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Electro Optics

Photonics business, applications & technology

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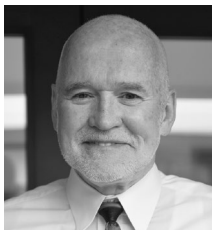
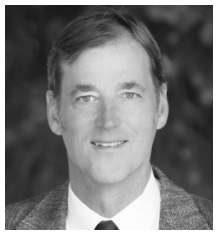
50 Years

Electro Optics turns 50 in 2018. To mark the occasion, experts across industry and academia review the current state of photonics and highlight what needs to happen for the field to prosper over the next five decades





With the industry gearing up for Photonics West 2018, **Dr Eugene Arthurs**, CEO, and **Peter Hallett**, director of marketing and industry relations, SPIE, point to science advocacy and education outreach as key for the future of photonics

How would you describe the current state of the photonics industry?

Hallett: The core optics and photonics market is healthy and growing, with many suppliers working overtime to meet customer demand. Meanwhile manufacturers from Asia are investing to expand their export business. At SPIE Photonics West for example, we have more requests for new booths from global competitors than we have available space; the exhibition is sold-out.

Some of these 'new' market entrants use premium manufacturing and metrology tools, which may close the gap in component quality. Their challenge is customer development, not product development.

Meanwhile in photonics-enabled markets such as life sciences and healthcare, communications, semiconductor manufacturing, robotics and digital production (Industry 4.0), virtual/mixed reality, consumer electronics, and autonomous transportation are stronger than ever. One lidar innovator told me he sees this environment as bigger than the telecom boom without the threat of overcapacity.

High corporate valuations may be justified assuming product shipments and profitability will be correspondingly high, sparked by markets including autonomous vehicles, lasers for manufacturing, ubiquitous sensing, or better virtual and mixed reality headsets. Programmes for high-powered lasers are pushing thresholds in the world of defence technology.

Healthcare investments, including US National Institutes of Health programmes such as the BRAIN Initiative and Cancer Moonshot, rely heavily on photonics and imaging for discovery, diagnosis, and treatment. Companies like Intuitive Surgical, Illumina, and Abbott are revolutionising healthcare using optics, while Samsung, Apple, Google, and others will create wearable sensors that improve self-care.

The world of astronomical instrumentation for both ground-based and space-based exploration is heavily reliant on optics and photonics, with amazing results on the horizon. Satellites for remote sensing, like GOES-16 launched one year ago, are already improving our view of our planet and beyond.

Mainstream markets are more reliant on optical engineering than ever with Google, Facebook, Apple, Microsoft, Intel, GoPro, Amazon and other household names hiring many optical engineers. When recruiters from these companies meet qualified candidates, as happens at the SPIE Career Fair at Photonics West, hiring is accelerated and tough development targets are easier to reach.

The dynamics of competition, visions of beneficial technology, and generally healthy financials of suppliers leads me to believe the current state of the photonics industry is the best it has ever been. The outlook is positive because so many technology trends and new products are powered by photonics.

How important are trade shows for supporting innovation and growth?

Hallett: My appreciation for face-to-face introductions has been confirmed by hundreds of people who have told me how their business – or their life – has benefitted from the new connections they have made at SPIE events including exhibitions, conference rooms, and 'after hours' socialising.

I am a firm believer that face-to-face discussions help stimulate new ideas, accelerate understanding of needs and possibilities, and lead to smarter strategies on the path forward into an uncertain future. Connecting with people from across disciplines and across regions helps us all build new perspectives and insights about unexpected opportunity and potential risk.

"We urge our technical community to get personally involved in science advocacy... or educational outreach in schools"

How else can you meet new customers, demonstrate the strength of your company, feel the pulse of the industry, talk with the press, see what other companies are doing, deepen personal relationships with collaborators, or connect with thought leaders as easily? I have been going to trade shows for more than 30 years and I have not seen a reduction in these benefits, though not all exhibitions are equal.

Most buyers can do a better job assessing options when they can get hands-on with the technology and face-to-face with potential suppliers and partners. Photonics West has a focus on customer development in the exhibition hall and product development in the conference rooms. Programmes that recognise technology innovation and new products – like the SPIE Startup Challenge, the Prism Awards, and the new Fast Pitch Lunch – are vital because they help motivated people, exciting ideas, and innovative companies gain visibility.

Arthurs: Buyers find many solutions under one roof. This is where product development shifts to customer development, which is vital for innovation and growth. There are more new product launches at Photonics West than any other event in our field. New personal connections and relationships that form help exhibitors grow and give technology users new ways to innovate with applications.

How do changes in the number of visitors and exhibitors at SPIE Photonics West reflect the photonics market?

Arthurs: The number of visitors keeps growing, and the size of the exhibition continues to expand. There is a long waitlist of companies trying to get into Photonics West. We allowed existing companies to expand, so the number of companies may be down slightly but that is simply because we ran out of space at The Moscone Centre.

The three symposia at Photonics West – BiOS, LASE, and OPTO – all have grown significantly again, reaching record numbers and this reflects what we see as growth in the overall industry.

What will be the most important factors for enabling growth going forwards?

Hallett: Potential cuts to US government R&D funding have many researchers concerned, for good reason. SPIE encourages strong science investment across the world, and lobbies for this investment with staff and volunteer support. We also urge our technical community to get personally involved in science advocacy at the political level or educational outreach in schools to encourage the next generation of scientists and engineers. SPIE has free resources available for this, including posters for teachers (or politicians) – email: help@spie.org.

Executives have told me there is a 'war for talent' as well-funded firms compete to hire →

→ all the talented engineers, project managers, and technicians they need to design and build new products with aggressive schedules. The number of available jobs is another indicator of the health of our field. How does SPIE help here? SPIE student chapters are a source of new talent, career fairs at events and the top focused job site (spiecareercenter.org) connect recruiters with candidates to help companies find the staff they need to grow. People with a growth mindset can help sponsor SPIE student programmes to get early access and personal engagement with exceptional potential new hires. Expanding this pipeline is one of the most important goals of SPIE because talent availability, education, innovation, customer development, and economic growth are interconnected in a virtuous cycle.

Arthurs: The majority of R&D funding is actually performed in the private sector[1], although aggressive government funding of science is vital to support long-term research, discoveries, and future jobs. Meanwhile, Silicon Valley is probably investing more in autonomy than the Department of Defence or the Defence Advanced Research Projects Agency (DARPA), notably in lidar but also specialised cameras, and other remote sensing systems, too.

Each country has a unique collaboration process ranging from (nearly) laissez-faire to government-planned investment. But, no matter the initial funding, ultimately to be useful the ideas must be transformed into products; facilitating commercialisation is a major goal of SPIE. Once on the market, the initial financial support is irrelevant to buyers. **EO**

References:

[1] www.nsf.gov/statistics/2016/nsf16316/nsf16316.pdf and www.oecd.org/sti/msti.htm

Katja Stolle, exhibition director, Laser World of Photonics, on how industry events support the diversity of photonics

What are the current trends in optics and photonics?

One trend benefiting photonics is Industry 4.0. Namely digitally networked and automated manufacturing – with photonics providing the appropriate technologies. 3D printing adds the option of fully automated, digitally controlled series production. Lasers create highly complex components from metal or plastic powder one layer at a time. We are already witnessing the first manufacturers building fully networked process chains on this basis, transforming 3D data into tangible products in a digital manufacturing process. The new world of production would be simply inconceivable without lasers.

A hot topic still on the very first rung of the value chain ladder is quantum photonics. It enables extremely precise and highly secure information transmission. In the future, data will be one of the most valuable resources and as such their secure transmission will be an important topic. At the same time, data processing is also essential – under the quantum computing banner. Here too photonics will play a pivotal role.

What are the growth prospects for photonics?

Photonics provides a wealth of growth areas. It is the key to boosting efficiency in the medical arena, which is why optical health technologies or biophotonics will certainly assume greater importance in the years ahead. For example, optical imaging processes in endoscopy and microscopy are already a very important complement to radiological imaging for diagnosis and therapeutic support.

Imaging and sensor technology are also very promising growth areas: a great many measuring techniques harness the extraordinary attributes of light. For example, surfaces are scanned with light to check their shape accuracy or determine height differences. The optics industry itself uses light for quality control – for example in interferometric measuring techniques. The same goes for sensor technology: in the autonomous driving mega-trend alone, photonics is an indispensable technology enabler.

What role do trade fairs like Laser World of Photonics play in the industry?

Keeping abreast of the latest developments requires a comprehensive overview of the entire market and its participants. Laser World of Photonics is the platform that makes this compact overview possible within very short order, every two years. As a trade fair, we have constantly developed in tandem with the market and taken our lead from it – which is how our practical formats such as the application panels came about. You could say that we have one eye on the market and one on the visitor.

"We are seeing ever more representatives of cross-cutting technologies attending Laser World of Photonics"

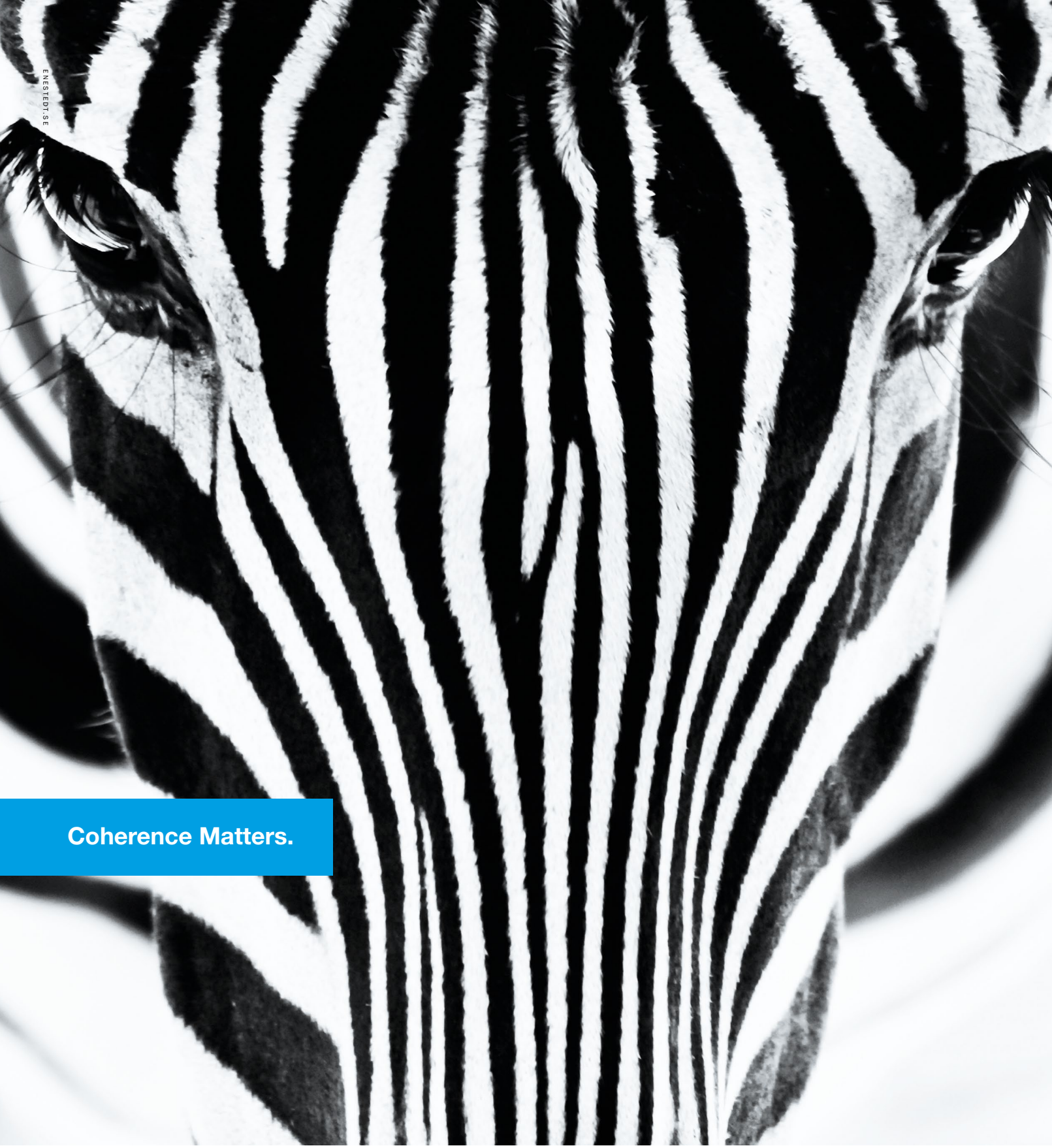
Also, trade fairs always reflect their markets. The photonics market is on an upward trend; trade association Spectaris is forecasting total turnover of almost €33 billion for 2017 in Germany alone. Laser World of Photonics sees this development in increasing exhibitor and visitor numbers: more than 32,500 visitors attended the trade fair in June 2017 to find out about the 1,290 exhibitors' innovations. We use our supporting programme, which ranges from guided tours to forums, as an additional vehicle for transferring know-how between trade visitors.

And for an industry that boasts R&D spending of almost 10 per cent of total turnover, there needs of course to be a corresponding platform in the scientific arena as well: the World of Photonics Congress, which runs in parallel with Laser World of Photonics, is our forum for creating networking opportunities for the world's leading experts in this important arena.

How do visitor numbers reflect changes in the photonics industry?

Be it aerospace, vehicle manufacturing, logistics or the construction industry, we are seeing ever more representatives of cross-cutting technologies attending Laser World of Photonics to find concrete solutions for the problems they face. We are now even welcoming trade visitors from the agricultural sector to the trade fair, on the lookout for sensor system solutions for precision farming technologies.

This diversity illustrates that photonics has long since ceased to be a matter for conventional manufacturing industry alone but has become a true all-rounder: technical progress is based on photonics and Laser World of Photonics is where companies showcase the appropriate innovations. The great importance accorded to optical technologies worldwide is also reflected in the event's internationality – the proportion of our international trade fair visitors is now almost 60 per cent. **EO**



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Dr Andrew Rickman, OBE, CEO of Rockley Photonics, believes silicon photonics will drive a technology revolution in data communications

Electronic and optical technologies have contributed tremendously to the growth and knowledge base of human society. These technologies are used separately and together in a vast and growing number of ways, from building infrastructure to satisfy our seemingly insatiable demand for digital services, to creating miniature electro-optic sensors enabling the internet of things revolution.

As naturally as optical and electrical technologies synergise, they operate on fundamentally different principles. Developing efficient and cost-effective interfaces between optical and electronic circuits is a perennial challenge for research teams. In practice, interfaces can be costly, power hungry and in many cases quite awkward to design, but they are an essential piece of the puzzle if we are to get the best from both the electronics and photonics worlds.

Despite these technical challenges, engineering teams have deployed hundreds of thousands of such interfaces in hyperscale data centres, albeit at unsustainable cost and power consumption.

Critical applications

Data speeds and data centre deployments continue to grow with no end in sight. Indeed, Stratistics MRC expects the global hyperscale data centre market to grow from $20.24 billion in 2016 to $102.19 billion by 2023, with a compound annual growth rate of 26 per cent. Here we see the electrical-optical interface having a major impact on the cost and power of the data centre network. The optical interface is critical to continued forward progress in this industry unlike any other. Successfully tackling this issue will have far-reaching benefits for the data centre industry – and our ability to satisfy global demand for data-driven applications.

Data centres currently consume about three per cent of the global electricity supply. That is more than the total consumed energy of many individual European countries. As well as handling and manipulating the enormous amounts of data associated with the modern world, we must be able to manage the energy implications of doing so. Key to this challenge is improving the architectural structure, the computational and networking elements, as well as the individual components used in data centres. Silicon photonics is widely regarded as one of the primary technologies that can be used to solve these critical challenges, particularly in the deployment of energy efficient solutions for large data centres.

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"The true potential for silicon photonics lies not in discrete single function devices but in the intimate integration with digital CMOS electronics"

Disruptive technology trends

At Rockley Photonics, we have a deep understanding of silicon photonics and its most pressing applications.

Our primary vision is to introduce disruptive, highly integrated optical interconnects for network ASICs in data centres that will enable continued bandwidth growth at dramatically lower cost and power.

We are focused on high volume, manufacturable silicon photonics that is tightly integrated with CMOS electronics. An integrated digital CMOS ASIC with direct photonic interfaces, co-packaged in a single device, will drive a technology revolution in data communications.

Driving optical outputs directly from the chip package enables chip-to-chip communication at higher speeds and over greater distances than present day high-speed circuit board and backplane technology allows – at much lower cost and power. We realise these savings from multiple factors, including reducing the number of discrete components required per port, and shared substrate advantages that eliminate the need for high-power electrical data drivers and multiple printed circuit board assemblies.

Our platform enables terabit-class devices with integrated photonic interfaces, which represent the highest level of photonic integration in the world.

Realising the true potential of silicon photonics

The team bringing this silicon photonics platform to market has experience across multiple technologies, spanning some 25 years. Addressing these complex engineering challenges requires a long-term, multi-disciplinary approach, bringing together experts in photonics, analogue, digital and mixed-signal CMOS technology along with firmware, packaging and assembly.

The true potential for silicon photonics lies not in discrete single function devices but in the intimate integration with digital CMOS electronics. This approach enables us to exploit the properties of the photonic and electronic technologies to their fullest, delivering solutions that a world with an inexhaustible thirst for data requires. This interface, executed properly, provides a seamless transition between the optical and electrical domains, eliminating numerous components compared to traditional interfaces and provides significant cost and yield advantages.

Addressing the skills shortage in high-value photonics manufacturing is important to scaling the technology's potential to ensure we can continue to deliver the technology solutions to meet the global challenges. Various countries have initiated government-funded programmes, including the United States and the United Kingdom. Such programmes aim to address some of the issues around skills and collaborative research, and these efforts are certainly to be applauded and need to continue.

Einstein once said: 'We cannot solve our problems with the same level of thinking that created them.' The stratospheric growth in data is the problem we have created. Now, integrated silicon photonics is ready to deliver the solution. EO

Dr Tom Pearsall, founder of the European Photonics Industry Consortium, argues that industry associations must be agile to stay relevant

Photonics is often characterised as an enabling and pervasive technology. Actually, it is much more than that. Photonics is a strategic and structuring technology, leading and creating critical industrial applications. An important example that illustrates this principle is the laser. Following its discovery over 50 years ago, the laser was referred to affectionately as 'a solution looking for a problem'. The laser is in fact leading the way to new paradigms for manufacturing, surgery, communications, and opening avenues to new fundamental scientific research in chemistry and physics about the very nature of the world we live in.

In our lifetimes, photonics has created new forms of lighting, telecommunications, manufacturing, and medicine. European scientists, engineers and innovators have been leading the development of photonics since its creation by Albert Einstein and his Nobel Prize-winning work on the photoelectric effect. For 15 years, the European Photonics Industry Consortium (EPIC) has been dedicated to the task of building solidarity and synergy among organisations that are committed to advancing discovery, innovation and commercialisation of photonics technologies.

A truly independent association

EPIC, of course, is not alone. There are numerous photonics associations in Europe; many of these have been created following the encouragement of the European technology platform Photonics21. Typically, these associations are funded by local or national governments, and assure a liaison between the region that they represent and sources of funding and subventions for research and development. Such organisations have a natural responsibility to represent and defend the priorities of the regional or national governments that provide their funding.

Because EPIC accepts no direct funding from any public authority, and is financed mainly through membership, it remains independent and free to represent the best interest of its industry members. Rather than trying to provide a link between the photonics industry and public authorities, EPIC builds links between its members by providing services that they ask for and that will benefit them most. Examples include exploratory missions around the world, focused meetings with decision makers, and reports to stay abreast of market and technology trends.

Today, with more than 350 industry members, several thousand individuals benefit from membership in EPIC, making it one of the larger photonics associations focused on innovation and industrial implementation.

Keeping agile to stay relevant

EPIC is agile, recreating itself and sharing its products, knowledge and structures. Like any robust technology, photonics is constantly changing and re-inventing itself. When we founded EPIC 15 years ago, important member needs were to help build the industrial-scale manufacture of LED lighting, and to respond to the needs of optical fibre communications companies, whose principal market was devastated by the dot-com implosion of 2001-2002. The synergy between the laser-assisted manufacturing industry and optical fibre amplifiers led to the development of fibre lasers for manufacturing. One of EPIC's first workshops addressed this topic.

"We can see some areas where transformative change may be happening: in biophotonics, both for imaging and treatment; in 3D printing; and in the industrial manufacture of photonic integrated circuits"

Today, LED lighting is a commodity, and optical communications innovation takes place at the system and software levels. However, laser-assisted manufacturing is still an area of significant innovation at the photonics level, as diode lasers are steadily replacing gas and solid state lasers in many applications.

The best response to change is agility, and we try to pay attention every day to innovations that will lead to changes, both disruptive and evolutionary. With employees located in six different countries, and 120 visits to leading companies each year, we listen to what industry has to say. Market and technology reports have proved to be an important tool in bringing discipline to this effort. We were able to keep our members informed about the timing and the tipping points related to the transformation of LED lighting from a high-growth, technology-driven market to a high-volume, low-margin commodity market.

What is happening next?

On the road ahead, we can see some areas where transformative change may be happening: in biophotonics, both for imaging and treatment; in 3D and additive printing; and in the industrial manufacture of photonic integrated circuits.

The manufacture of photonic integrated circuits (PICs) is an area of important evolutionary and disruptive change. One key breakthrough is the building-block concept of creating functionality by using a standard set of components: laser, modulator, coupler, amplifier, detector and waveguide. An OEM can design and receive functioning PICs, without having to learn the underlying materials and device technologies. A foundry with basic device capability can manufacture the chip without having to learn about the application. This is a mature idea, and its application to PICs is an example of evolutionary innovation. At the same time, the creation of a reduced set of components and processes could lead to the design and manufacture of specialised equipment that is optimised for PIC fabrication. This would be disruptive innovation that could implement PIC manufacture on the same scale as that for electronic integrated circuits. EPIC is providing initiatives to support this development through focused workshops, market studies and through its participation in several projects. **EO**

In addition to founding EPIC in 2003, Tom Pearsall has made major contributions to fibre-optic telecommunications and silicon photonics. A graduate of Cornell University, he worked in research at Bell Labs for over a decade. In 1990, Pearsall was named Boeing-Johnson Chair and Professor at the University of Washington. From 1998 to 2002, he directed research on planar photonic crystals at Corning in Fontainebleau, France. He is a Fellow of the American Physical Society and a Fellow of the IEEE.

Dr Wenko Süptitz, head of photonics at German industry association, Spectaris, discusses Industry 4.0 and how far advanced German and European companies are with implementing digital production processes

How do you define internet of things?
For us, we're focused on the industrial internet of things (IoT). Although we do look at applications like sensors in smart phones, for example, as an industry association, the companies we represent are more involved in the production equipment of smart phones, not in the production of smart phones themselves (which tends to happen in Asia).

There are three areas where we see photonics contributing to Industry 4.0 or IoT – optical sensors, human-machine interaces, and additive manufacturing. Sensors are required to get the data into the digital world, and actuators to get the digital processing back into a physical motion. Also, photonics will be essential for enabling the human-machine interaction – how robots interact with each other, with people and how they move in their 3D environment.

Lasers are very well suited to processing materials according to a digital blueprint, which works better than the traditional machines. Many laser processing applications – like cutting, welding, marking, and more recently laser additive manufacturing – are all driven by digital input.

How can companies collaborate to enable these IoT concepts?
In Germany we have strong government support for these concepts. We have platforms for Industry 4.0, and there are several regional clusters that hold regular workshops. There are also testbeds that photonic companies are involved in.

These activities provide good opportunities for networking and collaboration between SMEs and larger companies such as Siemens or Trumpf. We see that networking and collaboration is strong in Germany, and Europe in general, which gives us an advantage. It also provides an opportunity for solving complex issues surrounding digitisation that may not be the focus point of Google and other large software firms, which seek applications that are similar everywhere in the world. But for applications involving a large extent hardware, European companies can really benefit from the strong networks we have across Europe.

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What is Spectaris doing to help advance Industry 4.0 in Europe?
We organise annual meetings and conferences – for example we've organised a series of conferences, called Photonik 4.0, which in 2016 had a focus on production technology, and in 2017 on medical applications.

After these conferences, we bring together what was discussed during the presentations, round-table discussions, and workshops. If possible, we also ask all of the participants to give their personal opinion. We then collate all of this in a white paper aimed at the German government.

On a regular basis, we put forward industry needs and interests, and emphasise the special interests of photonics to the German Federal Ministry of Economy so that these points are included in their large strategic roadmaps.

