Volume 19 December 2022 / January 2023

6

PhotonicsViews

OPTICS • PHOTONICS • LASER TECHNOLOGY

JPT

Coverstory

Laser technology for precise material machining applications

Focus

Photonics for quantum technology

With 26-page Capabilities Guide from Edmund Optics page 51

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"Quantum is the new language to learn"

The emerging field of quantum technology continues to boom, although the known talent shortage will become more critical than ever

It was the middle of the pandemic when I wrote a special quantum focus article for PhotonicsViews. At that point, my goal was to provide an overview of the technology, the public investment up to that date, how the start-ups landscape was booming all over the world, and the job market forecast. The terms 'education' and 'workforce' were just starting to be two important topics in most quantum conversations.

Now, two years later, global investment has increased by almost 10 billion dollars, and start-ups continue to appear and grow worldwide. It is difficult not to find a discussion panel or hear the importance of 'quantum skills and the global quantum workforce' at any quantum event or interview.

How to have a pipeline ready to join an emerging workforce goes back to how 'educated' that workforce is. If you are not aware that your skills could be applied in quantum technologies, or even about that emerging market, how can we expect the workforce to be ready?

Every year, there are more undergraduate and postgraduate programs on quantum technology being launched all around the world, either from an optics and photonics perspective, or with a focus on quantum computing programming. Either way, the creation of those curricula should be done in parallel with analyzing industry needs. And there comes the next challenge: the specification of those needs.

In our role as service providers, we have seen the whole spectrum of industry 'maturity' with respect to quantum technologies. There are the newcomers looking for insights into the field to understand how they could fit in the landscape. Then we have corporations who started to include quantum in their innovation roadmap – some are even working on specific use cases – and are now looking for partners and new opportunities. And finally we can see a few industry actors already having a quantum strategy and team in place.

It is a marathon, not a sprint, as a new language takes time to learn. Understanding your role and position in the quantum journey is the first step in learning this new language. You are all invited to join!

Sincerely,

Araceli Venegas-Gomez

Dr Araceli Venegas-Gomez
Founder & CEO
QURECA Ltd

Reference: *A. Venegas-Gomez:* The Quantum Ecosystem and Its Future Workforce – A journey through the funding, the hype, the opportunities, and the risks related to the emerging field of quantum technologies, PhotonicsViews **17**(6) December 2020/January 2021, pp. 34-38; DOI: 10.1002/phvs.202000044

PhotonicsViews
OPTICS • PHOTONICS • LASER TECHNOLOGY

Contents

Cover: Shenzhen JPT Opto-electronics focuses on the development of various laser sources, such as MOPA fiber lasers, DPSS lasers, ultrafast lasers and cw fiber lasers p. 46

Photonics for quantum technology

6/2022

Radiation Safety

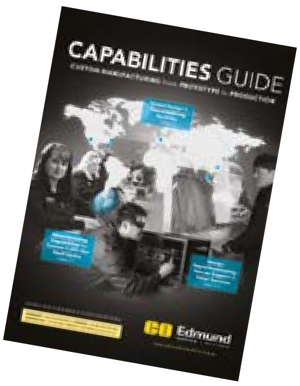
Cooling Systems

Filter Systems

Positioning Systems

Previews

With 26-page **Capabilities Guide** from Edmund Optics
p. 51



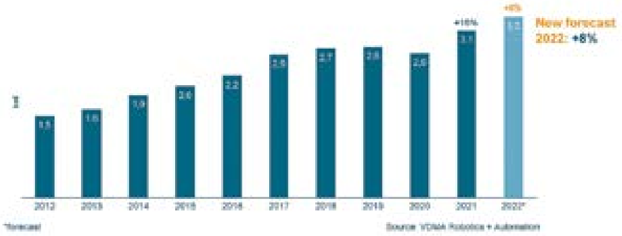
VDMA forecasts growth for German machine vision

Industrial image processing in Germany is expected to generate sales of 3.3 billion euros in 2022 – this corresponds to an increase of 8 % compared to the previous year.

Last year, German manufacturers of machine vision achieved 97 % of their sales in the two segments 'components' (50 %) and 'systems' (47 %). The export ratio of these branches of business is high. The manufacturers of image processing components generated 66 % of their sales abroad: exports to Asian countries contributed 30 % to sales in 2021 – the strongest individual market was China with a market share of 56 % of Asian exports. Exports to China rose by 20 % in 2021. The largest growth market in the region was India with a plus of 89 %. Exports to North America grew by 15 % in 2021. Exports to other European countries contributed 22 % to sales. Sales in Europe as a whole grew by 15 %.

The manufacturers of image processing systems achieved 74 % of their sales in foreign markets. Asian countries contributed 33 % to sales – exports increased by 22 % in 2021. The business in China accounted for 38 % of Asia exports and grew by 16 %. The largest growth market in this segment was India with growth of 20 %. Exports to other European countries contributed 24 % to sales. The recovery of the European market is reflected in the books with a sales increase of 22 %. Exports to America accounted for 16 % of sales. Most of these exports went to North America (95 %). Sales here increased by 23 % in 2021. Exports to South and Central America recovered from their 2020 slump – a 63 % drop – and rose 62 %.

The manufacturing industry is the largest customer sector for industrial image processing in Germany and has a market share of around 60 %. In the application fields of image processing components and systems, object recognition (21 %) and quality control (20 %) have the largest market shares.



German machine vision turnover in billion euros, 2012 – 2022.

www.vdma.org

Trumpf and KDPOF become partners

Trumpf Photonic Components, a subsidiary of Trumpf and provider of high-speed VCSEL and photodiode solutions for data communication, and KDPOF, an expert in high-speed optical networking solutions based in Spain, have become strategic partners for automotive datacom solutions.


Source: Trumpf

State-of-the-art clean-room production at Trumpf Photonic Components

Both companies pursue the goal of implementing state-of-the-art optical data communication standards and solutions for the automotive industry, for instance as participants in the IEEE P802.3cz task force. Trumpf and KDPOF are formally combining their knowledge in components and networks for data communication. "With our strategic partnership we are going one step further and aim to establish VCSEL and optical networks as an indispensable element of future cars," explained Rubén Pérez-Aranda, CTO at KDPOF.

Due to the push in the automotive branch towards autonomous driving, a large amount of data has to be processed in cars. Consequently, optical interconnects are required to manage the data flow, acting as a nervous system connecting sensors and electronic brains, while meeting tight electro-magnetic interference requirements. "After a long-term cooperation, it is great to enter a strategic partnership with KDPOF now, combining our long-term expertise to shape the future of data communication within car networks," said Joseph Pankert, VP product management at Trumpf Photonic Components.

www.trumpf.com/s/VCSEL-solutions
www.kdpof.com

Lasea acquires Laser Cheval

The Lasea Group, a designer and manufacturer of precision laser machines, has bought Laser Cheval, located in Marnay near Besançon, France. With offices in Belgium, France, Switzerland and the United States, Lasea develops and produces extremely precise laser micromachining systems and solutions for various industries. Its main customers, spread over five continents, are leading players or technological innovators active in the luxury sector, medtech, big tech and electronics, as well as research institutes.

Previously a member of the Industries Micromécaniques Internationales (IMI) group, Laser Cheval strengthens Lasea's European presence while expanding its product range. With fifty years of laser expertise, Laser Cheval designs and manufactures proven and effective solutions for laser marking, engraving, fine welding and microcutting applications. Located in the center of a region specializing in high precision machining, Laser Cheval is the leading French manufacturer of industrial lasers. Through its values, its know-how and its detailed knowledge of the trades – watchmaking, jewellery, luxury, medical technologies, micromechanics, aerospace, etc. – it is a reference in this market.

Following this acquisition, Laser Cheval will continue to carry out its activities autonomously under the direction of its managing director, Emric Verwaerde: "Within the IMI Group, Laser Cheval has grown for fifty years. In recent years, we have seen major technical developments and successes with the redesign of our range of machines, the integration of femtosecond technology and the strengthening of our customer services. By joining the Lasea group, we will be able to take advantage of these."

The new group will employ 160 people in six locations in four countries.

www.lasea.eu
www.lasercheval.com

Leadership duo for Lumics

Beate Sauter and Dennis George have been appointed as the company's chief executive officers effective immediately. Lumics is a provider of high-power diode laser components and part of the Berlin Industrial Group (BIG).

Sauter has more than 23 years of international management experience in the laser and photonics industry and is a globally recognized technical sales and application expert in this market. She joined Lumics in 2013 and has been instrumental in leaping the company forward to becoming one of the top leaders of diode laser solutions.

Prior to Lumics she held senior management positions at a number of leading photonics companies, including sales director Europe for US diodemaker Intense, key account manager South Europe for Edmund Optics, and director sales and marketing for Toptica Photonics where she played a key role in the company's first years.

Dennis George has been with the Berlin Industrial Group for more than three years as finance manager where he was already the responsible portfolio manager for Lumics.


Source: Lumics

www.lumics.de

Samsung Venture invests in Elfys

Finnish photodiode startup Elfys is tapping into the growing demand for photodetectors – due to the ever-growing trend of measuring one's health and wellbeing through wearables.

The new €3M round announced today is complementing a round of the same size from last summer, and the money raised is dedicated to ramping up production to match the growing demand from the industry. The lead investor of the round is Samsung Venture Investment Corporation, together with the company's earlier round's lead Voima Ventures. The investment is complemented by other earlier shareholders, including the founders of Oura Health, the company behind the Oura Ring.


Source: Elfys

Photodetectors are most commonly used in devices such as smartwatches and other wearables. With the growing trend of tracking one's well-being, the demand for detectors is constantly growing. The sensitivity and energy efficiency of the Elfys technology improves the performance of these health monitoring devices significantly across solutions. This is truly groundbreaking, as photodetectors are often the biggest limiting factor for making these devices better.

www.elfys.fi

Di-Soric opens office in China

The south German company Di-Soric has been providing sales, marketing and technical support since September 2022 through an office in China. Local employees serve and advise customers and sales partners, shorten delivery times and open up strategic growth markets. With a large warehouse for finished goods, the company also greatly reduces delivery times in China.

With its own local subsidiary, the sensor specialist intends to align products and solutions precisely to local requirements and intensify cooperation with plant manufacturers and sales partners. The technically experienced staff is trained in project planning, application and customer service.

The focus on application-specific sensor and machine vision products in conjunction with competent consulting is offered for the automotive, food and beverage, pharma and cosmetics, and electronics industries, as well as for assembly and handling, robotics, packaging, machine tools, and measurement and testing applications.

Source: Di-Soric

The team from Di-Soric's Chinese branch

www.di-soric.com

Jenoptik invests more than 70 millionen euros

Construction work on Jenoptik Group's new high-tech fab at Dresden Airport Park began September 6, 2022, with a ceremony attended by Saxony's Minister-President Michael Kretschmer and Mayor Stephan Kühn, Dresden's Councillor for Urban Development, Construction, Transport and Real Estate. The two politicians ceremonially broke ground together with Jenoptik executive board members Stefan Traeger and Hans-Dieter Schumacher and other representatives of the photonics group.

"Dresden will become a main location for our micro-optics activities. We deliberately chose one of the most important locations for the semiconductor industry in Germany and Europe, where many global companies and research institutions of the industry are present," said Stefan Traeger, president and CEO of Jenoptik AG.

