Volume 20 June / July 2023

3

PhotonicsViews

OPTICS • PHOTONICS • LASER TECHNOLOGY

COVER STORY

Fiber optics for quantum

FOCUS SECTION

Photonics for quantum technology

LASER World of PHOTONICS

WILEY

published in media partnership with

EPIC

publishing medium of

PHOTONICS GERMANY

DGaO

‘Laser Munich’, the photon, and its industry

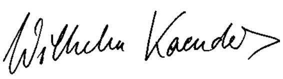
A time of review and foresight

After the first laser was built, commercial success was not an automatic expectation of the broader public (‘solution looking for a problem’), but technologists already had a clearer vision back then. We see this reflected in the regularly updated titles of our beloved Laser Munich event, which started exactly 50 years ago. We, as a laser industry, have significantly broadened our scope from ‘lasers only’. We have been addressing the field as photonics, and now wisely in the updated name of Laser World of Photonics. The term photonics has become a synonym for technological merging of electronics with the optical world, solving electronic bottlenecks such as crosstalk, overheating and adding new features like wavelength multiplexing, but it has more to offer.

The technical control that we can exert today on the level of the individual light particle, namely the photon, has improved drastically over the last couple of decades. As an example, today we are using our deep understanding of photon quantum statistics to devise light sources with controlled single or entangled photon emissions, producing coherent or even number states.

Addressing the photon as a ‘flying qubit’ is putting these light particles into yet another new role. The first quantum computer companies critically dependent or based on photons are sticking their heads out of the ground, and again the Messe München has taken a wise step by extending its conference and exhibition format with World of Quantum. Against former wisdom, we as technologists are starting to generate photons that are interacting with each other, by skillfully coupling them to beam splitters, resonators or atomic transitions for the generation of a quantum internet.

Photonics has a lot to offer for solving our most urgent issues of the future, i.e. reducing our non-regenerative energy consumption with LED lighting and photovoltaics, curing diseases, constantly increasing bandwidth, and adding another layer of security in communications. Photons are equally so an indispensable tool for glass microprocessing, diagnosing biological tissue, and a tool for battery research and production. On top of all that, lasers and photons are still fun to play with, hopefully strongly pulling the next generation into our bright field of light.



Wilhelm Kaenders

Wilhelm Kaenders
founder and president
Toptica Photonics AG
chair of the industrial advisory committee
Laser World of Photonics

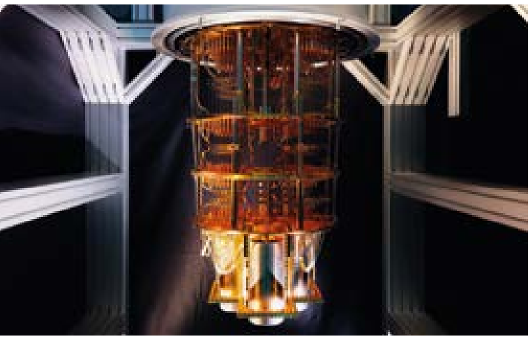
www.twitter.com/photonicviews
LinkedIn www.linkedin.com/company/photonicsviews

media partner
EPIC European Photonics Industry Consortium

publishing medium of
Photonics Germany
DGaO

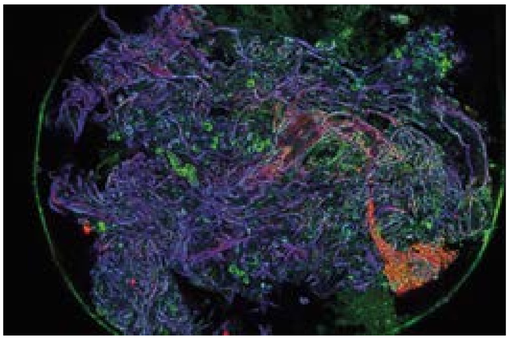
contributing partners
ASAM
emva
PhotonDelta
Photonics Finland
Photonics France
SECPhO
spectronet
Swiss Photonics
VDMA

PhotonicsViews
OPTICS • PHOTONICS • LASER TECHNOLOGY



Contents

3/2023



stock.adobe.com / Schäfter+Kirchhoff.

Cover:
Fiber optics has been proven to be a powerful tool for quantum optics experiments for decades. These profit from the increased stability and convenience, as will future quantum computers. The specific needs regarding precision, stability and ruggedness call for high quality components and tailored fiber optic solution.

p. 39

Food production using integrated photonic microchips

During the Post Harvest Unlimited Conference, Lex Oosterveld presented the roadmap.

The public-private PhotonDelta initiative and the OnePlanet Research Center launched the 'Integrated Photonics for Agrifood' roadmap during the Post Harvest Unlimited Conference (PHUC) at Wageningen University, the Netherlands, in May. It was presented by Lex Oosterveld, principal member of the technical staff at OnePlanet Research Center.

The roadmap describes the role integrated photonics will play in the transformation of sustainable farming practices and food distribution – maximizing yield and minimizing food waste throughout the food supply chain. Multiple organizations have contributed to the roadmap's creation, including MantiSpectra, Eindhoven University of Technology, and Delft University of Technology.

Precision agriculture is at the forefront of this transformation. It uses sensors to enable highly precise and optimized growing and distribution techniques. That is where photonic integrated circuits come in. Miniaturization and low power consumption make them well-suited to handheld devices. They are ideal for optical sensing applications, particularly real-time remote sensing of crop and food composition, both in the field and throughout the supply chain.

Integrated photonic sensors enable farmers to give crops the optimum amount of water, light, and nutrients – and food producers are able to accurately assess crop yield and quality. Sensors also allow early detection of crop conditions and diseases, avoiding waste. A small number of platforms have multiple applications, opening up exciting opportunities within the agrifood industry. Not only that, these improvements also lead to significant cost savings.

www.photondelta.com

Study: Photonics is a key factor in feeding the world

Around ten percent of humanity is starving. By the year 2100, the world population will increase by forty percent to eleven billion people. Added to this are declining areas under cultivation, soil degradation and increasing water scarcity. In order to be able to feed humanity equally efficiently and sustainably, there is no way around the innovative technologies of precision agriculture, and consequent photonics solutions. This is confirmed by a new study by the industry association Spectaris and Messe München in cooperation with the market research company Tematys.

Traditional agriculture will not be able to sustainably expand acreage and yields to the extent demographically required. "For a long time, fertilizers and pesticides were able to increase yields, but these options have now been largely exhausted and environmental aspects are becoming increasingly important," emphasizes Dr. Bernhard Ohnesorge, chairman of photonics at Spectaris. Globally, agriculture already accounts for 72 % of all surface and groundwater abstraction, mainly for irrigation.

This is where so-called precision farming comes into play: with the help of precision farming, fertilizers and water among other things can be used in a more targeted manner and pesticides can be reduced or even avoided altogether in the future. At the same time, yields are increased through continuous monitoring of animals and plants, and new forms of agriculture, such as urban or vertical farming, are made possible. Digital networking and the increase in self-controlling units, including agricultural robots, are leading to a significant increase in efficiency and can help to counteract the shortage of skilled workers or reduce the workload of farmers. "Photonics is becoming a key factor in the generation of nutrition around the world," explains Ohnesorge.

Examples include the centimeter-precise, partially or fully autonomous driving of agricultural vehicles as well as the collection and mapping of data on moisture, nutrients, compaction and plant health using optical sensors or cameras. Precision farming also includes robotic weeding and pest control as an alternative to chemicals. Optimized, energy-efficient lighting systems are used in greenhouses and in vertical farming. The authors of the study forecast annual growth of around 15 % for these still young applications of photonics and a doubling of the global market from € 4.6 B in 2022 to € 9.1 B in 2027.

Photonics solutions for agriculture are also playing an increasingly important role at the international Laser World of Photonics trade fair: "We can see that the topic is becoming more and more important for our exhibitors. Manufacturers have already reacted to the new revolution in the agricultural sector and are increasingly offering solutions for precision farming," notes Dr Reinhard Pfeiffer, CEO of Messe München, which organizes the Laser World of Photonics. The world's leading trade fair for the laser and photonics industry will take place this year from June 27 – 30 in Munich.

www.spectaris.de

Apple investments with European suppliers top 20 billion euros

The tech giant's suppliers in Europe range from large multinational companies to small family-owned businesses. Apple's spend with European suppliers has increased more than fifty percent since 2018, totaling € 85 B over the past five years and more than € 20 B in 2022 alone. The investments reach more than four thousand European suppliers and support cutting-edge innovations that can be found in every product the company makes. Apple now supports more than 2.6 million jobs in Europe.

"Europe's spirit of innovation and incredible talent brought Apple here more than forty years ago, and the region's contribution to our products has never been stronger," said Cathy Kearney, Apple's vice president of operations.

Trumpf is a global leader in industrial lasers, machinery, and technology. Its high-tech components have been used for a number of Apple products, including a small laser to enable a proximity sensor for iPhone that turns off the screen when it detects an object that is close by – such as when a user holds iPhone up to their ear – saving power and preventing inadvertent touches. To date, the family-owned technology company has manufactured and delivered more than one billion of these small lasers to Apple.

STMicroelectronics, a global semicon company with strong roots in France and Italy, develops and manufactures chips that contribute to the industry-leading performance and incredible efficiency of Apple devices. The company has worked with Apple teams on sensors, power management, and wireless integrated circuits for iPhone and other Apple products.


Source: Apple / STMicroelectronics

STMicroelectronics has been powering its Apple-related operations with 100 % renewable energy since 2021 and is increasing its capacity.

Austrian chip manufacturer AMS is one of the latest European companies to join Apple's Supplier Clean Energy Program. Companies like DSM Engineering Materials in the Netherlands, Infineon in Germany and Austria, and Solvay in Belgium are supporting a range of renewable energy solutions. Of the European manufacturing partners committed to clean energy, eight are already achieving one hundred percent renewable electricity for their Apple production – including Viscom and Victrex, Robert Bosch, which recently joined Apple's Supplier Clean Energy Program, and Varta Microbattery. (Source: Apple)

www.trumpf.com
www.st.com

Swiss PIC to support the photonics industry

The "Swiss Photonics Integration Center" technology transfer center was founded at the beginning of January 2023. Swiss PIC will be located in the Park Innovaare, in the immediate vicinity of the Paul Scherrer Institute (PSI), one of its founding partners alongside other industry and research stakeholders. The new center aims to facilitate innovation in the packaging and integration of optical systems and to make the findings accessible to industry.

The new technology transfer center in the canton of Aargau will offer the transfer of know-how from academic partners, putting it at the service of the photonics industry, using photonic integrated circuits (PICs) needed by future-oriented industries such as optical communications, sensor technology, the development of quantum computers, autonomous driving, artificial intelligence and augmented or virtual reality.

Embedding integrated photonic systems in enclosed components with established interfaces to optical fibers is a complex task. This photonic packaging is a prerequisite for industry to be able to use the technology commercially, and it is one of the starting points for Swiss PIC.

The founding partners of Swiss PIC include the non-profit company Swiss Photonics, which was in charge of the project application, the PSI and the Eastern Switzerland University of Applied Sciences OST, as well as the companies Ligentec and Polariton Technologies, which both specialize in integrated optics.

www.psi.ch

Toptica opens new headquarters


Source: Toptica

Dr Thomas Weber, Dr Dieter Schenk (chairman), Dr Thomas Renner (member of the management board, CSO), Dr Wilhelm Kaenders (member of the management board, CTO), Simon Grimminger, and Dr Martin Hohla

The company welcomes its customers and employees to new premises at the Gräfelfing site near Munich. A modern reception area with a customer lounge and showroom as well as two new, large meeting rooms with state-of-the-art presentation technology have been created. At the same time, an additional 2,000 m² of office and laboratory space was developed and opened at the site.

The extensive renovations and new leases were necessary to meet the increasing demands and requirements for office space, logistics areas, production facilities and clean rooms. The supervisory board saw this as a positive step in paving the way for the company's successful growth and continuous improvement in product quality.

www.toptica.com

Laseroptik wins Supplier Award

Sponsored content: Laseroptik

Award ceremony attendants from left to right: Dr Paul Ilten, European Director Strategic Supply Chain, Coherent, Julia Strozyk, Strategic Sourcing Manager, Coherent, Dr. Wolfgang Ebert, President, Laseroptik, Werner Moorhoff, Senior Coating Manager, Laseroptik, and Oliver Bissmeyer, Team Leader Europe Global Supply Chain, Coherent

Coherent Corp, a global leader in materials, networking and lasers, has recognized Laseroptik GmbH, the German manufacturer of optical coatings and laser optics, with their Global Supplier Excellence Award for their outstanding performance in 2023. Coherent Global Supplier Awards are given in recognition of a supplier's excellence in collaborating with Coherent to achieve the highest levels of performance, innovation and service. Only the highest-achieving suppliers are awarded this honor, in Laseroptik's case with a special focus on environmental, social and governance criteria.

Coherent Supplier Award

The award was handed over in a ceremony at Coherent's site in Luebeck, Germany. Laseroptik's president Dr Wolfgang Ebert highlighted: "My company and I personally feel honored by this award and the appreciation coming along with it. We have been working for Coherent sites for almost 40 years now and developed unique optics manufacturing capabilities for their needs. I thank Coherent for their recognition and their continued trust in us."

Dr Paul Ilten, director strategic supply chain Europe, added: "Laseroptik has been an important, innovative and reliable partner to Coherent for decades. We are very much looking forward to continuing this successful business partnership."

Coherent empowers market innovators to define the future through breakthrough technologies, from materials to systems. It delivers innovations that resonate with customers in diversified applications for the industrial, communications, electronics, and instrumentation markets. Headquartered in Saxonburg, Pennsylvania, Coherent has research and development, manufacturing, sales, service, and distribution facilities worldwide. For more information, please visit https://www.coherent.com.

Laseroptik is a renowned manufacturer of optical coatings and laser optics from VUV to IR and employs more than forty coating machines with seven different coating methods. Founded in 1984 as a spin-off from Hanover University, the company produces on average 180,000 coated optics per year, mainly for laser applications in industry, medicine, space and research. For more information, please visit

www.laseroptik.com

Chromacity targets key industrial markets together with AMS Technologies

Ultrafast laser company Chromacity joined forces with the provider of photonics technologies AMS Technologies as it focuses on biomedical, semiconductor, energy and defense sectors.

AMS Technologies will promote and sell Chromacity's range of fixed wavelength femtosecond lasers for biomedical imaging and semiconductor testing applications, which can benefit from the ultrashort pulses and high peak power provided by the company's lasers.

Source: Chromacity

(l–r) Jan Meise & Benno Oderkerk (AMS Technologies), Shahida Imani & Bertrand Frossard (Chromacity)

The German company will also promote the gas sensing capabilities of Chromacity's range of tunable laser sources in markets such as oil and gas, environment, and defense.

The two companies will also jointly explore potential applications in the field of quantum optics. Chromacity has already demonstrated photon entanglement capabilities, which are key to the development of optical quantum technologies, such as enhanced imaging, information, and communication.

The two companies showcase together on the AMS booth B2.203 at Laser World of Photonics.

https://chromacitylasers.com
www.amstechnologies.com

Increasing semiconductor laser production capacity

3D rendering of the planned building at the Miyakoda Factory

Source: Hamamatsu Photonics

Hamamatsu Photonics develops, manufactures and supplies semiconductor lasers and laser oscillators used for many purposes, such as measurement, analysis, laser processing, factory automation and medical applications. These include optoelectronic devices requiring a broad range of laser types.

The company is now putting up a brand new building on the Miyakoda Factory site to consolidate post-processing steps in semiconductor laser manufacture. Currently these are dispersed over different locations on the site. The construction of the new factory building will allow the company to optimize workflow lines between production processes and also to install the latest in manufacturing and inspection equipment. This will promote process automation and efficiency and thereby improve productivity.

The groundbreaking ceremony for the new factory building was held on May 10, 2023, and the completion is scheduled for July 2024.

www.hamamatsu.com

Mitsubishi and Coherent signed a memorandum of understanding on SiC manufacturing

"We are excited to build on our relationship with Mitsubishi Electric, a pioneer in SiC power devices and a global market leader in SiC power modules for high-speed trains, including the famous Shinkansen in Japan," said Sohail Khan, executive vice president, new ventures and wide-bandgap electronics technologies at Coherent. "We have a long track record of supplying SiC substrates to Mitsubishi Electric and are looking forward to expanding our relationship with them to scale their new 200 mm SiC platform."

The market for electric vehicles is expanding worldwide and is just one of several emerging applications driving the exponential growth in SiC power devices, which have lower energy losses, higher operating temperatures, and higher switching speeds compared with power devices based on silicon. To meet the rapidly growing demand, Mitsubishi Electric announced an investment of around ¥ 260 B ($ 1.86 B) in the five-year period ending March 2026. A major portion of the investment, approximately ¥ 100 B, will be used to construct a new plant for SiC power devices based on a 200-mm technology platform, and to enhance related production facilities.

Under the memorandum of understanding, Coherent will develop a supply of 200-mm n-type 4H SiC substrates for Mitsubishi Electric's future SiC power devices manufactured at the new facility.


Source: Coherent

200-mm silicon carbide wafer

www.coherent.com
www.mitsubishielectric.com

Avonix Imaging to be aquired by Nikon

Nikon's US subsidiary has executed an equity purchase agreement with Avonix Imaging, which engages in manufacturing, sales, and services relating to X-ray and CT Systems, and has commenced the procedures to acquire Avonix, subject to applicable regulatory clearances and customary closing conditions. NAI is anticipated to acquire all shares of Avonix in Summer 2023, following the clearance of the acquisition by regulatory authorities and satisfaction of the other applicable closing conditions.

Since 2015, Nikon and Avonix have worked together in joint development, sales, and provision of services relating to CT systems for large-scale inspection, which is one of the lines of products by Nikon's industrial metrology business unit. Nikon and Avonix will together further advance the development of new products as well as enhance their business by utilizing Avonix' customer base in the automotive and aerospace markets.

www.nikoninstruments.eu

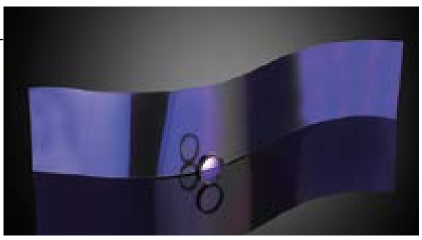
Edmund Optics partners with Meta Materials

Through the new partnership, Edmund Optics now offers holographic notch filters. "Meta Materials' collaboration with major OEMs for product and technology development, coupled with Edmund Optics' distribution capabilities for optics, imaging and photonics products, creates an easy way for global customers to try this new and exciting technology," said Ed Kay, vice president retail marketplace at Edmund Optics.

George Palikaras, president and CEO of Meta Materials, added, "This makes the filters available to engineers and scientists around the world for use in multiphoton microscopy, laser-based fluorescence devices and other life science applications."

The Meta Holooptix notch filters offer constant notch filter central wavelengths for s and p-polarization even at high angles of incidence – a unique property that distinguishes them from other comparable filters. Two different versions are available: Flex and Strata. The filters are optimized for high transmission for either red, green or blue laser lines. The non-transmitted light is blocked with an average optical density of >4 (cf. p. 51).

www.edmundoptics.com
https://metamaterial.com


Source: Edmund Optics

Notch filters provide constant central wavelengths for s and p-polarization even at high angles of incidence.

Entangled photon pairs to help fight against cancer

An important challenge in clinical cancer diagnostics is the need for rapid analysis of tissue sections. A new project aims to transfer measurement information from the clinically relevant mid to the near-infrared by developing a novel imaging technique. Sample throughput could be significantly increased by developing a microscopy method that enables the study of tissue samples without staining and reducing the measurement time of a 10-MP image to two minutes, sample throughput could be significantly increased, according to the research project. This would allow the examination of label-free tissue samples to be directly integrated into clinical workflows for the first time.

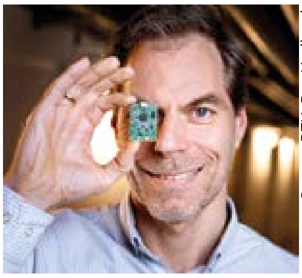
Sill Optics is already present in optical quantum technology with its trapped ion lenses, and its contribution to the new Quantum-Enhanced Early Diagnostics (QEED) research project marks another significant step. In QEED, Sill Optics contributes to the project by developing and producing the scanner module consisting of a mirror scanner and adapted microscope objectives.

The Ferdinand Braun Institute has comprehensive experience in realizing highly specialized diode laser modules (Source: FBH)

QEED is coordinated by Lavision Biotec, a Miltenyi Biotec company. Other industry partners are Art Photonics and Sacher Lasertechnik.

www.silloptics.de

Laser diode generates random numbers



Source: DTU, Bax Lindhardt

Ulrik Lund Andersen shows the latest version of his quantum-mechanical randomness generator

In a few years, protection of communication through quantum encryption may become a permanent fixture in mobile phones. The technology has already been demonstrated in large data transfers in the financial sector in Denmark, and now DTU spin-out company Alea Quantum Technologies has developed a quantum-mechanical random number generator that is so simple that it can be produced at a low price and support encryption of 4 GB/s. The technology is so simple that it can be developed into a chip version.

The device measures 3 × 5 cm and will be tested by QTI, Quantum Telecommunication Italy. The EU has granted seven million krones under the Digital Europe program for the further development of the technology, which in 2022 also formed part of a larger system tested to deliver quantum-secured data transfer between two servers in Danske Bank.

www.dtu.dk

www.alea-quantum.com

Secure data communication using quantum cryptography and Li-Fi

Project partners led by Keequant are developing a new approach to secure optical data transmission in wireless networks using light and quantum keys. As the connections to the end user on the last kilometer have so far still been served by classical technologies and remain vulnerable to attack, QuINSiDa – Quantum-based Infrastructure Networks for Safety-critical Wireless Data Communication was launched last fall. Other partners of the project, funded by the BMBF with a sum of two million euros, are the Fraunhofer Institutes IPMS and IOF, Telco Tech, Infosim, and Bescom Elektronik.

In quantum key distribution, quantum states in the form of light are prepared and exchanged between participants in the network when the keys are generated. When the quantum states are received, they are measured and post-processed to produce keys that are identical on both sides but secret to an attacker. The project is the first to combine both technologies into a "QKD over Li-Fi" system. This makes it possible to carry QKD, which until now has been thought of more in a building-to-building scenario, all the way to the end user.

"The intention of the project is to demonstrate a quantum-based data communication network that wirelessly and flexibly connects multiple end users to a secure backbone infrastructure or which can be deployed separately as a secure campus network," says Imran Khan, managing director of Keequant GmbH.

www.ipms.fraunhofer.de

Quantum Bridge secures funding to build quantum repeaters for communication networks

The funding equivalent to 700,000 USD is part of a collaborative research agreement with the National Research Council of Canada's Quantum Sensors Challenge program. The collaboration will see the development of the first all-photonic quantum repeater used to channel entanglement over very long distances.

Mattia Montagna, CEO at Quantum Bridge, says "Our goal is to build a deterministic cluster state generator that can have multiple uses in the quantum industry." These quantum repeaters will use quantum dots as a single photon source to carry entanglement between the repeaters, and right across quantum-safe communication networks. When hit with a sequence of laser pulses, this semiconducting technology emits entangled photons, creating a bundle known as quantum cluster states. These then allow quantum networks to be developed without quantum memories, thereby providing significant advantages in the performance, speed and scalability of such networks.

https://qubridge.io

Source: Quantum Bridge

Kai Sum Chan, Priya Vaish, and Samridhi Gambhir (l–r), working on the hardware Quantum Bridge is developing in NRC's Ottawa lab.

9-million euro project unites German quantum stakeholders

The SQuaD project participants and representatives of the project executing organization at the kick-off in Berlin. (Source: PTB)

After intensive research in quantum-based key distribution, the technological leap into industry is now imminent: the German Federal Ministry of Education and Research (BMBF) is funding 36 institutions in the Innovation Hub for Quantum Communication to link research institutes and companies. The accompanying umbrella project "Schirmprojekt Quantenkommunikation Deutschland – SQuaD" is coordinated by the Physikalisch-Technische Bundesanstalt (PTB) in close cooperation with the Federal Office for Information Security (BSI) and brings together players from research and industry. It also expands existing test environments for quantum communication technology.

"Our main goal over the next few years is to ensure that companies and research institutions are well networked so that they benefit from each other in close exchange," explains Dr Nicolas Spethmann, coordinator of the umbrella project. "The use of quantum-based key distribution to complement post-quantum cryptography can contribute significantly to Germany's IT security and technological sovereignty."

Another task of SQuaD is to lay the foundations for the emerging ecosystem in quantum communication, for example by providing test environments, reliable setups for testing components, and driving standardization and certification.

Partners include Keequant, Quantum Business Network, and Quantum Optics Jena.

www.ptb.de

Launch of the Quantum Secure Networks Partnership QSNP

March 1, 2023, saw the official launch of the Quantum Secure Networks Partnership, or QSNP, a new project in the area of quantum communications of the Quantum Flagship. Coordinated by Valerio Pruneri, an ICREA professor at ICFO, QSNP brings together more than forty partners from all over Europe, ranging from academia, foundries and RTOs, SMEs and spin-offs, to network and cryptography integrators and telecom operators. The experts hope to fulfil three main goals within a time span of 3½ years and a budget of € 25 M.

Firstly, they will develop advanced quantum technology for quantum secure communication networks against the ever-increasing power of computers and the sophistication of algorithms, even for quantum computers. That is, they will work on the development and deployment of next generation protocols based on quantum key distribution (QKD) cryptography techniques, that can help reduce the security assumptions needed for the networks, extend the range of secure communication, and search for new functionalities that could beyond these techniques.

Secondly, they will aim to integrate this innovative quantum cryptography technology not only at the component, system and network levels, but also into existing classical telecommunication systems and post-quantum protocols.

Finally, they will apply all the know-how and capabilities acquired and the technology developed into different use cases, mainly into delivering critical European technology for government infrastructures such as the European Quantum Communications Infrastructure (EuroQCI).

In addition, the project will be a launchpad for future applications, to exploit new capabilities, evaluate new cost/effective features, measure use/integration easiness levels, and explore new sectors where quantum technology could take over markets that are not currently being reached.

www.icfo.eu

ALSO OF INTEREST

Creaform opens new repair center near Grenoble

Partners and end customers in the EMEA region can now benefit from a local service

€19M project set to enable next-generation IR sensors

Four-year defense project HEROIC is led by Lynred

Smart Vision Lights appoints vice president of engineering

Steve VanderZwaag now responsible for the LED lighting solutions manufacturer's technology

Denkweit and IDS cooperate

Fraunhofer spin-off and the machine vision company join forces

MVTec opens subsidary

New office in Lyon for customer support in France, Belgium, and Switzerland

AI-based self-driving perception

Daimler Truck subsidiary Torc Robotics acquires Algolux

Kimsoptec renames to Instrument Systems Korea

After being acquired in 2022, the Korean manufacturer of display measurement systems changed its name

TKH acquires Euresys

Dutch group takes over provider of 2D and 3D image analysis software

Nuburu appoints chief marketing and sales officer

Experienced laser industry veteran Matthew Philpott to lead growth plans

EPIC honors Kęstutis Jasiūnas and Håkan Karlsson during annual meeting in Helsinki

At its annual general meeting, the European Photonics Industry Consortium recognized Kęstutis Jasiūnas with the EPIC Lifetime Achievement Award for his outstanding contributions and leadership in the laser industry. Jasiūnas, the chairman of the board of Ekspla, has led the company to become a major player in the global market for scientific picosecond lasers.


Basil Garabet, president of EPIC, delivers the EPIC Lifetime Achievement to Kęstutis Jasiūnas, former CEO of Ekspla, for his leadership in the laser industry. (Source: EPIC)

Born in 1959 and a graduate of Vilnius University, Jasiūnas began his career at the Institute of Physics of the Lithuanian Academy of Sciences before co-founding Ekspla in 1992. Under his leadership, the company developed and manufactured cutting-edge femtosecond, picosecond, and nanosecond lasers and laser systems for scientific and industrial institutions. The company occupies more than half of the global market for scientific picosecond lasers and is the only manufacturer of SFG spectrometers for studying material surfaces.

Håkan Karlsson, the head of the photonics division at Hübner Group and CEO of Cobolt, received the EPIC CEO Award 2023.

With a PhD from KTH Stockholm, Karlsson has been a driving force in the field of compact single-frequency lasers for advanced analytical instrumentation. He co-founded Cobolt AB in 2000, as the first company to bring diode-pumped lasers using periodically-poled nonlinear optical materials to the market with a unique manufacturing method. After selling Cobolt to Hübner in 2015, Karlsson continues to lead the group's photonics division which now spans five sites worldwide and offers a range of technologies and products. These include single frequency lasers, laser combiners, ultrashort femtosecond lasers, and the unique and award-winning C-WAVE tunable single-frequency laser.

www.epic-assoc.com

Optical blood pressure monitoring method honored

For the second year in a row, CSEM has granted its Inventor Award to a patented technological innovation with a high impact on our business, the industry and society in general. Four CSEM researchers have developed a continuous optical blood pressure measurement system that allows non-invasive monitoring for millions of patients worldwide.


Source: CSEM / M. Othenin-Girard

(l–r) Martin Lemay, CSEM CEO Alexandre Pauchard, and Martin Proença

The patent of Martin Proença, Josep Solà, Mathieu Lemay, and Christophe Verjus "Method, apparatus and computer program for determining a blood pressure value" is one of CSEM's major innovations. Filed in 2015 and called oBPM for optical blood pressure monitoring, it represents a great success in terms of technology transfer to industry with its first commercialized application, the blood pressure monitoring of the Aktiia spin-off.

www.csem.ch

Femtosecond fiber lasers for high-precision measurement technology

The chair of ultrafast physics and photonics at the Center for Applied Photonics (CAP) of the University of Constance and Toptica Photonics AG from Gräfelfing near Munich have jointly been awarded the 2023 DPG Technology Transfer Prize for the application of scientific findings in the field of femtosecond fiber lasers,.

"The decisive factor was the successful transfer of scientific findings on a high-precision 'frequency comb technology' for lasers to industrial applications," says Lutz Schröter, vice president of the German Physical Society (DPG). Fiber lasers

are special solid-state lasers based on optical fibers made of glass fibers.

The cooperation between Toptica and the chair of ultrafast physics and photonics of professor Alfred Leitenstorfer at the University of Konstanz began in 2004. Read the full story in the August/September issue of PhotonicsViews.

www.dpg-physik.de
www.toptica.com

Bosch Rexroth and MantiSpectra win awards at Hannover Messe

Companies from Germany and The Netherlands were presented with prestigious industrial prizes at the opening ceremony of the Hannover Messe.


Source: Deutsche Messe

MantiSpectra from Eindhoven was awarded the coveted Hermes Startup Award

The jury awarded the Hermes Award for a product geared to the dynamic robotics market. The Bosch Rexroth Smart Flex Effector project consists of a sensor-based compensation module (end effector) for robots, featuring independent, precise kinematics in six degrees of freedom.

The young company MantiSpectra from Eindhoven was awarded the coveted Hermes Startup Award for its ChipSense product, a fully integrated near-infrared sensor – the smallest of its kind on the market, with a footprint of 1 mm^2. The sensor enables rapid, highly accurate analysis and is used directly on the production line, from where it delivers real-time data. This makes it possible for defects to be detected as soon as they occur and for savings to be made through immediate quality control on the spot, on the production line. The product is already in use in industry, agriculture and food processing.

www.messe.de

Zygo makes strategic appointment

Source: Zygo

Jennifer Hellberg

The Ametek subsidiary from Connecticut has appointed Jennifer Hellberg as the division vice president, business unit manager, reinforcing the importance the company places on continuous improvement and customer focus.

Hellberg says, "It is truly exciting to take up my new role at a company that is at the forefront of precision metrology and precision optics manufacturing. Zygo adheres to continuous improvement methodologies, and I am looking forward to contributing to the identification of opportunities to streamline work, to ensure a total focus on higher customer service standards and to reduce waste."

Prior to her nomination to Zygo, Hellberg was most recently vice president and general manager with Thermo Fisher Scientific based in Wisconsin, where her focus was on increasing responsibility in operational excellence and general management. Before joining Thermo Fisher, she built her career in engineering, operations, and supply chain at Proctor & Gamble, also in Wisconsin. Hellberg holds a BSc in environmental engineering from Michigan Technological University and an MBA from the University of Wisconsin, Madison.

www.zygo.com
www.ametek.com

Robert Franz becomes CEO of Allied Vision and TKH's German 2D Vision Group

Allied Vision Technologies GmbH, part of the TKH Group, has appointed Robert Franz as Managing Director. Along with this role, Franz will also assume the role of CEO for the German 2D vision companies within the TKH Group, which include companies such as Chromasens, NET, SVS-Vistek, Mikrotron and Nerian. These companies all operate under the TKH Vision umbrella.

Franz has many years of experience in companies in the automation technology and machine vision industries. Among other positions, he was head of the global optical sensing business unit at Honeywell, president of Rittal in the Americas region and senior vice president of global sales and marketing at Datalogic. Franz is a lawyer and earned an MBA from TIAS Business School in Utrecht (NL). "I am looking forward to working with a great team to further develop the products and strategy and to grow the business together," says Franz.

"With Robert Franz, we have found an excellent candidate with a strong background in strategy, sales and product management to take over the role of CEO of Allied Vision," said Alexander van der Lof, chairman and CEO of the TKH Group.

www.alliedvision.com
www.tkhgroup.com

Source: Allied Vision

Robert Franz

Quix Quantum appoints new CTO

Devin Smith steps up as CTO to lead the technology direction and development of Quix Quantum. He joined the company in 2021 and was previously a senior quantum engineer leading the quantum science team.

Smith has worked on integrated photonics as a postdoctoral fellow at the NTT Basic Research Laboratories in Japan, and as a research fellow at the Optoelectronics Research Center (ORC), University of Southampton in the UK. Smith's unique comprehension in both fields, quantum computing and integrated photonics, have allowed him to easily communicate across boundaries and between fields. His strong lead in the quantum science team is essential for the development of the technology vision.

Source: Quix Quantum

Drs Devin H Smith (l) and Jelmer Renema

Jelmer Renema co-founded Quix Quantum and provided technology leadership in the creation of the business and the technology. He is also active in the broader quantum and photonics ecosystem in his role as assistant professor of quantum optics at the University of Twente in the Netherlands.

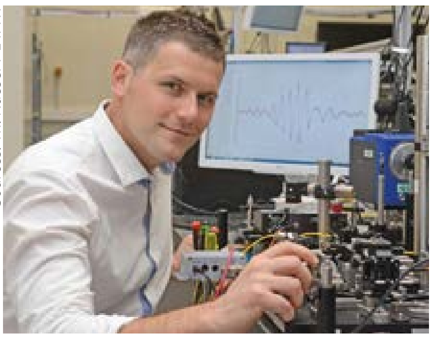
Dr Stefan Hengesbach, CEO of Quix Quantum says: "I am delighted that Devin has agreed to become our CTO with Jelmer as chief scientist to continue his technical guidance."

www.quixquantum.com

Pupeza expands IPHT's range of optical methods in medicine

The Leibniz Institute in Jena has established a new working group for field-resolved spectroscopic measurement methods, headed by ERC Consolidator Grant winner Ioachim Pupeza.

Dr Pupeza moved from the Max Planck Institute of Quantum Optics in Garching to the Leibniz Institute of Photonic Technology, where he heads the new research group Field-Resolved Optical Precision Metrology since February 2023. He is an expert in electric-field-resolving spectroscopic methods. At the IPHT, the physicist intends to further improve the technology and open up new applications, such as label-free cell detection and sorting at high speeds.



Sources: Th. Naeser / L-IPHT

PD Dr Ioachim Pupeza

In his ERC Consolidator Grant funded Laser-Based Infrared Vibrational Electric Field Fingerprinting (LIVE) project, Pupeza is working toward developing novel light sources and innovative approaches to recording optical electric fields. The goal is to use the control over light at the level of single optical field oscillations afforded by femtosecond lasers and nonlinear optics to overcome current technological limitations, and thereby tap the full potential of vibrational spectroscopic fingerprinting.

www.leibniz-ipht.de

Changes in the Trumpf boards

Source: Trumpf

(l–r) Dr Björn Dymke, Dr Berthold Schmidt, Dr Hagen Zimer

In the year of its 100th anniversary, the high-tech Trumpf company is reorganizing its management bodies taking effect with the start of the new fiscal year 2023/24 on July 1, 2023.

Dr-Ing eh Peter Leibinger (55), vice chairman of the managing board and chief technology officer, is moving from the managing board to the supervisory board, where he assumes chairmanship, succeeding the retiring Dr Jürgen Hambrecht (76). Elke Reichart (58), formerly CDO of TUI AG, succeeds Prof Dr Claudia Eckert (64) on the supervisory board.

Dr Berthold Schmidt (54) will succeed Peter Leibinger as the new CTO on the managing board. The physicist has been the managing director of Trumpf Photonic Components in Ulm since April 2020 and has been with the company since 2013.

Dr Christian Schmitz (63), member of the managing board responsible for the laser technology business division, is retiring. He is succeeded by Dr Hagen Zimer (50). The physicist has been the managing director of Trumpf Laser GmbH in Schramberg since 2020.

Dr Zimer's successor for Schramberg will be Dr Björn Dymke (47). Dymke has been with Trumpf since 2008 and was most recently head of finance and controlling at the group in Ditzingen.

In the extended management team, Peter Bokelmann (62) is leaving the company as general counsel for reasons of age.

www.trumpf.com

AT – Automation Technology opens office in Boston

With the new branch in the US, AT wants to expand its network and strengthen sales and support for its local customers. The location in the Boston metropolitan area will be managed by Gretchen Alper, who already has many years of experience in the field of machine vision. She was jointly responsible for the successful business development of a Dutch company in North America for almost two decades.

"Compared to Europe, the USA and the North American market have a completely different understanding of product marketing. It is not all about having a good product. Customers need to understand why the product is special and how it is used," explains Alper.

Source: AT

Gretchen Alper

The Boston area already has many companies that are active in the fields of optics or image processing and also numerous universities as a talent pool of talented people who are interested in the industry.

www.automationtechnology.de

200 MHz low-noise variable gain photoreceiver

Manufacturer: Femto Messtechnik
Product: Low-noise photoreceiver "OE-300" with InGaAs or Si photodiode for the wavelength range from 320 nm to 1700 nm and variable amplification from 10^2 to 10^8 V/A for the detection of optical signals from the nanowatt to milliwatt range. The optical input is either free space or fiber optic.
Features: The photoreceiver series consists of a high-quality photodiode followed by a high-end, variable gain transimpedance amplifier. The wide amplification range in combination with a bandwidth up to 200 MHz and an input noise (NEP) down to 47 fW/√Hz make the device a real universal photo receiver for the MHz range. Various models with InGaAs or Si photodiodes cover the wavelength range from 320 nm to 1700 nm. The large-area detectors facilitate optical focusing. The free space input has a 1.035"-40 thread, suitable for standard optical accessories

from various manufacturers. Optical fibers can be attached to the silicon models with free space input in no time at all using screw-on adapters (FC/PC, FC/APC or FSMA). With the smaller-area InGaAs photoreceivers, there is a choice between a free space input and a model with a fixed FC fiber connection. The optionally available post adapter plate (PRA-PAP) with M4 and 8-32 UNC thread enables mounting on an optical bench.
Applications: The wide range of applications includes spectroscopy, characterization of light sources, optical power measurements, time-resolved pulse measurements and much more.

FEMTO Messtechnik GmbH
Klosterstr. 64
10179 Berlin, Germany
phone: +49 30 2804711-0
e-mail: info@femto.de
Website: www.femto.de

Femtosecond lasers lower costs in microscopy, nano-fabrication, and inspection

Manufacturer: Coherent.
Product: Market proven compact fs laser "Axon 780" with emission at 780 nm. Other models of the series with powers up to 3.5 W are available at 920 nm and 1064 nm. They all are showcased at the Laser World of Photonics fair in Munich.
Features: All "Axon" lasers enjoy a common fit, form and functionality for simple integration. Short pulses, less than 150 fs, are delivered with dispersion precompensation and users may also select the "Total Power Control" (TPC) for fast modulation with >1,000:1 contrast ratio.
The value-priced "Axon 780" offers 800 mW of power for brightest images, faster process speeds, and more efficient non-linear processes. The fully integrated group delay dispersion pre-compensation ensures minimized and consistent pulse duration at the sample. The TPC option allows for reduced system cost and complexity. For two-photon microscopy techniques, the laser offers a combination of wavelength and power that enables label-free imaging techniques. These include second harmonic generation (SHG) for imaging collagen fibers, as well as exciting endogenous fluorescence in NADH and flavins in both living and fixed tissue samples. This makes the compact, cost-effective, and OEM-friendly series a promising pathway for future clinical instruments, plus the TPC option simplifies these microscopy systems by allowing direct flyback blanking.
Applications: Label-free two-photon microscopy, two photon nanofabrication, and inspection of wafers and thin films, all get a major boost in speed and performance.

Coherent Shared Services B.V.
Dieselstr. 5b
64807 Dieburg, Germany
phone: +49 6071 968-0
e-mail: sales.germany@coherent.com
Web: www.coherent.com
Laser World of Photonics, Hall B3, Booth 321

Building a sustainable future

EPIC members collaborate beyond technology innovation

This spring, EPIC traveled to the HBK FiberSensing facilities in Porto, Portugal, to discuss the challenges and opportunities in the fiber sensing market. The discussion included advancements in fiber Bragg gratings, distributed sensors and interrogators and other monitoring options.

The meeting featured several informative presentations from experts in academia and industry. The consensus reached was that fiber sensing is a well-established technology, with numerous companies developing solutions for various applications. The medical market is experiencing rapid growth and benefiting from new integrated solutions, although the highest sales still pertain to defense and security.

Following the Porto meeting, the EPIC team traveled to Jena, Germany, to engage in discussions on photonics for AR/VR/MR, specifically focusing on design, system integration, and mass production. The meeting brought together key players in the AR/VR industry. The primary topic of discussion was the need for technology to be presented in a user-friendly form factor, necessitating even smaller optical components. However, the main challenge lies in balancing design requirements with user needs.

Source: Jabil Optics

Group picture of the EPIC Meeting on Photonics for AR/VR/MR: from Design to System Integration and Mass Production at Jabil Optics.

Recently, the association had two delegation trips, one to Japan including some company visits to Optosigma / SigmaKoki, AGC and Nikon, and the other to Abu Dhabi, UAE, to visit the Technology Innovation Institute. EPIC was also very active on online channels, organizing technology meetings on topics such as climate change monitoring, additive manufacturing, and non-telecom VCSEL applications. Furthermore, an Online Marketing Meeting on press content for photonics was conducted.

EPIC also initiated two working groups among its members. The first group addresses human resources, aiming to meet talent acquisition challenges. The second group focuses on sustainable photonics, aiming to educate and promote circular design and sustainable production methods.

www.epic-assoc.com

Upcoming EPIC events:

- 27 June 2023
  EPIC Meeting on Micro-Optics at the Laser World of Photonics
- 28 June 2023
  EPIC Meting on Ultrafast Laser Processing at the Laser World of Photonics
- 29 June 2023
  EPIC CEO Exhibitor Breakfast at the Laser World of Photonics
- 29 June 2023
  EPIC Technology Workshop on PIC Post-Processing & Packaging at the Laser World of Photonics
- 10 July 2023
  EPIC Online Technology Meeting on Photonics for Wearables
- 1 September 2023
  EPIC HR Workgroup Meeting: hiring outside Europe
- 6 – 7 September 2023
  EPIC Technology Meeting on Photonics in Defense. Kielce, Poland
- 7 September 2023
  EPIC TechWatch at CIOE on Optical Components, Materials and Innovative Applications, Shenzhen, China
- 18 September 2023
  EPIC Online Technology Meeting on Hybrid Photonics Integration
- 2 October 2023
  EPIC VIP Networking Reception at ECOC, Glasgow, Scotland
- 4 October 2023
  EPIC TechWatch at ECOC, Glasgow, Scotland
- 9 October 2023. Online Event
  EPIC Online Technology Meeting on Optical Metrology Solutions for the Industry
- 11 – 12 October 2023
  EPIC Technology Meeting on Industrial Quantum Photonics Technology at Toptica, Munich, Germany
- 16 October 2023
  EPIC Online Marketing Meeting: Google Analytics – Unlock the Power of GA4
- 21 October 2023
  Day of Photonics
- 23 October 2023
  EPIC Online Technology Meeting on LIDARs on Chips
- 24 – 25 October 2023
  EPIC Meeting on Laser Applications Along the Battery Manufacturing Process at ARENA2036, Stuttgart, Germany

For the list of all events, visit:
www.epic-assoc.com/epic-events

New president and board member for EPIC

Basil Garabet becomes new president of the European Photonics Industry Consortium, Shahida Imani takes the place on the board of past six years' president Benno Oderkerk

Basil Garabet (r) taking over presidency from Benno Oderkerk (Source: EPIC)

During the annual general meeting 2023 celebrated in Helsinki, Finland, the European Photonics Industry Consortium announced that Basil Garabet will be the new president of EPIC, succeeding Benno Oderkerk who served six years of the EPIC presidency.

The EPIC team expresses their gratitude to Benno Oderkerk for his dedication and guidance throughout the years. As per Carlos Lee, the director general of EPIC, "Benno has been a reliable support in these years of strong expansion, guiding in strategic decisions and networking events such as the now famous EPIC Runs."

Benno Oderkerk initially joined EPIC as the founder and CEO of Avantes and, after selling the company, he shifted his focus to mentoring and continued connecting photonics companies. Benno shares, "Working with EPIC members and the Photonics Industry has been personally fulfilling, though it requires a lot of time and effort, the great moments we shared and the achievements we attained are priceless". He is followed by Basil Garabet as the new president.

Garabet, the president and CEO of NKT Photonics, has been successfully leading the company since 2015. With 38 years of experience in photonics, he has been a serial entrepreneur who has started, led, and turned around a number of international photonics companies, including JK Lasers, EM4, Altitun, Melles Griot, and Lasertron. Basil is actively involved in promoting photonics worldwide, particularly in new applications such as Quantum, and holds various honorary positions.

"I am honored to be appointed as the new president of EPIC," declared Basil Garabet. "As an organization, we have persevered through challenging times, and now it is crucial that we forge new bridges to ensure that we can gather input from every voice."

With Oderkerk departing from the board, Shahida Imani, CEO of Chromacity, is filling the place. "We are delighted to welcome Shahida Imani to EPIC's board of directors," said Lee. "She is a highly respected professional, and I am confident that her expertise, from the leadership of Chromacity, experience in raising capital, and her involvement in high-growth SMEs, will contribute significantly to the success of the organization and the members." Garabet expressed, "With Shahida's appointment, we welcome the valuable perspectives of SMEs and UK's regional representation to our board of directors. We look forward to broadening our horizons with her joining our team."

www.epic-assoc.com

The status of fiber optic sensing technology

Industry leaders evaluated the potential of integrated solutions and addressed the need for education on the real value of fiber optic sensors at an EPIC event in Porto, Portugal

EPIC organized a meeting focused on fiber sensors in collaboration with HBK FiberSensing on the 19th and 20th April 2023. The event aimed to discuss the latest advancements in fiber sensing solutions and to foster collaboration and knowledge-sharing among industry professionals.

Attendees from various industries participated in the event. The meeting saw intense debates on the challenges and opportunities in the fiber sensing market and the new developments of fiber Bragg gratings, distributed sensors and interrogators and other monitoring options. The meeting featured several informative presentations from experts in academia and industry. Werner Lienhart from Graz University gave a review of the different projects performed by their group related to structural health monitoring of bridges and roads.

The meeting concluded with a consensus that fiber sensing is a well-known technology with many companies developing solutions for various applications. The medical market is growing rapidly and taking advantage of the new integrated solutions, although the highest sales are still related to defense and security. Finding niche markets could be a challenge for manufacturers in the near future. Overall, the meeting provided valuable insights into the state of the art of fiber sensors and opened up new possibilities for collaboration and innovation in the industry.

Redondo Optics – Fiber Optic Sensor Systems for Applications where Weight, Size, and Power are Critical for Operation – Edgar Mendoza, CEO (Source: EPIC)

www.epic-assoc.com

IVSM: Standards for multibillion vision-tech market

More than 100 developers convened at the Standards Working Group Meeting in Vienna

The participants of the meeting in Vienna (Source: AIT / Johannes Zinner)

Participants from Europe, North America and Asia representing about forty machine vision companies met during the spring edition of the International Vision Standards Meeting (IVSM) from 17 – 20 April in Vienna, which was hosted by the EMVA and the Austrian Institute of Technology (AIT) where the event was held. The International Vision Standards Meeting combines the global machine vision standardization efforts and goes back two decades to the kick-off meeting for the GigE Vision standard in June 2003. Since then, the supporting associations A3 (North America), CMVU (China), EMVA (Europe), JIIA (Japan), and VDMA (Germany) alternate as hosts for the biannual meetings.

The event was a complete success for both EMVA and AIT. Markus Clabian, head of the high-performance vision systems research group at the AIT Center for Vision, Automation & Control (VAC), comments: "It was a strategic decision for us to host the IVSM. Our aim is to significantly increase the visibility of AIT and our technologies in the professional community, demonstrating the deep expertise in the field of machine vision at the VAC. In addition, as a research and development organization, the exchange with experts is crucial to us, not only on a professional level but also to understand the needs of the market. At the IVSM we talked to the experts and companies from China, Japan, Canada, USA, Belgium, Germany, and many more, and discussed opportunities for collaboration. Thirdly, during the tours through various AIT Labs, we were able to show different innovative application fields of machine vision, where vision standards clearly demonstrate their value."

The 'Plugfest' is a special highlight at each meeting, where experts apply the standards and connect a wide range of products, some of which are new. Reynold Dodson, president of the company BitFlow and chair of the Camera-Link standard, as well as a member of the CoaXPress working group, regards the plugfest as an important part of the meeting: "It is chance for all the firms that work on the standard to test the interoperability of their products. These plugfests serve a number of purposes: they improve specifications, they provide a venue for mandatory interoperability testing and they tighten and enhance the social aspects of standards creation." During the meeting in Vienna, the plugfest was opened to the professional community outside the companies and institutions involved in the standards working groups for the first time.

www.emva.org
www.ait.ac.at

VDI publishes new guidelines for OCT processes

Guideline VDI/VDE 5565 Sheet 1 describes the OCT process and defines the terms required terms

Optical coherence tomography (OCT) is an imaging method that creates high-resolution cross-sectional images of transparent and semi-transparent media. It is used both in industrial measurement technology, for example in component monitoring, and in biomedical diagnostics, such as in ophthalmology or tissue diagnostics. Industrial measurement technology and medical technology companies expect to find many more uses. They work together in the VDI/VDE Society for Measurement and Automation Technology (GMA) in a specialist committee on OCT and have now published guideline VDI/VDE 5565 Sheet 1 with standardized process descriptions.

The goal of the Optical Coherence Tomography Technical Committee 1.32 within the 'Methodology of measurement and sensor technology' department of the GMA is to bring together expertise from industry and research and jointly publish a standardized set of rules for OCT, opening the way to more OCT applications in the future. This is because the comparatively new measurement method has not yet been described in general terms, and various methods and characteristics have not yet been standardized. The comparability of different OCT systems is not yet given and a wider distribution is restricted. This should change with the guideline work of the technical committee.

The guideline VDI/VDE 5565 Sheet 1 "Optical coherence tomography (OCT); Process Descriptions" was published in January 2023 in a bilingual edition (German/English) (www.vdi.de/5565). The guideline describes the OCT procedures and defines the necessary terms. The committee is already working on VDI/VDE 5565 sheet 2 on the subject of "Signal processing and data evaluation". The metrological characterization of OCT systems is on the roadmap for further guideline projects.

www.vdi.de

Cooperation with added value

VDMA and Photonics Germany have signed a memorandum of understanding for closer collaboration

On March 16, 2023, representatives of Photonics Germany and VDMA signed a cooperation agreement in Frankfurt am Main, Germany, to systematically intensify their cooperation and launch joint activities in the future. Photonics Germany is the alliance of OptecNet Deutschland and Spectaris, which aims to strengthen the position of the German high-tech industry on a national and European level. With more than 3,500 members, VDMA is the largest network organization and important voice of the mechanical engineering industry in Germany and Europe.

