pulse duration, combined with tunability, but these capabilities are complemented by ytterbium sources," he said.

"I don't know what will be the end-stage of this market, but replacement is gradually happening."

Prism shortlist

Thanks to the 100W Tangor, the latest in its fruit-themed series of ultrafast fiber lasers, Amplitude will be represented at tonight's Prism Awards — where it is up against QD Laser and Photonics Industries International in the industrial lasers category. With its high average power and a sub-500fs pulse duration, the Tangor is suited to high-throughput manufacturing and could give the company its second win in the competition — the Satsuma fiber laser having triumphed in 2012.

Mottay told *Show Daily*, "Winning a Prism Award is a stamp of credibility because it's recognition by people who actually know about these technologies. It's also a nice acknowledgment for our R&D team, because they don't usually get much recognition externally. We will use this nomination for promotion because the Prisms are the best-known awards in our industry."

At this year's exhibition, Amplitude is showing new developments in the form of beam engineering modules and devices, alongside a brand new laser. "We will continue to develop lasers that are dedicated to specific applications," said the CEO. "For example, we are introducing a very small laser called the Yuja, which is making its world debut in San Francisco."

Described as a versatile, high-energy laser, the Yuja is designed for cutting and drilling delicate materials. Delivering more than 100 µJ pulse energy, with a flexible repetition rate from 100 kHz to 2 MHz, it will be suited to high-speed drilling in applications with geometries demanding micrometer-range accuracy. A pulse duration of below 500 fs allows for high-quality processing of many materials, with minimal heat transfer.

As the largest laser company in western France, Amplitude has also played a major role in the Route des Lasers cluster, which until recently covered the region of Aquitaine. The French government

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Amplitude continued from page 21

has since changed the definition of the country's administrative areas, so that the expanded "Nouvelle Aquitaine" region now includes Limoges and several other locations with photonics expertise — especially fiber lasers, microwave sources and hollow-core fibers. Companies and research groups in these areas are now part of Route des Lasers — which Mottay believes is a positive development.

"It is good because Route des Lasers is now strong in both active and passive technologies, and the new additions are complementary to the skill-set that Amplitude has," he said. "We were one of the first participants in the Route des Lasers and since the company has grown it has been a very active member of the cluster."

Now a region with an international reputation for photonics excellence, Bordeaux is also home to the photonics investment conference "InPho" (formerly Invest in Photonics), which has evolved into a biennial meeting for high-tech startups and financiers. Mottay attended the latest edition in October 2016, where Chronocam, a Parisian firm developing biologically inspired sensor technology for machine vision, scooped the €5000 first prize in the startup competition.

"Photonics has always been a tough sell to the financial community because it's still regarded by many as an enabling technology, rather than as a standalone, valuable market in itself," Mottay reflected. "One of the reasons that photonics is trying to stretch its reach at events like InPho is to attract investment."

EU and Brexit

The investor community may still be somewhat cautious but the European Commission has long recognized photonics as an industry, as well as a key enabling technology. Mottay, whose involvement on the board of the Laser Institute of America gives him a transatlantic perspective on the status of photonics and its attractiveness to investors, feels this is a significant step forward in terms of encouraging funding and support.

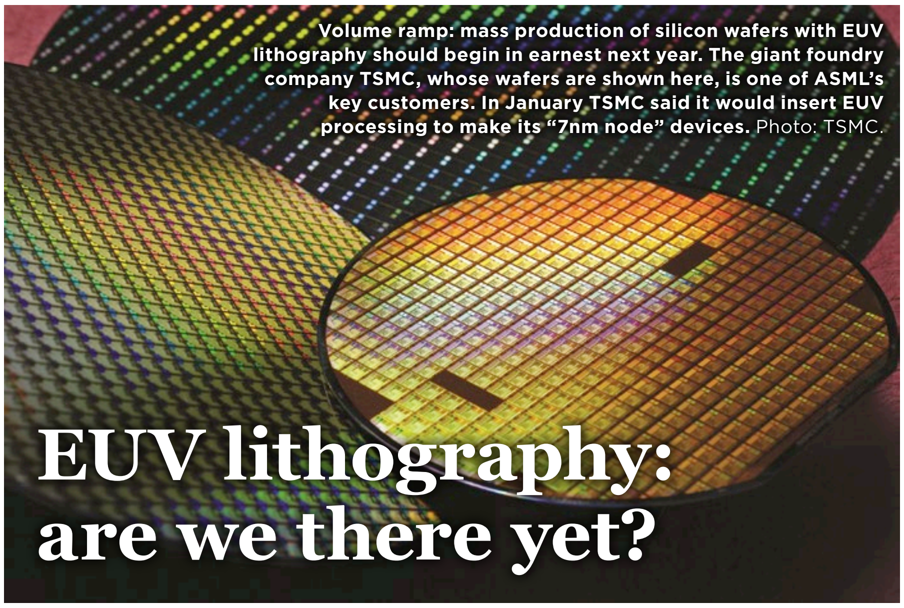
"Considering its approach to photonics as a business, the European Union is the envy of the US, because Europe has recognized photonics as an industry," he said. "For Amplitude, being part of the EU is very important for our co-development of projects and solutions."

"I want to open the door as much as possible in terms of partnerships," Mottay added. "Gone is the time when a single company can do all of its own research and development. So the European drive for partnerships and joint innovation is also necessary." Another advantage of centralized funding programs like the European Commission's Horizon 2020 scheme is that it can offset any shortfalls in investment opportunities at the national level. Amplitude has been active in a number of Horizon 2020 projects, benefiting from both the financial support and establishment of innovation networks.