How far advanced is Industry 4.0?
I think the technical groundwork is already pretty far advanced. The other element is to look at how far ahead companies are with the implementation of these concepts in routine production in Germany, in Europe, or all over the world. And there we see a gap. From our experience most companies do not immediately jump on these new concepts – there needs to be a certain market pressure in order for them to do so.

Companies will first try to optimise existing procedures that they've been used to for many years before they start to implement Industry 4.0 processes. So, there is a time delay. However, we are noticing that more and more companies are starting to realise that implementing Industry 4.0 equipment and procedures is a must to survive in the future.

There is a gap between the technology, what is possible in principle, and what is found on production floors today.

How have SMEs adopted Industry 4.0 practices compared to large companies?
I think large companies can afford to dedicate a reasonable amount of money to new production concepts. It's much more difficult for smaller ones – they find the concepts interesting, but only see them as an option for larger firms because they cannot make that level of investment.

With SMEs, to a certain extent, it also depends on the owner and what kind of vision they have for the company over the next 10 to 20 years.

> "Companies do not immediately jump on these new concepts [of Industry 4.0]"

There are a few advanced companies who have been early adopters. Other firms hesitate because they will look at their estimated revenues for the next few years, and if the figures are already healthy, then they will be reluctant to invest in new technology when it is not clear how quickly – and to what extent – it will increase profits.

What needs to happen to advance the concept of Industry 4.0?
Of course standardisation is important for diffusing uncertainty among companies when they are deciding if it's time to invest in these technologies or not. As long as many things are still experimental and it's not clear what the regulations or the standards are, then many companies will continue to hesitate to invest.

In Germany, I would add that it's very important – especially for SMEs – for areas outside of cities to get faster internet, so that companies in these locations can reap the full benefits of having a highly interconnected production environment. At the moment this is still an obstacle for many SMEs. We hope that the new government will put more attention and money into it. **EO**

Rob Morris, marketing director at Ocean Optics, says that science, education and entrepreneurship initiatives need to be supported to enable further innovation and growth in spectroscopy and photonics

Spectroscopy has become more accessible to more people than ever; no longer is the technology limited to the lab and available only to the most highly trained professionals. Across virtually all spectroscopy methods, from atomic to mass, systems have become less expensive to own and simpler to operate.

Our view is that the next evolution in spectroscopy will be in adding layers of connectivity (for example, by connecting the instrument to the internet and connecting instrument data to a community) and understanding (via more advanced algorithms and data management). On another level, the idea of emerging technologies like augmented reality could enhance how we make measurements and analyse the results.

Market changes

Over the next decade, global concerns such as food safety, healthcare and security will help drive the spectroscopy market. For example, an issue like food safety relates to many areas beyond food and agriculture, including the environment, climate control and well-being. The focus on these areas drives investment in research and development among institutions, entrepreneurs and corporations.

Consider the consequences of counterfeiting – an economic crime with an estimated $1 trillion annual cost to consumers and businesses. Spectroscopy offers many ways to counter this fraud, potentially thwarting wrongdoers, ensuring brand integrity, and assisting regulators.

Also, although the spectroscopy market is still dominated by instrumentation and hardware, one can envision a future where knowledge and expertise are what distinguish the most successful companies and entrepreneurs.

That's not to suggest that manufacturing expertise is any less important. On the contrary, the further development of precision manufacturing – including automation of processes – is what will enable the scaling of applied science solutions for high-volume applications. Indeed, if industrial customers continue to value ease of use, convenience, time savings and prestige (a quality product), the ability to develop and produce application-specific measurement systems will distinguish the top suppliers.

"In some countries, government, institution and even public support of science initiatives is threatened by varying degrees of politics, scepticism and lack of awareness"

Challenges in spectroscopy

Challenges exist across several fronts. In some countries, government, institution and even public support of science initiatives is threatened by varying degrees of politics, scepticism and lack of awareness. What's more, the effects are felt not just by those who rely on institutional funding for their work, but on the corporate sector that often supports their efforts via products and consultation.

One way to take on these challenges is to improve the way scientists and technologists explain and promote their work to all people. Industry efforts like the 2015 International Year of Light are excellent vehicles for sharing how the science of light applies to the daily lives of everyone on the planet. At Ocean Optics, we believe that making science relatable and relevant takes more than lip service.

Enabling future innovation

In education, encouraging science, technology, engineering and maths (STEM) educational policy and curricula development is important, but we also should consider teaching how creativity and entrepreneurship drive technology.

Also, the industry should encourage affordable photonics education in less developed parts of the world, where major threats prevent citizens from enjoying the quality of life that many of us take for granted.

Ultimately, the photonics industry can encourage leaders across government and industry to take bold action on technology initiatives that address key concerns, articulate and promote those initiatives, and share the industry's successes. If there are effective ways to harness the collective problem-solving power of scientists and developers, we can begin to solve some of the existential threats we face together. EO

Aldo Kamper, president of Photonics21, reveals the association's 2030 mission and discusses how Europe is to translate its current competencies into future leadership in a fast-growing global market

The photon will do for the 21st century what the electron did for the twentieth. Europe is already at the forefront of this technological revolution: harnessing the power of light to solve our greatest global challenges.

Photonics, the science of creating, manipulating, transmitting and detecting light, is part of our everyday lives. It is literally everywhere, from smartphone displays, fibre-optic broadband transmission, to the laser-assisted medical tools revolutionising healthcare.

As light particles, or photons, replace electrons in many of our most important technologies, innovations already in the pipeline are improving healthcare, growing food, saving energy, reducing pollution, expanding connectivity, transforming manufacturing and ushering in a new era of mobility. Across the economy, photonics technology will create new jobs and drive growth.

Best in H2020

The Horizon 2020 Photonics Public-Private Partnership (PPP) was created to build on the strengths of the European photonics sector and reinforce its competitiveness. For this purpose, the European Commission joined forces with the photonics industry – represented by Photonics21 – and the research community.

The result is a dynamic and effective partnership with 3,000 members, recognised as the best-in-class contractual PPP in Horizon 2020 by the Commission's independent evaluators, and as demonstrated by the PPP's impact on jobs and growth in Europe.

And the effort will continue. It is the mission of the European photonics community over the next ten years to deliver instant diagnosis of major diseases, quality food from farm to fork, accident and congestion-free road transport, a truly circular economy, a million new jobs, 10 per cent higher productivity, and zero downtime in a terabit economy.

Today, Europe's photonics sector comprises some 5,000 companies producing optical components and systems. Most of them are highly specialised SMEs. The sector is export-oriented and research-intensive. It invests close to 10 per cent of revenues in R&D, about twice the rate of manufacturing as a whole.

The sector directly employs over 300,000 people. If we include everyone whose livelihood depends on the use of photonics – from workers using industrial lasers to doctors performing endoscopic surgery – 10 per cent of the workforce and as much as 30 per cent of the entire economy already depend on photonics technology.

Photonics is a highly dynamic and fiercely competitive global market that was worth €447 billion in 2015. At a compound annual growth

Amy Eskilson, president and CEO of Inrad Optics, says Industry 4.0 could help bridge the workforce gap

Over the last 25 years it has been fantastic to watch and participate in the ongoing commercialisation of optical technologies. When we aggregate just a few of the broadly deployed technologies enabled by photonics like smart phone cameras, optical communications, medical lasers for everything from cardiac ablation to tattoo removal, fibre lasers and high-power lasers for industrial applications, the cumulative impact is staggering. Most importantly, the industry is still young, and this is what is so exciting about the work we do every day.

At Inrad Optics we are focused on high barrier to entry and niche technologies well suited to our unique capabilities, specifically crystalline materials development, certain high precision optical components, complex optomechanical assemblies and optomechatronic subassemblies. We have found that there is an unmet need in the marketplace for companies willing to work collaboratively with their customers on multi-dimensional optical projects. This need is evident in all market sectors we serve, not just in the scientific R&D community.

We see requirements that demand collaboration in the defence, process control and metrology, and the laser systems sectors. Our bent crystals expertise for x-ray monochromator design is a great example of this type of collaboration. Here we work with key customers involved in plasma studies in the scientific R&D community, as well as process control and metrology customers developing commercial solutions in semiconductor wafer inspection and x-ray photoelectron spectroscopy systems (XPS).

One of the major challenges companies like Inrad Optics face is the availability of trained optical technicians, especially individuals at a more senior level. While there is much discussion of implementing European-type apprenticeship programmes in the United States, this effort is still developmental, and resource intensive for SMEs to implement. I believe that public-private partnerships are essential in bridging this workforce chasm.

Additionally, the continued evolution of cyber-physical systems, known as Industry 4.0, holds great promise to help bridge the workforce gap. Recent advances in laser-based ablative digital processing for shaping, polishing and assembling optics made of optical glasses and fused silica could offset the US scarcity of qualified technicians.

"Public-private partnerships are essential in bridging this workforce chasm"

Looking longer term, full integration and deployment of the digital and optical worlds at the chip level will provide step changes in the areas of quantum computing, integrated photonics and lab-on-a-chip devices. All these advances will hopefully lead to lower cost quality of life improvements that can be accessed by communities the world over, especially in second and third world areas of the globe. **EO**

rate of 6.2 per cent between 2011 and 2015, the global market has been growing substantially faster than the economy as a whole. A global market share of 15.5 per cent makes Europe the world's second-biggest supplier of photonics, after China.

With China currently focusing on photovoltaics, displays, lighting and other commodity products, Europe is arguably the centre of global photonics innovation today. That said China is pushing strategically into more innovative areas.

European companies are market leaders in sectors such as production technology (including industrial lasers), optical components and systems, sensors and automated vision, as well as photonics in medicine and life sciences.

The future of photonics

Fundamental innovation trends will continue to drive strong growth in photonics employment and revenues up to 2030 and beyond. These trends include the development of optical computing to replace silicon circuits, as well as the spread of optical sensing and light technologies in healthcare, mobility, manufacturing, energy and other sectors.

If Europe is to translate today's mastery of key technologies into future leadership in a fast-growing global market, further challenges need to be overcome.

Joint action by the European Commission, the member states and the photonics industry will clear the way to future innovation. However, this will require a long term concerted public-private effort that pools Europe's strengths in photonics and builds out a highly innovative transnational ecosystem.

"A truly European lab-to-fab infrastructure for accelerating innovation and competitiveness must be created"

To achieve these goals, a number of specific measures will be needed:

1. A European strategy for photonics leadership that focuses on mission-oriented breakthrough innovations and large-scale collaborative projects across industries and sectors must be created and implemented.
2. A coordinated strategy involving all public and private stakeholders creates the momentum and unleashes the broad spill-over effects needed to address global challenges, exploit future markets and create jobs in Europe.
3. Boosting opportunities for entrepreneurship in the photonics sector is essential. Access to risk finance must be improved by establishing a Europe-wide fund for photonics start-up, growth and bridge capital.
4. A truly European lab-to-fab infrastructure for accelerating innovation and competitiveness must be created. Europe needs to speed up the uptake of technology and its translation into new products and services.
5. The education and training of tomorrow's specialists today cannot be over emphasised. Measures should include a coordinated public-private plan to define skill sets and curricula for professions in photonics. The harnessing of light should be a flagship science in schools, universities and across the education system.

With its industry and research community, Photonics21 provides a strong European platform of stakeholders with a proven track record of collaborating within this sector ready to complete these objectives. EO

Benno Oderkerk, director and founder of Avantes, believes that finding skilled workers will be crucial for enabling growth

How does spectroscopy differ now to your predictions when Avantes first formed?
When we started the company 23 years ago (1994), because of my background in sensor technology I believed that, in the end, a spectrometer would be nothing other than a smart sensor.

It took over 20 years, but what you see now is that spectroscopy is becoming a very common technology being applied in many different application fields as a kind of smart sensor.

When we first entered the field of spectroscopy, spectrometers were large, benchtop laboratory instruments. Then, around 10 to 12 years ago, they became smaller, handheld devices that allowed scientists to take the lab to the sample. At first, it was a case of trying to convince – mainly the scientific world – that these portable instruments could work almost as well as the larger laboratory spectrometers. Nowadays, the questions are completely different. People want to push the technology further – for example they want to integrate spectrometers onto a tractor, or for it to be robust enough to work in an automotive production environment.

So, it took quite a while for the handheld technology to be accepted. Then it took another period of time before spectroscopy was accepted as a 'smart sensor'.

How has the operation of Avantes adapted to these technology developments?
For Avantes there have been huge changes. We used to build our spectrometers in a very manual way, but nowadays we are focused on automated production techniques. So, we have robotic-type systems for producing spectrometers, because we cannot get employees trained fast enough to sustain our growth. The whole production area for Avantes is completely different to what it was even three or four years ago.

In the next three or four years, the challenges will be mainly in optimising our production process to build spectrometers automatically.

What will be the most significant developments in spectroscopy?
What we already see now is what are called 'fit for use' devices, so tiny devices that are small enough to be integrated onto a chip. This introduces a whole new field of applications. You can imagine these kinds of sensors in wearable devices – like in a watch – or integrated into a phone.

These chips would need to be at the right price point ($5-10) in order to realise these types of devices, but then you could use them for all kinds of uses – for example health and environmental monitoring and food sensing. These kinds of applications will become available to the consumer market once spectrometers reach the right size and cost.

"There needs to be, within Europe, a lot of educational programmes that support photonics"

Will be the biggest driver for future growth?
We see three basic target markets for our large OEM customers as being the largest drivers.

One is medical applications, or critical

Dr Graeme Malcolm OBE, CEO and co-founder of M Squared Lasers, notes that businesses and governments must be prepared for the quantum age

When asked about the future of technology and computing, quantum is front-of-mind for those in the know.

What's little known by many outside this group of people working closely in the quantum technology space, is that at the heart of the quantum revolution is the lesser-known photonics industry.

Lasers and photonics tools have always been used in computers, but as they have increased in accuracy and capability, we have started to see much smaller-scale, quantum devices being developed. We can now use lasers to cool down atoms, and turn lattices of 'entangled' atoms into semiconductors with extraordinary processing powers, far removed from those of conventional computers. These come with a whole new set of engineering challenges.

Lasers have long been used in computers, and many other technological devices we rely on today. The next revolution will see the realisation of increased accuracy, capability and speed. Conventional information processing is based on storing and processing data as bits, units of information that have two possible states, 0 and 1. Quantum computation similarly uses units of information that can be 0 or 1, but also a quantum-mechanical superposition of both at the same time, known as qubits. This will scale computing power exponentially.

Early stage feasibility has been demonstrated that, once truly scalable, these computers will transform our ability to solve problems that cannot be done with classical computers.

As Google, Microsoft and IBM are close to creating quantum computers, very soon, digital industries will not be looking back and the transformative effects will be seen across many sectors, from financial services to medicine. But as the technology industry rapidly becomes more specialised and sophisticated, it's less and less likely that businesses can find the skilled work they need unless there is a strategic response to the changing face of industry.

Take my business – we need photonics specialists, and the vast majority of people walking through the door have PhDs in photonics or quantum physics. It's only through close ties with industry that universities will be able to produce the next generation of specialists.

Instead of teaching students code that hasn't been used in Silicon Valley for years, universities need to work with universities to identify the cutting edge of research, and to make sure they are providing students with the correct skills to reach this point.

It's not just upskilling the next generation and plugging the skills that collaboration between industry and academia will stimulate, but also the growth of the tech sector and

care – for example, having a device in an ambulance that can do rapid analyses of blood and skin to monitor health. We also see a lot of applications for skin cancer screening. These kinds of devices are made by our OEM customers, and they are growing very quickly.

The second field is what we call green-tech, so the agriculture and food industry. Many applications we see nowadays are related to monitoring how fertiliser is applied to crops. Spectroscopy plays a very big role here.

Finally, we have the clean-tech sector, which is the process industry – such as semiconductor, glass and coating industries, where online monitoring is the main driver for growth.

So we see these three different markets as our biggest drivers for growth. It's very widespread.

What are the biggest challenges facing the photonics industry?

A major challenge is to find technically skilled people. We at Avantes are struggling with this, but many of my colleagues are also screaming out for skilled personnel. We are a very innovative industry, so we need people with a technical background. Nowadays, we train staff ourselves in our company, but we would like to have more educational opportunities for young people to learn about photonics. That's very important for our industry to grow.

And, what we need is the basic skills. We don't need people as much who can write an app, but that can programme an electronics board at a low level. A lot of youngsters, when they think of programming, they think of making apps – but we need people who can write code in bits and bytes. I find that young people are looking for sexy jobs, but sometimes what is required is just hard engineering work.

How could this issue be improved?

I think it comes down to education, so there needs to be, within Europe, a lot of educational programmes that support photonics. I think the EU is already aware of that – there is now more education focus in the field of photonics. It's a similar case to the need for electronic engineers 20 years ago – now photonics engineers are very important.

We see that a lot of applications are putting photonics on a chip (integrated photonics). However, if you want to build a chip with integrated photonics elements you need to study the core photonics principles first, and for this you need the right education. This is slowly coming, but it's not fast enough to fulfil the current industry need.

But overall, I think photonics has a great future – I think all of us can be proud to contribute to a better world where people live longer, healthier lives and can protect the environment for future generations. EO

sparking innovations that are society-changing.

And the UK government does recognise the importance of this. Over the five years to 2020, the government has committed to investing £270m in four quantum technology hubs. Incorporating Birmingham, Glasgow, Nottingham, Southampton, Strathclyde and Sussex Universities, the aim is to further quantum research to commercialise it for UK businesses to harness.

The UK has always competed globally in science, but bridging the gap to industry and boosting the UK's intellectual property and exports requires a joined-up strategy. The UK National Quantum Technology programme is a step in the right direction for the UK – but the key to keeping the UK and Europe on the map is to continue the investments into R&D.

With quantum science expected to become a £100 billion industry, it's vital that the UK acts now in order to remain competitive. As we start to realise the potential of quantum technologies in solving global problems – from cybersecurity to climate change – the world's biggest businesses are making heavy investments in photonics and quantum, and the talent and expertise creating these innovations.

"With quantum science expected to become a £100 billion industry, it's vital that the UK acts now in order to remain competitive"

One trait of the US tech sector is the proximity of technology hubs to world-class universities. MIT and Harvard, Stanford and CalTech; both Boston and San Francisco have universities with top tech specialisms on their doorsteps – and that's no coincidence.

The UK needs a cohesive industrial strategy with the collaboration of universities and tech companies at its core in order to remain competitive in the quantum sphere. The collaboration of researchers and industry in this sphere will lead to huge leaps forward in both research and commercial applications.

The consequences of businesses and governments being unprepared for the quantum age are vast. The UK government needs to treat education and industry as one in order to achieve the growth and innovations that will keep the UK on the world stage when it comes to quantum. EO

Growth in the biophotonics sector requires rapid translation of innovations into the clinic, write **Professor Jürgen Popp** (left) and **Dr Thomas Mayerhöfer**

Biophotonics is both a vibrant research field on the rise as well as a fast growing market with double-digit growth rates. In order to ensure that biophotonics continues to grow strongly in the future, it is necessary to understand the traits that are specific to the field. First of all, as it is an extremely broad and diverse field, it is important to realise its short-, mid- and long-term goals.

In the long term, biophotonics methods and technologies aim to decipher the cell functions and the 'language' cells use to communicate with each other. Of course, this is not a mere academic exercise! On the contrary, this knowledge will allow us to detect diseases and initiate countermeasures far before their outbreak. To achieve this long-term goal, long-term and continuous funding is necessary. It is obvious that such funding is not easy to maintain, in particular as funding is also subjected to certain trends and, certainly, funding agencies have to justify how the money from taxpayers is spent. Luckily, biophotonics offers many benefits at earlier stages.

One fast-emerging sector where biophotonics is already able to contribute, and will continue to do so also in the medium term, is 'theranostics', which could also be termed precision medicine. The goal of theranostics is to intermesh diagnostics and therapy to give a precise dose in treatment, be it in surgery or the administration of a drug. In the case of surgery, in particular in cancer treatment, merging different biophotonics techniques allows imaging tissues label-free – for example, Raman-, fluorescence-, and optical coherence tomography-based methods – which holds great promise. Such a combination can be used to guide the surgeons on-the-fly and in real time and let them know precisely where to cut in order to excise malignant tissue.

"To achieve this long-term goal, long-term and continuous funding is necessary"

Sepsis – and infectious diseases in general – is another medical speciality where biophotonics will help to enable precision medicine by a fast and precise determination of the pathogen and potential resistances against antibiotics, the correct dose of which will also be identified

Herve Floch, general director of the French competitiveness cluster Alpha-RLH, on raising awareness of photonics technologies

What is the current state of the photonics industry and what are the notable future growth areas?
Photonics is a young, vibrant and thriving industry, currently estimated at €520 billion, globally. This is up from €480 billion in 2012, with expected growth to reach €650 billion by 2020.

As a key enabling technology, photonics continues to make inroads in transforming and reshaping many traditional industries; semiconductors, aerospace, automotive, construction, agro-food and medical devices are all areas where lasers and sensors are having a strong impact on production, efficiency and sustainable development. There are strong indications for future growth for photonics technologies in consumer electronics, smart buildings, smart homes and cities, lighting, energy production, energy efficiency applications and communications, as well as materials.

How is Alpha-RLH promoting awareness and supporting growth?
As a result of last year's merger between two competitiveness clusters, the Route des Lasers and Elopsys in the Nouvelle-Aquitaine region, we have considerably strengthened the support we can bring our cluster members who are on the path to growth. Our aggregate skills in photonics, lasers, microwave and digital technologies are allowing Alpha-RLH to prioritise strategic innovations, which we see are key to stimulating economic development and creating jobs.

Innovation programmes we are spearheading to accelerate the use of photonics include SAPHyR, a project to improve the aerospace industry's understanding of photonics and thereby lower the risks they perceive in adopting these technologies. X-ray or proton therapy is another exciting development. Photonics will drastically impact the size and cost of equipment used to generate secondary x-ray beams by making use of a primary laser source for both diagnostics and therapeutic treatments. This will provide both doctor and patient access to equipment that today is considerably out of reach.

On the international front, Alpha-RLH is heightening its activities by exploring new opportunities for its cluster members in China and the US, with plans to have representation in Japan by 2019. We continue to help companies find new customers and new partners, as well as export products.

What should governments be doing to ensure photonics in Europe remains strong?
It is paramount that the French government maintains the level of interest and support it has already given the photonics industry. Having political support at both national and regional levels and access to the right level of financing on a long-term basis are required; this is the German model.

and controlled by photonic point-of-care methods.

To achieve these medium term goals, however, it is a requirement that we all do our homework. This homework consists of ensuring that all the biophotonics technologies and methods able to cure patients and improve their quality of life make it quickly into clinics. Here, we have an enormous backlog caused by firstly the gap between basic and applied research, and secondly development of a prototype into a product. Further obstacles include obtaining FDA approval, as well as acceptance by the health insurance companies and the public healthcare providers. To bridge these gaps, funding is usually not available.

To remove the corresponding hurdles and the backlog is therefore of utmost importance, not only to let biophotonics prosper, both as a research field and a market, but also to remove burden from the patients and society as a whole. **EO**

Professor Jürgen Popp is director of Physical Chemistry at the Friedrich-Schiller University Jena, and is the scientific director of the Leibniz Institute of Photonic Technology (IPHT), also based in Jena. Thomas Mayerhöfer is a senior researcher, also at the Leibniz IPHT.

To optimise the full potential of photonics requires stability. For example, our ROI in Japan will not occur within the first year of activity. Due to the business culture of the country, it will take several years. However, there is progress. The French government has significantly opened its eyes in support of photonics technologies. It has made competitiveness clusters a national policy, accompanying innovation for economic development and growth. It has sent clear

"The French government has opened its eyes in support of photonics technologies"

signals in support of R&D and technological innovation by transferring powers to the regional authorities, allowing autonomous management of resources and a regrouping of the ecosystem.

Although the photonics industry has received positive signals from the government, more resources are always welcome. Photonics is a domain where we need to raise the curiosity of investors and increase their understanding of how photonics will enable future developments in digital, materials and robotics industries. **EO**

Nicoletta Casanova, CEO of Femtoprint, on overcoming the challenges of being a startup

Femtoprint produces 3D microdevices out of glass and other transparent materials. The firm uses femtosecond lasers to generate monolithic microdevices integrating optics, fluidics and mechanical functionality. These devices can be disruptive in fields such as the medical industry or the watch industry, where they are changing the way that microdevices are conceived and built.

The production technique is creating new opportunities in several fields. While it was initially intended to be used for rapid prototyping and at the moment is mainly used to fabricate high-value products, Femtoprint believes the technique could be scaled up for mass production, potentially for optics, photonics, and electronics manufacture.