The aim of the agreement is to strengthen the importance of the photonics and laser industry through political information and public relations, as well as through joint activities in promoting young talent and recruiting skilled workers. In addition, the framework conditions in research and industry are to be improved. Another goal is to jointly advance quantum technology and to support or accelerateits implementation. To achieve these goals, Photonics Germany and VDMA Lasers and Laser Systems for Material Processing Working Group as well as the VDMA Quantum Technologies and Photonics Forum will work closely together.

https://photonics-germany.de
www.vdma.org


Source: VDMA

(l–r) Ralf Niggemann (OptecNet Deutschland), Dr Wenko Süptitz (Spectaris), Dr Sven Breitung (VDMA Laser Working Group and Quantum Technologies and Photonics Forum)

New board of directors

Elections at the VDMA Working Group Laser and Laser Systems for Material Processing


Source: VDMA

Management and board of the Working Group Laser and Laser Systems for Material Processing: Dr Christoph Ullmann, Laserline (chairman), Dr Stefan Ruppik, Coherent (vice chairman); Dr Sven Breitung, VDMA; Nikolas Meyer, EMAG LaserTec.

At the spring meeting of the VDMA "WG Laser", the board elected a new chairman and a new deputy chairman. Dr Christoph Ullmann, general manager of Laserline GmbH, was elected chairman and Dr Stefan Ruppik, vice president and general manager high power CO_2 lasers and profile welding systems at Coherent, was elected as his deputy.

Dr Christian Schmitz from Trumpf was bidden farewell as chairman of the laser working group, and thanked for his long commitment. He was on the board for twelve years and was its chairman for almost eight years.

The newly elected board is composed of: Nikolas Meyer, business unit manager – sales and application EMAG LaserTec GmbH, Dr Stefan Ruppik, and Dr Christoph Ullmann.

The VDMA Working Group represents the interests of 47 companies from Germany, Austria and Switzerland vis-à-vis politicians, business partners, the interested public, and the media. The circle of member companies includes the leading manufacturers of beam sources, laser processing systems, suppliers of components with direct reference to the end application as well as research institutes and universities.

www.vdma.org

VDMA is the sponsor of Laser World of Photonics

The VDMA Working Group on Lasers and Laser Systems for Material Processing assumes the conceptual sponsorship of the trade fair for components, systems, and applications in photonics

The Laser World of Photonics has a new cooperation partner: the VDMA Working Group on Lasers and Laser Systems for Material Processing is taking on the conceptual sponsorship of the world's leading trade fair for components, systems and applications in photonics. With its member companies from laser and automation technology and its forum for quantum technologies and photonics, the working group is a link between the Laser World of Photonics, the World of Quantum, and Automatica, the leading trade fair for intelligent automation and robotics, which will be held simultaneously for the first time from June 27th to 30th, 2023.

www.vdma.org

Adapting test methods for optics to high-power laser components

The LZH is working together with Laseroptik and Raylase on the cw-LIDT project

Laseroptik develops advanced coatings of the highest destruction resistance for the deflection unit of their partner Raylase. (Source: Laseroptik)

A limiting factor in developing new laser systems is the optical resilience of the components with which the laser radiation is generated and guided. These are necessary to achieve ever higher outputs. At the same time, there is a growing demand for low-weight components, for example for use in galvanometer scanners in material processing.

Scientists at the LZH are therefore developing measurement routines in the project to test and consequently guarantee the compatibility of such optics. Naturally, the results of tests performed on current optics components cannot also be expected to apply to much smaller and lighter elements. For example, according to ISO standard 21254, the optics are irradiated at one hundred positions. This is not possible with smaller surface areas since the measuring points influence each other, for example through thermal conduction or thermal stresses.

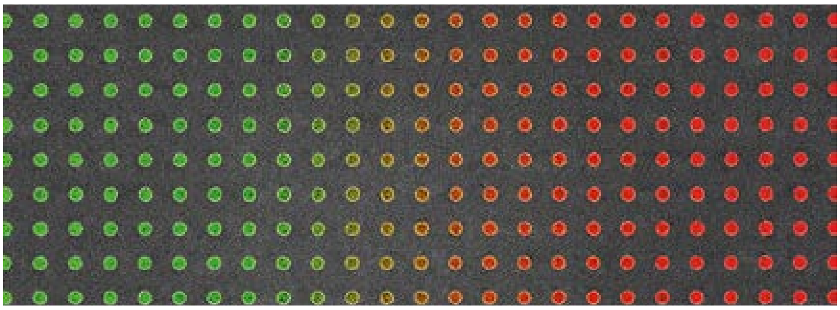
With the new measurement routine, the photonic materials group of the LZH investigates different optics and uses the results to create models to make optics even more robust in the future. In doing so, they take into account different materials, geometries, and different manufacturing processes. Laseroptik develops optics coatings of the highest destructive strength adapted to special geometries. These components are then inserted into a deflection unit manufactured by Raylase and tested by the LZH close to the application, i.e. in the finished module and with parameters similar to the later application. The aim is to develop more stable scanner modules.

www.lzh.de
www.laseroptik.de
www.raylase.de

New optical sensor detects hydrogen leaks

Many metal nanoparticles work together to detect record low levels of hydrogen

Hydrogen plays an important role in the pursuit of clean and renewable energy, but a major challenge facing this transition is that the gas is explosive when mixed with air. For this reason, it is crucial to be able to detect hydrogen leaks as early as possible. Researchers at Chalmers University of Technology, Vrije Universiteit Amsterdam and Eindhoven University of Technology, have developed an optical sensor that can detect record low levels of hydrogen.



The new sensor consists of many metal nanoparticles that work together to detect hydrogen in their surroundings. (Source: Y. Strandqvist, Chalmers U.)

The sensor that the researchers have developed is based on plasmons, which occur when metal nanoparticles capture light and give the particles a distinct color. If the nanoparticles are made of palladium or a palladium alloy, their color changes when the amount of hydrogen in the surroundings varies, and the sensor can trigger an alarm if the levels become critical. The researchers used particle swarm optimization to find the best arrangement and geometry of the particles of the particles on the surface of the sensor and achieve the highest possible sensitivity when exposed to hydrogen. Placing the particles in a very precisely defined regular pattern turned out to be the answer. Based on the AI-design, the optimized optical hydrogen sensor was fabricated and verified to be the first of its kind to optically detect hydrogen in the parts per billion range (250 ppb). The new sensor's practical applicability will now be further investigated within the TechForH2 competence center. (Source: Chalmers U.)

Reference: *F. A. A. Nugroho* et al.: Inverse designed plasmonic metasurface with parts per billion optical hydrogen detection, Nat. Commun. **13**, 5737 (2022); DOI: 10.1038/s41467-022-33466-8

https://langhammerlab.se

Lidar improves safety features in vehicles

Differentiating between static and moving objects and seeing in the dark in real time

Starting in 2022, seventeen car manufacturers announced plans to use or are currently using lidar sensors across twenty-one different models. However, there are a few things that need to be overcome: a lack of object movement distinction, high levels of noise, and trouble viewing non-moving objects that are in the vehicle's path.

Utah State University associate professor Scott Budge and his student Chaz Cornwall compared two lidar maps developed by biology-inspired processes: one with the original technology and the other adjusted to correct the issues mentioned above. Their improved lidar map was successfully able to recognize and distinguish between obstacles and detect movement without errors.

"One possible way of removing false positives is to concentrate on alerting to a possible collision based on movement," Budge said. "Another solution is to exploit the obstacle distance so that a photon is associated with a specific pixel location to estimate a collision." This essentially means that adjusting the where, what, and when of a light photon, of which lidar uses billions at once, can fix the current issues.

Source: M. Jensen, USU

Scott Budge and his graduate students

Reference: *C. B. Cornwall & S. E. Budge:* Obstacle detection using range-difference events, Opt. Eng. **62**, 031203 (2022); DOI: 10.1117/1.OE.62.3.031203

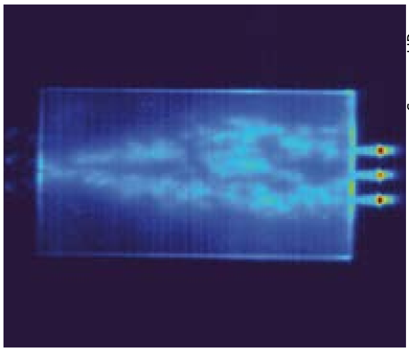
https://engineering.usu.edu/ece/faculty-sites/cail/

Lithography-free photonic chip offers high speed and accuracy

New photonic device provides programmable on-chip information processing for AI applications

Both photonics and electronics rely on lithography to define their circuit elements and connect them sequentially. Now researchers at the University of Pennsylvania have created a photonic device that provides programmable on-chip information processing without lithography, offering the speed of photonics augmented by superior accuracy and flexibility for AI applications.

Achieving unparalleled control of light, this device consists of spatially distributed optical gain and loss. Lasers cast light directly on a semiconductor wafer, without the need for defined lithographic pathways. Liang Feng, Tianwei Wu, Zihe Gao and Marco Menarini developed the new microchip. Without lithography, these chips become adaptable data-processing powerhouses. Because patterns are not pre-defined and etched in, the device is intrinsically free of defects. Perhaps more impressively, the lack of lithography renders the microchip impressively reprogrammable, able to tailor its laser-cast patterns for optimal performance, be the task simple – few inputs, small datasets – or complex – many inputs, large datasets. In other words, the intricacy or minimalism of the device is a sort of living thing, adaptable in ways no etched microchip could be.



Source: UPenn

Reference: *T. Wu* et al.: Lithography-free reconfigurable integrated photonic processor, Nat. Photon., online 27 April 2023; DOI: 10.1038/s41566-023-01205-0

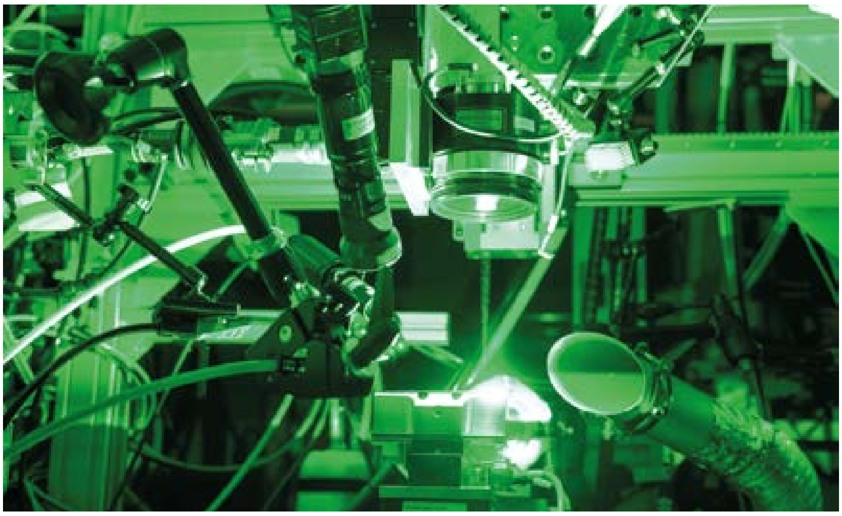
https://fenglab.seas.upenn.edu

Manufacturing is more sustainable with green lasers

Most detailed of insights into laser welding processes to date thanks to a particle accelerator

Lots of raw material can be saved during the welding of high-performance electronics. This is the result of an investigation at the German Electron Synchrotron DESY of the Helmholtz Association in Hamburg. Trumpf, Fraunhofer ILT, DESY and the Helmholtz Center Hereon each contributed their highly specialized knowledge of x-rays, laser sources and welding processes. As a result, insights that remain invisible to the eye and even to microscopes have now been achieved for the first time. The result: when a laser with a green wavelength is used, far fewer rejects are produced than with other laser welding processes. Car manufacturers save raw material and contribute to more sustainable manufacturing.

"We wanted to use the investigations at the particle accelerator to find out exactly what makes the difference in copper welding. A stable welding process is important because manufacturers of electric vehicles have to weld several billion connections of the highest quality," says Marc Hummel, a scientist at Fraunhofer ILT. In the future, Trumpf and the Fraunhofer ILT plan to expand research to other areas such as 3D printing, laser cutting and laser drilling with ultrashort pulse lasers, and to bring other industry partners on board.



Trumpf and the Fraunhofer ILT investigated the laser welding of copper connections by using a particle accelerator (Source: Trumpf)

Copper absorbs green or blue wavelengths much better than the infrared. Because the material reaches its melting temperature more quickly, the welding process also starts faster and less laser power is required. "More stable processes when welding mean fewer rejects and greater sustainability, which is a major issue in e-mobility," said Mauritz Möller, automotive industry manager at Trumpf.

To study welding processes in detail, experts from the Fraunhofer ILT, in collaboration with the laser technology group at RWTH Aachen University, used the Petra III X-ray light source on the experimental setup at the Helmholtz Center Hereon using two different laser systems: an NIR laser and a laser with a green wavelength. "This is a great opportunity for us to study welding processes on industrial parts. For example, how do spatters and pores form, and how does the heat from the welding process affect sensitive components such as electronic parts," said Möller.

www.trumpf.com
www.ilt.fraunhofer.de

Easier production of photonic MEMS

New approach could enable more efficient fiber-optical telecommunications and quantum computers

A team of researchers led by Niels Quack, University of Sydney, has developed a new technology to combine optics and microelectro-mechanical systems (MEMS) in a microchip, paving the way for the creation of devices like micro-3D cameras and gas sensors for precision air quality measurement, and their use in mobile phones. The new fabrication process builds on silicon photonics and uses semiconductor manufacturing techniques to enable a new, more energy-efficient generation of devices for fiber-optical communications, sensors and even quantum computers.

Quack said that the photonic MEMS are unique in that they are compact, consume very little power, are fast, support a broad range of optical carrier signals and have low optical loss. "This is the first time that nano-electro-mechanical actuators have been integrated in a standard silicon photonics technology platform," Quack said. "It is an important step towards mature large-scale, reliable photonic circuits with integrated MEMS. This technology is being prepared for high-volume production, with potential applications in 3D imaging for autonomous vehicles or new photonic assisted computing."

"Current similar technologies consume a lot of power and occupy a large area on-chip. They also have high optical losses. This makes the integration of a large number of components on a single chip challenging," he said. "Our silicon photonic MEMS technology overcomes these shortcomings, providing a route for efficient scaling of photonic integrated circuits. The technology will advance knowledge in the field of micro and nanofabrication, photonics and semiconductors, with a wide range of applications. These include beam steering for lidar 3D sensing in autonomous vehicles, programmable photonic chips, or information processing in quantum photonics." (Source: U. Sydney)

Reference: *N. Quack* et al.: Integrated silicon photonic MEMS, Microsyst. Nanoeng. **9**, 27 (2023); DOI: 10.1038/s41378-023-00498-z

www.sydney.edu.au

Scraping the skies

Tall buildings should follow an environmental approach, such as a climate adaptive envelope, potentially saving 30 % of energy

Sky-Walls is a technology company that has developed a module that can be added to the glass envelope of a building to make it more sustainable. The module works like a climate-adaptive skin, similar to the way a human body adapts to the environment, and can save almost a third of a building's energy consumption. The module is designed to be added to an existing curtain wall panel and includes built-in temperature sensors and solar radiation detectors that can be used to monitor the building and control its air conditioning.

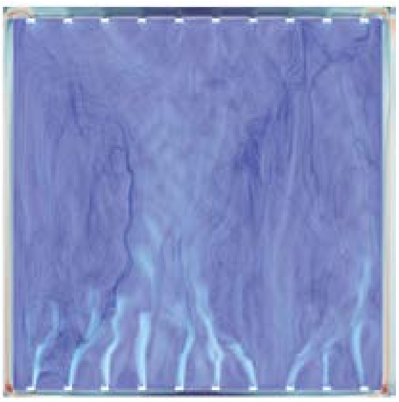
Glass buildings present a unique challenge with conflicting demands of high visibility and insulation. Transparency allows for sunlight to enter the building, but insulation prevents heat from escaping through the same windows, leading to a greenhouse effect and high energy consumption for air conditioning. Architects and engineers are calling for a ban on all-glass skyscrapers. However, this new autonomous technology offers a solution by adapting the insulation value (U-value) and solar heat gain coefficient (SHGC) through a simple yet effective method.

Typical window arrangement with active heat transfer control and adjustable U-value for a climate adaptive building envelope. The module mounted on top of the curtain wall or window is hermetically connected to the window's cavity, and air circulating fans draw their energy from built-in solar panels.

Traditionally, glass-fronted offices and high-rise buildings are designed with a lot of natural light and great views, which is why they are so popular. However, their curtain walls, usually based on a hermetic double-glazing design, can create a greenhouse effect, resulting in high energy consumption and an increased carbon footprint. Triple-glazing design is becoming more popular, but it only offers a partial solution. Once installed, these curtain walls are passive and do not offer any adaptation to changing climate conditions.

A new photonics-based technology for buildings uses an autonomous hermetically sealed curtain wall panel that replaces existing technology. The panels are driven by AI and can adapt their heat management characteristics to the building's needs by controlling solar harvesting and continuously changing their insulation characteristics. The system is differential, with each panel being independent, and inputs to the AI system are done via Wi-Fi using common protocols such as Apple Siri, Google Now, Microsoft Cortana, etc.

To reduce the temperature during summer and raise the inside temperature during winter, the new technology utilizes a double-glazing façade, which includes built-in solar-powered fans that circulate the hermetically sealed insulation air to create a thermal short circuit-like effect, increasing the heat transfer between the environment and the interior. In its passive mode, it provides a high insulation value (U-value) that surpasses current technology. It also controls the solar heat gain coefficient to better manage the building's solar energy. For non-visible areas, built-in PV panels harvest electricity and heat at the same time.

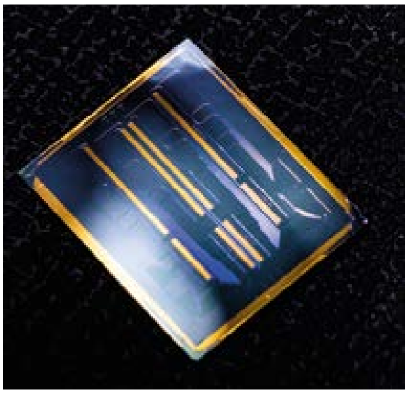


The module's hermetically sealed inner wherein the circulating air significantly changes the U-value of the curtain wall panel (Buildwind simulation)

www.sky-walls.com

Lithium niobate as a platform material in photonics

Artificial crystals could overtake silicon chips in light-based technologies



Source: RMIT U

This chip is the size of a fingernail, is made on thin film lithium niobate and can be used in telecommunications.

Super-thin chips made from lithium niobate are set to overtake silicon chips in light-based technologies, according to leading scientists in the field, with potential applications ranging from remote ripening-fruit detection on Earth to navigation on the Moon. They say the artificial crystal offers the platform of choice for these technologies due to its superior performance and recent advances in manufacturing capabilities. Arnan Mitchell from the RMIT University and Andy Boes from the University of Adelaide led a global team to review lithium niobate's capabilities and potential applications.

The team, including scientists from Peking University and Harvard University, is working with industry to make navigation systems that are planned to help rovers drive on the Moon later this decade. As it is impossible to use global positioning system (GPS) technology on the Moon, navigation systems in lunar rovers will need to use an alternative system, which is where the team's innovation comes in. By detecting tiny changes in laser light, the lithium-niobate chip can be used to measure movement without needing external signals.

"This artificial crystal is being used to develop a range of exciting applications. And competition to harness the potential of this versatile technology is heating up," said Mitchell, director of the Integrated Photonics and Applications Center. "Our lithium niobate chip technology is also versatile enough to be rapidly adapted to almost any application that uses light," Mitchell said. "We are focused on navigation now, but the same technology could also be used to link Internet on the Moon to the Internet on Earth."

The team is working with the Australian company Advanced Navigation to create optical gyroscopes, where laser light is launched in both clockwise and anticlockwise directions in a coil of fiber, Mitchell said. "As the coil is moved the fibre is slightly shorter in one direction than the other, according to the theory of relativity," he said. "Our photonic chips are sensitive enough to measure this tiny difference and use it to determine how the coil is moving. If you can keep track of your movements, then you know where you are relative to where you started. This is called inertial navigation."

This technology can also be used to remotely detect the ripeness of fruit. "Gas emitted by ripe fruit is absorbed by light in the mid-infrared part of the spectrum," Mitchell said. "A drone hovering in an orchard would transmit light to another which would sense the degree to which the light is absorbed and when fruit is ready for harvesting. Our microchip technology is much smaller, cheaper and more accurate than current technology and can be used with very small drones that won't damage fruit trees."

Reference: *A. Boes* et al.: Lithium niobate photonics: Unlocking the electromagnetic spectrum, Science **379**, abj4396 (2023); DOI: 10.1126/science.abj4396

www.rmit.edu.au

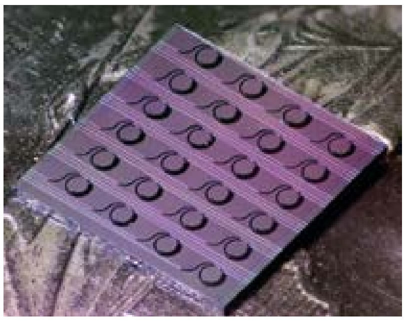
New platform for tunable lasers

Combination of lithium niobate with silicon nitride for a new type of hybrid integrated lasers

Scientists at EPFL and IBM have developed a new type of laser based on lithium niobate that could have a significant impact on optical ranging technology. Lithium niobate is particularly useful because it can handle a lot of optical power and has a high Pockels coefficient – it can change its optical properties when an electric field is applied to it.

The researchers achieved their result by combining lithium niobate with silicon nitride, which allowed them to produce a new type of hybrid integrated tunable laser. To do this, the team manufactured photonic integrated circuits based on silicon nitride at EPFL, and then bonded them with lithium niobate wafers at IBM. The approach produced a laser with low frequency noise and simultaneously with fast wavelength tuning – both great qualities for a laser used in light detection and ranging (lidar) applications. Then they performed an optical ranging experiment where they used the laser to measure distances with high precision.

Beyond integrated lasers, the hybrid platform has the potential to realize integrated transceivers for telecommunications as well as microwave-optical transducers for use in quantum computing. "What is remarkable about the result is that the laser simultaneously provides low phase noise and fast petahertz-per-second tuning, something that has never before been achieved with such a chip-scale integrated laser," says Tobias Kippenberg, who led the EPFL side of the project. (Source: EPFL)



Source: G. Likhachev, EPFL

PIC based on silicon nitride, bonded on a lithium niobate wafers.

Reference: *V. Snigirev* et al.: Ultrafast tunable lasers using lithium niobate integrated photonics, Nature **615**, 411 (2023); DOI: 10.1038/s41586-023-05724-2

www.epfl.ch/research/domains/quantum-center/
www.zurich.ibm.com/brnc/

"Making lives easier for integrators …"

Emmanuel Hannart, CEO of Acqiris talks to EPIC's Ivan Nikitski

The Swiss developer of high quality, high-speed signal acquisition products, reveals his secrets in a conversation with EPIC's technology manager for quantum and PICs.

Source: Acqiris

What is the background to your appointment as CEO of Acqiris?
I started my career with Digital Equipment Corporation, a US company that at that time was a co-leader with IBM in the electronics market. In 1981, I moved to Schneider Electric to the financial control and sales departments, and later worked as an R&D project manager and quality manager. Then in 2001, Schneider acquired Positec, the automation technology division of Switzerland's SIG Schweitz Industrie Holding. I was asked to go to Switzerland to close Selectron, its PLC company. Instead of closing it, together with the employees we created a spin-off with a new business model leading to rentable growth. Selectron Systems AG became a specialist in control, network and communications technology for the rail rolling stock industry. I stayed at Selectron as their CEO until 2017 when the company was merged with Knorr-Bremse. I became CEO at LBO Consult Swiss SA, consultants on business acquisition and restructuring operations.

At that time, I became involved with Acqiris SA, a Swiss company developing high-speed signal acquisition products. The company was founded in 1998, and joined Agilent in 2006. In 2017, Agilent decided to sell the company as they considered it would be cheaper to buy the technology from outside rather than to continue developing and manufacturing it in-house. As no buyers came forward, I helped to organize an employee buyout. In 2019, as the company was struggling, I took the lead and became CEO.

What were the best learning experiences in your career?
One of the qualities of the Swiss technical education system is an emphasis on collective rather than individual problem solving, and my management philosophy has always been to listen to the ideas of employees and customers and, wherever appropriate, to adopt a collaborative approach to decision-making. For me, the key aspect of managing a company is the people – on the side of both customer and the side of the company – so my most valuable learning experiences have been about how to manage and motivate people, how to build teams that have a good understanding of the market and the customers. Of course, technology is important but it is not key because it can always be bought. The crucial thing is to organize people so that they do what the market expects and design devices that are easy to implement and manufacture with consistent quality. Functionality required by the customer requires adaptation or tailoring of our products; our product cannot then be substituted by that of another supplier. It has to run one hundred percent of the time, and be easy to replace in case of default. These are the key aspects and it is very important to organize the company in such a way that the solutions provided are efficient and adequate.

What are your main products and application fields?
We provide a range of signal acquisition devices that enable the fast acquisition of analog signals and conversion into digital signals with excellent signal fidelity across a wide bandwidth. The ability to analyze analog signals in a very detailed and fine-tuned way and capture that information on electronics is essential for reading and understanding microelements in many application fields. For example, time-of-flight mass spectrometry can be used for metabolite identification, peptide analysis and drug discovery, while swept-source optical coherence tomography is a high-speed imaging technique for retinal angiography. Similarly, distributed strain and temperature sensing is used for environmental, industrial, and

structural monitoring, and lidar is crucial for autonomous vehicles.

How is the company structured?
We are a small company with a workforce of 25 and an annual turnover of ten million euros – well balanced between China, Japan, North America and Europe. Our headquarters are in Geneva, but we have technical teams in the US, Europe, Japan and China to support our customers with the implementation or integration of our devices into their systems and to help whenever difficulties arise. The company is organized in three departments: sales and marketing, applications and development, and operations, which is responsible from when orders arrive to when we receive payment. We do not have separate quality, HR or finance departments because I consider that responsibility for these functions should rest on the shoulders of the managers of the three main departments.

A major difference between Acquiris and other companies in the sector is that most of the employees are shareholders. This means that as CEO I have to communicate about the company's financial performance in great detail and that I allocate enough time to understand how the people want to grow, in which direction and what they expect for the future.

How do you see the future?
Currently, our two most important markets are time-of-flight mass spectrometry and swept-source optical coherence tomography. Although they use similar knowledge and technology, the time of flight market has just a few large players while optical coherence tomography has smaller players and wider areas of application. Our aim is to address complementary markets to these two areas. If we find that our products are too sophisticated in one area, we will try to rebuild or design products to make them more compatible with the sole functionality needed by these customers.

Another interesting market for us is AI, which will have application possibilities in the various markets we are in. More specifically, as our products focus on capturing information and digesting or tracking it, we have the ability to add some value that will enable the machine to react quicker to various elements. However, while the speed of reaction is an important factor, sometimes the quality of the image on the screen is more significant, so it will depend on the application.

As regards the technology, the prime factor for the future development of our products is not so much miniaturization but the software and firmware tools to make life easier for integrators and our OEM customers. Making their lives easier will make them more successful and bring more business for us.
Ultimately, our strategy, especially with our key customers, is to build enough intimacy to ensure we understand where their integration challenges are and what functionality could bring them competitive advantages. Our target is thereby to develop and co-manage an innovation process.

What is your advice for the next generation of entrepreneurs?
Firstly, you obviously need the right human qualities to be a good CEO, but it is also very important to have some cross-departmental experience of a company. As everything is so complex, learning on paper is not enough and the only way to learn is by doing. For this reason, try to accept some sideways moves when you are in your thirties or forties. In this way, you can experience new challenges and new learning opportunities and gain valuable experience in two or three pillars of the company i.e., engineering, production, and sales and marketing.

Secondly, try to enjoy and cherish every moment in life and continually search to improve your education so you can be a better person and be able to help and inspire others; as Mahatma Gandhi once said: "Live as if you were to die tomorrow, learn as if you were to live forever."

*

Author: Dr Ivan Nikitski, European Photonics Industry Consortium, Rue Hamelin 17, Paris, France; e-mail: ivan.nikitski@epic-assoc.com, Web: www.epic-assoc.com, in inikitski

Phabulous developments in European micro-optics

Interview with Jessica van Heck and Ton Offermans from the European pilot line

Source: Phabulous

Jessica van Heck, managing director, and Ton Offermans, technical coordinator of the European pilot-line association Phabulous which is providing highly advanced and robust manufacturing technology for optical free-form microstructures, talk to EPIC photonics technologies program manager Jérémy Picot-Clémente.

▲ Use case samples – top left: double-sided FMLA replicas produced by Nanocomp for the Hella use case. Bottom Left: Smart glasses from Microoled featuring Advanced FMLAs designed by Phabulous partners. Top right: unmirrored foil with backlight for Swarovksi.

What is Phabulous and what are your roles within the free-form micro-optics industry?

Jessica: Phabulous is a pilot line association for the manufacturing of free-form micro-optics. We work with Europe's leading RTOs and industrial companies as a single service provider. This means we have one NDA covering all the members and we offer single or multiple services through a single contract. As a result, companies can now get access to design services, origination, tooling, replication and even integration, all through a single-entry point with a single contract executed by leading micro-optics companies. As managing director of Phabulous, my main role is to make all of this easily accessible for customers. I am the initial point of contact and coordinate the entire process.

Ton: Once the NDA is signed, I take over the discussions with the customers in my role as technical coordinator of Phabulous to understand their technical needs and specifications. Based on that, I propose the right partners for the technical team, and lead the discussions on potential solutions to prepare an offer that best matches the needs of the customer.

How does Phabulous work with other companies and organizations in the micro-optics industry to drive innovation and create new products?

Jessica: At the core, we have our members with whom we are able to execute a full range of services. We have several partners who can provide support in the design phase, making sure that any design and/or prototype is always suitable for upscaling to large volume production. Then we have several originators who can offer at least seven different origination technologies, so we can always make sure we find the right origination that fits the application requirements. We also offer tooling to upscale a master for replication, from tools for wafer-scale replication to large drums used for roll-to-roll replication. One of Phabulous' strengths is UV imprint technologies – at not only wafer-scale, but also roll-to-plate and roll-to-roll – and we even have partners that can offer compression injection molding or hot embossing. Many of these partners can also tweak their recipes, providing more flexibility in finding the right material for a specific application. Once the optics are produced, we also have partners that can help with coatings and ultimately with the integration of the optics in systems.

On occasions, customers require technology that is not yet inside of the association, and in these cases, we work with other partners in the ecosystem. We can choose to include their services in our offering or, if it is an individual service, we are more than happy to bring them into contact with the customer directly. In this way, we have created an ecosystem for micro-optics that comprises all our members together with other European-based companies that offer services in the field of micro-optics. Filters are available to search for offerings based on the technology pillar, the market, or position in the value chain. Our aim is to create a strong European ecosystem that makes free-form micro-optics easily accessible.

What are some of the most exciting or impactful uses of micro-optics, and how do you see the future of the technology?

Jessica: The type of impact differs from market to market, but the two main key words are miniaturization and efficiency. A major thing at the moment is energy, and more specifically energy reduction. Micro-optics can increase the efficiency of solar panels by capturing more sunlight and making light fixtures more efficient by using less LEDs, not only saving on materials but also on energy consumption. In fact, one of the core objectives of one of our use cases is the production of large luminaires for the transportation sector – making them smaller with fewer LEDs but still having an attractive and uniform light distribution. This is a perfect example of where we will see a bigger impact of free-form micro-optics in future: improving the efficiency and light distribution of lighting systems. We will also see an increasing role for free-form micro-optics in the consumer market.

Jessica van Heck Ton Offermans

You can replace several lenses of your smartphone's camera module with a free-form optic that has similar or even improved functionality.

Ton: Display performance can be similarly enhanced, and we know that the AR/VR markets will boom in the near future. In fact, we have been working with several companies on these kinds of applications, involving free form micro-lens arrays that enable smaller VR headsets while maintaining or even improving the resolution and field of view for example. Similarly, with AR applications like smart glasses, we have already gained experience working with a company looking at using free-form micro-optics to enhance the brightness of the display. Of course, these kinds of solutions must have a small form factor to be accepted in the consumer market, and that is exactly where free-form micro-optics can play a significant role. Another impactful use is in life sciences. For example, the efficiency of certain biosensors can be significantly improved with a micro-optical structure, and we are currently in discussion with a customer who wants to produce such biosensors with an advanced optical structure in larger numbers.

What are some of the key advancements that Phabulous has achieved in micro-optics?

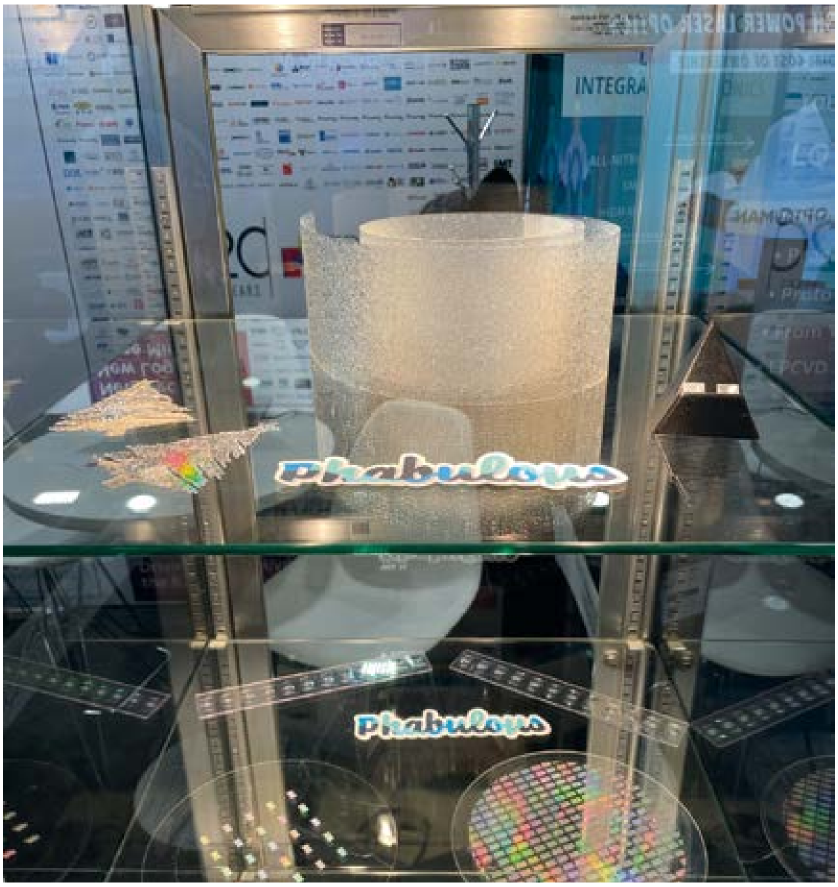
Ton: The ability to create optics in any shape without any symmetry constraints and miniaturizing them to the micro-scale has opened up many new possibilities for revolutionary micro-optics products. The market is becoming aware of this, and the number of papers published and technology patents requested is growing exponentially. One of the main reasons we created Phabulous was to help to bring these revolutionary ideas to market. Technology-wise, Phabulous has made significant improvements in the processes for origination, replication and integration. The work for our initial use case partners is now resulting in the first sets of demonstrators of these technologies. In addition, Phabulous has developed design-for-manufacturing software tools to facilitate the analysis of complex free-form designs, and to evaluate the performance of fabricated structures by means of optical simulations rather than functional testing, resulting in an acceleration of the development phase.

What are some of the challenges that Phabulous has faced and how you have addressed them?

Jessica: One of the challenges of using UV imprint technology is general shrinkage of the material during the UV curing process. By working together and learning from each other's processes, especially between designers, originators and replicators, we have acquired a lot of knowledge on how to compensate for that early on in the design phase. We have also developed tools that can help to identify constraints in the design that could cause issues during the manufacturing process. With this collective approach, we have gained a better understanding of each other's processes and limitations, and been able to limit the number of iterations needed to develop the right optic for a particular application.

How does Phabulous balance the need for precision and accuracy in micro-optics with the demands of mass production and cost-effectiveness?

Jessica: The first question we need to ask is: how much precision and accuracy is really needed for a particular application? Yes, there is a trade-off: wafer-scale replication, although already a mass production method, is of course nowhere near as fast or cost-effective as a roll-to-roll process for instance. On the other hand, alignment precision in a roll-to-



Source: Phabulous

Top: roll of mirror paper and mirror paper cut in the shape of a Christmas tree. Bottom: UV printing replication wafers.

roll process is also not nearly as accurate as a wafer-scale process. The trick is to find the right technology that fits the requirements of the application. We are working with customers that want to move their process from a wafer-scale process to a roll-to-plate process while still maintaining the specification range required for the application. That means a significant reduction of cost in the production process. In general, each manufacturing process – whether it is a choice between a wafer-scale, roll-to-plate or roll-to-roll process or a choice between injection molding, hot embossing or UV imprint replication – has its own specific capabilities and its own limitations. One of the unique assets of Phabulous is that our knowledge and understanding of all these different processes enable us to help customers select the right one that fits their application best.

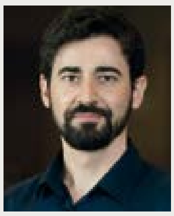
What role do you see Phabulous playing in shaping the future of the micro-optics industry in Europe and beyond?

Jessica: Micro-optics are already manufactured and used in volume around the globe. The main role of Phabulous will be in those never-before manufactured micro-optics, i.e., those micro-optics that will revolutionize markets. It is these kinds of optics that we want to work on together with the members of the association. We work with some amazing companies that all have a deep specialization in either a technology, an application, or both, and it is here where we can really bring value to customers. How many times have companies created one prototype after the other until they find the one that functions, but then it turns out that it cannot be manufactured in volume? To address this, we have RTOs with comprehensive knowledge and understanding of the processes of the big industrial companies, so they know what to take into account in the early stages of development in order to be able to scale up in the future. This is our strength, and this is what will allow us to shape the future of micro-optics manufacturing in Europe and beyond.

Finally, what is your message for companies wanting to develop new products based on free-form micro-optics?

Jessica: If you are a European company, then come forward now and contact Phabulous because we have an open call running with three million euros available for European companies looking to implement free-form micro-optics. The funding rate is up to ninety percent, depending on company size, and it is the perfect opportunity to try to create that special component that will make the difference between you and your competitors. Funding is available for the entire value chain, from design support and origination to replication to integration, either for an individual service or for the entire production chain. So please be sure to contact us to take advantage, because although the available technologies are cost-effective, the initial investment in creating the tools, for instance, can be significant. This funding can make a huge difference both in the initial outlay, and also for future production cycles. And to the large enterprises or those located in other areas of the world, I would like to say that Phabulous is the place to come to benefit from the expertise of leading companies in their field. If you have ever heard that it is difficult, hard or even impossible, then I urge you to contact Phabulous because we would love to take a look at your ideas and show you what we are capable of. As we say, we are Phabulous!

Author



Jérémy Picot-Clémente is a physicist specialized in optics and a program manager at the European Photonics Industry Consortium (EPIC). After a PhD in physics/optics and an MBA, he decided to explore the industry for several years through various missions in managing photonics systems integration, for several applications and in different companies. At EPIC, Jeremy is in charge of the development of the optics and micro-optics fields, and all related technology and applications. He has a strong interest in new technology involving photonics, such as AR/VR, lidar, 3D sensing and imaging devices.

Dr. Jérémy Picot-Clémente, EPIC – European Photonics Consortium Industry, 17 Rue Hamelin, Paris, France; e-mail: jeremy.picot-clemente@epic-assoc.com, Web: www.epic-assoc.com in jeremy-picotclemente

Innovating for success

Quantum Effects Award 2023

The presentation of the Quantum Effects Award 2023 will be one of the highlights during Quantum Effects, Trade Fair and Conference for Quantum Technologies, which will be held in Stuttgart on 10 and 11 October 2023. The Award recognizes outstanding innovations that connect the classical and quantum worlds, are used in different industries, enable individual services and open up new perspectives. This also applies to components that significantly advance quantum technologies and solutions.

Start-ups, established companies and research institutions can submit ideas and solutions from the quantum mechanical field of sensor technology, communication, computing and security. Partial solutions from the quantum mechanical field of sensor technology, communication, computing and security are eligible to participate. Registration is available online at quantum-effects.com/award

Four award categories

- Quantum computing hardware
- Quantum computing software & algorithms
- Quantum sensors
- Quantum communication

Entries must also have a Technology-Ready-Level (TRL) of at least 5 or higher, as well as a significant degree of innovation and clear future potential or already be used in initial solutions. The publication or market launch should not have taken place more than three years ago.

The evaluation will be made by a top-class jury of experts in the field of quantum technologies and other partners on the basis of the written and visualized entries.

Each submission should not exceed a five-page short presentation or a five-minute video clip and must be entered until July 16th 2023 and will be evaluated according to the criteria:

Application prospects and potential (25 %):

- Applicability and potential impacts
- Improvement potential compared with current technologies
- Extent of new functionalities
- Solution to well-known problems through innovative approaches
- Social/technological benefits

Degree of innovation / invention level (30 %):

- Improvement compared with conventional technologies
- Differentiation compared with the current state of the art

Solution approach and feasibility (30 %):

- Originality of the application
- Selected approach
- Can be implemented in a realistic period of time (< 5 years)
- Probability of success/participating partners/teams/networks
- Hybrid solutions / software solutions for earlier use

Cooperation / teaming (15 %):

- Cooperation between research and industry (manufacturers, suppliers, users)

Close cooperation and a high level of networking will have a positive effect on the judging.

All submitted competition entries will be presented during Quantum Effects at Messe Stuttgart on 10 and 11 October 2023. The award ceremony will take place as one of the highlights of Quantum Effects on the first day of the trade fair (10 October).

There is no right of appeal. Participation in the competition is free of charge. Detailed information, conditions of participation and the online application form are available at quantum-effects.com/award

About Quantum Effects

Quantum Effects, a trade fair and conference for quantum technologies, will take place for the first time on 10 and 11 October 2023 at Messe Stuttgart. It is intended to support the development of a European ecosystem and build a bridge between science, start-ups and industry. The first edition will focus on four pillars in this area: Computing & Enabling Technologies, Software, Sensor Technology, and Communication.

The State of Baden-Württemberg's Ministry of Economics, Labor and Tourism has taken over the patronage of Quantum Effects, PhotonicsViews is media partner.

www.quantum-effects.com

"We find new applications every week"

An interview with Michael Förtsch, the founder and CEO of Qant

Maike Pfalz

Source: Qant

The physicist Michael Förtsch founded the high-tech startup Qant out of the Trumpf Group in 2018 to develop novel sensors and photonic computer chips. The company uses light as the fundamental resource to realize the potential of quantum technology. Qant now has almost eighty employees at its Stuttgart location.

What are you working on at Qant?
Our company name is an acronym and stands for "we are revolutionizing the Quality of how machines Analyze the environment, how people Notice information, and the way humans Think."

If we want to make use of all the advantages of quantum computers, we first of all have to consider how we are going to apply quantum technology in the most profitable way. If we were to calculate something on a normal computer today and on a quantum computer tomorrow, we would miss a lot of potential.

What do you do differently to other companies?
Together with our partners and customers, we want to improve our understanding of what quantum technology is capable of and how we can apply it most profitably. That is our basic philosophy.

What products are you working on?
We have four product lines that we are developing and industrializing. The first has to do with particle metrology. This can detect the smallest particles with a size from 500 nanometers up to some hundreds of micrometers. Our quantum sensors enable us to determine the size, direction, speed and shape of the particles during the same measurement.

Is there already an application for this?
We are developing a sensor together with Festo to measure the shape of algae in real time. Our particle sensor is the first worldwide that provides a direct feedback on how lively the algae are in a bioreactor.

How do you do that?
Our sensor recognizes the shape of the

algae and can thereby identify how many of the algae are currently dividing. The more that are dividing, the more productive the bioreactor is. That was previously only possible under the microscope or in offline measurements. The applications for the particle sensor range from the measurement of coffee powder to bioreactors, or from the cosmetic to the chemical industries. We find new applications almost every week that even surprise us.

What is your second product line?
That is magnetic field sensors, working at room temperatur and normal environmental conditions outside of a lab. They make extremely weak magnetic fields visible, such as those produced by human muscles, to make it possible to control a prosthetic limb for example. Our sensor is not invasive and provides the signals that allow our partners to develop a control system for prosthetics. Our third product line concerns atomic-level gyroscopes.

And what are these?
In general, the larger a gyroscope is, the more accurate it is. A gyroscope on the ISS can be quite big, in a mobile phone very small, and if you compare the precision of them both, the gyroscope in the mobile phone is of course less precise.

But you do it differently?
Our technology makes it possible to manufacture gyroscopes with our technology that are as small as a MEMS-based rotational sensor – but with the precision of an aircraft gyroscope.
And what are the applications for this?
For example, the attitude stabilization of small satellites, the cubesats. These are economic systems to form a satellite network in orbit in their thousands. We are currently working on a publicly funded project that has planned its rocket launch in 2027. We have already largely qualified the components of the gyroscope, and now we have to make them smaller and integrate them into the system.

What is last the product range?
That is photonic quantum computing. We use lithium niobate for this, apply a thin film on silicon and structure it lithographically. Our technology allows us to create very fine structures that are optimized for photonic applications. All the objects that we need for a photonic chip can thus be etched into the thin film.

That sounds like a very broad product range for such a young startup …
All our developments follow the same logic: we are always building an electron-to-electron converter. At the start of every system, I convert electrical current into photons or light, and at the end, I convert the modified light – the photonic qubits – back into current, i.e. into data or information. This common technological foundation we call our 'quantum photonics framework'.

What is special about Qant?

Michael Förtsch did his doctorate at the Max-Planck Institute for the Science of Light in Erlangen and was later appointed as an advisor to the company management and personal advisor of the CTO of Trumpf GmbH. In 2018, he founded the Qant company that he has led as CEO since then.

On the one hand we have built up a whole community of trusted partners with whom we work because we cannot do everything ourselves. But when we identify a technology as essential for us, then we develop it ourselves from scratch.

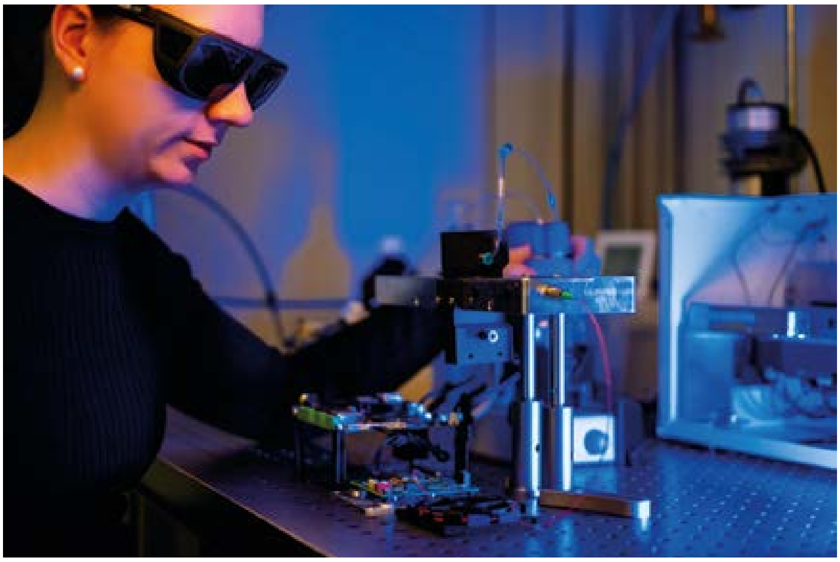
Could you give us an example?
We purchase silicon and lithium niobate wafers for quantum computing, but then our part of the value chain begins. Only when we thoroughly understand something from its basic idea we have the possibility to build something revolutionary new.

How was the company founded?
The story is rather unusual. I was working as inhouse consultant when I started at Trumpf. At some point, Peter Leibinger, the vice-chairman of the board, asked me if I would like to be his advisor. He gave me the job of finding out what benefits quantum technology would have for Trumpf. Some time later I received a memo back from him with the comment that I should set up my own startup and he would invest in it.

But why was that necessary?
There was no overlap between our research and the core technology of Trumpf, the high-power lasers. The second aspect is that we can work much more freely in a startup.

In what way?
When you form a startup, it is like open-

A 'Qantie' presenting a photonic chip



The company's potential new employees – so-called 'Quanties' – are also selected by serving employees.

ing an office door and finding just a carpet on the floor. It was exactly the same for us. Our first purchases were desks and laptops; the next step was setting up the company's email address. After that, we negotiated with the university to be able to use a laboratory there. Even if you start with your sleeves rolled up as we did, it is quicker than getting going within a large company with its established business processes.

With which idea did you initially start?
We started with two ideas, namely thin-layer lithium niobate technology and the particle sensors. For the first of these, we were not initially concerned with quantum computing; we have only been following up that idea since 2020. The other two product lines developed in 2019 from our first discoveries.

Were there other companies that are researching similar things?
There are companies that manufacture laser-based particle sensors, but apart from us, nobody uses superposition states for this. We have patented this process in the meantime.

What are the benefits of superposition statuses?
The current methods to date are only able to determine the size of a particle after it has crossed a laser beam. Contamination though can spoil the results. We create a large number of superposition statuses in the laser beam whose arrangement we know exactly. A particle in such a laser beam temporarily disturbes these conditions, and from that we know exactly when a particle was at a specific location and what contour it has.

Do others work with thin-film lithium niobate?
There have been scientific groups that have worked on this but nobody had recognized the industrial potential of this material to date. We quickly started to make photonic integrated circuits out of it, PICs in short. If we think about the future world of photonics, we must get rid of lenses and bondings and build fully integrated monolithic systems instead. Lithium niobate is ideal for this.

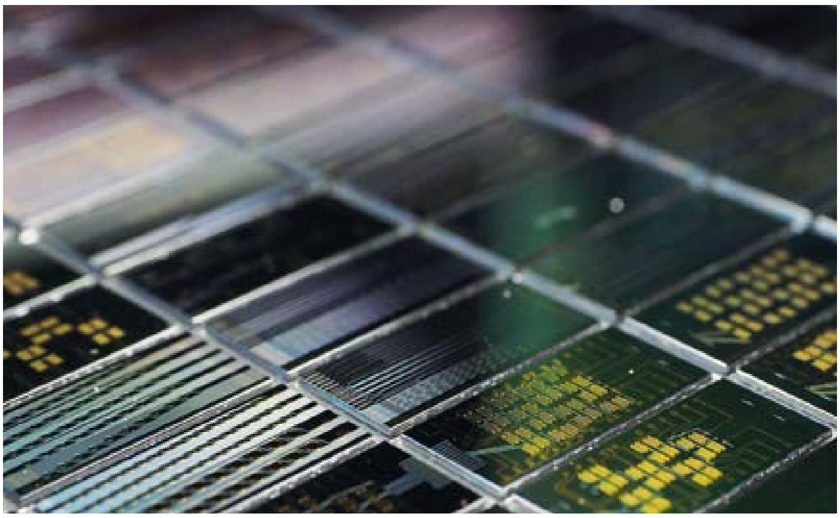
What does Qant contribute to Quantum Technology 2.0?
We want to be the first to commercialize quantum sensors in the field of particle and magnetic field sensors and gyroscopes. In photonic quantum computing, we strive to make relevant everyday problems solvable.