Considering the potential fall-out of the UK's "Brexit" referendum and the whiff of nationalism drifting across Europe, Mottay noted: "So far, the Brexit referendum has had virtually zero consequences for Amplitude, as we are still doing business with the UK. Our business is mainly exports within Europe and beyond. I cannot say I am happy with the apparent trend towards more inward-looking politics, because our business and research and development programs are international; we have development programs everywhere."

MATTHEW PEACH

Amplitude is exhibiting its range of ultrafast sources, including its 100W Prism-shortlisted Tangor and compact Yuja lasers, at booth #1707. The company will also maintain a strong presence in the conference rooms, with 12 technical presentations.



Volume ramp: mass production of silicon wafers with EUV lithography should begin in earnest next year. The giant foundry company TSMC, whose wafers are shown here, is one of ASML's key customers. In January TSMC said it would insert EUV processing to make its "7nm node" devices. Photo: TSMC.

EUV lithography: are we there yet?

After decades in development, extreme ultraviolet lithography is finally set to make its mark in volume production.

For a while it had seemed that the long and frankly tortuous road towards extreme ultraviolet (EUV) lithography deployment might in fact be the road to nowhere. First included in the International Technology Roadmap for Semiconductors (ITRS) in the mid-1990s, and after billions of dollars of research investment, it's only really in the past few months that the case for EUV has started to look certain.

Even now, some doubts linger, with key elements of the production ecosystem still in development and more than a few naysayers remaining to be convinced. But what changed in 2016 was the tone of the debate, shifting to "when" and not "if" EUV will really hit its straps.

ASML, the lithography giant that has pretty much bet the house on the technology, is the key player in all things EUV. Nikon and Canon, its rivals in the earlier and current generations of lithography equipment, have decided that EUV development is not a risk worth taking: safe in the knowledge that chip fabrication will still rely on several processing steps using more conventional deep-UV (DUV) lithography tools and a certain amount of multi-patterning.

Anxiety levels

Speaking at an investor event hosted by Morgan Stanley in late 2016, ASML's CEO Peter Wennink said that — counter-intuitively — a recent increase in anxiety levels among its chip-making customers was actually a positive development. "Customers are not anxious about the EUV tool, but now that they have confidence in that, they start to worry about everything else," he told the assembled bankers. In this case, "everything else" relates to the wider EUV production ecosystem: things like mask blanks, pellicles, photoresists, and mask inspection tools.

The good news, Wennink says, is that despite a delayed start to ecosystem development, things are now moving quickly. Companies providing all those different elements needed more certainty about the key piece of equipment, ASML's tool, before investing in their own EUV technology development, he reasons.

"Now it is all about hard work," Wennink said. "Some of these developments only began a matter of months ago. But it is all solvable. The focus is on having everything ready for the 2018-2019 time frame, when the EUV systems will start volume production runs. There's very little doubt that the necessary ecosystem will be there."

The fact that six different customers have now signed up for production EUV tool deliveries is one of Wennink's key pieces of evidence. "The tone has changed to 'it's going to happen'," he stressed, with one chip foundry even embarking on a customer roadshow to sell the new EUV chip design possibilities. "What ASML's customers — and their customers — say about EUV is more significant than what ASML says," Wennink points out.

So what exactly have those chip manufacturers been saying? Well in recent months Samsung has gone on the record with its expectation of adopting EUV for the future 7nm production "node", while TSMC anticipates using it "extensively" in 5nm logic device production after initial insertion in the second year of its 7nm device node. Intel previously said that it may deploy EUV in its 7nm process flow — provided that uptime, availability, and throughput targets are met. During the Consumer Electronics Show (CES) in Las Vegas just a few weeks ago Intel's CEO Brian Krzanich did not mention EUV directly but he sounded confident about the lithographic future when he kicked off a virtual-reality-themed CES keynote by focusing on the health of Moore's law.

"Is [Moore's law] alive?" he asked the Las Vegas throng, demonstrating a new laptop powered by one of the firm's very first 10nm-node "Cannonlake" processors. "It's alive and well and flourishing. I believe Moore's law will be well beyond my career."

Another chip maker, GlobalFoundries, is keeping its options open at 7nm, but CEO Sanjay Jha pointed out at the firm's technology conference last September that if it doesn't use EUV, more than 84 mask processing steps would be needed with DUV — highlighting the potential value of the new tools for simplifying the wafer patterning process.

In terms of direct competition to ASML in the EUV realm, things look simple enough: there is none. Last November its long-time rival Nikon said that it would move hundreds of workers out of research on semiconductor wafer exposure and redeploy them in other projects. During EUV's introductory period, DUV lithography tools will remain the workhorse of the industry, carrying out a large proportion of the processing steps needed to fabricate a silicon wafer full of transistors.

"The real competition is the cost of the [EUV] technology for our customers," is how Wennink puts it, in the sense that ASML is competing against its own DUV tools and multi-patterning approaches while Nikon is retrenching.

The problem with the multi-patterning approach is that it gets very complicated very quickly when considering how to make wafers at the 10nm node and beyond. According to a recent presentation by Hans Meiling, ASML's VP of EUV product management, where a DUV tool would require 34 separate lithography steps (and nearly twice as many as that when also counting critical alignment overlays), an EUV lithography tool could produce the same critical wafer patterns in just nine steps.