Femtoprint is a growing startup. Its technology is the result of a collaborative European project, with technical and commercial input from academia and industry. I believe that the various entities with different competences around the world have a tremendous advantage by working together in order to succeed. Projects and programmes that bring industry and academia together enable the expertise of each to be shared to increase the speed of development and boost innovation globally.

Events like Photonics West and Laser World of Photonics are also wonderful occasions for startups to demonstrate their technology, capabilities and potential. Thanks to specific programmes in Switzerland, we also have exchanges with offices worldwide – in the US, Israel, Singapore and Germany – that connect startups with partners in industry and universities. These are offered at reduced rates to small companies.

One of the general concerns with programmes like Horizon 2020 is that the application for funds at the European level is quite difficult and competitive, and in general the bigger players are more likely to be successful. However, if smaller companies like Femtoprint are able to get involved in these larger collaborative projects, they can take advantage of the expertise of all partners in the consortium.

Since Femtoprint works in a new, disruptive field, there aren't as many experienced individuals available as there might be in other fields. Education is therefore important, and one of Femtoprint's employees serves as a member of the education committee of SPIE. This activity aims to inform and stimulate educational and training activities related to what the market really needs in terms of new competences, because, technology and the market are changing, with new trends coming through such as Industry 4.0.

In terms of working in Switzerland, I am a member of a local industry association in Ticino, in the southern part of Switzerland, called AITI – the association of Ticino's industries – which aims to secure an effective environment to the industries and to suggest strategies that will support innovation. We need the government to

"Application for funds at the European level is quite difficult and competitive"

support small companies to enable us to be creative, as we have new competition coming from nearby European companies, and there is the Swiss franc exchange rate as well to contend with as well when doing business. With foresight, in Ticino, a law supports financially innovative companies when they make investments in ground-breaking projects. The government also provides support in the application phase of European projects, and pays some of the company's expenses when exhibiting at shows like Photonics West. We've secured this government support also through AITI.

I am also one of 20 councillors of InnoSuisse, the Swiss innovation agency, nominated to work on the next government's programme for science-based innovation, which will be operative from 2021-2024. We are considering many ways to support startups and high-tech companies that innovate in a cooperative way. These initiatives will also encourage students graduating from universities to develop their own products, ideas and companies. **EO**

In order to enable the technologies of tomorrow, optics manufacturers need to continue to invest in innovation and new techniques, writes **Dan Adams**, product marketing manager at Edmund Optics

Optics are the driving force behind many scientific discoveries and technological advancements. This fact is still just as true now as it was when the first microscopes and telescopes were built at the turn of the 17th century. Today, optics and photonics are at the heart of modern technology and have an impact across all aspects of life and society.

In biomedical applications, advanced diagnostic techniques like flow cytometry, optical coherence tomography, and multiphoton microscopy are all being used to diagnose and treat an aging global population. All of these methods and others like them can help doctors diagnose and treat patients faster, more effectively, and even non-invasively. Quality optical components are the key to improving the performance of these methods.

In flow cytometry, maintaining beam quality is important for getting a good signal-to-noise ratio and has a direct impact on the number of false positives recorded. With a large number of filters in the optical path, the transmitted wavefront error of each component needs to be as small as possible; in this scenario, dichroic filters with a high quality surface can have a huge impact on the overall effectiveness of the whole system.

It is a similar situation in areas like advanced robotics and the rapidly developing field of autonomous vehicles. These applications and many others require multiple machine vision systems to allow them to function at all. 3D stereo systems used for sensing in robotic manufacturing, for example, employ multiple cameras and lenses. These lenses must withstand rapid acceleration, which creates a large amount of shock and vibration, while also maintaining a pointing stability of less than a single pixel. A misalignment of only a few microns could mean a drop in accuracy and the whole system might require recalibration.

Laser processes are another key growth area and are becoming more important as manufacturers push to increase production and yield or ensure quality on a new generation of high-tech products. Precision optics are needed to focus lasers down to increasingly smaller spot sizes for machining or to produce ultra-thin laser lines for metrology. In addition, all these optics need to have high-energy coatings to deliver high transmission and longer lifetimes. This is even more important as the trend towards shorter pulse lengths and higher energies continues. While small differences in optical specifications can seem insignificant, on a production line running continuously these differences can quickly add up. Going from replacing a lens once a month to once every three months can have a significant impact on efficiency and the bottom line.

Investing in precision

Precision optical components underpin all of these application areas and many others. They are so important in fact that very large, expensive, and complex systems will often not function without them. Therefore, it makes sense that as technology advances the quality and specifications of the optics required to support it must advance. Higher energy lasers need lenses with more resilient coatings and improved surface flatness. Fluorescence microscopes need filters with deeper blocking and steeper curves. New broadband systems will need good performance across a wide spectral range and precision aspheric lenses will be required to produce small, compact assemblies for weight-critical applications. It is clear that in order to enable the technologies of tomorrow, optics manufacturers need to continue to invest in innovation and new techniques to continue pushing the limits of quality and precision.

Edmund Optics understands these challenges. It uses a range of five-axis CNC grinding and polishing machines enhanced by magnetorheological finishing for producing components with a surface accuracy exceeding λ/20. Ultrasonic CNC machining is another high-tech solution for optics with complex geometries, tight tolerances, and speciality features, such as holes, inserts or slots. To ensure that finished components meet specifications, all of these methods are supported by metrology systems, including interferometers, spectrophotometers, profilometers, and coordinate measuring machines, as well as advanced techniques such as computer generated hologram asphere metrology.

"So much relies on optics. The level of precision required is only set to increase"

So much relies on optics. The level of precision required is only set to increase, and it is up to optics manufacturers to continue to develop their capabilities and produce components that can meet the challenges of tomorrow. The future depends on optics. EO

Dr Eric Mounier, cofounder of market research firm Yole Développement, gives predictions for the silicon photonics market

With Big Data getting bigger by the second, transporting this level of data with existing technologies will soon reach its limit in terms of power consumption, density, and weight. It is now clear that photons will continue replacing electrons throughout networks, including in the data centre, the rack, and very soon on the board. The question is: how to achieve this at low cost?

The answer is quite simple: market volume in million units will allow a scale factor that will drive the cost down. This is the quite simple equation that silicon photonics, fundamentally a semiconductor-based process, must solve.

Silicon photonics has been under development for years, but there are still only a few products on the market. However, now that this technology is being pushed hard by large web companies like Google, Amazon, Facebook, and Microsoft, we believe we have reached the tipping point that precedes massive growth.

"In semiconductors, silicon accounts for 80 per cent of the cost, while packaging is 20 per cent. In optics, it is the opposite, as packaging can be as high as 80 per cent of the final cost"

Back in 2000, Bookham was the first to commercialise silicon photonics components (AWG, transceivers). Then in 2006, VOA was commercialised by Kotura. Today, we see new startups and more and more products reaching the market, mostly for 100G but soon for 400G. There are also very encouraging signs in terms of growing investments from the VC community.

Silicon photonics is a mix of several technical blocks (optical, but also IC for processing, MEMS for packaging, copper pillars, etc.), and involves several core components: laser source, modulator, optical waveguides, multiplexers/demultiplexers and photo detectors. The laser source integration is still a major cost factor today. As silicon cannot have a laser effect because of its indirect bandgap, the laser cannot be monolithically built on the silicon die, so there are different solutions for laser integration. After years of R&D, Intel succeeded in doing wafer-level integration of the laser by bonding an InP chip then doing post-processing (alignment is not so crucial as it will be performed by lithography). The second solution is to flip-chip the laser source, but it is a complex process due to low throughput and high alignment accuracy.

Packaging is another drawback. As always when dealing with optics, packaging accounts for a major share of the final component cost, because of alignment issues and the need to integrate different chips in the same package. In semiconductors, silicon accounts for 80 per cent of the cost, while packaging is 20 per cent. In optics, it is the opposite, as packaging can be as high as 80 per cent of the final cost. So, solutions are currently being developed to reduce cost by increasing assembly throughput at high accuracy.

Despite these challenges, we believe silicon photonics will have a bright future. Although it is creating a lot of buzz, the market is still modest, with estimated sales below $100 million in 2016 (chip level) and with very few companies actually shipping products to the open market. However, we estimate the packaged transceivers market to be a multi-billion-dollar industry in 10 years.

Silicon photonics is a market of big promises, especially in data centres and HPC – huge markets that will dwarf all other silicon photonics applications in the near future. Also, silicon photonics can be seen as an enabling technology for other applications such as sensors, life science, quantum computing, telecom, consumer, automotive and so on. For example, future autonomous vehicles will require a high level of security with very low latency in the sensors. Lidar is also an interesting application for silicon photonics. **EO**

Dr Eric Mounier (mounier@yole.fr) has a PhD in microelectronics from the INPG in Grenoble. He previously worked at CEA LETI R&D lab in Grenoble, France in the marketing department. In 1998 he was a cofounder of Yole Développement, a market research company based in France.

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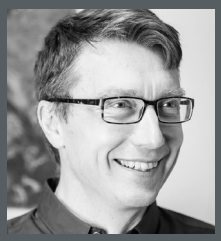


Dr John Lincoln, director at Harlin, chief executive of UK Photonics Leadership Group, and outreach manager at The Future Photonics Hub, reports on the UK market and the challenges the region faces

For over 350 years the UK has excelled in harnessing light into innovations with global impact. Going back to Sir Issac Newton's reflecting telescope of 1668, UK photonics has combined scientific discovery with practical engineering to produce breakthrough innovations with broad impact. As illustrated with the invention of the optical amplifier and high-power fibre laser and most recently innovations in quantum technology, UK photonics has an enduring ability to refresh itself to stay at the cutting edge of innovation. As one photonics technology becomes commoditised and taken for granted, the UK is already working on the next application of light.

The UK's innovative capacity in light is exemplified in the multiple world-leading academic institutes and photonics researchers based in universities throughout the country. Harnessing this innovation has led the growth of a £12.9 billion industry employing over 65,000 people in more than 1500 firms, with a productivity three times the national average. Many of these companies export almost all of their output, an unrivalled export fraction in British industry, illustrating the very high international regard for UK photonics.

Photonics is simultaneously an age old enabling technology, invisibly integrated into modern life from fibre optic networks to the lasers welding our cars, and emerging technology that will change our future lives. Accumulating cross industry input, the Photonics Leadership Group has identified the future grand challenges presenting the biggest opportunities for photonics in the future and where the need for further innovation is greatest:

Delivering Internet 5.0, where data delivery is ubiquitous, invisible and instantaneous to all people and all factories, no matter where they are or what they are doing. I5.0 will require the seamless integration of optical, electrical and RF technologies and will break the link between digital demand and economic, energy and security costs that if unresolved, will constrain the digital economy.

Affordable, accurate location information, overcoming security threats and enabling autonomous vehicles with instantaneous awareness of rapidly changing local surroundings. Light has long been used to capture information remotely, the challenge is to make detection adaptable, flexible, infallible and compatible with all situations. For many applications, such as in autonomous cars, this must be done with components compatible with aesthetic integration and high volume, low-cost manufacture.

Enabling UK manufacture of the car of the future, with advanced digital manufacturing using light to process, monitor and control cutting, joining, marking and assembly for lighter weight, safer, more efficient vehicles. Already deployed at key processing steps, wide deployment of digital laser manufacturing and laser metrology and extension to new materials will be critical for automotive production and raising productivity across UK manufacturing.

"Perhaps the greatest challenge for UK photonics is to support increased domestic use of photonics, to improve the productivity of the wider UK industry"

Making home healthcare as effective as hospital care by 2030, by providing simple pre-clinical diagnoses and health screening tools for use in the home and pharmacy, decreasing the load on primary and hospital care. As light penetrates the skin, it can be deployed in non-sterile user-friendly methods to significantly improve healthcare productivity enabling health professionals to focus on patients most in need of their time.

These photonics challenges are closely aligned to the four grand challenges identified in the UK industry Strategy: Building a Britain for the future (https://www.gov.uk/government/publications/industrial-strategy-building-a-britain-fit-for-the-future).

- Putting the UK at the forefront of the artificial intelligence and data revolution,
- Being a world leader in shaping the future of mobility,
- Maximising the advantages from the global shift to clean growth,
- Harnessing the power of innovation to help meet the needs of an ageing society.

Backed by the industry strategy, these four challenges will attract a significant proportion of the £725 million committed to new Industrial Strategy Challenge Fund (ISCF) programmes. UK photonics innovation is likely to appear in a great many of the proposed solutions.

The critical role of photonics is, however, not recognised in the industry strategy, and UK photonics remains focused on how important challenges where photonics has a major role can be integrated into future ISCF waves. Global challenges such as the energy consumption in data centres, solutions which are vital for growth in AI to be compatible with clean growth, are seen as prime candidates.

The industry strategy also marks the announcement of the first four sector deals with the life science, artificial intelligence, automotive and construction industries, with more in negotiation with creative, nuclear and industrial digitisation. Photonics is important to many of these, but the role of supporting enabling hardware development and integration needs to be more directly incorporated in such sector deals, especially in industrial digitisation.

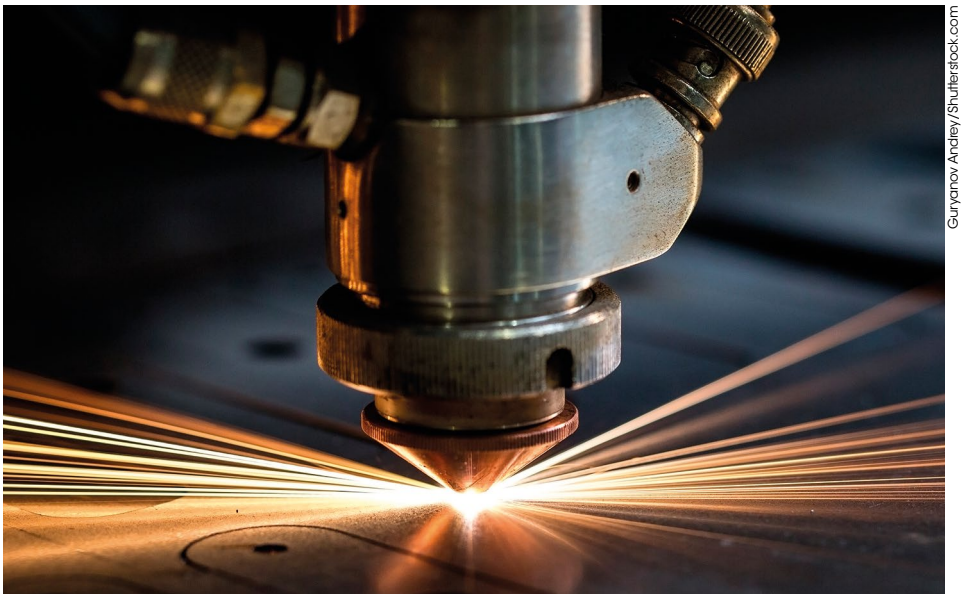
Through the PLG, the UK photonics industry has already drafted proposals for a photonics sector deal and in parallel with evaluating how UK photonics can participate in deals already announced, PLG will discuss with government if it is possible or desirable to develop a sector deal with a clear impact on photonics productivity, output, exports and investment. As an industry UK photonics excels in many of these areas already, exporting heavily and attracting significant foreign direct investment. Which means perhaps the greatest challenge for UK photonics is to support increased domestic use of photonics, to improve the productivity of the wider UK industry. **EO**

FOCUS BUSINESS NEWS

Growth in industrial lasers, microelectronics and optical systems leads to record financial results

- *Trumpf, IPG, Coherent and Jenoptik all report significant growth*
- *Global politics has had little effect on business so far, Trumpf says*

Records in both annual sales and orders received have been broken by laser manufacturers throughout 2017, with Trumpf and IPG Photonics exceeding €3 billion and $1 billion in annual sales for the first time respectively, and Coherent receiving over $2 billion in annual orders. Photonics group Jenoptik also posted record order intake at €576 million for the first nine months of the year.



Guryanov Andrey/Shutterstock.com

Prevailing over politics

In addition to exceeding €3 billion in annual sales for the first time, Germany-based Trumpf reported pre-tax income increases of 11.3 per cent to €337.2 million and increases in orders received of 21 per cent to €3.4 billion over its 2016/17 fiscal year ending 30 June 2017. Performance was particularly impressive in South Korea, where sales increased 58 per cent to €211 million, making the region Trumpf's fourth-largest market worldwide this year.

Trumpf, which now employs more than 12,000 people, attributes its upturn in sales to the strong global economy, according to CEO Dr Nicola Leibinger-Kammüller, who stated that political developments worldwide have had little impact so far on business in Europe, Asia and the Americas.

'The prevailing strength of the global economy has been outweighing potential impediments to investing: pledges of protectionist measures, the Chinese government's approaches to disseminating information, and the UK's exit negotiations with the European Union,' she said. 'All the same, we do forecast clouds over the investment landscape in the medium term.'

Germany continued to be the largest single market for the firm, with sales of €622 million, followed by the United States (€421 million), China (€404 million) and South Korea (€211 million). Markets in Western Europe also performed well, with year-on-year sales growing 55 per cent in the Netherlands and by 28 per cent in Italy.

Trumpf expects orders received and sales to continue to rise in this fiscal year as well.

Industrial laser growth

For US firm IPG Photonics, after reporting annual sales exceeding $1 billion at the start of the year, revenue and net income for the first nine months of 2017 were $1.05 billion and $294.7 million respectively, up 44 per cent and 59 per cent compared to the same period last year.

Throughout the third quarter of 2017, the fibre laser manufacturer generated revenue of $392.6 million and a net income of $115.6 million, a significant 48 per cent and 69.2 per cent increase year-over-year respectively.

The results were driven mainly by a rapid growth in cutting, welding, and 3D printing applications, which saw materials processing sales increase by 52 per cent year-over-year, accounting for 95 per cent of the firm's total sales throughout the quarter. Sales made to non-materials-processing markets declined by nine per cent year-over-year.

> **"The prevailing strength of the global economy has been outweighing potential impediments to investing"**

China continued to demonstrate an impressive performance throughout the quarter for IPG, with sales to the region increasing more than 70 per cent year-over-year. European sales increased by 50 per cent year-over-year, while sales to Japan decreased by 10 per cent.

'Based on our third quarter outperformance and current backlog, we are now targeting approximately 37 per cent to 39 per cent revenue growth for the full year, up from 32 per cent to 34 per cent previously,' commented IPG CEO Dr Valentin Gapontsev. 'This would represent our strongest annual revenue growth in six years.'

→

→ The OLED effect

Coherent's excess of $2 billion in annual orders were coupled with net sales of $1.72 billion and a net income of $207.1 million for its fiscal year ending 30 September 2017, a 101 per cent and 137 per cent increase respectively compared to its previous year. The dramatic increases reflect Coherent's $942 million acquisition of industrial laser manufacturer Rofin-Sinar Technologies in November last year, in addition to strong performance in the microelectronics sector due to the continuing growth of OLED technology.

The figures were announced after the closing of the Coherent's fourth quarter, for which it posted net sales of $490.3 million and a net income of $73.8 million, increases of 97 per cent and 140 per cent year-over-year, and 5.6 per cent and 20.7 per cent compared to its third-quarter results.

The largest portion of sales were of laser technologies for microelectronics fabrication, thanks to sustained strength in OLED deployment and service, high semiconductor capital expenditure spending and a modest rebound in advanced packaging. Materials processing orders were also impressive, having grown dramatically due to both organic growth and Coherent's acquisition of Rofin.

Significant sales for OEM instrumentation were recorded as well, as growth in the core diagnostic and therapeutic space was complemented by organic and acquisitive growth in the aerospace and defence market.

Semiconductor success

Jenoptik's record €576.2 million order intake for the first nine months of the year was spurred by continued growth in solutions for the semiconductor equipment industry, as well as growth in the healthcare and industry sector. The group's revenue therefore rose to €526.8 million in the first nine months, a 7.0 per cent increase year-over-year, with revenue increasing 7.7 per cent year-over-year in the third quarter alone.

On a regional level, growth momentum came from abroad, particularly from the Americas, where initial nine-month revenue increased by 34.9 per cent year-over-year to €120 million (from €89 million previously). Overall the share of revenue generated abroad rose to 71.3 per cent, up from 65.3 per cent last year.

The group's optics and life science segment posted a strong 16.3 per cent increase in revenue for the first nine months to €191.3 million (from €164.5 million previously). This performance is being driven by the continued success of optical systems for the semiconductor equipment industry, the group reported.

On the back of strong demand, the healthcare and industry business segment earnings before interest and tax also improved significantly by 50.6 per cent to €36.9 million (previously €24.5 million). Order intake rose sharply as well by 29.4 per cent to €222.8 million (up from €172.2 million).

NEWS FROM SPECTARIS *By Dr Wenko Süptitz, head of photonics*

Photonics takeaways from the Medica trade fair

Medica, one of the largest annual exhibitions for the medical industry, took place in Düsseldorf in November. The trade show figures are impressive – and tiring for the feet! Some 5,000 exhibitors from 70 nations presented their products in 17 exhibition halls. By comparison, the largest photonics fair in Europe, Laser World of Photonics in Munich, has some 1,300 exhibitors from 40 countries in five exhibition halls.

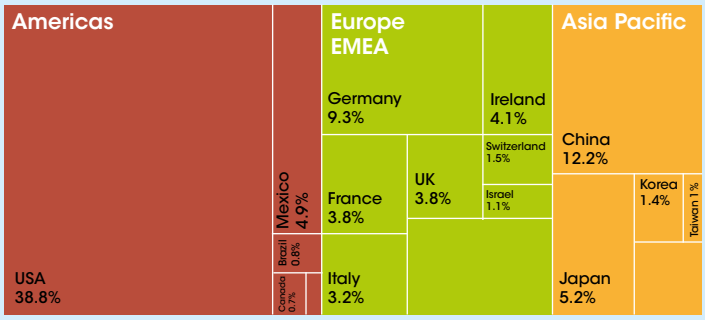
Indeed, medical technology (medtec) is one of the most interesting applications for the photonics industry. With in-vitro optical diagnostics, endoscopy, microscopy, medical lasers and image processing there is a whole range of photonic technologies at one's disposal.

The trend towards the digitisation of medical technologies also fits well with photonics, which was also made clear during the recent Spectaris forum 'Photonik 4.0 – Optical Health Technologies' in Berlin. Optical image processing, point of care and telemedicine are the hot topics where photonics is an integral part of the new digital era in hospitals and doctors' offices.

On the patient side, there are a number of factors driving growth in the health industry and its suppliers. These include a higher proportion of the global population that can afford medical treatment; the ageing population, not only in western countries; and an increase in the number of people who are spending money to stay healthy.

But there are also reasons why medtec is well-known as being a difficult market for suppliers. There is a strong price pressure that has come as a result of shrinking public budgets. And, companies that try to escape from the price pressure with innovative products face an even higher hurdle: Extensive medical device regulations, which turn every product launch into a test of strength and patience between innovators and regulators.

Extensive medical device regulations... turn every product launch into a test of strength and patience between innovators and regulators



The countries suppliers for medtec solutions should look for: the world market for medical technologies by region
Source: Spectaris 2016 (calculation based on GTAI data, US Economic Service and Eurostat)

Only those companies that master the regulations barrier will survive in the long run. At Medica this was one of the talking points during a four-day long forum organised by Spectaris, where a large number of experts joined sessions covering the latest developments in medical device regulations.

Ford's Argo AI acquires Princeton Lightwave

Argo AI, an artificial intelligence subsidiary of Ford that produces software for autonomous vehicles, has acquired lidar firm Princeton Lightwave to accelerate the development of its own self-driving technology.

In February, Ford announced its investment of $1 billion over the next five years into Argo AI, a start-up formed by CEO Bryan Salesky, previously with Google's self-driving team, and COO Peter Rander, who headed Uber's autonomous activities. Argo AI is helping Ford develop an affordable autonomous system for a self-driving vehicle that it plans will be on roads by 2021.

'Princeton Lightwave's technology... will help us unlock new capabilities that will aid our virtual driver system in handling object detection in challenging scenarios, such as poor weather conditions, and safely operating at high speeds in dynamic environments,' Salesky commented.

The expanded Argo and Princeton team will focus on accelerating the development of a virtual driver system mandated for SAE levels four and five, meaning it will operate without the need of a driver behind the wheel.

IN BRIEF

Princeton Instruments has signed a distribution agreement with Quantum Design UK and Ireland for its new Fergie line of imaging spectrographs.

The Zeiss Microscopy business has signed a strategic partnership agreement with Denmark-based Xnovo Technology, a developer of software-based 3D X-ray imaging and analysis solutions, to further develop its diffraction contrast tomography technique, commercialised as LabDCT, on Zeiss Xradia 520 Versa.