Do you think photonic quantum computing will be successful here?
I believe that we will have ion-based, superconducting, spin-based and photonic quantum computers in parallel for quite some time. Each system has its niche and particular advantages. One cannot yet say if there will be a consolidation within these platforms because we still do not understand enough about the algorithms.

What do we need to bring quantum sensors to commercialization?
In particle sensing we have an evaluation kit available. The magnetic field sensor has been introduced at Hanover Fair. So commercialization has already begun. With the atomic gyroscopes, there still is a little engineering missing.

And this is?
It always apears when I miniaturize a system. For example, there is lots of space in larger systems for a fan and thermal dissipation. We now have to fit these components into a significantly smaller space while maintaining their performance.

But is this extreme miniaturization necessary?
As a rule of thumb, the smaller the sensor, the larger the market. While we could perhaps sell a few thousand systems that are as large as half a packet of milk, it would be millions for a system the size of a fingernail. That is the chal-



Photonic quantum computer chips are among Qant's products that are built on the basis of thin-film lithium niobate.

lenge of commercialization: how small does a system have to be in order to reach a significant market penetration?

In which branches of quantum technology do you expect the greatest breakthroughs over the coming years?
Subjectively, I expect the most progress in magnetic field sensors. I believe it is realistic that we can shrink them to the size of a matchbox within five years.

What about photonic quantum computing?
Our target must be to demonstrate a speed advantage for an everyday task within the next five years. Then we would have enough evidence to show that these systems can be developed into viable products. If we do not manage that, then we must question this type of technology in general.

Where do you want to see Qant at the end of the decade?
We have reached our break even by then to finance our research and development from our own cash flow. This means that we are selling our sensors from series production. We should have the first photonic quantum computing systems that deliver a real benefit to our customers in the form of additional computing power.

What aspects are still unresolved?
There will continue to be numerous exciting research and development in all four areas of quantum technology – that is, sensors, cryptography, communication and computing – in particular with quantum computing. However, it will be one or two decades until we have reached the professionalization that the semiconductor industry enjoys today.

For what reason?
Hardware development cycles cannot be accelerated: at the start there is an idea, then you have to build a system and test it, learn from this and build and test the next system on this basis. The semiconductor industry was also not slow, but it took forty years until transistors were shrunk to just seven nanometers. We will certainly increase the potential of quantum computing over many years – always in coexistence with the classic semiconductor industry. We will experience a very exciting era of further development.

Q.ANT GmbH
Handwerkstraße 29
70565 Stuttgart,
Germany
phone: +49 711 4596 9613
e-mail: michael.foertsch@qant.gmbh
Web: https://qant.de

Text: Maike Pfalz, first appeared in Physik Journal **22** (2023) Nr. 4

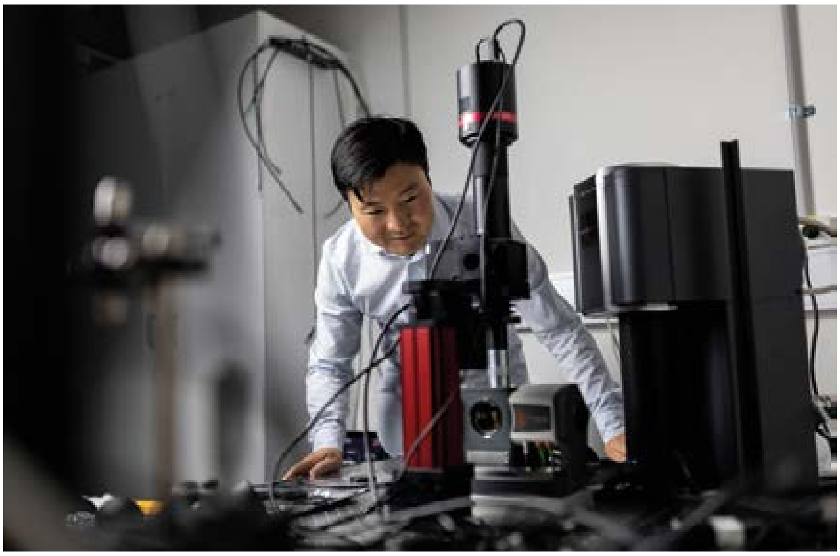
Quantum sensing in your pocket

OLEDs can be used to map magnetic fields using magnetic resonance

Smartphones could one day become portable quantum sensors thanks to a new chip-scale approach that uses organic light-emitting diodes (OLEDs) to image magnetic fields. Researchers from the ARC Centre of Excellence in Exciton Science at UNSW Sydney have demonstrated that OLEDs can be used to map magnetic fields using magnetic resonance. Sensing of magnetic fields has important applications in scientific research, industry and medicine. This technique is able to function at micro-chip scale and does not require either optical pumping from a high-powered laser or very low cryogenic temperatures.

In contrast, the OLED sensing device prototyped in this work would ultimately be small, flexible and mass-producible. The techniques involved in achieving this are electrically-detected magnetic resonance (EDMR) and optically detected magnetic resonance (ODMR). These are achieved using a camera and microwave electronics to optically detect magnetic resonance, the same physics that enables magnetic resonance imaging (MRI).

Source: ARC / UNSW



Rugang Geng from the ARC Centre of Excellence in Exciton Science

OLEDs, which are highly sensitive to magnetic fields, are already found in mass-produced electronics like televisions and smartphones, making them an attractive prospect for commercial development in new technologies. Dane McCamey of UNSW said: “Our device is designed to be compatible with commercially available OLED technologies, providing the unique ability to map the magnetic field over a large area or even a curved surface. ”Rugang Geng added: “While our study demonstrates a clear technology pathway, more work will be required to increase the sensitivity and readout times.” (Source: ARC / UNSW)

Reference: *R. Geng* et al.: Sub-micron spin-based magnetic field imaging with an organic light emitting diode, Nat. Commun. **14**, 1441 (2023); DOI: 10.1038/s41467-023-37090-y

https://excitonscience.com

Seeing objects without looking at them

A new and very effective way to carry out interaction-free experiments

We see the world around us because light is being absorbed by specialized cells in our retina. But can vision happen without any absorption at all – without even a single particle of light? Surprisingly, the answer is yes. Anton Zeilinger, one of the winners of the 2022 Nobel Prize in Physics, was the first to experimentally implement the idea of an interaction-free experiment using optics. Now, in a study exploring the connection between the quantum and classical worlds, Shruti Dogra, John McCord, and Gheorghe Sorin Paraoanu of Aalto University have discovered a new and much more effective way to carry out interaction-free experiments. The team used transmon devices – superconducting circuits that are relatively large but still show quantum behaviour – to detect the presence of microwave pulses generated by classical instruments.

Although Dogra and Paraoanu were fascinated by the work done by Zeilinger’s research group, their lab is centered around microwaves and superconductors instead of lasers and mirrors. “We had to adapt the concept to the different experimental tools available for superconducting devices. Because of that, we also had to change the standard interaction-free protocol in a crucial way: we added another layer of quantumness by using a higher energy level of the transmon. Then, we used the quantum coherence of the resulting three-level system as a resource,” Paraoanu says. However, quantum coherence is delicate and easily collapses, so it was not immediately obvious that the new protocol would work.

To the team’s pleasant surprise, the first runs of the experiment showed a marked increase in detection efficiency. They ran theoretical models confirming their results, and double-checked everything. The effect was definitely there. “We also demonstrated that even very low-power microwave pulses can be detected efficiently using our protocol,” says Dogra. The experiment also showed a new way in which quantum devices can achieve results that are impossible for classical devices, a quantum advantage. Researchers generally believe that achieving quantum advantage will require quantum computers with many qubits, but this experiment demonstrated genuine quantum advantage using a relatively simple setup.

Reference: *S. Dogra* et al.: Coherent interaction-free detection of microwave pulses with a superconducting circuit, Nat. Commun. **13**, 7528 (2022); DOI: 10.1038/s41467-022-35049-z

https://qtf.fi

The quantum twisting microscope

New tool can visualize the quantum electronic waves of two twisted atomically-thin layers directly

Researchers from the Weizmann Institute of Science used the wave – particle duality to develop a new type of tool – the quantum twisting microscope (QTM) – that can create novel quantum materials while simultaneously gazing into the most fundamental quantum nature of their electrons. The study's findings may be used to create electronic materials with unprecedented functionality. The QTM involves the twisting or rotating of two atomically-thin layers of material with respect to one another.

To achieve this, the researchers replaced the atomically sharp tip of the scanning tunneling microscope with a tip that contains a flat layer of a quantum material, such as a single layer of graphene. When this layer is brought into contact with the surface of the sample of interest, it forms a two-dimensional interface across which electrons can tunnel at many different locations. Quantum mechanically, they tunnel in all locations simultaneously, and the tunneling events at different locations interfere with each other. This interference allows an electron to tunnel only if its wave functions on both sides of the interface match exactly. "To see a quantum electron, we have to be gentle," says Shahal Ilani of Weizmann's condensed matter physics department. "If we don't ask it the rude question 'Where are you?' but instead provide it with multiple routes to cross into our detector without us knowing where it actually crossed, we allow it to preserve its fragile wave-like nature."

Researchers from the Weizmann Institute of Science make use of a new quantum twisting microscope to create novel quantum materials. (Source: Weizmann Inst.)

Generally, the electronic waves in the tip and the sample propagate in different directions and therefore do not match. Merely knowing at which angles electrons cross the interface supplies the researchers with a great deal of information about the probed material. In this manner they can learn about the collective organization of electrons within the sample.

Reference: *A. Inbar* et al.: The quantum twisting microscope, Nature **614**, 682 (2023); DOI: 10.1038/s41586-022-05685-y

www.weizmann.ac.il/condmat

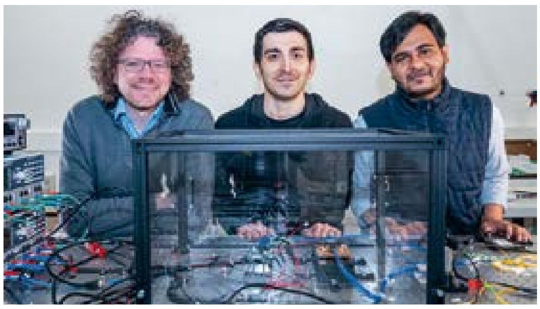
Quantum light source goes fully on-chip

The new development is scalable and suitable for use in photonic quantum computers

An international team of researchers from Leibniz University Hannover, the University of Twente and the start-up company QuiX Quantum has presented an entangled quantum light source fully integrated for the first time on a chip. "Our breakthrough allowed us to shrink the source size by a factor of more than 1000, allowing reproducibility, stability over a longer time, scaling, and potentially mass-production. All these characteristics are required for real-world applications such as quantum processors," says Michael Kues, head of the Institute of Photonics at Leibniz University Hannover.

On-chip photonics has become a leading platform for processing optical quantum states as it is compact, robust, and allows many elements to be accommodated and arranged on a single chip. "Until now, quantum light sources required external, off-chip and bulky laser systems, which limited their use in the field. However, we have overcome these challenges with a novel chip design and by exploiting different integrated platforms," says Hatam Mahmudlu, a PhD student in Kues' team.

"Qubits are very susceptible to noise. The chip must be driven by the laser field, completely free from noise, requiring an on-chip filter. Previously, it was a major challenge to integrate laser, filter, and a cavity on the same chip as there was no single material that was efficient to build these different components," says Raktim Haldar, a Humboldt fellow in Kues' group. The key was the hybrid technology that holds the laser made of indium phosphide, a filter, and a cavity made of silicon nitride and brings them together into a single chip. Two entangled photons are created from a laser field on the chip in a spontaneous nonlinear process.



Michael Kues, doctoral student Hatam Mahmudlu and Raktim Haldar developed the new integrated quantum light source. (Source: S. Smalian, PhoenixD)

Reference: *H. Mahmudlu* et al.: Fully on-chip photonic turnkey quantum source for entangled qubit/qudit state generation, Nat. Phot., online 17 April 2023; DOI: 10.1038/s41566-023-01193-1

www.phoenixd.uni-hannover.de

New way to connect quantum computers

New approach to convert quantum information to the format needed for quantum communication

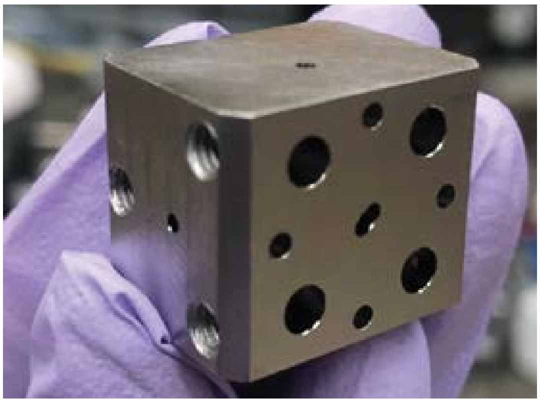
A team around researchers from the University of Chicago have found a way to translate quantum information between different kinds of quantum technologies, with significant implications for quantum computing, communication and networking. The research represents a new way to convert quantum information from the format used by quantum computers to the format needed for quantum communication.

Some of the most common quantum computing technology is based on superconducting qubits, such as those used by tech giants Google and IBM. These qubits store quantum information in photons that move at microwave frequencies. But if you want to build a quantum network, or connect quantum computers, you cannot send around microwave photons because their grip on their quantum information is too weak to survive the trip.

Rubidium atoms happen to have two gaps in their levels that the technology of Aishwarya Kumar, a postdoc at the James Franck Institute at University of Chicago, exploits: one that exactly equals the energy of a microwave photon, and one that exactly equals the energy of an optical photon. By using lasers to shift the atom's electron energies up and down, the technology allows the atom to absorb a microwave photon with quantum information and then emit an optical photon with that quantum information. This translation between different modes of quantum information is called transduction.

A secret to success is the field's progress in cavity quantum electrodynamics, where a photon is trapped in a superconducting, reflective chamber. Forcing the photon to bounce around in an enclosed space, the superconducting cavity strengthens the interaction between the photon and whatever matter is placed inside it. Their chamber does not look very enclosed – it more closely resembles a block of Swiss cheese. But what look like holes are actually tunnels that intersect in a very specific geometry, so that photons or atoms can be trapped at an intersection. This design also allows researchers to access the chamber so they can inject the atoms and the photons. The technology works both ways: it can transfer quantum information from microwave photons to optical photons, and vice versa. So it can be on either side of a long-distance connection between two superconducting qubit quantum computers, and serve as a fundamental building block to a quantum internet.

There may be a lot more applications for this technology than just quantum networking. Its core ability is to strongly entangle atoms and photons – an essential and difficult task in many different quantum technologies.



Source: A. Kumar

A niobium superconducting cavity. The holes lead to tunnels which intersect to trap light and atoms.

Reference: *A. Kumar* et al.: Quantum-enabled millimetre wave to optical transduction using neutral atoms, Nature **615**, 614 (2023); DOI: 10.1038/s41586-023-05740-2

https://live-cqe-main.pantheonsite.io

Control of two quantum light sources

New approach has the potential to build a universal error-corrected quantum computer

Researchers at the University of Copenhagen, in collaboration with Ruhr University Bochum, have solved a problem that has caused quantum researchers headaches for years. The researchers can now control two quantum light sources rather than one. Trivial as it may seem to those uninitiated in quantum, this result allows researchers to create entanglement better.

According to Peter Lodahl from Niels Bohr Institute, stable quantum light sources are crucial in the effort to take the development of quantum technology to the next level and to quantize society's computers, encryption and the Internet.

"We can now control two quantum light sources and connect them to each other. It might not sound like much, but it is a major advancement and builds upon the past twenty years of work. By doing so, we have revealed the key to scaling up the technology, which is crucial for the most ground-breaking of quantum hardware applications," says Lodahl. So far, they have only been able to control one light source at a time. This is because light sources are extraordinarily sensitive to outside noise, making them very difficult to copy. In their new result, the research group succeeded in creating two identical quantum light sources rather than just one.

According to Lodahl, just 100 photons emitted from a single quantum light source will contain more information than the world's largest supercomputer can process.

By using 20 to 30 entangled quantum light sources, there is the potential to build a universal error-corrected quantum computer – the ultimate 'holy grail' for quantum technology, that large IT companies are now pumping many billions into. According to Lodahl, the biggest challenge has been to go from controlling one to two quantum light sources. Among other things, this has made it necessary for researchers to develop extremely quiet nanochips and have precise control over each light source.

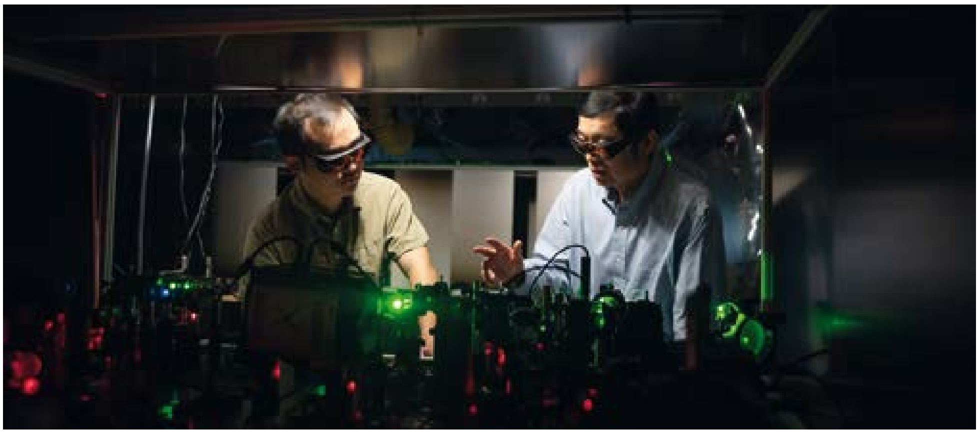
With the new research result, the fundamental quantum physics research is in place. Now it is time for other actors to take the researchers' work and use it in their quests to deploy quantum physics in a range of technologies, including computers, the internet and encryption. (Source: U. Copenhagen)

Reference: *A. Tiranov* et al.: Collective super- and subradiant dynamics between distant optical quantum emitters, Science **379**, 389 (2023); DOI: 10.1126/science.ade9324

https://hy-q.nbi.ku.dk

Quantum entanglement doubles microscope resolution

Quantum microscopy by coincidence enables super-resolution imaging at the Heisenberg limit



Zhe He and Lihong Wang use entangled photons to double microscope resolution. (Source: Caltech)

Caltech researchers have discovered a way to double the resolution of light microscopes. A team led by Lihong Wang achieved of a leap forward in microscopy through quantum entanglement. Quantum entanglement is a phenomenon in which two particles are linked such that the state of one particle is tied to the state of the other particle regardless of whether the particles are anywhere near each other.

In the case of Wang's new microscopy technique, dubbed quantum microscopy by coincidence (QMC), the entangled particles are photons. Collectively, two entangled photons are known as a biphoton which behaves in some ways as a single particle that has double the momentum of a single photon, therefore its wavelength is half that of the individual photons.

This is key to how QMC works. Reducing the wavelength of that light means the microscope can see even smaller things, which results in increased resolution. Quantum entanglement is not the only way to reduce the wavelength of light being used in a microscope. Due to another quirk of quantum physics, light with shorter wavelengths carries more energy. So, once you get down to light with a wavelength small enough to image tiny things, the light carries so much energy that it will damage the items being imaged, especially living things such as cells.

QMC gets around this limit by using biphotons that carry the lower energy of longer-wavelength photons while having the shorter wavelength of higher-energy photons. "Cells don't like UV light," Wang says. "But if we can use 400-nm light to image the cell and achieve the effect of 200-nm light, the cells will be happy, and we get the resolution of UV." To achieve that, Wang's team built an optical apparatus that converts some of the photons passing through it into biphotons. Even using this special crystal, the conversion is very rare and occurs in about one in a million photons. Using a series of mirrors, lenses, and prisms, each biphoton is split up and shuttled along two paths, so that one of the paired photons passes through the object being imaged and the other does not.

The signal photon passes through the object and the idler photon does not. These photons then continue along through more optics until they reach a detector connected to a computer that builds an image of the cell based on the information carried by the signal photon. Amazingly, the paired photons remain entangled as a biphoton behaving at half the wavelength, despite the presence of the object and their separate pathways.

Wang's lab was not the first to work on this kind of biphoton imaging, but it was the first to create a viable system using the concept. "We developed what we believe is a rigorous theory as well as a faster and more accurate entanglement-measurement method. We reached microscopic resolution and imaged cells." While there is no theoretical limit to the number of photons that can be entangled with each other, each additional photon would further increase the momentum of the resulting multiphoton while further decreasing its wavelength.

Reference: *Z. He* et al.: Quantum microscopy of cells at the Heisenberg limit, Nat. Commun. **14**, 2441 (2023); DOI: 10.1038/s41467-023-38191-4

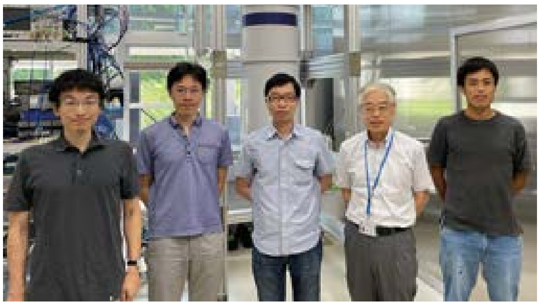
http://coilab.caltech.edu

Connecting distant silicon qubits

New approach will help to develop larger, more complex quantum computers based on silicon quantum dots

In a demonstration that promises to help scale up quantum computers based on tiny dots of silicon, physicists of Japan's largest research institution Riken have succeeded in connecting two qubits that are physically distant from each other.

Many big IT players including the likes of IBM, Google and Microsoft are racing to develop quantum computers, some of which have already demonstrated the ability to greatly outperform conventional computers for certain types of calculations. But one of the greatest challenges to developing commercially viable quantum computers is the ability to scale them up from a hundred or so qubits to millions of qubits.



Akito Noiri (far right) and co-workers have demonstrated a logic gate based on two distant qubits linked by coherent spin shuttling. (Source: RIKEN)

In terms of technologies, one of the front-runners to achieve large-scale quantum computing is silicon quantum dots that are a few tens of nanometers in diameter. A key advantage is that they can be fabricated using existing silicon fabrication technology. But one hurdle is that, while it is straightforward to connect two quantum dots that are next to each other, it has proved difficult to link quantum dots that are far from each other. “In order to connect many qubits, we have to densely cram many of them into a very small area,” says Akito Noiri of the Riken Center for Emergent Matter Science. “And it is very hard to use wires to connect such very densely packed qubits.”

Now, Noiri and co-workers have realized a two-qubit logic gate between physically distant silicon spin qubits. “While there has been a lot of work in this area using various approaches, this is the first time that anyone has succeeded in demonstrating a reliable logic gate formed by two distant qubits,” says Noiri. “The demonstration opens up the potential to scale up quantum computing based on silicon quantum dots.”

The team used coherent spin shuttling to connect the two qubits, which allows single spin qubits to be moved across an array of quantum dots without affecting their phase coherence. This method involves pushing electrons through an array of qubits by applying a voltage. Although the physical separation between the two qubits was relatively short, Noiri is confident that it can be extended in future studies. “We want to increase the separation to about a micrometer or so,” he says. “That will make the method more practical for future use.” (Source: RIKEN)

Reference: *A. Noiri* et al.: A shuttling-based two-qubit logic gate for linking distant silicon quantum processors, Nat. Commun. **13**, 5740 (2022); DOI: 10.1038/s41467-022-33453-z

https://cems.riken.jp/en/laboratory/qfsrg

Quantum processor reveals bound states of photons

Microwave photons can be made to interact in an array of superconducting qubits

Researchers have used a quantum processor to make microwave photons uncharacteristically sticky. They coaxed them to clump together into bound states, then found that these photon clusters survived in a regime where they were expected to dissolve into their usual, solitary states. The discovery was first made on a quantum processor, marking the growing role that these platforms are playing in studying quantum dynamics.

Microwave photons can be made to interact in an array of superconducting qubits. Google Quantum AI researchers engineered this unusual situation. They studied a ring of 24 superconducting qubits that could host microwave photons. By applying quantum gates to pairs of neighboring qubits, photons could travel around by hopping between neighboring sites and interacting with nearby photons.

The interactions between the photons affected their phase. When the photons are non-interacting, their phase accumulation is rather uninteresting. In this case, a photon that was initially next to another photon can hop away from its neighbor without getting out of sync. Every possible path the photon can take contributes to the photon’s overall wavefunction. A group of photons initially clustered on neighboring sites will evolve into a superposition of all possible paths each photon might have taken.

When photons interact with their neighbors, this is no longer the case. If one photon hops away from its neighbor, its rate of phase accumulation changes, becoming out of sync with its neighbors. All paths in which the photons split apart overlap, leading to destructive interference. Among all the possible configuration paths, the only possible scenario that survives is the configuration in which all photons remain clustered together in a bound state. This is why interaction can enhance and lead to the formation of a bound state: by suppressing all other possibilities in which photons are not bound together.

Before this experiment, it was reasonably assumed that the bound states would fall apart in the midst of chaos. To test this, the researchers pushed beyond integrability by adjusting the simple ring geometry to a more complex, gear-shaped network of connected qubits. They were surprised to find that bound states persisted well into the chaotic regime.

The team at Google Quantum AI is still unsure where these bound states derive their unexpected resilience, but it could have something to do with prethermalization.

Reference: *A. Morvan* et al.: Formation of robust bound states of interacting microwave photons, Nature **612**, 240 (2022); DOI: 10.1038/s41586-022-05348-y

https://research.google

Fiber optics for quantum

How to get light into quantum computers

Anja Knigge, Christian Knothe, and Tobias Kroker

Technical progress in both industry and science has enabled the preparation, manipulation, and probing of quantum systems with an unprecedented level of control. This provides the basis for a multitude of so-called quantum technologies like quantum cryptography, quantum sensors and quantum computers, which are currently developing from laboratory experiments into commercial applications.

▲ **Fig. 1** Fiber optics has proven to be a powerful tool for quantum optics experiments for decades. They profit from increasing stability and convenience, as will future quantum computers. The specific requirements of precision, stability and ruggedness call for high quality components and customized fiber optic solutions.

Quantum computers are expected to efficiently solve optimization problems occurring in logistics or urban development and to enable computation-intensive simulations required for biotechnology and drug design. Billions of dollars are currently being invested in the research of quantum computers in search of the optimal physical platform for their realization.

Among the most promising platforms are ultracold atom or ion systems where the logical units, the 'qubits' are encoded within the internal states of the single atoms or ions. The preparation, programming and read-out of these systems uses reliable laser light with highest level of control over intensity, frequency, and the state of polarization.

How do qubits profit from fiber optics?

The fundament for most quantum optics experiments is a laser system that provides coherent laser light with a specific intensity, frequency, and state of polarization. In order to use this light for cooling, manipulation, and detection of atoms and ions, it has to be transported, distributed, and analyzed. Polarization-maintaining fiber cables, fiber couplers and collimators, fiber port clusters, and polarization analyzers can be used for this task.

Traditional setups often require large breadboard configurations that require frequent adjustment of opto-mechanical devices because of their instability. Compact, robust and modular fiber optic solutions as building blocks for laser systems add both stability and convenience. They are the perfect basis for developing laboratory setups into turnkey, low-maintenance end products. These self-contained setups also increase laser safety and reduce laser safety classification. In addition, fiber-based light transport provides a defined interface between the laser sources and the more sensitive environment of the

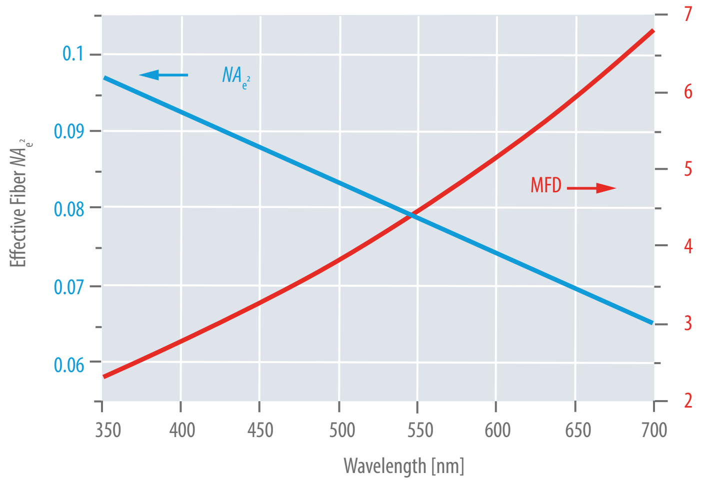


Fig. 2 Effective numerical aperture $NA_{e}2$ and the corresponding MFD for an RGB fiber that can be used between 400 and 640 nm. The $NA_{e}2$ decreases significantly with increasing wavelength.

quantum gas experiment or quantum information platform. It provides a physical separation for mechanical and thermal decoupling, which helps to suppress mutually adverse effects. The assurance of stability in the opto-mechanics means that the full focus can be on the experiment (and not on the equipment).

A large and complex quantum setup can be built by using fiber optics to connect each individual module, as well as using fiber optics in different parts of the modules needed for a quantum computer.

Single-mode and PM fiber cables

Single-mode fibers are specialized fibers that transmit light in the LP_{01} transverse fundamental mode. The field distribution (mode field) of the light exiting the fiber is nearly Gaussian. In standard single-mode fibers, light is guided in two principal polarization states. However, imperfections in the fiber cause random power transfer between the two principal polarization states, so that the polarization is not maintained.

Polarization-maintaining single-mode fibers (PM fibers) are rotationally asymmetric, for example due to integrated strain elements that break the degeneracy of the two principle states of polarization (SOP). Light is guided in either the 'fast' or 'slow' axis. Linearly polarized light coupled into one of these axes is preserved. The polarization extinction ratio (PER) – the ratio of the power carried in the two polarization axes – is a critical measure of fiber alignment. Since polarization is essential for many stages of a quantum experiment, PM fibers are often preferred over standard single-mode fibers for light transport.

Standard single-mode and PM fibers are characterized by their numerical aperture *(NA)*, mode field diameter (MFD), and cut-off wavelength (λ_0). Only at wavelengths above this cut-off is the coupled light guided in a single-mode and not in multiple modes, where the beam and intensity profiles are no longer stable and Gaussian. The MFD is wavelength dependent and inversely proportional to the fiber's *NA*. While fibers used for telecommunications in the infrared, around wavelengths of 1550 nm, are characterized by relatively large mode field diameters of about 10 µm, the MFD in the UV is small for a typical single-mode or polarization-maintaining fiber, e.g. 3 µm for 405 nm and a fiber with nominal $NA = 0.12$ ($NA_{e}2 = 0.1$).

The nominal *NA* does not exactly reflect the divergence properties of the emitted radiation. However, when coupling a beam into a fiber, the divergence properties (among the collimated beam diameter) define the best coupling focal length, see below. It is therefore important to measure an effective $NA_{e}2$ for each fiber, for different wavelengths, and for each fiber reel. These detailed measurements, as shown in Fig. 2, demonstrate that for short wavelength fibers, the effective numerical aperture varies with wavelength and is not constant as assumed in the standard model and for telecom fibers.

The effective $NA_{e}2$ for standard single-mode fibers and PM fibers typically decreases with increasing wavelength λ [1].

Long-term stable coupling into PM fibers

Long-term stable, rugged and highly efficient fiber coupling is the foundation of all fiber-based setups. This is even more important when the goal is to build low-maintenance, turnkey products. A fiber coupler or laser beam coupler is often used for coupling into the (PM) fiber cable.

When coupling into single-mode fibers, laser beam couplers should produce a diffraction-limited spot that matches the mode field diameter and effective numerical aperture of the fiber to achieve maximum coupling efficiency. Fiber coupling with high efficiency of up to 85 % can only be achieved if this condition is met.

Accurate information about the effective $NA_{e}2$ is essential to determine the correct coupling focal length which is calculated from both the laser beam

Company

Schäfter+Kirchhoff

Schäfter+Kirchhoff has accumulated substantial experience in the development of opto-mechanical and opto-electronic systems for use in research, aviation and in space, as well as for demanding medical and industrial applications. Schäfter+Kirchhoff design and manufacture their own line scan camera systems, laser sources, beam-shaping optics and fiber-optic components, including laser beam couplers, fiber collimators, and fiber port clusters for customers worldwide.

www.sukhamburg.com

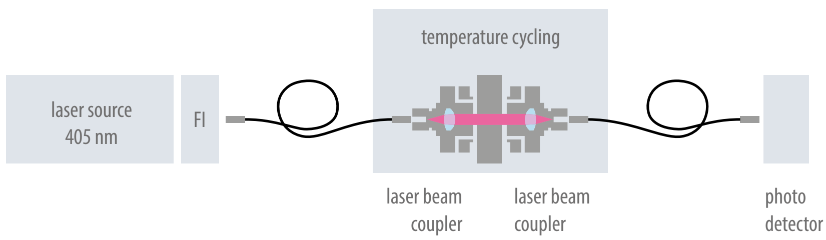


Fig. 3 Test setup for measuring the stability of two laser beam couplers ($f = 4.5$ mm, $\lambda = 405$ nm) during successive temperature cycling between 15 and 35 °C.

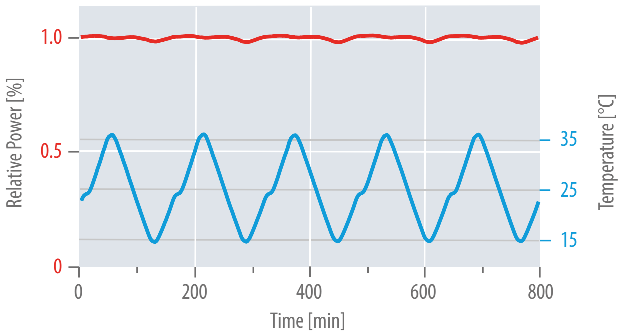


Fig. 4 The relative power (normalized with respect to the mean power) shows a repetitive pattern following the temperature (below) and has a maximum deviation of ±1.5 %.

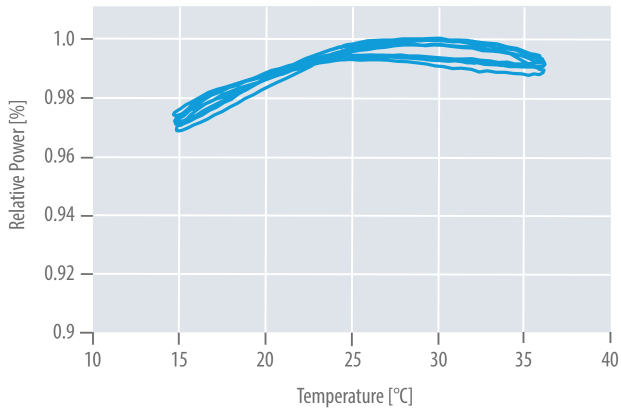


Fig. 5 The relative power curves (normalized with respect to the maximum power) are almost coincident and confirm the high reproducibility of the pointing stability during temperature cycling. The maximum deviation is only 3 %.

diameter and the effective fiber NA_{e2}. A focal length that is too large is inefficient because the focused laser spot is larger than the mode field diameter. If the focal length is too small, the convergence angle of the focused laser spot is larger than the maximum acceptable divergence angle of the fiber – the coupling efficiency is reduced. For an optimally chosen focal length, an ideal Gaussian beam is almost completely coupled, except for losses due to Fresnel reflection at both uncoated fiber ends of about 4 % each.

The required pointing stability of the laser beam coupler when coupling a free beam into a polarization-maintaining fiber can be illustrated by an example: at a focal length of 5 mm, an angular misalignment of the coupler of only 0.2 mrad (0.01°) would result in a lateral displacement between the laser spot and the mode field of the fiber of 1 µm. At λ = 400 nm and a nominal *NA* of 0.12, a displacement of just 0.4 µm is sufficient to reduce the coupling efficiency by as much as 10 %. Submicron precision and pointing stability of the coupling optics is therefore required for high coupling efficiency and long-term stability, especially in the blue region.

The high stability of fiber coupling using a fiber coupler is demonstrated in temperature stability tests using different focal lengths and wavelengths. The test setup is shown in Fig. 3. The setup is described in detail in [1].

Fig. 4 shows typical results of the relative transmitted power over five measurement cycles using a focal length of 4.5 mm and a wavelength of 405 nm. The power is normalized with respect to the mean power obtained over all measurement cycles. The power deviation from the mean power is ±1.5 %.

The repetitive pattern in relative power caused by temperature cycling is more clearly shown in Fig. 5, where relative power (normalized to the maximum) is plotted against the temperature of the laser beam couplers. The maximum coupling efficiency is reached just above 25 °C and decreases faster at lower temperatures than at higher temperatures, with the smallest slope near the desired operating point (25 °C). The corresponding power curves for each measurement cycle are nearly coincident, and the power variation at points of equal temperature is <1 %. This demonstrates the reproducibility of the pointing stability during temperature cycling and the long-term stability of the fiber

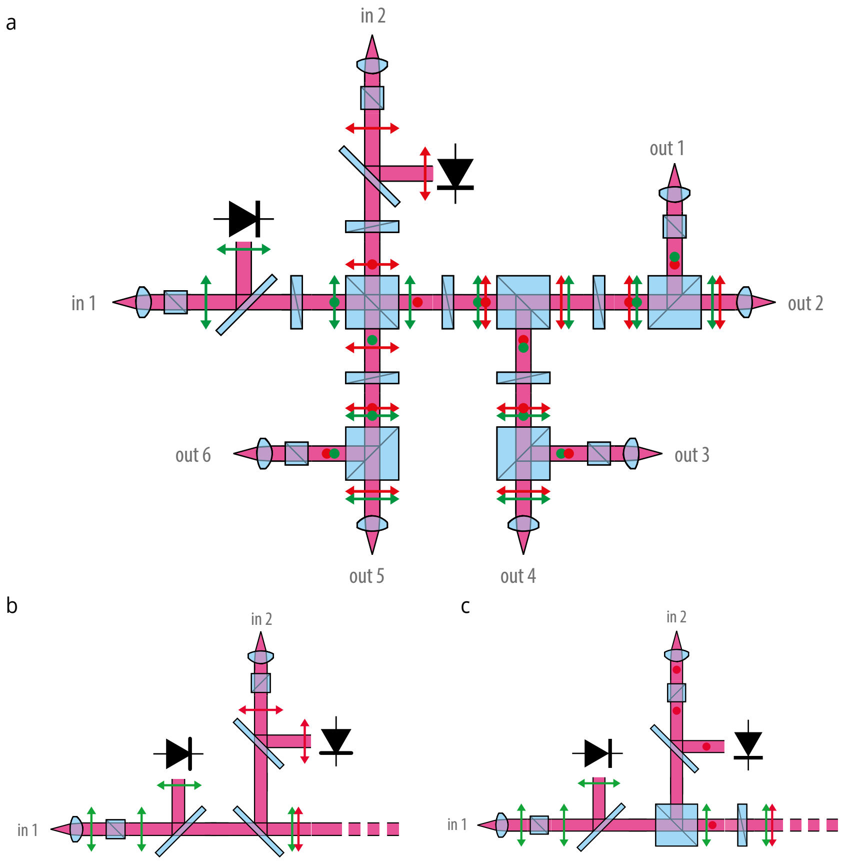


Fig. 6 a) Optical scheme of a fiber port cluster 2 – 6. The arrows and the dots denote the state of polarization. b) Input group for combining two wavelengths with a dichroic beam combiner (with two power monitors). c) Scheme of combining two wavelengths by means of a polarization beam combiner followed by a dichroic wave plate. Input group with two power monitors.

coupling. The maximum deviation with respect to the maximum power is only 3 %, making it an ideal basis for quantum endeavors.

As an alternative to laser beam couplers, fiber collimators can also be used in reverse for coupling into PM fibers. Fiber couplers and collimators with fine-focusing mechanisms provide easy, highly defined adjustment of the focus without backlash. This ensures high coupling efficiency, even when the divergence or wavelength of the laser source used varies frequently.

Beam distribution – fiber port clusters

The preparation and manipulation of quantum gases requires the illumination of the atomic ensembles with coherent laser light from different spatial directions. Therefore, the laser light must be split into different beam paths while maintaining control over its polarization state.

Fiber port clusters are compact opto-mechanical units that split the radiation from one or more polarization-maintaining (PM) fibers into multiple output polarization-maintaining fiber cables with high efficiency and a variable splitting ratio. The beam delivery system consists of compact, modular, opto-mechanical units. The modularity ensures that almost any desired system can be assembled in a compact and sealed manner. PM fibers are used to transport light to the cluster with defined linear polarization due to the polarization-sensitive nature of the optical components within the fiber port cluster. The fibers used have a polarization extinction ratio (PER) greater than 26 dB (measured at 780 nm).

Beam splitting is achieved in single input wavelength fiber port clusters using a cascade of rotating half-wave plates in combination with polarization beam splitters. Integrated elements, such as photodiodes, provide useful input power monitoring. The inputs and/or outputs can be equipped with electromagnetic shutters. Through the use of the rotating half-wave plates, it is possible to achieve almost any desired beam splitting ratio. Various experiments [2] and [3] have demonstrated the high stability and robustness of standard fiber port clusters.

Schäfter+Kirchhoff also offers fiber port clusters with two input ports, for example for the cool and repump frequency for a MOT at 780 nm (Fig. 6a).

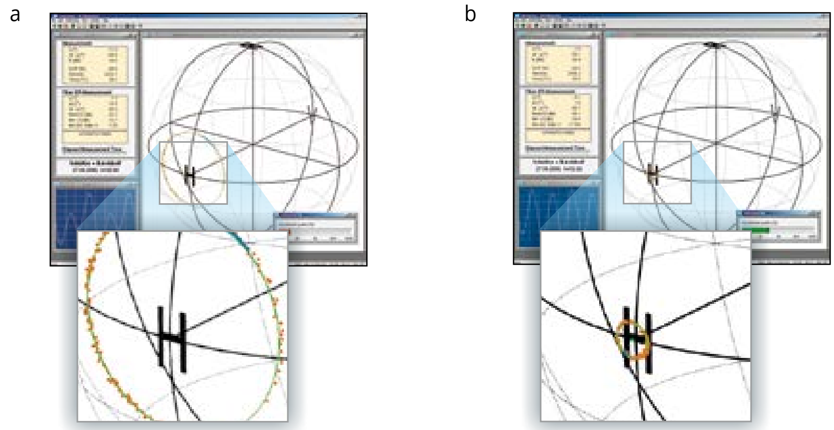


Fig. 7 Adjustment of a polarization-maintaining fiber with a coherent laser source. The goal of the adjustment is to minimize the data circle radius. When the fiber polarization axis and the laser polarization axis have a high angular deviation, the state of polarization varies significantly when bending the fiber or when the ambient temperature changes (a). The better the angular alignment of the fiber, the smaller the change in polarization and the smaller the radius of the data circle (b).

It is also possible to combine beams of different wavelengths at the input port of a fiber port cluster for subsequent equal splitting of both components, as required for a dual-species MOT for example. When using multiple wavelength inputs, the wavelength difference between the input ports determines how the combination can be achieved. A dichroic beam combiner is used for two laser sources with a large wavelength difference (Fig. 6b). If the wavelength difference is too small for a dichroic beam combination, a polarization beam splitter and a subsequent dichroic waveplate allows multiplexing (Fig. 6c).

Fiber collimators are then used to collimate the light exiting from the PM fibers attached to the output ports of the fiber port clusters. For cases where the wavelength difference of the two lasers is too large to be guided in a common single-mode fiber, Schäfter+Kirchhoff has developed special fiber collimators with an integrated dichroic beam combiner that have two separate input ports for the two sources. Fiber collimators with directly integrated quarter-wave plates can be used if circularly polarized light is required.

Analyzing the polarization

Control over the state of polarization and its analysis is essential for quantum platforms such as ultracold atoms or ionic systems. It is also important for the PM fiber coupling process. The polarization analyzer described here has two main applications: one is to monitor the alignment of the polarization-maintaining fibers with the polarization axis of the source; the other is to determine the state of polarization in general and its defined setting according to the requirements. More details can be found in [4].

The polarization is determined by evaluating the light arriving at a photodiode after passing through a rotating quarter-wave plate and a static polarizer. The Stokes parameters are obtained from a detailed analysis of the photodiode signal and the time/position information of the quarter-wave plate. The polarization state is then plotted on the Poincaré sphere where any change in the polarization state as well as the sense of rotation (plotted on the northern or southern hemisphere) is easily visible.

For the fast and accurate alignment of PM fibers with linearly polarized light sources it is essential to efficiently determine and display the polarization extinction ratio (PER). The polarization of linearly polarized light that is not fully coupled into one of the polarization axes is not maintained, and the polarization changes with temperature and strain variations. This is visualized on the Poincaré sphere by carefully and purposefully introducing environmental changes, such as temperature variation or slow bending of the fiber, which causes a data circle to be formed on the Poincaré sphere resulting from the induced phase shift between the two principal polarization states. This circle represents all possible polarization states for the current alignment, with the center representing the mean polarization extinction ratio. The mean polarization extinction ratio should be located at the equator for an ideal polarization-maintaining fiber. The data point farthest from the equator shows the worst possible polarization extinction ratio for the current alignment.

The radius of the circle on the Poincaré sphere is an indication of the quality of the alignment when adjusting the fiber coupling since it shows the angular deviation between the fiber polarization axis and the source polarization axis. Assuming an ideal linearly polarized source, the radius of the circle is large for poorly aligned fibers – the polarization varies greatly with ambient conditions – and small for precisely aligned fibers. The data circle converges to a single point on the equator of the Poincaré sphere for an optimally aligned ideal fiber. A series of measurement points is taken when adjusting the fiber coupling while changing the temperature or carefully bending the fiber to generate a circular trajectory of data points. A circle is automatically fitted to the data points and the mean and minimal PER are displayed (Fig. 7a). The polarization axis of the fiber can now be rotated with respect to the polarization axis of the source until the radius of the circle reaches a minimum (Fig. 7b). A second measurement then reveals the parameters of the optimized fiber alignment.

Conclusion

The progress made in fiber optics over the years has enabled a variety of so-called quantum technologies, such as quantum cryptography, quantum sensors and quantum computers, which are rapidly moving from the lab to commercial applications. Their special requirements for precision, stability and robustness require high-quality components such as polarization-maintaining fiber cables, fiber couplers and collimators, fiber port clusters and polarization analyzers, which are available from UV– IR.

DOI: 10.1002/phvs.202300018

[1] *A. Knigge, M. Rahmel, C. Knothe:* Fiber Coupling to Polarization-Maintaining Fibers and Collimation, PhotonicsViews **17**, 3/2020 , https://doi.org/10.1002/phvs.202000021

[2] *G. Varoquaux* et al.: I.C.E., An ultra-cold atom source for long-baseline interferometric inertial sensors in reduced gravity, arXiv: 0705.2922 (2007)

[3] *T. Könemann* et al.: A freely falling magneto-optical trap drop tower experiment, Applied Physics B: Lasers and Optics **89** (4), 431 (2007)

[4] *A. Krischke, M. Schulz, Ch. Knothe, and U. Oechsner:* Polarization Analyzer for Fiber Optics and Free Beam Applications, Optik Photonik 1/2013; DOI: 10.1002/opph.201300006

Authors

Anja Knigge (née Krischke) studied physics at the University of Würzburg with a focus on the description of ultrashort laser pulses and quantum control. She joined Schäfter+Kirchhoff in 2011 and now works in optics development.

Christian Knothe studied physics at the University of Freiburg i.Br., concentrating on laser spectroscopy before completing his doctoral thesis in fiber optics at the Technical University of Hamburg-Harburg. Since he joined Schäfter+Kirchhoff in 2005, he has been responsible for laser diode sources and advanced fiber optic applications.

Tobias Kroker studied physics at the University of Hamburg, specializing on quantum gases and laser physics. After completing his doctoral thesis on quantum optics, he joined Schäfter+Kirchhoff in 2022 and works in research and development within the fiber optics section.

Anja Knigge, Schäfter+Kirchhoff GmbH – Optics, Metrology and Photonics, Kieler Str. 212, 22525 Hamburg, Germany; phone: +49 40 853 9970, fax: +49 40 853 99779, e-mail: info@sukhamburg.de; Web: www.sukhamburg.com

Fastlane to quantum advantage through co-design

Acceleration of quantum advantage for selected use cases in chemistry, finance, and logistics

Stefan Rank & Frank Deppe

Quantum computers promise to solve certain advanced computational tasks with higher computational speed, higher accuracy, and less energy consumption. To be useful for real-world applications, traditional quantum algorithms typically require significantly more sophisticated quantum computers than are available today.

Co-designing application-specific quantum integrated circuits (ASICs) is one avenue being explored by quantum computing scientists and engineers to achieve quantum advantage in the near future. Currently, the co-design paradigm is most prominently pursued in the field of superconducting quantum systems, which operate in the microwave regime.

Nevertheless, due to the universality of the underlying light-matter coupling mechanisms, insights taken from the field of photonics could provide valuable contributions to the advancement of co-designed quantum computers.

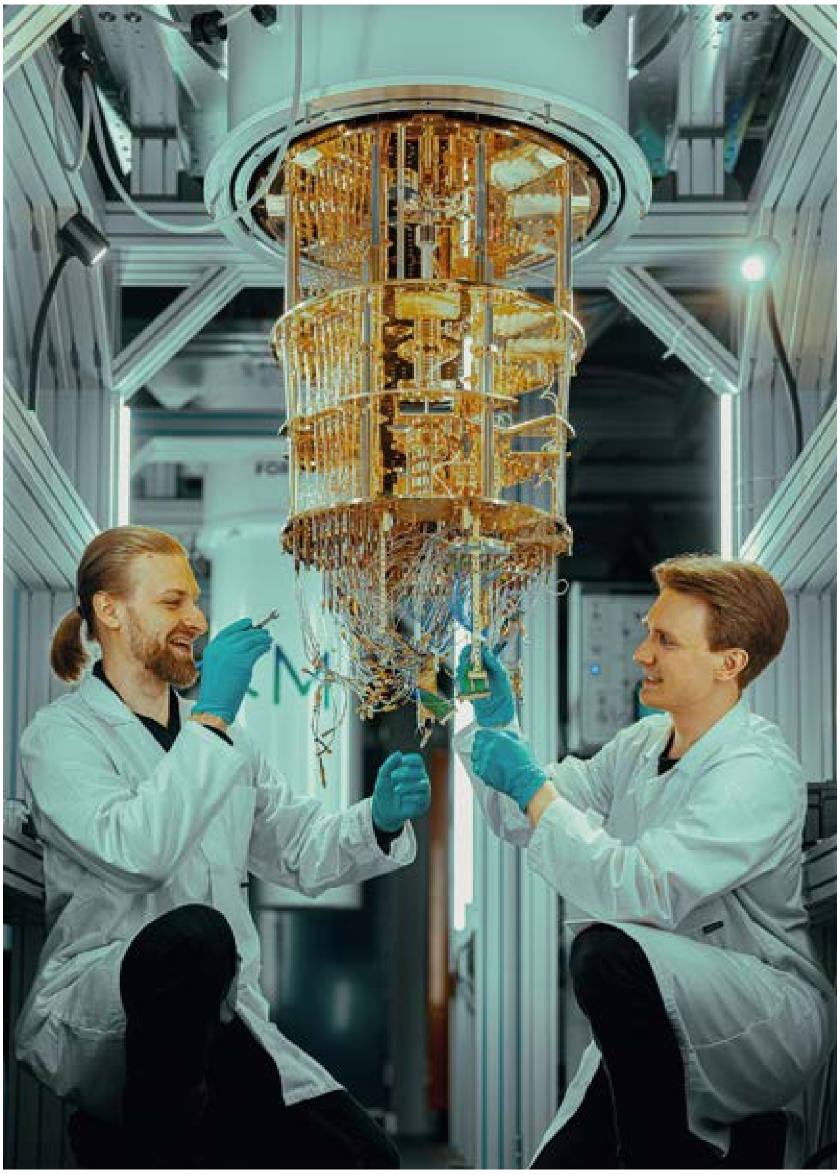


Fig. 1 Assembly of an IQM quantum computing system (Source all images: IQM Quantum Computers)

Journey of a quantum algorithm

Let us approach the co-design paradigm from a quantum education point of view. One of the first things quantum computing students may learn is the 'journey of a quantum algorithm' in a quantum computer. This journey begins with the user trying to solve a computational problem. Known classical solutions may not have sufficient computational speed or accuracy or may not exist at all, at which point the quantum computer comes into play. The user identifies a quantum algorithm that has the potential to solve the real-world problem with less resources than a classical approach. The resulting computational advantage is called 'quantum advantage'. Prominent examples are Shor's algorithm for prime number factorization or the Grover database search algorithms. As with Deep Learning, data input and data output must be considered. Quantum algorithms must first be transpiled or converted to an equivalent circuit with hardware-supported gates. The resulting gate sequences are typically expressed as Python code operating the classical control electronics of the quantum computer via a dedicated server. In this process, the so-called 'pulse compiler' expands the circuit into a series of electromagnetic pulses. The control electronics leverages specialized hardware and firmware to execute pulse sequences with nanosecond precision, as it is required for high-performance superconducting quantum processing units (QPUs). The qubits on the QPU make use of fundamental quantum mechanical effects such as superposition, entanglement, and interference to execute the quantum logic required for quantum computing. Finally, a series of measurements provides the results, which are probabilistic by nature. Usually, a quantum circuit is executed many times and a suitable set of averaged measurement results provides the user with the computation result. In practice, these results are sent back to the user's classical Python-based software framework for analysis and visualization [1].