Now, what does all this have to do with Photonics West? Well, each of ASML's new tools relies on a wealth of laser and optics technology: primarily to produce the EUV light by firing high-power carbon dioxide lasers and other "priming" beams at a stream of tiny tin droplets in the massively complex EUV source chamber. And although this principle is now well established, improvements to system availability and chip-production economics will rely in part on refining the drive laser's consistency — it is ultimately more raw EUV power that is required to hit future productivity goals. The high-power lasers in ASML's tools come from Trumpf, with 40 kW systems used to produce the EUV-emitting plasmas that provide the broadband source light needed. However, fluctuations in laser and therefore EUV source power are one of the final issues that still need to be ironed out before full volume production of semiconductor wafers with the technology can begin.

Optics challenge

One of the critical relationships in the food chain concerns the lithography tool's optics, where ASML's key partner is Zeiss. Before EUV, these were all based on transmissive designs, but the 13.5nm EUV wavelength means that reflective optics are necessary for the new generation. Such is the complexity and intricacy of the new designs that the cost of the optics alone in each new EUV lithography tool is estimated at an extraordinary €20 million, up from €8 million in a DUV stepper.

And that cost is only going to go up for future generations, observes Wennink. "The EUV mirrors need to be ridiculously flat," he says. To illustrate just how flat, he uses a well-worn analogy: if the mirrors were the size of Germany, the highest "hills" on a map of the country would be just a millimeter high. "Nobody can do this right now," he says.

One of ASML's "NXE:3300" EUVL tools, installed in a cleanroom at the State University of New York (SUNY) Albany Nanotech complex. SUNY is working on a $500M, five-year EUVL development program with chip maker GlobalFoundries. Photo: Melissa Renzi/SUNY Poly.

In fact, the challenge of future EUV optics is well beyond the means of a company even as large and technologically advanced as Zeiss, necessitating a new relationship that will see ASML take a large equity stake in the historic optics firm, in exchange for a billion-euro investment.

"The current generation of EUV optics will work for another 15 years, but [we] will need high-NA [numerical aperture] designs after that," Wennink explains. "It