ProPhotonix, a manufacturer of LED illumination systems and laser diode modules, has become a new distributor for Integrated Optics' laser modules.

Correction: Gooch & Housego is a supplier of couplers for submarine fibre optical networks, rather than a supplier of submarine network optical fibres as stated in the November issue of *Electro Optics*.

51 experts in photonics integrated circuits gather in Tokyo

NEWS FROM EPIC *By Dr Jose Pozo, director of technology and innovation, EPIC*

Delegation to Japan highlights photonic integrated circuits

EPIC European Photonics Industry Consortium

While the majority of EPIC events are held in Europe, technology and business have no borders, so we strive to connect our members with leaders and experts from the international photonics community. This year, delegation trips have been organised to Israel, Singapore, China and Japan. In addition, events are held annually at OFC and Photonics West in the USA.

From 7 to 10 November in Tokyo, EPIC brought together various industrial actors in photonic integrated circuits (PICs), and arranged a company visit to Hamamatsu Photonics. The size of the group was perfect for networking, and well-balanced for a global event (15 Europeans, 5 Canada/USA and 31 Japanese).

The main market for the Japanese companies remains datacom-telecom, evidenced by the presentations by Fujikura, the National Institute of Advanced Industrial Science and Technology (AIST) and Fujitsu, while in Europe newer markets such as medical imaging, biosensors, lidar, microwave photonics and even quantum are predominant.

A presentation by NTT Microsystem Integration Laboratories on the integration of silicon photonics and III-V materials by means of membrane technology was one of the highlights of the event. Imec in Belgium has also done extensive research on this topic, and their collaboration with TU Eindhoven on silicon photonics integration was mentioned as the European counterpart. As platforms for low losses, the thick silicon platform developed by the VTT Technical Research Centre of Finland was presented, as well as the TripleX platforms and their benefits for imaging and sensing.

The integration of PICs and electronics on chip, such as the BiCMOS integration proposed by the German Innovations for High Performance Microelectronics (IHP) institute, could solve some of the problems raised by companies in Japan, such as Fujitsu and Kyocera, which are proposing a 2.5D integration approach. The H2020 PETRA (Photonic Environment moniToring and Risk Assessment) project has developed a FPGA for the integration of electronics on PIC, also using a 2.5D approach. InP PIC platforms of Smart Photonics and Fraunhofer HHI were considered of high relevance and a clear alternative to hybrid integration of silicon photonics.

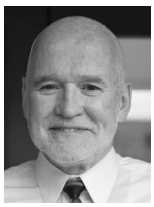
Packaging and testing are still two major bottlenecks in PIC technology. FiconTec and AifoTec showed their important role in the value chain as equipment manufacturer

"Polymer photonics is a more popular solution as a PIC platform in Japan than in Europe"

for both the packaging and testing. Physik Instrumente (PI) and OFS showed how the tools for such automation are as important as the equipment itself.

Pixapp was presented as the European pilot line for the manufacturing of PICs. On the testing side, Yenista showed how to test at wafer level and Yelo at device level. One of the conclusions was that polymer photonics is a more popular solution as a PIC platform in Japan than in Europe, as was evidenced by the presentation by Sumitomo. New parts of the value chain such as the materials provided for silicon photonics by Nissan Chemical Industries, showing the Sunconnect polymer for waveguide fabrication. Europe is clearly a very strong player in the field of photonic integrated circuits!

A luminary in light



In January 2018, Dr Eugene Arthurs is to retire as CEO of SPIE following 18 years with the society. He speaks to *Electro Optics* about his time heading the international photonics association

What aspects of your position as SPIE CEO have you enjoyed the most?
I have greatly enjoyed the people of our community and the many SPIE staff who have inspired me with their dedication to serving with ever higher levels of professionalism. I used to have a desk sign, 'Good enough isn't', but I found it redundant at SPIE. Other very enjoyable aspects of the role have been the intellectual stimulation from the constant advances in photonics, from nano to celestial, and not forgetting the bio wetware, and for someone with my passion for innovation, where else would one find such a cornucopia?

How has the role of SPIE evolved over the past two decades?
SPIE has always been an important element in the photonics industry, with our events and publications, the latter being the most cited in photonics patents. Over the last two decades I'd like to think that SPIE has played an important role in establishing the identity of the photonics industry. We're not there yet, but we are gaining recognition. I recall going round an exhibit in our industry with a potential investor in the 1980s and he said this struck him as a hobby show. The analysts at Photonics West, walking around The Moscone Centre, in perhaps the prime top tier city for emerging technology in the US, have a completely different view. No more second tier for photonics.

In a time when students have many choices, a good number of them less than desirable perhaps, SPIE has supported and encouraged countless students. I'd have to go back and add to my answer to your first question. There is nothing better than someone saying they are enjoying a productive, rewarding and fun career in photonics, and saying that SPIE played a formative role in getting them involved or interested when they were a student. These students are the fuel for photonics innovation. We continue to foster the future.

What do you see as the main strengths of the European photonics industry in the future, given the growth seen in other regions such as Asia?
Germany has always been an optics and photonics power and I have previously noted that Jena was to optics what Silicon Valley was to the early semiconductor industry. I give the European Union great credit for its recognition of photonics, and being a founder member of the board of stakeholders for Photonics21 I have had the privilege to be part of this cooperative effort spanning industry, academia and EU administration to keep Europe strong in photonics.

Arthurs speaking at Photonics West early in 2017

One side effect of the speed of technology development within our industry is the plethora of options that it offers to those beginning their careers. What can the industry do to retain and develop that talent, so the core needs of photonics remain fulfilled?
The dizzying rate of development impacts technology broadly and the expansion of science makes me wonder how anyone can call himself or herself a scientist today. This requires lifelong learning, which is another key goal of SPIE. The technology our community has created has pervaded life generally with much more to come. Any company that wants the brightest and best to fuel growth must provide a stimulating environment, one where talent has the encouragement and freedom

"There is nothing better than someone saying they are enjoying a productive, rewarding and fun career in photonics, and saying that SPIE played a formative role in getting them involved or interested when they were a student"

to keep developing. And get the recognition for accomplishments. In vibrant tech companies the engineers and scientists will be part of the decision making process – making the future – and not just an expense item in the financial reports. As I see more consolidation in the industry, I wonder whether innovation will suffer. In recent decades, large traditional companies in the US have tended to think of R&D talent as in the 'back room'. Our industry has rightly been called fragmented, with a lot of technical leadership, and as a result has been a hotbed of creation. We can benefit somewhat by embracing business school concepts particularly the focus on potential customers, but need to protect the inventive spirit.

You asked what the industry must do to retain talent, and I suggested a real commitment to ongoing growth of these skilled people. Personnel reviews, if they survive, should have a significant focus on technical growth of the individual. While I say this, I note that the individual has a responsibility here. S/he should seek and make use of opportunities to keep current. I really believe that engagement with professional associations like SPIE will help both companies and individuals meet these challenges and help both nurture the excitement that drives so many of these brilliant young people.

Is enough being done to encourage collaboration between the industry, academia and government?
You have hit one of my hot buttons here. Though the short answer is 'no', I am glad to see some movement in this, particularly in the UK. I think Germany has done more here and has the results to show for it in our domain.

What excites you most about having more time for advocacy/analysis work?
It is obvious that aspects of the economic model that has served us fairly well are not sustainable. Significant changes in ratios, such as the number of workers to retirees, pose pretty fundamental challenges. Population growth underpinned how we came to behave. In most of the developed world, that tide has turned, and in countries like the US universities are already seeing smaller numbers of native students. With the old ratios, countries could afford to support science and I believe we became to expect this, and more support, and we became lazy about justifying this support from taxpayers. Fortunately there is growing interest in science policy, but the bottom line is that we can't afford all the science that the science community wants. I think it is an important time to develop a better understanding of innovation and to advocate for science. I believe photonics has extraordinary potential to improve lives and save our planet. We can and must contribute strongly to the UN's Sustainable Development Goals. We need to sustain the momentum, and understanding and advocacy will be key. **EO**

VCSELs in every home, every mobile device and every car

Despite having already been around for more than 40 years, VCSELs are still at the start of their life cycle. Now the technology is set to reach its full potential, writes Dr Joseph Pankert, general manager at Philips Photonics

It's been over a decade since I started working with vertical cavity surface emitting laser (VCSEL) technology. At that time, the basic invention was already 30 years old, and the first commercial applications were more than 10 years old. Yet, despite this, the full potential of the technology is only really coming to fruition now.

To put that into perspective, global revenues for the VCSEL market currently stand at several hundred million, and are expected to swell to above $1 billion in 2022, according to analysts at Yole Développement. If you were to ask me why that is, I would tell you that VCSELs have been waiting for the 'digital revolution'.

Let me explain. The digital revolution constitutes a huge amount of data transmission from one device to another. If we consider the technologies equipped to cope with this, VCSEL emitters are unmatched in terms of energy, volume or cost per transferred bit. Now real world objects are interfacing via sensors with the digital domain. VCSELs enable many classes of optical sensors, with unmatched performance and cost.

Finally, the digital revolution applies to numerous industrial applications, with production processes becoming increasingly digital. VCSEL technology supports this with sensors, in addition to specific components for plastic processing or surface treatment.

What exactly is a VCSEL?

A VCSEL is a (micro-) laser, is monochromatic, coherent, and has a beam shape that conveniently couples into optical fibres. The small cavity also allows for fast modulation, thereby lending itself well to high-speed data transmission.

However, the one outstanding additional property that sets VCSELs apart from any other laser is its compatibility with electronics manufacturing flows. VCSELs are processed and tested on the wafer scale, and conveniently integrate into printed circuit boards just like almost any other electronics component.

This has enabled a supply chain for high volume devices such as time-of-flight sensors or optical transceivers with unmatched price points.

Philips Photonics

Philips Photonics produces VCSELs in its production facility in Ulm, Germany

Philips Photonics

Since announcing in November 2016 that it was doubling the capacity of its laser diode facility in Ulm (due for completion by the end of this year), Philips has produced more than 700 million VCSELs, which has triggered follow-up investments that will lead to a further doubling of capacity by early 2018

Where are we with VCSEL adoption today?

If we think about the current penetration of VCSELs into the digital technology markets, it really is across the board. Mobile devices and industry products increasingly use sensors to scan the environment and interact with other objects, and many of these sensors are optical sensors that rely on sophisticated light sources. VCSELs can provide this – in many cases better than other light sources, like LEDs or edge-emitting lasers.

Nowadays, hundreds of millions of smart phones are using VCSELs for either proximity sensing or autofocus assist. Most data centres use VCSELs for fibre interconnects, and an increasing number of industrial sensors are using VCSELs for position and speed sensing. However, this is only the beginning.

What is the future potential of the technology?

Despite the initial headway, for now, the vast majority of smart phones and interconnects are not yet using VCSEL technology, although forecasted

performance and cost roadmaps make an almost compelling case for very high penetration in a few years from now.

Secondly, we have seen a number of new VCSEL-enabled applications on the horizon that will add an entirely new dimension to VCSEL usage. These include things like 3D mapping to support AR/VR and identification; 3D printing and surface finishing; high power devices using millions of VCSELs that may radically change the way we do processing of plastics; and using VCSEL arrays as light source for lidar, which would be a key enabler for autonomous driving.

The third reason is more of a vision than a reality, and is what I call 'integration'. Today, most VCSELs are designed to fulfill a single purpose, which is emitting light with a certain power level, wavelength and so on. Collimation or diffusing optics, as well as driver circuits, are externally connected to the VCSEL to define the entire function. Wafer level processing, however, allows a more integrated approach of which we have seen the first examples: Datacom VCSELs often come as multi-channel chips (4x, 12x or higher).

"We have seen a number of new VCSEL-enabled applications on the horizon that will add an entirely new dimension to VCSEL usage"

Moreover, we have seen optical elements for mode control or polarisation control integrated right into the GaAs chip, and we have seen devices that have lasers and photo diodes all on the same chip.

All of this bears the promise of a kind of 'Moore's law for VCSELs', where we can expect to see more and more functions integrated on a single chip. Nobody knows which new applications will benefit from integration, and what drives the progress of integration. But I am sure there are plenty of ideas that are out there waiting for VCSELs to take the next step in their ongoing evolution.

A lasting impact on European manufacturing

While we expect the growth of 3D sensing in smart phones to be a major driver, we are also seeing increased demand from industrial applications, and eventually, we will see demand rise from automotive as well, but this could take a few years.

In the future, we expect VCSELs to grow on a global scale. Europe is likely to emerge as one of the strongest regions in adopting VCSELs in industrial and automotive products, as these are traditionally strong industries.

Despite having already been around for more than 40 years, VCSELs are still in the beginning of their life cycle. There are many more innovations to come, and these changes will have a deep and lasting impact on many digital applications, and thereby on all of our lives. **EO**

● If you would like to find out more about the work that Philips is doing with VCSELs, you can read more at **www.photonics.philips.com/about**

Finding common ground on gender issues in optics and photonics

Optical research engineer, Katie Schwertz, discusses the need for mutual understanding and empathy within the photonics community in order to move towards gender equity

As an active member of local and national advocacy efforts regarding women in optics and STEM fields, I have participated in many women in optics and gender equity events, including panels, keynote speakers, and networking receptions. It's incredibly empowering to attend these events and participate in conversations about addressing gender issues in the workplace and in STEM culture. It is eye opening to see what issues are frequently discussed and how universal many experiences are for women in engineering.

When preparing to write this article, I considered focusing on many of the typical topics that come up with regards to women in science, and several of the proposed solutions to tackle gender inequalities. However, one thing kept nagging at me: outside of events and conversations focused on addressing gender issues, I often hear statements such as, 'I know there are problems, but I've just never experienced them myself,' or 'all the women I know seem happy in their work'. I also hear variations of, 'but it's so much better than it used to be'. These sentiments frequently come from people in positions of power, who have generally been successful in their careers. They are often stated by men, but I've also heard them from women too.

A recent study showed that perceptions of gender issues differ across a variety of factors including education, age, personal experiences, and political affiliations[1]. I realised that while I could write many opinions regarding what issues need to be addressed, or how to tackle gender issues in optics and photonics, until we are all on the same page – namely willing to acknowledge that a problem exists – substantial progress will not be achieved.

I wrote this to provide a perspective to those who have been privileged enough to not have their career impeded or affected by their gender. I acknowledge my perspective may be different from yours, and I am not writing from a place of derision towards those who hold different views. My goal is to provide insight, in the hope that I encourage the optics and photonics industry to find common ground in our perceptions, so that we can make a real and lasting impact towards gender equity.

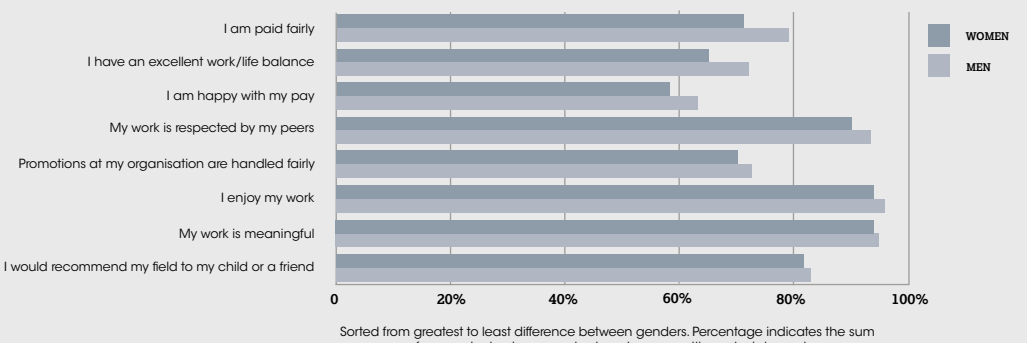
First, the term 'gender equity' and differentiating it from the term 'gender equality'. Picture a race track at the Olympics, with athletes preparing to run laps around the track. All the athletes line up in a row next to each other, and have to stay in their lane throughout the race. You could argue that they are all being treated equally – they all start from the same place at the same time. However, the outer lane is longer than the inner lane, so the athletes are staggered such that the athlete on the outside lane is positioned in front of the athlete on the inside lane. We recognise the fact that the race is not truly fair without this compensation. The concept of gender equity means we recognise disadvantages people or groups face solely because of their gender, and work to remedy those differences.

Now picture instead your co-workers or colleagues lined up in a single row at the start line. You place all the men towards the inside lane and all the women towards the outside lane. This may be an 'equal' start, but everyone in the inside lane you know will have an advantage. Therefore, we need to take actions to provide a more equitable 'race' by promoting programmes and policies that support women.

Now, you may argue: 'Katie! But in a race, we can measure the distance differences from the inner lane to the outer lane, so we can make an accurate compensation'. Fortunately, we can measure differences in

"Gender equity policies are not meant for advancing one group over the other, but to improve fairness by recognising inequities and working to correct them"

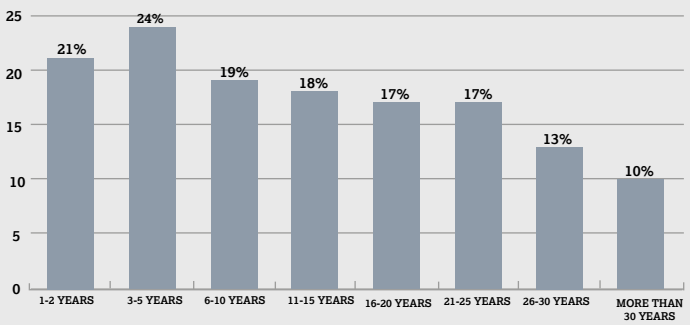
Job satisfaction by gender



Sorted from greatest to least difference between genders. Percentage indicates the sum of respondents who agree, to strongly agree, with each statement

Graph depicting job satisfaction by gender, taken from the SPIE 2017 Optics & Photonics Global Salary Report
The International Society for Optics and Photonics, SPIE

Women as percentage of workers, by years employed



Graph showing the retention of women in photonics careers, taken from the SPIE 2017 Gender Equity Report. At the earliest career stage, 21 per cent of workers are women, but participation declines to 10 per cent for workers with 30-plus years of employment
The International Society for Optics and Photonics, SPIE

"You might find that even the most successful and happy women in your workplace have to deal with frustrating gendered commentary and attitudes"

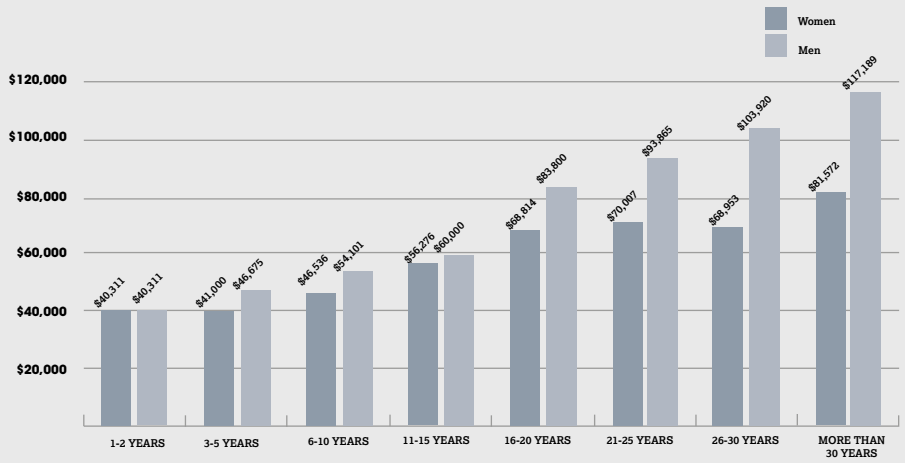
women's abilities to advance in their careers just the same. We have robust global data that shows us exactly how much of a pay gap exists and how little representation women have in leadership and executive positions[2]. Gender equity policies are not meant for advancing one group over the other, but to improve fairness by recognising inequities and working to correct them.

If you're a male reading this article, I'd like you to try a thought experiment. Picture that tomorrow when you arrive at work, all of your colleagues are female. Every meeting you are in, you are the only male (really picture this and consider how it feels!). Every customer visit you make and trade show you attend, you are working entirely with women. When preparing for a trade show, you request a company shirt, and they say that they'll have to figure something out because all the official work attire they have are women's blouses. The most common comment you receive is about the fact that you're a male in the industry. What is your gut reaction to this scenario? Was it negative? Do you feel like an outsider even if you're just doing your job? Are you constantly aware of your gender as an obvious difference from your co-workers? This is the gender minority experience that many women experience on a daily basis in engineering.

Undoubtedly, the working environment for women in STEM, in general, has improved over time. Many women in the generation ahead of me can share experiences that would be vastly out of place if they happened today. However, just because one has not personally experienced or observed sexism in the modern workplace, it does not mean that nobody has. I will always recall once in an interview when my interviewer mused out loud that I seemed 'too pretty of a girl to be an engineer'. Other personal accounts I have been privy to include everything from relatively minor transgressions to significantly more offensive actions and statements. Ask any woman in STEM and I guarantee she has a story to share. The term 'microaggression' has been used to describe the type of pervasive comments that are casual or subtle but still offensive. Think of it this way: Inevitably you have a partner, co-worker, or friend that has an annoying habit. Maybe their habit isn't frustrating when it happens the first few times, but after many, many repetitions of the same action you feel ready to snap. The habit may seem minor to someone who's only seen it once or twice, but it becomes intolerable to the person who experiences it constantly. My point is, while some statements rooted in sexism may have been 'meant as a joke', or seem minor to an outside observer, it is important to realise that women receive these kinds of comments regularly, and they build up over time.

The SPIE Global Salary Survey[3] shows consistently that people are happy in their workplaces within the optics and photonics industry, but this does not mean we are all satisfied with the gender inequities that are so consistently pervasive. I encourage you to start a conversation with some of your female co-workers or colleagues in the industry. Take into account that women don't often go around to their colleagues expressing every time someone was dismissive of them in a meeting or someone makes a sexist remark. If you don't feel as though you've experienced sexism, or think that the women you interact with don't →

Salary by gender and years employed



Bar chart of mean salaries by gender and years employed, taken from SPIE 2017 Optics & Photonics Global Salary Report. Women earn less than men overall, with respective median salaries of $50,500 and $68,953. At early career stages, earnings are similar for both genders, but the gap grows with increasing years on the job.
The International Society for Optics and Photonics, SPIE

→ experience sexism, I encourage you to talk to others outside of your normal circle. You might find that even the most successful and happy women in your workplace have to deal with frustrating gendered commentary and attitudes.

For better or for worse, gender issues are not unique to the optics and photonics industry. We fall very much in line with other STEM fields with regards to attitudes, the pay gap, and representation[4]. I think that if there was any community or industry that would appreciate the need to have confidence in aggregate data and not personal observations, it seems that one rooted in science would be the most likely. To me this presents an incredible opportunity to differentiate ourselves as an industry. There is a rising concern about a global shortage of optics and photonics talent in industry[5]. Imagine all the untapped talent we could gain and retain by having a reputation as an inclusive and progressive industry.

With all this being said, I have learned I can't teach empathy. If you finish reading this article and recognise these are real phenomena happening in your industry but don't care,

"There is a rising concern about a global shortage of optics and photonics talent in industry. Imagine all the untapped talent we could gain and retain by having a reputation as an inclusive and progressive industry"

I don't think anything I write will help. The viewpoints of indifference and disbelief are fundamental to the overall problem of gender bias in STEM. That bias has a tangible impact on women's careers, including their ability to earn a fair wage, be promoted into positions of power, and receive equal awards and recognition.

One more thing, as full disclosure. I'm one of those women that's incredibly happy at their job and has been privileged enough to feel that their career has not been significantly impeded by their gender. But so many people have shared their stories with me and I've heard the same questions, concerns, and narratives over and over again. I'm hoping to raise awareness of those who have never thought twice about their place in the optics and photonics industry, in the hope we can all work together to advocate for and implement gender equity policies and practices.

Understanding the context of our viewpoints can help provide common ground in improving gender issues, so continue the conversations, educate yourselves, and support gender equity in optics and photonics. It will make our industry a better place for everyone. **EO**

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4 Corbett, C., Hill, C. AAUW, Washington, DC. Solving the Equation: The Variables for Women's Success in Engineering and Computing. March 26 2015. Available at: www.aauw.org/research/solving-the-equation/

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The road from research to business: challenges and triumphs

Following the recent publication of an article on ultrafast semiconductor disk lasers in *Biomedical Optics Express*, Dr Florian Emaury, CEO of MicPulse and a semi-finalist in last year's SPIE StartUp Challenge, discusses his entrepreneurial journey in commercialising research-grade semiconductor lasers and forming a profitable business

Coming from a physics background, setting up a business comes with its fair share of challenges, but I've also found it to be an exciting process. Compared to working in a more closed research environment, numerous issues come unexpected and must be taken into account. Researchers all too often forget that you cannot sell a 'technology', but rather a solution to a problem. Discovering the benefits that a technology invented in a university laboratory could bring to potential customers has been exciting. A major part of this evaluation involves countless discussions with experts in the targeted application field, reviews of numerous papers and case studies, but also thorough market research to identify existing products and recognise competitors. This makes the commercialisation of a university technology a real challenge but one with many interesting aspects.