Quantum computing technology stack

From an engineer's perspective, this journey of a quantum algorithm takes place within the quantum computing technology stack. This breaks the complex quantum computing system down into its major components.

In this technology stack, only the QPU describes the quantum computing system. It is connected to the classical computing hard and software stack via multiple layers. These include instruments such as digital-to-analog converters (DAC) and analog-to-digital converters (ADC), which convert digital to analog signals and vice versa. Shown above are several layers of firmware for calibration, control, transpilation, routing and execution. Further above are the hardware-agnostic software layers including quantum algorithms, libraries, and applications. Most quantum computing is performed in a hybrid architecture that uses classical and quantum computing symbiotically. In HPC (high performance computing) integration projects, IQM and its partners are working on an optimal integration of quantum and classical computing.

A solution for advanced computational challenges?

Following the general verdict of the worldwide quantum computing community, we are currently in the early stages of an envisioned quantum computing era, where qubits do show impressive quantum behavior but suffer from environmental noise. Consequently, the current state of technology does not support the implementation of univer-

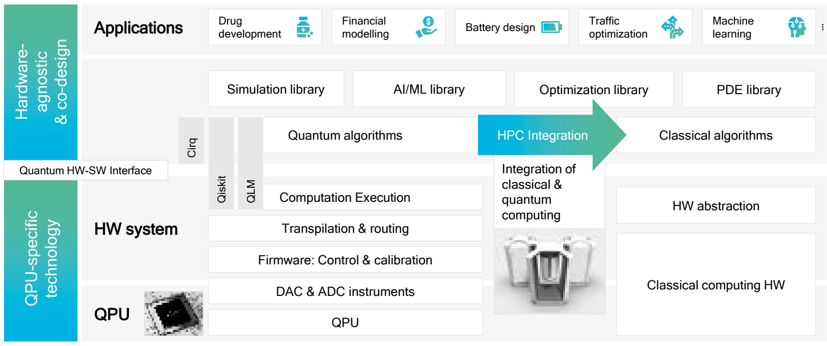


Fig. 2 Quantum computing technology stack

sal fault-tolerant quantum computing. However, a long-term path towards it is well conceivable upon straightforward but tedious scaling. For this reason, the present state is also called the noisy intermediate scale quantum (NISQ) era. The technical challenges mainly arise from noise, errors, and the necessity of excessive scaling. We need more high-quality qubits for superposition, entanglement, and interference than we currently have available to produce meaningful results with the currently known application-relevant quantum algorithms. As a consequence, unlocking the quantum power of NISQ devices requires novel quantum computing paradigms that are less resource-hungry than universal fault-tolerant quantum computing. And it is precisely here that co-design comes into play.

The aim of co-design for quantum computing is to develop a specific combination of quantum hardware and control software optimized for a specific algorithm that has been identified as the most promising, or even proven to be the best possible quantum algorithm for a selected use case. The technical goal is to provide novel QPU topologies, compute elements, and control operations to reduce the required number of qubits, circuit depth, and operation fidelities for precisely this one use-case. Although this approach sounds somewhat narrow at first glance, it could nevertheless ultimately result in better products and materials, more efficient use of energy, or optimized processes in logistics and production. Putting it into business terms, co-designed quantum computers can contribute to higher sales and profits, a faster time to market, higher market share, or a shorter time to publication.

At IQM, co-design development is carried out with partners from industry within innovation partnerships. In such a co-design project, experts in quantum hardware, quantum algorithms and software work hand-in-hand with domain experts from industry. In this context, discussions with industry members have shown that companies today have not one, but in many cases more than a hundred unresolved computational challenges. The first step in an innovation partnership is to identify the use cases to be addressed in the project. This decision depends on technical feasibility and schedule, algorithm benchmarking and metrics definition, simulation results, the competitive landscape, and the strategic goals outlined above. Once the use case is selected, the cross-functional project team conducts a multi-step, iterative and agile development process to find the best mapping of the quantum algorithm to the quantum hardware and software to minimize quantum overhead and maximize performance according to the predefined metrics. If the solution delivers the desired results, several industrialization options are possible.

Company

IQM Quantum Computers

IQM is the European leader in building quantum computers. The company provides on-premises quantum computers for supercomputing centers and research labs and offers full access to its hardware. For industrial customers, IQM delivers quantum advantage through a unique application-specific co-design approach. IQM's commercial quantum computers include Finland's first commercial 54-qubit quantum computer with VTT. IQM has over 260 employees with offices in Paris, Madrid, Munich, Singapore, and Espoo.

https://meetiqm.com

Meet us at Laser World of Photonics – World of Quantum A1.518-1

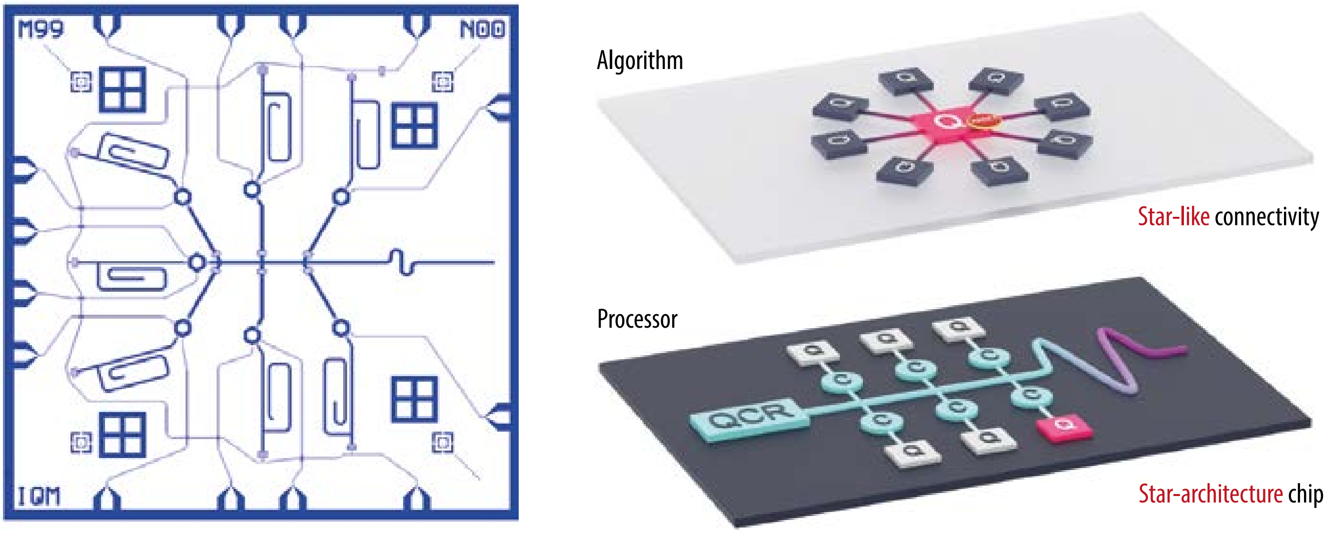


Fig. 3 Qubit-resonator star architecture and chip design

Co-design of quantum ASICs and co-design toolbox

It is not unexpected that there is a learning curve in implementing quantum ASICs. One aspect of this learning curve is that the field is still new and wide open for innovation in quantum hardware, software, and algorithms. Another aspect is that some 'recipes' work better than others, depending on which algorithm is to be implemented for a particular use case. A co-design flow should specify the path from a standard implementation to a customized implementation. This goal is best achieved by setting up a reasonably flexible co-design toolbox that ideally builds on controlled-effort variations of available, proven, and tested quantum computing components. For example, the toolbox can be used to co-design quantum ASICs with carefully selected novel computational elements and operations in a topology optimized for the selected use case. Such a scenario has been evaluated by the IQM developers Manuel Algaba, Mario Ponce-Martinez et al. They have identified a co-design architecture tailored to quantum simulation projects in the NISQ era, and as a tool to drive innovation in the medical imaging space. The underlying quantum ASIC consists of a star-shaped, all-to-all connectivity architecture, which connects standard transmon qubits capacitively via tunable couplers to a central coplanar waveguide resonator serving as a novel co-design element. A population exchange between any qubit and the central resonator is a necessary co-design operation. The first target of the qubit-resonator star implementation is an enhanced image resolution combined with high biocompatibility in magnetic resonance imaging (MRI). Specifically, one aims at simulating the dynamics of nanodiamond-based contrast agents, which are injected into a patients' blood stream to enhance image resolution in MRI. The simulation target is the achievement of a hyperpolarization state that is polarized beyond the level of a thermal state in a magnetic field. Such a quantum computer-based simulation could lead to improved detection of various malformations in tissues – such as the heart or brain – without the use of ionizing radiation [2]. In a broader context, the qubit-resonator star platform can simulate all problems based on the transverse Spin-Ising model.

The fundamental driving concept behind the qubit-resonator star co-design platform is the reduction of noisy SWAP gates for the use case described above by up to ninety percent for quantum ASICS with more than twenty qubits. For proof-of-principle demonstrations, the base implementation of the qubit-resonator star features six qubits. Upcoming innovation partnerships can leverage second generation qubit-resonator platforms with significantly more compute elements and other target applications. Innovation partnerships typically start with an educational program, develop a customized solution in a multistep quantum advantage program, and include various industrialization options. In this context, we emphasize that one important aspect of a co-design project is solution metrics defined early in the project. The goal is to reduce quantum computing resource requirements for the identified quantum algorithm. We estimate that the qubit reduction factor could reach significant values such as ten or higher in specific co-design projects.

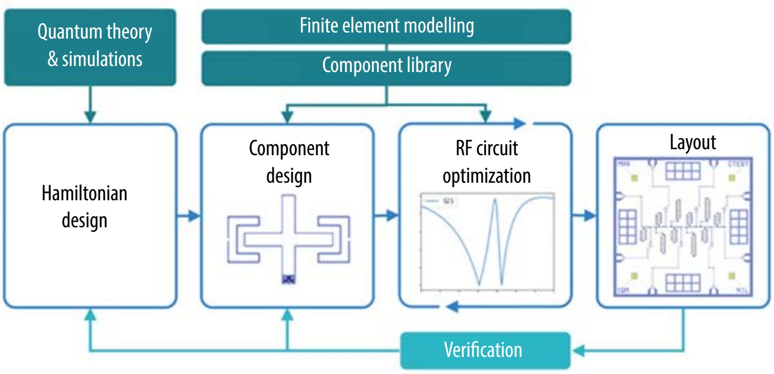


Fig. 4 QPU design steps

A design tool for fast innovation cycles

Fast innovation cycles are key to building a fast lane to quantum advantage. Co-design is an iterative process in which hardware, software, and algorithm teams work closely together to implement the best mapping of high-level quantum algorithms for a specific use case to a specific hardware and software architecture. Open-source software tools such as KQCircuits can be used for QPU design, which provides ease-of-use with drag-and-drop options and design consistency through parametrized geometrical circuit elements. The QPU design flow typically starts with Hamiltonian design, then moves on to component design, RF circuit optimization and layout. New designs are then evaluated with predefined performance metrics. Meaningful innovation in materials and design for quantum computers is performed by the MATQu consortium [3], among others.

Superconducting quantum computers and photonics

For both fault-tolerant quantum computing and NISQ-friendly co-design, scaling to higher qubit numbers and operation fidelities remains an inevitable requirement for sustainable success. A plethora of advanced scaling technologies are being developed today, many of which are not yet part of production but could be integrated into production a few years down the road. In this context, we want to highlight two specific interfaces to the field of photonics. The first one is the discipline of HPC integration where superconducting and photonics-based quantum computers can be interfaced via a classical HPC cluster, distributing tasks to them and processing their output in a highly parallelized fashion. The second topic is microwave-to-optical conversion: when control signals for a superconducting qubit QPU are routed into the cryostat via optical fibers, both space consumption and heat load constraints could be greatly reduced for large qubit numbers with obvious advantages [4]. These and similar technologies may also be used for multi-QPU architectures, error correction and non-destructive measurements. German research historically has had a strong focus on photonics that can also deliver valuable insights for superconducting quantum computers. Such considerations include coherence, energy levels, nonlinearities and resonances, quantum fluctuations, external control, as well as read-out and detection. IQM actively partners with the German and European quantum computing ecosystems, including the Munich Quantum Valley (MQV), to address these and similar topics on the advancement of quantum computing.

DOI: 10.1002/phvs.202300020

[1] https://academy.meetiqm.com

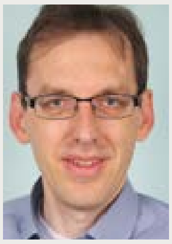
[2] *M.G. Algaba, M. Ponce-Martinez* et al.: Co-design quantum simulation of nanoscale NMR, Phys. Rev. Research 4, 043089 – Published 8 November 2022, https://journals.aps.org/prresearch/abstract/10.1103/PhysRevResearch.4.043089

[3] https://www.matqu.eu

[4] https://meetiqm.com/articles/press-releases/iqm-and-qphox-to-develop-optical-interface/

Authors

Stefan Rank is marketing manager at IQM Quantum Computers. He holds a master's degree in physics from the Technical University in Munich and an MBA in marketing (San Diego, California). He has held several EMEA and global marketing management positions in the computing space.

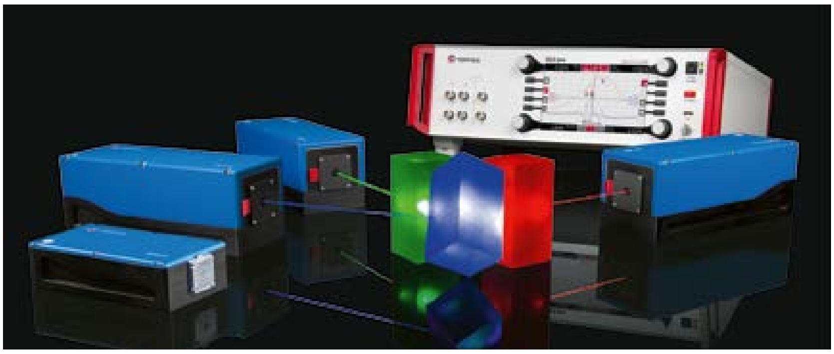


Frank Deppe leads the co-design-implementation team developing advanced co-design quantum computers at IQM Quantum Computers. He holds a PhD in physics and a private lectureship ("Privatdozentur") at the Technical University in Munich. Before joining IQM, he worked in academia for 20 years on superconducting quantum circuits as well as on microwave communication and sensing.

Stefan Rank, IQM Quantum Computers, Nymphenburgerstrasse 86, 80636 Munich, Germany; phone: +49 170 785 7874; e-mail: stefan.rank@meetiqm.com, Web: www.meetiqm.com, stefan-rank-b24b3521a

The quad laser operation for DLC pro: one step further into the second quantum revolution

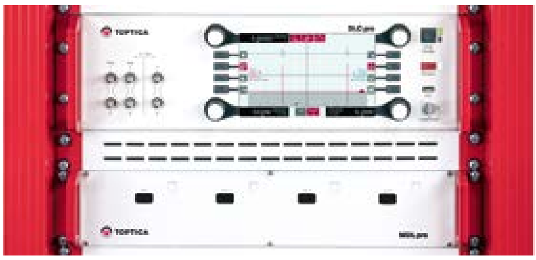
The Quantum 2.0 shift needs excellent industrial laser systems that exceed key benchmarks such as integration, scalability, and ease of use. Toptica has taken bold steps to meet the need by introducing an innovative feature, the 'quad laser operation' option. This groundbreaking addition allows users to easily control up to four DFB or DL pros.



Digital Laser Controller DLC pro with a DFB pro and three DL pros

Over the last decade, the situation has drastically changed within the quantum community as the second quantum revolution takes place. Three distinct fields can be distinguished here: quantum computing and simulation, quantum sensing and quantum communication. Direct applications beyond the laboratory are now a reality, and Toptica is of course contributing to the emergence of quantum products, lasers being one of the cornerstones of such technologies.

The DL and DFB pros have established themselves as a standard during this period. They have been major actors for cooling and controlling atoms and ions, allowing breakthroughs not only in the academic setting, but also in the industrial domain.



The top selling DLC MDL pro Ca^+ equipped with the quad laser operation option now fits in 7U.

The new GUI driving the DLC MDL pro Ca^+ equipped with the quad laser operation option. The status of the four lasers is visible at a glance from the dashboard and laser activation can be directly controlled.

This success has only been possible because these lasers were driven by the Digital Laser Controller (DLC pro). The performance of a diode laser is indeed largely determined by its controller. The DLC pro was the first diode laser controller based on a digital foundation, which is essential to obtain the best performance of all key parameters: low current noise for narrow laser linewidths, excellent temperature control for stable operation, and precise piezo control for frequency tuning. The digital foundation also enables full remote control, including a GUI for Windows and a command interface. Many applications also require stabilization of the laser frequency, and Toptica provides solutions for all such needs: the convenient DLC pro Lock software solution is directly integrated into the DLC pro, while high performance locking is provided by the FALC pro. The DLC pro also supports all the options available to extend the functionality of the DL pro, including motorization of the coarse tuning and the ability to drive two lasers with a single controller. DLC pro-controlled laser systems are available both as tabletop and as rack-mounted variants. The latter is seamlessly integrated into Toptica's T-Rack laser rack systems.

The transition towards Quantum 2.0 requires industrial laser systems that excel in the aspects

- Integration: the same functionality with less power consumption, in a smaller volume
- Scalability: providing many complex systems controlled within a single platform
- Operational ease: the product must be able to be operated in a user-friendly way by non-specialized people.

To move forward in meeting these requirements, Toptica recently developed a new function: the 'quad laser operation' option. It will offer the end-user the possibility to drive up to four DFB or DL pros or MTA DL pros at the same time. An upgrade for existing systems will be available. All existing options will continue to be supported for each laser: DLC lock option, DL/MOT, FALC pro ...

The integration of the systems will be improved by allowing more compact configurations of the T-Rack laser rack systems.

For tabletop lasers, in addition to saving space in the lab, it will become easier to use one single GUI for all four lasers.

Together with the hardware improvement, the Toptica graphical user interface has been revisited to offer a better experience to the end-customer – the layout has been reviewed. A dashboard will enable clear supervision of all lasers at the same time, while it will always be possible to address the laser parameters individually.

In conclusion, with this new option, Toptica continues to support their customers by developing solutions adapted to their current and future needs.

TOPTICA Photonics AG

Guillaume Stern
product manager tunable diode lasers
(quantum technologies)
Lochhamer Schlag 19
82166 Graefelfing / Munich
Germany
phone: +49 89 858370
e-mail: sales@toptica.com
Web: www.toptica.com

High LIDT coatings on large optics for petawatt lasers and line beam systems

Laseroptik uses dedicated equipment to apply dielectric coatings to large optics up to 2 m in length (long axis for rectangular shapes) or 1 m in diameter with a superior spectral uniformity over the complete surface and high LIDT values.

"Maxima", the patented IBS coating machine for large optics (long shapes)

Approved automated ultrasonic and manual cleaning procedures guarantee optimum cleanliness even at these large-scale geometries – the possible sizes and techniques are listed in the table at the bottom of the page.

The uniformity of the coatings is a critical factor for industrial laser applications, e.g. for laser beam expansion and delivery systems. The coating design, inner architecture of the machine and in-situ process control help to reduce gradient effects to a minimum. The uniformity can also be adapted to the radii of curvature, for example with cylindrical lenses.

Rectangular shapes

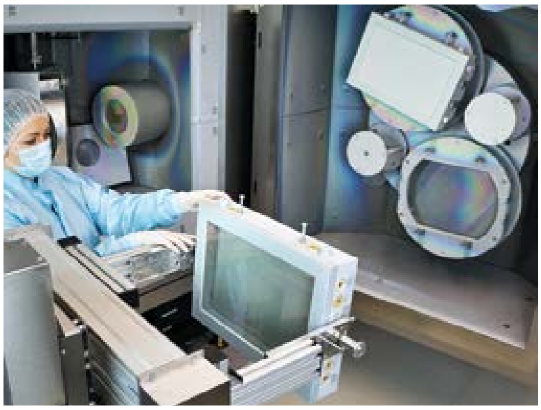
For bar-like rectangular substrates, plane or curved, Laseroptik can coat laser mirrors that are among the largest in the world (up to 2000 mm in length) by using Ion Beam Sputtering (IBS). This method is commonly known for producing the highest quality thin films, but just on small areas. However, by redefining an advanced substrate motion, a unique method for long optics was found and has been patented. Two custom-built machines are currently available to offer this unique process. A variance in central wavelength of below ±1 % can be achieved for optics up to 2000 mm in length.

Round shapes

As with long substrates, large diameter round optics can also be coated by IBS when it comes to providing complex coating designs and superior spectral performance. Laseroptik has commercial coating systems for substrates up to ⌀ 400 mm and custom-built machines for up to ⌀ 550 mm in operation, which are also ideal for rectangular shapes fitting onto the carrier planet.

These specialized machines allow the use of several coating materials, which is important for advanced thin-film design strategies aiming at the highest LIDT. This capability has been used to coat the 440 × 290 × 75 mm^3 beam transport mirrors for HAPLS, the world's highest average power petawatt laser system, located at ELI Beamlines, Prague. A field-optimized hybrid coating design was applied after specific design studies. With a measured LIDT of 0.9 J/cm^2 at 42 fs, 1 kHz and @820 nm / 45°, these coatings exceeded the high power requirements of ELI (see detailed report [1]).

Another common use of large round optics is gravitational wave research. The detector's sensitivity is dependent on the end mirrors' perfection, i.e. the total losses and Brownian noise have to be reduced to a minimum. IBS is well suited to this task as its low loss coatings are approved for gyroscope applications. A tailored environment of separate cleanrooms with dedicated inspection metrology, optic cleaning and annealing solutions was built to support this innovative equipment. It is part of a department that specializes in working with large round and rectangular optics, addressing the highest requirements for LIDT, low losses and spectral performance.



"Teresa", the largest IBS machine suitable for substrates up to ⌀ 550 mm

A space-resolved quality inspection is performed on the whole dimension to check for surface defects and spectral properties, including an interferometric inspection. Large optics are held in custom-built lifting and handling tools for inspection, transport and fixing in the coating machine.

Coating technique	rectangular		round Ø
	long axis	short axis*	
IBS	2000 mm	250 mm	550 mm
IAD	940 mm	80 mm	350 mm
EBE	940 mm	80 mm	500 mm

* at the given maximum of the long axis, can be larger with a shorter long axis

[1] *T. Willemsen, U. Chaulagain, S. Borneis, & W. Ebert:* New IBS coatings boost performance of petawatt laser mirrors, PhotonicsViews (2022)2, 55–58; DOI: 10.1002/phvs.202200016

LASEROPTIK GMBH
Horster Str. 20
30826 Garbsen
Germany
phone: +49 5131 4597-0
e-mail: service@laseroptik.de
web: www.laseroptik.com

Precise characterization of IR emitters

Spectroradiometers are the key component for a wide range of light measurement tasks in many innovative applications. Radiometric, photometric and colorimetric properties are calculated from their spectral data with the aid of extensive software suites, such as SpecWin Pro. Their precision and accuracy are therefore especially important for exact readings.

The mapping of the radiation source via an additional screen and subsequent 2D imaging by the camera make the measuring system considerably more flexible.

Instrument Systems will be presenting its latest spectroradiometer, the CAS 140D IR which is optimized for measurements in the SWIR (short-wave infrared) wavelength range, at Laser World of Photonics 2023. It offers the proven high measurement accuracy and reliability of the CAS140D series – internationally recognized as a reference for wavelengths of 200 – 2150 nm. The new model has a significantly better performance compared to its predecessor in the CAS 140CT series. Thanks to a new design of the optical architecture, throughput has been increased by up to 70 %, and the stray light proportion has again been significantly reduced. A new electronic platform enables faster processing of measurements with a minimum possible integration time of 1 ms and a total scanning time of 9 ms. This guarantees higher productivity due to shorter measuring times, accompanied by greater precision and repeatability. As a supplement to the broadband model, high-resolution devices are available especially for the measurement of narrow-band laser diodes such as VCSELs.

The VTC 4000 without fiber can determine the power, polarization and spatial radiation properties of single emitters. An additional fiber output also enables the analysis of wavelengths with a spectrometer.

Instrument Systems has also developed specific infrared cameras for the comprehensive analysis of VCSEL applications. Due to their unique properties, vertical-cavity surface-emitting lasers (VCSELs) are indispensable components for price-sensitive, laser-based applications. In particular with safety-relevant components such as lidar systems or face-ID, manufacturers must ensure that each VCSEL reacts correctly in their applications. For this purpose, each single emitter must be tested in the near field, as well as the complete VCSEL array in the far field.

The VTC 4000 near-field camera was especially developed for ultrafast, precise 2D analysis of VCSEL arrays. It enables polarization-controlled, simultaneous characterization of all relevant parameters of the single emitters of the array. The 2D quality analysis is performed with unprecedented measurement accuracy thanks to a unique calibration procedure that is based on flat-field and polarization correction, and corrects the polarization dependence of the optical system. Once calibrated, the VTC 4000 enables absolute measurement of power and polarization properties within the field of view in a one-shot process.

The VTC 2400 far-field camera is a high-resolution infrared camera that was developed specifically for the 2D far-field analysis of the radiant intensity distribution of VCSELs and IR emitters. The cost-efficient measuring system consists of a light-permeable, diffusely scattering screen and a monochrome camera. Thanks to the light-shielding camera housing, the system is suitable for both lab and production applications. In the measurement setup, the screen stands between the radiation source (DUT) and the infrared camera so that the typical spatial radiation properties of the DUT are displayed on the screen. The VTC 2400 infrared camera captures this 2-dimensional image in a single measurement and converts the irradiance [W/m^2] to the radiant intensity distribution [W/sr] of the DUT.

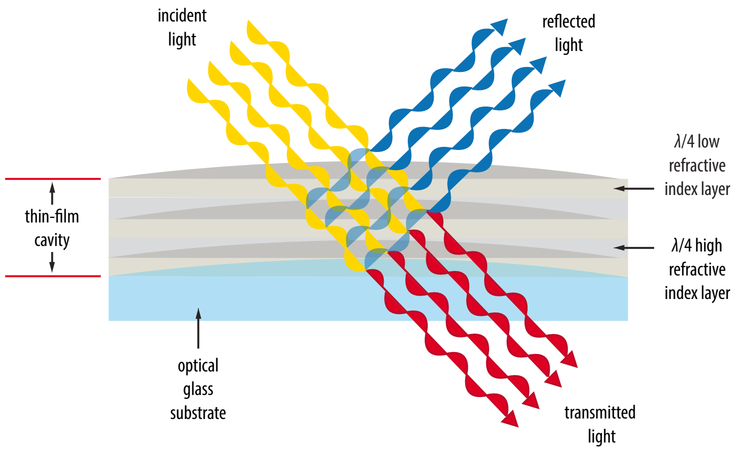
Like all measuring equipment from Instrument Systems, the devices are traceably calibrated to national standards (PTB) and deliver readings with absolute precision. Together with their unique measurement method, this guarantees a minimum error budget and a high level of measurement precision, and manufacturers are able to exploit the full performance potential of VCSELs while ensuring reliable operation.

Instrument Systems GmbH
Kastenbauerstrasse 2
81677 Munich, Germany
phone: +49 89 454 9430
e-mail: sales@instrumentsystems.com
Web: www.instrumentsystems.com

Meet us at Laser World of Photonics 2023, Booth A3.209

Filtering through many options – an introduction to optical filters

Optical filters selectively control light of a particular wavelength or polarization and are essential across many industries in applications such as machine vision, microscopy, spectroscopy, or chemical analysis. Because optical filters are available in numerous sizes and specifications, understanding the nomenclature and key terms will help to differentiate between them.



Interference or dielectric filters consist of multiple deposited layers upon a substrate.

Optical filter designs

Filters transmit and reject particular portions of light energy. Transmission and reflection are typically displayed over a spectral band of interest. Designs are numerous, the most common are longpass, shortpass, bandpass, notch, neutral density (ND), dichroic filters, and polarizing filters. Table 1 summarizes the designs and describes their purpose.

Filter design	Description
Longpass	Transmits and rejects light with a wavelength greater than and less than a particular threshold, respectively.
Shortpass	Rejects and transmits light with a wavelength greater than and less than a particular threshold, respectively.
Bandpass	Transmits light with wavelengths within a particular range and rejects all others.
Notch	Rejects light with wavelengths within a particular range and transmits all others.
Neutral density (ND)	Evenly attenuates light across a broad spectral range.
Polarizing or polarizer	Transmits and rejects light depending on its polarization.

Table 1. A summary of optical filters and their function.

Key design terminologies

Transmission and **transmittance** are slightly different. Transmission is the difference in intensity (radiant flux) between the interfaces of the two surfaces of the filter with the bulk media. Internal and external transmission are measured at the internal and external sides of the interface boundaries, inside and outside of the filter respectively. Transmittance is the ratio between the light intensity exiting the filter to the entering intensity and represents the energy not absorbed or scattered. Rejected light absorbs, scatters, or reflects.

The thresholds for **longpass** and **shortpass filters** are called the **cut-on** and **cut-off wavelengths** respectively, where the absolute transmission is 50 %. The similar specifications for bandpass and notch filters are the combination of the **central** or **center wavelength** (CWL) with the **full width at half maximum** (FWHM). The CWL is the midpoint of the passband of a bandpass filter, or blocking band of a notch filter respectively. The FWHM is defined as width in wavelength units of the spectral range between the two points where the filter has a relative transmission of 50 % of the peak transmission (half of the maximum transmission).

Optical density $OD = -\log_{10}(T)$ describes blocking, where T is transmission as a fraction or decimal.

Filter categories

Optical filters can be divided into different categories based on their construction. Colored glass filters typically consist of molten glass doped with metal oxides or metal powder to obtain their characteristic absorption and transmission characteristics. They absorb the unwanted portion of the light and are a cost-effective alternative to other filter types. They are commonly used in machine vision applications and work well with a wide range of angles of incidence (AOI). More demanding applications such as fluorescence imaging often require higher performance optical interference filters that are created by having alternating layers of high and low refractive index materials. These include traditionally-coated, hard-coated (dielectric), as well as flexible filters. Blocking and transmission characteristics of these filters are much more tightly controlled and they typically have narrower AOI tolerances. With these types of filters, the rejected light is commonly reflected rather than absorbed leading to better damage thresholds.

Cutting through the noise

As outlined briefly above there are a vast range of optical filters, from color glass filters to complex, hard-coated filters. These filters are used in applications spanning machine vision to laser materials processing and biomedical fluorescence imaging and it is important to understand the technical terminologies before considering particular challenges and requirements of the application. Once technical terms are understood and application requirements are specified, the appropriate type of filter design and material construction can be selected.

www.edmundoptics.de

Application of JPT's MOPA fiber lasers in laser technology

Laser technology is based on the principles of quantum mechanics and works by exciting atoms or molecules to a higher energy level, and then allowing them to release that energy in the form of a highly focused beam of light. This technology has many advantages over traditional technologies, such as greater precision, faster processing speeds, and higher energy efficiency.

MOPA fiber laser marking

As the core laser light source in laser technology, a master oscillator power amplification (MOPA) fiber laser is a type of laser that uses a master oscillator to generate a pulsed laser beam, which is then amplified by a power amplifier. This type of fiber laser with tunable pulse width and arbitrary repetition rate is used in many applications where precise control over the laser pulse duration, energy, and frequency is required.

Product description

JPT's MOPA Fiber Laser: YDFLP-M8-20 is a compact, single-mode, MOPA nanosecond ytterbium fiber laser, which has a high peak power of up to 50 kW and adjustable pulse waveforms in the range of 1 – 350 ns.

JPT's MOPA Fiber Laser: YDFLP-M8-20

Technical innovation

Apart from having an independent adjustment of pulse width and pulse repetition rate, the M8-20 focuses on the optimization of pulse peak power and beam quality to enable special material processing. By optimizing the fiber amplifier and utilizing high reliability optical devices, the laser beam of the M8-20 achieves high peak power and good beam quality. Based on its compact components and integrated circuit design, the original structural design now enables better heat dissipation performance and has a smaller volume.

Application advantages

Compared to regular fiber lasers, the M8-20 with five times higher peak power can be applied to more materials that could not be processed by fiber lasers before, which is a significant breakthrough for nonmetal processing of materials such as glass marking, or applying QR codes of 0.5 × 0.5 mm to an aluminum surface.

Laser marking

As an example of nonmetal glass marking, because glass is a transparent material, more than 90 % of the laser energy will go through when a nanosecond fiber laser source with a wavelength of 1064 nm lights the glass surface, but only less than 10 % of the laser energy is absorbed. The regular nanosecond fiber laser's peak power is 15 kW, which cannot achieve the threshold value of damage so as to engrave the glass. However, the M8-20 can reach 50 kW peak power with the appropriate pulse width, which enables perfect glass marking by applying enough peak power with a good beam quality.

Solution provider

For consumers who wish to purchase a laser that can do precision marking of special metal materials, JPT's M8-20 is especially suitable for glass drilling and other applications with requirements for peak power and brightness because the product can maintain excellent beam quality under high-power working conditions, with maximum peak power and brightness.

Shenzhen JPT Opto-electronics Co., Ltd.
1201, Bldg A, Kemron S&T Park, Guanlan
Hi-tech Ind. Area, Longhua Dist.
Shenzhen, China, 518110
phone: +86 755 29528181
e-mail: sales@jptoe.com
Web: www.jptoe.com

Burst mode boosts net cutting speed

Lithium-ion battery foil cutting with picosecond IR lasers and burst mode

Jim Bovatsek

Source all images: MKS | Spectra-Physics

Lithium-ion batteries are the energy storage medium of choice for myriad applications. The enormous demand worldwide is reaching new heights, motivating the development of lower cost, faster production methods. With all these efforts to economic efficiency, the quality of the manufactured batteries must remain at the highest level, a goal that can only be achieved if all the individual components meet their respective quality specifications. MKS, with its different brands in the photonics industry, has conducted intensive research to support customers in optimizing their laser-based production processes. The latest research shows the advantages of using picosecond IR lasers with burst mode.

Lithium-ion batteries have a layered structure comprised of several elements: a cathode battery foil, an anode battery foil, a separator material, and an electrolyte. The battery foils consist of a metal substrate – typically copper for the anode and aluminum for the cathode – and an active material applied as a coating to that substrate. The active material for the anode is very often graphite.

However, for the cathode, several different active material chemistries such as NMC ($LiNiMnCoO_2$), LFP ($LiFePO_4$), or LNMO ($LiNi_{0.5}Mn_{1.5}O_4$) are employed. Battery foils are processed reel to reel, usually requiring that they be cut using a single pass as rapidly as possible. Cut quality is also of particular importance because flaws in the cut edge have the potential to lead to shorting between foils, and subsequent thermal runaway leading to catastrophic failure. Ultrashort pulse lasers are a natural fit to meet this demand for cutting speed and quality given their ability to process a wide variety of materials with minimal heating or melting.

Lasers with burst mode

The advent of high-power, high repetition rate lasers does not by itself lead to high throughput processing. It is well known that an optimal fluence (energy density, typically in J/cm^2) exists for efficient ablation that minimizes thermal damage to the surrounding material. The practical implications of this are that high-energy pulses become efficient only by increasing the spot size (and correspondingly the scan speed), by increasing the number of spots for parallel processing (via beam splitting), or by splitting pulses into many subpulses of lower energy (burst pulses).

While the first two approaches require costly, very high-speed scanning equipment or additional optics for beam splitting, industrial picosecond lasers capable of generating burst pulses now offer a viable alternative. In burst-mode operation, a single high-energy pulse is split into several lower-energy pulses to achieve an optimal fluence by adjusting the optical output in the temporal domain. The burst envelope can be shaped in some advanced implementations of this technology, that is, the energy of each sub-pulse in a burst can be varied.

Focus on key parameters

To further analyze cutting processes, the Spectra-Physics IceFyre IR50 picosecond laser was applied on battery foil materials using the TimeShift burst mode. The results were compared to conventional single pulse processing using a single pass net cutting speed – i.e. the maximum speed at which the material is cut (though some negligible amount of bridging across the kerf is permitted) – and the coating excess ablation, i.e. the distance the coating has receded from the cut edge of the metal foil due to its lower ablation threshold compared to the foil substrate. A cathode material was used consisting of an ~16 µm thick aluminum foil coated on both sides with NMC for a total thickness of ~100 µm. The anode material consisted of an ~11 µm thick copper foil coated on both sides with graphite for a total thickness of ~98 µm.

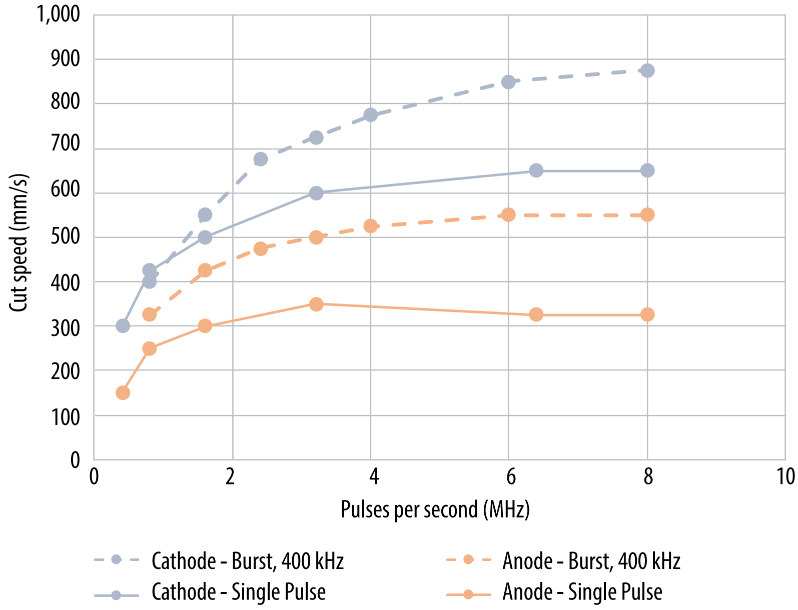


Fig. 1 Net cut speed versus pulses per second for cut results, comparing burst versus single pulse for both anode and cathode foils

Battery foil samples were processed using a single pass, and data was collected for both single-pulse processing with a range of repetition rates from 400 kHz to 8 MHz, and burst-mode processing for a range of burst numbers (two to twenty burst subpulses), all at 400 kHz. To compare the results, the burst-mode data was assigned an equivalent repetition rate computed by multiplying burst sub-pulse numbers by the set repetition rate of 400 kHz. For example, a burst with ten subpulses operating at 400 kHz has 10 × 400,000 = 4,000,000 pulses per second and the corresponding data point was therefore plotted at the 4 MHz point along the horizontal (x) axis. Similarly, a burst data point at the 8 MHz location indicated that the actual laser output (at 400 kHz) was 8,000 kHz / 400 kHz = 20 burst pulses. This data representation allowed both data sets to be plotted versus repetition rate on the same graph. Importantly, for a value along the horizontal plot axis (pulses per second), the individual pulse energies – and hence fluences – are the same for both the single pulse and the burst data points, since the respective average power levels and focus spot sizes are the same.

Higher speed and superior quality

The net cut speed was plotted versus pulses per second for both the cathode and anode materials (**Fig. 1**). For both materials, the plot shows the clear speed benefit of higher burst sub-pulse counts

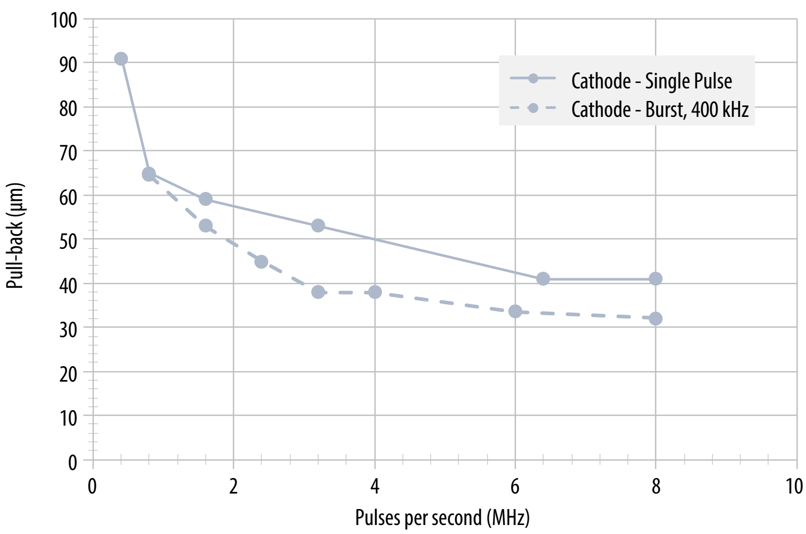


Fig. 2 Excess ablation versus pulses per second for cut results comparing burst versus single pulse for cathode foils

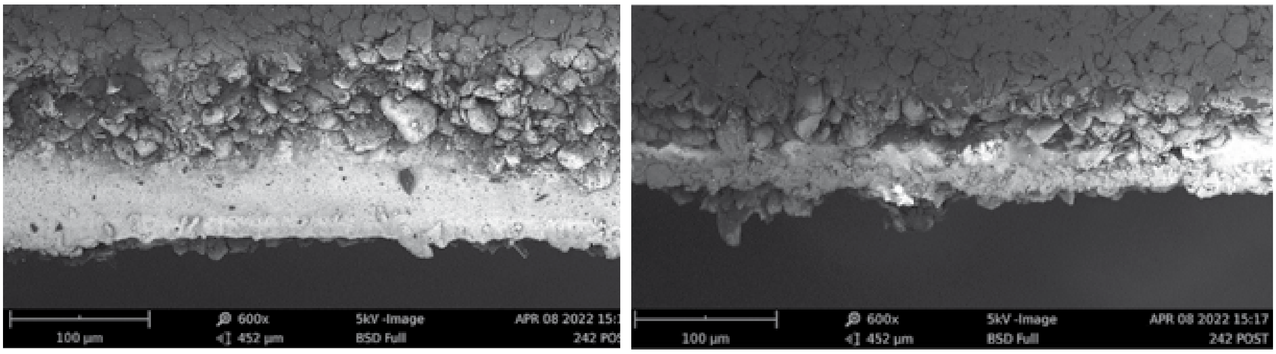


Fig. 3 SEM images of anode foil cut edge. Top: sample was processed at 400 kHz using single pulse mode. Bottom: sample was processed at 400 kHz using a burst of 20 pulses. Images show some protrusion of the metal foil as expected due to the coating excess ablation. The foil is confined to its layer, showing minimal burr or smearing.

that quickly surpasses the single pulse cutting speeds. Burst mode shows an increase in net cutting speed over single pulses of ~35 % and ~57 % for the cathode and anode materials respectively. A similar plot was produced for the coating excess ablation, showing excess ablation versus pulses per second for the cathode material (Fig. 2).

This plot shows that for both single pulse and burst mode the excess ablation is reduced for increased pulses per second, and that burst mode shows a ~22 % decrease in excess ablation versus single pulses when compared at their lowest values. Images were taken for visual inspection, providing a qualitative look at edge quality. Fig. 3 shows two scanning electron microscope images taken of the cut edges of the anode foil. In this case, both were processed at 400 kHz with the upper and lower images showing cuts produced using single-pulse and twenty-pulse burst processing respectively. Both images show the excess ablation of the coating from the metal foil cut edge; however, the ablation is much greater for the non-optimized single-pulse process. It is also noteworthy that in both cases – burst and single-pulse – the quality is very good, with little evidence of melting, burr formation, etc., that could otherwise negatively impact the long-term reliability of high-performance battery cells.

In addition to looking at the coated battery foils, the net cutting speed was investigated for bare copper and aluminum foils. Burst performance was compared with single-pulse performance (Fig. 4) and, as with the coated foils, burst performance was significantly better, showing a ~71 % increase in net cutting speed for aluminum and a ~165 % increase for copper. Based on these results, it is clear that burst processing has distinct advantages over single-pulse processing, leading to higher throughput with improved overall quality. A picosecond laser with TimeShift technology such as the Spectra-Physics IceFyre IR50 laser can tailor the burst parameters and optimize the various cutting processes required in lithium-ion battery manufacturing.

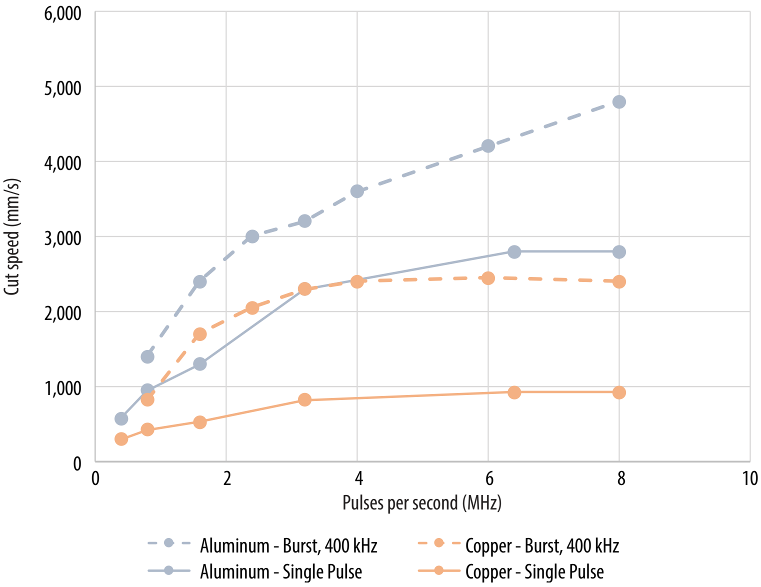


Fig. 4 Cut speed versus pulses per second for bare aluminum and bare copper, showing both burst and single-pulse processing

DOI: 10.1002/phvs.202300016

Author

Jim Bovatsek is a manager of applications engineering at MKS Spectra-Physics' industrial applications laboratory in Milpitas, California. He has concentrated on laser applications development using nanosecond, picosecond, and femtosecond pulsed lasers since 2000, generating various patents and publications. He holds a bachelor of science (physics) degree from the University of California, Santa Barbara.

Jim Bovatsek, MKS Instruments; e-mail: jim.bovatsek@mksinst.com, Web: www.spectra-physics.com, www.mks.com. Local contact: Dr Boris Ruffing, Newport-Spectra-Physics GmbH, Guerickeweg 7, 64291 Darmstadt, Germany; boris.ruffing@mksinst.com, phone +49 6151 708-0

Eye safety assessment of VCSELs

Step-by-step analysis of how to assess the laser safety of typical pulsed VCSELs and VCSEL arrays

Günther Leschhorn

Source: lassedesignen / Adobe Stock. All other images: Instrument Systems / Coherent

Vertical-cavity surface-emitting lasers (VCSELs) are perfectly suited to fulfill the requirements of present and future 3D-sensing applications. However, prior to operating VCSEL-based devices in public, manufacturers must ensure safe operation compliant with the IEC 60825-1 standard or corresponding national equivalents.

Even though vertical-cavity surface-emitting lasers (VCSELs) have been used in various industrial applications for more than three decades, they first gained great popularity and experienced economic growth following the launch of Apple's iPhone X and Face ID technology. On the one hand, VCSEL technology is poised for a breakthrough in consumer electronics and has become a standard part of mobile phones and AR/VR systems. On the other hand, as part of lidar systems, VCSELs could become indispensable components for autonomous driving.

Like all types of lasers, VCSELs are potentially harmful to the human eye or skin, and may cause severe problems such as retinal damage or skin burns. Consumer electronics and lidar manufacturers must therefore carry out a laser safety assessment for their products pursuant to the international IEC60825-1 laser safety standard or equivalent national safety regulations.

VCSELs have special properties in contrast to other typical laser sources, so the determination of the correct laser class is not trivial, and even more so because no easily understandable guideline for the assessment of VCSEL safety has yet been published. In a previous article, we discussed these specialties and outlined a guideline for laser safety class evaluation [3].

In this article, we present a step-by-step analysis of how to assess the laser safety of typical pulsed VCSELs and VCSEL arrays as often used in consumer electronics and automotive lidar applications. We offer two examples that represent typical challenges when dealing with VCSEL sources.

The first focuses on the often very complex temporal emission characteristics. For this evaluation we chose a VCSEL light source used in Apple's iPhone 12.

The second example is a VCSEL array consisting of hundreds of single emitters. This array produced by Coherent [4] is an extended source by the definition of IEC60825-1 and must be evaluated accordingly.

Example 1: iPhone 12 front light source

How do you perform an eye safety assessment and laser class assignment of a VCSEL source with a characteristic temporal behavior? Many VCSEL-based modules in 3D sensing are operated in pulsed mode, requiring a more complex safety evaluation than continuous wave lasers. We chose the example of a light source used in Apple's iPhone 12 (see Fig. 1 top).

The source is a surface emitter with an outline of approximately 83.1 × 84.5 µm and a distinct substructure consisting of four circular-shaped emitters (see Fig. 1 bottom). Intentional long-term viewing is inherent in the function of the product and this should be taken into account when choosing the emission duration to be considered for classification (the so-called time base).

To start with, an evaluation must be performed to establish if this source needs to be treated as a small size or an extended source. The outcome not only affects the emission limits for a certain laser class, but also influences the correction factors used in the assessment.

In order to do this, the angular subtense α must be calculated and compared to the threshold $\alpha_{min} = 1.5$ mrad, beyond which a source is considered extended. Paragraph 7.5.3.3 of [2] states: for surface emitters, the real source is the same as the apparent source, and the size of the real source can be used to determine the angular subtense α. Using the diameter d of the surface emitter (we omit the circular substructures) and the distance r between the surface emitter and the measurement aperture, the angular subtense α is given by

$$\alpha = 2\tan^{-1}\left(\frac{d}{2r}\right)$$

$$= 2\tan^{-1}\left(\frac{\sqrt{\mathrm{DUT}_x^{\,2} + \mathrm{DUT}_y^{\,2}}}{2r}\right)$$

$$= 2\tan^{-1}\left(\frac{118.5\ \mu\mathrm{m}}{2 \cdot 100\ \mathrm{mm}}\right) = 1.18\ \mathrm{mrad}$$

With $\alpha < \alpha_{min} = 1.5$ mrad, the iPhone 12 front light source does not need to be considered as an extended source following the definition given in [2].