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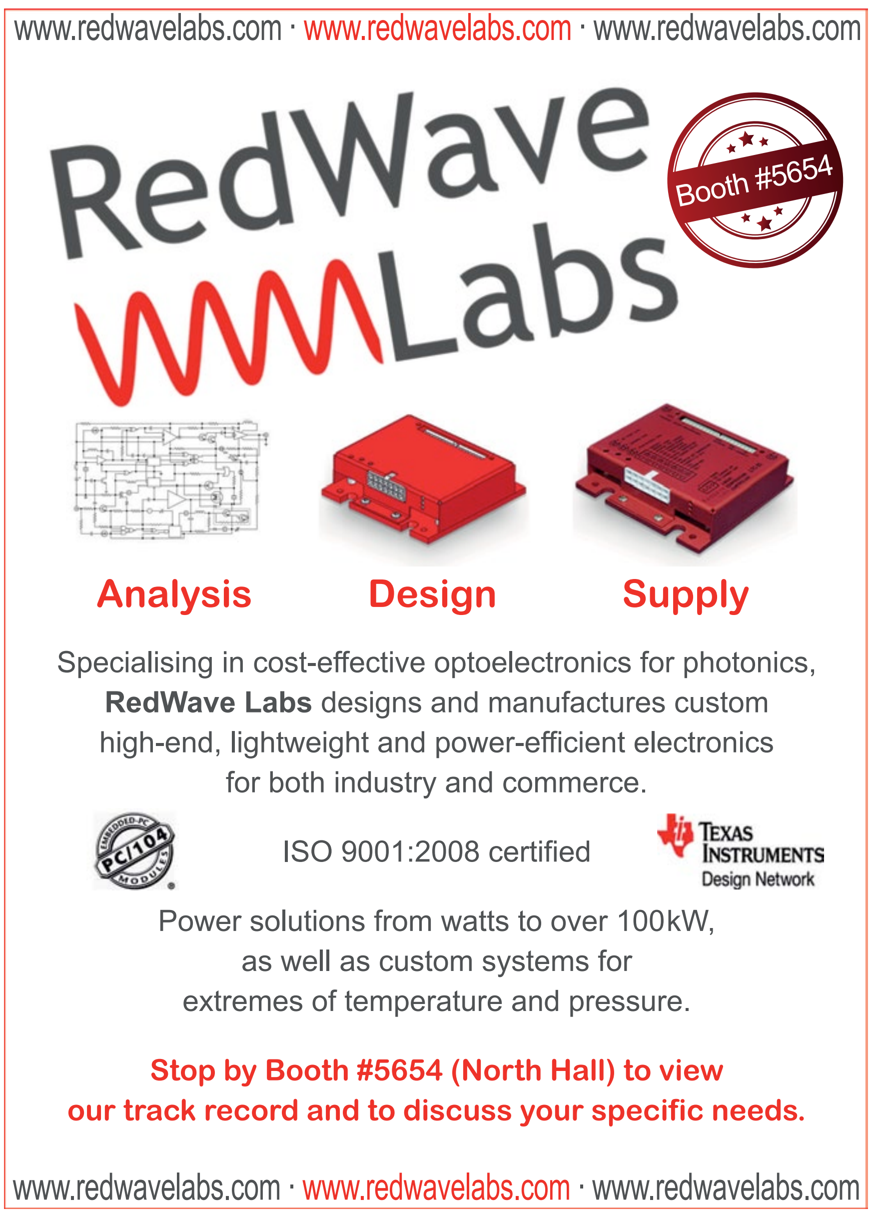
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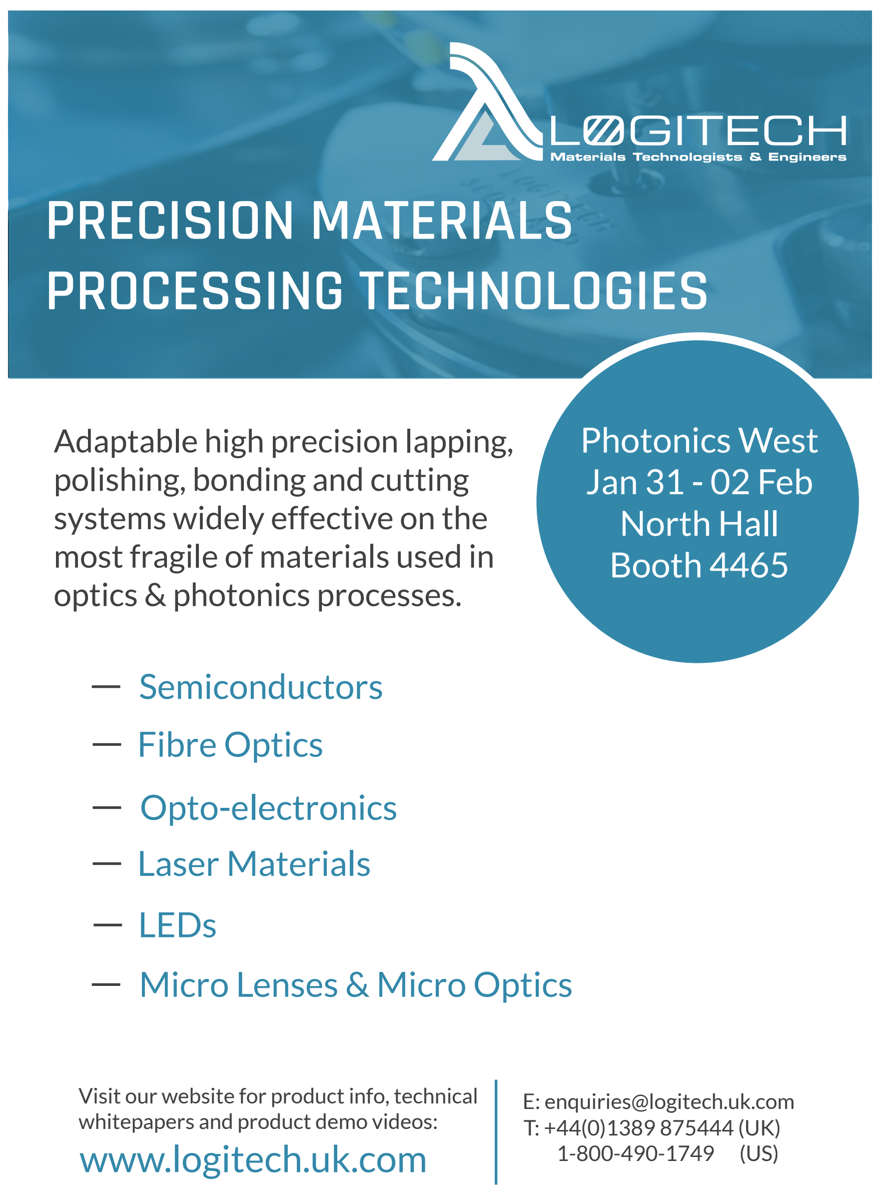
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requires a different optical system that will be hugely costly to develop. It involves optics that are absolutely world-class. In fact nobody can make them at the moment, not even Zeiss."

For Zeiss, making that investment on its own would represent a level of risk that the optics firm was simply not prepared to take; it would effectively consume the company's entire R&D spending, leaving none for the three other divisions belonging to the portfolio company. The ASML equity deal allows it to share that risk with the only customer in town, while ASML benefits from the profitability of Zeiss' semiconductor manufacturing technology (SMT) business — of which it is the near-exclusive customer.

"The most important aspect is that ASML and SMT executives get to sit together on the board and make decisions about the future of the business, such as taking appropriate levels of risk," Wennink says. Until now, ASML's number-one risk factor has in fact been Carl Zeiss — because it was completely dependent on the optics company. But as co-owner of Zeiss SMT, that risk will be much-reduced.

Gigaphoton source efficiency

An area where ASML faces a competitor of sorts is in the equally tough development of EUV source technology, in the form of the Japanese company Gigaphoton — whose CTO Hakaru Mizoguchi is delivering a plenary speech on the topic at this year's LASE symposium.

Ultimately, ASML needs a 250W power EUV source to deliver the kind of wafer productivity throughput demanded by its chip-manufacturing customers. For years, that power level had looked all but impossible, before technicians at ASML's Cymer subsidiary and Gigaphoton both hit upon the idea of using two types of lasers in their sources: one the hugely powerful drive beam that produces broadband (including EUV) light when fired at tin droplets, and a second "pre-pulse" or trigger laser that effectively primes those droplets to maximize EUV generation and the overall efficiency of the process.