Advancing the ultrafast world with semiconductor lasers

MicPulse aims to commercialise ultrafast semiconductor disk lasers (also known as VECSEL, or MIXSEL) to provide affordable ultrafast laser sources to research and industrial applications. Thanks to the bandgap engineering capabilities of semiconductors, we can design an ultrafast laser for any central wavelength in the 900-1,100nm range, providing an adapted source for each customer.

Our main target is the field of bio-imaging, which requires a wavelength-defined ultrafast laser to drive the multiphoton processes used in in-vivo imaging. Currently-used sources are expensive (>$80k), thus leading to an overall microscope system price (>$0.5m) only affordable by shared facilities or by a few well-funded research groups. This is dramatically limiting the dissemination of these systems to more users or other medical applications.

In our recent article in *Biomedical Optics Express*[1] we demonstrated, for the first time, the full potential of these lasers for in-vivo multiphoton imaging in real and useful research applications (in-vivo experiments with drosophila or in the brain of living mice with structural and functional imagining). We also performed a thorough comparison with a standard Ti:Sapphire laser, showing that equivalent image quality can be achieved with our significantly less complex lasers. These experiments were performed with the research group of Professor Fritjof Helmchen[2] (University of Zürich, Switzerland), a pioneer in multiphoton imaging for neuroscience. Figure 2 shows an example of the type of high quality image that can be obtained with our semiconductor disk lasers, demonstrating that a simple, compact ultrafast laser is a competitive and attractive source for such imaging.

More generally, our vision is to develop an easy-to-use and affordable ultrafast laser that can open up new applications. While the whole ultrafast industry has experienced around an 8 to 10 per cent price reduction every year over the last decade – driven in particular by micro-machining

Dr Florian Emaury / MicPulse

Figure 1: MicPulse's vision is to bring an air-cooled and maintenance-free laser system to the market that will allow customers to drive non-linear processes at any wavelength in the range 900-1,100nm in an easy and affordable way

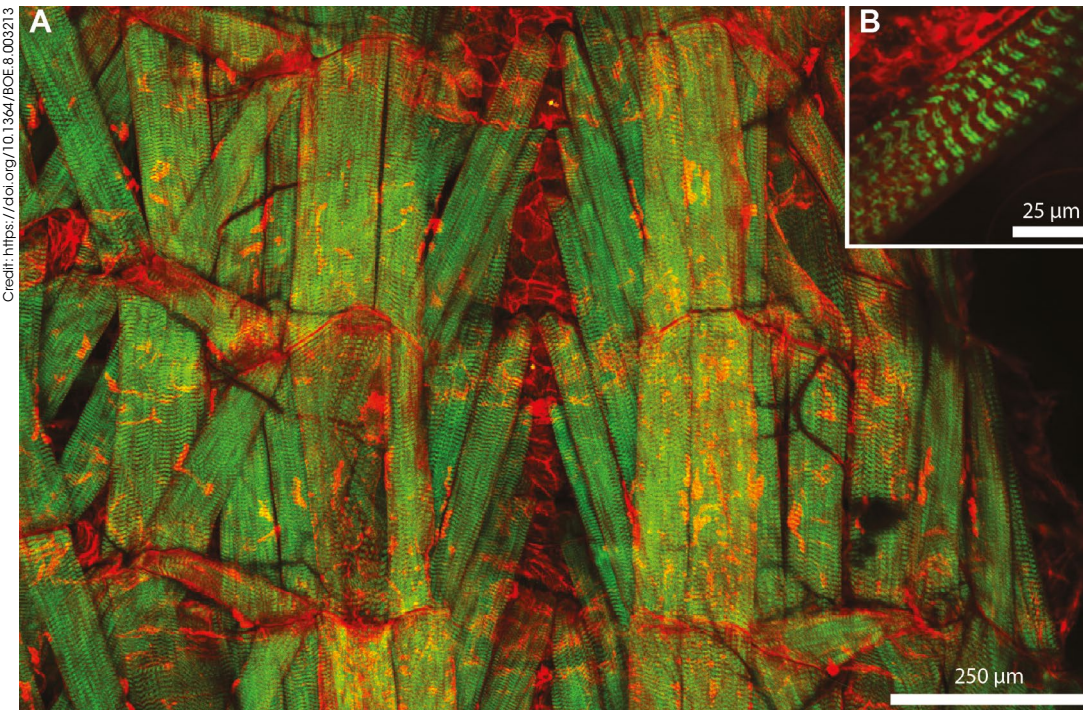


Figure 2: a) Multiphoton imaging of a Drosophila larva using MicPulse's ultrafast semiconductor disk laser. Fluorescence from mKate2 and SHG signals from sarcomeres in the muscles. b) Image of the sarcomeres at a higher zoom showing the characteristic double-band structure

or eye surgery applications – ultrafast sources are still rather complex and too expensive to become integrated in large markets (>10k units a year). While it took a long time to see CO_2 or diode lasers integrated in mass-market products, nowadays, laser-based systems priced at just a few thousand dollars – such as laser 3D printers, laser cutting machines and many more – are widely available.

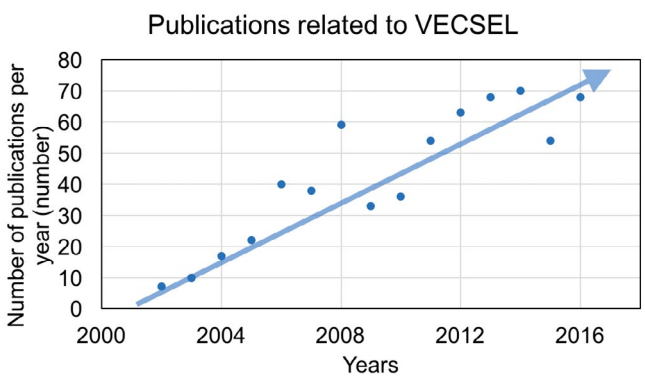
We anticipate that the cost of our ultrafast lasers could open up multiple applications, while mature and standardised components trickle down from high-end and high-price markets. Who would have forecast just 10 years ago that reliable femtosecond lasers are now so prevalent in industry and have a constantly growing market share?

The entrepreneurial journey

My entrepreneurial journey started almost 18 months ago, when thorough analysis showed that the semiconductor technology being developed for more than 15 years by Professor Ursula Keller's laboratory at ETH Zürich[3] had now reached a performance and maturity level that was suited for commercialisation.

With origins at the Optoelectronics Research Centre in Southampton (UK), the first mode-locked semiconductor disk lasers were realised at ETH in 2000. Since then, the performance has constantly improved, reaching the sub-100fs or watt-level milestones recently. Nowadays, more than 20 research groups are working on related topics from laser research to application development.

In order to pursue this journey, I had the chance to receive a BRIDGE proof-of-concept grant from the Swiss government[4]. It allows researchers to start a kind-of 'intrapreneurship within the university'. Coming with financial and administrative support, it aims to help researchers develop a full understanding of the business opportunities that could be created with the technology in question. In a 12-18 month timeframe, it gives support for prototype development, travelling, and other business dealings. The grant is a unique chance for evaluating how to develop a sustainable business based on our previous research. This allows them to be prepared for the next rounds of financing through application-oriented research grants and BA/VC funding.



Dr Florian Emaury / MicPulse

Figure 3: Evolution of the number of publications related to vertical external cavity surface emitting lasers (VECSELs) showing the growing trends of development

"Who would have thought 10 years ago that reliable femtosecond lasers are now so prevalent in industry and have a constantly growing market share?"

Looking back, I realise that, in order to develop an appropriate and convincing product, talking regularly to potential customers and researchers in the targeted application field is crucial. Doing one's homework correctly by evaluating production costs and the unique selling proposition is another important aspect of such a project.

Turning a research prototype into a product is a lengthy process, and the value it will bring to customers in the end may greatly differ from the initial thoughts. Thus, if you are to start on such a journey, do not forget to keep focus, and always keep your eyes open without assuming that past decisions and visions were always correct. **EO**

www.micpulse.ch
www.linkedin.com/in/florianemaury

Dr Florian Emaury leads the startup project MicPulse, in collaboration with ETH Zürich. After graduating in 2010 from the Institut d'Optique Graduate School (IOGS) in Paris (MSc in Photonics/Physics), his career started with engineer experiences in Fianium (UK) and Coherent (CA, USA) before joining ETH Zürich to obtain a PhD in Physics in 2015.

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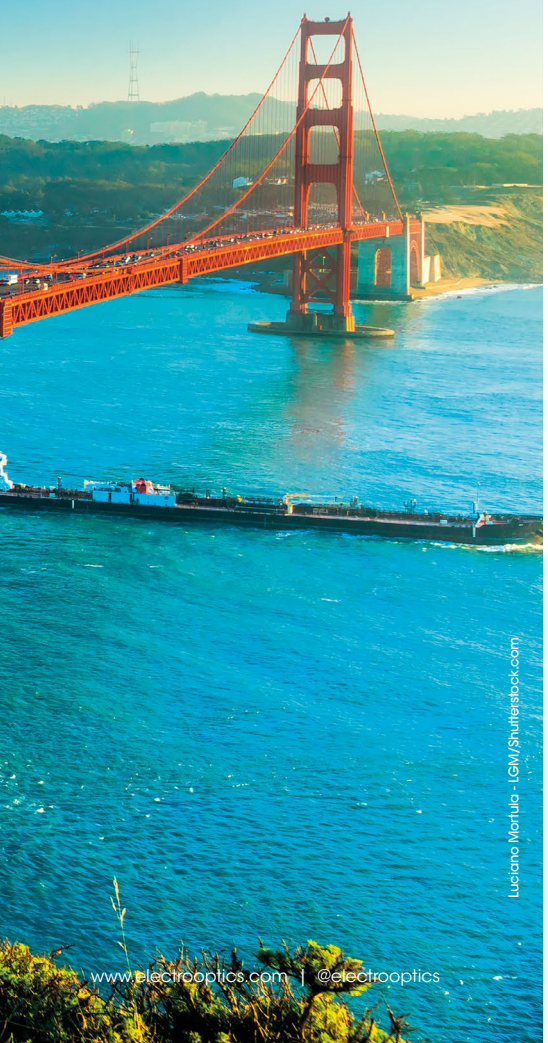
2 www.hifo.uzh.ch/en/research/helmchen.html

3 www.ulp.ethz.ch/

4 http://bridge.ch/en/for-young-researchers-proof-of-concept/

Photonics' golden gateway

San Francisco will once again play host to two major international exhibitions in early 2018 – the BiOS Expo on 27 and 28 January, and the Photonics West exhibition from 30 January to 1 February – which will showcase the latest photonics components and systems. Here we preview some of what to expect at the event



Luciano Mortula - LGM/Shutterstock.com

Avantes will feature its expanded line of compact spectrometers at booth 1815, which includes the first-ever CMOS spectrometer with a 4,096 pixel detector. The Mini4096CL has both speed and sensitivity packed into a small footprint. Like all other AvaSpec instruments, the Mini4096CL is affordable, compact, and ideal for OEM integration. The Mini4096CL permits less than 0.2 per cent stray light and delivers a signal-to-noise ratio of 319:1.
www.avantes.com

A new laser attenuator has been developed, which utilises an ultra-hard coated, Laser Optical Multilayer Attenuator (LOMA) filter from **Delta Optical Thin Film**.

The laser attenuator enables computer-controlled attenuation of a monochromatic light source from 1 to 99 per cent within the wavelength region of ~ 550-1,000nm. It provides the user with safe, repeatable, and real-time control over the attenuation by combining the LOMA filter with a linear drive, controlled electronics, and dedicated software.

This filter is based on an optical thin film coating that works on reflection, unlike other filters that work on absorption. This feature allows the LOMA filters to withstand high laser power, as it attenuates the laser with no absorption of the input power.

The laser beam is transmitted without distortion of the beam profile, and no extra optics are required. No pulse broadening is observed, even with short laser pulses down to 70fs. The optical coating works independently of polarisation, and it is designed for a wide range of laser wavelengths between 550 and 1,000nm.
www.deltaopticalthinfilm.com

Edmund Optics will be exhibiting at booth 823 with a strong focus on laser optics, showcasing its new Nd:YAG laser line mirrors at UV wavelengths, divergence adjustable beam expanders and monolithic reflective beam expanders, in addition to a selection of its regular portfolio.

Also at the booth will be product expos on a UV laser materials processing system, drone-based imaging for analysing the health of crops, well-plate inspection for advanced medical diagnostics and an exhibit visualising the firm's manufacturing capabilities.

The company will also be at Bios, booth 8620, where it will present products specifically addressing the life science market.
www.edmundoptics.eu

Excelitas Technologies will be debuting Qioptiq's closed-loop modulation (CLM) feature for the iFLEX-iRIS and iFLEX-Gemini laser systems at booth 1031. The innovative CLM feature provides modulation capabilities without the need for recalibration, combined with ultra-low →

Cobolt, a part of Hübner Photonics, will highlight new wavelengths of 457nm, 473nm, 515nm, 660nm and 1,064nm on its 08-01 series, complementing the already available wavelengths of 405nm, 532nm, 561nm and 785nm. The 08-01 series of single frequency and narrow linewidth lasers are ideal for Raman spectroscopy.

The 08-01 series consists of high performance, ultra-compact, single longitudinal mode (SLM) diode pumped lasers (08-DPL) up to 400mW and narrow linewidth diode lasers (08-NLD) up to 500mW, all having very good wavelength stability and spectral purity. With integrated electronics, an integrated optional optical isolator and clean up filter, the lasers from the 08-01 series are easily integrated into high-end,

Raman-based systems or other analytical instrumentation.

All Cobolt lasers are manufactured using proprietary HTCure technology, and the resulting compact hermetically sealed package provides a very high level of immunity to varying environmental conditions along with excellent reliability.
www.coboltlasers.com

→ noise and high-power stability performance over the laser's lifetime. It is ideal for biomedical imaging and metrology applications where repeatable performance and low signal-to-noise ratio are required.

Unlike traditional open-loop laser modulation, the iFLEX CLM maintains consistent output during both continuous-wave and modulated operation. The CLM feature enables analogue, digital and dual-mode modulation for reliable stability from 0.1 per cent to 100 per cent power and maximum repeatability for ultra-stable performance. IFLEX lasers with CLM are also ultra-low noise in terms of RMS, RIN and periodic noise. They offer precision adjustment at all output power levels for applications where a stable, ultra-low noise source will improve signal-to-noise ratio and data consistency over time.
www.excelitas.com

The laser diode module for 3D vision systems to be showcased by **Frankfurt Laser Company** from its HAML-F series is compact, reliable and delivers a highly uniform and stable line output beam. It comes in visible and IR wavelengths with up to 100mW power output and is graded

at IP67 for industrial protection. Available with special features such as digital and analogue modulation, different beam shapes and power adjustments, the HAML-F can be used in a wide range of applications.
www.frlaserco.com

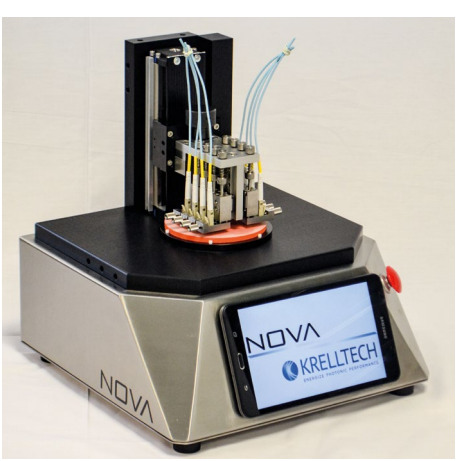
Gentec-EO's product line, some of which will be on display at the show, includes a complete range of laser power and energy meters, photo detectors, broadband pyroelectric detectors, terahertz detectors, OEM detectors and beam diagnostics. This

year the company introduced new wireless laser power detectors, M^2 beam diagnostics, and Pronto HP power meters.
www.gentec-eo.com

KrellTech will be exhibiting its line of fibre optic and photonic polishing equipment at Photonic West (booth 4322) and introducing the Nova system.

Maximum flexibility for optical surface processing is now available with Nova. KrellTech has integrated the proven performance and features of its Scepter, Trig and FLex polishers into this configurable and cost-effective system.

Nova supports a variety of polishing applications from connectors to waveguides, and bare fibres to custom components. →



Prism Award finalists

Disruptive technology for assessing chemical composition in real time, a lidar system for self-driving vehicles, and a smartphone-add-on sensor for non-contact blood pressure and other healthcare tests are among the finalists for the 2018 Prism Awards for Photonics Innovation competition.

The annual event, which is celebrating its 10th year in 2018, recognises innovative product inventions within the optics and photonics field.

Winners will be announced on 31 January at a gala banquet during Photonics West, boosting visibility, recognition, and brand equity for companies bringing innovative products to the market.

'Ten years in, the Prism Awards are casting an even wider light on the photonics industry. Each year, categories for the awards are driven by the innovations entered, providing direct insight into thriving and emerging "hot" markets,' said SPIE CEO Eugene Arthurs. 'New this year are categories for inventions in environmental monitoring and for illumination and light sources – very timely as the world continues to work toward more sustainable energy sources and devices.'

The finalists are as follows:

Detectors and sensors
- **NKT Photonics:** LIOS EN.SURE Long Range DTS and RTTR
- **Princeton Infrared Technologies:** LineCam12
- **Xenics:** XLIN FC 2048 detector

Environmental monitoring
- **Block Engineering:** LaserWarn analyser
- **Blue Industry and Science:** X-FLR8 V2
- **Daylight Solutions:** ChemDetect mid-IR liquid analyser

Illumination and light sources
- **Lumileds:** Luxeon 3535L HE Plus line LEDs
- **Osram Opto Semiconductors:** SFH 4735 high-power infrared emitter
- **SoraaLaser:** LaserLight fibre module

Imaging and cameras
- **Daylight Solutions:** Spero-QT infrared microscope
- **Luminar:** Model-G 3D Lidar
- **Teledyne Dalsa:** Piranha4 polarisation line scan camera

Lasers
- **Class 5 Photonics:** Supernova OPCPA
- **KMLabs:** Y-Fi OPA
- **Optores:** NG-FDML (wavelength-swept laser)

Life science instrumentation
- **neaspec:** cryo-neaSNOM
- **Quantumcyte:** Q1
- **Tomocube:** HT-2 (Holotomographic microscopy with 3D fluorescence imaging)

Material processing and additive manufacturing
- **Han's Laser Technology Industry Group:** (UV laser system for PVD ablation processing)
- **Limo:** Activation Line UV-L750
- **Nuburu:** AO-150 (high-speed infrared 150W laser)

Medical diagnostics and therapeutics
- **ContinUse Biometrics:** SmartHealth Mod (smartphone biosensor)
- **Lightpoint Medical:** LightPath Imaging System (intra-operative luminescence imaging)
- **Lumedica:** OQ LabScope (low-cost OCT)

Optics and optomechanical components
- **AdlOptica Optical Systems:** foXXus (multi-focus optics)
- **Optotune Switzerland:** MR-15-30 (dual axis vector scan mirror with position feedback)
- **Spectrolight:** Flexible Wavelength Selector

Test and measurement
- **Gamma Scientific:** GS-1290-NED (near eye display measurement system)
- **Si-Ware Systems:** NeoSpectra Micro (chip-sized spectral sensor)
- **Spheryx:** xSight (holographic suspension analysis device)

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→ Nova is scalable for R&D projects, high volume production, and the rigours of high-reliability field installation.

Wireless tablet control with a familiar Android interface provides the programming flexibility required for research, as well as simplified step-by-step operation for manufacturing technicians. Workholder fixtures are easily interchangeable for each task, and optional videoscopes are available for real-time process monitoring and in-line surface inspection.

Whether developing new optical devices, improving component performance or manufacturing Telcordia-compliant cable assemblies, Nova is the ideal polishing system.

https://krelltech.com

At booth number 5137, Laser Beam Products (**LBP Optics**), a worldwide manufacturer of industrial and scientific metal laser mirrors and infrared optics, will be co-exhibiting with new owners **ULO Optics**.

ULO Optics will be showcasing its new Compact2 range of CO_2 beam delivery equipment, along with the first of their range of fused silica collimators for fibre lasers. Compact2 is a cost-effective, low maintenance, modular solution to CO_2 beam delivery. Offering twice the power handling of the existing Compact range, the Compact2 range is suited to lasers up to 1kW with beam sizes up to 38mm.

LBP Optics will be exhibiting a range of precision metal mirrors including gold-coated copper and aluminium. LBP mirrors are chemically polished to a unique, super-smooth finish and examples of these fully tested, super-polished metal substrates ready for coating will be on display.

www.lbp.co.uk
www.ulooptics.com

Lew Techniques will be showing its capabilities in the precision custom manufacture of submounts and carriers for laser diodes, laser bars, laser stacks and photodiodes.

Product types include tungsten/copper (WCu) submounts with super-sharp edges (<5µm radius), allowing precise mount-edge positioning of laser diodes. WCu inserts brazed to solid copper bodies maximise heat-sinking, while minimising expansion mismatch between carrier and laser die.

Submounts in aluminium nitride (AlN) with photo-patterned metallisation provide high-precision circuits. Metal structures can be tailored to meet individual requirements for soldering, wire bonding, electrical and thermal performance.

WCu- and AlN-style mounts selectively coated with a thin layer of AuSn solder allow accurate and consistent mounting of the laser die. Strict maintenance of metal coatings and solder alloy consistency ensure optimum reflow results.

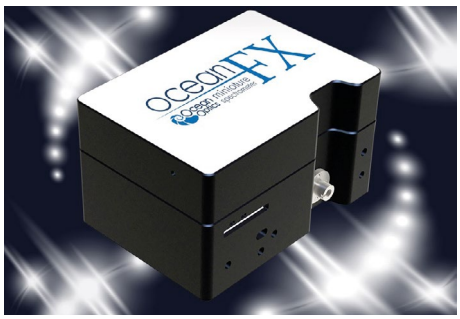
Mounts for photodiodes on ceramics with wrap-over conductors are also available. Circuits can be defined on multiple faces allowing greater interconnect flexibility, and ceramic can be precision-machined for the greatest functionality.

www.lewtec.co.uk/

At booth 723, **Ocean Optics'** Ocean FX versatile spectrometer will be on show, distinguished by an acquisition speed of up to 4,500 scans per second, onboard processing for favorable SNR and reduced transfer time, and robust communications via USB, Gigabit Ethernet and Wi-Fi. The Ocean FX is an ideal choice for high-speed process applications, measurement of transient events and reaction monitoring.

The Ocean FX is available in application-ready, custom and OEM spectrometer configurations. The spectrometer can be integrated into other devices as a component, subassembly or turnkey solution. It is well suited for environments where fast sampling rates are necessary, such as monitoring sample colour, quality and other characteristics on a process line.

In addition, the Ocean FX's integration



Conference details

Talks by two Nobel Laureates will be among more than 5,200 technical presentations held alongside the Photonics West exhibition in San Francisco. The symposium is expected to attract an international audience of more than 20,000.

Conferences are organised into tracks on biomedical optics (BiOS), industrial laser sources and applications (LASE) and optoelectronics and photonic materials and devices (OPTO).

Stefan Hell (Max-Planck-Institut Göttingen) and William Moerner (Stanford University), who shared the 2014 Nobel Prize in Chemistry with Eric Betzig (Janelia Research Campus) for their work in ultrahigh-resolution fluorescence microscopy, will give details on the latest advances in the field.

A comprehensive training programme is set to offer more than 70 courses in lasers and applications, sensors, imaging, IR systems, and optical and optomechanical engineering, plus professional development seminars and industry workshops.

Receptions and other networking events will provide many opportunities to share ideas, connect around community issues such as diversity and inclusion, or to meet new potential collaborators.

HIGHLIGHTS

New among this year's 44 BiOS conferences – comprising 2,400 presentations – is the theme, 'Photonic Diagnosis and Treatment of Infections and Inflammatory Diseases'.

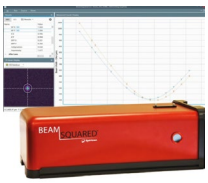
Nine talks in the popular BiOS Hot Topics session will cover topics such as biophotonics for low-resource settings (Katarina Svanberg, Lund University and Sune Svanberg, South China Normal University) and near-future developments in photodynamic therapy (Tayyaba Hasan, Wellman Centre for Photomedicine).