Next, all safety-relevant VCSEL parameters must be determined. Of special interest is temporal behavior, measured with the help of an oscilloscope. The source emits pulses of 2.5 ns duration with a period of 7.1 ns. These pulses then form groups of approximately 15 µs duration with a period of 17 µs. The groups are finally emitted in bursts of approx. 10 ms with a period of 334 ms (see Fig. 2). It can be shown that the iPhone 12 front light source is safe, even under the very rough approximation of a regular pulse train with pulse width $t = 2.5$ ns and period $T = 7.1$ ns. However, for the sake of education, we have taken the group and burst structure into account.

Beyond the characteristics of the waveform, we must measure the wavelength and averaged absolute power. The source emits at approximately 934 nm. The spectrum and centroid wavelength are shown in Fig. 3. The averaged absolute power is determined to be 156 µW/nm.

In conclusion, all parameters needed for the classification of this light source are summarized in Table 1.

From these input parameters we can calculate all the necessary correction factors and time points shown as a summary in Table 2. Most of the correction factors depend either on the wavelength of the emission and/or the fact that the source can be considered as small with $\alpha < \alpha_{min}$. As stated above, the time base is chosen for intentional long-term viewing and 30,000 seconds is the emission duration to be considered for classification.

Next, we must calculate the so-called accessible emission limits (AEL). The exposure of the VCSEL source must be smaller than the most restrictive AEL for the anticipated laser class. For pulsed VCSEL sources as described here, three criteria apply (see paragraph 4.3 f) in [1], [3]).

- The single pulse energy must not exceed its corresponding AEL
- The average power of a pulse train must not exceed the AEL of a single pulse of same length
- The energy per pulse must not exceed the AEL of a single pulse multiplied by the correction factor C_5

We will calculate the AEL of the iPhone 12 front light source for Laser Class 1.

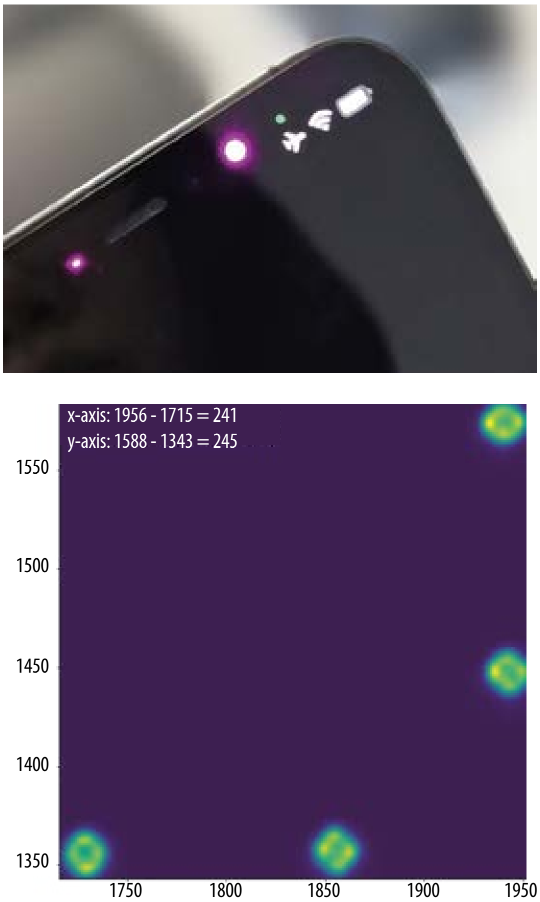


Fig. 1 iPhone 12 front light source. Top: The VCSEL array under examination in this study is shown by a circle. Bottom: the VCSEL array in a closer look. It consists of four VCSELs with an outline of approximately 83.1 × 84.5 µm

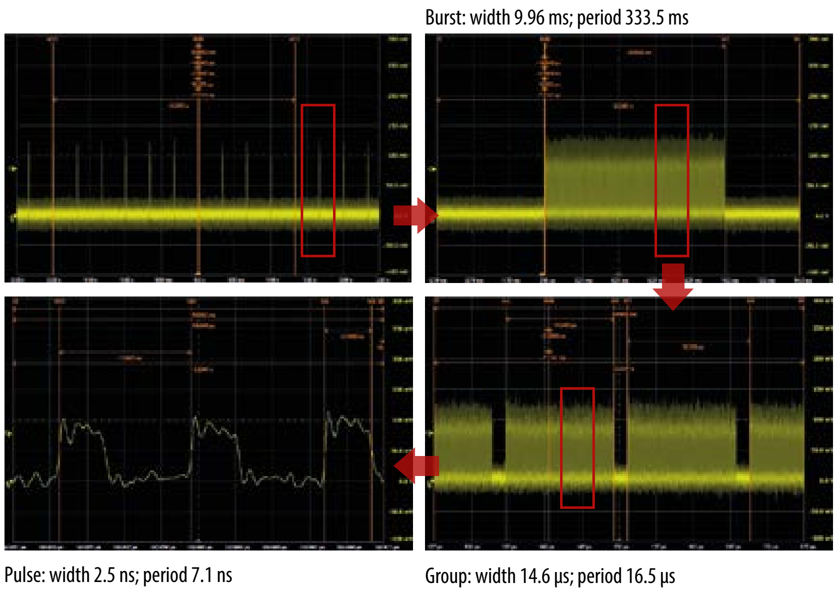


Fig. 2 Series of zoom-in oscilloscope measurements of the temporal characteristic of the iPhone 12 front VCSEL source. It can be seen that the emission is characterized by three time domains (pulse, group and burst)

Limit for a single pulse, based on the pulse width

This criterion states that the exposure from a single pulse may not exceed the accessible emission limit for a single pulse (AEL_{single}). Consulting Table 3 "Accessible emission limits for Class 1 and Class 1M" on page 34 of [1] gives a duration $t = 2.5$ ns for the emission:

$$AEL_{single}\,(t = 2.5\ \mathrm{ns}) = 7.7 \cdot 10^{-8} \cdot C_4\ \mathrm{J}$$

$$= 7.7 \cdot 10^{-8} \cdot 2.94\ \mathrm{J} = 226.4\ \mathrm{nJ}$$

According to 4.3 f) in [1], the accessible

Parameter	Symbol	iPhone	Coherent	Unit	Source	Dependence
Wavelength	λ	934.4	936.3	nm	Spectral measurement with a spectroradiometer (CAS 120HR)	
			Single pulse			
Pulse width	t	2.5	98	ns	Measurement with oscilloscope	
Pulse period	T	7.1	10000	ns	Measurement with oscilloscope	
Pulse repetition frequency	PRF	140.8	0.1	MHz	calculated	$PRF=1/T$
Duty cycle	DC	35.2	0.0098	%	calculated	$DC= t/T$
			Group			
Group width	t_{group}	14.6	-	µs	Measurement with oscilloscope	
Group period	T_{group}	16.5	-	µs	Measurement with oscilloscope	
Group repetition frequency	PRF_{group}	60.6	-	kHz	calculated	$PRF_{group}=1/T_{group}$
Group duty cycle	DC_{group}	88.5	-	%	calculated	$DC_{group}= t/T_{group}$
			Burst			
Burst width	t_{burst}	10	-	ms	Measurement with oscilloscope	
Burst period	T_{burst}	334	-	ms	Measurement with oscilloscope	
Burst repetition frequency	PRF_{burst}	3	-	Hz	calculated	$PRF_{burst}=1/T_{burst}$
Burst duty cycle	DC_{burst}	3	-	%	calculated	$DC_{burst}= t/T_{burst}$
			DUT / emitter			
Dimension *x*	DUT_x	83.1	427.8	µm	Measured with a camera system (VTC4000)	
Dimension *y*	DUT_y	84.5	520.26	µm	Measured with a camera system (VTC4000)	
Beam divergence	Div	209		mrad	Measured with a far-field camera system (VTC2400)	
Average optical power	$P_{average}$	156	-	µW	Measured with a spectroradiometer	
Average optical power hotspot	$P_{average}$(7 mm)	–	1.8	mW	Measured with a far-field camera system (VTC2400)	
Peak output power	P_{peak}	16.7		mW	calculated	$P_{peak}=P_{average}/DC_{burst}/DC_{goup}/DC$

Table 1: Summary of the input parameters needed to perform an eye safety classification.

Company

Instrument Systems

Founded in Munich in 1986, Instrument Systems GmbH develops and manufactures high-end light measurement technology that is indispensable for manufacturers of consumer electronics, (AR / VR) displays, LED wafers, VCSEL / laser systems, automotive lighting and LED / SSL modules. All solutions benefit from our high-precision CAS series of spectroradiometers, widely recognized and in use worldwide. In combination with 2D imaging cameras, integrating spheres and goniometer systems, highly precise and accurate measurements from UV to IR can be performed with traceable results to PTB or NIST. Today, Instrument Systems is one of the world's leading manufacturers of light measurement technology. The Optronik Line products for the automotive industry and traffic technology are developed and marketed at our Berlin facility. Our branch in Korea adds the Kimsoptec Line products to our portfolio and addresses mainly the Korean light and display markets. Instrument Systems has been a subsidiary of the Konica Minolta Group since 2012.

www.instrumentsystems.com

emission of any group of pulses delivered in any given time may not exceed the AEL for that given time, considering every possible emission duration. AEL_{single} must therefore be evaluated for the group-pulse width as well as for the burst-pulse width. Table 3, page 34 of [1] gives emission durations as follows:

$$AEL_{single}(t) = 7 \cdot 10^{-4} \cdot t^{0.75} \cdot C_4 \text{ J}$$

For the group-pulse width and the burst-pulse width this results in:

$$AEL_{single}(t = 14.6\ \mu s)$$
$$= 7 \cdot 10^{-4} \cdot 14.6\ \mu s^{0.75} \cdot 2.94 \text{ J} = 0.5\ \mu J$$

$$AEL_{single}(t = 10\ ms)$$
$$= 7 \cdot 10^{-4} \cdot 10\ ms^{0.75} \cdot 2.94 \text{ J} = 65\ \mu J$$

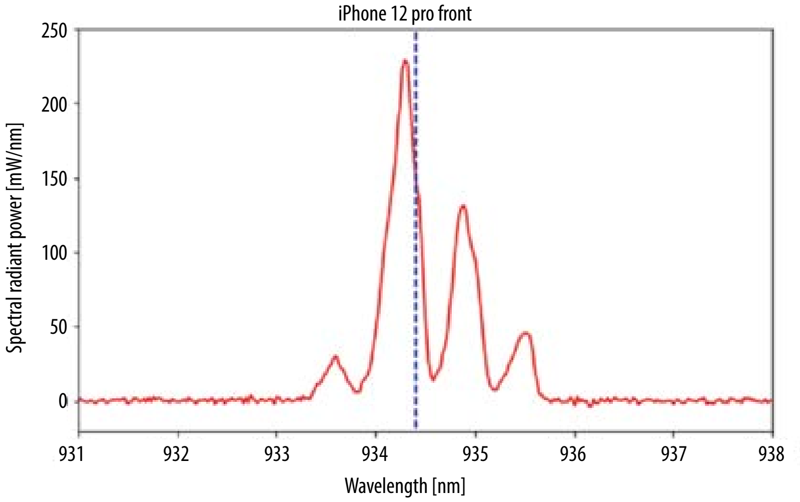


Fig. 3 The spectrum of the iPhone 12 VCSEL front light source. The centroid wavelength is 934.4 nm.

Average power limit for a pulse train, based on the time base

This criterion states that the average power for a pulse train of duration T shall not exceed AEL_T, the limit for a single pulse of duration T. The iPhone 12 front light source has an encoded (irregular) series of pulses. The irregular series can be considered as a regular series, because the maximum duty factor is known (see 7.4.3.1 in [2]). The effective pulse repetition rate is therefore:

$$PRF_{eff} = DC_{burst} \cdot DC_{group} \cdot DC / t$$
$$= 3.74 \text{ MHz}$$

The limit for a single pulse evaluated for the time base is:

$$AEL_T(\text{time base}) =$$
$$3.9 \cdot 10^{-4} \cdot C_4 \cdot C_7 \text{ W} = 1.15 \text{ mW}$$

Converted to energy, the limit for average power for a pulse train is:

$$AEL_{s.p.T}\ (\text{time base}) =$$
$$AEL_T\ (\text{time base}) / PRF_{eff} = 0.31 \text{ nJ}$$

Weighted single pulse limit

The energy per pulse may not exceed the AEL of a single pulse multiplied by the correction factor C_5. The AEL for a single pulse in the pulse train is therefore given by:

$$AEL_{s.p.train} = AEL_{single} \times C_5$$

According to 4.3 f) in [1], a check must be performed whether multiple pulses appear within the period of T_i = 5 µs. Because T= 7.1 ns < T_i, this is indeed the case and therefore, the individual pulses within T_i are counted as a single pulse to determine the effective number of pulses N and the energies are added to be compared to the AEL of T_i.

To determine N, the maximum emission duration that needs to be considered is T_2. The effective number of pulses is given by:

$$N = \frac{T_2}{T_i} = 2 \cdot 10^6$$

The pulse duration t is smaller than T_i and N > 600. Therefore, the equation $C_5 = 5 * N^{-0.25}$ (with a minimum value of $C_5 = 0.4$) must be used to determine the correction factor C_5. Because of the high

Parameter	iPhone	Coherent	Unit	Source in [1]	Description/Explanation
			Time points for λ = 934 nm		
T_i	5	5	µs	Table 2; page 28	valid for spectral range 400 – 1050 nm
T_2	10	-	s	Table 9; page 39	valid for small sources with $\alpha < \alpha_{min}$=1.5 mrad
T_2	-	10	s	Table 9; page 39	valid for extended sources with $\alpha \leq$ 100 mrad
Time base	30000	100	s	4.3 e) 3); page 27	λ > 400 nm and intentional long-term viewing
			Correction factors for λ = 934 nm		
C_4	2.94	2.97	-	Table 9; page 39	Calculated from $C_4 = 10^{0.002\ (\lambda - 700)}$
C_5	0.4	0.4	-	Table 9; page 39	Calculated from $C_5 = 5 \cdot N^{-0.25}$ (with a minimum value of C_5 = 0.4)
C_6	1	-	-	Table 9; page 39	valid for small sources with $\alpha < \alpha_{min}$= 1.5 mrad
C_6	-	3.33	-	Table 9; page 39	valid for extended sources with $\alpha > \alpha_{max}$= 5 mrad
C_7	1	1	-	Table 9; page 39	valid for spectral range 700 – 1150 nm

Table 2: Time points and correction factors defined in [1] and determined using the emission wavelength and small source condition.

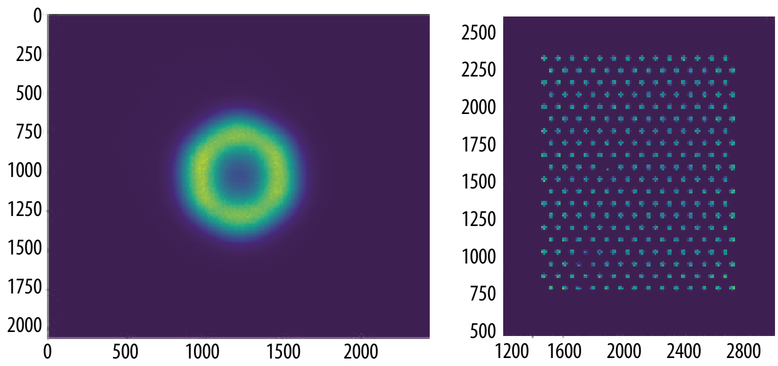


Fig. 4 Coherent module consisting of 280 VCSELs (right) and the resulting beam profile (left), values in [µm]

number of effective pulses, the minimum value of C_5 must be used. The *AEL* of T_i is thus:

$AEL_{\text{s.p.train}}(T_i) = AEL_{\text{single}}(T_i) \times C_5$
$= 7 \cdot 10^{-4} \cdot T_i^{0.75} \times C_4 \cdot C_5 = 87\text{ nJ}$

In conclusion, the accessible emission limit for the average power, based on the time base

$AEL_{\text{s.p.T}}(\text{time base}) = 0.31\text{ nJ}$

is the most restrictive requirement. This is the *AEL* for Laser Class 1 of the iPhone 12 front light source and the exposure of the VCSEL source must be smaller in order to be classified as a source with Laser Class 1. We take the simplest approach and compare the total laser energy per pulse with the *AEL*.

The laser energy per pulse is given by

$Q = P_{\text{peak}} \cdot t = 16.7\text{ mW} \cdot 2.5\text{ ns}$

$= 0.04\text{ nJ} < 0.31\text{ nJ}$

and therefore, the iPhone 12 front source is a laser with Laser Class 1.

Example 2: Coherent VCSEL array

How do you perform an eye safety assessment and laser class assignment of an extended VCSEL source? We examine a VCSEL array in pulsed-operation mode with a light emission in the infrared wavelength region at 936.3 nm. We have chosen a Coherent V940-5903-G01 VCSEL array with 280 single emitters as a typical representative of 3D sensing modules (see Fig. 4). The Coherent VCSEL array is operated at 98 ns pulse width and a period of 10 µs. The time base is 100 s because intentional long-term viewing is not inherent in the function of the product. The laser energy per pulse is measured and given by

$Q = P_{\text{average}}\,(7\text{ mm}) \cdot \frac{t}{DC}$

$= 1.8\text{ mW} \cdot \frac{98\text{ ns}}{0.0098} = 18\text{ nJ}$

Although the DUT is obviously an extended array of sources, a classification assessment should always start with the assumption that the source is small and C_6=1 can be assumed. This is the most conservative assessment and eliminates the need to determine the angular subtense. If the *AEL* values of the pursued laser class are not exceeded, no further analysis is needed.

Following this best practice, we start by calculating the *AELs* for Laser Class 1, assuming a small source. Starting with the single pulse limit criterion, we consult Table 3 "Accessible emission limits for Class 1 and Class 1M" on page 34 of [1] and obtain the following encouraging result for the emission duration $t = 98$ ns:

$AEL_{\text{single}}\,(t = 98\text{ ns}) = 7.7 \cdot 10^{-8} \cdot C_4\text{ J}$
$= 229\text{ nJ} > Q = 18\text{ nJ}$

However, analyzing the criterion of the average power for a pulse train, we must face the fact that the laser energy per pulse is higher than the AEL:

$AEL_{\text{s.p.T}}(\text{time base})$

$= AEL_T(100\text{ s}) \,/\, PRF$

$= \frac{3.9 \cdot 10^{-4} \cdot C_4 \cdot C_7}{PRF} = \frac{3.9 \cdot 10^{-4} \cdot 2.97 \cdot 1\text{ W}}{0.1\text{ MHz}}$

Since the conservative assessment unfortunately did not work out, we proceed by taking the extended nature of the source into account. The spread of energy over a larger retinal spot reduces the retinal hazard and this fact might still allow for classifying the source as Laser Class 1.

The angular subtense α must be calculated and compared to the threshold α_{min}= 1.5 mrad, beyond which a source is considered extended:

$\alpha = 2\tan^{-1}\left(\frac{d}{2r}\right)$

$= 2\tan^{-1}\left(\frac{\sqrt{\text{DUT}_x^{\,2} + \text{DUT}_y^{\,2}}}{2r}\right)$

$= 2\tan^{-1}\left(\frac{673.6\text{ µm}}{2 \cdot 100\text{ mm}}\right) = 6.74\text{ mrad}$

With $\alpha > \alpha_{\text{min}} = 1.5$ mrad, the Coherent module is indeed an extended source by the definition given in [2].

This fact changes the time point T_2 and correction factor C_6. According to Table 9[1)] on page 39 of IEC 60825-1,

$T_2 = 10 \times 10^{\left(\frac{\alpha - \alpha_{\text{min}}}{98.5}\right)}\text{ s} = 11.303\text{ s}$

and

$C_6 = \alpha_{\text{max}} / \alpha_{\text{min}} = 3.33$

Consulting Table 4 "Accessible emission limits for Class 1 laser products: extended sources" on page 35 of [1] gives for the emission duration $t = 98$ ns:

$AEL_{\text{single}}\,(t = 98\text{ ns}) =$
$7.7 \cdot 10^{-8} \cdot C_4\,C_6\text{ J} = 762\text{ nJ}$

$AEL_{\text{s.p.T}}\,(\text{time base}) = AEL_T\,(100\text{ s})/PRF$
$= 7 \cdot 10^{-4} \cdot C_4\,C_6\,T_2^{-0.25}/PRF = 38.9\text{ nJ}$

$AEL_{\text{s.p.train}} = AEL_{\text{single}}(t = 98\text{ ns}) \times C_5$
$= 7 \cdot 10^{-4} \cdot C_4\,C_6\,C_5 = 304.6\text{ nJ}$

Before calculating the last equation covering the weighted single pulse limit, we checked that there are no multiple pulses within T_i. For the weighted single pulse limit, the correction factor C_5 is needed. This is calculated according the procedure described in Section 4.3 f) in [1]. T_2 is shorter than time base and therefore used to calculate the effective number of pulses in the emission duration.

$N = \frac{T_2}{T} \approx 10^6 > 600$

N is much larger than 600 and hence the formula $C_5 = 5 \cdot N^{-0.25} = 0.158$ for the correction factor C_5 applies. The calculated value is so small that we must use the minimal value of 0.4.

In conclusion, the accessible emission limit for the average power, based on the time base

1) We encourage users of IEC 60825-1 to be very careful when calculating the change of T_2 with angular subtense. The formula $T_2 = 10 \times 10^{(\alpha - \alpha_{\text{min}}/98.5)}$ s in the standard is misleading and errors here are highly likely. The authors of the standard intended alpha to be inserted in milliradian and the unit omitted. The radian is a dimensionless unit and from our point of view a clearer way of presenting this formula would be $T_2 = 10 \times 10^{(\alpha - \alpha_{\text{min}}/0.0985)}$ s and the radian used together with the proper unit prefix.

$$AEL_{s.p.T}(\text{time base}) = 38.9\ \mu\text{J} > Q$$

is the most restrictive requirement and is larger than the laser energy per pulse. Therefore, the Coherent VCSEL array is an extended laser source with Laser Class 1.

*

The authors would like to acknowledge very helpful discussions and advice on eye-safety assessment of VCSELs from Coherent, Inc.

DOI: 10.1002/phvs.202300022

[1] International Standard IEC 60825-1 Edition 3.0 2014-05 Safety of laser products – Part 1: Equipment classification and requirements

[2] Technical Report IEC/TR 60825-13 Edition 2.0 2011-10 Safety of laser products – Part 13: Measurements for classification of laser products

[3] *G. Leschhorn* et al.: How to assess the Eye Safety of VCSELs – Introduction, LED professional Review (LpR), Issue 93/Sept-Oct/2022

[4] https://ii-vi.com/vcsel-technology/

Author

Günther Leschhorn joined Instrument Systems, based in Munich (Germany), in 2012 as a product manager and headed the product management department until 2020. Today, Dr Leschhorn serves as a business researcher coordinating the business activities of the Konica Minolta Sensing Group.

Dr. Günther Leschhorn, Instrument Systems GmbH, Kastenbauerstraße 2, 81677 München, Germany; phone: +49 89 4549430; e-mail: leschhorn@instrumentsystems.com, Web: www.instrumentsystems.com

Changing the landscape of automotive 3D sensing

VCSEL technology enables high performance, accurate sensing, and increased reliability

Matthew Everett, Jay Skidmore, and Alex Ju

Source all images: Lumentum

VCSEL-based lidar solutions can accelerate the adoption of ADAS – and ultimately, fully autonomous vehicles – by providing higher performance, greater efficiency, increased accuracy, and higher reliability at a lower cost, compared to existing systems. The flexibility of VCSEL technology makes these systems suitable for 3D sensing applications throughout the car, including in-cabin sensing, short-range sensing (<1 m), and long-range sensing (>200 m).

While the automotive industry has transitioned from the testing phase of increasingly complex systems for advanced driver assistance systems (ADAS) and autonomous vehicles (AVs) to mass volume production, conventional manufacturing limitations and high costs have inhibited the broad adoption of these systems. Until now, many of the light detection and ranging (lidar) sensors in early ADAS and AV systems used edge-emitting lasers (EELs) because requirements were relatively low, the technology was effective, market volumes were modest, and price sensitivity was secondary to the demonstration of the technology's performance. However, as the demand for smaller, more economical, higher-performing solutions grows, advances in vertical cavity surface emitting laser (VCSEL) and lidar technology are now making it possible to implement lower cost, more accurate, and higher reliability 3D sensing solutions for lidar than ever before.

Advantages of VCSEL technology over EELs

Using a VCSEL array as the light source instead of an EEL can significantly improve lidar cost competitiveness, scalability, and reliability. In terms of raw performance, EELs can provide a higher power density than VCSEL arrays (i.e., power per mm^2). However, the output from an EEL is in the plane and has an asymmetric output that makes both the optical design and delivery more complex. Depending on the configuration, VCSEL arrays may enable the designers to focus light better, improving overall illumination of objects of interest within the FOV that result in higher accuracy of reflectivity and depth perception (i.e., distance/size of object to be detected).

Ultimately, EELs and VCSEL arrays are both illumination sources. As such, wavelength, power, performance, size, and reliability all play a decisive role in whether a particular technology is viable for sensing. The performance of a sensor is judged by how much of the power

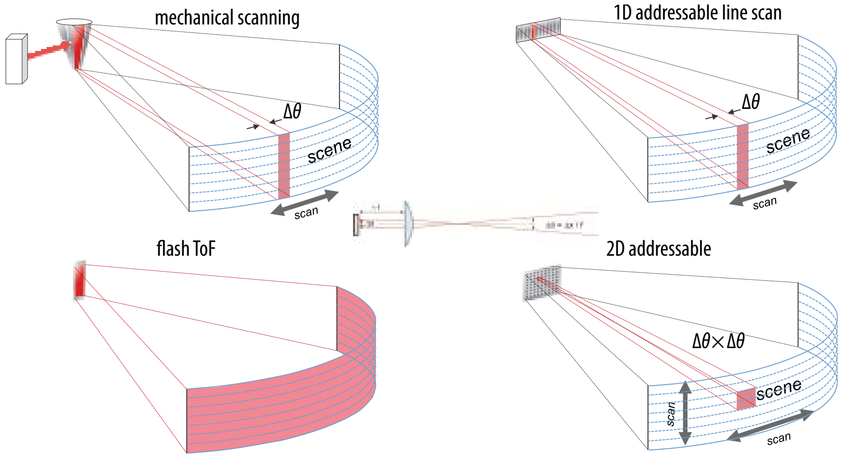


Fig. 1 Common lidar architectures for long-range sensing

is used to illuminate the target FOV and provides useful information. The wavelength and power of long-range sensors are important for eye safety as well as other factors such as the signal-to-noise ratio (SNR). If too much power is directed to the same area, depending on wavelength, the illuminator could cause eye injury.

The overall size of the sensor determines where it can be deployed within the vehicle and how flexible those options may be. While integrated circuit size affects printed circuit board footprint, the profile (i.e., height) of the sensor is impacted by the complexity of the optics. As EELs require mechanical scanning using mirrors or other methods, they often need more complex optics than VCSEL-based sensors.

Reliability is critical for automotive applications. Both EEL and VCSEL technology have a long history of meeting demanding reliability requirements owing to their telecom heritage e.g., undersea pumps and high-speed datacom chips that need to operate reliably over a long lifetime. However, one key advantage that favors VCSEL arrays over EELs is their intrinsic redundancy: if a VCSEL cell fails, the rest of the array is still operational. For example, the total illumination of a VCSEL array with 128 cells is reduced by less than 1 % if a single VCSEL cell fails. If an EEL fails, the sensor itself fails. Another benefit of multiple-emitter sources is improved depth accuracy due to the randomization of the optical modes, which reduces speckle.

Addressing the need for more accurate in-cabin sensing

Playing increasingly important roles in effective ADAS functionality are the driver monitoring systems (DMS) and occupancy monitoring systems (OMS). These increase driver and passenger safety in a number of different ways. While on the move, they can determine whether seatbelts are fastened, assess occupant size and position, track driver eye-gaze, and measure biometrics such as driver heart rate and temperature to confirm the driver is focused and aware. Other safety features include driver face recognition, rear seat occupancy sensing when exiting and leaving the vehicle, and movement detection after the vehicle is parked. In-cabin 3D sensing can also enable features like gesture recognition of in-cabin controls to make it easier – and safer – for drivers to interact with the console and not have to take their eyes off the road.

Note that many of these features have made their way into automotive regulations. For example, DMS has become or is scheduled to become mandatory in the US and Europe in the coming years [1]. Elements of OMS, particularly for child safety, are slated to be standardized by 2025 [2]. As a consequence, automotive OEMs need 3D sensing technology that can accurately and reliably perform DMS and OMS functions.

There are numerous design challenges to overcome for in-cabin sensing applications. 3D sensing systems need to accurately detect the driver and occupants under a variety of environmental conditions, including nighttime darkness and very bright direct sunlight. They also need to be able to transition quickly between these extremes, such as when a car drives into a tunnel and then out again. FOV challenges include accurate detection within the FOV even under obscured conditions; system challenges include maintaining the security of the sensing system and reducing overall power consumption.

Light emitting diodes (LEDs) have been used for illumination in implementations of early 2D, camera-based DMS/OMS systems. However, to address in-cabin challenges, systems need higher peak power, better efficiency, and a more compact footprint. For example, the wide spectral bandwidth of LEDs means that energy is spread across more of the spectrum, leading to a lower SNR, reduced depth perception, and higher light losses outside the FOV.

VCSEL arrays are replacing LEDs in many in-cabin applications. They focus energy within a narrow spectral bandwidth, resulting in better spectral stability and faster rise and fall times compared to LEDs. Field of illumination (FOI) flexibility and optimized beam shape allow the VCSEL array FOV to fit the sensor better, reducing light losses for higher system efficiency. Their narrow spectral bandwidth also allows the use of a narrower band pass filter for a higher SNR and superior depth resolution and, with that, VCSEL-based systems can more accurately detect hand gestures and eye movements, enabling recognition and tracking capabilities that are not feasible with LEDs.

The narrow spectral bandwidth of VCSELs means there is no red present in the emitted light that can potentially distract drivers. VCSEL light is also more flexible in how it can be projected, enabling the in-cabin sensing system to diffuse, scan, or diffract light into different areas efficiently. Higher brightness (i.e., lower divergence) makes it easier for the system to direct light where it needs to be, while the current shift to time-of-flight (TOF) processing benefits from the faster VCSEL array speed. High power efficiency and a compact size also make it possible for VCSEL-based sensors to be implemented in-dash.

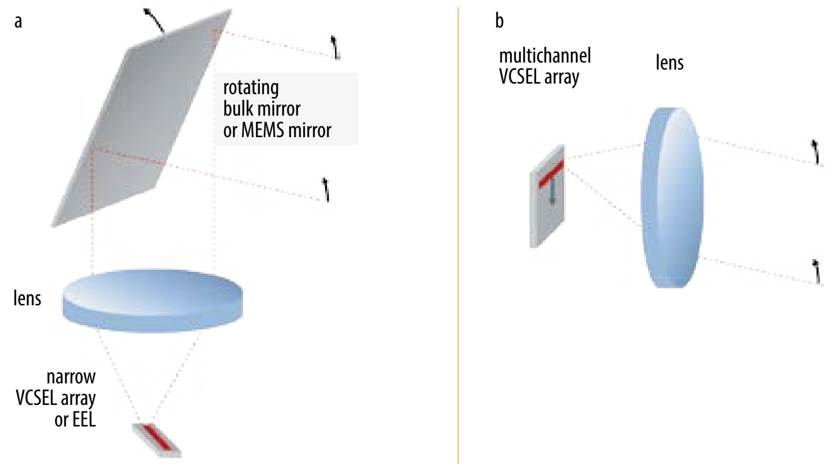


Fig. 2 Mechanical (a) vs electronic (b) scanning

The many advantages of VCSEL arrays over LEDs and other EELs set the foundation for the expansion of next-generation in-cabin capabilities as the industry shifts from ADAS to AVs with DMS and OMS, including safety, biometrics, and custom data features to name a few.

Higher power mid to long-range 3D sensing

Outside the cabin, AVs need mid to long-range sensing of the order of 10 m to 200 m. Common lidar architectures for long-range sensing include mechanical scanning, flash ToF, and 1D-addressable and 2D-addressable line scan architectures (see Fig. 1).

For efficient, long-range lidar sensing, the system must be able to deliver high power within narrow angular slices or blocks. Higher power at a distance means higher power at the light source. Power can be delivered at a low ($\lesssim$0.1 %) duty cycle to decrease power consumption and address heat dissipation issues. In effect, a short, high-power pulse of the order of a few nanoseconds can be sent with several microseconds between pulses and still achieve a reasonable z-resolution. Consider that a 1 ns roundtrip for light is about 0.15 m. Thus, a 1 µs roundtrip is required to sense objects that are 150 m away.

Multijunction VCSELs can deliver the high power needed for long-range lidar. Typically, higher output power requires higher current, with power losses equal to the square of the current (I^2R). However, more junctions in a VCSEL means that it can deliver more photons (higher output power) for the same input current. The overall laser efficiency is increased because the parasitic resistive losses are shared amongst many junctions instead of just one. Furthermore, reducing the drive current required improves the driver efficiency. Combine this with a low ($\lesssim$0.1 %) duty cycle, and a 200 mW to 3 W multijunction VCSEL can achieve high power density ranging from 100 W/mm^2 to 1.5 kW/mm^2.

Existing long-range lidar systems utilize 905 nm EELs combined with mechanical scanning using either a rotating bulk mirror or MEMS controlled mirror (see Fig. 2). By its physical nature, mechanical scanning is complex and requires large, more expensive optics.

The flexibility of multijunction VCSELs has made all-electronic lidar scanning possible (i.e., fully solid-state), enabling OEMs to simplify scanning and lower the optics cost (see Fig. 2). Rather than having to control a physical mirror, the lidar sensor scans by selecting and energizing different VCSELs in an array. A larger IC is required because of the size of the VCSEL array, but the overall optics are simple and compact. The scanning system is also more robust because there are no mechanical parts, which is especially beneficial in automotive environments that inherently experience ongoing vibration.

All-electronic lidar scanning is achieved through an addressable VCSEL array geometry. This can be column addressable for 1D-addressable ToF scanning, or matrix addressable for 2D-addressable ToF scanning (see Fig. 3). Overall, electronic scanning using a multijunction VCSEL array lowers the system cost while increasing performance, range, power efficiency, and accuracy. The complete long-range system is also more compact because of the smaller optics required, making it more flexible as to where it can be built into the vehicle.

Column addressability has the advantage of simpler fabrication, and it works with commonly available line read-out, single-photon avalanche diodes (SPADs). A larger chip or many bond-pads are often required. There is another set of trade-offs depending on the width/number of channels. With narrow spacing, there is higher resistance and lower power-output uniformity but better overlap with the SPAD column. With wider spacing, resistance is lower and uniformity is better, but the overlap with the SPAD column is worse.

Matrix addressability requires more complex VCSEL fabrication as well as a detector with a block read-out format. However, the VCSEL area can be reduced with fewer contact pads (i.e., $M + N$ pads for a $M \times N$ array) compared to column addressable architectures for a similar number of channels. As current flows over a wider path, there is better uniformity over the sub-array.

Company

Lumentum

Lumentum (NASDAQ: LITE) is a market-leading designer and manufacturer of innovative optical and photonic products enabling optical networking and laser applications worldwide, including vertical-cavity, surface-emitting laser (VCSEL) arrays for 3D sensing and other applications. Lumentum optical components and subsystems are part of virtually every type of telecom, enterprise, and data center network, while the company's lasers enable advanced manufacturing techniques and diverse applications including next-generation 3D sensing capabilities. Lumentum is headquartered in San Jose, California with R&D, manufacturing, and sales offices worldwide.

www.lumentum.com

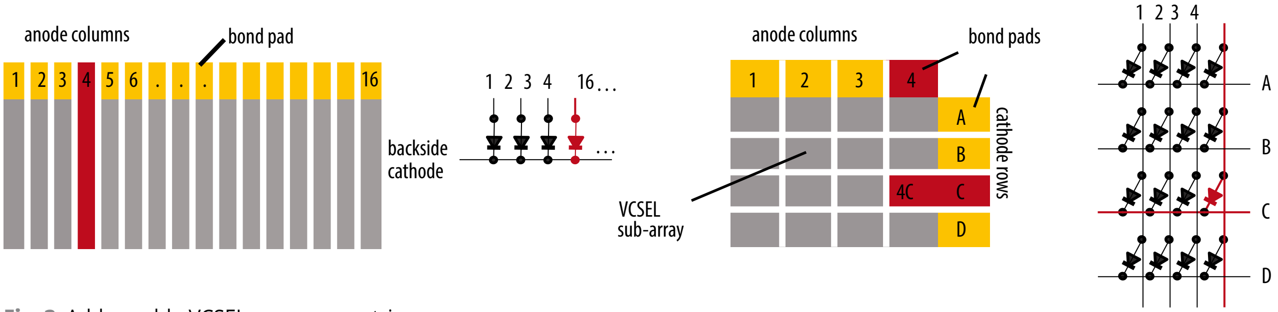


Fig. 3 Addressable VCSEL array geometries

A matrix-addressable architecture is more efficient with optical power, supporting longer ranges. By comparison, EELs do not adapt well for addressable configurations given that they are typically discretely fabricated. This is why VCSELs are the preferred choice for 1D and 2D-addressable arrays.

To illustrate the effectiveness of VCSEL-based sensing, consider the AT128 lidar from Hesai Technology, the industry's first 200-meter long-range, VCSEL-based, hybrid solid-state lidar for ADAS. Lumentum worked with Hesai to achieve an all-VCSEL design with an array of 128 high-power, multijunction VCSELs emitting at 905 nm. The sensor achieves 200 m range with 10 % reflectivity and a high point density of over 1.5 million points per second.

Reflectivity is an important characteristic of a long-range sensor, as it determines how much light an object has to reflect at a specific distance in order for the sensor to detect it. Original equipment manufacturers (OEMs) can expect to detect even smaller objects at greater range with the next-generation VCSEL arrays that are anticipated to lower reflectivity down to between 5 and 3 %.

Higher resolution short-range sensing

Lidar is also replacing ultrasonic sensors around the vehicle for short-range (<1 m) scanning that detects if a person or another vehicle is within close proximity. The size and shape of EELs, combined with the way they operate, does not work well for sensing within one meter. Camera-based short-range sensors also have problems, such as achieving sufficiently high resolution at close distances and/or operating under extreme lighting conditions such as direct sunlight.

VCSELs are already being deployed in industrial robotic applications for short-range scanning, and the technology supporting capabilities such as proximity sensing have already been proven on the factory floor. Flash scanning enables the sensor to scan the whole scene at close range and at a wide angle, collecting all relevant data in the scene at once. This same technology is also used in mass consumer applications, including gaming devices and phones. As a cost-effective technology, OEMs will be able to deploy VCSEL-based systems in new ways to further increase safety, check if there is an animal or object under the vehicle when starting the engine for example.

Short-range VCSEL-based lidar also provides 3D sensing information rather than just distance data on nearby objects. This means that advanced short-range systems could provide object detection and identification if required. Flexible VCSEL arrays make it simple to scale lidar power, and VCSEL 'point cloud' processing simplifies image processing compared to camera images. Short-range sensing is affected less by extreme light conditions because VCSEL-based lidar uses infrared.

The future of automotive 3D sensing

Automotive systems have to operate for more than a decade, and the robustness of VCSELs can give automotive OEMs greater confidence in their long-term reliability compared to sensors with mechanical architectures. Over a billion VCSELs have been deployed worldwide over the past decade in a wide range of demanding mobile, consumer electronics, and industrial applications that have proven the reliability of the technology under challenging operating conditions subject to vibration and extreme temperatures.

From a supply chain standpoint, the scalability, quality, and reliability are important advantages of VCSEL-based lidar. VCSEL array technology already leverages significant manufacturing economies of scale with millions of VCSELs shipped weekly to consumer and automotive applications. As a component of emerging ADAS systems, VCSEL array quality and reliability has been well established, and the manufacturing infrastructure is already in place to keep pace with rising demand as ADAS becomes more pervasive and advanced. In contrast, EELs are more complex to build and do not practically support all-solid-state solutions (i.e., 1D and 2D matrix addressable). Manufacturers will have difficulty scaling operations to keep up with growth when considering the full optical solution.

In addition to keeping costs down, VCSEL technology already meets the reliability requirements for use in vehicles, due in part to their intrinsic redundancy as mentioned earlier. AEC-Q102 qualified VCSEL arrays that provide leading optical power density and efficiency are available in volume today, making them ideal for high-performance ADAS and AV applications.

Enabling next-generation capabilities cost-effectively

VCSEL-based lidar is rapidly changing the landscape of automotive sensing. The latest generation of high-power, multijunction VCSEL technology is the light source of choice for lidar sensors in automotive applications, delivering higher performance, greater accuracy, increased reliability, and lower cost than existing EELs. Higher peak power density enables accurate sensing at longer distances and, when combined with simpler optics, results in a smaller footprint.

VCSEL-based sensing has a proven history of quality and reliability at consumer levels of production. The technology is flexible enough to support short-range sensing around the vehicle, extended in-cabin sensing capabilities, and even long-range sensing of oncoming vehicles. It is not surprising, then that the automotive lidar market is expected to grow exponentially over the next five years, increasing to over 2.6 billion dollars by 2026 [3].

True solid-state, electronic scanning, lidar systems enable smaller package sizes that OEMs can integrate nearly anywhere in the vehicle, including into the roofline, mirrors, pillars, grilles, or bumpers. Solid-state scanning also makes lidar inherently robust, enabling it to be used in a wider range of applications. Innovations like column and matrix addressability enable VCSEL arrays to implement evolving capabilities through 3D sensing, and, because the same base technology can be used across different ranges, OEMs can bring the reliability of VCSEL technology to all parts of the vehicle.

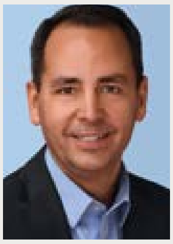
DOI: 10.1002/phvs.202300017

[1] https://cdn.euroncap.com/media/30700/euroncap-roadmap-2025-v4.pdf

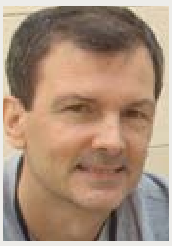
[2] https://unece.org/sites/default/files/2021-12/GRSP-70-30e.pdf, https://www.congress.gov/bill/117th-congress/house-bill/3164/text

[3] https://www.yolegroup.com/press-release/china-is-leading-the-automotive-lidar-market/

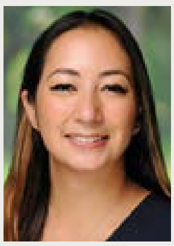
Authors



Matthew Everett is senior director of product line management for imaging and sensing products at Lumentum. He studied chemical engineering at Carnegie Mellon University and obtained an MBA from Santa Clara University. Throughout his career, Matt has held several positions within the semiconductor industry, specializing in lasers and light emitting diodes (LEDs) for a variety of applications.



Jay Skidmore is the VP of the imaging and sensing R&D team at Lumentum. He received his PhD in electrical engineering at UCSB under Dr Larry Coldren, fabricating GaAs/AlGaAs semiconductor lasers. He has held several positions, managing worldwide teams in both R&D and reliability. He holds more than 25 granted patents and has contributed many book and journal publications on high-power semiconductor lasers and packaging.



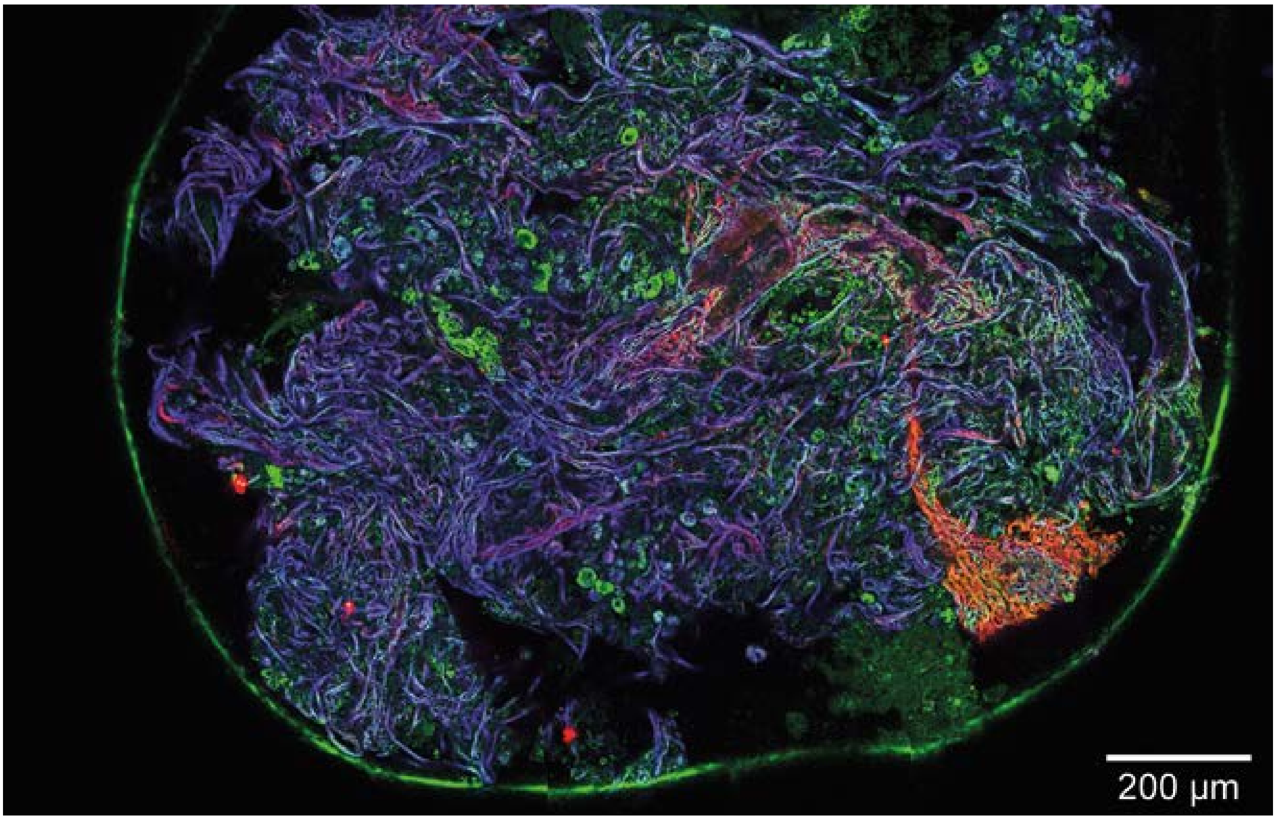
Alex Ju is a product line manager for Lumentum imaging and sensing products. Previously, Alex has worked in research and design roles for emerging technologies, including wearables and additive manufacturing. She received her BFA from the Rhode Island School of Design and her MBA from the New York University Stern School of Business.

Matthew Everett, Jay Skidmore, Alex Ju, Lumentum, 1001 Ridder Park Drive, San Jose, CA USA 95131; e-mails: Matthew.Everett@lumentum.com, Jay.Skidmore@lumentum.com, Alex.Ju@lumentum.com, Web: www.lumentum.com

Ultrashort-pulse lasers help to observe more

Sub-50 femtosecond pulse lasers take a gentle approach to multiphoton microscopy

Frank van Mourik, Marloes Groot, and Oliver Prochnow



The choice of femtosecond lasers for use in multiphoton microscopy is not trivial. It is a fine balance between peak power, pulse energy and laser wavelength. In this white paper we discuss important laser parameters and the impact these have on the quality of the results.

▲ Granular detail: femtosecond lasers were used to produce this multiphoton microscopy image of lung tissue. (Source: M. L. Groot, VU Amsterdam / Flash Pathology)

Multiphoton and higher-order harmonics generation microscopy is particularly suitable for high-resolution three-dimensional and live-cell imaging where single photon techniques are limited by an out-of-focus fluorescent background and the penetration depth. Imaging techniques based on multiple photon interactions – such as two or three photon excitation and higher-order harmonics generation such as second or third harmonic generation (SHG or THG) imaging – have become very useful tools in many biomedical research or clinical diagnosis applications as they provide high contrast imaging capabilities with reduced tissue damage while not necessarily needing artificially induced fluorescent dyes.

For multiphoton excitations to occur, incident photons must arrive at the sample at the same time and place in order to increase the probability of simultaneous multiphoton absorption events by a single fluorescent compound, which means that the efficiency in multiphoton excitation is strongly dependent on the peak intensity of the incident light during the pulse. Therefore, the shorter the pulse, the higher the peak intensity and the stronger the generated signal.

As a consequence of the nonlinear dependence on the light intensity in multiphoton microscopy and higher-order harmonics imaging, the signal is also only collected from within the plane of focus and the excitation light produces almost no out-of-focus emission. This resulting confined multiphoton excitation volume is especially suitable for live-cell imaging as it results in higher depth resolution and significantly less

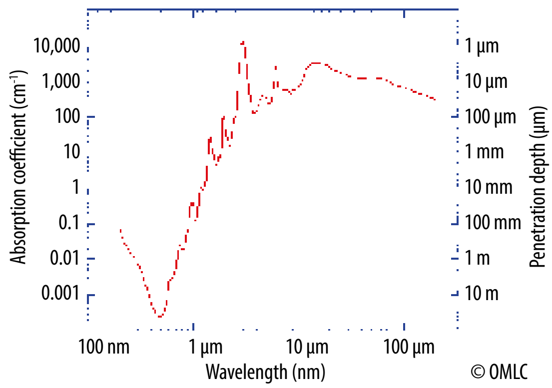


Fig. 1 Absorption cross section of water [3]

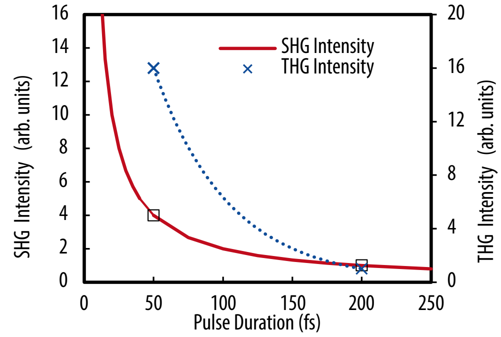


Fig. 2 SHG and THG intensity vs. pulse duration

photodamage through the sample, which prolongs cell viability.

In addition, the longer wavelengths used in multiphoton imaging increase the penetration depth into the sample thanks to the lower scattering. Multiphoton microscopy is therefore often preferred over other techniques for experiments requiring deep penetration and imaging of living cells and tissue. Multiphoton excitation and higher-order harmonics imaging require high peak intensities, which dictates the use of mode-locked lasers with ultrashort femtosecond pulses. The photon density during the pulse must be orders of magnitude larger than in single photon absorption to trigger a significant number of multiphoton absorption events. Previously published results [1, 2] suggest that even shorter pulses than the commonly used pulse durations of 100–200 fs cause lower cell lethality rates and allow for longer-term live-cell imaging. In this article we show that the use of sub-50 fs pulsed lasers produces very bright multiphoton and higher-order harmonics images while keeping the average laser power low, and that this presents a distinct advantage in extending live-cell imaging.

Imaging depth – longer wavelength?

One of the initial considerations in three-dimensional imaging is sample transparency at the selected laser wavelength. In most tissue, the penetration depth is limited by light-scattering due to the inhomogeneous nature of tissue. Light is scattered in anisotropic media, but longer wavelengths undergo less scattering than shorter wavelengths and therefore enable deeper optical sectioning, a greater penetration depth and three-dimensional imaging into thick samples. Light scattering (Rayleigh scattering) scales with $1/\lambda^4$, meaning that scattering is about three times less at 1,050 nm compared to 800 nm. Although even longer NIR wavelengths (e.g. 1.3 µm or 1.7 µm) will further reduce light scattering effects, excellent deep tissue microscopy results can be obtained using wavelengths at around 1,050 nm.

Absorption – shorter wavelengths?