According to a technical communication published last year by Mizoguchi's development team in the *Journal of Laser Micro/Nanoengineering*, the "GL200E" production source will be able to generate 250W of EUV output from a 20 kilowatt carbon dioxide drive laser — suggesting that the team has found a way to make the laser-to-EUV conversion process significantly more efficient. And given the colossal laser powers required, such energy savings could be extremely valuable.

Gigaphoton's approach uses a dual-laser

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Reflective optics developed for EUV lithography applications by Rigaku. ASML and Zeiss have joined forces to develop future generations of high numerical aperture (high-NA) EUV optics. It is hoped this will circumvent the need for multiple-patterning with EUV, which is viewed as prohibitively expensive. Photo: Rigaku Innovative Technologies.

EUV Lithography continued from page 27

"priming" pulse ahead of a nanosecond-duration carbon dioxide blast, with a prototype said to deliver more than 100W of "clean" EUV power at a repetition rate of 100kHz and a claimed conversion efficiency of 5% — a figure that can be considered remarkably high for EUV sources. One way to improve the conversion efficiency is to use picosecond pulses in the "primer", and Gigaphoton has previously experimented with frequency-tripled Ti:sapphire sources to excite specific electronic transitions within the target tin atoms to achieve this.

Mizoguchi says that the success in achieving the record-breaking conversion efficiency while attaining a 100W average output, combined with stable operation and a high duty rate of 95%, shows that the Japanese firm's engineers are "very close to the market introduction stage" for EUV light sources offering lower running costs than has been the case so far.

Specialist optics

Such are the power levels involved in laser-driven EUV sources that specialist optics are needed to handle the beams — with Photonics West exhibitor and diamond optics maker Element Six among those involved. Henk de Wit, general manager and business manager of the company's optical activities, backed up ASML's assertions, telling *Show Daily*: "EUVL is now really gearing up for introduction in 2017 and 2018."

The complexities of CVD diamond optics manufacture mean that lead times are measured in months rather than weeks, and so the Element Six order book ought to make a good proxy for both the rate of EUV tool deployment and development.

"Current CVD diamond technology is sufficient for the current generation of EUVL light sources," de Wit said. "However, as demands increase for faster throughput, advanced solutions are required to produce more robust optics. To enable further increases in power levels, Element Six has introduced 'Diamond PureOptics', an all-diamond optics range, to enhance the stability of anti-reflective solutions, increasing system reliability at high optical power densities."

Ideally suited to EUV applications, this range of products is said to exhibit a factor-of-ten higher laser-induced damage threshold compared with anti-reflection coated windows, combined with a reflectance of less than 0.5 percent and a transmission above 99 percent.

Although the company does not reveal how many diamond optics components are needed in the first generation of production EUV tools, de Wit added: "Further increases in power levels to enhance wafer throughput may require more components to use CVD diamond. As an example, we have seen common interest in another product in the PureOptics family, the quarter-wave plate."

Meanwhile, Rigaku Innovative Technologies (RIT) has announced a range of precision lithography optical coatings for manufacturing the ultra-reflective mirrors needed for EUV wafer patterning. "RIT's reflective optics are critical elements of the optical chain used inside scanner tools that print chip patterns onto a wafer at rates of speed as high as 125 wafers per hour," states the Japan-headquartered firm.

Exploiting three decades of experience in reflective optics production, RIT can claim to be the only truly independent volume manufacturer in the industry — and one of the first to invest in research and development of multilayer coatings designed specifically for EUV lithography.

The company says it recently installed a second in-line, high-throughput deposition system, meaning that it now has two independent systems that can simultaneously deposit coatings onto four large optics of up to 800 mm in diameter — again supporting the notion that the EUV era is nearly upon us.

So, is EUV lithography there yet? Well, no, not quite. But it's getting real close — those attending this morning's LASE plenary talk by Hakaru Mizoguchi should find out just how close.


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NKT Photonics on the hunt for talent