Jenoptik is investing more than 70 million euros in the new high-tech fab with a total of 11,000 square meters of net floor space, including 2,000 square meters for clean room production. Production is scheduled to start at the beginning of 2025.

Groundbreaking ceremony, l–r.: Dr Andreas Morak, Dr Ralf Kuschnereit, Dr Stefan Traeger, Minister-President Michael Kretschmer, Mayor Stephan Kühn, Hans-Dieter Schumacher, Hermann Spinner, Julian Winkelhofer (Source: Jenoptik)

www.jenoptik.de

Manz opens Laser Application Center

Since September 2022, companies can check the best joining technology for new products in terms of mechanical strength, welding time, cost and quality, in Manz's new Laser Application Center (LAC).

With the LAC in Reutlingen, Manz now offers companies a unique production environment to test and optimize various laser welding processes and material combinations under real conditions and for creating samples of the respective products. The production facilities at the LAC cover all common laser welding processes and laser sources. Manz categorizes them into four different processes: short-pulse laser welding, single-mode laser and local laser beam oscillation ('wobbling'), multimode laser (IR) and special beam shaping, and frequency-doubled multimode lasers ('green' lasers).

The LAC's test environment offers companies an ideal opportunity to test and analyze the appropriate laser welding application for their specific requirements in advance. For example, they can evaluate the best joining technique in terms of mechanical strength, welding time, cost, and quality. The LAC is already being used by

Laser Application Center (Source: Manz)

companies in the automotive and energy storage industries, for example to develop processes for manufacturing battery cells and modules or to optimize existing production processes.

In addition to providing access to the LAC, Manz also offers companies accompanying service packages. For example, its laser competence team advises on the preselection of materials and processes, provides support for any necessary pre and post-processing of the materials (such as cleaning before welding), and can conduct quality tests if required.

www.manz.com

Scanlab expands its premises

The existing building in the west of Munich will be expanded in a fourth con-

Company campus (Source: Scanlab)

struction phase. In addition to the groundwater heat exchangers, a heat pump system will be used so that the gas boilers that were previously required can be retired. The new wing of the building will also be equipped with a photovoltaic system, which will cover a large part of the electricity requirements.

Around 6,500 square meters of new space will be created by March 2024, the total floor area will then increase to around 18,700 square meters, enough space for additional laser laboratories and the expansion of clean room production.

www.scanlab.de

EO receives certification for medical devices

Edmund Optics (EO) is now certified according to ISO 13485. The company thus fulfils the requirements for the manufacture of components and assemblies for medical devices.

The certification formally attests that Edmund Optics has a quality management system that meets user and regulatory requirements for the manufacture of medical device components and assemblies.

Core components of the certified global quality control programme are preventive and corrective actions, advanced measurement platforms and a commitment to continuous improvement.

The company supplies optical components and assemblies for medical applications ranging from fluorescence imaging to flow cytometry to optical coherence tomography and more. These applications use Edmund Optics components such as optical filters, lenses and microscope objectives.

www.edmundoptics.com

Pilot Photonics uses pilot line services to create new products

Using the JePPIX MPW server, which covers all the processes from the design to the foundry, Irish company

At ECOC 2022 (l–r): sales director Damian McGillivar, CTO Frank Smyth, R&D manager Gaurav Jain, and director of photonics Desi Gutierrez (Source: JePPIX)

Pilot Photonics has developed three new products that have been presented at the European Conference on Optical Communication 2022 (ECOC): a low linewidth fast tunable laser, an InP-based monolithic single mode laser in the C-band; an integrated comb laser assembly (iCLA) for scaling coherent transceiver capacity, and SuperTROSA a comb-based superchannel transmitter.

"JePPIX has allowed us to offer photonic integrated circuits with enhanced performance and capability and enabled us to target new industry verticals," says Frank Smyth, founder and chief technology officer of Pilot Photonics. Kevin Williams, professor and chair of the photonic integration group at TU Eindhoven, a JePPIX partner, considers it "an excellent example of how an early stage company can create new products that may route to production thanks to the JePPIX pilot line."

The JePPIX platform covers the whole value chain of indium phosphide photonic integrated circuits. On October 31, 2022, the most recent Deep-Dive PIC Design Course took place. This is technology training that is celebrated every year and that focuses on the theory and practice of integrated photonic components and circuit design. The aim of this course is to up-skill the engineering team of companies, RTOs or universities.

www.jeppix.eu
www.pilotphotonics.com

Evident opens new Asia-Pacific headquarters in Singapore


Source: Evident

A new facility supports Evident customers and employees in the APAC region and expands the company's business and operations in the region. The HQ leads the company's strategy, technology and innovation in that region, which includes operations in Australia, New Zealand, India and Korea. The company has doubled its headcount in Singapore since the beginning of 2022 and plans to further expand its presence in APAC.

A manufacturer of life science and industrial microscopes, videoscopes for remote visual inspection, nondestructive testing equipment, and x-ray fluorescence analyzers for elemental analysis, Evident plans to strengthen its core business for greater agility and adaptability.

"We aim to become more agile by integrating smart technologies in our solutions," said Akio Hirohashi, chief strategy officer at Evident and head of Evident APAC and Evident China.

The new APAC headquarters features a technology center to expand NDT solutions with robotics, automation and system integration, a microscopy center with a range of microscopes, videoscopes, NDT equipment and x-ray analyzers, as well as a dedicated service and repair center to provide technical support for customers.

www.evidentscientific.com

Spinout to develop thin film optical coatings and photonic sensors


Source: UWS, Elaine Livingstone

Johnny Mone (l.) and Prof Des Gibson

A new spinout company from University of the West of Scotland is set to disrupt the thin film and sensor industry – currently valued at more than £ 2.5 B globally. AlbaSense, based within UWS's Institute of Thin Films, Sensors and Imaging (ITFSI), is the third spinout company from the University and will develop low-cost, high-performance thin film optical coatings and photonic sensors, using exclusive patented processes.

Thin films are a key component in a wide range of applications, including autonomous photonic-based gas sensors, medical devices such as breath analyzers, non-contact thermometers and advanced imaging systems.

The company will license core IP, including three patents, from UWS on a worldwide exclusive basis. Its team is made up of six UWS academics with previous industry experience: Dr David Hutson, expert for thin film devices; Dr Shigeng Song, expert in thin film physics and applications; Dr Lewis Fleming, specialist in gas sensors; Dr Parag Vichare, expert in manufacturing research; Dr Ewan Waddell, expert in optical and physical modelling, and company founder and CEO, Prof Des Gibson.

www.uws.ac.uk/business

Lumibird acquires Innoptics

The European laser technologies group Lumibird took over the Bordeaux-based company Innoptics on September 22, 2022. This extension of its areas of technological expertise will enable the group to ramp up its verticalization strategy while developing a new range of products to address new markets, focusing in particular on low-cost laser segments for higher-volume markets.

Innoptics offers a range of optoelectronic packaging and bespoke component development services for industrial clients. It covers design, prototyping, process development and manufacturing for small to mid-size volumes, as well as consulting services for industrialization. Integrating an extensive selection of laser diode technologies across a vast range of wavelengths, the company develops products for medical, space or scientific instrumentation applications.

Founded in 2010, Innoptics is based in Talence, near Bordeaux. It has revenues of just over €300k and five staff, including four engineers. The two co-founders, Stéphane Denet and Vincent Lecocq, are committed to this project with Lumibird.

Through its acquisition, the Lumibird Group will be able to integrate advanced technical development-related expertise covering a specific market segment. This will enable it to extend the range of products and related services.

The operation was carried out in cash, with an earn-out component based on future performance levels, for an amount that has been kept confidential.

www.lumibird.com
http://innoptics.com

FAU is set to become a beacon in quantum research

In recognition of their expertise, eleven researchers from Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU) will receive roughly three million euros in funding by 2025.

Their new lighthouse project Quantum Measurement and Control for the Enablement of Quantum Computing and Quantum Sensing (QuMeCo) will ignite basic research into quantum computing, sensing and imaging, combining physics and electrical engineering in new ways in the field of light and matter.

Source: FAU, Celina Henning)

Erlangen university

"FAU has already become well established in quantum research thanks to a number of projects from our newly acquired professorship for Applied Quantum Technology, to the latest Humboldt professorship, to the collaborative research center 'Quantum Cooperativity of Light and Matter'," states FAU president Prof Dr Joachim Hornegger. "The funding provided to the lighthouse project QuMeCo as part of the Bavarian quantum initiative Munich Quantum Valley further underlines our leading position."

QuMeCo bundles the unique expertise of FAU in the physics of light and matter with its expertise in electrical engineering, as reflected in the aims of the project. One of its goals is to lay the foundations for the next generation of superconducting quantum computers.

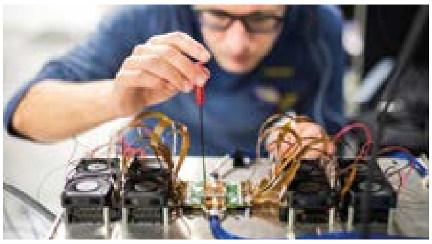
A particular challenge for quantum computing is posed by electronic control systems. The consortium aims to develop microwave circuits that are located as close as possible to the quantum chips.

An innovative laboratory is to be established in Erlangen for the purpose of characterizing circuits such as these at extremely low temperatures.

www.fau.eu

Quix Quantum to deliver a 64-qubit quantum computer based on light

A 14 million euro contract with the German Aerospace Center runs within the framework of DLR's Quantum Computing Initiative and is in line with the roadmap of Quix Quantum to develop a universal quantum computer.



Assembly of a photonic quantum computer (Source: Quix Quantum / D. Verkijk)

The Dutch company will deliver 8 and 64-qubit fully universal quantum computers based on photonics, integrating the existing technologies from their processors with sources, detectors, and feedforward to create a modular photonic quantum computer. This represents the first commercial sale of universal quantum computers based on light.

"We merge competencies from the Netherlands and Germany in one location at the innovation center of the DLR Quantum Computing Initiative in Ulm. Quix Quantum has already proven the functionality of its integrated quantum photonics and is successfully supplying quantum photonic processors to customers," says Quix CEO Dr-Ing Stefan Hengesbach.

www.quixquantum.com
www.dlr.de

Intercontinental quantum network through Hyperspace

Researchers from Europe and Canada want to create the basis for an intercontinental network for quantum communication. Project 'Hyperspace' focuses on the investigation of the distribution of entangled photons via satellite. The research project has now started its three-year term.

At short distances, entangled photons have already been successfully exchanged in various experiments. Now, the strategic collaboration will focus on research into integrated quantum photonics and optical space communications with the goal of creating a satellite-based quantum network between the continents by direct exchange of entangled photons in space via optical satellite links.

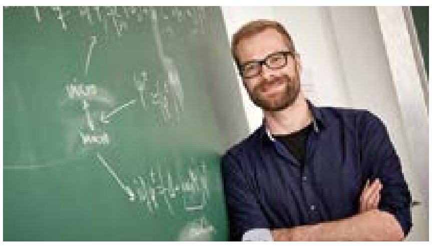
To this end, Hyperspace encompasses research and innovation along the entire process chain of photonic quantum communication: from noise-resilient state coding, fully fiber-embedded and photonically integrated quantum light sources and free-space compatible state analyzers, to the implementation of advanced protocols.