As shown in Fig. 1, another challenge for penetration depth – and increasingly pronounced for longer NIR wavelengths – is absorption within the sample, especially by water. Exchanging water with D_2O can help to alleviate this to some degree, but the laser power will need to be reduced to avoid heating of the sample. The main chemical component of tissue is water and the absorption cross section of water in Fig. 1 can be used to help identify a suitable excitation wavelength. As can be seen, the water absorption is lowest in the visible region. With 0.2 % of the light absorbed per mm, there is also a local absorption minimum around 800 nm.

For three photon microscopy, however, a wavelength of 800 nm poses the problem that the signals emitted by samples are in the UV range (800/3 nm = 266 nm) which is a significant challenge in episcopic detection where the emitted light travels along the same path as the excitation light. Emitted light from the sample passes through the same microscope objective that focuses the excitation light, which typically has limited UV transmission, especially below 350 nm. So a wavelength should be selected for episcopic detection that is long enough to minimize light scattering and avoid poor UV transmission of third order signals, but short enough to minimize water absorption. In terms of scattering and absorption, using a center wavelength of around 1,050 nm provides optimal conditions. By using very short (sub-50 fs) pulses, it is possible to achieve a high signal-to-noise ratio and a deep penetration depth while keeping the average laser power down.

Avoid heating – lower average power

Optical absorption of water at around 1,050 nm amounts to about 2 % per millimeter of path length, which is considerable, but still orders of magnitude lower than at 1,700 nm. At 1,050 nm, with 100 mW average power focused into a field of view (FOV) of 0.5 × 0.5 mm^2, this leads to a local heat deposition of 8 mW per mm^3 ($0.02 \cdot 100 / 0.5^2$), which could cause a temperature increase of about two degrees per second (specific heat of water: 4.2 J g^{-1} K^{-1}) [5]. For most tissues it would not create major problems when the temperature is raised by one degree, but for more sensitive tissue, such as lung tissue with trapped air, the sample may show significant 'dynamics' due to the air expansion. Also, prolonged exposure to a single area can cause thermal problems in all tissues at this power. With a smaller FOV, the average power is deposited on smaller volumes and the thermal heating increases and scales with the inverse of the FOV area [5]. Fortunately, at a length

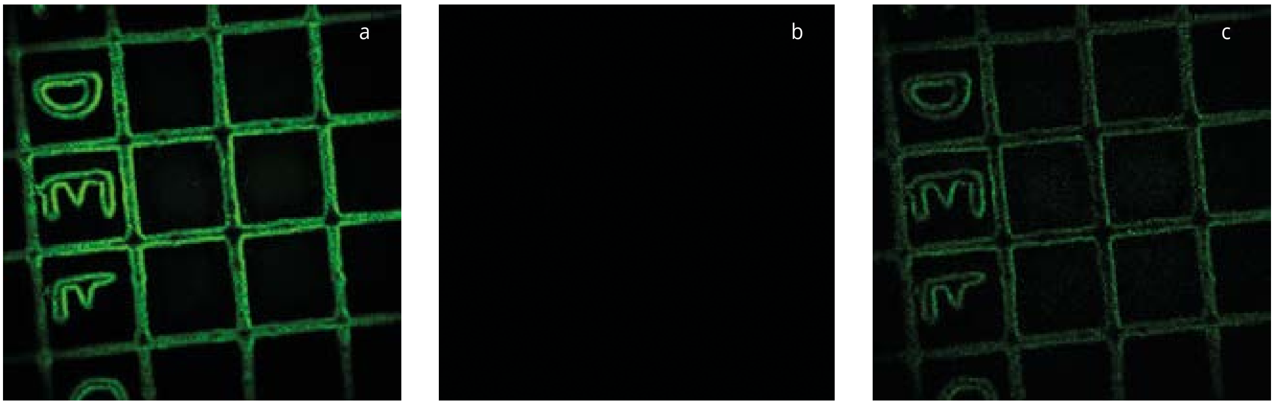


Fig. 3 Third harmonics of a calibration grid (Ibidi) with 50 micrometer squares. a) 4.7 mW, full spectrum short pulses (<50 fs; VALO Femtosecond Series). b) 6 mW with laser spectrum limited to 10 nm bandwidth (~160 fs). c) Scaled up contrast for the 6 mW laser spectrum limited to 10 nm bandwidth (~160 fs). (Source: Marloes Groot Group, VU Amsterdam)

scale of 0.5 mm, thermal diffusion also takes place at a timescale of seconds (the thermal diffusion constant of tissue is about 0.1 mm^2/s), which assists in removing heat. For high average powers it is inevitably a challenge to remove the generated heat fast enough to avoid causing thermal problems or damage in the tissue, so it is of great interest to achieve the best image quality using as low average laser powers as possible.

Why sub-50 fs pulses are gentler

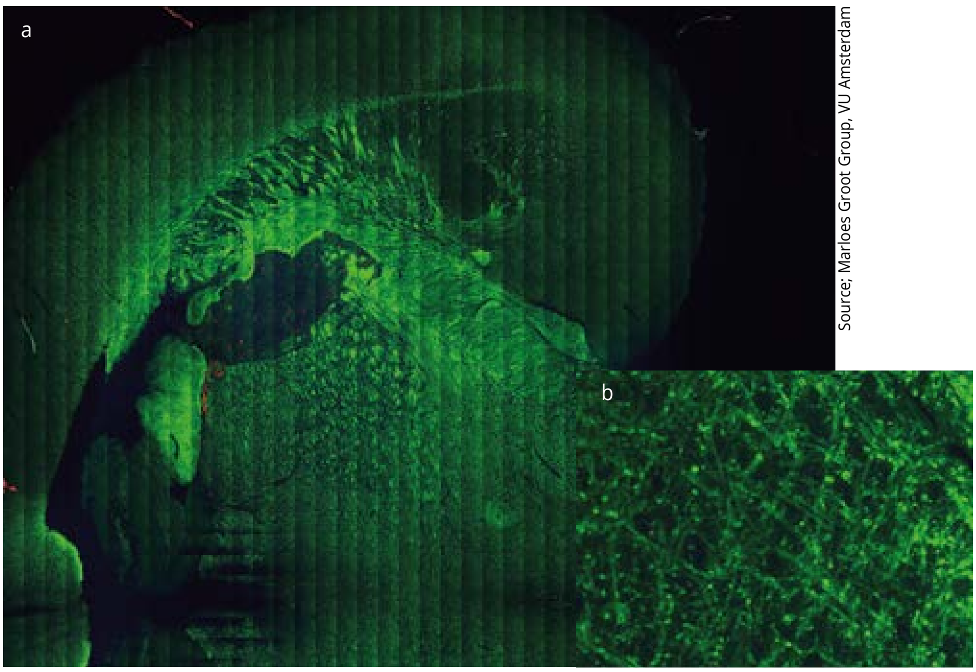
Decreasing the pulse duration by a factor of four from 200 fs to 50 fs will result in a four times higher peak power (or peak intensity) for a given average power. Multiphoton and higher-order harmonic signals depend non-linearly on the laser peak power. High intensity increases the likelihood of simultaneous multiphoton absorption events and the SHG and THG signals scale with the square and the cube of the incident light intensity respectively, so the corresponding signal increase is substantial for an increase in the laser peak power. Ultrashort sub-50 fs pulses then considerably improve multiphoton efficiency and higher-order harmonic generation efficiency and hence drastically increase image brightness.

Fig. 2 shows the proposed inverse relationship between the SHG and THG signal strengths and the pulse duration [1,2] (SHG intensity ~ $1/\tau$). However, to experimentally apply this relationship it is essential to accurately determine the pulse duration at the sample. If dispersion in the microscope optics is not properly compensated for, the pulses will be stretched, and lower peak power will be measured at the sample. In such a case, the relationship between pulse duration and higher-order harmonics generation efficiency cannot be accurately verified experimentally. Sub-50 fs pulses and the use of dispersion pre-compensation are essential to generate sufficient non-linear SHG and THG signals to achieve the required signal-to-noise ratio at average power levels that are gentle to the sample.

Fig. 3a shows the third harmonic signal from a calibration grid using an average power of 4.7 mW on the sample, with the full bandwidth of the Valo series femtosecond laser, yielding ~40 fs pulses. In **Fig. 3b,** the spectral bandwidth of the laser was restricted to 10 nm FWHM around 1,064 nm, resulting in ~160 fs pulses. The images in **Fig. 3a** and **3b** are identically scaled, but **Fig. 3b** shows no THG signal. Only after rescaling the lower THG signal from the longer ~160 fs pulses, was it possible to obtain an image above the experimental noise floor, as shown in **Fig. 3c**. In this case, a 2½ times higher average laser power was needed to achieve a signal-to-noise ratio comparable to that of THG signals obtained from shorter sub-50 fs pulses. In summary, ultrashort sub-50 fs pulses provide considerably higher pulse peak powers, which results in optimal signal-to-noise ratio images at much lower average power, which in turn reduces photobleaching and extends cell viability.

Intense pulses – advantages for THG

THG microscopy is a high-resolution deep optical sectioning and label-free imaging technique, with reduced tissue damage and without the need for artificially induced fluorescent probes, but it requires higher peak powers and shorter pulses while maintaining a low average laser power to extend cell viability. The emissions from endogenous



Source: Marloes Groot Group, VU Amsterdam

Fig. 4 Mouse brain THG signals a) large image mosaic, b) close-up image (200 × 200 µm)

Source: Marloes Groot Group, VU Amsterdam

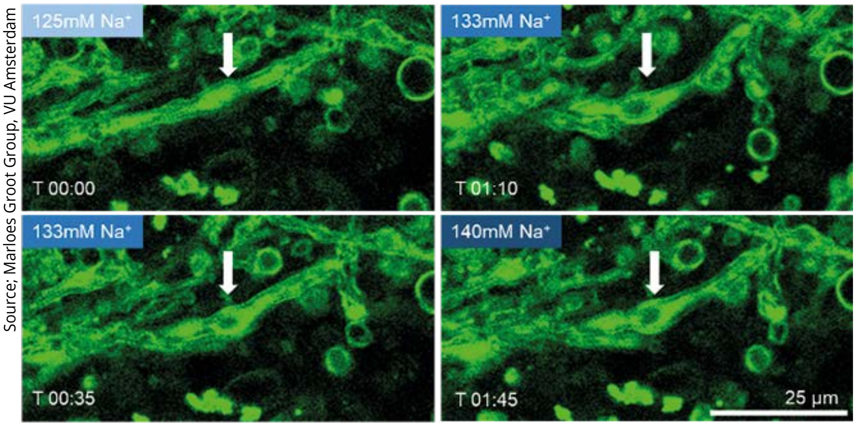


Fig. 5 Time-lapse imaging of the induction of myelin-swelling during gradual high sodium perfusion, an indicator characterising the onset of multiple sclerosis (MS).

biomolecules and the naturally occurring second-order harmonic signals have a chemical specificity for certain chromophores and are only produced in non-centrosymmetric molecules like collagen. THG signals in particular are much less chemically specific, and every spatial variation of the refractive index enables the generation of THG signals. As such, THG microscopy can be seen as a 3D equivalent of phase contrast microscopy [6]. Localized variations in the refractive index to within half the laser focus dimension are particularly efficient at generating THG signals. Due to the Gouy phase shift in the focus, the laser field before and after the focus is 180 degrees out of phase. The same is true for all third order (and other odd order) signals, where they have destructive interference and cancel out. Therefore THG signals are not generated in a homogeneous medium, and a symmetry break is needed within the focus. Cellular and sub-cellular details can be

Pulse Duration	Peak power (30 MHz)	Average Power *For the same TPEF
200 fs	16 kW	100 MW
50 fs	16 KW	25 mW

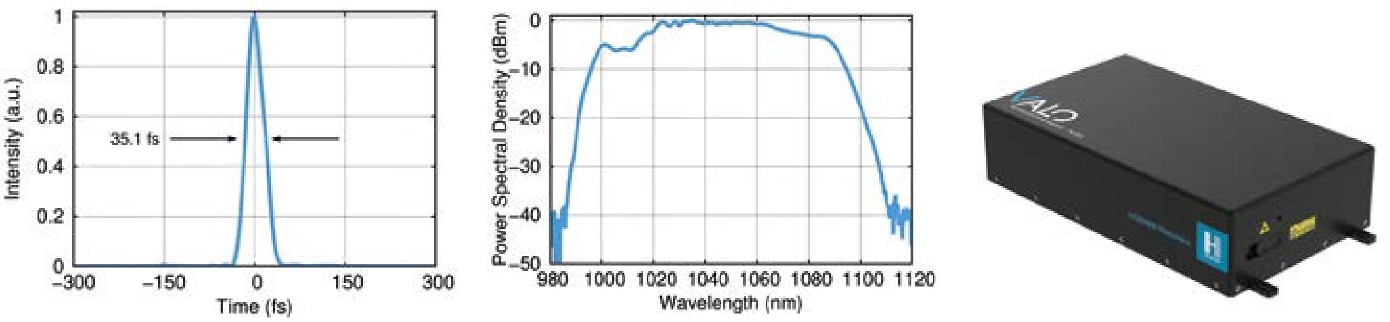
Table 1 Pulse duration, peak and average power

observed due to this universal principle, some giving weak and some giving strong signals. This asks for intense pulses to make both strong and weak features visible, and a detection system with a high dynamic range. Since THG signals scale with the cube of the peak power of pulses, the use of considerably more intense and thus shorter pulses is required to produce the required high signal to noise ratio. Fig. 4a and 4b shows mouse brain images obtained using the VALO Series laser with a sub-50 fs pulse duration and emphasize the need for ultrashort pulses to enhance THG imaging.

Molecules undergo several excitation/emission cycles before photobleaching: some may be more sensitive while others may perform several cycles before additional incident photons are unable to excite more molecules. Photodamage is one of the main limiting factors in time-lapse microscopy when observing living cells or tissue over extended periods of time. While phototoxicity is a function of molecular structure and the experimental environment, it is inevitably accelerated by constant exposure to a high average laser power. So for live-cell imaging, sensitive to phototoxicity, the combined low average laser power and high peak power delivered by sub-50 fs pulses enhance cell viability and considerably extend imaging times. As shown in Table 1 comparing 50 fs to 200 fs, a laser with only one fourth the average power output is needed for the same peak power, which translates into longer imaging durations while providing the same two-photon efficiency (TPEF). To achieve the lowest possible average power, lower repetition rate lasers are preferred, which also helps to reduce photobleaching effects.

Sub-50 fs fiber lasers

Fiber-based femtosecond lasers have become very attractive sources for various multiphoton and higher-harmonics imaging applications due to their robustness, flexibility, ease-of-use, and low cost of ownership. The compact VALO Aalto and VALO Tidal lasers deliver sub-50 fs pulses at a repetition rate of 30 MHz with pulse energies of 6.6 nJ and 66 nJ, and average powers of 200 mW and 2 W respectively. They produce an alignment-free, high quality beam profile (typical $M^2 < 1.1$ for Aalto and $M^2 < 1.2$ for Tidal) and include an integrated dispersion pre-compensation module. It is essential to pre-compensate for dispersion in light path components to fully benefit from sub-50 fs pulses and achieve the highest peak power possible at the sample. The VALO Series' sub-50 fs pulsed lasers are passively cooled with no fan or water cooling, and their short pulses and resulting high pulse peak powers enable a higher photon conversion efficiency while reducing photodamage and increasing cell viability. Both lasers are built into a compact and robust package, making them suitable for integration into industrial screening tools and benchtop analytical instruments. An example of a typical temporal pulse profile and beam profile is shown in Fig. 6a along with an example of the broad optical spectrum in 6b and a picture of the laser in 6c.



Source: Hübner Photonics

Fig. 6 Typical pulse width and beam profile (left), typical optical spectrum (center) of Hübner Photonics VALO Series femtosecond lasers (right)

Outlook

Multiphoton and THG microscopy have immense potential for use in various applications, including the development of screening tools at an industrial scale. This study has demonstrated how the Valo series sub-50 fs pulses with high pulse energy and peak power provide strong THG signals that enable extended live cell imaging and time-lapse measurements with a high level of sensitivity, without loss of fluorescence.

Using proprietary fiber laser technology, the VALO Femtosecond series' sub-50 fs pulses make it possible to increase the peak power while maintaining a low average power, thereby offering an efficient alternative and a proven solution for THG microscopy. They provide unprecedented multiphoton conversion efficiencies with intense peak powers that help to push frontiers in label-free, multiphoton applications and third harmonic generation imaging. The VALO Femtosecond series strives to deliver technological innovations in ultrafast lasers, and to pioneer advances into virtually every facet of future applications.

DOI: 10.1002/phvs.202300025

[1] *S. Tang, T. B. Krasieva, Z. Chen, G. Tempea, B. J. Tromberg:* Effect of pulse duration on two-photon excited fluorescence and second harmonic generation in nonlinear optical microscopy, , Journal of Biomedical Optics **11** (2006) 2, March/April,

[2] *M. Sibai, H. Mehidine, F. Poulon, A. Ibrahim, P. Varlet, M. Juchaux, J. Pallud, B. Devaux, A. Kudlinski, D. Abi Haidar:* The Impact of Compressed Femtosecond Laser Pulse Durations on Neuronal Tissue Used for Two-Photon Excitation Through an Endoscope, Scientific Reports | (2018) 8:11124 | DOI:10.1038/s41598-018-29404-8

[3] *G. M Hale* and *M. R. Querry:* Appl. Opt. **12** (1971) 555-561.

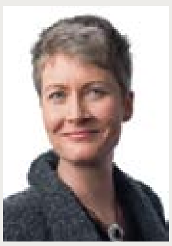
[4] *G.-J. Bakker, S. Weischer, J. Ferrer Ortas, J. Heidelin, V. Andresen, M. Beutler, E. Beaurepaire, P. Friedl:* Intravital Deep-Tumor Single-Beam 2-, 3- and 4-Photon Microscopy, eLife doi: 10.7554/eLife.63776

[5] *K. Giering , O. Minet , I. Lamprecht , G. Müller:* Review of thermal properties of biological tissues, SPIE PM **25** (1995) 45-65

[6] *S. A. Boppart, S. You, L. Li, J. Chen, and H. Tu:* Simultaneous label-free autofluorescence-multiharmonic microscopy and beyond, APL Photon. **4** (2019) 100901; doi: 10.1063/1.5098349

Authors

Frank van Mourik is co-founder of Flash Pathology. He has a PhD in biophysics and studied the femto-second dynamics of photosynthesis in Amsterdam (VU), Chicago, and Mülheim (Max-Planck-Institut für Strahlenchemie). From 2000 to 2017 he worked on the development and application of ultrafast spectroscopic techniques and instrumentation at the EPFL in Lausanne, Switzerland.



Marloes Groot is a professor for biophotonics and medical imaging at Vrije University in Amsterdam. She did her PhD in photosynthesis research and is the head of the VU LaserLab with a research line focused on deep tissue imaging using higher harmonic generation microscopy.

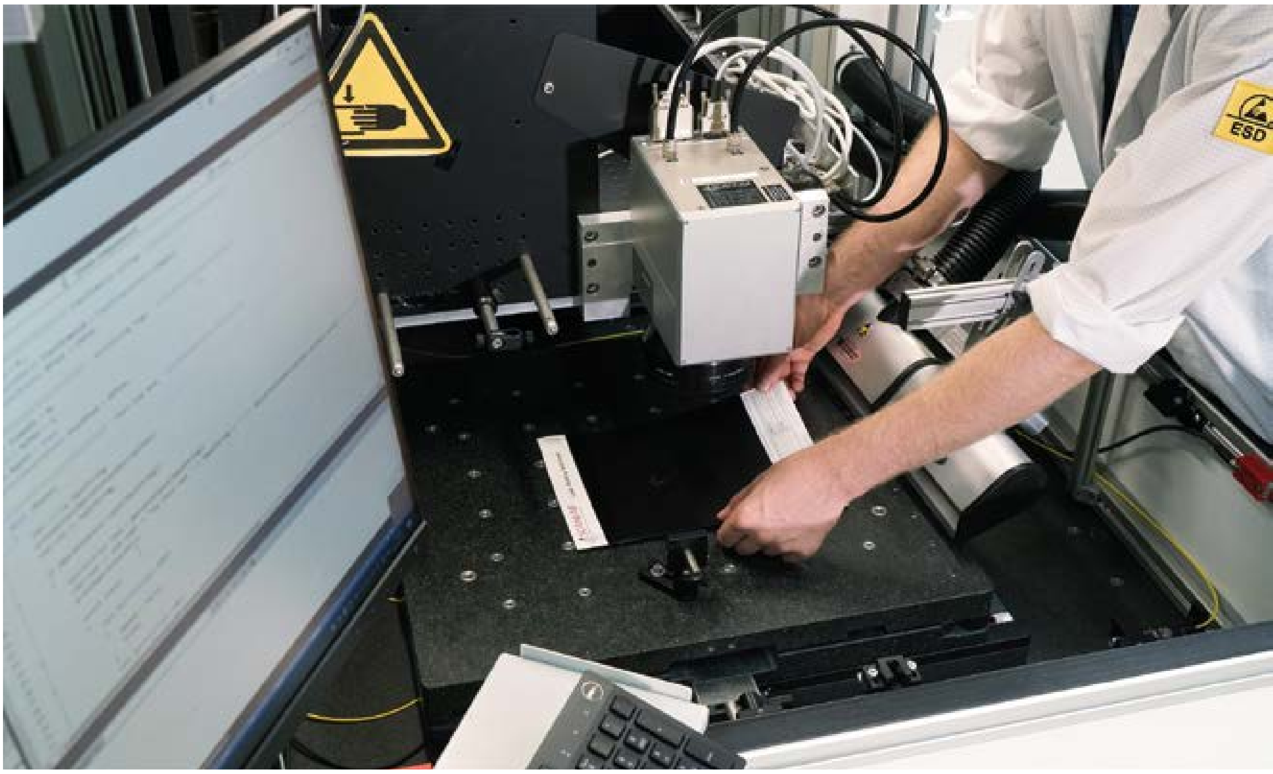
Oliver Prochnow is a founder of Valo Innovations, a part of Hübner Photonics since 2021. He developed the sub-50 femtosecond fiber lasers, which now forms the VALO Femtosecond Series from Hübner Photonics. He holds a PhD in physics from the University of Hanover, Germany. During his PhD, he worked at the Laser Zentrum Hanover, focusing on ultrafast fiber lasers and amplifiers. He is a (co)author of more than 45 scientific publications.

Dr. Oliver Prochnow, Managing Director (CEO) and Co-Founder, Hollerithallee 17, 30419 Hannover, Germany; phone: +49 511 260 390 70; e-mail: prochnow@valo-innovations.com, Web: www.valo-innovations.com

Micromachining gains from simulation

Innovative scanning control software reduces development times and time-to-market

Jan Wagner & Holger Schlüter



Source: Scanlab

▲ **Fig. 1** New scanning control software significantly simplifies the setup of laser jobs.

Developing laser processes for industrial applications is a challenging and laborious task. Conventional controllers for laser scan systems lack the ability to predict the actual path of the laser beam on the workpiece, making extensive trial-and-error testing of different parameters and delay settings necessary in order to achieve satisfactory results. Finding a balance between the accuracy achieved and throughput is typically a compromise, and varies from user to user. Thanks to the introduction of SCANmotionControl, a new software solution by Scanlab, the programming of laser processes has been revolutionized.

Offline analysis saves time in application development

SCANmotionControl is a pipeline-based trajectory planning software that enables the user to plan the trajectory of the laser beam ahead of runtime. The user is provided with a graph of the actual path before the laser is even turned on. The program automatically optimizes accuracy and throughput based on only two main input parameters: corner fidelity tolerance and mark speed. Delay adjustments and manual skywriting insertion become a thing of the past. Furthermore, the high-level API of the software reduces the effort required for machine integration. The software enables optimum throughput and highest accuracy, without the need for difficult determination of delays and time-consuming trial-and-error testing of processes.

The software offers different execution methods to meet the individual process requirements. Some laser processes require a constant processing speed; others aim to keep the laser always switched on during processing. Thanks to the software, the user can easily define their scanning strategy to prioritize the various process requirements.

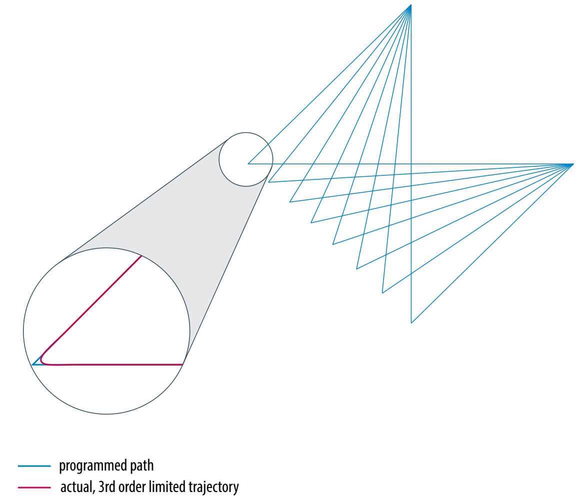


Fig. 2 The actual laser path can be calculated in advance based on the specified corner tolerance. Source: Scanlab

Fig. 3 The SCANmotionControl software displays various pre-calculated laser beam paths on the material for increasing velocities as a heatmap. Source: Scanlab

The software's algorithms allow the determination of different paths with various parameters, such as corner fidelity, before processing. Generally, with higher marking speeds, corners become rounded during processing due to the scanner's acceleration limit. When the user pre-sets a minimum corner fidelity, the algorithm reduces the marking speed just before marking corners in order to respect the requirements. So important settings can be made in the preparation phase without using valuable machine time.

Fig. 3 shows a maximum corner tolerance of 2.5 mm at a marking speed of 7.5 – 12.5 m/s.

Taking the simulation to action

To transfer the simulation to an actual process, the software needs to be combined with a scan-head equipped with an advanced trajectory controller. Conventional scan-heads using a time lag-based control strategy cannot follow SCANmotionControl's pre-calculated

Fig. 4 Numerous components of smartphones are produced with micromachining applications. Source: istock.com - tarras79

trajectories exactly. In comparison, Scanlab's established excelliSCAN series and the newly presented intelliSCAN IV series use a special trajectory controller that ensures optimal path following. The technical claim for both systems is 'What you see (in simulation) is what you get (in reality)'.

Especially in micromachining, a great deal of time can be saved through simulation and offline programming because a lot of effort is normally needed to optimize for high accuracy while keeping processing times as short as possible. One typical process with stringent requirements is the cutting of glass and polymers when manufacturing smartphone displays. The laser focus must lie within very tight tolerances and high repeatability is essential. The heat-affected zone also needs to be kept extremely small to avoid damage to the circuitry or producing visible defects.

The software offers several features that support the user to optimize demanding microprocessing applications. For example, Spot Distance Control enables the use of 'Pulse on Demand Lasers' to uniformly distrib-

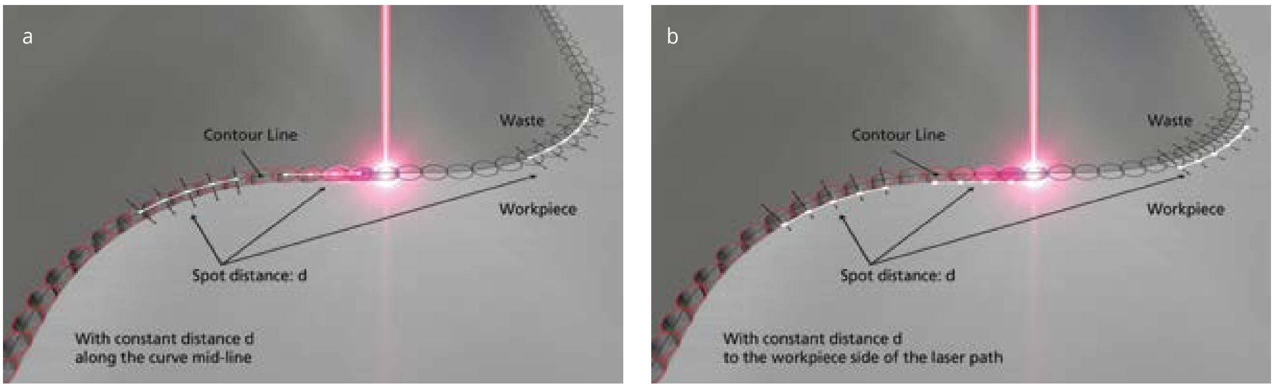


Fig. 5 (a) Spot Distance Control to place the laser pulses evenly. (b) Full control of contour line and spot distances (inner, middle or outer contour line with even spacing between pulses). Source: Scanlab

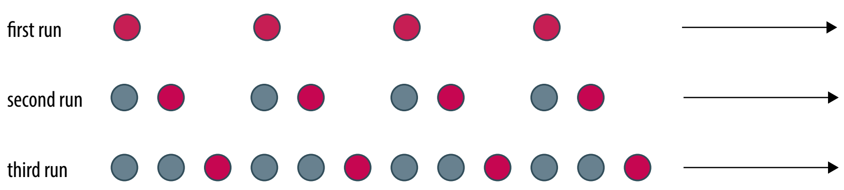


Fig. 6 Multiple passes with even spacing to distribute laser energy over time. Source: Scanlab

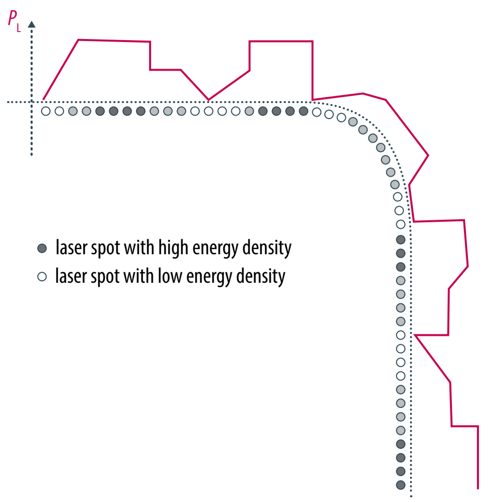


Fig. 7 Power ramping along the path planned ahead of time. Source: Scanlab

ute the energy along a path, even during phases of acceleration in corners (Fig. 5a).

To improve the process quality, it might be necessary to control not only the spot distances in relation to the spot's center point but in relation to the outer or inner contour (Fig. 5b).

To distribute the laser energy over an even greater time, the software offers an option to repeat the job execution multiple times while shifting the spot positions for each pass. This strategy ensures optimal heat dissipation while keeping the overall spot distances small (Fig. 6).

If the laser power needs to be varied, for example due to changing materials with different absorption rates, the software provides process engineers with another useful feature called 'power ramping' (Fig. 7). This allows the laser power at each position along the laser path to be precisely defined. All the features mentioned here can also be combined. In consumer electronics production for example, the software will help to increase throughput, improve product quality and reduce waste.

Infinite field of view

High-precision, high-throughput laser micromachining typically requires galvo scan heads with a short focal length, which in turn produces a small image field or field of view (FOV). However, a growing number of high-tech manufacturing areas, such as OLED display fabrication, require the processing of parts larger than can fit into these reduced image fields, while simultaneously requiring a high level of accuracy and throughput. Although high precision can be achieved by using a stationary laser and a moving mechanical stage, throughput will be low. Throughput is increased when the motion of a galvo scan head is combined with motion stages to produce the desired contour of the laser beam on the processed part. With this approach, the micromachining process field area will be limited only by the travel range of the stages, and throughput will not be compromised.

XL SCAN is a proven solution combining galvo and stage control, developed jointly with ACS Motion Control, while leveraging unique galvo scan head and motion control technology. This solution splits the motion path in an innovative way into one path for the scan head and one for the stage, and delivers them to the corresponding controller. The scan concept has been successfully used since 2017 and has demonstrated results with the highest accuracy. Its rich and field-tested feature set of underlying syncAXIS control software has now become part of SCANmotionControl.

Additional options for additive manufacturing

Additive manufacturing (AM) applications have specific requirements for laser control. The heat distribution during processing, particularly at the contours of the manufactured part, is often challenging and directly affects the quality of the part. To build support-free structures sustainably, a typical overhanging angle of 25° is used. However, a research project conducted by Fraunhofer ILT has shown that a strategy to adapt laser power on a micro-vector level in relation to the distance to the powder bed can help to decrease the overhanging angle down to 10°.

Precisely this strategy is integrated into the new control software, enabling

Company

SCANLAB

With about 40,000 systems produced annually, SCANLAB GmbH is an independent OEM manufacturer of scan solutions to deflect and position laser beams in three dimensions. Its exceptionally fast and precise high-performance galvanometer scanners, scan heads and scan systems are used in industrial materials processing and the electronics, food and beverage industries, as well as biotech and medical technology.

www.scanlab.de

Meet us at Laser World of Photonics in hall A3, booth 233

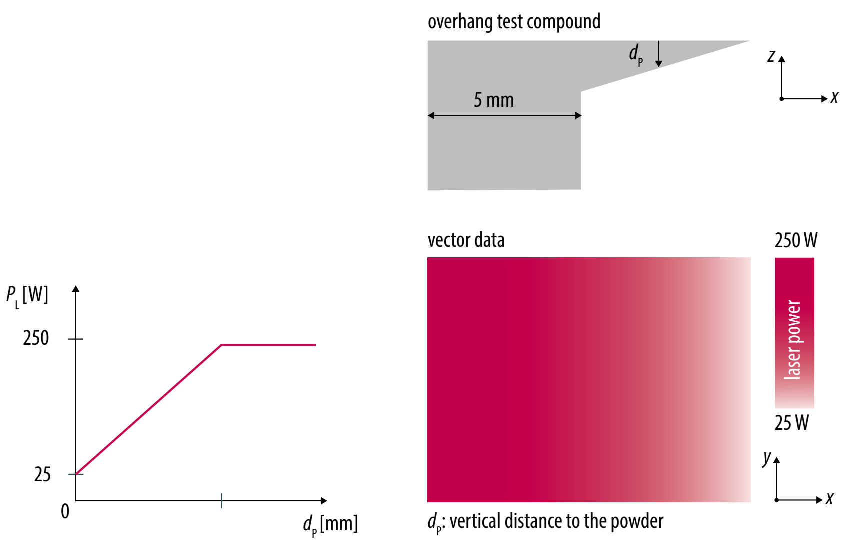


Fig. 8 Change in laser power on a micro-vector level along a scan path as a function of the distance to the powder bed. Source: Tobias Pichler, Adaptive Laser Powder Bed Fusion of the titanium alloy TiAl6V4

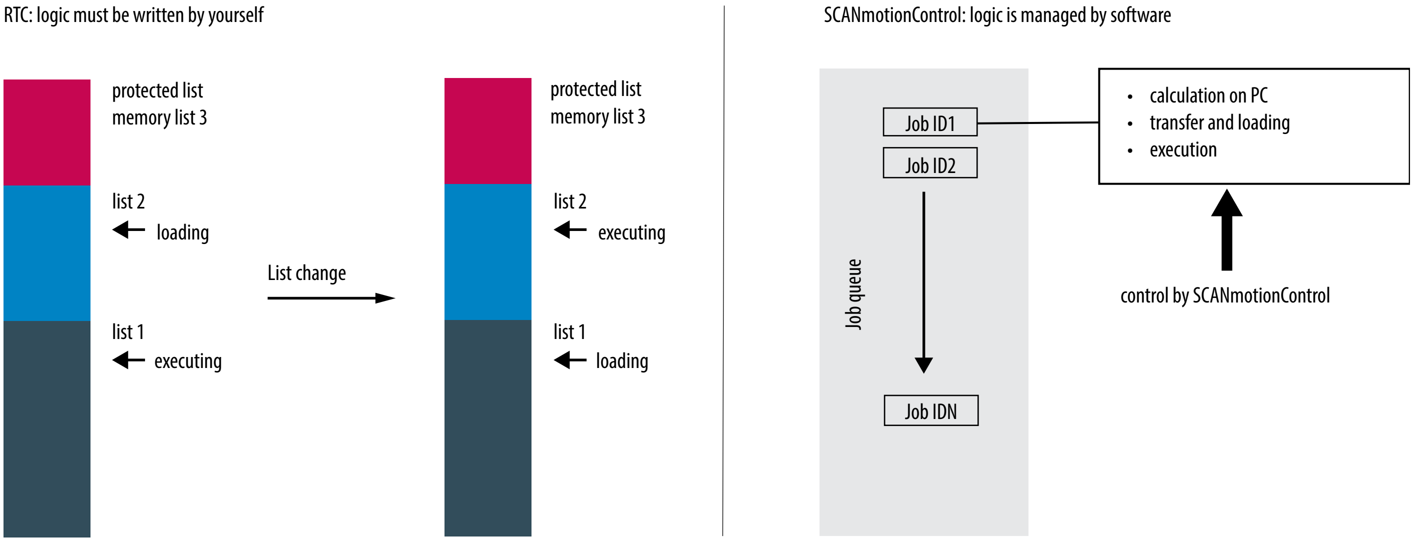


Fig. 9 Advantages of SCANmotionControl software in comparison to low-level programming. Source: Scanlab

automatic parametrization of laser power ramping along the scan path on a macro scale, while micro-vectorization is taken care of in the background. This not only provides a process advantage, but also allows most of the preoperational work to be done offline during processing of the STL files and preparation of 3D part analysis. In this way, expensive processing times in AM can be significantly reduced.

Machine integration through high-level API

In addition to all the benefits for users in actual laser processing, the new software also offers significant advantages for machine integrators. Previously, machine builders had to plan considerable time and programming hours for the integration of control cards for the laser, the scan system, and other components. SCANmotionControl reduces the effort for configuration and initialization significantly. The high-level API can be applied for most use cases without customization. In this case, 'high-level' means that the following functions have been bundled:

- Configuration of the scan system, including possible additional axes
- Initialization of the scan head and laser
- List handling to process arbitrarily long laser jobs
- Intuitive input parameters

Additionally, uniform return values were defined, meaningful error messages were created, and an integrated logging mechanism takes effect during execution. The individual configuration of each machine is stored in an external file.

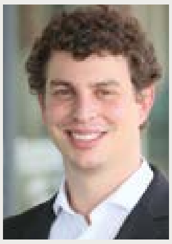
The pleasing result of this approach is a small, manageable code base that is easy to learn. The machine software runs more stably and supports consistent error handling. Debugging times can be reduced by quickly analyzing the log files. Last but not least, each system configuration can now be reproduced quickly using the new software, simply by transferring the configuration file. This works both from the application laboratory to the production system and from an initial machine to successor models.

Conclusion

SCANmotionControl is an innovative scanning control software that significantly reduces development times and time-to-market for industrial laser processing. The software's algorithms allow users to optimize accuracy and throughput while eliminating the need for difficult determination of delays and time-consuming trial-and-error testing of processes. It is a valuable technological development for companies in need of high accuracy and throughput in their laser processes, especially in micromachining, where the software's numerous features support the user to optimize processes for demanding requirements.

DOI: 10.1002/phvs.202300021

Authors



Jan Wagner studied electrical engineering and information technology at TU Munich with a focus on Mechatronics. From 2011 to 2021, he worked in the test and measurement industry supporting customers, and was responsible for product marketing. He has been responsible for the software and control products at Scanlab as a product manager for the past two years.

Holger Schlüter studied physics in Aachen and earned his PhD at the Fraunhofer Institute for Laser Technology in Aachen. Between 1996 and 2008, he held various positions in Germany and in the USA for Trumpf. He was CTO and COO at Technolas Perfect Vision in Germany and general manager of II-VI HighYAG. He has been head of business development for Scanlab for seven years.

Dr. Holger Schlüter, SCANLAB GmbH, Siemensstr. 2a, 82178 Puchheim, Germany; phone +49 89 800 746-0, e-mail: info@scanlab.de, www.scanlab.de

Where flexibility meets precision

Recent advancements of the industrial femtosecond laser

Lukas Rimgaila, Tadas Bartulevičius, Deividas Andriukaitis, Valdemar Stankevič, Arnas Vyšniauskas, and Oliver Rohm

Fig. 1 FemtoLux 30 femtosecond laser system with Harmonics unit.

Source all images: EKSPLA

The development of ultrafast lasers with higher functionality as a result of recent advances in the study of light-matter interaction has revolutionized the micromachining of materials with greater accuracy and a smaller heat-affected zone. The popularity of femtosecond lasers in industry has furthered enhancements to their flexibility and efficiency, including different methods of operation such as in the FemtoLux 30, enabling new techniques in material processing.

Recent discoveries in light-matter interaction have led to the development of lasers with increased functionality, and ultrafast lasers are among the most rapidly evolving light sources that have found new avenues in science and industry [1]. Femtosecond lasers have been a popular choice for industrial applications due to their short pulse duration, high peak intensity, and superior performance in material processing. These lasers have revolutionized material micromachining by enabling processing methods that were previously not possible with longer pulses, while also offering greater precision and a smaller heat-affected zone [2]. In addition, the compact size and robustness of the ultrafast fiber lasers make them highly attractive for industrial applications.

One of the most significant recent developments is the ability to use the laser in different ways, allowing users to tailor its performance to their specific needs. This article explores the recent improvements to the FemtoLux 30 industrial femtosecond laser where flexibility meets precision to enable new methods of material processing.

Requirements for an ideal industrial USP laser

It is always a great responsibility to choose the right industrial ultra-short pulse (USP) laser source for micromachining applications. Reliability is a crucial requirement of lasers because, if a laser encounters frequent issues, scientists would be unable to conduct their research effectively, potentially causing them to miss new discoveries. Laser malfunctions would result in financial losses for an industrial customer. Consequently, lasers should be stable, with parameters that remain constant and repeatable. To minimize downtime, maintenance requirements should also be minimal or, best of all, zero. It is also important to have plug-and-play laser compatibility with various external devices – stages, scanners, and other control equipment. The installation and integration of the laser should be quick and intuitive. There are a few other things that matter too – a laser should not produce excessive heat, have zero

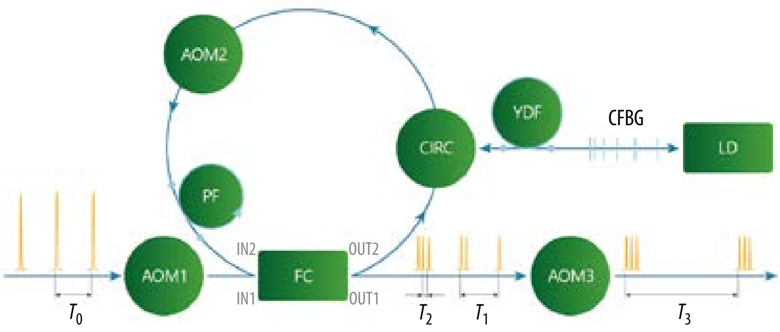


Fig. 2 Schematic setup of the AFL with the AOMs for temporal control of GHz bursts. FC – 2 × 2 fiber coupler (50/50 splitting ratio), CIRC – optical circulator, YDF – ytterbium-doped fiber, CFBG – chirped fiber Bragg grating, LD – single-mode laser diode, AOM1–3 – acousto-optic modulators, PF – a segment of a passive optical fiber. IN1,2 – input ports of the fiber coupler, OUT1,2 – output ports of the fiber coupler. Time delays between: T_0 – input pulses, T_1 – a delayed replica of an input pulse and an undelayed replica of the pulse, T_2 – intra-burst pulses, T_3 – bursts of pulses.

risk of damage to other equipment, and it should be compact and light. Knowing all these details, Ekspla R&D engineers developed the FemtoLux 30, an industrial USP laser capable of performing almost all micromachining tasks. It is designed to work in an industrial environment 24/7 and can also satisfy the scientific community with its flexibility and precision – the laser has a true pulse-on-demand option, MHz, short and long GHz burst modes, all in a single unit.

Core features

Ekspla has extensive experience in developing and implementing fiber technology. The FemtoLux 30 laser uses hybrid technology to generate amplified femtosecond pulses. It is based on the use of chirped pulse amplification (CPA) technology and consists of a fiber-based seed source and a solid-state amplifier. The laser delivers 30 W at a 1 MHz pulse repetition rate (PRR); the highest pulse energy is 100 µJ at 200 kHz PRR. The standard pulse duration is 350 fs, which is seamlessly tunable up to 1 ps. If broader tunability is required, there is an option to have pulse durations even up to nanoseconds. The standard laser has a MHz burst mode; optionally one can choose to have probably the most flexible GHz burst option on the market. One of the key features of the laser design is an integrated innovative cooling system – direct refrigerant cooling (DRC). The major components of a DRC system are the compressor, condenser, expansion valve, and evaporator. The compressor takes in low-temperature, low-pressure refrigerant vapor and compresses it to high pressure and temperature. The refrigerant then undergoes phase changes, first from gas to liquid in the condenser and then from liquid to gas in the evaporator, while transferring heat to the ambient environment and absorbing heat from the heat source, before returning to the compressor to complete the cycle. This cooling solution does not require any maintenance, there is no water in the system, and it is compact and reliable.

The FemtoLux 30 can be operated in pulse-on-demand mode. This feature enables the laser to fire a pulse only when required, rather than at a constant repetition rate, enabling precise control over the laser's output and resulting in higher efficiency, accuracy and quality. This capability is especially valuable in micromachining applications where a high processing speed, constant energy, and accuracy are essential. To achieve these requirements, it is necessary to ensure that the repetition rate of the pulses is adjusted to follow complex curvature at high speed and to maintain equidistant spacing. One may try to adapt the PRR but, due to laser system limitations, the jitter will be from several µs to tens of µs, which will result in random spacing of the pulses. The FemtoLux 30 laser has the pulse-on-demand feature with jitter as low as 25 ns, and it can therefore tackle all the challenges and maximize process efficiency, precision and quality.

Different operation modes

Nowadays, we can find a variety of ultrafast lasers that can provide different operation modes; the most com-

Companies

EKSPLA

Celebrating its 30-year anniversary, the laser manufacturer Ekspla from Vilnius, Lithuania, designs and manufactures advanced lasers systems. With a key strength in tailoring products to specific requirements, the company has gained recognition from eighty of the top one hundred universities worldwide. The main product line includes femtosecond, picosecond, and nanosecond lasers for industrial applications, as well as tunable wavelength, spectroscopy, and high-intensity laser systems for scientific applications.

www.ekspla.com

Akoneer

Akoneer is a Lithuanian company that has been designing and manufacturing laser micromachining systems for industrial and scientific applications since 2010. The company is based in Vilnius and creates laser micromachining systems for the electronics and semiconductor industries, as well as for hard material processing, such as composites, ceramics, and PCD. The highly customized micromachining workstations incorporate nanosecond, picosecond, and femtosecond laser sources in combination with advanced beam steering to achieve micrometer-scale machining precision and repeatability.

www.akoneer.com

TOPAG Lasertechnik

Incorporated in 1993 and located in Darmstadt, Germany, TOPAG is focused on sales of pulsed solid-state lasers for scientific and industrial applications, and distributes and services Ekspla lasers in Germany and Austria.
Further products include lasers from other manufacturers, ultrashort pulse metrology, spectrometers, infrared viewers, optics and crystals. In addition, TOPAG develops and manufactures innovative laser beam shaping optics for the optimization of laser processes.

www.topag.de

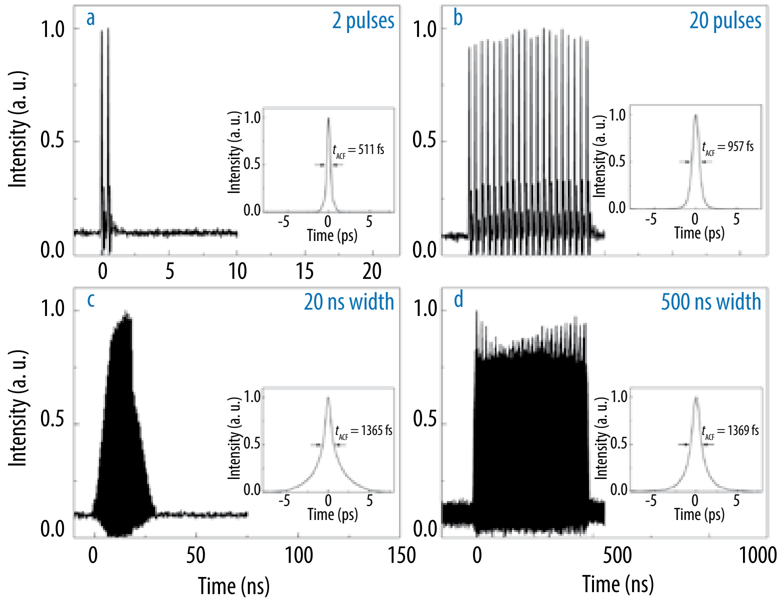


Fig. 3 Measured 2.2 GHz pre-shaped rectangular-like bursts containing from 2 to approx. 1100 pulses (a–d) at 233 kHz BRR and 31.5 W output power (corresponding to a burst energy of 135 µJ) at the output of the system. Inset: Measured autocorrelation functions of the compressed pulses. (c) bell-shaped and (b, d) rectangular-like shape of the GHz bursts. Adapted with permission from [10].

mon is the single-pulse mode. It outputs single pulses in kHz-MHz PRRs and can be seen used in the majority of micromachining tasks since all of the femtosecond lasers have this operation mode as a default configuration. One of the drawbacks of femtosecond lasers is the ablation efficiency. Since the femtosecond pulse energy can be localized in a small volume, a trade-off must be made between increased accuracy and ablation efficiency. One way to optimize the micromachining process is to group single pulses into packets of pulses with a repetition rate between adjacent pulses in the MHz/GHz range, i.e. forming MHz/GHz bursts. There are a few published articles presenting the usage of bursts to increase ablation efficiency, but the majority of authors indicate that further research is needed [3–6]. Unfortunately, one of the main bottlenecks is the flexibility of the laser source. At the moment, lasers in the ultrafast laser market provide only MHz, short GHz (up to twenty pulses), or long GHz (up to thousands of pulses) bursts. This complicates the creation of a comprehensive study on the influence of different operation modes on ablation efficiency, and there is a rising need for a more flexible solution that could provide multiple operation modes.

Innovative GHz burst formation – active fiber loop

A patent-pending solution for the formation of short and long GHz bursts is realized in an all-in-fiber design [7–9]. The developed method is based on an active fiber loop (AFL) (Fig. 2) that consists of acousto-optical modulators (AOM1 – 3) to control the number of pulses in the burst, a fiber coupler (FC) that completes the loop with a 50/50 splitting ratio, an ytterbium-doped fiber (YDF) pumped by a laser diode (LD) for round-trip loss compensation, and a chirped fiber Bragg grating (CFBG) for dispersion compensation. The GHz burst formation technique splits and delays ultrafast pulses from the MHz master oscillator. After each round-trip, the delayed replicas from previous cycles add to an undelayed replica of the next input pulse. When pulses that circulate inside the AFL fill the entire time delay between two input pulses T_0, AOM1 blocks the next pulse so that no overlay would occur – the system switches from short burst formation to long burst formation mode. The bursts with a desired number of pulses are selected by the AOM3 determining the burst repetition rate (BRR). Burst formation with AFL poses many advantages for the end-user, such as the formation of bursts with any desired number of pulses within a burst, the ability to have any pre-defined intra-burst PRR that can vary from a couple to hundreds of GHz and does not depend on the initial PRR of a master oscillator. In addition, different burst shapes can be obtained by changing amplification conditions in the YDF amplifier or temporally modulated transmission of the AOM3. Different shapes are possible, such as decaying, rising, triangular, square, or bell-shaped.