A multi-speaker Neurotechnologies plenary session will include topics such as strategies for observing and controlling neural circuits (Ed Boyden, MIT) and in-vivo imaging of the brain (Na Ji, University of California, Berkeley). Track chairs are David Boas (Martinos Centre, Massachusetts General Hospital, Harvard Medical School) and Raphael Yuste (Columbia University).

A Nano/Biophotonics plenary talk on shaped light will be presented by Kishan Dholakia (University of St Andrews, Scotland).

The Translational Research forum will present outcomes-based studies on technologies, tools and techniques with high potential to change the lives of patients. Organisers are Bruce Tromberg (Beckman Laser Institute and Medical Centre, University of California, Irvine) and Gabriela Apiou (Wellman Centre for Photomedicine,

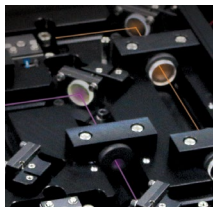
periods can be as brief as 10µs, effectively managing saturation intensity when measuring high-intensity sources and plasmas. The Ocean FX acquires spectra with such speed that short-lived events can be measured confidently and otherwise undetected spectral effects made evident.
www.oceanoptics.com



Ophir will be displaying the BeamSquared, an M2 laser beam propagation system designed to help users optimise laser performance. A robust, portable device, BeamSquared automatically measures the propagation characteristics of CW and pulsed lasers in less than a minute. It can optionally measure wavelengths above 1.8µm in manual mode, including CO_2 and terahertz. BeamSquared is designed for continuous use applications, from scientific research to rapid prototyping, fabrication and machining.

The system includes BeamSquared M^2 software and an optical train. The software measures beam propagation characteristics on both the X and Y axes, including waist diameters, full angle divergences, waist locations, Rayleigh lengths, M^2 or K and BPP factors, astigmatism and asymmetry. The system displays 2D or 3D beam profiles for visual verification of beam behaviour through focus.
www.ophiropt.com

PicoQuant will be showcasing its latest innovations in picosecond pulsed diode lasers for single photon counting, microscopy and spectroscopy applications at booths 306, 4853 and 4859. The highlights at the exhibition will include the high-power pulsed laser VisIR/VisUV platform with the new wavelengths 266, 280, 295, 532, 560 and 590nm, as well as PicoQuant's new quantum correlation analysis software QuCoa.



The company will also be sponsoring presentations in the field of single molecule spectroscopy and super resolution imaging at the conference session BO503, where Nobel Prize winner Stefan Hell will also hold a talk focused on his most recent research.
www.picoquant.com

Visitors to **Quantel** and **Keopsys** booths (8742 and 417) will be able to see both groups' range of diodes modules and laser solutions. Quantel and Keopsys groups are merging their resources into a new laser group to offer an extended product portfolio in addition to their existing laser solutions for a variety of application fields like: biotech and medical, material processing, defence, scientific instrumentation, LIBS, laser pumping and fluid dynamics.

Quantel and Keopsys groups are also consolidating their activities in the lidar →

LIDAR de Dumont d'Urville © C. FRESSER-IPEV

Princeton Instruments will introduce its Blaze spectroscopy CCD cameras at the show, featuring revolutionary new sensors with up to three times higher NIR sensitivity and low dark current, which make the camera exceptional for demanding applications such as Raman spectroscopy, fluorescence or photoluminescence. Blaze provides spectral rates of up to thousands of spectra per second. For low light applications, Blaze delivers true -100°C cooling for ultra-low dark current, ideal for long exposures.
www.princetoninstruments.com

Massachusetts General Hospital, Harvard Medical School).

BiOS symposium chairs are James Fujimoto (MIT) and Rox Anderson (Wellman Centre for Photomedicine, Massachusetts General Hospital, Harvard Medical School).

Among the 900 presentations in the LASE conference will be plenary talks on laser frequency combs and dual-comb spectroscopy (Ursula Keller, ETH Zurich), optical lattice clocks (Hidetoshi Katori, University of Tokyo and Riken), and industrial laser systems and applications (Berthold Schmidt, Trumpf Photonics).

LASE symposium chairs are Koji Sugioka (Riken) and Reinhart Poprawe (Fraunhofer Institute for Laser Technology).

"A multi-speaker Neurotechnologies plenary session will include topics such as strategies for observing and controlling neural circuits and in-vivo imaging of the brain"

Highlighting 2,000 presentations in OPTO, plenary talks will cover silicon photonics (Andrew Rickman, Rockley Photonics), nanowire LEDs and diode lasers (Pallab Bhattacharya, University of Michigan), and photonics beyond the diffraction limit (Min Gu, RMIT University). There are three new conferences, on 2D Photonic Materials and Devices, Optical Data Science, and UltraHigh-Definition Imaging Systems.

OPTO symposium chairs are Connie Chang-Hasnain (University of California, Berkeley) and Graham Reed (Optoelectronics Research Centre, University of Southampton).

INDUSTRY FOCUS

Market trends and business opportunities will be explored in a variety industry-focused sessions, including: a conference on virtual, augmented and mixed reality technology challenges and successes, featuring Bernard Kress (Microsoft/Hololens) and Leo Baldwin (Amazon Functional Photonics); panel discussions on silicon photonics and photonic integrated circuits, 3D printing and other hot technology topics; updated SPIE analysis on the size of the core photonics market; tips on navigating the innovation ecosystem; the annual SPIE Startup Challenge pitch competition for pre-revenue companies; a Fast Pitch Lunch connecting entrepreneurs with potential investors and mentors; and a gala awards banquet where industry leaders will announce winners of the 2018 Prism Awards for Photonics Innovation (see finalists on page 36 panel).

Recruiters from more than 30 companies are expected at the SPIE Career Centre Job Fair (30-31 January).

→ application space, with a full range of solutions including: integrated high-power diode solutions for automotive and surveillance needs; ultra-compact fibre lasers for wind sensing, range finding and 3D scanning; high energy flash or diode pumped solid-state lasers for atmospheric lidar and environmental measurements; and various customised solutions for defence, space and high-end applications.
www.quantel-laser.com

F-Theta lenses are important in material processing applications like cutting, welding, ablation and many more. They are designed to focus laser beams down on a plane scan area with a consistent spot size. Additionally they are available at various focal lengths from UV to IR and some even with telecentricity. **Sill Optics** presents the S4LFT4125/075 for UV lasers. The scan area has been improved from 35 x 35mm up to 50.5 x 50.5mm. Despite the higher focal length, a focal diameter of 8µm (1/e²) can be reached inside the whole scan area with a 10mm input beam diameter. The lens is made of fused silica and is without internal or external back reflection focus points.
www.silloptics.de

Scanlab will be featuring its soon-to-be available intelliScanse 20 and 30 scan head systems, with 20mm and 30mm apertures for a larger working field. Their integrated digital encoder technology ensures the highest dynamics along with high resolution and long-term stability. These factors make the systems especially interesting for demanding applications such as 3D printing, micro-structuring and micro-processing. An attractive price/performance ratio also underscores the systems' suitability for efficient industrial usage.

The intelliScanse 20 and 30, both equipped with high-performance dynAxisse L galvanometer scanners, can fulfil the market's demand for large-aperture systems. These are designed to enable larger working volumes with unchanged spot sizes. The integrated digital se-encoder technology guarantees outstanding precision and dynamics, while enabling maximum throughput.

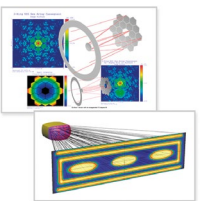
Scanlab will be located in the south hall, at booth number 2025.
www.scanlab-america.com

Synopsys' Optical Solutions Group (OSG) is a developer of optical design and analysis tools, with Code V imaging design software, LightTools illumination design software, LucidShape products for automotive lighting, and RSoft products for photonic and optical network design.

At Photonics West, Synopsys will exhibit Code V, LightTools, and RSoft software solutions. Code V has powerful capabilities for lens optimisation, analysis, tolerancing, beam propagation and coupling efficiency.

LightTools is a 3D optical engineering and design software product that supports virtual prototyping, simulation, optimisation and photorealistic renderings of illumination applications.

RSoft products provide a full range of design, optimisation and planning tools for optical communications, as well as award-winning solutions for optoelectronics components and subsystems.



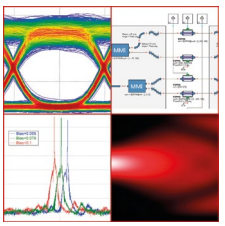
OSG is also an independent supplier of optical systems design services, with more than 5,000 completed projects in imaging, illumination, and optical systems engineering.
www.synopsys.com/optical-solutions

At booth 807 **Thorlabs** will be displaying new products and manufacturing capabilities from its portfolio of optomechanics, motion control, light sources, optoelectronics, optics, fibre, instrumentation, and imaging product lines. Highlights include Thorlabs' new line of high-speed instrumentation for photonics applications up to 70GHz.

Fibre-optic reference transmitters, electro-optic modulator drivers, C-Band and L-Band tunable lasers, and calibrated electrical-to-optical converters are all available in the portfolio in benchtop units with integrated, easy-to-use touchscreen controls. These systems are ideal for use in an R&D laboratory or manufacturing environment

for creating optical links, performing experiments, or testing components.
www.thorlabs.com

Visitors to **VPIphotonics'** booth can learn about library extensions to VPIcomponentMaker Photonic Circuits, which provide circuit-level support of a Process Design Kit (PDK) for various integrated photonics technologies.



These pluggable toolkits support a cost-effective generic foundry approach for application-specific photonic integrated circuits design. Within this approach, the designer can choose photonic devices from a fixed list of so-called building blocks (BBs) supported by the individual foundry.

The seamless integration with photonic layout design tools allows users to specify physical locations and orientations of BBs of standardised PDKs on the final layout. Designers can gradually elaborate its layout, easily incorporating requirements such as adequate layout connectivity, packaging, and functional specifications.

VPIphotonics' integrated design solutions allow users to combine graphical schematic capture, including automated parameter sweeps and optimisation, as well as automated waveguide routing of PICs utilising any combination of different technology platforms.
http://vpiphotonics.com

Veeco's Spector-HT Advanced Ion Beam Sputtering System will be on show, offering excellent layer thickness control, enhanced process stability and the lowest published optical losses in the industry.

For cutting-edge optical interference coating applications ranging from bandpass filters to beam splitters and laser passives, the Spector-HT has been engineered to improve key production parameters. The Spector-HT gives manufacturers the qualitative advantages of ion beam sputtering technology in a more robust package.
www.veeco.com

The brightest brains

Jane Burgermeister reports on world-class neuroscience research that's being advanced by photonics

Fedorov Oleksiy/Shutterstock.com

Neurophotonics, described as the application of light-based tools and technologies to observe the finest details of the human nervous system and brain, is advancing brain research and the development of therapies for neuro-diseases and psychiatric disorders.

Valentin Nägerl, professor of neuroscience and bio-imaging at the University of Bordeaux, noted that the development of new kinds of bio-sensors (and actuators), advanced microscopy techniques and image analysis tools among other elements is helping to push the broad and dynamic field of neuroscience forwards.

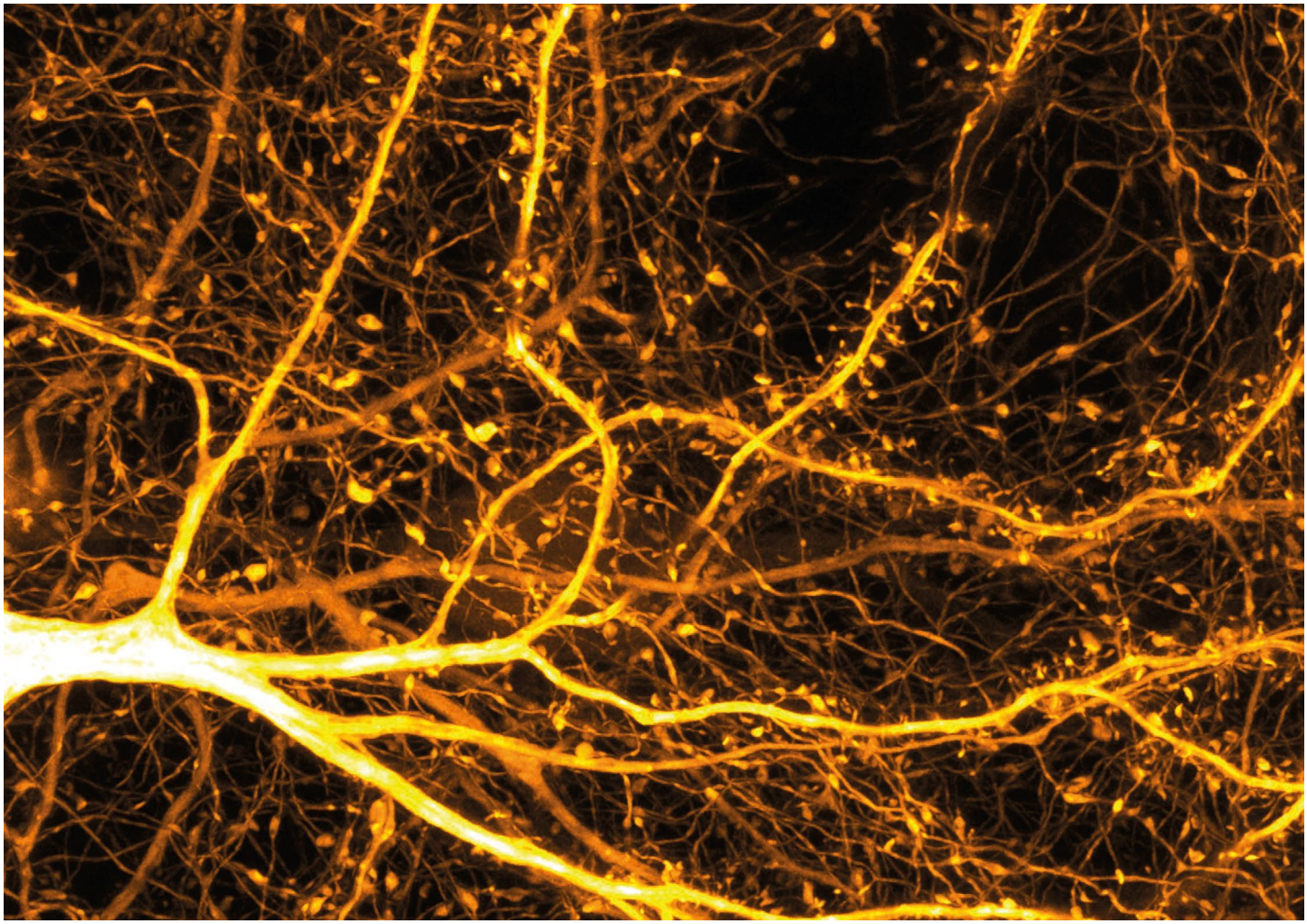
However, further improvements across every area are needed to advance the scope and usefulness of neurophotonics methods. Research groups across the

"The more we can see and understand, the more hope there is that we will be able to find cures and therapies"

globe are working on such developments, integrating elements of optics, biology and physics to craft ever better technologies to penetrate ever deeper into living tissues such as brain.

While substantial funding programmes like the BRAIN initiative put the US in a strong position for neuroscience research, other regions are also excelling in the development of neurophotonics instruments and techniques.

With a history of manufacturing optical systems and pioneers like Leica and Zeiss, Germany is at the forefront of the commercialisation of super-resolution →



Prof U Valentin Nägerl / Institut Universitaire de France (IUF), Synaptic Plasticity and Super-Resolution Microscopy Group, Institut Interdisciplinaire de Neurosciences (IINS), Université de Bordeaux

The dendritic tree of a fluorescent-labelled neuron inside living brain tissue, acquired with a STED microscope

→ microscopy techniques, which have made it possible to study the complex and dynamic inner life of cells at the level of the individual protein building blocks. Meanwhile, in France scientists have been focusing on biological applications and discoveries enabled by these new techniques, Nägerl pointed out.

Of the many emerging developments in neuroscience, Nägerl considers the new generation of super-resolution light microscopes to be a breakthrough. By improving the ability to look deep inside biological tissue, these microscopes for instance allow taking extremely sharp and detailed images of neurons and their activity in real time as the animal subject goes about its everyday tasks.

This discovery brought professor Stefan Hell, director at the Max Planck Institute for Biophysical Chemistry in Göttingen, and his colleagues a Nobel Prize in 2014.

By breaking Abbe's limit, the diffraction barrier in optical microscopy, Hell was able to increase the power of resolution tenfold, and he also showed there was room to obtain even better resolutions.

'These advances in imaging make it possible to study, in real time, molecules and processes within the brain that have so far been out of reach for non-invasive optical methods,' commented Nägerl. 'We can now see things at the nanoscale, way beyond the old textbook limit set by the diffraction of light. And we can do so not by just scratching at the surface but really looking deep into it.'

The higher spatial resolution allows scientists to see molecules, for example, as they move dynamically in a natural context in real time.

'The more we can see and understand, the more hope there is that we will be able to find cures and therapies,' said Nägerl. 'There is always a thirst to see more.'

Neural highway

A traffic management structure can be used to demonstrate how neurons in the brain communicate. City traffic systems can flow very smoothly, but they can also malfunction. Traffic lights can fail in one place. A car accident can lead to a jam in another. In the same way, neurons can fail to flow as they should or make proper connections. Malfunctions in neuron communications and processes inside our brains can lead to degenerative diseases such as Alzheimers and Parkinsons. But now that advances in neurophotonics allow scientists to see the mechanisms behind such neuronal degeneration, they are much better placed to correct processes and find cures.

Optogenetics is one neurophotonics technique that allows scientists to use light to observe, or even control, the activity of neuronal circuits in order to better understand how the brain works.

'Akin to the different traffic lights and signals that allow to control or direct the flow of traffic circulation on a road, neurophotonics [specifically optogenetics] can also be used to up or down-regulate the activity of a specific subset of neurons, using genetically engineered light-sensitive proteins,' explained Mario Méthot, coordinator at the Neurophotonics Center of the Canadian Neurophotonics Platform.

'As for now, [optogenetics] is applied in

basic science research… but scientists have great hopes that knowledge acquired using model systems could eventually be applied in humans to treat various diseases affecting the brain,' said Méthot.

Marie Carlen, associate professor of Neuroscience at the Karolinska Institute at the University in Solna, Sweden, is one research who is studying living animals using optogenetics techniques.

Laser and fibre optics are used to 'insert' varying intensities of light to be directly into specific areas in the brains of experimental animals, which causes specific neurons to be turned on and off.

The corresponding changes observed in the animals' behaviour give clues as to which cells and regions of the brain are involved in different emotional and physical responses, such as those associated with hunger, fear, anxiety, learning, motivation and more.

This element of control happens because of opsins, the molecules in neurons that can be activated by light. Some types of opsins fire off positively charged ions in response to light, making it possible to activate or switch on neurons. Other opsins, by contrast, send out negatively charged ions when in contact with light, and inhibit or turn off neurons. Genetic engineering has allowed opsins to be tailor-made to fulfill specific functions and better meet the needs of researchers seeking clues as to which neuronal functions correlate with behaviours. It is already the case that light can be used to manipulate opsins with a high degree of precision allowing for neurons in specific locations to be turned on and off for specific lengths of times.

"Scientists have great hopes that knowledge acquired using model systems could eventually be applied in humans to treat various diseases affecting the brain"

The lasers and optics needed for optogenetic experiments are specialised. Marie Carlen works with Swedish photonics firm Cobolt to develop the laser devices that best enable her team to advance their studies of the cognitive functions of animals. Calibrating laser tools so that they deliver sufficient light to the area of an animal brain to switch specific neurons on and off without damaging the tissue is a complex task, involving the correlation and adjustment of many different factors such as wavelength, power output and stability. In addition, the laser devices have to be flexible enough to move as the animals move. Cobolt offers a variety of user-friendly lasers to meet the various needs of researchers such as Marie Carlen.

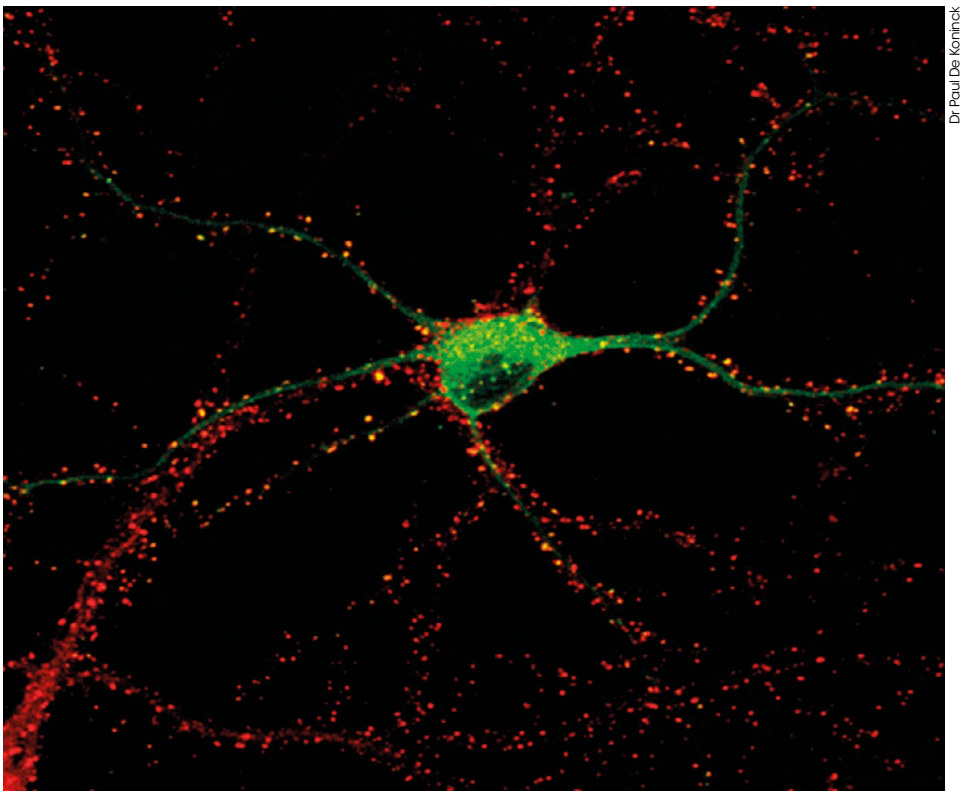
In other research, Benjamin Judkewitz, professor in Bioimaging and Neurophotonics at the NeuroCure Cluster in Berlin, is developing a technique to track and image neurons as they interact with each other and communicate inside their natural networks, potentially allowing scientists to model brain activity in real time, as subjects perceive multiple real world phenomena simultaneously and respond. This technique would help scientists, for example, track the emergence and growth of a tumor in a particular location and develop therapies. Immunologists, on the other hand, may be able to study the process by which lymph nodes become swollen – and not just cells in a petri dish.

The sheer complexity of the brain and nervous system, however, makes the task of modelling them a long term project. The brain alone has about 86 billion neurons. Tracking them as they interact with each other to generate complex and ever changing patterns of movement as they respond to their environment is a staggering challenge.

To go back to the metaphor of the traffic system, Judkewitz and his team seek to monitor and model the trajectory not just of one vehicle moving inside a city, but the movement of all vehicles, airplanes and pedestrians in all the cities and transport systems across world at same time and all in real time multiplied by a factor of a billions and all this, on a molecular scale.