A total of eight partners are involved: Fraunhofer IOF (coordinating), Università degli Studi di Pavia, Università degli Studi di Padova, CEA-LETI, Vienna UT, INRS, and the Universities of Toronto and Waterloo.

www.iof.fraunhofer.de

Funding for French-German quantum technology research project

In a project funded by the German Research Foundation (DFG), a team of researchers aims to solve the challenges of effective equations in quantum technology. Sören Petrat, professor of mathematics at Jacobs University Bremen, is scientific coordinator of the project on the German side.



Prof Sören Petrat (Source: Jacobs U)

The German-French team is investigating ways to control entanglement, because it causes the equations describing realistic quantum systems to become far too complicated to solve analytically or numerically. Simpler, so-called effective equations provide a remedy.

In the research project, the team is investigating ultracold gases near the absolute zero of minus 273.15 degrees Celsius – cold Fermi and Bose gases – whose properties are used in quantum technology.

Five scientists from four universities are involved in the "Effective approximation and dynamics of many-body quantum systems" research project. In addition to Petrat, these are Prof Volker Bach, mathematical physicist at TU Braunschweig, and professors Sébastien Breteaux and Jérémy Faupin from the Université de Lorraine and Zied Ammari from the Université de Rennes.

https://jacobs-university.de

Nobel Prize in physics goes to Aspect, Clauser, and Zeilinger

The Royal Swedish Academy of Sciences honors "experiments with entangled photons, establishing the violation of Bell inequalities and pioneering quantum information science". Alain Aspect, John Clauser and Anton Zeilinger have each conducted groundbreaking experiments using entangled quantum states, where two particles behave like a single unit even when they are separated. Their results have cleared the way for new technology based upon quantum information, stated the Academy.

One key factor in this development is how quantum mechanics allows two or more particles to exist in what is called an entangled state. What happens to one of the particles in an entangled pair determines what happens to the other particle, even if they are far apart.

For a long time, the question was whether the correlation was because the particles in an entangled pair contained hidden variables, instructions that tell them which result they should give in an experiment. In the 1960s, John Stewart Bell developed the mathematical inequality that is named after him. This states that if there are hidden variables, the correlation between the results of a large number of measurements will never exceed a certain value. However, quantum mechanics predicts that a certain type of experiment will violate Bell's inequality, thus resulting in a stronger correlation than would otherwise be possible.

John Clauser developed John Bell's ideas, leading to a practical experiment. When he took the measurements, they supported quantum mechanics by clearly violating a Bell inequality. This means that quantum mechanics cannot be replaced by a theory that uses hidden variables.

Alain Aspect, John Clauser, and Anton Zeilinger (Sources: Royal Society / John Clauser / Jaqueline Godany)

Some loopholes remained after John Clauser's experiment. Alain Aspect developed the setup, using it in a way that closed an important loophole. He was able to switch the measurement settings after an entangled pair had left its source, so the setting that existed when they were emitted could not affect the result.

Using refined tools and long series of experiments, Anton Zeilinger started to use entangled quantum states. Among other things, his research group has demonstrated a phenomenon called quantum teleportation, which makes it possible to move a quantum state from one particle to one at a distance.

www.nobelprize.org

TU Ilmenau appoints honorary professor

Ronny Stolz will be strengthening research and teaching in the field of quantum engineering at the faculty of electrical engineering and information technology. The physicist has been working at Leibniz IPHT since 1994 and heads the quantum systems department since 2019.

Source: L-IPHT

Dr Ronny Stolz

Starting in the winter semester of 2022/2023, bachelor's and master's students at Technische Universität Ilmenau benefit from this expertise and decades of quantum technology experience in courses on quantum engineering. Stolz works on research projects such as SuperLSI (Highly Integrated Superconducting Nanostructures for Quantum Technologies) and HiQuP (Highly Integrated and Scalable Interface Circuits for Quantum Processors). His team's research interests include the improvement of quantum systems through new superconducting circuits and their fabrication technologies. In the collaborative project QSolid (Quantum Computer in the Solid State), he and his team are contributing to the construction of a complete quantum computer.

Stolz joined the Leibniz-Institut für Photonische Technologien in Jena in 1994. In 2017, he received the prestigious ESAS Excellence Award from the European Society for Applied Superconductivity (ESAS).

www.leibniz-ipht.de

More quantum for Hesse

Since October, Markus Gräfe is a professor of experimental solid-state quantum optics at Darmstadt Technical University's department of physics. The 35-year old was previously head of the quantum-enhanced imaging group at the Fraunhofer Institute for Applied Optics and Precision Engineering IOF in Jena.

Source: TU Darmstadt, P. Bal

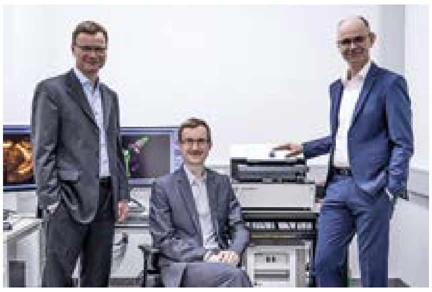
Professor Markus Gräfe

His research focuses on quantum imaging – that is, imaging and sensing with non-classical states of light, focusing on nonlinear interferometers, quantum walks of non-classical states of light in photonic lattice or network structures, the development of sources for non-classical states of light with a focus on photon pair sources. He also investigates concepts in quantum physics and quantum optics such as quantum coherence, quantum correlations, or quantum entanglement.

Gräfe's research often takes place in close collaboration with industry, both in national and international projects such as 'FastGhost', with FBK from Italy and Single Quantum, LIVE2QMIC together with M-squared Lasers Germany and Picoquant, QUANCER with Toptica, n-Hands, Rapp Optoelectronics, or 'Quantifisens', a Thuringian BMBF project with a regional alliance of 13 partners, among those Active Fiber Systems and Quantum Optics Jena (cf. p. 16).

www.tu-darmstadt.de

Microscope developers win the Deutscher Zukunftspreis 2022



r – l: Dr. Thomas Kalkbrenner, Dr. Jörg Siebenmorgen and Ralf Wolleschensky (Source: Dt. Zukunftspreis / A. Pudenz)

The President of Germany, Frank-Walter Steinmeier, awarded the Deutscher Zukunftspreis 2022, the Federal President's Award for Technology and Innovation, to a team from Zeiss during a festive ceremony. The jury recognized Dr Thomas Kalkbrenner, Dr Jörg Siebenmorgen, and Ralf Wolleschensky for their significant contribution to the development of the Lattice Lightsheet 7 microscope system.

This award honors scientists for exceptional achievements in technology, engineering and the life sciences as well as software and algorithm-based achievements that have resulted in viable products. It has a cash value of 250,000 euros.

Lattice Lightsheet 7 enables, for the first time, biomedical researchers to observe living cells live and in 3D for hours or even days. With light sheet microscopy, unlike other microscopes, the laser beam is applied in the form of a light sheet only in the area of the sample that is in the focus of the objective lens, avoiding radiation damage. The team had to rearrange the objective lenses because the cells grow on the cover slips in culture vessels like Petri dishes or multiwell plates. The researchers developed a completely new type of microscope optic that enables a person to look through the sample vessels – at an angle and from below – at the cells inside without artifacts.

www.zeiss.de/messtechnik
www.deutscher-zukunftspreis.de

Winners of the Applied Photonics Award 2022 presented

Bioanalytics, mobile communication, weather research – this year, the winners of the Applied Photonics Award have once again demonstrated how broad photonics research is. The young researcher award of the Fraunhofer IOF was presented to the five award winners of 2022 on October 5 as part of Photonics Days Jena by Dr Robert Kammel, head of the strategy, organization, communication department at Fraunhofer IOF, together with Prof Dr Michèle Heurs, gravitational wave researcher and this year's keynote speaker at Photonics Days Jena.

A jury of experts, consisting of representatives from science and industry, had previously selected the award-winning theses. A total of three theses were awarded in the categories Bachelor, Master/Diploma and Dissertation to Magdalena Hilbert, Felix Wechsler (both University of Jena), and Dr René Kirrbach (Technische Universität Dresden).

Group picture with the 2022 award winners, framed by Robert Kammel and Michèle Heurs (Source: Fh. IOF)

In addition, the jury awarded graduate and postgraduate special prizes for scientific excellence this year: Jan-Wilke Henke (Georg-August-Universität Göttingen), and Dr Daniel Werdehausen (University of Jena).

The award is endowed by Fraunhofer IOF and sposored this year by VDI and the companies Active Fiber Systems, Jenoptik, and Trumpf.

www.iof.fraunhofer.de

Bioabsorbable breast implants and robotic post-processing …

Source: Mesago / Mathias Kutt

Formnext start-up area

For the eighth time, the international Formnext Start-up Challenge has recognized young companies from the world of additive manufacturing for their business ideas and technical developments.

The international winners, who all made presentations to the AM world at Formnext 2022, are Photosynthetic (The Netherlands), Lattice Medical (France), Rivelin Robotics (UK), SphereCube (Italy) and Alpha Powders (Poland). The AM Ventures Impact Award also went to Lattice Medical.

The innovations of these start-ups were selected both for the high level of creativity demonstrated in product development as well as the viability of the business models. The start-ups were able to provide proof of existing patents or patents pending and also demonstrated extremely promising applications.

Warsaw-based start-up Alpha Powders has developed and patented a technology for the pulverization, spheroidization and on-demand modification of polymer powders.

Lattice Medical has patented 3D technology in cooperation with CHU Lille-France that enables the natural regeneration of adipose tissue, bringing enormous improvements in breast implant procedures. They can entirely reconstruct breasts from the patient's own tissue.

Photosynthetic specializes in fast and cost-effective micro 3D printing using single-photon polymerization and computer algorithms.

With its NetShape robots, British start-up Rivelin Robotics has developed a solution for the rapid post-processing of additively manufactured metal parts and components. The NetShape control software uses both machine learning and traditional deterministic control theory.

Italian start-up SphereCube has developed 3D printing technology that is able to process polymer-based composite materials or a thermosetting matrix with continuous fiber reinforcement, thus enabling the automated manufacture of products from high-performance composites in any desired shape.

www.formnext.com/startup

High-precision optical filters for quantum technology

Manufacturer: AHF analysentechnik
Product: Optical filters, optimally matched to the customer's optical setup and the laser wavelengths used.
Background: For the optical setup in quantum technology, the precise coupling of different laser wavelengths is a crucial condition. For this to succeed, optical filters or beam splitters play an important role, as they are needed to focus the different wavelengths and also to avoid unwanted stray light outside the primary line of the laser.
Features: A clear definition of the reflection and transmission range is a must, taking polarization into account. Polarization shift in dichroics at specific wavelengths can be avoided with special filter designs. The optical filters are optimally matched to the optical setup and the laser wavelengths used. The company has many years of interdisciplinary experience in the selection and specification of optical filters for a wide range of applications in research and industry. They can draw on an extensive range of filter designs and, if required, can also have special designs produced promptly in small quantities. Special specifications regarding substrate quality and thickness are also possible.