The AFL technology was built into the FemtoLux 30 industrial-grade femtosecond laser system – short and long

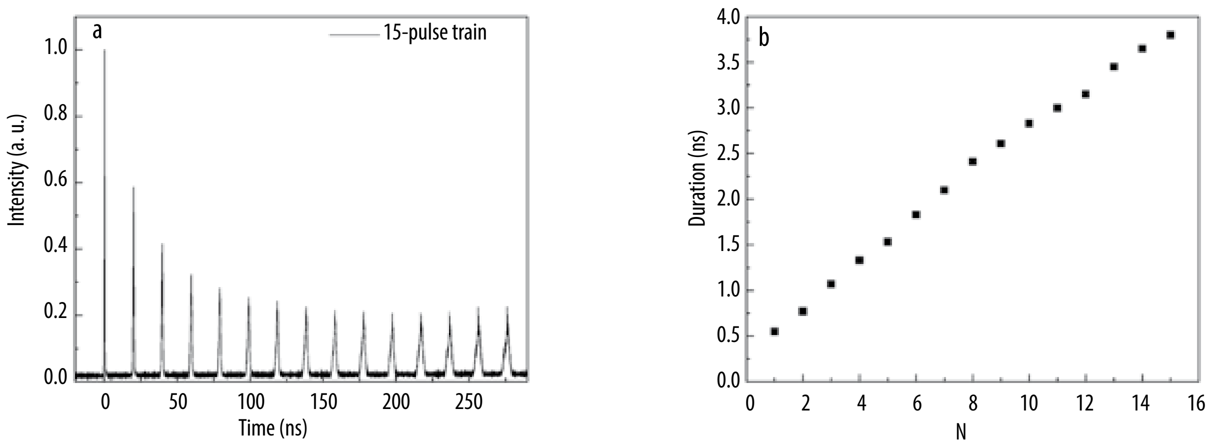


Fig. 4 a) A sequence of pulses at the output of the AFL where pulse duration varies from 0.55 ns to 3.8 ns. b) Dependence of pulse duration on the number of round-trips inside the AFL. Adapted with permission from [10].

GHz bursts were amplified up to 140 µJ at 200 kHz BRR (Fig. 3). The standard FemtoLux 30 with the GHz burst feature offers the end-user 2 GHz intraburst PRR, tunable BRR, control of the burst amplitude envelope and the number of pulses within the burst (2 – 22 and 44 – 1100, approximately). Furthermore, the AFL technology gives the end-user the ability to operate the laser in single-pulse, MHz, short and long GHz burst modes while at the same time maintaining the ultrashort pulse duration.

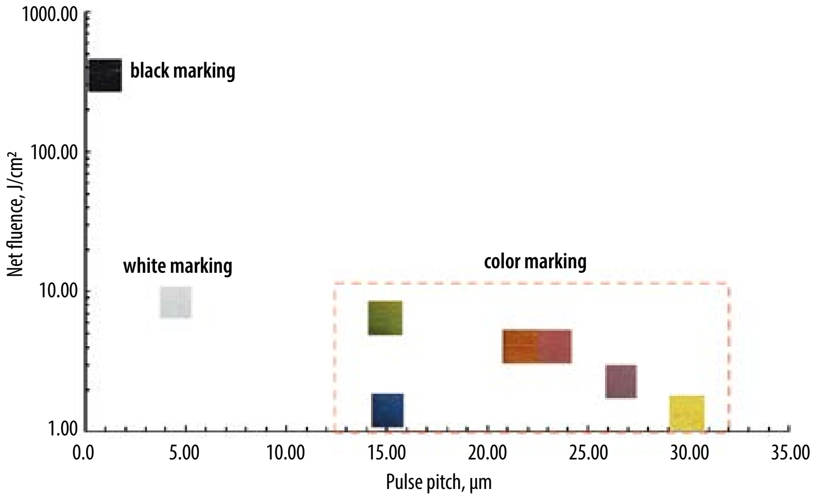


Fig. 5 The Net fluence and pulse pitch map of the possible colors on the stainless steel sample.

Pulse duration tuning from femtoseconds to nanoseconds

The patent-pending AFL technology allows the pulse duration to be tuned by controlling the dispersion accumulation in the loop [10, 11]. In this case, CFBG is used to add additional dispersion and thereby to stretch the pulses in time during each round trip. The duration of the single pulse passing through the AFL increases after each round-trip, forming a sequence of pulses of different duration outside the AFL (Fig. 4a). When the desired pulse sequence is obtained, the AOM2 closes and the pulse of a desired duration is selected from the pulse sequence by the AOM3, also determining the time delay T_3 between these pulses. The formation of the pulse sequence of a different duration is restarted when the AOM2 is turned on again. The dependence of pulse duration on the number of round trips inside the AFL is depicted in Fig. 4b. A discrete linear increase in pulse duration was obtained. In this study, after 15 round trips inside the AFL, the pulse duration was increased from an initial 300 fs to nearly 4 ns (FWHM).

This pulse duration tuning technique may be successfully implemented together with the AFL modification used for GHz burst formation. These two methods combined and integrated into the industrial-grade, 30-W level

Fig. 6 Stainless steel sample coloring of Ekspla logo using FemtoLux 30 with GHz burst feature.

average power, femtosecond laser may be beneficial for laser processing applications, allowing the selection of different operation modes and pulse parameters.

Stainless steel coloring with GHz bursts

The laser coloring of metals paves the way to large-scale industrial applications such as anti-counterfeiting, biocompatibility, and the decoration of consumer products such as jewelry, art, architectural elements and even luxury sanitary items. The use of bursts to machine metals is of interest due to its increasing ablation yield and faster cutting times [12]. The colors on a metal surface can be generated by a few methods: 1) color generation by surface heating and oxide layer growth on the surface [13–14] and color generation from femtosecond laser-induced nanostructures [15]. There are two methods using GHz burst pulses, however due to the surface melting on low fluences in the GHz burst method, the oxide layer formation is the predominant process used. Only poor color palettes were obtained on stainless steel when processing with non-burst pulses. The GHz burst processing allowed us to achieve a much higher range of colors, as demonstrated in Fig. 5.

A wide range of colors was demonstrated on the stainless steel surface, including violet, blue, green, yellow, orange, and red. Multiple color shades are possible by fine tuning the processing parameters. The white and black markings are achieved with different settings compared to the color marking modes. For black marking, a ten-times higher fluence is needed to form a light-absorbing surface. The color marking of the visible range can be classified by the applied net fluence and pulse pitch. The net fluence for the steel varies from 1 to 10 J/cm^2. The application of GHz burst pulses allows gentle surface heating and conditional oxide layer growth. The energy-dispersive spectroscopy (EDS) chemical analysis clearly shows the enhanced oxygen atomic proportion growth of up to twenty percent compared to the non-processed steel material. It shows the formation of a metal oxide layer, which is responsible for the color change. The scanning electron microscopy (SEM) analysis demonstrated a smooth surface resulting from melting. Additionally, the color appears to be independent of the angle of incidence of light. As a result, by using the FemtoLux 30 laser in GHz burst mode and carefully adjusting the processing parameters, an Ekspla logo was colored onto a stainless steel sample (Fig. 6).

Conclusion

The development of ultrafast lasers, particularly femtosecond lasers, has revolutionized material micromachining, offering greater precision and smaller heat-affected zones. Recent advancements have enhanced the flexibility and efficiency of femtosecond lasers, allowing users to tailor the laser's performance to their specific needs. The FemtoLux 30 industrial-grade femtosecond laser system stands out in the market as it offers different operation modes in one unit – single-pulse, MHz, short GHz, and long GHz – at the same time, while maintaining the ultrashort single-pulse duration. With features such as DRC and pulse-on-demand, the FemtoLux 30 has a level of flexibility and control that is unmatched in the ultrafast laser market, making the laser system an ideal choice for a wide range of micromachining applications.

DOI: 10.1002/phvs.202300019

[1] *K. Sugioka:* Progress in ultrafast laser processing and future prospects, Nanophotonics **6**(2), 393–413 (2017).

[2] *K. Sugioka and Y. Cheng*: Ultrafast lasers – reliable tools for advanced materials processing, Light: Sci. Appl. **3**(4), e149 (2014).

[3] *D. J. Förster, B. Jäggi, A. Michalowski, and B. Neuenschwander:* Review on Experimental and Theoretical Investigations of Ultra-Short Pulsed Laser Ablation of Metals with Burst Pulses, Materials **14**(12), 3331 (2021).

[4] *G. Bonamis, E. Audouard, C. Hönninger, J. Lopez, K. Mishchik, E. Mottay, and I. Manek-Hönninger:* Systematic study of laser ablation with GHz bursts of femtosecond pulses, Opt. Express **28**(19), 27702–27714 (2020).

[5] *D. Metzner, P. Lickschat, and S. Weißmantel:* Optimization of the ablation process using ultrashort pulsed laser radiation in different burst modes, J. Laser Appl. **33**(1), 012057 (2021).

[6] *G. Račiukaitis:* Ultra-Short Pulse Lasers for Microfabrication: A Review, IEEE J. Sel. Top. Quantum Electron. **27**(6), 1-12 (2021).

[7] *A. Michailovas and T. Bartulevicius:* Published international patent application WO2021/059003 (A1) (2021).

[8] *T. Bartulevicius, K. Madeikis, L. Veselis, V. Petrauskiene, and A. Michailovas:* Active fiber loop for synthesizing GHz bursts of equidistant ultrashort pulses, Opt. Express **28**, 13059-13067 (2020).

[9] *T. Bartulevičius M. Lipnickas, V. Petrauskiene, K. Madeikis, and A. Michailovas:* 30 W-average-power femtosecond

NIR laser operating in a flexible GHz-burst-regime, Opt. Express **30**(20) (2022).

[10] *T. Bartulevičius, M. Lipnickas, K. Madeikis, R. Burokas, A. Michailovas:* Versatile ultrashort pulse laser tunable up to nanosecond range, Proc. SPIE 12399, 1239904 (2023).

[11] *T. Bartulevicius:* (not published), Lithuanian Patent Application LT2022 526, filed June 30, 2022.

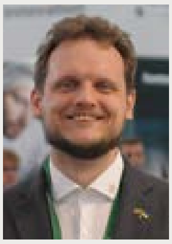
[12] *C. Hartmann A. Gillner, Ü. Aydin, R. Noll, T. Fehr, C. Gehlen, R. Poprawe:* Investigation on laser micro ablation of metals using ns multi-pulses, J. Phys. Conf. Ser. **59**, 440–444 (2007).

[13] *L. Baufay, F. A. Houle, R. J. Wilson:* Optical self-regulation during laser-induced oxidation of copper, J. Appl. Phys. **61**, 4640–4651 (1987).

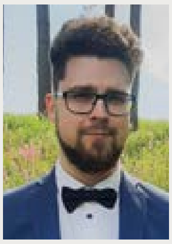
[14] *H. Y. Zheng, G. C. Lim, X. C. Wang, J. L. Tan:* Process study for laser-induced surface coloration," J. Laser Appl., **14**(4), 215-220 (2002).

[15] *B. Dusser, Z. Sagan, H. Soder, N. Faure, J.P. Colombier, M. Jourlin and E. Audouard:* Controlled nanostructrures formation by ultra fast laser pulses for color marking," Opt. Express **18**(3) (2010).

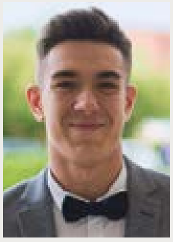
Authors



Lukas Rimgaila is the head of OEM lasers at Ekspla, with a bachelor's degree in physics from Kaunas University of Technology and a master's degree in laser physics and optical technologies from Vilnius University. His research interest is in micromachining, and he is involved in developing lasers for scientific and industrial applications. As head of OEM lasers, he oversees the development and production of custom laser solutions. Lukas plays a key role in advancing laser technology for science and industry.

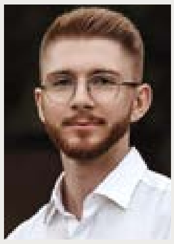


Tadas Bartulevičius obtained a PhD at the Center for Physical Sciences and Technology in Vilnius, Lithuania, in laser physics in 2021. Tadas has been working at the laser manufacturing company Ekspla in the R&D department as a R&D product engineer since 2014. His main activity is the construction of fiber lasers and the development of new technologies.

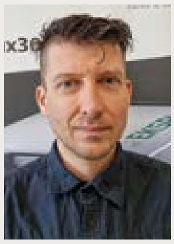


Deividas Andriukaitis is an OEM lasers sales manager for Ekspla, with a bachelor's degree in light engineering from Vilnius University's faculty of physics in 2022. He is currently pursuing a master's degree in laser technology from the same institution. He is very interested in femtosecond lasers and microfabrication, especially for industrial applications. Deividas is developing new femtosecond laser solutions that meet the needs of industrial clients.

Valdemar Stankevič is presently serving as the chief technical officer at Akoneer. He earned his PhD in materials engineering in 2017 from Vilnius University, Lithuania. Dr Stankevič gained valuable experience during his internships at Politecnico di Milano, Italy, and the Institute of Applied Physics in Germany. He has the expertise to develop advanced technologies and specializes in the processing of transparent and ultrahard materials using ultrafast lasers.



Arnas Vyšniauskas is a laser application engineer at Akoneer. He earned his master's degree in laser technologies from Vilnius University. he specializes in color generation on different types of metals and provides solutions for micro-level machining.



Oliver Rohm obtained his diploma in laser technology from the University of Koblenz and has been working as a product manager for Ekspla laser systems at Topag Lasertechnik since 2018. His focus is on understanding the complex requirements of laser applications and designing appropriate laser systems. He is responsible for developing industrial business with USP lasers and is the main contact person for industrial customers.

Lukas Rimgaila, Tadas Bartulevičius, Deividas Andriukaitis, EKSPLA uab, Savanoriu Av. 237, 02300 Vilnius, Lithuania; e-mails: l.rimgaila@ekspla.com, t.bartulevicius@ekspla.com, d.andriukaitis@ekspla.com, Web: www.ekspla.com ■ Valdemar Stankevič, Arnas Vyšniauskas, Akoneer uab, Mokslininku str. 6B, 08412 Vilnius, Lithuania; e-mail: valdemar@akoneer.com, Web: www.akoneer.com ■ Oliver Rohm, TOPAG Lasertechnik GmbH, Nieder-Ramstädter Str. 247, 64285 Darmstadt, Germany; e-mail: rohm@topag.de, Web: www.topag.de

MKS Instruments presents multiple measurement solutions for additive manufacturing

The Ophir BeamPeek integrated beam analysis and power measurement system offers fast, accurate, real-time measurement of lasers in additive manufacturing chambers. The compact device provides simultaneous beam profiling, focal spot analysis, and power measurement in just three seconds. There is no need for water or fan cooling as the system includes a replaceable, passive cooling, beam dump tray that eliminates downtime between measurement sessions. The BeamPeek system is ideal for field service testing of additive manufacturing chamber powder beds. It is able to withstand rough chamber conditions, including the presence of metal powder residuals and when cooling agents or airflow connection points are not available. The device is a compact, ruggedized, high power laser measurement tool that measures powers up to 1 kW for two minutes for both green (532 nm) and NIR wavelengths (1030 – 1080 nm).

Ophir StarViewer iOS app

The BeamPeek system is supported by a range of Ophir software options: StarLab, BeamPeek Tool, and BeamGage Professional. BeamGage is based on Ultracal, Ophir's patented, baseline correction algorithm that helped to establish the ISO 11146-3 standard for beam measurement accuracy. The software includes all the calculations needed to make accurate, ISO-approved laser beam measurements, including power and spot diameter, power density, spot position, and more.

The Ophir Ariel power meter is self-contained and ultracompact, and therefore well suited for measuring

Ophir BeamPeek system

high power industrial lasers up to 8 kW. Designed for OEM and end-user applications in closed and confined spaces such as additive manufacturing, metal cutting, and welding, the power meter is a robust, battery-powered device that requires no water or fan cooling and is small enough to fit in the palm of your hand. The system measures laser powers from 200 mW to 8 kW, and a wide range of wavelengths, including the 440 – 550 nm green and blue lasers that are increasingly popular in copper welding, 900 – 1100 nm fiber lasers used in most metal processing, 10.6 µm CO_2 lasers, and 2.94 µm medical lasers. Unlike competitive offerings, the Ariel power meter provides a range of features for more flexible measurement options: it measures a wider range of wavelengths; it can be operated in continuous or short exposure mode; it can be used with or without a diffuser for higher power densities; it delivers three to five times faster reading times; it can also be operated stand-alone or wirelessly.

The Ariel industrial power meter combines two modes of operation to provide a large measurement range of 200 mW to 8 kW: (a) measurement of the energy of a short time exposure for high power lasers up to 8 kW, and (b) longer cw power measurements for lower powers up to 500 W. The system's high thermal capacity of 14 kJ means it can measure several consecutive pulses with an accumulated energy of 14 kJ before it needs to cool down. A detachable diffuser allows the measurement of high power density beams.

The Ariel power meter features a robust housing that is dust-proof,

Ophir Ariel power meter

resistant to splashes of water, and easy to transport. Communication options include Bluetooth for passing readings from inside a closed machine to a mobile phone or laptop, and a USB-C interface. The power meter can also be operated in stand-alone mode with data displayed on a built-in 128 × 64-pixel LCD display or saved in internal memory. Software support is provided by Ophir StarViewer or Ophir StarLab.

MKS recently introduced the Ophir StarViewer iOS app, which delivers laser power/energy measurements wirelessly to iOS iPhones and iPads. Data can be displayed in a variety of formats: time-based line graph, needle display, or a large numeric display with statistics. Users can also capture a screenshot and share it, such as when a field technician needs to report results back to the lab. The StarViewer iOS app – as well as the Android app – are designed to work with the Ophir Ariel laser power meter to remotely support applications in additive manufacturing, as well as industrial cutting and welding, medical devices, laboratory research, and more.
Visit MKS at booth A3.219 at Laser World of Photonics to learn more about state-of-the-art additive manufacturing measurement solutions.

Ophir Spiricon Europe GmbH (MKS Instruments)
Guerickeweg 7
D-64291 Darmstadt
Germany
e-mail: info-ophir-eu@mksinst.com
Web: www.ophiropt.com
phone: +49 6151 708-0

Scansonic with broad portfolio of optics for laser welding of battery boxes in electric cars

Battery boxes in electric vehicles can influence more than just vehicle dynamics. The fire risk posed by batteries makes them crash-relevant components. For this reason, high-strength aluminum alloy structures are used in production, although they are markedly susceptible to hot cracking; the quality of the weld seams is a decisive factor in their strength. Scansonic, one of the world's leading manufacturers of laser machining optics, is presenting its product portfolio at Laser World of Photonics in Munich.

Source: Scansonic MI GmbH

The manufacture of battery boxes presents a number of significant challenges to welding technology: the weld seams must be gas-tight; the geometry is elaborate; depending on the aluminum alloy, there is susceptibility to cracking; warping must be avoided. As production quantities increase, so faster cycle times have moved into focus. Laser welding is the preferred production method, in particular because of its lower energy input into the component and its greater speed. Scansonic has created various solutions for these applications and offers the appropriate optics.

A new combination of tactile seam tracking with laser beam oscillation

The ALO4-O is the newest optic in Scansonic's portfolio, and was specially designed for use in the production of battery boxes. The laser processing head combines tactile seam tracking with the laser beam oscillation of a remote optic. The tactile seam tracking compensates for component tolerances and ensures stable process control and the highest seam quality. Two synchronized scanner axes are integrated into the ALO4-O for defined 2D laser beam oscillation at up to 1000 Hz. Oscillation shapes, amplitudes and frequencies are freely programmable for each scanner axis. This combination enables a wide joint cross-section in the seam with minimal heat input, and at the same time improves the seam properties due to the integrated filler wire.

RLW-A remote welding optic for the underside

The fillet seams on the underside protection of the battery boxes can be reliably produced using remote laser welding. This method offers particular cost advantages and high efficiency because of its comparably high speed and because of its comparably high speed and low costs. The RLW-A remote welding optic from Scansonic is distinguished by its robust system engineering, easy parameterization, and stable optical seam tracking. The optic also has two separate 2D scanners for positioning and oscillation. These allow the optic to influence melting by oscillating the beam without disturbing the seam tracking itself. With its three lines instead of the usual single line, the laser line scanner supplies more information on the position of the weld seam. Together, these ensure perfect weld seams and a high level of process safety. Laser power levels of up to 8 kW and welding speeds between six and ten meters per minute are possible.

Tactile laser welding with filler wire for internal stiffness

The weld seams on the inner side of the battery boxes that are created when inserting crash structures for example can be optimally produced by tactile laser welding and the use of filler wire. Here Scansonic offers an appropriate solution with its ALO4 optic. Joint tracking is achieved mechanically by means of a wire introduced into the weld seam. The ALO4 produces automated, repeatable welding results to meet the high fitting accuracy requirements of the battery box. In addition, the supplied filler wire – such as 4000 series aluminum wire for 6000 series aluminum sheets – significantly reduces susceptibility to cracking in aluminum alloys and ensures greater strength. The precise energy input minimizes heating of the part and prevents warping. For welding operations with particularly demanding geometric configurations, Scansonic offers the ALO4-Long version, which can create a weld seam even in cramped conditions within the battery box.

Development partner for new applications

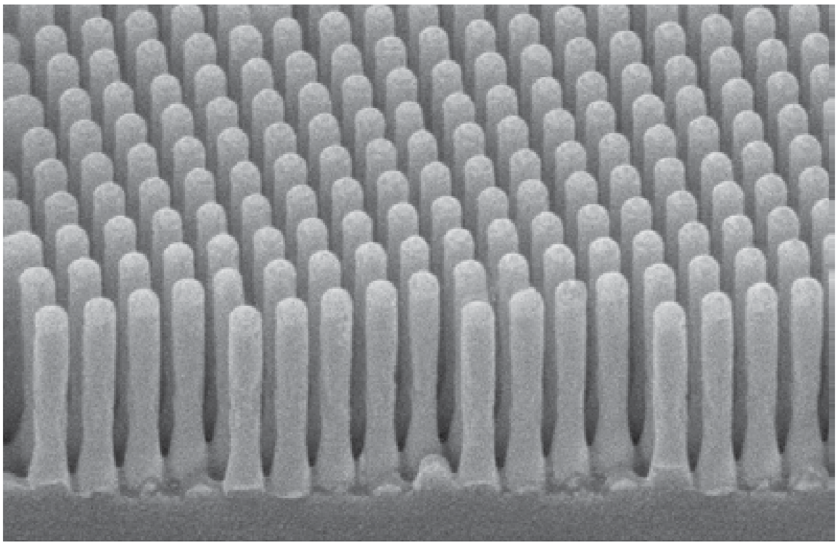
In its work on producing sophisticated welding applications for battery boxes, Scansonic builds on more than twenty years of process expertise in laser welding. The company's own Laser Application Center is one of the best equipped centers of its kind in the world. All of its processes are thoroughly tested and customer-specific solutions are developed here that will function reliably in serial production. The RLW-A and ALO4 optics are based on common system engineering in areas such as media supply, user interface, operation, and parameterization.More information on Scansonic optics can be found at: https://www.scansonic.de/en/applications/laser-welding/

Scansonic MI GmbH

Schwarze Pumpe Weg 16
12681 Berlin, Germany
phone: +49 30 912 074 360
e-mail: info@scansonic.de
Web: www.scansonic.de
www.berlin.industrial.group

Metasurfaces and metalenses

Lenses are widely used as a basic optical element in daily life. They are used in cameras, eyeglasses, microscopes, and many other devices. The lenses are developed based on classical refractive optics, which leads to unavoidable imaging errors such as chromatic as well as spherical aberration and coma. To minimize these, conventional imaging systems usually use multiple lenses of different powers and materials.

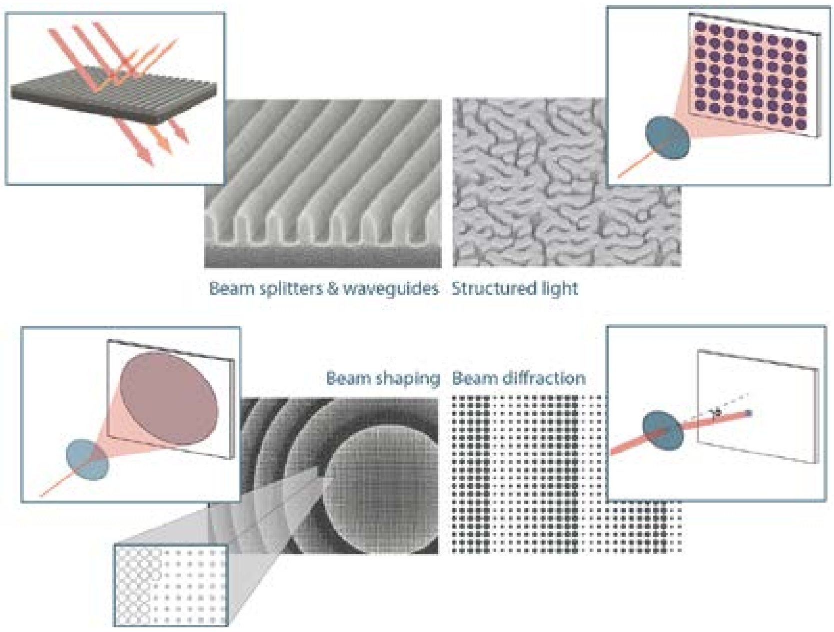


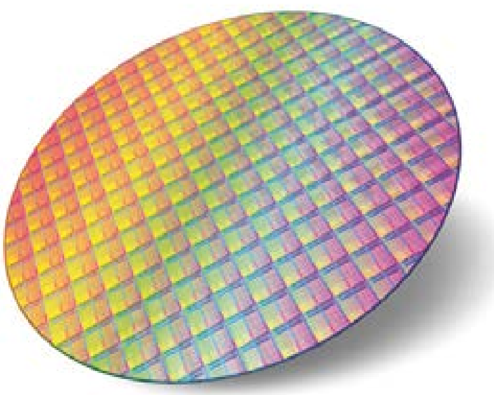
800 nm tall oxide pillars (high refractive index)

Metasurfaces and lenses offer high potential as replacements for many classical optical components. They are a fundamentally new method of light manipulation based on scattering by nanostructures rather than conventional refraction. As a result, they enable efficient phase, polarization and intensity control.

They can precisely influence the wavefront of light and produce impressive optical phenomena. At the same time, they are usually much smaller and less expensive than conventional solutions. Multidimensional meta surfaces achieve new functionality that is difficult or impossible to obtain with conventional lenses.

Our partner Moxtek has been manufacturing nanostructured optical components for over twenty years and can mass-produce a wide variety of structures on wafers of 200 mm diameter.





200 mm wafer

The range includes functional nanostructures such as micro lens arrays, waveguides, patterned meta surfaces, diffractive optical elements (DOE), photonic crystals and biosensor arrays. These devices for imaging, illumination, and display systems are used for a variety of applications in the automotive industry, medical/dental imaging, camera systems, and many others.

Prototype samples can be created on an in-house design master shuttle. This nanoimprint lithography (NIL) master shuttle design includes space for multiple (different) design structures, allowing several designs to be tested in a single shuttle iteration. This significantly reduces development time and cost. These design shuttles are processed several times a year.

Quantum Design GmbH
Im Tiefen See 58
64293 Darmstadt, Germany
phone: +49 6151 8806-0
e-mail: germany@qd-europe.com
Web: https://qd-europe.com

Narrow linewidth 10 kHz tunable laser

Features

- Hands-free, no gap wavelength tuning in 210 – 2600 nm range
- High repetition rate 10 kHz
- Narrow linewidth down to 1.5 cm^{-1}
- Up to 0.7 W output
- Monolithic rugged frame
- Easy control via keypad or PC

Applications

- Laser-induced fluorescence spectroscopy
- Photoacoustic microscopy
- Metrology and equipment calibration
- Pump-probe spectroscopy, photolysis
- Mass spectroscopy
- Environment monitoring, lidar

Ekspla NT 262

The NT 262 series tunable lasers offer tunable, automated wavelength output from UV to IR out of one small-footprint box. Integrated into a single compact housing, the diode-pumped, Q-switched, Nd:YAG laser and OPO provide hands-free, no-gap tuning across the specified range.

Narrow band excitation

The NT262 features a unique narrow linewidth and a high 10 kHz repetition rate. Pioneering patented technology enables a powerful output of up to 0.7 W in the 210 – 2600 nm wavelength range while maintaining <3 cm^{-1} linewidth (typically <2 cm^{-1} at most wavelengths) that is highly beneficial both for standard and highly demanding applications requiring a narrow linewidth and high spectral brightness pulses. Besides the most popular applications like fluorescence and pump-probe spectroscopy, the system is also suitable for applications where a high resolution and a narrow linewidth are required, like the calibration of detectors and spectroradiometers, metrology or gas spectroscopy.

Laser source for fast data acquisition

The high 10 kHz repetition rate and hands-free wavelength tuning enable fast experiment data acquisition. The system is very stable, ensures excellent short and long-term energy and power stability, and has a smaller M^2 value when compared with traditional OPO systems. In addition to its superior specifications, the laser is highly reliable due to its low generation threshold and easy running mode.

A built-in OPO pump energy monitor allows the monitoring of pump laser performance without the use of external power meters. The output wavelength can be set from a control pad with a backlit display that is easy to read, even while wearing laser safety glasses. Alternatively, the laser can be controlled from a personal computer using the supplied LabVIEW drivers.

Monolithic housing for maximum stability

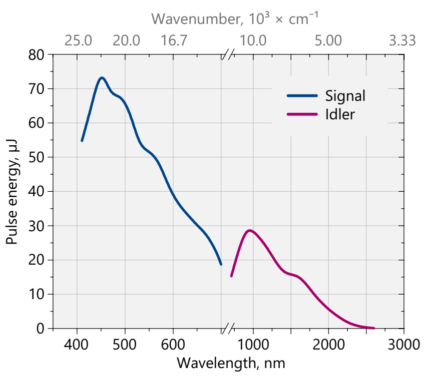
Compared to solutions offering the laser and OPO in separate units, the NT262 has better overall stability as the all-in-one-box solution contains all the components in one compact, monolithic housing. In addition, this results in almost half the footprint, a shorter installation time, better stability, and other substantial benefits for the user. All potential causes of misalignment between separate units of the pump laser and the optical parametric oscillator are eliminated. There is also a separate output beam for the pump laser (available as an option), so users can appreciate a real 2-in-1 solution by having a nanosecond laser or tunable wavelength output. In systems with separate boxes, customers can have only one output from the parametric generator (as the laser should be connected to the parametric generator).

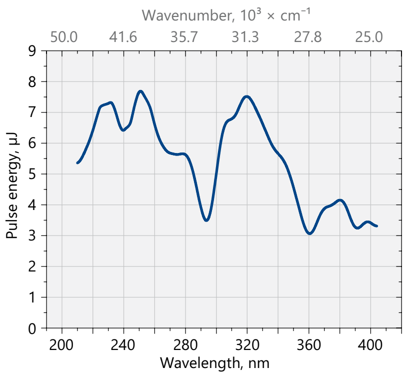
All models feature hands-free wavelength tuning, a valuable optical components protection system as well as a wide range of accessories and extension units. Long-term experience and close cooperation with scientific institutions has made it possible to create a range of models, offering a wide tuning range from 193 to 16,000 nm. Versions offering near transform-limited linewidth <2 cm^{-1} are available. A wide range of available options, accessories and modifications enable you to tailor the lasers to best fit your requirements.

For researchers demanding a wide tuning range, high conversion efficiency and narrow line-width, Ekspla NT and PT series tunable lasers are an excellent choice. In Germany and Austria, Ekspla lasers are distributed and serviced by Topag Lasertechnik.

EKSPLA
Savanoriu Ave 237
LT-02300 Vilnius, Lithuania
phone: +370 5 264 9629
e-mail: sales@ekspla.com
Web: www.ekspla.com

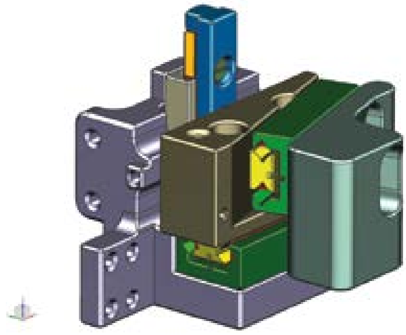
TOPAG Lasertechnik GmbH
Nieder-Ramstädter Str. 247
phone: +49 6151 429440
64285 Darmstadt, Germany
e-mail: info@topag.de
Web: www.topag.de
Web: www.instrumentsystems.com





Looking for the smallest linear slide in the world?

PM bv, a manufacturer of precision linear bearings and linear slides in the Netherlands, has the smallest linear precision slide available in the industry, the MSR 3. It is designed for the optical, microelectronics, and laser industry where precise movements are required, often within tight installation spaces. The design offers ultrasmooth motion and high repeatability.



XYZ-assembly with MSR miniature slides

Crossed roller cage with anti-cage creep technology

The MSR 3 is a real innovation in the industry. With a height of only 3.2 mm and a width of 5.5 mm it offers maximum space savings, and provides the advantages of cross roller bearings together with anti-cage creep technology. The slide is free of play, and preloading is done at the factory by matching the rollers in tolerances of 0.1 micron to the raceways. The MSR slide is the only slide available in the industry with all these features in a small package.

Available lengths and stroke

The slide top and base have equal lengths. The MSR 3 comes in four lengths: 8, 15, 20 and 25 mm with stroke lengths of 5 – 20 mm. The dynamic load rating ranges from 191 – 393 N. Other specifications:

- 100 % made of stainless steel
- crossed roller design allow loads in every direction
- crossed roller design offers high stiffness and precision
- factory preloaded, ready-to-install
- zero cage creep
- can be used in every mounting orientation
- ultrasmall footprint makes the slide attractive for miniature machines and instruments.

Customized

Beyond the catalogue products, the MSR series miniature slides are customizable for applications with specific needs, such as:

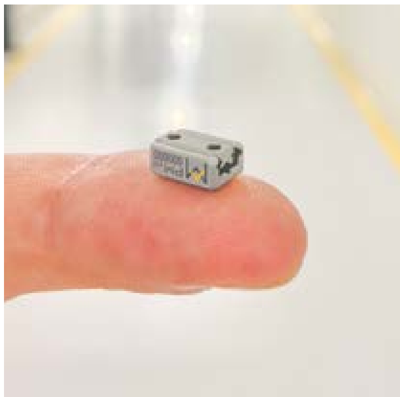
- alternative lubricants
- specific pushing forces
- a specific table design
- a customized stroke
- additional holes
- cleanroom and vacuum compatible.

The MSR 3 is the latest member of the MSR series. The whole range includes seven sizes and covers over thirty lengths. The stroke ranges from 5 – 112 mm and the dynamic load carrying capacity ranges from 191 – 7819 N.

The company

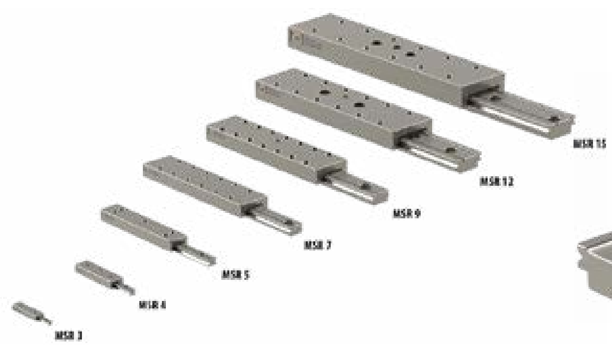
PM bv was founded in 1966 in the Netherlands. It is a technologically-driven family business that is active in:

- precision linear guides;
- linear slides
- rotating turntable precision bearings
- customized positioning stages
- mechatronic systems



The MSR 3 miniature slide on fingertip

The linear guides and slides are known for their high precision, low friction and smooth running performance. PM design and manufacture all key components in-house to guarantee top-notch quality and maximum flexibility. Beyond the catalogue products, PM offers customized versions to meet specific requirements. This service is available for both small and high volume series. PM's network of sales partners covers the important technologically-driven countries. They have many years of experience, and are well trained in the products to give local support to customers.



The MSR rang include seven sizes

Inside the MSR slide

PM B.V.
Galileistraat 2
7701 SK Dedemsvaart
The Netherlands
e-mail: sales@pm.nl
Web: www.pm.nl

3D-printed GRIN tools for synchrospeed polishing

A first experimental study towards the use of hardness-gradient polishing tools for micro-optics manufacturing

Oliver Fähnle, Kerstin Kern, Jan Allaart, Henrik Surberg, Jens Bliedtner, Christian Schulze, Sebastian Henkel, Volker Heineck, Jürgen Bode, Michael Wagner

Source: EAH

▲ Synchrospeed GRIN pad polishing process using the novel 3D printed foil tool

Additive technologies allow the flexible production of gradient index (GRIN) polishing tools with specifically adaptable removal functions. These were successfully developed and investigated for synchrospeed polishing.

The use of micro-optical systems (usually with diameters and radii ranging from dozens of micrometers to a few millimeters) has increased tremendously with applications ranging from medical optics such as endoscopy and implants, to optical transmission systems for fiber coupling, space missions, and laser diode beam shaping devices, as well as virtual reality (VR) applications, or lidar. Due to their small dimensions, it is almost impossible to apply on machine, in-situ, in-process quality control during their manufacture. The use of stable manufacturing processes is therefore crucial. Two different approaches are feasible to achieve this: (a) the invention and development of new fabrication technologies such as the direct 3D printing of optical elements or the application of metasurfaces, and (b) inventions and developments to also enable the use of established state-of-the-art fabrication technology for the production of microlenses.

A new process, gradient index (GRIN) polishing, which allows a high degree of design freedom in the configuration of polishing agent carriers was presented in [1]. This follow-up paper reports on a first experimental study towards its implementation.

The state-of-the-art in the mass production of macroscopic spherical optics is the CNC machine-based synchrospeed polishing method, first published by Brück in 1981 [2]. Spherical surfaces are polished by area contact with tool diameters twice the size of the lens diameters with both rotating in the same direction. If the ratio of the rotary speeds of tool and lens equals the cosine of the inclination of the tool rotary axis with respect to the workpiece axis, the relative speeds between tool and workpiece surface are almost constant for each point within the clear aperture, resulting in constant stock

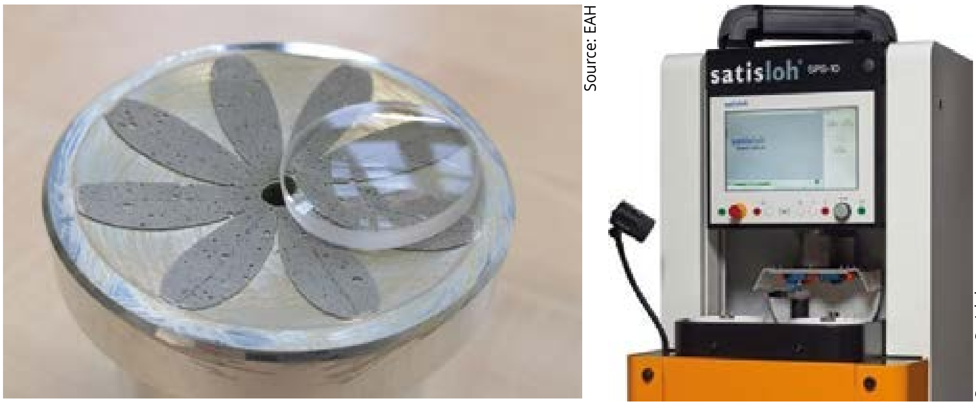


Fig. 1 Traditional synchrospeed polishing method applying spherical polishing pads made of metal featuring the exact workpiece radius and partially covered by flower-shaped polishing foils (directly right). A Satisloh SPS-100 CNC polishing machine (far right)

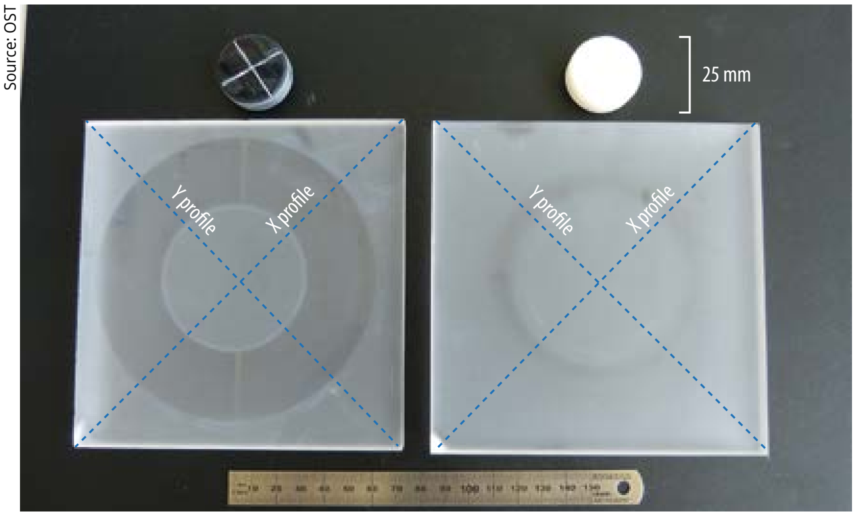


Fig. 2 Two polishing pad materials have been developed: the black one (on the left) featuring substantially higher removal rates than the white one (on the right). This can be seen in the two circular grooves polished into two 130 mm diameter N-BK7 samples. Polishing was stopped after 20 minutes with the black pad causing a more than 4× higher volume removal than the white pad.

removal over the entire surface to be polished.

So-called tool assignment is important and refers to the calculation of the polishing medium distribution and its arrangement on the polishing tool. An attempt is made to design the tool layout resulting from the path simulation in such a way that, as far as possible, uniform removal can take place at all workpiece points during the polishing process. In this way, less polishing area is provided at the diameter areas of the tool where a higher cutting speed is to be expected (outer area). Another important process variable is tool wear. Ideally, the polish carrier should wear evenly so that the workpiece accuracy of many components can be achieved without dressing.

The synchrospeed polishing process produces differently calculated polish carrier structures. Important objectives of synchrospeed polishing are:
1. uniform workpiece material removal (constant removal)
2. uniform tool wear.
However, for components with unfavorable workpiece opening angles

$$\alpha = \arcsin \frac{d_w}{2r}$$

with workpiece diameter d_w and radius of the lens r, this goal is often not achievable [3].

This is the prerequisite for stable mass production [3] (see Fig. 1). One essential feature of synchrospeed polishing is the preparation of the lateral pad surface shape to generate stable wear-distribution within the clear aperture. This is done by calculating the tool assignment for the optical component and deriving the corresponding polishing foil geometry to achieve a constant removal rate over the entire component surface, as shown in Fig. 1. Unfortunately, this feature prohibits the application of synchrospeed for micro-optics polishing since it is very hard to generate the required polishing foil microshapes.

Recently, a new approach to solve this problem called GRIN pad polishing

Institutes

Ostschweizer Fachhochschule

The Eastern Switzerland University of Applied Sciences, generally known as OST, is the university of applied sciences for the six cantons of Eastern Switzerland and the Principality of Liechtenstein. It is the region's educational hub, with around 3,800 students in six schools, 1,500 professionals in executive education, and more than 1,000 ongoing research projects. OST brings together 170 years of tradition in education and research.

www.ost.ch

Ernst Abbe University of Applied Sciences

The Ernst Abbe University of Applied Sciences (EAH Jena) offers a wide variety of study courses in eight departments covering engineering sciences, business administration and social sciences. One of eight main research fields focuses on optics and production engineering, especially on modern laser technologs. Our activities in laser material processing are the fundamental research of laser beam interactions, the development of special processing methods and the solving of industrial applications.

www.eah-jena.de/scitec

Fig. 3 Novel GRIN polishing pads for synchrospeed polishing are currently under investigation: (a) a full material synchrospeed polishing pad, (b) a lightweight synchrospeed polishing pad and (c) a special, full material synchrospeed polishing pad in two sizes: for lens diameters of 9 mm and for small lens diameters of 4 mm. Smaller pad dimensions are currently under investigation.

has been developed and experimentally tested in a feasibility study. As shown in Fig. 2, two different polishing pads (black and white) have been developed and 3D printed, featuring two different types of plastic material of substantially different hardness. While both differ substantially in material removal rates during polishing (applying a water-based cerium oxide slurry on N-BK7), both enable the generation of P3 optical surface roughness levels below 2 nm rms (1.8 nm rms using the black pad and 1.4 nm rms using the white pad). Both materials can therefore be printed onto one single GRIN synchrospeed polishing pad as shown in Fig. 3. These 3D printed tools remove substantially more material in the black flower-shaped part and much less material within the part in between (the white part of the pad). These 3D synchrospeed pads are mounted on a flat interface to the CNC tool axis, removing the need to use the traditional, metallic synchrospeed tools for the workpiece radius. The required workpiece radius can easily be generated directly on the 3D printed pad.

A multijet method was used for the 3D printing process that makes it possible to use two different plastic materials in one build process. These materials can be applied individually or mixed during the layer application process. If material component *A* is selected with a high hardness and component *B* with a low hardness, the hardness between the two limits can be accurately mixed and metered during the printing process. In this way, hardness transitions can be selectively set in a layer and in the component. The hardness of the printed polishing carrier can be adjusted as a function of the changing relative speed during synchrospeed polishing, which. simplifies tool assignment. The level of removal over the polishing process can be set more precisely with the printed polishing medium carriers, whereby layer resolutions of 16 µm are possible with the selected printing processes.

Two different 3D printed synchrospeed pad designs are currently under investigation: the full material GRIN pad shown in Fig. 3a, and a lightweight-structured GRIN pad shown in Fig. 3b, where the white part of the pad is only partially present to guarantee mechanical stability during polishing. Fig. 3c shows a miniaturized polishing pad, the generation of which is possible thanks to the less than 10 µm lateral resolution of 3D-printing multiplastics and hardness gradient GRIN pads.

Experimental investigations were carried out for the polishing of a biconvex lens with a diameter of 32 mm made from BK7 glass. A synchrospeed polishing process was applied using a 6-axis CNC polishing machine. The polishing suspension consisted of water with cerium oxide as polishing grain. In the experiments, a comparison between a standard synchrospeed polishing tool consisting of a polyurethane (PU) pad applied to a metal base body and new 3D-printed polishing pads was made. The additively manufactured polishing pad had a thickness of 0.25 mm. The black areas of the tool (with greater hardness) were designed in the form of a classic synchrospeed 'flower' structure. An additional crossed groove pattern for better polishing agent distribution was inserted. In a first step the tool was

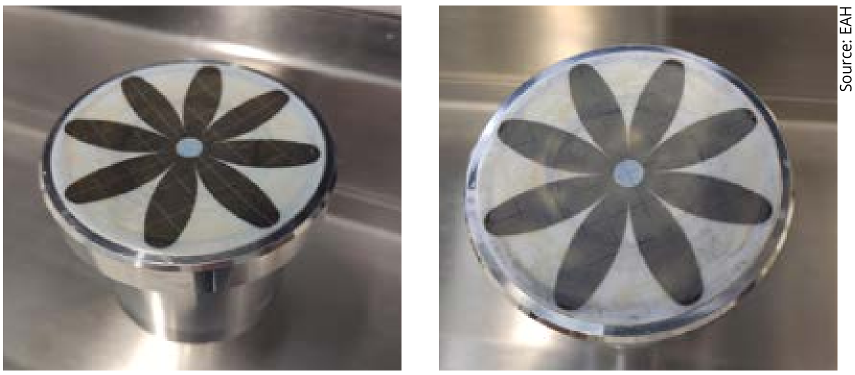


Fig. 4 Preparation of a novel GRIN pad polishing tool including dressing of the tool for a uniform surface structure with the required radius; left: before dressing, right: after dressing

dressed to the desired shape radius (see Fig. 4). Both tools were dressed in the polishing machine in the same manner using a diamond dressing tool. The biconvex lenses described were manufactured beforehand in a classic lens grinding process and then lapped with silicon carbide suspension (F600 grain size) for a uniform and polishable starting condition with about 0.5 µm rms roughness.

After completion of the preparations, the polishing process was started (see opening image page 1) using polishing times of 5 minutes for each lens, later increased to 10 minutes, investigating the long term stability of the tools. It can be stated that the new 3D-printed GRIN foil achieved a similar polishing behavior compared to the established PU foil. A visual inspection after 5 minutes revealed that the lenses were completely polished (see Fig. 5). Roughness values below Sq of 7 nm were achieved after that time. Increased polishing durations of 10 minutes could decrease the Sq roughness to between 0.9 and 2.1 nm. In Fig. 6, the resulting surface after 10 minutes of polishing in an area of about 0.4 × 0.3 mm is depicted using a white light interferometer (WLI) TMS-1400 from Polytec (20× magnification). Both images are at the same scale. Only very small deviations with a PV-value of below 10 nm Wt are recognizable. The surface topography for both types of tool appears to be nearly identical. With regard to the shape deviation, the percentage difference between target radius and actual radius was at -1.7 % for the 3D-printed foil and -1.3 % for the PU foil with target radii of 178.5 mm and 89.8 mm respectively.

The polishing process was carried out for ninety minutes in total, fabricating multiple lenses. The 3D-printed foil showed some delamination on the edges with increasing polishing time, yet still produced suitable lens surfaces until the end of the experiments. This demonstrated sufficient long-time usability that can still be improved with future optimizations.

One optimization is the introduction of structures and channels to accurately supply the polishing suspension and remove it. The ability to print support material in the layers means that any geometric structures can be provided. The support material can be removed after completion of the building process, and this structuring of polishing support will increase the tool life. The use of 3D printing also offers an opportunity in the future to transfer fluid dynamic simulations of the transport and distribution of the polishing suspension to the process better.

In conclusion, GRIN pad polishing, a new class of 3D printed synchrospeed polishing pads, has been developed and tested. These new tools enable the replacement of spherical, metallic polishing foil carriers with cost-efficient 3D printed planar pads, possibly enabling their use for synchrospeed polishing of microlenses.

It was demonstrated that the additively manufactured polish carriers can be successfully used to polish spherical lenses. Both the requirements for shape accuracy and micro-roughness could be reliably met. The achievable polishing times are comparable to classic foil polishing. This new process technology offers the ability to polish workpieces with unfavourable opening angles α in the future. The significant design freedom of the GRIN polishing process opens up great potential for processing aspheres and free-form surfaces in the future. The corresponding process windows in terms of the smallest processable radii, tool lifetimes and industrial applicability are currently under investigation in the labs of the Applied Universities of EAH (Jena, Germany) and OCB (Buchs, Switzerland) as well as in industry.