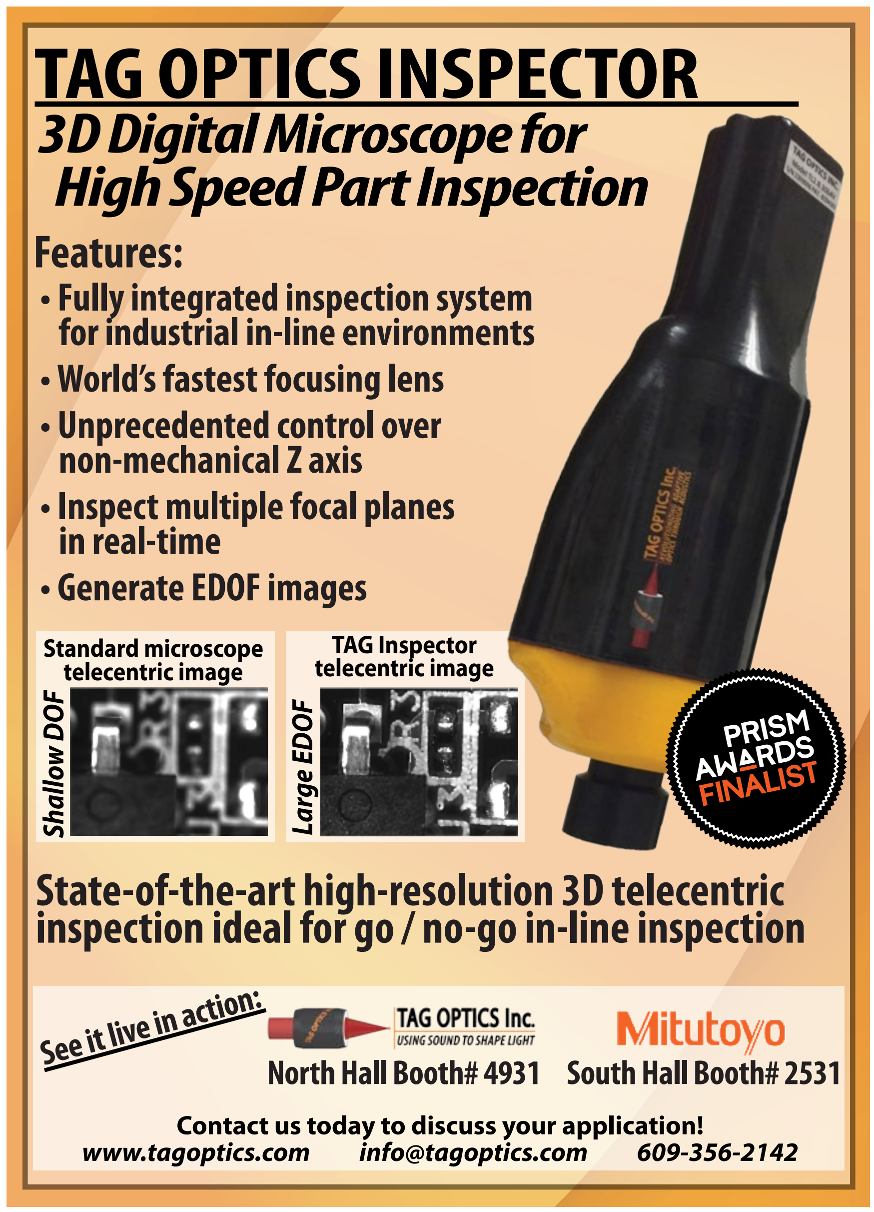
In the laser industry, the switch to fiber technology has been a hot topic for years and at the forefront of the wave we find photonics crystal fiber pioneers NKT Photonics. With a comprehensive product line spanning everything from supercontinuum lasers, ultrafast- and single-frequency lasers, to distributed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

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

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

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

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



Excited Excelitas targets lidar with laser module

Photonics West exhibitor Excelitas Technologies launched a new pulsed laser diode array, aimed at lidar applications including drones and the emerging era of autonomous vehicles.

The Waltham, Massachusetts, firm says that, unlike single-pixel lasers, the 1x4 linear configuration enables each pixel to be situated in very close proximity to its neighbor - minimizing space requirements in the assembly and enabling the use of smaller, less costly optical components. Reducing the size and cost of lidar units is seen as a critical element of the move towards autonomous driving, where a fusion of data from lidar, radar and imaging sensors would be used to control vehicles.

Excelitas adds that each laser pixel can have up to four emitting stripes, enabling high per-channel optical power levels in excess of 85 W, for long-range detection with minimal power consumption and a rise time of less than 5 nanoseconds with suitable drive electronics.

Denis Boudreau, product leader at Excelitas, told *Show Daily*: “Our design can be used either with all pixels fired at once, or selectively one channel at a time.” He added that with VCSELs, which others are pursuing as an option for compact lidar units, the much lower output means that a larger two-dimensional matrix is needed to get the necessary power. “This leads to larger and more expensive optics, which does not make that technology practical for long-range applications,” Boudreau said.

Customized Excelitas products using the same laser technology are currently being designed into various lidar systems, says the firm, with a range of approximately 200 meters possible using appropriate drive electronics and heat-sinking. “While this technology gives great range, it also allows greater field of view and smaller objects to be resolved,” Boudreau added.

“There definitely is a high level of demand in this area, with a sharp increase in the last couple of years, everyone from small startups to large OEMs all jumping in,” he said of the emerging application in autonomous driving. “It certainly will be very interesting to see how this evolves over the next three to five years. These are exciting times!”

MIKE HATCHER

LIVING LASERS: TIME TO GO *IN VIVO*

“Lasers inside live cells” was the title of a tantalizing topic presented as part of BiOS conference Biophysics Biology and Biophotonics II: The Crossroads on Saturday, courtesy of Matjaž Humar from the Jožef Institute and University of Ljubljana, Slovenia, and Harvard Medical School.

Humar’s group first demonstrated laser implantation and operation inside a single live human cell in July 2015. “We have also demonstrated that the fat cells in our body already contain lasers, which need only to be activated,” he told the conference, referring to cells which can act as resonant cavities when stimulated with light.

The lasers are in the form of small solid spheres or lipid droplets. Deformation enables accurate measurements of the forces inside the cells. One of the beneficial uses of living tissue lasers is that the emission of each laser can be used as a barcode with enough unique combinations to tag each of the millions of cells in the human body, which would be impossible to achieve with dyes.

“Previously, to insert a laser into cells or into biological tissues, researchers have used many different light sources, such as quantum dots or proteins. But the problem is that they have a very broad emission spectra, so if you want to make and use a lot of those probes they will have a lot of overlap of the wavelengths,” he explained.