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Gentle crystallization of sensitive silicon layers

Laser-based silicon crystallization for monolithic integration in MEMS sensors

MEMS sensor units can only fulfil their tasks reliably and safely when they are combined with an electronic, application-specific integrated circuit (ASIC) that sits on a silicon carrier unit (wafer).

Manufacture of MEMS sensor units directly on active circuits (Source: Fh. ILT)

To make such MEMS more powerful in the future, researchers at the Fraunhofer Institute for Laser Technology ILT in Aachen have developed a CMOS-compatible deposition and laser crystallization process in collaboration with the Fraunhofer ISIT and IST. However, because the ambient temperature near the integrated circuit with its temperature-sensitive CMOS transistors may not exceed 450 °C, MEMS sensors made of crystalline silicon are first manufactured separately due to the conventionally high manufacturing temperatures. Then they are contacted with the circuit via wire and solder connections or wafer bonding processes. “But conventional interconnection technology prevents further miniaturization of the MEMS,” explains Florian Fuchs, a research associate in the thin film processing group at Fraunhofer ILT.

Instead of using conventional joining techniques, Fraunhofer ILT is relying on a laser-based process which enables it to build MEMS sensors of crystalline silicon directly (monolithically) on the temperature-sensitive circuits. The project focuses on the deposition of Si layers by Fraunhofer IST and ISIT, selective laser crystallization by Fraunhofer ILT, and the design and microelectronic processing of the layers into sensors by Fraunhofer ISIT. The researchers are taking advantage of the fact that amorphous silicon layers can already be produced on the wafer holding the circuit at temperatures below 450 °C with high deposition rates. The laser not only crystallizes this silicon layer, but also activates the dopants it contains, thus ensuring suitable electrical conductivity. Subsequently, the sensor units are processed further using classic microelectronic manufacturing processes.

The newly-developed laser process reduces the electrical resistance of the silicon layers by more than four orders of magnitude, down to below a value of 0.05 Ω cm.

This opens interesting applications for the automotive industry, medical technology and fire departments.

www.ilt.fraunhofer.de

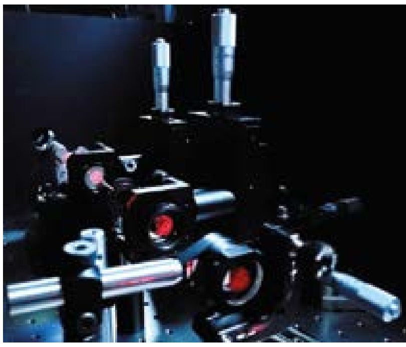
A perfect trap for light

Thin device cancels all back-reflections by wave interference

Whether in photosynthesis or in a photovoltaic system: if you want to use light efficiently, you have to absorb it as completely as possible. However, this is difficult if the absorption is to take place in a thin layer of material that normally lets a large part of the light pass through. Now, research teams from TU Wien and from the Hebrew University of Jerusalem (HU) have found a trick that allows a beam of light to be completely absorbed even in the thinnest of layers.

The scientists built a light trap around the thin layer using mirrors and lenses, in which the light beam is steered in a circle and then superimposed on itself – exactly in such a way that the beam of light blocks itself and can no longer leave the system. “Absorbing light is easy when it hits a solid object,” Stefan Rotter from TU Wien says. “But in many technical applications, you only have a thin layer of material available and you want the light to be absorbed exactly in this layer.” There have already been attempts to improve the absorption of materials: for example, the material can be placed between two mirrors. The light is reflected back and forth between the two mirrors, passing through the material each time and thus having a greater chance of being absorbed. However, for one of the mirrors must be partially transparent, otherwise the light cannot penetrate the area between the two mirrors at all. But this also means some of the light is lost.

Helmut Hörner from TU Wien explained, “In our method, too, the light first falls on a partially transparent mirror. If you send a laser beam onto this mirror, it is split into two parts: the larger part is reflected, a smaller part penetrates the mirror.” This part of the light beam that penetrates the mirror is now sent through the absorbing material layer and then returned to the partially transparent mirror with lenses and another mirror. The mirror, which used to be partially transparent, now becomes completely transparent for the incident laser beam. This creates a one-way street for the light: the light beam can enter the system, but then it can no longer escape because of the superposition of the reflected portion and the portion guided through the system in a circle. So, the light has no choice but to be absorbed.



Source: Hebrew U.

Experimental setup of the new light trap.

“The system has to be tuned exactly to the wavelength you want to absorb,” explained Rotter. “But apart from that, there are no limiting requirements. The laser beam does not have to have a specific shape.” (Source: TU Wien)

Reference: *Y. Slobidkin* et al.: Massively degenerate coherent perfect absorber for arbitrary wavefronts, Science **377**, 955 (2022); DOI: 10.1126/science.abq8103

https://scholars.huji.ac.il/orikatz
www.itp.tuwien.ac.at

Optimized integrated digital pathology workflows

Collaboration announced between Indica Labs and Hamamatsu Photonics

Indica Labs and Hamamatsu Photonics agreed to maintain long-term interoperability between Indica Lab's Halo AP software platform and Hamamatsu's NanoZoomer family of high-speed, high-resolution scanners.

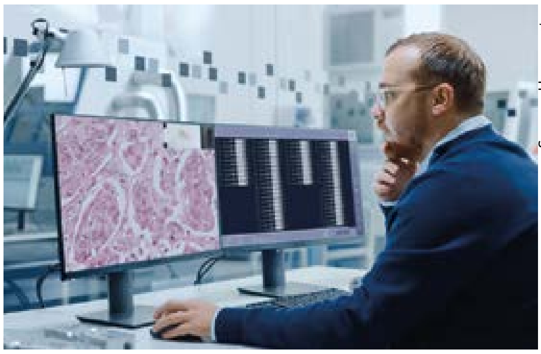
The browser-based, CE-marked software from Indica Lab brings case-centric digital pathology slide management, collaboration, and AI-powered quantitative image analysis to anatomic pathology labs. Halo AP is scanner-agnostic and integrates with a variety of third-party software applications, including AI solutions and LIS/LIMS platforms, using flexible APIs and a software development kit (SDK).

As laboratories adopt digital solutions, the challenge for laboratory managers is to integrate an array of hardware and software and achieve maximum efficiency. This collaboration between Indica Labs and Hamamatsu streamlines this process.

"Providing interoperability and scalable solutions is critical to the adoption of digital pathology," commented Don Ariyakumar, NanoZoomer product manager at Hamamatsu. "We believe that customers should be able to choose best-of-class products. The option to implement the most appropriate hardware and software for their specific needs increases the value of digital pathology for all stakeholders."

Hamamatsu's technical collaboration with Indica Labs' will facilitate Indica Labs approach to regulatory clearances utilizing the Halo AP system in conjunction with the NanoZoomer S360MD for primary diagnosis. Ongoing technical performance assessments to verify that Hamamatsu's image format is accurately displayed in all Indica Labs' viewers guarantees continued interoperability of the companies' products.

Indica Labs' CEO, Steven Hashagen commented: "This agreement is an important reassurance to our mutual customers that both companies are committed to working together on technical, regulatory, and commercial fronts. It ensures we can achieve image fidelity and interoperability across our viewing and analysis software, allows us to align our regulatory submissions, and facilitates sales and support cooperation for our mutual customers as we have demonstrated in the past."


Source: Hamamatsu

NanoZoomer scanners provide scalable solutions with each workflow to gain such efficiencies

The relationship between the two companies resulted in the win of significant digital pathology tenders in the United Kingdom, most notably Nottingham University Hospitals (NUH) NHS Trust, which is the third largest NHS Trust in the United Kingdom, serving over 2.5 million patients and generating 340,000 pathology slides per year. The goal of the NUH implementation is full digitization of the pathology workflow.

https://indicalab.com
www.hamamatsu.com

Fluorescence microscopy with ease-of-use

A new system makes quantitative time-resolved fluorescence microscopy accessible to a broader range of scientists

Over the past decades, the developers at PicoQuant have focused on making quantitative and reproducible time-resolved fluorescence microscopes. Their new Luminosa instrument now allows every researcher in molecular biophysics or structural biology to integrate methods from single molecule and time-resolved fluorescence microscopy into their toolbox.

"Today I need the help of my physics post-doc when I want to exploit the capabilities of my single photon fluorescence microscope," says a prominent group leader in biochemistry. "The new system with this judicious technology would release him to do his actual work." That statement was given when developers from PicoQuant in Germany asked the professor for his feedback on their latest prototype of a new single photon counting fluorescence microscope. In the meantime, the prototype has become a full product named Luminosa.

The Main features of the Luminosa system include a one-click auto-alignment procedure and context-based intuitive workflows. For example, the system can automatically recognize individual molecules, or it may determine correction factors for single-molecule FRET (smFRET) automatically.

For the experienced expert it still offers advanced flexibility. All optomechanical components are accessible, data is stored in open formats, and the workflow as well as the graphical user interface can be customized. The user is given full access to experimental parameters such as the adjustable observation volume.

The new Luminosa is made for research in dynamic structural biology at the single molecule level. The methodologies include fluorescence lifetime imaging (FLIM), rapidFLIMHiRes for fast processes, FLIM-FRET, single molecule FRET (burst and time trace analysis), fluorescence correlation spectroscopy (FCS), anisotropy imaging, and differential interference contrast (DIC) imaging.

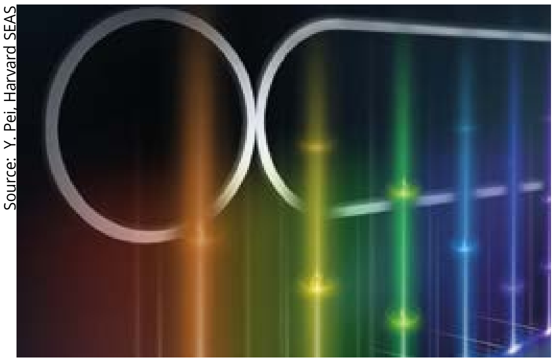
Luminosa – the new single photon counting fluorescence microscope. (Source: PicoQuant)

www.picoquant.com

Highly efficient on-chip frequency comb

New laser source combines high efficiency and broad bandwidth

Source: Y. Pei, Harvard SEAS



A new on-chip frequency comb combines a coupled resonator with an electro-optical frequency comb to improve the efficiency and the bandwidth.

On-chip laser frequency combs are a promising technology for a range of applications such as environmental monitoring, optical computing, astronomy, and metrology. However, on-chip frequency combs are still limited by one serious problem – they are not always efficient. There are several ways to mitigate the efficiency problem, but they all suffer from trade-offs. The inability to design an on-chip laser frequency comb that is both efficient and broad has stymied researchers for years and hindered the widespread commercialization of these devices. Now, a team from the Harvard John A. Paulson School of Engineering and Applied Sciences (SEAS) has developed an electro-optic frequency comb that is 100-times more efficient and has more than twice the bandwidth of previous state-of-the-art versions.