DOI: 10.1002/phvs.202300014

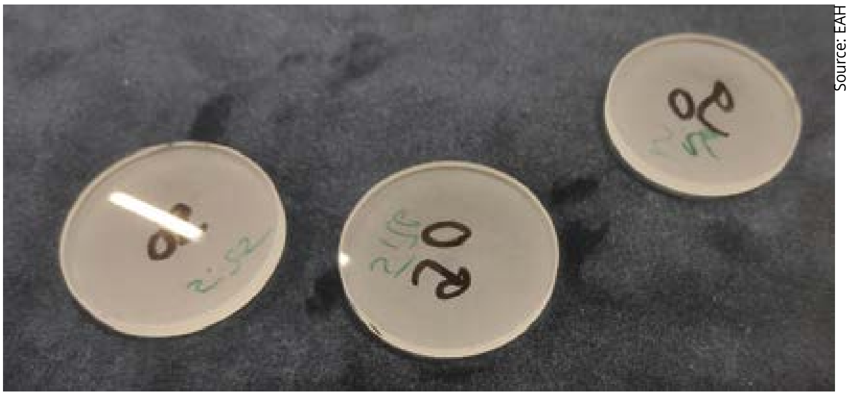


Fig. 5 Biconvex lenses after 5 min of polishing, each using the new 3D printed foil tool

[1] *O. Fähnle* et al.: GRIN pad polishing – 3D-printed hardness-gradient polishing tools for micro-optics synchrospeed pol-

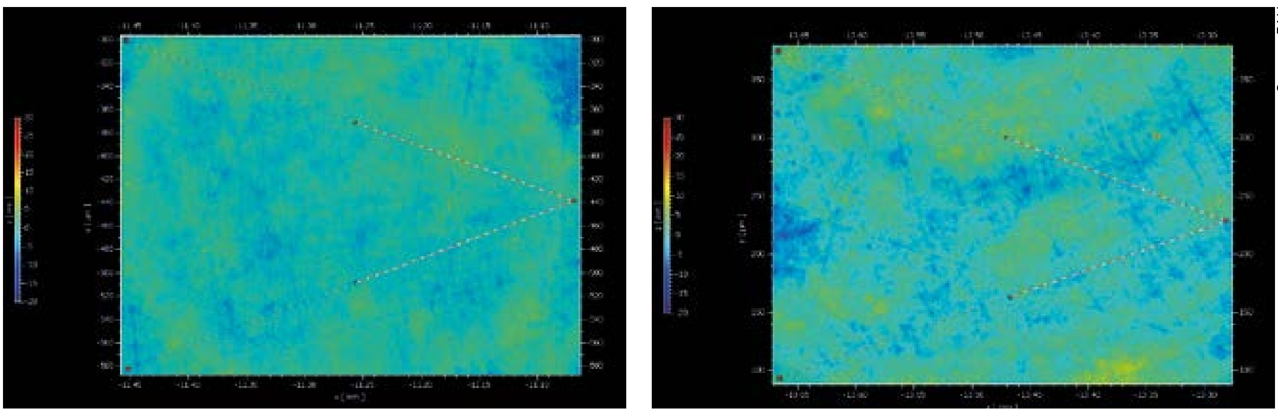


Fig. 6 WLI images of polished lenses (radius form removed) after 10 minutes of processing time at the outer area of the lenses; above: lens polished with 3D-printed foil tool, below: lens polished with conventional PU foil tool

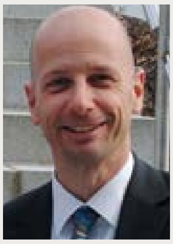
ishing, PhotonicsViews **20** (2023) 1, 68 – 69, first published December 2022; DOI: 10.1002/phvs.202200042

[2] *E. Brück:* Synchrospeed Verfahren, Loh company publication, 1981

[3] *S. Hambücker:* Technologie der Politur sphärischer Optiken mit Hilfe der Synchrospeed-Kinematik. Dissertation, Berichte aus der Produktionstechnik, Shaker Verlag, Berlin 2001

[4] *R. Williamson:* Field guide to optical fabrication, SPIE ISBN-13: 978-0819486769, 2011

Authors



Oliver Fähnle received his PhD from the Technical University Delft, The Netherlands. From 1999 to 2020 he was working as senior expert optical fabrication technology for Fisba, St Gallen, Switzerland. Since 2020, he heads the photonics systems generation group at the OST – University of Applied Sciences, Buchs, Switzerland. He is chairman of the industrial advisory board of the European Optical Society and a senior member of Optica and SPIE.

Jens Bliedtner studied precision engineering at the Friedrich Schiller University in Jena. He wrote his doctoral thesis on the development of pulsed laser systems and special methods in macro material processing. Since 2000, Bliedtner has been a professor at the Ernst Abbe University of Applied Sciences in Jena and the head of the production engineering and automation of production processes department. Currently, he is carrying out research in optical technology, laser material processing and AM.

Jürgen Bode has worked in the optical industry since 1998 and joined Satisloh in 2016. He is vice president precision optics for Satisloh, a leading manufacturer of surfacing, coating and finishing equipment. Bode holds a PhD in physics from the University of Göttingen and an MBA degree from the University of Bradford, UK.

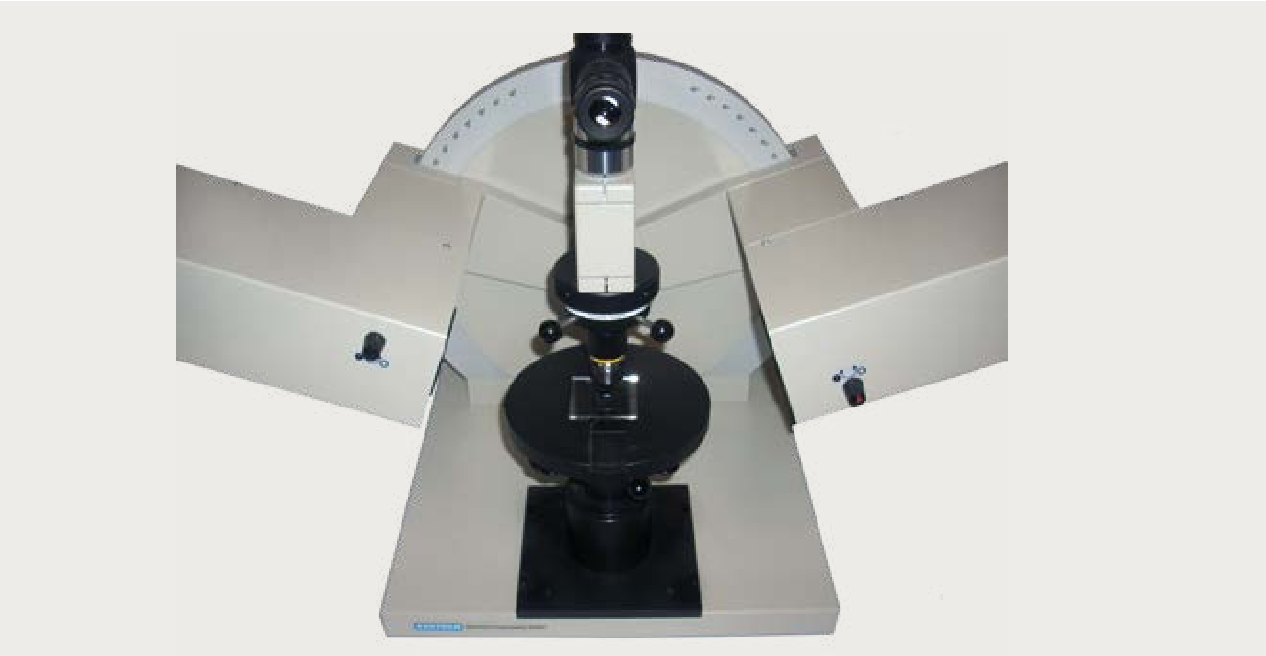
Further authors:
Kerstin Kern, Jan Allaart, Henrik Surberg (all of OST), **Christian Schulze, Sebastian Henkel, Volker Heineck** (all of EAH), and **Michael Wagner** (Satisloh)

Dr Oliver Fähnle, OST – Eastern Switzerland University of Applied Sciences, IMP Institute for Microtechnology and Photonics, Werdenbergstrasse 4, 9471 Buchs, Switzerland; phone +41 58 2573359; e-mail: oliver.faehnle@ost.ch, Web: www.ost.ch ■ Prof Dr Jens Bliedtner, Carl-Zeiss-Promenade 2, 07745 Jena, Germany, phone: +49 3641 205 444 e-mail: jens.bliedtner@eah-jena.de, Web: www.eah-jena.de/scitec ■ Dr Jürgen Bode, Wilhelm-Loh-Str. 2–4, 35578 Wetzlar, Germany, phone: +49 6441 912326 e-mail: juergen.bode@satisloh.com, Web: www.satisloh.com

Measuring the thickness of thin sintered layers precisely

Considering the influence of sintering on optical constants, the thickness of sintered Al_2O_3 layers in quartz tubes can be accurately determined

Faiza Houta & Michael Quinten



Source all images unless noted otherwise: Dr Quinten Wissenschaftlich-technische Software

Optical thickness determination with miniaturized spectrometers is a commonly used technique that works quite well in many applications. For sintered materials however, this technique must be extended by the determination of the optical constants of the sintered material. This can be done using a combination of scanning electron microscopy and effective medium approaches. In this article, we demonstrate this for the optical thickness determination of sintered Al_2O_3 layers in quartz tubes.

The production of safe drinking water consists of several treatment steps. One step is the cleaning of the water from bacteria and viruses. This process is done in the water treatment facility with UV lamps that deactivate the DNA of the germs in the water. However, the mercury-based UV lamps reduce their UV intensity over time by forming HgO at the quartz wall. This reduces their usable lifetime and their energy efficiency. It is usual to coat the inner surface of the tubes with a sintered Al_2O_3 layer to protect the quartz tube and stabilize the long-term UV output.

The thickness of the coating must be controlled to ensure optimal protection. In the past this was done by a destructive SEM analysis, which was very expensive and time consuming. With the method described here, this can be done by optical reflectometric measurement, which is very fast, contactless and nondestructive method. It presumes that the optical properties, i.e. the refractive index, of all involved materials are well known. This however is difficult for sintered materials. In this report we describe the determination of the thickness of the sintered Al_2O_3 layer by consideration of the structural properties of the layer to model its optical constants. With these optical constants we arrive at a thickness determination of the sintered films with an error of ±0.5 nm.

Basics of thin film optical thickness determination

Optical layer thickness determination with a reflectometer is a fast, contactless method for the reliable monitoring of the thickness of one or more layers in a layer stack or the thickness of unsupported thick layers. With this method, the thickness is not measured directly but is deduced from the reflectance spectrum with the help of a mathematical algorithm. For thin layers, a nonlinear regression analysis (fit algorithm) is used that allows the determination of the thickness of more than one layer in a layer stack, even to nanometer resolution. The calculation is quite extensive even for a single layer on a substrate as in our case. The complete calculation for a layer or layer stack can be read, for example in [1]. Here, we concentrate on the case of one layer on a substrate and take into account only the interference of the two first beams reflected at both interfaces (see Fig. 1).

In this approximation the reflectance $R(\lambda, d)$ becomes

$$R(\lambda, d) = R_{01}(\lambda) + R_{12}(\lambda) + 2\sqrt{R_{01}(\lambda)R_{12}(\lambda)} \cdot \cos\left(\frac{4\pi}{\lambda}\, n(\lambda) \cdot d\right). \quad (1)$$

R_{01} is the reflectivity at the interface air-layer and R_{12} is the reflectivity at the interface layer-substrate. The prominent result is that for a constant thickness d the reflectance changes oscillatory with the wavelength λ. From the evaluation of the oscillatory term – the cosine in Eq. (1) – the thickness d can be determined. This presumes that the materials of the layer and the substrate have homogeneous optical constants that are well-known. This, however, is not the case for layers of sintered materials.

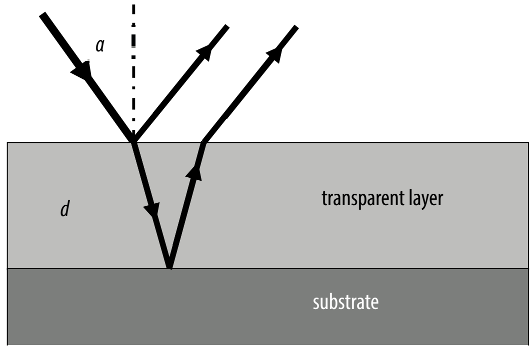


Fig. 1 Layer thickness interference of a transparent layer on a substrate

Therefore, for a correct determination of the thickness of the sintered Al_2O_3 layer we must look at the structural properties of the film.

SEM characterization of the coated quartz tubes

Examination with scanning electron microscopy (SEM) yields detailed information on the topography and the compound of the investigated object. The interaction of the electrons with the different materials leads to a contrast that allows a thin film to be distinguished from a substrate and to determine the film thickness. However, this method is elaborate in preparation and needs to destroy the quartz tube. Therefore, only exemplary SEM examinations were carried out on coated quartz tubes. The results for three samples are summarized in Fig. 2. They result in a film thickness of $d = 250$ nm, 325 nm, and 450 nm.

The SEM pictures reveal still more than the layer thickness, namely that the Al_2O_3 layer is not homogeneous in its composition. Rather, the films have a granular composition, similar to sintered small particles. Then however, the optical properties (i.e. the refractive index) of the sintered film differ from the refractive index of the homogeneous Al_2O_3. In addition, the granularity leads to a certain roughness at both interfaces. It can therefore be expected

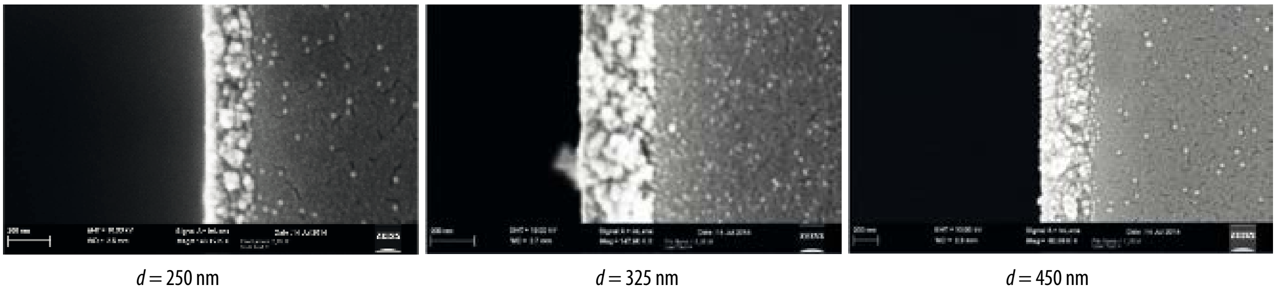


Fig. 2 SEM pictures of three coated quartz tubes (courtesy of Xylem Water Solutions)

that the thickness from optical thickness determination does not coincide with the thickness from SEM.

Optical thickness determination

As already mentioned, the granular structure of the Al_2O_3 films will lead to a refractive index of the film that differs from the refractive index of homogeneous Al_2O_3. The determination of the film thickness to nanometer resolution requires however the exact knowledge of the refractive index and its dependence upon the wavelength. Hence, we first determine the refractive index of the granular film by using effective medium approaches.

Optical constants of the sintered Al_2O_3 film

The determination of the optical constants of the sintered Al_2O_3 film is a challenge because the film is granular and because the grains are partly agglomerated. From the SEM pictures in Fig. 2, a mean grain size of about 55 to 60 nm can be estimated. Moreover, a packing density or volume fraction of $f = 0.5 – 0.65$ is obtained. These results are an estimation because agglomeration renders the evaluation more difficult. Nevertheless, with this information, the optical constants of the granular film can be approximated. For this, an effective medium approach (EMA) was applied. The basic idea of an EMA is to simulate the optical constants of a heterogeneous medium of two or more immiscible media with effective optical constants (see Fig. 4). Here, we have Al_2O_3 grains in air as a heterogeneous medium.

The existing effective medium approaches differ in the way they determine the effective dielectric function from the dielectric functions of the components and the volume fraction f. The simplest approach that also considers the topography of the inclusions (grains) stems from J. C. Maxwell Garnett [2] for spherical inclusions

$$\frac{\varepsilon_{\mathrm{eff}} - \varepsilon_{\mathrm{M}}}{\varepsilon_{\mathrm{eff}} + 2\varepsilon_{\mathrm{M}}} = f \frac{\varepsilon - \varepsilon_{\mathrm{M}}}{\varepsilon + 2\varepsilon_{\mathrm{M}}} \,. \quad (2)$$

This solution is useful for heterogeneous media with low volume fractions f. For higher volume fractions with even percolation, the approach of D. A. G. Bruggeman [3] is more appropriate:

$$f \cdot \frac{\varepsilon - \varepsilon_{\mathrm{eff}}}{\varepsilon + 2\varepsilon_{\mathrm{eff}}} + (1 - f) \cdot \frac{\varepsilon_{\mathrm{M}} - \varepsilon_{\mathrm{eff}}}{\varepsilon_{\mathrm{M}} + 2\varepsilon_{\mathrm{eff}}} = 0 \quad (3)$$

For an overview of effective medium approximations we refer to [1, 4]. In our case of the sintered Al_2O_3 film, the Bruggeman approach is the most appropriate. Al_2O_3 is a transparent material with a quite high refractive index n of about $n = 1.75$ in the visible spectral region. It can be expected that the refractive index for the sintered Al_2O_3 film is lower because the amount of Al_2O_3 in the film is only 50 – 65%. The evaluation with the Bruggeman EMA and a volume fraction of $f = 0.52$ yielded optical constants for the granular film with a refractive index of about $n = 1.346$ in the visible spectral region. The error in the determination of the refractive index amounts to ± 0.025.

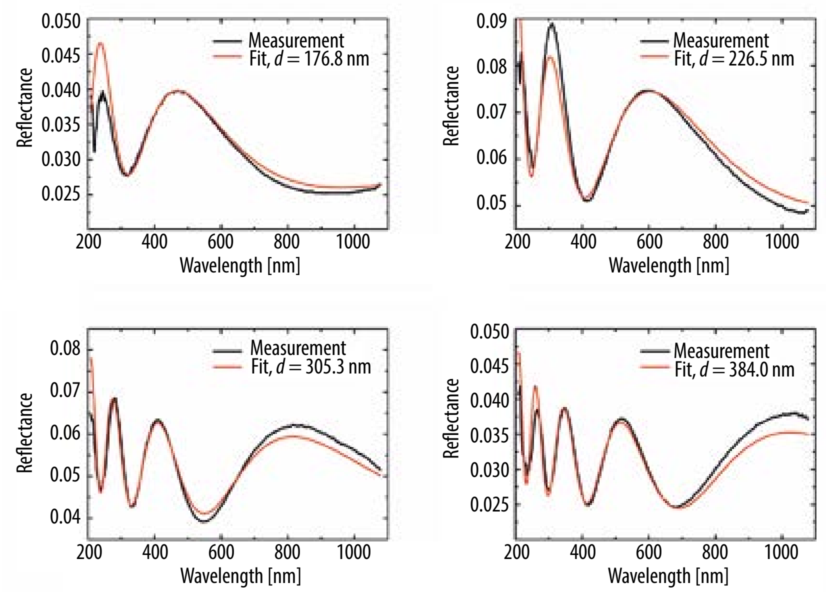


Fig. 3 Fits on the measured reflectance spectra of a sintered Al_2O_3 film on the inner side of a quartz tube. For calculation, the optical constants from the EMA modeling in the previous section are used.

Results of optical thickness determination

Before we show the results obtained with the determined optical constants of the granular film, we first show in Fig. 5 an example for a fit using optical constants of homogeneous Al_2O_3 [5].

Obviously, the calculated spectrum differs greatly from the measured spectrum. The thickness obtained from this fit cannot be realistic. However, with the optical constants from the previous section, we arrive at quite good agreement of measurement and calculation. This is demonstrated in Fig. 3 for four exemplary coatings. The corresponding thickness amounts to $d = 176.8$ nm, 226.5 nm, 305.3 nm, and 384.0 nm with an error of ± 0.5 nm. Differences in the magnitude indicate the non-optimal determination of the optical constants.

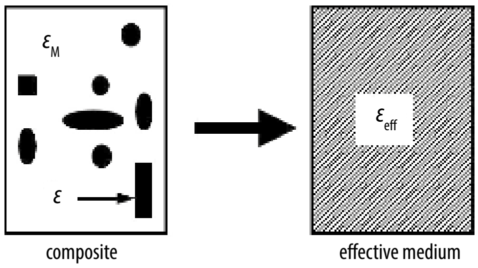


Fig. 4 Scheme of the effective medium: The realistic composite is replaced by a homogeneous effective medium

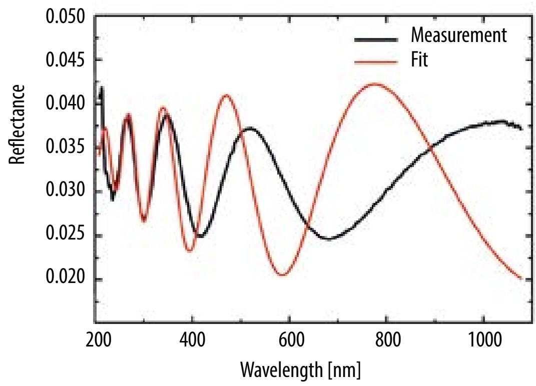


Fig. 5 Fit of the reflectance spectrum of a sintered Al_2O_3 layer on the inner side of a quartz tube. For calculation, optical constants from literature [5] are used for the film.

Summary

In this report we showed that the expensive and destructive layer thickness control with SEM can be replaced by contactless, nondestructive optical layer thickness determination. However, the optical thickness determination is also not free of problems. Presumptions for the use of the optical method are that the optical constants of all layers and substrates are well-known and are homogeneous. Then, with a nonlinear regression analysis, the thickness can be derived from the measured reflectance or transmittance. In the current application we had to solve the problem that the optical constants of the sintered Al_2O_3 film on the inner side of a quartz tube do not coincide with the optical constants of Al_2O_3 from literature. With the help of the Bruggeman effective medium approach and the topological evaluation of SEM pictures, we arrived at a set of optical constants for the granular sintered films. Applying these optical constants, we arrived at an exact determination of the film thickness with an error of ±0.5 nm.

DOI: 10.1002/phvs.202300013

[1] *M. Quinten:* A Practical Guide to Optical Metrology for Thin Films, Wiley-VCH, Weinheim (2012)

[2] *J. C. M. Garnett:* Colours in metal glasses and in metallic films, Phil. Trans. Royal Soc. London, **A 203** (1904) 385-420.

[3] *D. A. G. Bruggeman:* Berechnung verschiedener physikalischer Konstanten von heterogenen Substanzen, I. Dielektrizitätskonstanten und Leitfähigkeiten der Mischkörper aus isotropen Substanzen, Ann. Phys. (Leipzig), **24** (1935) 636-679.

[4] *M. Quinten:* Optical Properties of Nanoparticle Systems - Mie and Beyond, Wiley-VCH, Berlin (2011).

[5] *E. D. Palik* (Ed.): Handbook of Optical Constants of Solids I, Academic Press, San Diego (1985), and, Handbook of Optical Constants of Solids II, Academic Press, San Diego (1991).

Authors

Faiza Houta obtained her diploma in engineering at the University of Applied Sciences Cologne within the Institute of Applied Optics and Electronics in 2009. From 2010 to 2021 she worked at FRT GmbH in Bergisch Gladbach, Germany, in the sensors R&D department and is now with the Bundesamt für Sicherheit in der Informationstechnik, Bonn, Germany.

Michael Quinten obtained his diploma degree and PhD in physics at the University of Saarland, Saarbrucken, Germany, and joined the Technical University RWTH Aachen for habilitation. In 2001 he moved to ETA-Optik GmbH, Germany, then to FRT GmbH in 2007 where he is now head of the R&D sensors department. In 1996 he founded Dr. Michael Quinten Wissenschaftlich-technische Software.

Dr. rer. nat. habil. Michael Quinten, Wissenschaftlich-technische Software, 52457 Aldenhoven, Germany; phone: +49 2464 2649, e-mail: ulmi.quinten@dn-connect.de

Full articles now online and in PhotonicsViews issue 4/2023

High-performance welding for safety-relevant applications

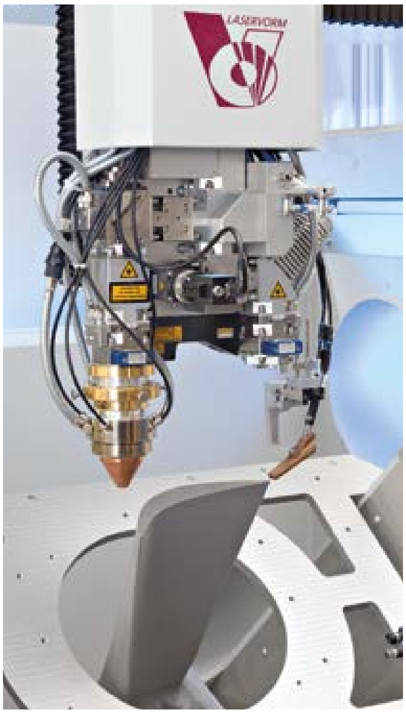
Deposition welding with reproducible, predictable quality

It helps to speed up the repair process and reduces costs. An important component for this is the new tracing technology from Laservorm, which records at exactly which point of the component which parameters have had what effect. Turbines are among the most powerful machines: they operate as gas turbines in engines, as steam and hydroelectric turbines in power generation, or in aircraft engines. Gas turbines have an output of up to 600 MW mech, in contrast to steam turbines generating almost 1.8 gigawatts in the largest nuclear power plants, such as the Olkiluoto nuclear power plant in Finland. Several individual steam turbines often operate here at high output in parallel. Hydroelectric turbines can reach over 700 MW, and jet engines in aircraft create up to 510 kN of thrust power.

The blades rotating in the turbines are subjected to enormous forces and are correspondingly susceptible to wear. In order to operate efficiently, turbine blades must be optimally shaped to ensure the best flow and are therefore built to very strict manufacturing tolerances. Even the smallest deviation from the optimum shape will reduce power or engine performance and increase fuel consumption.

Laservorm GmbH
Thomas Kimme, CEO
Südstraße 8
09648 Altmittweida
Germany
phone: +49 3727 9974-11
e-mail: thomas.kimme@laservorm.com
Web: www.laservorm.com

Schweissen & Schneiden, Hall 5, Booth B14



https://doi.org/10.1002/phvs.202300023

New lasers for climate research

How do you measure the temperature of individual atoms at an altitude of ninety kilometers?

Weather reports, climate models, or rocket launches – they all need precise data from the atmosphere. Scientists can use lidar systems to shoot laser beams into the sky to acquire such data. A team from the Fraunhofer Institute for Laser Technology ILT and the Leibniz Institute for Atmospheric Physics IAP has developed a portable lidar system that works autonomously.

It took ten years from the first discussions to the first successful mesosphere measurement with the new diode-pumped alexandrite laser. Alexandrite is a very special laser crystal: It can be tuned over a broad spectrum from 730 to 800 nm. Unlike titanium sapphire, it can also store abundant energy in the process. Thanks to these properties, it is particularly suitable for high pulse energies.

The prototype of the alexandrite lasers, illustrating the conversion from (infra)red to (ultra)violet, will be exhibited at Laser World of Photonics.

The mobile lidar system sends five beams into the night sky. With four small and one large telescope, it detects the photons from up to 100 km altitude and provides climate data in real time.

Source: Fraunhofer ILT / Ralf Baumgarten

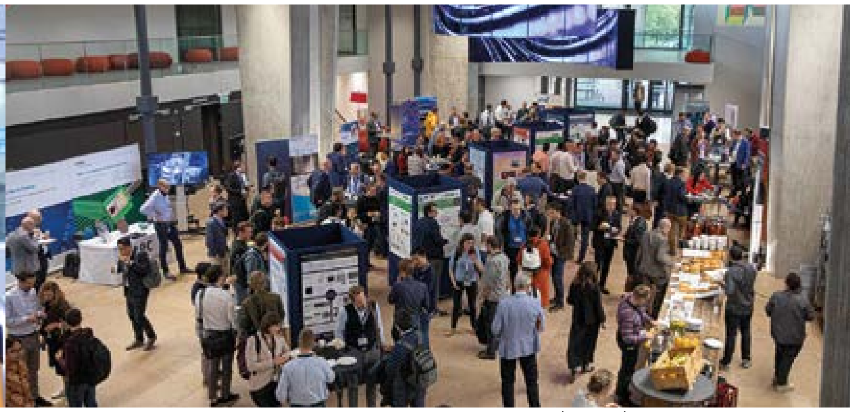
Fraunhofer Institute for Laser Technology (ILT)
Dr. Michael Strotkamp
NLO and Tunable Lasers Group
Steinbachstrasse 15
52074 Aachen, Germany
phone +49 241 890 6132
e-mail: michael.strotkamp@ilt.fraunhofer.de
Web: www.ilt.fraunhofer.de

Laser World of Photonics, Hall A3, Booth 441

Leibniz Institute for Atmospheric Physics (IAP)
Dr. Josef Höffner
Schlossstrasse 6
18225 Kühlungsborn, Germany
phone +49 38293 68130
e-mail: hoeffner@iap-kborn.de

https://doi.org/10.1002/phvs.202300024

Source: Messe München



Source: PhotonDelta

June 27 – 30, 2023
Laser World of Photonics
Munich, Germany
https://world-of-photonics.com

June 27 – 30, 2023
Automatica
Munich, Germany
https://automatica-munich.com

July 11 – 13, 2023
SEMICON West
San Francisco, CA, USA
www.semiconwest.org

August 20 – 24, 2023
SPIE Optics + Photonics
San Diego, CA, USA
https://spie.org/conferences-and-exhibitions/optics-and-photonics

September 6 – 8, 2023
CIOE
Shenzhen, China
https://cioe.cn

September 11 – 15, 2023
Schweissen & Schneiden
Essen, Germany
www.schweissen-schneiden.com

September 11 – 15, 2023
EOSAM 2023
Dijon, France
www.europeanoptics.org

September 11 – 23, 2023
EMO
Hanover, Germany
https://emo-hannover.com

September 13 – 15, 2023
LASER World of PHOTONICS India
Bengaluru, India
www.world-of-photonics-india.com

October 1 – 5, 2023
ECOC 2023
Glasgow, Scotland
www.ecocexhibition.com

October 10 – 13, 2023
Motek
Stuttgart, Germany
www.motek-messe.de

October 12 – 13, 2023
6th European Machine Vision Forum
Wageningen, The Netherlands
www.emva.org/emva-events

October 17 – 21, 2023
Fakuma
Friedrichshafen, Germany
www.fakuma-messe.de

November 7 – 10, 2023
Schweisstec
Stuttgart, Germany
www.schweisstec-messe.de

Read event previews and reviews on www.wileyindustrynews.com/en/events

Two days of innovation, inspiration and networking for future technologies

Review: W3+ Fair, 29 – 30 March 2023, Wetzlar, Germany

Source: Fleet Events

W3+ Wetzlar 2023

The networking fair kept its word: more than 150 exhibitors and speakers and over 1,900 visitors used the platform in the Buderus Arena Wetzlar to exchange information about new innovations and solutions and to forge new alliances across industries. 27 % of the exhibiting companies from the optics, photonics, electronics and mechanics sectors came from the high-tech region of Wetzlar / Central Hesse, 48 % from other German states and 25 % from abroad – more than ever before. Ten countries were represented, including Switzerland, Italy, France, UK, the US and the Netherlands. The common goal was to launch new technology-driven innovations for medical technology, life science, automotive, aerospace, or tools and machinery.

In addition to the exhibition, there was plenty of inspiration from the extensive supporting program. At the accompanying Enabling Technologies conference, around thirty speakers spoke on topics such as optics manufacturing, photonics and microtechnology, innovative solutions from Hessen, trends in optics and others. A new feature was the associated High Level Expert Meeting (HLEM) of the Competence Center Ultraprecise Surface Processing UPOB eV, which was held in parallel for the first time.

The special areas of IHK Hessen innovativ as well as that of VDI with AI, 3D printing, cobots and automation, the joint booth of the high-tech region Thuringia as well as the special 'Microtechnologies for optical devices' area of IVAM were well attended. The microtechnology network also used the trade show to hold the first live meeting of the photonics focus group. The Regionalmanagement Mittelhessen were involved twice: with the meeting of the new TeamMIT automotive network on site and – together with the Business Angels Mittelhessen – with the top-class Start-up Matching.

Wetzlar Network invited everyone to C-Level Coffee, while there was a visit of the sensor technology expert working group of the IHK Gießen-Friedberg as well as the Federal Association for Materials Management and Purchasing (BME e.V.).

Jörg Brück, project director of the W3+ Fair, draws a positive balance after the fair: "The W3+ Fair is the central industry fair for enabling technologies in Germany. People are very happy with the inspiring cross-industry exchange with existing customers and new contacts. For the 10th anniversary next year, we want to focus even more on innovation, inspiration and networking and will enrich the concept accordingly."

W3+ Fair Rhine Valley was suspended in 2023. After a promising first event in 2019, the fair in the four-country region has recently not developed as required for the satisfaction of all stakeholders. A revision of the concept is needed to regenerate stakeholder interest in the Rhine Valley. The organizers have therefore decided to fully concentrate their resources on the new location in Jena on 29 – 30 November 2023.

W3+ Fair Wetzlar will return on 13 – 14 March 2024.

www.fleet-events.de

Organizer satisfied with the number of visitors

Review: 35th Control, 9 – 12 May 2023, Stuttgart, Germany

Source: Schall

Exhibitors and trade visitors confirmed the importance of Control – the international trade fair for quality assurance – for the manufacturing industry this year. The proportion of foreign exhibitors was 34.5 percent. A total of 21,310 trade visitors at Control 2023 experienced the current trend and driver topics in the quality assurance industry – automation, end-to-end digitization, modern software, inline test processes and AI-supported systems – directly and in practical use.

After Control is before Control: as the organizers noted, many national and international exhibitors already booked their stand space for 2024 during Control 2023 in order to be able to present their products at the 36th Control from 23 – 26 April 2024 to the interested public in Stuttgart.

www.schall-messen.de

The organizer draws a positive conclusion

Review: Sensor + Test, 9 – 11 May 2023, Nuremberg, Germany

More than 5,000 trade visitors from Germany and abroad found their way to the Nuremberg exhibition halls, around twenty percent more than in the previous year. At 338, the number of exhibitors was slightly below that of the previous year, with the proportion of exhibitors from abroad rising again significantly at forty percent. The Sensor + Test event has once again confirmed its position as a leading international event for sensor, measurement and testing technology.

Source: AMA

After three eagerly awaited days, the Sensor + Test measurement technology trade fair closed its doors. 338 exhibitors, over 5,000 visitors and almost 700 participants at the SMSI 2023 Sensor and Measurement Science International Conference came to Nuremberg and contributed to the success of an intensive innovation dialogue on an exhibition area of 5,400 m^2.

With 133 exhibiting companies from 26 foreign countries, the international popularity returned to the level of the time before Corona, as did the proportion of visitors from all over the world at 27%.

A Job Lounge was part of the action program for the first time this year. Exhibitors presented their human resources topics here over two days to an interested audience. The program was rounded off by the job exchange and the Career Center, so that recruiting was given more space at the fair. The new format enabled even more targeted contact between specialists and companies.

Next year, the Sensor + Test will take place from 11 – 13 June 2024 in Nuremberg. The organizer is again planning to fill two complete halls.

www.sensorfairs.de

“From the island to the mainland”

Review: 19th RapidTech 3D, 9 – 11 May 2023, Erfurt, Germany

Additive manufacturing (AM) has gained a firm foothold in the industry. 3D printing islands are increasingly becoming end-to-end integrated solutions that encompass all links in the value chain from design to final product and make an important contribution to resilient and sustainable supply chains. The dynamics in the development and application of new materials, methods and processes were conspicuously reflected in the lectures, discussions and presentations at RapidTech 3D. Around 2,700 visitors from Germany and abroad appreciated the high quality of the trade congress and exhibition once again.

Source: Messe Erfurt, Christian Seeling

Discussion advanced training additive manufacturing

“The 19th Rapid.Tech 3D has once again shown that Erfurt is an important platform for user-related technical exchange on additive manufacturing. We are delighted with the very good response and would like to thank all the players and supporters who contributed to the success of the event,” says Michael Kynast, managing director of Messe Erfurt.

Inspiration for concrete applications as well as for new methods using advanced technology was provided by the more than 70 expert lectures and 93 exhibitor presentations. Numerous suppliers and users established in the AM sector, such as AIM3D, Arburg, Farsoon, FIT, Intamsys, Sinterit, Stratasys, Toolcraft and Trumpf, as well as innovative start-ups and university projects, showed their current range of services.

RapidTech3D also showed perspectives for future development of the event during its 19th edition, including even stronger cooperation with partners and multipliers at both a national and an international level. For example, the Additive Manufacturing Working Group within the VDMA will become the conceptual sponsor.

The next RapidTech 3D will take place on May 14 – 16, 2024.

www.messe-erfurt.de

Preview: 24th China International Optoelectronic Exposition, CIOE 2023

6 – 8 September 2023, Shenzhen, China

After three years of quarantine policies, thousands of Chinese manufacturers have been starved of global resources and want to speak to the world again. In 2023 we are offering a free shuttle bus service, and we look forward to shaking hands with you on site. As one of the world's largest and most influential optoelectronics event, CIOE 2023 – The 24th China International Optoelectronic Exposition – will be held in September at Shenzhen World Exhibition and Convention Center. Featuring 240,000 square meters of floor space and over 3,000 professional exhibitors, it will bring global optoelectronic peers and buyers the world's most comprehensive optoelectronic ecosystems, from components, devices, and equipment to various innovative applications.

With an improved floor plan, this year's CIOE integrates seven sub-expos under one roof, covering information and communication, precision optics, lasers, infrared, intelligent sensing, photonics, and displays.

The highly recommended Information and Communication Expo subshow by optoelectronic professionals covers optical chips, optical devices, fiber optic cables, optical modules, and various other optical equipment, which shows the significant requirements of infrastructure construction, especially in 5G, data centers, IIoT and AI. The second large sub-expo is Precision Optics and Camera Expo, which shows the entire optics supply chain of optical materials, components, measuring instruments, processing equipment, manufacturing equipment, optical lenses, camera modules, AR/VR, endoscopes, and accessories. China's only infrared show, the Infrared Applications Expo has played a pivotal role for China and around the world to fight against the pandemic caused by Covid-19. It presents IR products and technologies from infrared material and components, infrared thermal imaging technologies and THz monitoring and imaging to secure industrial production processes and our life. The Intelligent Sensing Expo will showcase the latest technologies of lidar, millimeter wave radar, 3D sensing, 3D cameras, biometrics, MEMS sensors, and other related sectors to follow up the emerging trends of sensor miniaturization, IoT and IIoT technology, as well as Industry 4.0/5.0. The Lasers Technology and Intelligent Manufacturing Expo will focus on the area of fine processing, which is widely used in the semiconductor and optical, display and consumer electronics industries. Specific products include lasers, material, components, equipment, 3D printing, robots, and 3C equipment.

The latest advanced photonics research incubated products or technologies will be presented in the Photonics Innovation Expo by national research institutes and universities. Then there is a brand-new section, the Display Technology Expo that was launched when the industry size in China reached the number one position. It will present cutting-edge products like display panels and modules, materials, and manufacturing equipment in front of 100,000 industry professionals from application fields in consumer electronics, automotive, medical, advanced manufacturing, light and displays.

Over eighty forums and conferences, seminars and networking activities between China and international peers will be organized to assist your network expansion. Yole group will collaborate with CIOE once again to hold global forums on 3D sensing, lidar, and silicon photonics. The organizers also offer a comprehensive service for international visitors by providing invitation letters for visa applications, hotel bookings and a free shuttle bus, among other things. CIOE is known as an annual industry gathering where you can meet partners and collect the latest market information. Register now for your free admission, and prepare for your trip to China!

https://cioe.cn/en/

Preview: ECOC 2023

1 – 5 / 2 – 4 October 2023, Glasgow, Scotland, United Kingdom

Now running for over 25 years, the European Conference on Optical Communications attracts over 6,000 decision makers from all around the world – bringing together manufacturers, suppliers and service providers to networking, and gain insights on the latest developments, new products and trends in the industry.

Taking place in the historic and vibrant city of Glasgow this year, ECOC will showcase the latest cutting-edge developments in optical communication, as well as an extensive social programme that will allow delegates to network and share ideas whilst experiencing the best of Scottish culture.

Parallel to the scientific conference from 1 – 5 October, the ECOC exhibition covers a wide range of optical communication products and services from 2 – 4 October. It is the largest optical communications exhibition in Europe, usually held in September in a different European city each year. The event is the key meeting place for decision makers from across the fiber optic communications technology industry.

Covering everything from data centers, photonics integrations and digital silicon photonics to fiber access, service and content providers and optical transmission, the Market Focus presentations provide the very latest news and developments from leading organizations within the fiber optics community.

Alongside over 300 international exhibitors, the exhibition is filled with interactive features and seminars. The extremely popular Market Focus Theatre includes thought-provoking presentations from some of the most innovative and forward-thinking companies working in optics today, discussing the key issues facing the market and Product Focus Theatre covering the latest innovative products, live demonstrations and technology announcements.

www.ecocexhibition.com

Components and accessories

Cooling systems

KKT chillers
Industriestraße 3 • 95359 Kasendorf
T +49 9228 9977 0
F +49 9228 9977 149
E info@kkt-chillers.com
W www.kkt-chillers.com

termotek GmbH
Gottlieb-Daimler-Str. 3-9
76532 Baden-Baden
Tel.: +49 7221 9711-0 Fax.: -111
www.termotek.de
info@termotek.de

Extraction systems, AIR PuriFication

Fuchs Umwelttechnik P+V GmbH
Gassenäcker 35-39
89195 Steinberg
Tel.: +49 (0) 7346 / 9614-0
Fax: +49 (0) 7346 / 8422
E-Mail: info@fuchs-umwelttechnik.com
www.fuchs-umwelttechnik.com

TEKA Absaug- und Entsorgungstechnologie GmbH
Millenkamp 9
48653 Coesfeld
Tel: +49 (0) 2541/84841-0/Fax -72
E-Mail: info@teka.eu
Web: www.teka.eu
Facebook: www.facebook.com/TEKAGmbH

Laser beam sources: Solid-state lasers

Diode lasers, for material processing

Laserline GmbH
56218 Mülheim-Kärlich
Tel. 02630/964-0, Fax 02630/964-1018
www.laserline.com, info@laserline.com

Fiber lasers up to 100 W

PHOTON ENERGY GMBH
Bräunleinsberg 10, 91242 Ottensoos
Tel. +49(0)9123-99034-0, Fax. –22
info@photon-energy.de, www.photon-energy.de

Nd:YAG lasers, diode-pumped

PHOTON ENERGY GMBH
Bräunleinsberg 10, 91242 Ottensoos
Tel. +49(0)9123-99034-0, Fax. –22
info@photon-energy.de, www.photon-energy.de

Nd:YAG lasers, pulsed

PHOTON ENERGY GMBH
Bräunleinsberg 10, 91242 Ottensoos
Tel. +49(0)9123-99034-0, Fax –22
info@photon-energy.de, www.photon-energy.de

Nd:YAG lasers, up to 500 W

PHOTON ENERGY GMBH
Bräunleinsberg 10, 91242 Ottensoos
Tel. +49(0)9123-99034-0, Fax. –22
info@photon-energy.de, www.photon-energy.de

Short-pulse lasers

PHOTON ENERGY GMBH
Bräunleinsberg 10, 91242 Ottensoos
Tel. +49(0)9123-99034-0, Fax –22
info@photon-energy.de, www.photon-energy.de

Laser optics and components

Beam splitters

Optics Balzers AG
Balzers, Liechtenstein
Phone +423 388 92 00
info.mbo@materion.com
www.materion.com/balzersoptics

Zünd precision Optics ltd
Prismastr. 5
CH-9444 Diepoldsau
Tel. +41(0)71 737 74 00
Fax +41(0)71 737 74 10
info@zuendoptics.com
www.zuendoptics.com

Filters, optical

Optics Balzers AG
Balzers, Liechtenstein
Phone +423 388 92 00
info.mbo@materion.com
www.materion.com/balzersoptics

Free-form optics

Trionplas Technologies GmbH
Permoserstr. 15
D-04318 Leipzig
Tel. +49(0)3412352234
info@trionplas.de
www.trionplas.de

Galvanometer Scanning Systems

SCANLAB GmbH
Siemensstr. 2 a
82178 Puchheim
Tel. +49 (0) 89 800 746-0
Fax +49 (0) 89 800 746-199
info@scanlab.de
www.scanlab.de

Microoptics

Zünd precision Optics ltd
Prismastr. 5
CH-9444 Diepoldsau
Tel. +41(0)71 737 74 00
Fax +41(0)71 737 74 10
info@zuendoptics.com
www.zuendoptics.com

Mirror coatings

Optics Balzers AG
Balzers, Liechtenstein
Phone +423 388 92 00
info.mbo@materion.com
www.materion.com/balzersoptics

Mirrors

B&M Optik GmbH
Am Fleckenberg 20, 65549 Limburg
+49 (0) 6431 9860 – 0
info@bm-optik.de / www.bm-optik.de

Optics Balzers AG
Balzers, Liechtenstein
Phone +423 388 92 00
info.mbo@materion.com
www.materion.com/balzersoptics

Zünd precision Optics ltd
Prismastr. 5
CH-9444 Diepoldsau
Tel. +41(0)71 737 74 00
Fax +41(0)71 737 74 10
info@zuendoptics.com
www.zuendoptics.com

Mirros, UV

Optics Balzers AG
Balzers, Liechtenstein
Phone +423 388 92 00
info.mbo@materion.com
www.materion.com/balzersoptics

Optical Components

B&M Optik GmbH
Am Fleckenberg 20, 65549 Limburg
+49 (0) 6431 9860 – 0
info@bm-optik.de / www.bm-optik.de

Optics Balzers AG
Balzers, Liechtenstein
Phone +423 388 92 00
info.mbo@materion.com
www.materion.com/balzersoptics

Zünd precision Optics ltd
Prismastr. 5
CH-9444 Diepoldsau
Tel. +41(0)71 737 74 00
Fax +41(0)71 737 74 10
info@zuendoptics.com
www.zuendoptics.com

Prisms

B&M Optik GmbH
Am Fleckenberg 20, 65549 Limburg
+49 (0) 6431 9860 – 0
info@bm-optik.de / www.bm-optik.de

Optics Balzers AG
Balzers, Liechtenstein
Phone +423 388 92 00
info.mbo@materion.com
www.materion.com/balzersoptics

Zünd precision Optics ltd
Prismastr. 5
CH-9444 Diepoldsau
Tel. +41(0)71 737 74 00
Fax +41(0)71 737 74 10
info@zuendoptics.com
www.zuendoptics.com

Windows, optical

B&M Optik GmbH
Am Fleckenberg 20, 65549 Limburg
+49 (0) 6431 9860 – 0
info@bm-optik.de / www.bm-optik.de

Zünd precision Optics ltd
Prismastr. 5
CH-9444 Diepoldsau
Tel. +41(0)71 737 74 00
Fax +41(0)71 737 74 10
info@zuendoptics.com
www.zuendoptics.com

Material processing systems

Laser welding

Evosys Laser GmbH
Erlangen, Tel. +49 9131-4088-0
www.evosys-laser.com
sales@evosys-laser.com

LPKF WeldingQuipment GmbH
Tel. +49-911-669859-0, Fax: -77
www.lpkf-laserwelding.de

Marking systems

PHOTON ENERGY GMBH
Bräunleinsberg 10, 91242 Ottensoos
Tel. +49(0)9123-99034-0, Fax. –22
info@photon-energy.de, www.photon-energy.de

Optical components

3D Anti-Glare-Spray

Helling GmbH, 25436 Heidgraben
3D-Laserscanning-Entspiegelungsspray
Tel.: 04122/922-0, Fax: 922-201
info@helling.de

Optical metrology

Acceleration sensors

POLYTEC GmbH
76337 Waldbronn
www.polytec.de
info@polytec.de

Dimensional gauging

POLYTEC GmbH
76337 Waldbronn
www.polytec.de
info@polytec.de

Film thickness measurements

POLYTEC GmbH
76337 Waldbronn
www.polytec.de
info@polytec.de

Interferometric measurements

POLYTEC GmbH
76337 Waldbronn
www.polytec.de
info@polytec.de

Surface quality measurements

POLYTEC GmbH
76337 Waldbronn
www.polytec.de
info@polytec.de

Transmission/reflection measurement of thin films

ESSENT OPTICS
Spectrophotometers for Coaters

EssentOptics Europe UAB
Mokslininkų g. 2A
Vilnius LT-08412, Lithuania
Tel. +370 616 19961
E-mail: office@essentoptics.com
www.essentoptics.com

Velocity measurement

POLYTEC GmbH
76337 Waldbronn
www.polytec.de
info@polytec.de

Vibration measurement

POLYTEC GmbH
76337 Waldbronn
www.polytec.de
info@polytec.de

Services

Application development/ Application laboratories

Fraunhofer-Institut für Lasertechnik
Steinbachstraße 15, 52074 Aachen
Tel: 0241/8906-0, Fax: 0241/8906-121
www.ilt.fraunhofer.de

Optical development and engineering companies

Fraunhofer-Institut für Lasertechnik
Steinbachstraße 15, 52074 Aachen
Tel: 0241/8906-0 Fax: 0241/8906-121
www.ilt.fraunhofer.de

System consulting

Fraunhofer-Institut für Lasertechnik
Steinbachstraße 15, 52074 Aachen
Tel: 0241/8906-0, Fax: 0241/8906-121
www.ilt.fraunhofer.de

PhotonicsViews

OPTICS • PHOTONICS • LASER TECHNOLOGY

PhotonicsViews is published with six international issues per year.

Don’t miss any issue

subscribe at an annual fee of 454 Euros per year*).

Or apply for a qualified subscription and receive individual issues **for free.**

*) including national/intl. shipping

I wish to receive all print issues of the chosen publication as a regular subscriber for 454.00 Euro per year

☐ PhotonicsViews

I wish to receive chosen issues free of charge as a qualified subscriber

☐ PhotonicsViews

Your principal job function

- ☐ Corporate Management
- ☐ Design & Development Engineering
- ☐ Engineering Management
- ☐ Manufacturing Production Engineering
- ☐ Marketing/Sales
- ☐ Purchasing/Procurement
- ☐ Quality Control
- ☐ Research and Development
- ☐ Technical Service
- ☐ Other: ______________

What industry do you work for?

- ☐ Aerospace
- ☐ Automotive
- ☐ Chemical
- ☐ Consulting
- ☐ Electronics
- ☐ General Manufacturing
- ☐ Government/Organization
- ☐ Industrial R&D
- ☐ Medical Equipment
- ☐ Military/Defense
- ☐ Optics/Precision Engineering
- ☐ Printing
- ☐ Scientific R&D
- ☐ Semiconductor
- ☐ Other: ________________

For advertising please contact

Änne Anders phone +49(0)6201 606-552
Nicole Schramm phone +49(0)6201 606-559

Please submit this form via telefax to +49 6123 9238 244 or send a scan as e-mail to WileyGIT@vuservice.de

☐ I agree to receive further electronic information from Wiley.

Your Contact Details / Billing Address:

Title/First Name/Last Name

Company/Organization

Address

Country/City/Zip-Code

E-Mail

Phone/Fax

Date/Signature

www.photonicsviews.com

WILEY

Company Index

published in media partnership with

EPIC

publishing medium of

PHOTONICS GERMANY

DGaO

PhotonicsViews

OPTICS • PHOTONICS • LASER TECHNOLOGY

Wiley-VCH GmbH
Boschstraße 12, 69469 Weinheim, Germany
ISSN 2626-1294

Editorial:
Dr. Oliver Dreissigacker (od; responsible), Sybille Lepper (sl), Stephanie Nickl (sn)
Phone: +49 (0)6201 606-181 / -030

Boschstr. 12, 69469 Weinheim, Germany
Fax: +49 (0)6201 606-328
e-mail: photonicsviews@wiley.com
www.photonicsviews.com

Contributing Editors:
Dr. Christel Budzinski (cb)
Carsten Heinisch
Jan Oliver Löfken

Copy editing: Matthias Erler, David Jayne

Subscriptions:
Wiley GIT Reader Service
65341 Eltville, Germany
Phone: +49 (0)6123 9238 246
Fax: +49 (0)6123 9238 244
e-mail: WileyGIT@vuservice.de
Our service is available for you from Monday to Friday 8 am – 5 pm (CEST)

Advertising:
Änne Anders (responsible)
Boschstraße 12, 69469 Weinheim, Germany
Phone: +49 (0)62 01 60 65 52
Fax: +49 (0)62 01 60 65 50
e-mail: aanders@wiley.com

Nicole Schramm (Executive)
Boschstraße 12, 69469 Weinheim, Germany
Phone: +49 (0)62 01 60 65 59
Fax: +49 (0)62 01 60 65 50
e-mail: nschramm@wiley.com

Valid advertising price list: 01 October 2022

Banking account:
JP Morgan AG, Frankfurt, Germany
Account number: 6161517443
BLZ: 50110800
BIC: CHASDEFX
IBAN: DE55550110800616151744З

Production and Layout:
Marita Beyer, Anja Hauck

Commercial Manager: Jörg Wüllner
Publishing Director: Steffen Ebert

Printed in Germany by westermann DRUCK I pva

Per media partnership or publishing co-operation, members of the European Photonics Industry Consortium EPIC, Photonics Germany – through OptecNet Deutschland e. V. and SPECTARIS Deutscher Industrieverband für Optik, Photonik, Analysen- und Medizintechnik e. V. – and Deutsche Gesellschaft für angewandte Optik e.V. (DGaO) receive PhotonicsViews with currently six issues per year.

JPT

www.jptoe.com

More Than Fiber Lasers