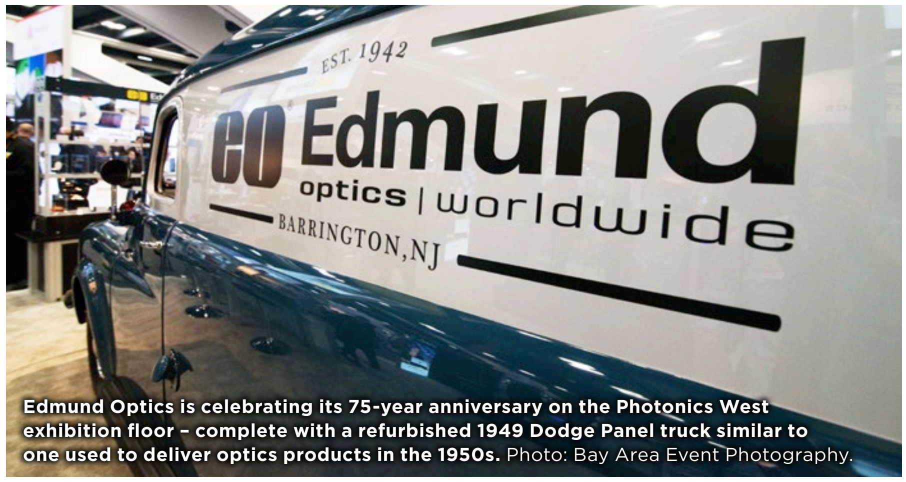
Instead, live cell lasers are more useful because they generate narrow lines, so that multilplexing and precise sensing are enabled. Humar’s aim has been to construct all the elements — laser cavity, medium and pump — from biological materials then place them inside living cells.

“I am using a whispering gallery mode laser, which is formed when light is trapped by total internal reflection at the surface of a transparent spherical object, such as a bead or droplet several micrometers in size,” he said.

Humar has also investigated lasers based on liquid crystals, including cholesterol. “They settle into nice periodic structures. When you put a dye inside this you obtain a good lasing medium. When you pump this then you can achieve very nice lasing; this laser is also very sensitive to the temperature, so by making a laser we are also making a biological temperature sensor.”

Looking ahead to the next stages of living cell laser development, Humar concluded, “In future work, we intend to further decrease the size of the lasers, thereby enabling even sub-cellular organelles to be targeted. We also plan to show the capability of cellular lasers *in vivo*.”

MATTHEW PEACH



Edmund Optics is celebrating its 75-year anniversary on the Photonics West exhibition floor – complete with a refurbished 1949 Dodge Panel truck similar to one used to deliver optics products in the 1950s. Photo: Bay Area Event Photography.

NAVITAR SNAPS UP PIXELINK FOR IMAGING

Rochester-headquartered Navitar is acquiring fellow exhibitor PixeLINK, which develops digital cameras for use in industrial, life science, and other advanced imaging applications.

Based in Ottawa, Canada, PixeLINK specializes in industrial cameras for machine vision applications and microscope cameras for life science and digital microscopy, incorporating both CMOS and CCD technology. Its latest models are equipped with the 12.3 megapixel Sony Pregius IMX253 and 8.9 megapixel IMX255 sensors to support 4K Ultra HD video.

Navitar president Michael Thomas said: “The addition of the PixeLINK business enables us to provide our Navitar core dealers and OEM customers in machine vision and life science a large range of visible spectrum camera solutions.”

Julian and Jeremy Goldstein, who own Navitar, added: “We look forward to developing ground-breaking integrated camera and lens solutions optimized for the sharpest, cleanest images available in the industry.”

Navitar will host live demonstrations with a PixeLINK camera at booth #638.

Extended focus promises endoscopy breakthrough

A new endoscope for imaging the esophagus offers three times higher resolution and better depth of focus than existing tethered capsule technology, according to Barry Vuong, a research fellow at Massachusetts General Hospital and Harvard presenting on Monday.

Vuong showed video from tests with the prototype screening technique, developed at MGH for a more precise look for signs of cancer and other diseases. “It’s a really big advance,” said Gary Tearney, a pathology professor at Harvard Medical School.

Current devices suffer from a lack of depth in imaging, Vuong said. The new device goes deeper while maintaining good lateral resolution — and is apparently more comfortable for patients. “Like taking a large candy,” said Vuong. “They don’t complain.”

The new technique, called extended depth of focus (EDOF), features a capsule 28 millimeters long by 11 millimeters wide. It spins on the end of an optical fiber inside a 2 meter-long tether, with screen-based diagnosis possible in real time.

EDOF can image the layers below the surface “beyond the expected 2 millimeters,” Vuong said, and the images shown in his video were indeed sharper than those made with existing technology. He showed the device to a packed hall at an early morning session of the BiOS symposium.

EDOF could become a low-cost, minimally invasive option for clinical work, thinks Vuong, adding that it is just a few months away from completion as a research device.

FORD BURKHART

Neurophotonics hits its stride at BiOS

Following in the footsteps of the popular Saturday night BiOS Hot Topics sessions, the first-ever neurophotonics plenary session at Photonics West on Sunday featured 10 rapid-fire presentations covering the broad spectrum of neurophotonics R&D currently taking place worldwide.

"There is a strong focus on developing the technologies to dramatically impact our understanding of how the brain works," said David Boas, who moderated the session and is editor-in-chief of SPIE's *Neurophotonics* journal.

One of the initial challenges has been to find new ways to measure tens of thousands of neurons simultaneously. This requires taking an interdisciplinary approach to technology development that brings together neuroscientists, engineers, physicists, and clinical researchers. It also prompted SPIE to add a technology application track on the brain this year.

"SPIE recognized the need to bring together all the different groups in this field to get an overview of the many neurophotonics activities going on," Boas said.