"Our device paves the way for practical optical frequency comb generators and opens the door for new applications, said Marko Lončar at SEAS. "It also provides a platform to investigate new areas of optical physics." This advancement builds upon previous research from Lončar and his team who, in 2019, demonstrated the first stable, on-chip frequency comb that could be controlled with microwaves. This electro-optical frequency comb, built on the lithium niobate platform, spanned the entire telecommunications bandwidth but was limited in its efficiency. In 2021, the team developed a coupled resonators device to control the flow of light, and used it to demonstrate on-chip frequency shifters – a device that can change the color of light at nearly 100 % efficiency.

The latest research applies the two concepts to address the challenge in resonator-based electro-optic frequency combs – efficiency-bandwidth tradeoff. "We demonstrated that by combining these two approaches – the coupled resonator with the electro-optical frequency comb – we could improve the efficiency a lot without sacrificing bandwidth. In fact, we actually improved bandwidth," said Yaowen Hu, an SEAS research assistant.

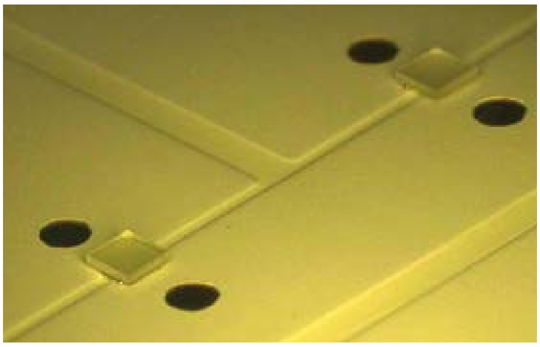
"We found that when you improve the performance of the comb source to this level, the device starts operating in an entirely new regime that combines the process of electro-optic frequency comb generation with the more traditional approach of a Kerr frequency comb," said Mengjie Yu, a former postdoctoral fellow. This new comb can generate ultrafast femtosecond pulses at high power. Together with the high-efficiency and broadband, this device can be useful for applications in astronomy, optical computing, ranging and optical metrology. (Source: Harvard SEAS)

Reference: *Y. Hu* et al.: High-efficiency and broadband on-chip electro-optic frequency comb generators, Nat. Phot. **16**, 679 (2022); DOI: 10.1038/s41566-022-01059-y

https://nano-optics.seas.harvard.edu

Rework of LED dies using new debonding solution

Tresky Automation develops a modified scrubbing function



LED chip on substrate (Source: Tresky)

In times of limited availability of components and materials, reworking takes on a very special significance. This also applies to LED manufacturing, where irregularities in processed LEDs are immediately visible at first sight.

Reworking faulty or incorrectly placed components is one of the more demanding tasks in electronics production. If the components are particularly small or fragile, this work is even more complex. A perfect light pattern is usually a prerequisite when using LEDs so it may be necessary to rework the LED dies to meet stringent quality assurance standards.

"Defective LED dies are a real challenge. These sensitive, fragile and very small components are usually processed in tight packing densities and can only be removed and reworked with a lot of knowledge, experience, a lot of care and the right tools. With the right technology, however, this is possible," explains Daniel Schultze, managing director of Tresky Automation.

Schultze and his team adapted a process known from component manufacturing at the request of a customer. "Our die bonding automation system allows LED dies to be easily and successfully removed in the rework configuration without damaging adjacent LED dies or affecting the solder and its surroundings," Schultze continues. The debonding process is carried out with the help of a modified scrubbing function, whereby the adhesion between the LED die and the solder is broken with the help of the heating temperature.

"Once the LED die is separated from the solder, it is carefully retrieved by a pick-up tool," explains Schultze. A new die can then be inserted in the same Tresky Automation machine. Since the die bonding systems are designed for high-precision processes, the entire reworking process of the LED dies is carried out according to the specifications of the semiconductor production and is therefore not only exact, but also controlled and reproducible.

www.tresky.de

Photonics Germany Future Summit – MoU with WLT

Memorandum of Understanding advocates greater innovative strength and competitiveness for the German photonics industry

An industry meeting with a view to the prospects of the German photonics sector. This is what the Photonics Germany Future Summit delivered on October 12 at the Karl Storz Visitor Center in Berlin. The eighty participants were offered an up-to-date program of the most promising application areas of photonics and the economic challenges of this high-tech industry. With their joint alliance Photonics Germany, the German industry association Spectaris and the innovation network for optical technologies, Optecnet Germany, set themselves the goal of strengthening the position of photonics as a German high-tech industry at a national and European level. In his video greeting, Mario Brandenburg, Parliamentary State Secretary at the Federal Ministry of Education and Research, emphasized how important the photonics industry is for securing and expanding Germany as a high-tech location.

"As a cross-sectional technology with an enormous leverage effect, photonics is becoming an enabling technology for a large number of other key industries," emphasized Optecnet board member Dr Andreas Ehrhardt. The importance of photonics in essential high-tech industries was reflected in the diverse daily program of the Future Summit: from the application of optical devices using the example of mini-endoscopy in healthcare, laser technology in smart production, to sensor technology in the mobility of tomorrow or the security industry. An assessment of the current global and German economic situation with the effects of the Corona pandemic to date and tips on financing opportunities for photonics startups rounded out the program.

But at the same time, pressing global challenges are emerging that need to be addressed. "Spending on photonics research funding in key global markets such as China and the United States is increasing rapidly. If we in Germany do not want to jeopardize our current strong position in the global photonics market, we will need adequate, broad-based funding in the future as well. The untapped innovation potential of photonics is immense. An emerging focus on the lighthouse technology of quantum science alone will therefore not do justice to the wide-ranging potential

Source: Photonics Germany

Memorandum of understanding (l–r) Dr Wenko Süptitz (Spectaris), Prof Ludger Overmeyer (WLT), Dr Andreas Ehrhardt (OptecNet), Dr Moritz Hinkelmann (WLT)

applications of photonics and its outstanding role as an enabling technology," appealed Dr Bernhard Ohnesorge, photonics chairman at Spectaris, in his keynote address.

A special highlight on the day's program was the presentation of a joint declaration of intent between the Scientific Society for Laser Technology and Photonics WLT and Photonics Germany. The two partners reaffirmed their goal of making photonics and laser technology more visible in economic and research policy through deeper cooperation.

https://photonics-germany.de

Industry leaders join Optica's board

Society announces 2023 vice president and directors-at-large

The membership of Optica (formerly OSA) has elected James Kafka, chief technology officer at Spectra-Physics and MKS Fellow, USA, as the society's 2023 vice president. Julie Sheridan Eng, chief technology officer at Coherent, USA, and Ulrike Fuchs, vice president for strategy and innovation, Asphericon, Germany, were elected as directors-at-large for a 2023 – 2025 term. The Optica board of directors appointed Aleksandra Boskovic, Corning, USA, as a director-at-large from 2023 – 2025.

Jim Kafka started his career in industry in 1983 as a senior scientist at Spectra-Physics Lasers, where he has since held a series of positions of increasing responsibility until becoming CTO, his current position. He was recently named a Fellow of MKS, the parent company of Spectra-Physics. Kafka has 45 United States patents and multiple foreign equivalents. Kafka was named an Optica Fellow in 2005 and served as a director-at-large on the Optica board of directors from 2012 to 2014.

Julie Sheridan Eng serves as CTO at Coherent Corp., Saxonburg, Pennsylvania. In this role, she focuses on the future technology platforms that are core to Coherent's strategy and to its drive for sustainably profitable growth.

At Asphericon, Ulrike Fuchs oversees all R&D activities as well as strategic product development. She develops concepts to improve system performance prediction during optical design and tolerancing. Most recently, she has emphasized transferring those ideas to freeform optics. In 2018, Fuchs was the inaugural winner of Optica's Kevin P. Thompson Optical Design Innovator Award.

Aleksandra Boskovic serves as vice president for optical communications

Source: Optica / Asphericon / Wiley

(t–b, l–r) James Kafka, Julie Sheridan Eng, Ulrike Fuchs, Aleksandra Boskovic

technology development at Corning. She is responsible for ensuring an integrated technology strategy and innovation delivery across fiber, cable, and connectivity.

www.optica.org

ASU launches new quantum research collaborative

Companies, academic institutions, startups and initiatives cooperating in Arizona

A state-funded and globally-oriented initiative, the Quantum Collaborative aims to promote understanding of this important technology and forge partnerships to advance it.

The Quantum Collaborative is a broad endeavor consisting of a community of companies, academic institutions, startups and initiatives cooperating across several strategic areas to deliver incremental advances across the emerging quantum technology landscape, as well as develop training and education for the future quantum workforce.

The Quantum Collaborative's founding industry partners include: Quantinuum – a combination of Honeywell Quantum Solutions and Cambridge Quantum – Google Quantum AI, SandboxAQ, and CR8DL – an artificial intelligence and cloud computing company.

Along with industry partnerships, the Quantum Collaborative is forging connections with leading academic institutions. Founding academic partners include: Purdue University in Indiana, with its Rosen Center for Advanced Computing and the Purdue Quantum Science and Engineering Institute, Tecnológico de Monterrey (Mexico), Virginia Tech, and the University of Texas at San Antonio.

ASU will also operate as a hub within the IBM Quantum Network, a global community of Fortune 500 companies, academic institutions, startups and national labs with cloud access to IBM's premium quantum computers, experts and resources. The first members to join ASU's IBM Quantum Hub are Purdue University and Virginia Tech.

In addition, the Quantum Collaborative recently joined the Quantum Economic Development Consortium, or QED-C, and is developing relationships with prospective international partners. (Source: ASU)

www.asu.edu

TU Dresden has joined the Quantum Internet Alliance

Researchers address quantum technology in new communication networks internet for Europe

The European Commission has identified quantum internet as a strategic area for future investment. In this context, TU Dresden joined the Quantum Internet Alliance (QIA) in October. The QIA's objective is to create a quantum internet that enables quantum communication between any two points on earth, independent of the usual network load.

Prof Frank Fitzek and Asst Prof Riccardo Bassoli from the Deutsche Telekom Chair of Communication Networks are representing TUD in the joint project. Together with forty partners from science and industry, they are researching a prototype for an innovative European quantum internet. Both researchers are primarily interested in how quantum technology can be used to improve telecommunication networks in the future. A quantum internet is needed to connect quantum computers to each other. Researchers have been trying to work out how to stabilize fragile qubits and how to connect more of them to each other for many years.

Founded in 2017 by the European market leaders QuTech, ICFO, the University of Innsbruck and the Paris Centre for Quantum Computing, the Quantum Internet Alliance is a team of academic institutions, telecommunication operators, system integrators and quantum tech start-ups from all over Europe. QIA receives funding from the EU Horizon 2020 Research and Innovation Programme.

In its first project phase covering a period of 3.5 years, QIA has been awarded a total budget of 24 million euros.

http://quantum-internet.team

New research alliance in Thuringia

Development of a sensor platform based on fiber-optics and quantum technology

The partners in the new 'Quantifisens' research alliance are working to ensure that both will soon be using highly efficient fiber and quantum-based sensors. An example may be on the operating table to detect cancer on the spot without having to wait for long pathological detours. On construction sites, self-learning fiber sensor systems integrated into the building structure can, among other things, monitor temperatures and warn of fire hazards.

The development of such sensor systems is the goal of the new research alliance: Quantifisens stands for omnifunctional, quantum-inspired fiber sensor systems and describes a novel, holistic approach to solving complex, sensor problems with the help of optical fibers, the relevant measurement technology and innovative self-learning software. With the slogan 'the sensing [r]evolution', the alliance aims to initiate a turning point in the evolutionary development of classical sensors and even revolutionize them using quantum technology.