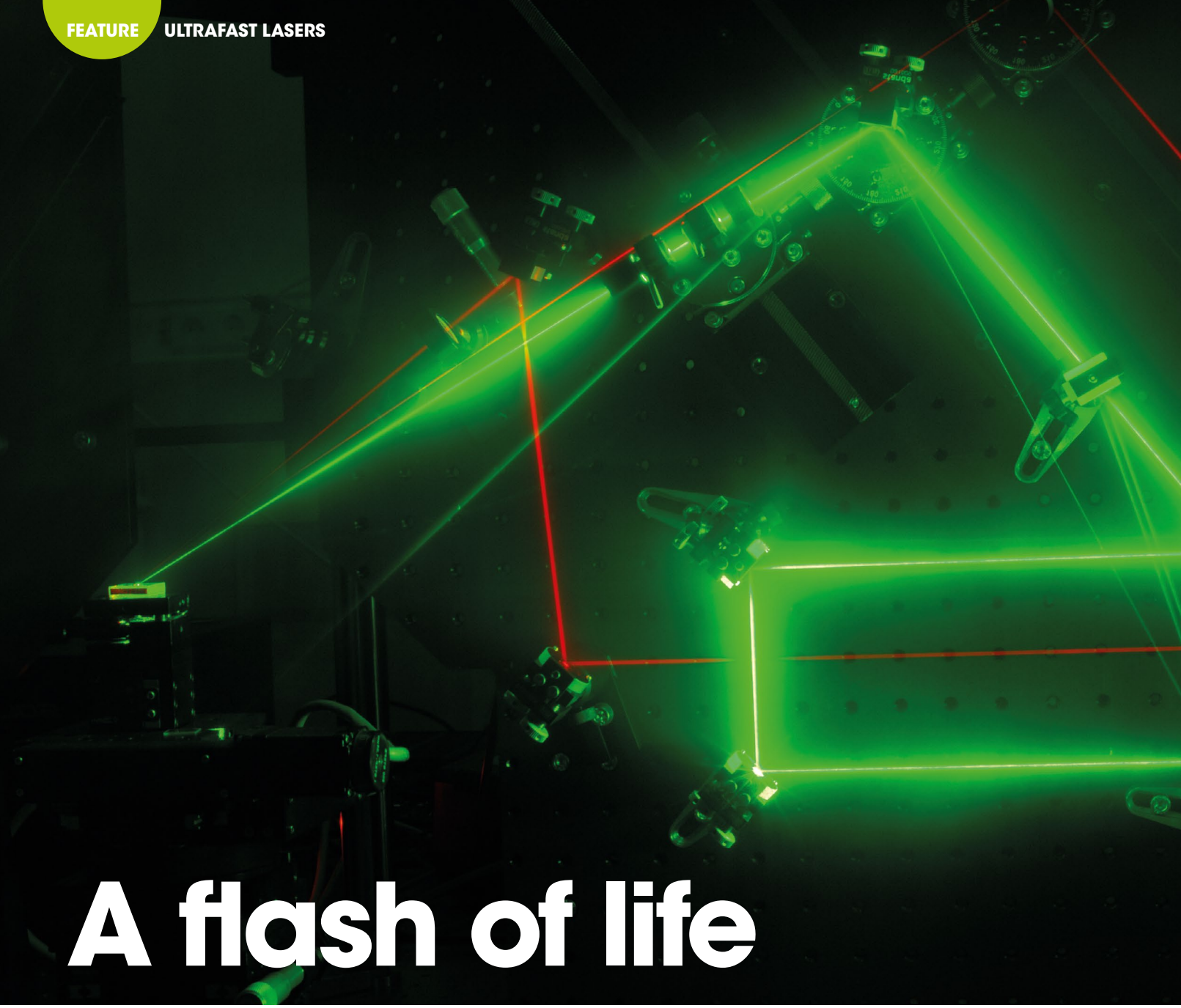
The limitations of optical microscopy make the challenge even more difficult. When light is scattered and defracted, it results in the destruction of the information that light photons have been carrying. Judkewitz is developing an optical time reversal technique to counteract the effect of light scattering and to harvest more information from photons. His approach involves using a microscope to send photons back along the path they have travelled, back in space and time, to reproduce what exactly it was that a photon encountered and saw when it was inside tissue.

With so many breakthroughs on so many fronts, there is every reason to be excited about the possibilities of the huge and ever expanding field of neurophotonics. Not only can it help answer fundamental questions of science such as those concerning the nature of consciousness, commented Professor Nägerl, but also be used to solve real-world problems, for example, cures for degenerative diseases such as Alzheimers. **EO**



Dr Paul De Koninck

Image showing a neuron (green) and synapses (red)



A flash of life

Manufacturers are increasing the power and wavelength of ultrafast sources used in live tissue imaging to aid researchers, Matthew Dale finds

With the ability to produce pulses only picoseconds, femtoseconds, or even attoseconds in duration, ultrafast lasers are able to deliver intense beams of energy to a focal point without causing damage to the materials they are targeting.

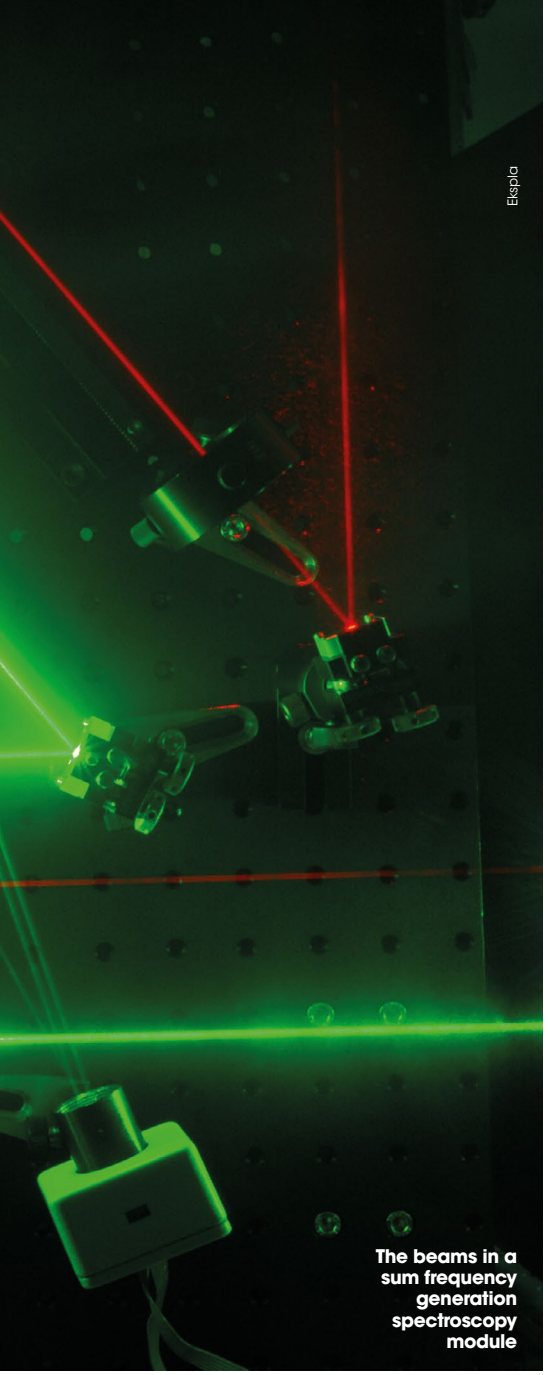
This has led to a widespread adoption by researchers in the life sciences field, as it permits the ever more detailed observation of live tissues without the samples being destroyed.

Ultrafast laser manufacturers are now improving these techniques by offering lasers of higher power, longer wavelength and narrower linewidth, which will allow researchers to reach larger depths and levels of detail when examining their live tissue samples.

In the right place at the right time

By being able to deliver high photon densities in their intense beams, ultrafast lasers can be used to perform multi-photon three-dimensional imaging. This technique involves the use of a laser pulse focused through the optics of a microscope to instigate the absorption of two or more photons at the exact same time and location in a live tissue sample, creating an excitation effect that can be observed and interpreted. Combining this with other techniques such as optogenetics, it is possible to excite neurons at certain depths in a brain tissue sample and image the surrounding areas.

'For example, if a mouse is watching a video, you can image what's happening in the brain,' explained Herman Chui, senior director of product marketing at Spectra-



Ekspla

The beams in a sum frequency generation spectroscopy module

Physics. 'The primary purpose in this case is to study the brain's structure and function, which could lead to a solution of solving neuro degenerative diseases.'

According to Chui, if a continuous-wave laser were to be used in a standard confocal microscopy setup, fluorescence would come from everything above and below the focal point of the laser, as the excitation wouldn't be localised, which generates background noise in the imaging process. For a multiphoton process using ultrafast lasers, the only place where the excitation could occur is extremely localised, due to the photons having to converge at an exact location, therefore preventing background noise and enabling clearer imaging.

Ultrafast lasers are the only way to achieve this type of imaging, which provides a very significant opportunity for the devices' manufacturers. 'For us it's one of the four main areas that our ultrafast lasers are used in,' Chui explained, the others being medicine, micromachining and high-energy physics. Spectra-Physics predominantly provides femtosecond lasers for life science applications, with picosecond lasers more commonly being used for industrial micromachining applications, according to Chui.

Toptica's new Femto Fiber Ultra series permits femtosecond pulses with up to 5W output power at 789nm or 1,050nm

While bio-imaging isn't a new application for ultrafast lasers, new techniques are being developed in the field to increase its capability.

'There's a lot of development focused on it,' confirmed Chui. 'For the multiphoton techniques, people are moving from using two-photon excitation to three-photon excitation, which requires three photons to be in the exact same place and time to produce an excitation. With that you get even more localised excitations and can image at higher depths into tissue.'

With two-photon excitation, depths of up to approximately 1mm can be imaged in live tissue. However, by switching to three-photon excitation, researchers could potentially reach depths of over a millimetre, which in a mouse brain would enable the imaging of the emotional and memory centres. 'This is one very interesting direction that has developed in the last year or two,' Chui commented.

To aid in increasing the depth of multiphoton imaging, manufacturers are now working to offer ultrafast lasers with longer wavelengths. While traditional imaging is performed using green fluorescent protein, which gets excited at around 900nm in a two-photon setup, the light can become scattered at this wavelength as it goes deeper in the tissue. When a longer wavelength is used, however, scattering drops off proportionally and a larger depth of imaging can be reached.

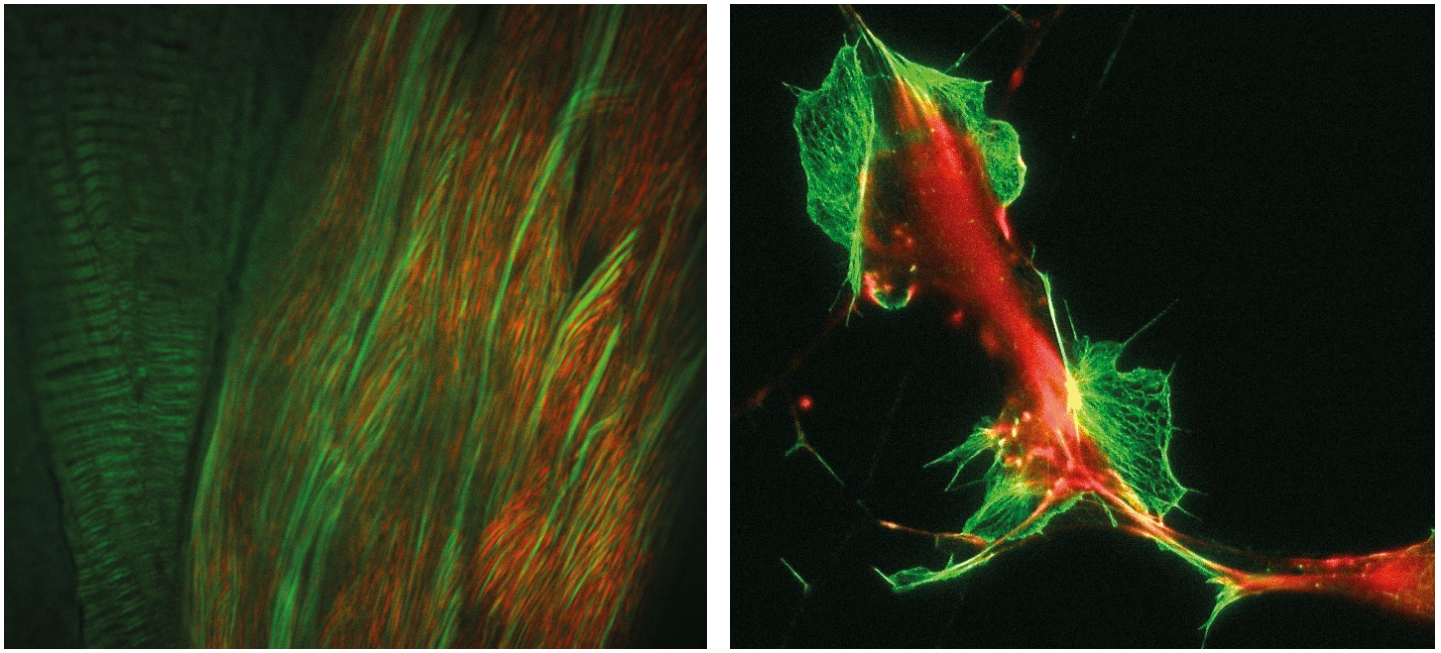
'There's a lot of work in moving to longer wavelengths with the two-photon technique. Sources that both we and others have developed are moving out to 1.3µm and are producing 100fs pulses,' said Chui. 'With three-photon techniques, people are looking to move further out from 1.3µm to 1.7µm in the future.'

Increasing the power of these longer wavelength lasers is also important, in order to improve their imaging quality. However, manufacturers must do this within the limitations of live tissue, as a significant increase in power could lead to it being damaged when examined. Additionally, because of the large amounts of water in live tissue cells, care must also be taken when choosing higher wavelengths to select those that aren't significantly absorbed by water, to ensure that imaging can be performed effectively.

"There's a lot of work in moving to longer wavelengths with the two-photon technique. Sources that we and others have developed are moving out to 1.3µm"

Earlier this year Spectra-Physics released its Insight X3 ultrafast laser for multi-photon imaging, a single-source device with a tuning range between 680nm to 1,300nm, nearly double that of Ti:sapphire ultrafast lasers. Suited to delivering higher powers at longer wavelengths – more than 2W at 900nm and 1.4W at 1,200nm – the Insight X3 fits within the limitations of live tissue imaging, and has apparently been well received by the company's research customers, according to Chui.

Higher power ultrafast lasers can also be coupled with optical parametric amplifiers (OPAs) to deliver suitable wavelengths for multiphoton imaging. Back in June, Spectra-Physics' new 100W Spirit 1030-100 →



Toptica Photonics

Time-resolved microscopy images of live tissue taken at sub-millimetre depths

→ industrial femtosecond hybrid fibre laser was featured at Laser World of Photonics in Munich. When coupled with the company's Spirit-OPA and Spirit-NOPA, the system delivers a high-energy tuneable laser output across the visible and infrared spectrum for three-photon deep-tissue bio-imaging and ultrafast spectroscopy applications.

The fastest of flashes

Ultrafast lasers provide numerous advantages over conventional imaging tools in microscopy applications, specifically time-resolved microscopy, which involves taking multiple high-resolution pictures of a sample one after the other in quick succession.

'A normal camera's ability to take a series of pictures quickly is limited by the mechanical speed of its rotating shutter, whereas ultrafast lasers feature no moving parts,' explained by Dr Tim Paasch-Colberg, director of marketing for Toptica Photonics, whose ultrafast lasers are often used for time-resolved microscopy. 'They can therefore achieve much faster imaging rates…as most of them operate at 20-80 million pulses per second, so in principle many images can be taken each second.' Achieving such speeds enables the study of processes on very fast time scale, for example the chemical processes occurring in live biological samples.

In principle there are two main wavelengths used in time-resolved microscopy according to Paasch-Colberg, 780nm and 1,050nm, as between them they can be used to study a broad variety of samples. Toptica Photonics offers both of these wavelengths in its FemtoFiber ultra product line, which was released only recently, at repetition rates of 80MHz and pulse widths of <150fs and <120fs respectively.

'Many ultrafast microscopy techniques also require a lot of power, and these two machines are at around the highest powers currently available at these wavelengths – up to 500mW for 780nm and up to 5W at 1,050nm,' Paasch-Colberg said.

According to Paasch-Colberg, a key feature sought after by researchers using ultrafast lasers is the ability to operate them hands-free without difficulty, having them act simply as another tool in their experiment. Manufactures therefore design ultrafast lasers to work completely maintenance-free and operate as a compact box that can be turned on when needed. This small footprint and simple functionality therefore makes them easy to integrate into a wide range of equipment setups.

Probing the surface

Lithuanian manufacturer Ekspla considers itself a specialist in picosecond lasers, for which it targets applications involving non-linear phenomena, such as sum frequency generation (SFG) vibrational spectroscopy, a highly sensitive technique used to analyse surfaces. The process uses two beams, one in the visible and one in the mid-IR region, that spatially and temporally overlap at the surface of a material. An output beam is then generated at a frequency equal to the sum of the two input beam frequencies, leaving the surface to be picked up by a detector.

'We develop special devices for this application,' said Dr Zenonas Kuprionis, commercial director at Ekspla. 'A single laser is used to produce both beams. One beam is going directly from the laser, and the same laser is used to pump an optical parametric amplifier. Both beams are precisely synchronised. In this particular application the visible beam is used to convert information coded in the absorption of the IR beam to the spectral range in which photon detectors are the most sensitive.'

The picosecond laser provided by Ekspla for SFG vibrational spectroscopy is its PL2230 series, a diode-pumped high energy picosecond Nd:YAG laser offering 20-80ps 35mJ pulses at a 50-100Hz repetition rate. The firm also produces its PG501 optical parametric amplifier for use in SFG vibrational spectroscopy, in addition to complete SFG spectrometer systems.

"A key feature sought after by researchers using ultrafast lasers is the ability to operate them hands-free without difficulty"

According to Kuprionis, one of the most important laser features for non-linear surface spectroscopy applications is the spectrum linewidth of the tuneable linewidth sources used. Ekspla is therefore trying to make this as narrow as possible in order to distinguish the different vibrational features of live tissue samples.

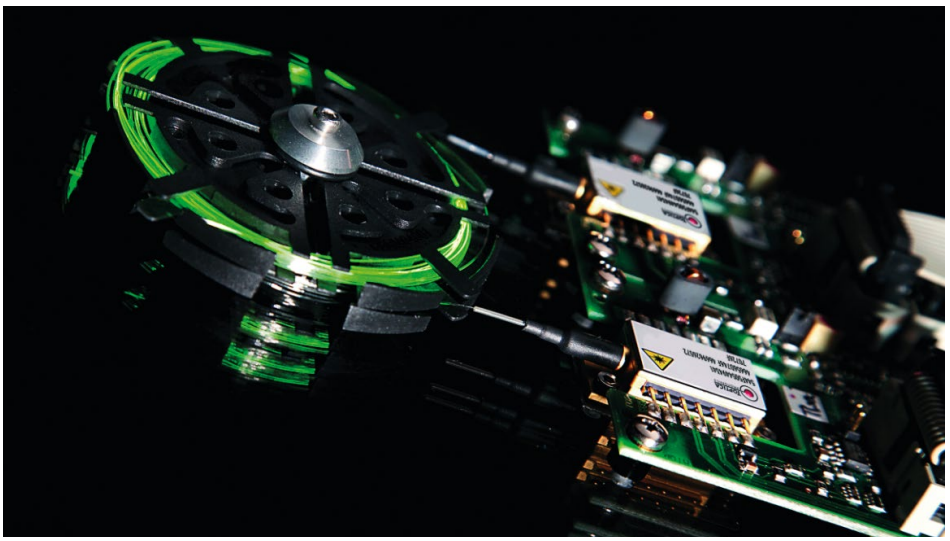
'To achieve a narrow spectrum line from OPAs you need to be very careful with the pumping laser line,' said Kuprionis, who

explained that the spectrum of ultrashort pulses broadens because of non-linear interactions, which need to be avoided. 'You need to apply some special techniques in optical parametric amplifiers to narrow the generation spectra. We use spectral filtration by diffraction gratings or synchronously pumped optical parametric oscillators in this case,' he said.

While femtosecond lasers do offer high temporal resolution, their spectra are usually too broad for probing molecules, according to Kuprionis, which is why Ekspla is selling more and more tuneable picosecond lasers that are synchronised with femtosecond lasers for this purpose. 'This allows scientists to achieve more accurate and precise results,' he commented.

Out of the various emerging advancements in laser design that have occurred, for Ekspla, according to Kuprionis, the most significant is the development of OPCPA (optical parametrical chirped pulse amplification) technology. 'For us it's a very important area because our picosecond lasers are very suitable to pump OPCPAs,' he said. 'With our partners Light Conversion and National Energetic, we develop ultra-high intensity ultrafast OPCPAs.'

With these partners Ekspla is producing OPCPAs for the European Extreme Light Infrastructure (ELI) project, which aims to develop and offer the world's most intense laser systems and make them available to the international scientific community. Ekspla has already produced a five terawatt, 1kHz OPCPA-based laser system worth €4 million with Light Conversion for the project. Now it is developing an additional terawatt laser system with 6fs pulse duration with Light Conversion, and an additional 10-petawatt laser system with National Energetics.



Toptica Photonics

Toptica's ultrafast lasers are based on fibre technology

'There are completely new types of applications for these sources,' commented Kuprionis. 'These are extreme light applications like fusion energy experiments, compact high gradient electron and proton accelerators. Also with these sources it's possible to generate ultrafast x-rays for structural studies of solids and molecules and to create extreme states of matter.' These extreme sources can also be used for generating pulses only attoseconds in duration, a completely new area of physics that is just at its beginning.

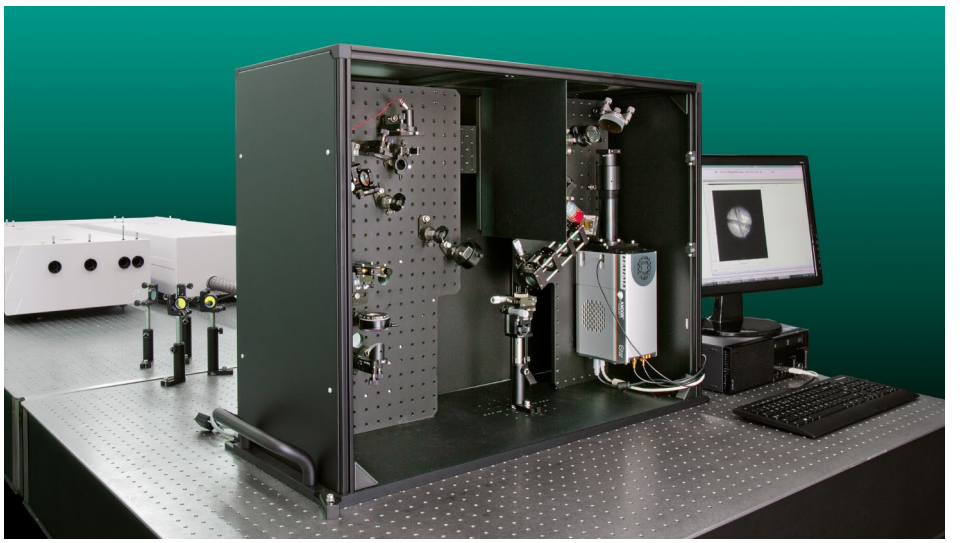
Lasers of the future

While ultrafast lasers are currently around the size of two shoeboxes – one containing the laser, the other the supply electronics – Paasch-Colberg of Toptica Photonics believes that they will be shrunk down even further in the coming years.

'I think the future will lead to size reductions without lowering the performance or changing the important laser parameters (wavelength, pulse duration etc),' he said. 'Micro optics will be a key technology for reducing the size of lasers, as well as photonic integrated circuits. Shrinking the components down to a smaller chip while maintaining the same level of power and other specifications will be a big true challenge. I think for biophotonics applications [however], this will be the future.'

Kuprionis of Ekspla believes that hybrid laser technology is set to have a positive impact on ultrafast lasers, a laser format already used in micromachining applications and for OPCPA pumping. 'This involves using a fibre-based seeder, which gives you a lot of opportunities to choose the pulse wavelength, duration and shape needed. But the limitation of fibre lasers is the intensity of the pulse, so for the final stage we use a diode-pumped free space amplifier,' he explained. 'So part of the hybrid laser is fibre, part of it is solid state.' These hybrid lasers can be made to be very compact, economical, and with very good output parameters, according to Kuprionis.

Chui of Spectra-Physics expressed that ultrafast lasers could progress in two particular directions in the future. 'One is achieving even more capability for research applications – imaging deeper, having higher peak power and longer wavelengths. The other is more towards clinical applications in the long term, finding the right parameter set for the end application and then optimising the solution for that.' While the tools that Spectra-Physics currently produces are very capable and flexible for research applications, for clinical applications, according to Chui, a more compact, single-purpose solution is needed. EO



Ekspla

Ekpla's sum frequency generation microscope provides the ability to investigate spatial and chemical variations across the surface as a function of time

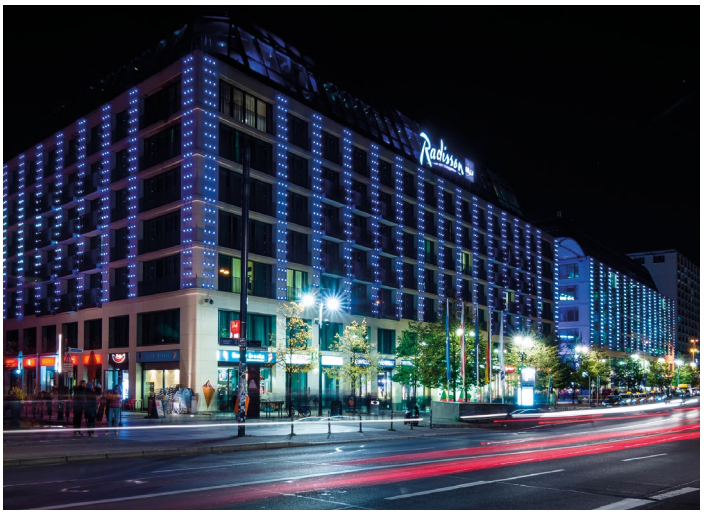
EOS NEWS

All the latest news from the European Optical Society
www.myeos.org

EOS topical meeting on Terahertz Science and Technology (TST 2018)

The European Optical Society proudly welcomes optics and photonics professionals to its sixth topical meeting on Terahertz Science and Technology (TST 2018) in Berlin, Germany. The topical meeting is expected to gather around 100 participants from Europe and all over the world to Radisson BLU Hotel, located in the heart of Berlin, from 6 to 8 May 2018.