The neurophotonics plenary session showcased the diversity of these research efforts, from genetically encoded indicators of neuronal activity to 3-photon microscopy for deep brain imaging, chemical sectioning for high-throughput brain imaging, and mapping functional connections in the brain.

"We need to step back and think about all of these important methods and the larger picture," said Rafael Yuste, professor of neuroscience at Columbia University and a pioneer in the development of optical methods for brain research. His presentation covered novel neurotechnologies and their impact on science, medicine, and society.

"Why don't we already understand the brain?" Yuste asked. "People say it's just too complicated, but I believe the reason … is that we don't have the right method yet. We do have methods that allow us to see the entire activity of the brain, but not enough resolution of a single neuron. We need to be able to record from inside the neuron and capture every single spike in every neuron in brain circuits."

Here are highlights from other plenary talks:

Genetically encoded indicators of neuronal activity. Taking a cue from Nobel Laureate Roger Tsien, a pioneer in the field of engineering proteins for neuroscience, Canadian researchers at the University of Alberta are working to develop new kinds of protein indicators to study neuronal activity, noted the university's Robert Campbell. While early calcium indicators were synthetic tools, the Campbell Lab is working on genetically encoded proteins, taking a fluorescent protein and turning it into a calcium indicator, "a proxy for neuronal activity," Campbell said. Most recently, they have developed FlicR1, a new type of red fluorescent voltage indicator that can be used to image spontaneous activity in neurons. "We are very optimistic about this new indicator," he said.

Optical detection of spatial-temporal correlations in whole brain activity. Studying these types of correlations is "very important because morphology and functionality in the brain are tightly correlated to each other," said Francesco Pavone of Università degli Studi di Firenze in Italy. His group is taking a multi-modality approach in mouse models to study brain rehabilitation following a stroke. They are using light-sheet microscopy to look at vasculature remodeling, two-photon imaging to study structural plastics, and wide-field meso-scale imaging to evaluate functional plasticity. "We would like to study at all brain levels the map of all activated cells," Pavone said.

Peter So, MIT. Photo: Amy Nelson

Two-photon optogenetics with millisecond temporal precision and cellular resolution. "Do we have the technology to develop multi-cell, multiplane optogenetics with millisecond temporal resolution and single-cell precision?" asked Valentina Emiliani, director of the Neurophotonics Laboratory at University Paris Descartes. Her lab is working with computer-generated holography, spatial light modulators (SLMs), and endoscopy to control the activity of a single neuronal cell. "We have been able to achieve very robust photostimulation of a cell while the mice were freely moving, with nice spatial resolution," she said.

Monitoring synaptic activity across the full dendritic arbor. Peter So, professor of mechanical and biological engineering at Massachusetts Institute of Technology, described his group's work using 3D holographic excitation for targeted scanning as a way to study and map synaptic locations in the brain. "Neurons generate responses from many synaptic inputs, and we found that there are over 10,000 synaptic locations we would like to look at in parallel and map using synaptic coordinates to map activity," he said.

Three-photon microscopy for deep brain imaging. "Three-photon has vastly improved the signal-to-background ratio for deep imaging in a non-sparsely labeled brain," said Cornell University's Chris Xu. By combining a long wavelength (1300-1700 nm, the optimum spectral windows for deep imaging) with high excitation, Xu said researchers are making new inroads into deep imaging of brain tissue. Three-photon microscopy is also valuable for structural imaging and for imaging brain activity "in an entire mouse cortical column," Xu added.

Mapping functional connections in the mouse brain for understanding and treating disease. Mapping brain function is typically performed using task-based approaches to relate brain topography to function, noted Adam Bauer of Washington University School of Medicine. "But we want to be able to help patients who are incapable of performing tasks, such as infants and those with impairments," he said. For this reason, the lab has developed a functional connectivity optical intrinsic signal (fcOIS) imaging system to study mouse models of Alzheimer's, functional connectivity following focal ischemia, and to map cell-specific connectivity in awake mice.

Clinical neuro-monitoring with NIRS-DCS. Maria Angela Franceschini of the Athinoula A. Martinos Center for Biomedical Imaging described her group's work developing MetaOX, a tissue oxygen consumption monitor. The instrument has been tested in neonatal intensive care units to monitor hypoxic ischemic injury and therapeutic hypothermia. It uses frequency-domain near infrared spectroscopy to acquire quantitative measurements of hemoglobin concentration and oxygenation and diffuse correlation spectroscopy (DCS) to create an index of blood flow. The device is also being evaluated in Africa to study the effects of malnutrition on brain development, and in Uganda to study hydrocephalus outcomes in newborns.

Chemical sectioning for high throughput ex-vivo brain imaging. Shaoqun Zeng of the Wuhan National Lab for Optoelectronics in China outlined his group's work using chemical sectioning for high-throughput fluorescence imaging of a whole mouse brain at synaptic resolution. The goal is to systematically and automatically obtain a complete morphology of individual neurons.

Rafael Yuste, Columbia University. Photo: Amy Nelson

Opportunities and priorities in neurophotonics: perspectives from the NIH. Edmund Talley of the US National Institutes of Health shared his experiences with the US BRAIN Initiative, which is slated to receive more than $430 million in the 2017 federal budget, plus $1.6 billion in dedicated funds through 2026 via the 21st Century Cures Act passed in December 2016. "There is some very serious investment in neurotechnologies to understand how the mind works, and there is bipartisan political support," Talley said. "Multiple federal agencies are funding this."

KATHY KINCADE

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