A total of eleven companies and two research institutions are members of the regional alliance, funded by the BMBF as part of the Regional Entrepreneurial Alliances for Innovation (RUBIN) with approximately twelve million euros: ADVA Optical Networking, Active Fiber Systems, Batix Software, epicinsights c/o SMA Dev., FBGS Technologies (coordinating), Fraunhofer Institute for Applied Optics and Precision Engineering IOF, Grintech, Heracle, Leibniz Institute for Photonic Technologies, Lasos Lasertechnik , Luna Innovations Germany, PreciPoint Innovation, Quantum Optics Jena.

www.iof.fraunhofer.de

European association Eunited Robotics joins VDMA

Members will be represented by VDMA from January 2023 onwards

The association Eunited Robotics is merging with the VDMA Robotics + Automation (R+A) which unites 370 member companies from 13 countries. "We will pool our resources in a strong European platform to reap the benefits of automation in Europe. This will allow us to become more efficient in developing standards for the smart factory of the future, more vocal on regulatory issues, and committed to advancing our approach to a human-centric future of work," says Wilfried Eberhardt, chairman of Eunited Robotics. Patrick Schwarzkopf, managing director of VDMA R+A, adds, "We look forward to continuing Eunited Robotics' many activities, such as the European Robotics Summit, advocacy at the European level, and the Good Work Charter campaign."

Klaus-Dieter Axt, executive director of Eunited AISBL, added: "The close cooperation between Eunited Robotics and VDMA R+A is already well established and reflected in the large overlap in membership between the two association platforms. With this strategic decision, Eunited Robotics' members will benefit from new synergies and will be able to take advantage of VDMA's full range of services."

Eunited AISBL is a European association that promotes the interests of machinery suppliers and equipment manufacturers in Europe at the EU level. Its members include ABB Robotics, Isra Vision and Fraunhofer IPA.

www.vdma.org

Official start of the 'Prometheus' Horizon-funded action

On September 1st, the kick-off meeting was held in Valencia, Spain

'Prometheus': programmable integrated photonic neuromorphic and quantum networks for high-speed imaging, communications and security applications.

The Prometheus consortium consists of twelve academic and industrial partners, and it is coordinated by the iPronics team in Valencia, Spain. Prometheus' vision is to shatter the boundaries between quantum and neuromorphic photonic processing by building an integrated silicon photonic platform able to accommodate the merits of both worlds, and paving new routes towards high performance computing and physical layer security.

In particular, Prometheus' chips will provide the basis for a new generation of holistic neuromorphic processors and a new toolbox for quantum-enhanced security features such as quantum random number generation, directly from the same silicon chip.

Prometheus consists of twelve partners from eight European countries with complementary expertise and roles, coming from top-notch academic and research institutes as well as SMEs with a strong R&D portfolio: iPronics (Spain), University of the Aegean (Greece), Technical University of Denmark (Denmark), University of West Attica (Greece), Ghent University (Belgium), QTI (Italy), CEA (France), Fraunhofer IZM (Germany), Scintil Photonics (France), IBM Research (Switzerland), Lumiphase (Switzerland) and Inivation (Switzerland).

Source: Prometheus Collab.

Kick-off meeting in Valencia

https://ipronics.com
https://prometheus-he.eu

18 projects selected in Pulsate's first open call

Network supports companies with implementation of LBAAM technologies

The projects selected by the Pulsate Consortium can start the support program and receive the grant to assess the feasibility of laser-based technology implementation in their environment.

The Pulsate network – funded with 7.9 million euros under EU's Horizon 2020 program – is designed and dedicated to boosting the adoption of laser-based advanced and additive manufacturing (LBAAM) technology that empowers the digitalization of the European manufacturing industry.

Most of the winning proposals are related to the green economy and sustainable manufacturing – topics at the heart of the EC's focus: GRAMLAS by Dausinger & Giesen (Germany), BEAM by iBreve Ltd (Ireland), RECREA by Hergome SL (Spain), an LCPG proposal of András Edina ev (Hungary), AEROGRAM by 3D-Components AS (Norway), ADI by Spem SRL (Italy), TATION by Mobility Ion Technologies SL (Spain), ABSORPTION by Optoprim Germany GmbH, Laser Riblets by Bionic Surface Technologies (Austria), REALISM by Favoritanswer Consultoria Em Engenharia Lda (Portugal), LAMAS by MB Proints (Lithuania), QUADLAM by StreamOwl (Greece), loom-state: 3D-woven garments by Weffan Ltd (UK), LADACOR by DOO Relja Junior Zrenjanin (Serbia), LEAN by Tricon Automation Ireland Ltd, LF4 by Euromodel Engineering SRL (Italy), LABOR by Beagle Optics UAB (Lithuania), and injected MLA manufacturing by Microrelleus (Spain).

The Pulsate Support Program for Adopters Use Cases started in September 2022 and lasts for three months. During the program, selected projects will receive up to 25,000 euros of funding and mentorship in conducting a feasibility assessment.

www.epic-assoc.com
www.photonics21.org

EPIC focuses this autumn on the photonics supply chain and promoting international relations

In collaboration with Photonics21, EPIC has launched a survey to know in depth about the different aspects of production and distribution

EPIC Members Delegation to Singapore, November 2022 (Source: EPIC)

In the current geopolitical situation, it is important to determine in a substantiated manner whether or not European photonic supply chains are broken and require immediate intervention, be it at the political or the business level. To know more about our critical supply chains and to be better positioned to argue on an evidential basis, EPIC and Photonics21 have launched a survey that looks more closely at the different aspects of the supply chains, both upstream and downstream. If you have not answered yet, you can access it by scanning the QR code:

Globalization means that supply chain management is more complex and business-critical than ever before. That is why EPIC helps its members to strengthen their international relations. In November, we organized the EPIC Members Delegation to Singapore that included local company visits, networking dinners and conference activities. There is no doubt that Singapore has a vibrant photonics ecosystem ready for business. Our next stop will be in December when we will be landing in Tel Aviv. Israel has long boasted of having more start-ups per capita than any other country, but today the 'start-up nation' would be better known as the 'nation of scale-ups', a sign of the strength of the Israeli innovation ecosystem.

Back to technology, some of the topics we have discussed at the EPIC Online Technology Meetings over the past few months are Photonics for Aesthetics and Cosmetics, Photonics for Mobility of the Future, Satellite Quantum Communication, and Fiber Sensing for Structural Health Monitoring. We have also visited relevant exhibitions such as Vision and Compamed, where we have organized the traditional TechWatch. And finally, to ensure that we address the right topics in our events, EPIC has created a committee of experts to listen to the voice of industry leaders. So far, we have welcomed the board of advisors for health issues, who have shared crucial insights with us about the photonics industry needs that we can build into our future events.

www.epic-assoc.com

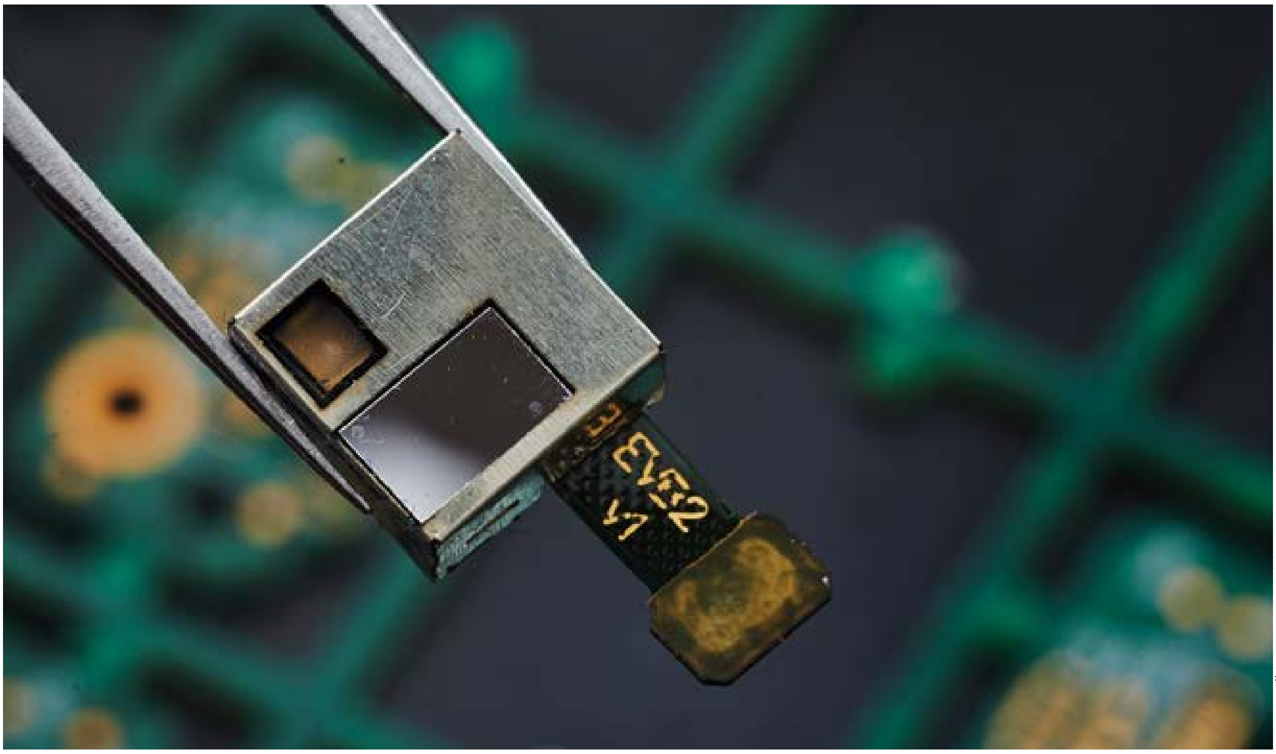
Upcoming EPIC events:

- 1 December 2022
  EPIC VIP Breakfast and
  EPIC TechWatch at W3+Fair 2022, Dornbirn, Austria
- 12 December 2022
  EPIC Online Technology Meeting on Photonics for Food and Beverages
- 13 December 2022
  Investors Workshop
- 12 – 14 December 2022
  EPIC Members Delegation to Israel
- 9 January 2023
  EPIC Online Technology Meeting on Metamaterials and Metalenses
- 23 January 2023
  EPIC Online Technology Meeting on Laser-based Manufacturing for Implants
- 31 January 2023
  Pilot Lines & Photonics Innovation Hubs Breakfast, San Francisco, USA
- EPIC VIP'S Networking Lunches & Reception, San Francisco, USA
- EPIC Members Networking Reception, San Francisco, USA
- 31 January – 2 February 2023
  EPIC Members Lunch, San Francisco, USA
- 1 February 2023
  EPIC Executive 5 Miles Run, San Francisco, USA
- 2 February 2023
  EPIC Members 5 Miles Run, San Francisco, USA
- 13 February 2023
  EPIC Online Technology Meeting on Bio-Imaging and Bio-Photonics
- 27 February 2023
  EPIC Online Technology Meeting on Quantum Metrology and Quantum Sensors

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

“Focus on getting MVPs out onto the market”

EPIC CTO interview with Mostafa Afgani



Source all images: PureLiFi

EPIC’s photonics technology manager Ivan Nikitskiy talks to Mostafa Afgani, CTO and co-founder at PureLiFi, a developer and innovator of Li-Fi technology.