The chairs of the conference are Professor Heinz-Wilhelm Hübers from the German Aerospace Centre and Dr Jozsef Fülöp from the University of Pecs, Hungary. The event provides a platform for the presentation and discussion of the latest results in the generation, detection and use of terahertz radiation in science and technology.



Sergey Kohl/Shutterstock.com

Radisson BLU Hotel, Berlin

This meeting includes the following topics:

- Emission of terahertz radiation (QCLs, HEMTs, FELs, synchrotrons, nonlinear optics etc.);
- Detection of terahertz radiation (quantum dots, single photon detectors, time-gated, transistors etc.);
- Terahertz integrated optics, waveguiding, plasmonics, metamaterials, photonic crystals;
- Interaction of terahertz radiation with matter (dielectrics, semiconductors, nanostructured materials, graphene, liquid-state dynamics, chemistry, biology, ultrafast spectroscopy etc.);
- Nonlinear phenomena induced by terahertz radiation;
- THz far-field and near-field imaging, terahertz microscopy and microspectroscopy;
- Remote sensing of gases and chemical/biological agents;
- Terahertz applications (security, telecom, remote detection etc.).

Submission opens on 8 January 2018. Visit the event website: **www.myeos.org/events/**

On behalf of everyone here at EOS, we wish you a prosperous New Year 2018 and hope to see you at our upcoming events

Elina Koistinen
EOS executive director

Nominate a fellow member!

The European Optical Society will again award accomplished members in 2018. We are now looking for nominations from our members. Any member of the EOS may nominate up to three fellow members to this honourary position. Nominations close 1 August 2018. More information on how to nominate a fellow member: www.myeos.org/members/fellows

The Fellows will be honoured with the official diplomas at the Annual General Assembly in Delft, Netherlands, held within the EOSAM2018 symposium, 8-12 October 2018.

UNESCO proclaims 16 May as International Day of Light

Light now occupies a very special place as one of the permanent and annual UNESCO International Day Celebrations, with UNESCO proclaiming 16 May as the International Day of Light.

This annual recognition will raise awareness of the central role that light and light-based technologies play in the lives of the citizens of the world in areas of science, technology, culture, education, and sustainable development.

Partners worldwide are now making plans for an ambitious series of outreach and education activities to take place in May 2018, with a special focus on students, young people and the public at large. In addition, a flagship inauguration featuring Nobel Laureates and leaders in areas of education, industry, design and lighting will take place on 16 May 2018 at UNESCO headquarters in Paris, France. **www.lightday.org**

PRODUCT FOCUS MADE TO MEASURE

A round-up of the latest light-based measurement solutions

4D Technology has introduced a Vertical Digital Radius Slide for precise radius of curvature (ROC) measurement of concave or convex optics.

The Vertical Digital Radius Slide (VDRS) provides axial positioning resolution to 1µm for extremely accurate ROC measurement using 4D Technology's AccuFiz compact laser interferometers.

The VDRS integrates with 4D Technology's 4Sight data analysis software for fast, wizard-based ROC measurement. The system can accurately measure ROC without precise null at the cat's-eye or confocal positions, resulting in increased accuracy and throughput. Easy-to-use controls and a long travel range make the VDRS simple to install and to use daily.

4D Technology's family of digital radius slides also includes an encoder-based horizontal slide, and a horizontal slide with Laser Doppler Distance Measurement (LDDM) for 10nm axial position resolution.

AccuFiz Fizeau laser interferometers offer excellent lateral resolution and the ability to measure optical components and systems without vibration isolation. With a wide range of apertures and wavelengths, and a comprehensive line of accessories, AccuFiz interferometers provide best-in-class value and performance.

www.4dtechnology.com

Sphere Optics has launched a new lighting laboratory to provide precise measurement services to manufacturers, light designers or even lidar users. It enables the cost-effective testing of classical parameters of luminaires and lamps, like luminous flux (lumens), spectrum, colour parameters (CIE colour values, colour rendering index, colour temperature, etc.), efficacy (lumens per watt), luminance (cd/m²) as well as near- and far-field light distribution (ray-files, IES and EULUMDAT data).

In addition, the firm offers specific measurement procedures for the determination of optical material properties, like scatter parameter (BRDF, BTDF, TIS), as well as reflectance- and transmittance factors. Finally radiometric calibrations of photo detectors, spectrometers and hyperspectral cameras complete are included in the range of customised services.

www.sphereoptics.de

Selected for their very high frequency stability, low frequency and intensity noise, the Koheras single frequency fibre lasers supplied by **Photonic Solutions** are playing a vital role in the development of Quantum Gravity sensors by the Quantum Technology Hub in Sensors and Metrology. Headed by the University of Birmingham in the UK, the hub is developing unique sensors that rely on the quantum superposition effect that can register minute changes in the gravity field. This in turn, is used for the detection of sinkholes, location of pipelines, archaeology and so on.

Quantum superposition lies at the heart of quantum theory, allowing two classically distinct and exclusive alternatives to coexist. This principle of quantum mechanics has been exploited by the Hub's 'atom trap' based quantum sensor.

Laser cooling and trapping methods are used to confine and control the atomic motion of rubidium atoms and the Koheras lasers are then used to create superposition states and recombine them after some measurement time, leading to interference in final state populations. Separating the paths vertically enables the measurement of gravity and rotation respectively. Thus the Quantum Gravity Sensor is realised.

www.photonicsolutions.co.uk

Zygo's Verifire HDX is a high-resolution Fizeau interferometer for surface form and wavefront metrology of optical components and systems. The high resolution camera and optimised optical design enable mid-spatial frequency content characterisation – a critical need for high precision applications.

For versatility and precision, the Verifire HDX interferometer includes all the great features of the popular Verifire HD – such as QPSI, and a long-life stabilised laser – and adds important enhancements like improved imaging and resolution for high instrument transfer function (ITF), superior characterisation of mid-spatial frequency content and high-slope surface deviations, as well as Zygo's DynaPhase dynamic acquisition technique (optional) that eliminates problems resulting from vibration and enables precision metrology in nearly any environment.

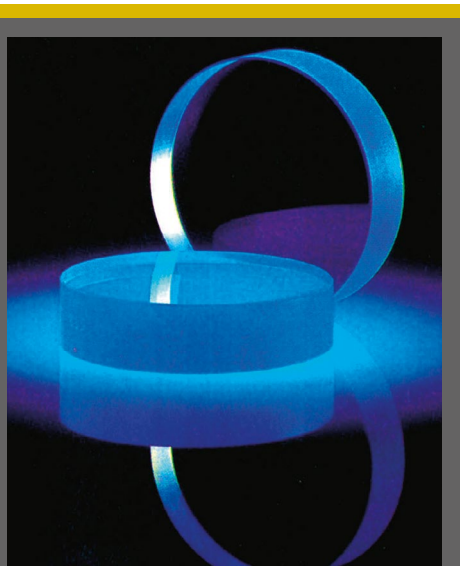
www.zygo.com

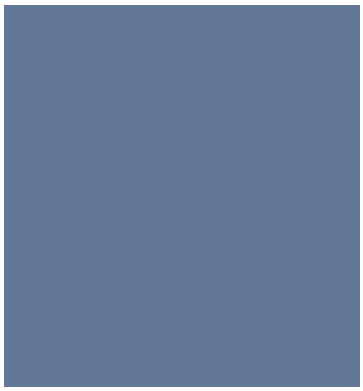
Optical Surfaces has received an order for precisely matched etalon pairs from The Table Stable (Mettmenstetten, Switzerland) for use as a component in their ultra-high resolution JRS series interferometers.

Optical Surfaces' production team is able to routinely produce the 50mm diameter fused silica etalons pairs for Table Stable with matching accuracies of better than lambda /200. Etalon manufacture places extreme demands on a company's production capabilities. Material purity, optical figure, plate parallelism, plus surface, spacer and coating quality are all critical to the overall performance of an etalon.

Optical Surfaces has been producing optical components and systems for more than 50 years and is now accepted as a specialist in the production of high-precision optics for interferometry.

www.optisurf.com





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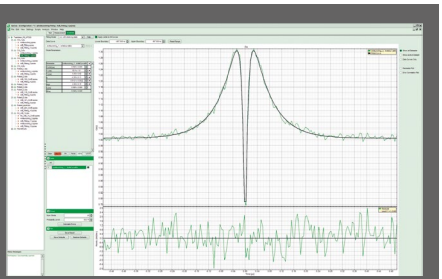
www.electrooptics.com/products

SOFTWARE



Software for analysing quantum correlations

PicoQuant has released the QuCoa software package, an integrated solution for data acquisition and analysis using the T2 time-tagging mode of PicoQuant's TCSPC electronics. QuCoa is aimed at research areas relying on coincidence detection such as Hanbury-Brown-Twiss set-ups to study single photon sources (g(2) / antibunching), quantum key distributions (QKD), general quantum optics, or the study of entanglement using Hong-Ou Mandel set-ups (HOM). The software offers special analysis routines for coincidence correlations as well as for coincidence counting applications.

The QuCoa software features one of the fastest software correlators for coincidence correlation, which permits the correlation of the absolute arrival times of photons in real time. This allows, for example, the assessment of the quality of an anti-bunching curve already during the measurement.

The g(2)(0) value and count rates on all detectors are continuously calculated and displayed.

SPECTROSCOPY

THz time-domain spectroscopy systems

Menlo Systems has introduced a new generation of THz time-domain spectroscopy (TDS) systems with improved features.

THz-TDS systems with an optomechanical scanning unit, like the Tera K15, Tera Sync, and TeraSmart, provide >5THz spectral bandwidth and >90dB signal-to-noise ratio.

With the latest fibre coupled photoconductive THz antenna technology, new software and system hardware, and modular design, the new generation of THz systems offers high flexibility and versatility with respect to system configuration and arrangement for a wide range of uses in THz spectroscopy and imaging.

The novel 'ScanControl' software is intuitive and easy to use, including new features and enabling centralised control of all system components, such as the lasers and amplifier drivers, or synchronisation electronics.

Menlo Systems' igure 9 technology for fibre laser mode-locking guarantees robust systems with highly reliable and reproducible performance. Options like multichannel outputs, and add-ons such as the imaging unit Tera Image, an additional scanning unit for THz spectroscopy of optically excited samples, or advanced THz evaluation software, hold solutions for the most demanding tasks.
www.menlosystems.com

Handheld spectrometers

Gamma Scientific has announced its new line of high-precision handheld spectrometers. The unit is particularly well adapted for applications in horticulture, photography, visual merchandising, health and safety and general research.

The unit has also generated interest among manufacturers and installers of lighting solutions, whether traditional lamp-based sources or LED devices. The PG100N model provides a robust and reliable solution for light measurement with fully NIST-traceable performance. Through an integrated, high resolution colour display, parameters such as LUX, CCT, chromaticity, CRI and SPD can be viewed instantaneously.

Its CMOS linear image sensor is effective from 380nm in the UVA to 780nm in the near-infrared. In addition to internal data logging, downloads via an SD card, USB port or wi-fi mode allow data tracking and analysis with download capability in Excel and JPG formats.

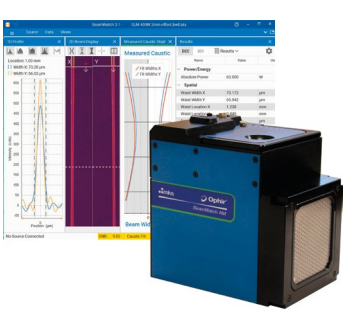
The detector head can be removed for optimal positioning and the operating time is up to five hours on a full battery charge.
www.gamma-sci.com/

ANALYSIS, TEST AND MEASUREMENT

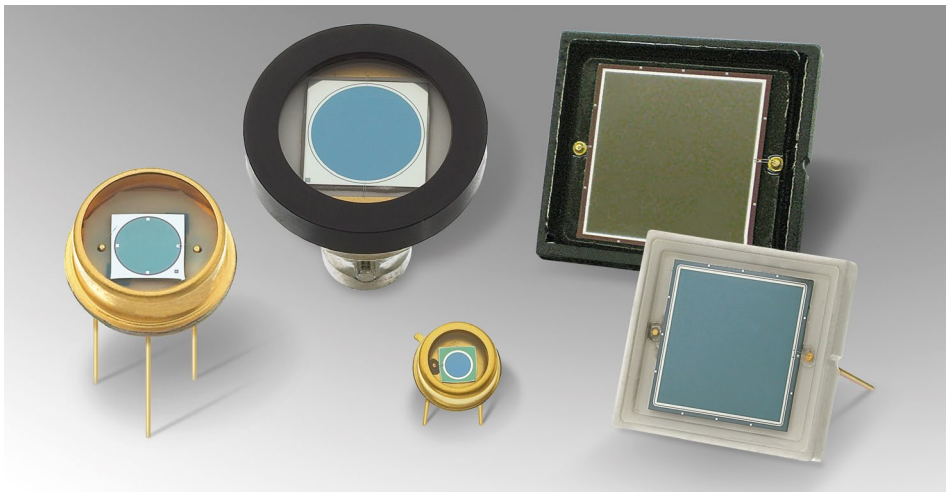
Laser beam monitor for additive manufacturing

MKS Instruments has released the Ophir BeamWatch AM, a non-contact laser beam monitoring system for additive manufacturing. BeamWatch AM is a lightweight, compact system designed for real-time measurement of focal shift during laser start-up of powder bed fusion manufacturing processes. It measures key beam size, position, and quality parameters, including focus spot size and beam caustic. These measurements allow users to more easily determine when the beam is aligned and in focus, providing more consistent metallurgy. Measurements can be displayed as tabular, 2D, and 3D views, providing a quick and realistic display of laser characteristics.

BeamWatch AM is the next generation of MKS Instrument's laser beam monitoring systems, which all use Rayleigh scatter to image the beam without contact. This removes potential for damage to the laser and speeds the measurement process by up to two minutes. The system can measure laser powers to 1,000W in-situ, at rates up to 14Hz.
www.mksinst.com
www.ophiropt.com



LASERS AND DIODES



UV-enhanced silicon photodiodes

OSI Optoelectronics (OSIO) now offers UV-enhanced planar diffused silicon photodiodes specially designed for low-light-level detection in the ultraviolet spectral range. The product series includes the UVD planar diffused and UVE planar diffused IR suppressed devices, both featuring excellent UV response.

The UVD and UVE photodiodes exhibit significant advantages, including lower capacitance and higher response times.

OSI Optoelectronics' UVD photodiodes peak at 970nm. The UVE devices peak at 720nm and suppress the near-infrared, making them particularly useful in applications where blocking the NIR spectral region is required. Both products can be biased for lower capacitance, wider dynamic range, and high speed response times. Alternatively, the UVD and UVE series may be operated in the photovoltaic (unbiased) mode for situations that require low drift with temperature variations.

Available in varying sizes and footprints.

www.osioptoelectronics.com

High-power red laser diodes

ProPhotonix has added two high-power red laser diodes from Ushio to its range.

The 637nm HL63283HD delivers an output power of 1.2W in continuous wave and up to 1.5W when pulsed. This powerful red laser diode is ideally suited for use in laser projectors, show lasers and as a light source in optical equipment.

The HL63290HD is a 638nm laser diode producing output powers up to 2.5W when pulsed. In continuous wave, the laser provides 2.2W of output power, making it well suited to laser projection applications. This higher power red laser diode is also suitable for those optical equipment applications requiring power levels above 2W.

Both diodes are packaged in compact 9mm cans, providing excellent heat dissipation.

www.prophotonix.com

Picowatt photoreceiver series

Femto Messtechnik has released a picowatt photoreceiver from 320 to 1,060nm and 900 to 1,700nm. The new picowatt photoreceiver series PWPR-2K with switchable gain (109 V/A, 1010 V/A) and a bandwidth from DC to 2kHz is the ideal choice for CW measurements, time resolved signal acquisitions and highly sensitive modulated measurements, in addition to precise and fast CW measurements.

The combination with lock-in amplifiers results in ultra-sensitive measurement systems being almost immune to disturbances from external sources. In this way the PWPR-2K can easily detect optical powers from about 100fW up to 10nW.

Offering both free space and fibre coupled formats, both Si and InGaAs PIN diode options are available. Carefully designed EMC housings include fixing holes for both

laboratory and OEM constructions.

The output voltage range is up to +10V, with an offset adjustment by a potentiometer.

The photoreceiver includes output short-circuit protection. As is standard for all Femto products, a power supply with ±15V via 3-pin Lemo socket, PS-15, is supplied separately.

www.lasercomponents.com/uk

LENSES AND OPTICS

Lab starter kits

Edmund Optics has introduced three new kits designed for starting a brand new lab and keeping it stocked.

The Lab Starter Kits are available in English and metric-based mounting versions and feature essential products useful for any lab, from optics to detectors to cleaning and tools.

The Lab Essentials Kit includes many components typically consumed in an optical lab. Both kits are RoHS compliant.

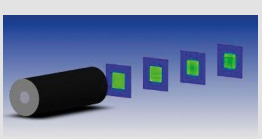
The Lab Starter Kits provide 255 individual parts including a range of lenses, filters, and prisms mainly suited for the visible spectrum.

Additional optomechanics and tools, such as stages, mounts, clamps, wrenches, hex and screw drivers, as well as adapters that are compatible with the included optics, also come in the kit.

The Lab Essentials Kit provides many items that are typically consumed or lost in an optical lab. It includes a wide variety of products including cleaning supplies, tools, and basic mounting components.

www.edmundoptics.eu

Collimated beam shaper module



Holo/Or's collimated beam shaper module is a tailored solution for applications requiring an extended working distance range or long depth of focus. With this module, the uniform-intensity beam is maintained with high fidelity, power uniformity, and constant size/shape over an extended working distance range. The shape is well-defined with sharp edges, and it can be round, square, rectangular, elliptical, line, or any other shape or dimension.

For multi-mode sources, the collimated homogeniser module is Holo/Or's tailored solution for applications requiring a long working distance range. The collimated homogeniser is the natural complement for the firm's standard diffractive homogenisers, which give a shaped intensity beam at a unique specified working distance. The collimated homogeniser is a good solution for applications such as industrial surface treatment, where the working surface is uneven or located at varying distances from the laser delivery system.

www.holoor.com

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Research into butterfly wings enhances solar cell absorption

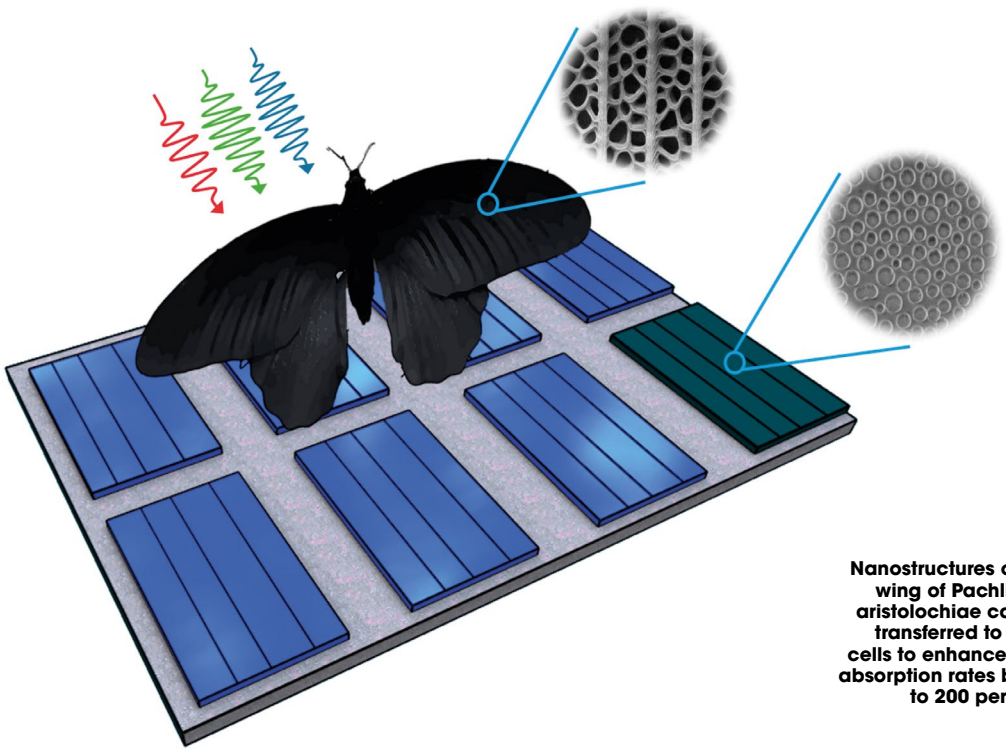
Nanostructures of the wing of the black butterfly can be transferred to solar cells to enhance their absorption rates by up to 200 per cent, researchers have found

Scientists from the Karlsruhe Institute of Technology (KIT) have taken inspiration from the nanostructures that optimise light harvesting on a black butterfly's wing to improve the rate of light aborption in thin-film solar cells, potentially by as much as 200 per cent.

The wings of the black butterfly 'Pachliopta aristolochiae' are covered by micro- and nanostructured scales that absorb sunlight over a wide spectral and angular range, hence their black appearance. In Science Advances, researchers from the Karlsruhe Institute of Technology (KIT) in Germany have described how these disordered structures absorb light far better than smooth surfaces, and how they can be introduced into thin-film photovoltaic absorbers to improve their functionality.

'The butterfly studied by us is very dark black. This signifies that it perfectly absorbs sunlight for optimum heat management,' said researcher Hendrik Hölscher. 'Even more fascinating than its appearance are the mechanisms that help reach the high absorption.'

In exploring the nanohole structures in the butterfly's wings, the KIT team used scanning electron microscopy to determine their diameter and arrangement, and then used computer simulations to analyse the rates of light absorption for their various patterns. It was found that disordered holes of varying diameters produced the most stable absorption rates over the complete spectrum at variable angles of incidence, compared to periodically arranged nanoholes of identical size.



Radwanul H Siddique, KIT/Caltech

Nanostructures of the wing of Pachliopta aristolochiae can be transferred to solar cells to enhance their absorption rates by up to 200 per cent

> "The absorbers were fabricated using a scalable, self-assembly patterning technique"

Inspired by the phase separation mechanism of these biological nanostructures, the researchers introduced disordered nanoholes with diameters varying from 133nm to 343nm in thin-film photovoltaic absorbers in order to improve their efficiency. The absorbers were fabricated using a scalable, self-assembly patterning technique based on the phase separation of a binary polymer mixture.

The nanopatterned 'bioinspired' absorbers demonstrated a relative integrated absorption increase of 90 per cent at a normal incident angle of light, to as high as a 200 per cent increase at large incident angles, thus showing the potential of adapting black butterfly structures for light-harvesting purposes in thin-film solar cells. 'The optimisation potential when transferring these structures to PV systems was found to be much higher than expected,' confirmed Hölscher.

While the results were very promising, the researchers did point out that this does not automatically imply that the efficiency of complete PV systems is enhanced by the same factor. 'Other components also play a role,' said Guillaume Gomard, another of the researchers. 'Hence, the 200 per cent is to be considered a theoretical limit for efficiency enhancement.'

Nevertheless, by combining bioinspired nanostructures with thin-film PV absorbers, the KIT researchers were able to improve the functionality of the absorbers by a factor of two. Their work could therefore provide a pathway for further systematic study of bioinspired nanostructures for the optimal design and function of PV devices.

The nanostructures were reproduced in the silicon absorbing layer of a thin-film solar cell, with the researchers themselves using hydrogenated amorphous silicon. They do believe, however, that any type of thin-film PV technology could be improved with using bioinspired nanostructures, and done so on an industrial scale. EO

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