In 2001, Mostafa embarked on a five-year combined BSc/MSc in communications engineering at Jacobs University Bremen in Germany. During his master’s work he did some research on modulation techniques for wireless communications with professor Harald Haas, who would later become a leading figure in Li-Fi and a co-founder of PureLiFi. In 2006, Harald returned to the University of Edinburgh and Mostafa joined him to do a PhD in engineering.

During his PhD, Mostafa worked as a research engineer at Edinburgh University where he developed a method for indoor navigation using RF signatures and a real-time method for anomaly detection. On graduating in 2010, he became a research fellow at the University of Edinburgh, working on the development of firmware and software for the D-Light proof-of-concept visible light communication (VLC) demonstrator with support from Scottish Enterprise. In 2012, PureVLC Ltd was formed as a spin-out from the University of Edinburgh to develop solutions for optical wireless communications.

PureLiFi

Mostafa successfully developed various proof-of-concepts over the next two years and by 2014, after conducting market research, Mostafa and his fellow co-founders felt the time was right and rebranded PureVLC to PureLiFi where Mostafa became CTO, and co-founder Harald Haas became the chief scientific officer.

The technology in question is Li-Fi (light fidelity), a term first coined by Harald Haas in 2011. Li-Fi uses light rather than radio frequencies to transmit data. It works by embedding data in varying intensities of light using special optical transceivers that can transmit and receive information at high speeds. Compared with Wi-Fi or cellular, Li-Fi can transmit at multiple gigabits, is more reliable, virtually interference free and uniquely more secure. These features endow Li-Fi with enormous potential for a wide range of applications. For example, Li-Fi can be safely used in many hospital applications because of the non-interference of Li-Fi with radiofrequency devices. With regard to security, Li-Fi internet cannot be intercepted as light cannot pass through opaque structures and is available only to those within a confined area, such as enclosed mission command platforms used by the police and the military. But perhaps most important are the advantages that Li-Fi can provide for everyday life – for example, opening up unprecedented bandwidth and multiple Gbps speeds in mobile devices, and enabling smart buildings, smart factories, smart homes, smart schools and specific Industry 4.0 applications.

Company development

There was a lot of trial and error at the beginning – investigating different applications, building prototypes and using customer feedback to refine their strategy and roadmap. This was a great learning experience for Mostafa because he had to do most of the work himself and gained valuable experience in understanding customer requirements, product specifications and the right trade-offs between function and cost.

During this process, he learnt the crucial lesson of how to distinguish between the technology and the product. As he points out, sometimes the technology can be the product, but more often than not technology is just one of the pieces that makes the product valuable for the customer. Consequently, the question is frequently what else needs to be wrapped round the core technology to make it a useful product that can actually solve the customer's problem. Li-Fi, for example, is a method of communicating over light, but it does not really do very much on its own; you still have to build a system and software that are compatible with the customer's network protocols so that the device can be deployed seamlessly within their wider network architecture.

A lot of effort was put into market and customer education in the early days when Li-Fi was unknown. So Mostafa developed a number of demonstrators including the first commercial Li-Fi product (Li-1st), the first mobile Li-Fi product (Li-Flame), the first high-speed LiFi dongle (LiFi-X), which provides Li-Fi connectivity into portable devices and, most recently, the world's first gigabit LiFi light antenna device, which is ready for integration into everyday devices.

Case studies

In addition to promoting their technology and products at trade fairs, particularly the Mobile World Congress, PureLiFi have initiated several case study projects that have involved the installation of its LiFi-XC system in real working environments. For example, students in a classroom of the Kyle Academy in Scotland have been pro-

Mostafa Afgani

vided with unprecedented connectivity and an enhanced learning environment through access to high bandwidth learning materials such as videos and e-books. In another project, PureLiFi's system was used to provide geofencing and geolocation in a hospital to enable wireless data connectivity free from electromagnetic pollution, which can cause highly problematic implications with life-saving machinery such as MRI scanners.

Other case studies include the use of their LiFi-X system to enable maintenance personnel to wirelessly trans-

Li-Fi in use

mit and gather previously unattainable information from a range of Li-Fi connected vibration sensors; a secure communications trial with BT Defence, a provider of ICT infrastructure and solutions to the UK military; and a project with UK telecom provider O2 involving Li-Fi-enabled LED light bulbs to facilitate a high-speed, bi-directional and fully networked wireless communication of data.

Products

Using feedback from these and other case studies, PureLiFi have refined their technology and now offer products for military applications and for device OEMS. The Kitefin is designed for military grade security. It is compliant with DISA WLAN STIGs, is not vulnerable to eavesdropping through walls or tent canvas and is highly resistant even to close-range jamming attempts. For OEMS, PureLiFi have designed a light antenna module that is capable of up to 1 Gbps and is ready for integration into mobile devices. In addition they have a range of evaluation kits (EVKs) that enable customers to test and develop the technology for their own specific use cases.

PureLiFi have also developed the world's first Li-Fi ecosystem vision for the home that consists of a Li-Fi downlighter, smartphone, TV accessory, and a Li-Fi enabled HaloLens. The LiFi@HomeDownlighter puts both Li-Fi and lighting into the form factor of a standard existing GU10 light fixture, and the device enables a connection to the home network over powerline communications or PoE.

The future

According to market reports, the global Li-Fi market was valued at almost 300 million dollars in 2020 and is expected to reach 4.2 billion dollars by 2026, at a CAGR of 69.7 % [1]. The CAGR for Europe is predicted to be slightly lower at 50 % between 2020 and 2030, with the European Li-Fi market reaching 2 billion dollars by the end of the period [2]. The two main market drivers are faster and safer data transfer than other challenging technologies, and the high emergence of new applications such as the IoT and 5G.

As Mostafa points out, underlying these predictions are several large-scale developments of Li-Fi over the last five years and everything points to Li-Fi becoming all pervasive, connecting everyone and everything in the near future. But although Li-Fi is here and real, he is under no illusions that there is still some way to go before Li-Fi is a part of everyday life and as pervasive as other wireless communication technologies are today.

As part of the push for large scale adoption, PureLiFi have made significant progress towards developing a global light communications standard. The objective is to extend 802.11 to include the light medium and produce a standard for input across the WiFi ecosystem i.e., 802.11bb TG by the end of 2022.

As CTO, Mostafa's main role will be to look ahead and see how to pull together the best bits of the software and transceivers as well as all the other things that push the envelopes of the technology in order to create more successful 'world-first' products. In general, he is optimistic about the future: they already have several customers around the world and have been particularly successful in the military sector, as exemplified by two large deals recently announced with the US military. Furthermore, they are receiving daily inquiries for their miniature gigabit light antenna which, as it can be integrated into any mobile device, will give PureLiFi the opportunity to break into the consumer electronics market.

If you started again, what would you do differently?

"Personally, I am not sure I would do anything differently because every step I have taken along the way has been rewarding in one way or another and a great learning experience. If I did something differently, I think I might miss out on some of those lessons. Regarding the company, maybe we should have focused on products a bit earlier. We came to realize that the market did not really want a completely new kind of communication system. What they wanted was to use what was already there but over a different channel or optical medium. For this reason, we shifted from building full systems with proprietary modems to one where we reuse existing 802.11 silicon systems and really provide an alternative front end."

What is your advice for the next generation of entrepreneurs?

Light antena module size comparison

"First, don't be afraid to take risks. Just focus on getting MVPs (minimum viable products) out onto the market so you can get feedback to improve the product.

Second, as the famous saying goes, 'fail often and fail fast' because the more feedback you get, the better it is. And as long as you don't make the same mistakes, it leads to faster improvements of your products to something that the customer actually wants.

Third, don't be too close-minded about your ideas and technologies. It is great to have a conviction and belief in your product and in your technology, but at the same time you have to listen to what the market is telling you. So be prepared to make adjustments and find the right balance."

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[1] Mordor Intelligence: Li-Fi (Light Fidelity) Market - Growth, Trends, Covid-19 Impact, and Forecasts (2022 - 2027)
[2] Graphical Research: Europe Li-Fi Market Size By Application, 2020 – 2030

Quantum computers: sensitive in their young days

Roland Wengenmayr

Shrouded in myths, powerful and sensitive: Prof Jens Eisert, physicist at the Freie Universität Berlin, explains how quantum computers work and how far their development has progressed.

Prof Dr Jens Eisert – Dahlem Center for Complex Quantum Systems

Quantum computers are almost a modern myth these days. The Internet is full of miracles that these machines will be able to perform one day. And large companies such as Google and countries such as China and the US are actually investing enormous amounts of money into the development of quantum information technology. Even Germany is doing it: the federal state is supporting the technology with two billion euros, and the state of Bavaria is investing 300 million euros in the Munich Quantum Valley. But what will quantum computers actually be able to do once the technology matures? And what can they not do? What is just hype and what is realistic? Jens Eisert, who is conducting research into this subject at the Dahlem Center for Complex Quantum Systems of the Freien Universität Berlin and has an enviable international network of contacts, takes a look at all these questions.

"Quantum computers are still babies," the physics professor affirms. "Basically, they are computers first of all, so they can solve tasks like conventional computers," he says: "But they work in a radically different way!" Traditional computers divide down the tasks that they are given into yes/no decisions as their logical basic vocabulary, that is, the famous ones and zeros of the bits. The quantum bits of quantum computers, known as qubits, also exist in two states that one could call one and zero. But now the laws of quantum mechanics come into play. "This is the theory that describes nature most accurately, but on the scale of atoms and light quantums, for the elementary physical parts," says Eisert. However, as we live in a world of big things, our understanding and perception are not trained for the peculiarities of the quantum world. This is why exactly these particularly sensitive quantum effects that are the victims of the omnipresent disturbances of the macro world appear extremely strange to us. The phenomenon of entanglement seems particularly weird: quantum elements can in principle form a single item with respect to a quantum property over any distance, and as soon as one element is altered, its distant partner 'notices' this at once.

Quantum computers use just such characteristics of the quantum world. This starts with the fact that both quantum states of zero and one of a qubit can be overlaid, which increases their quantum information content enormously. In addition, the states of multiple qubits can be overlaid and entangled with each other. So already with just a few qubits there is, theoretically, massive computing capacity. It is for this reason that quantum computers can in principle solve certain types of tasks that would overload even today's supercomputers. These are the tasks that would cause the computing time and memory requirements of conventional computers to explode exponentially; a sort of pandemic in the world of computing tasks. This type of task includes some that are technically highly interesting and that quantum computers could solve elegantly with just a few qubits within a reasonable time – that is the hope. "This has actually been demonstrated for certain paradigm problems," says Jens Eisert.

To illustrate this, he gives a concrete example: the multiplication of numbers. "That is simple, 3 × 5 = 15, my seven-year-old daughter can work that out," he says: "Even if the numbers get bigger, I can solve it on paper using the technique that I learnt in school." If one wants to find out how a number is the product of prime numbers that have been multiplied together, it suddenly becomes surprisingly complicated. This 'prime number factorizing' of larger numbers very quickly exceeds the capabilities of even a supercomputer.

This is the basis for today's common encryption methods. They are secure because even the best computer cannot break such a key within a period of time that is relevant for secrecy. Quantum computers, however, would be able to do exactly that by using a modest number of qubits, just because of their exponential computing power. The US American computer scientist Peter Shor already proved this theoretically in 1994: his Shor algorithm is one of the first quantum algorithms whose superiority over the world of conventional computers is guaranteed. In principle, the programing of quantum computers is quite similar to classical computers. "You break down complex functions into elementary functions," explains the physicist: "With conventional computers those are logical decisions, so-called gates, and similarly there are quantum gates for quantum computers."

The actual processor of quantum computers works in a radically different way. Instead of working through each calculation step-by-step, one after the other, everything happens at once within the ensemble of overlaid qubits, as soon as the quantum gates have been programed. This feature is known as quantum parallelism. It is important that the entangled qubits are left alone in perfect isolation during the process. You must not 'peek' too early because this would immediately stop the calculation process. One can imagine the process a little like using a pressure cooker into which you put in the ingredients, and only open it when the meal is – hopefully – ready.

The pressure cooker, however, has a pressure gauge that lets you know how the cooking process is getting on, but that would be forbidden on a quantum computer. A measurement in the quantum world has the undesirable effect of changing the measured object. "It would be like measuring a table and, as you did so, it would get longer or shorter," says Eisert. "We don't experience anything so absurd in our macroscopic world because the many disturbances in our environment disrupt such quantum effects."

This extreme sensitivity to the slightest disturbances is the Achilles heel of quantum computers. Physics has produced some fascinating technology that can trap individual atoms within laser beams and manipulate them as qubits, for example. Electrically charged atoms can be held for weeks, isolated within an electromagnetic trap. This has already enabled simple, fundamental quantum computing operations. This even works


Source : University of Science and Technology of China

Optical structure of a quantum computer in a Chinese laboratory. With more than 70 photon qubits, this was able to demonstrate quantum superiority over a conventional computer when used for a special task.

to some extent with tiny superconducting circuits as qubits; companies such as Google and IBM amongst others are pursuing this route. But it has not been possible so far to isolate the qubits well enough from their disturbing environment that larger quantum computers with hundreds, thousands, or even tens of thousands of qubits can be built. Such 'error-free' quantum computers still lie in the future – right now, no-one is predicting if or when they will become available.

Even so, Jens Eisert adds, the small 'dirty' quantum computers are available. By 'dirty' he means the disturbances in the form of noise that limit the lifetime of quantum information and make a quantum computation ever more dirty because of errors. "These small dirty quantum computers are still very valuable," the physicist stresses, because they are testbeds for what could already be achieved. The researchers are working hard on specially adapted quantum algorithms as 'software'. For the hardware, researchers such as Eisert are pursuing the idea that tasks can be divided into those that can be achieved by a conventional computer and those that require quantum computers. This leads to 'hybrid' computer architectures, he explains: "We insert our little quantum computers into a large classical computer as an environment."

With regard to possible applications, the researcher mentions the Deutsche Bahn (German state railways, DB). They currently have problems sticking to their timetables and want to improve with the help of new information technology. "Producing the timetables is a highly complex optimization problem," says Eisert. The most well-known of these optimization problems is that of the traveling salesman: he wants to visit a number of cities throughout the country and needs to find the shortest route. With a growing number of cities, he soon reaches the computational limits of the problem. Quantum computers can help here too, and Eisert's team is therefore in contact with the DB.

"It is just like a thriller," Eisert explains, enthusiastic about the state of his area of research: nobody can predict what new ideas will emerge. The more people that can experiment with existing technology, the more likely there will be some surprising applications. "This is swarm intelligence," says the scientist and laughs. But systematic work in physics, mathematics and informatics is necessary – Eisert's research in fact. However, he warns of unrealistic expectations because quantum computers, as he says, are still 'babies'.

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Text: Roland Wengenmayr, graduate physicist and scientific journalist, Frankfurt am Main, www.roland-wengenmayr.de. Interview carried out for the FU Berlin, the German edition appeared in the Tagesspiegel.

Further reading (in German): *Valeria Saggio & Philip Walther:* Quantenrechnen mit Licht – Photonische Quantencomputer, Phys. Unserer Zeit 2/2022 (53), p. 80; DOI: 10.1002/piuz.202101632

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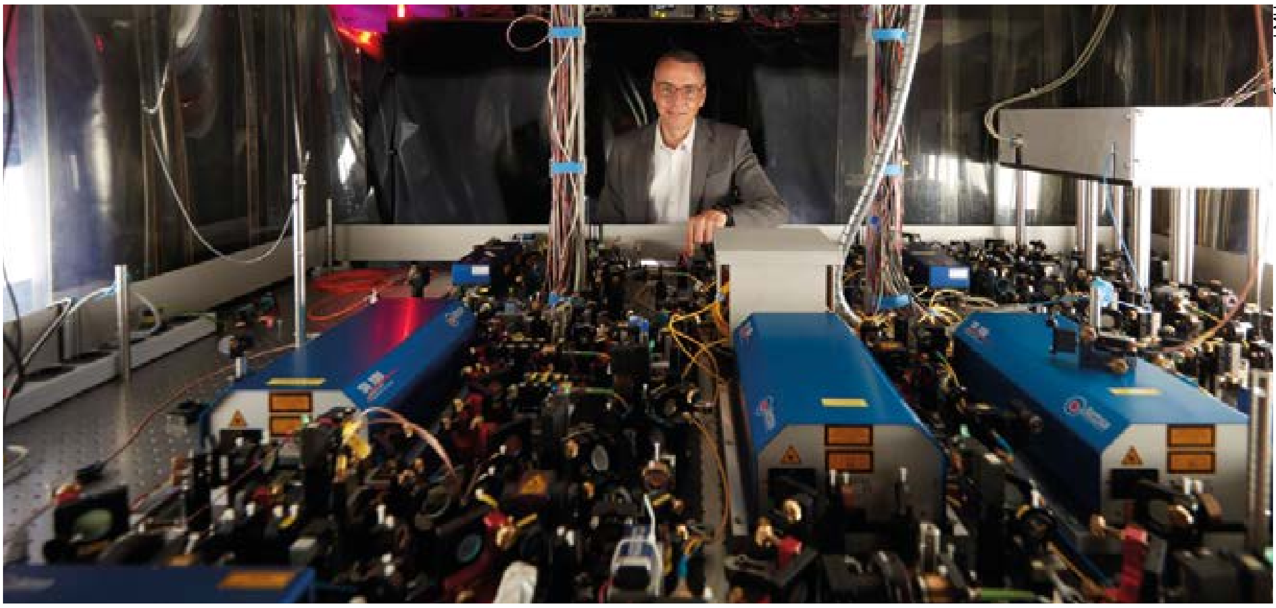
Exciting times in quantum technologies

Industry and academia stand side-by-side, like Prof Immanuel Bloch and Toptica's Thomas Renner



Source: LMU

▲ Prof Immanuel Bloch with a setup including Toptica lasers

The addition of the 'World of Quantum' exhibition area at the Laser World of Photonics exhibition in Munich brought together the most important scientific and industrial players in quantum technologies in 2022. We look at this cooperation of industry and science in an interview. Immanuel Bloch, professor for experimental physics at LMU Munich, director at the Max Planck Institute for Quantum Optics in Garching and one of the spokespersons for the Munich Center for Quantum Science and Technology (MCQST) excellence cluster, discusses with Dr Thomas Renner, CEO of Toptica Photonics AG, which lasers and quantum technology photonic solutions are currently sought after and what developments we can expect to see.

Professor Bloch: What is the Munich excellence cluster? Is the focus on basic research or specific applications?

Immanuel Bloch: The cluster concentrates more on basic research, but in Munich we also have the Munich Quantum Valley where the focus is on application-related technology development. Both initiatives are interlinked. The whole spectrum of quantum computing and simulation, from quantum communication to applications in metrology and sensors, is covered in the region.

Education is an important pillar in the MCQST. For example, we have established a master's course in quantum sciences and technologies, which is extremely popular. This year alone we had 300 international applications of which we admitted about 100.

The industry is crying out for graduates to meet the many challenges of this industry of the future.

Thomas Renner: I can confirm that. We currently have sixty vacancies!

Dr Renner, the second quantum revolution is currently taking place in scientific spheres, but to what extent is it an interesting market for Toptica?

Renner: We also split this into basic research and applications. Our roots are in science: Toptica was established almost 25 years ago as a scientific spin-off and still has very close connections to research. Sixty of our four hundred employees have a doctor's degree in quantum physics and quantum optics and contribute their knowledge not only to research and development but also to sales, applications, product management and production. When implementing laser systems and other photonic solutions, we get stimuli from research, which benefits us in all other user industries. This is because the requirement for precision and stability is extremely high in science. If you succeed here from a technological aspect, you will benefit from this in all other areas. Now quantum technology is ready to make the leap from basic research to industrial application. As a result, there are new challenges with the design and size of the systems, price levels and usability, and it is beneficial for us that we have been delivering about half of our lasers to industrial customers for many years.

Could you describe some of the upcoming changes in more detail?

Renner: Quantum applications – such as quantum computers – are relatively well understood in science. But these days, a qubit needs up to a dozen lasers with different wavelengths that are not among the classic standard wavelengths such as 633 or 1,064 nm. These lasers must also meet the highest demands in stability and linewidth. The many lasers are required for the different process steps of a quantum computer: generating, cooling, capturing, and preparing the atoms or ions and generating the entanglement. In the past, the technology that was needed for one qubit filled a vibration-cushioned optical laboratory bench that weighed a hundred kilograms. In the first step, it has been possible to accommodate this setup, including the lasers, in a head-high control cabinet. Even that was very challenging. The next step is to miniaturize the technology even further. This is because quantum computers not only need one qubit, but fifty or more to carry out practical computing operations; if you include error correction, another order of magnitude is needed. To achieve this, we need completely different, more compact and more powerful laser systems that must still be affordable. We are working on this to translate scientific acuity into industrial products and be able to service the quantum markets in the coming decades. The focus is on miniaturization and solutions that simultaneously generate a thousand individually controllable beams with one laser system and then couple them accordingly into the quantum computer systems.

Professor Bloch, what do you use lasers and other photonic tools and methods for in your research?

Bloch: We focus on quantum computing and quantum simulators. We use lasers to cool atoms so that we can capture them with laser tweezers and to position them and arrange them spatially. And we need extremely stable, low-noise laser systems to manipulate the qubits. Right now, we are actually experiencing the technological limits that Dr Renner spoke of. It is an extremely complex task to keep the many different laser systems running and to control them. I would immediately use the rack with one thousand beams from one laser that he mentioned (laughs). We need reliable, easy-to-operate, compact solutions that can also be modularized in the future. So we are collaborating with industrial partners to whom we explain our requirements and the bottlenecks in the application.


Source: LMU

Prof Immanuel Bloch in the laboratory for fermionic quantum gases at Ludwig Maximilians University, Munich

Dr Renner, today's work on quantum computers is only partly based on photonics. In which applications do you see more market potential for the photonics industry?

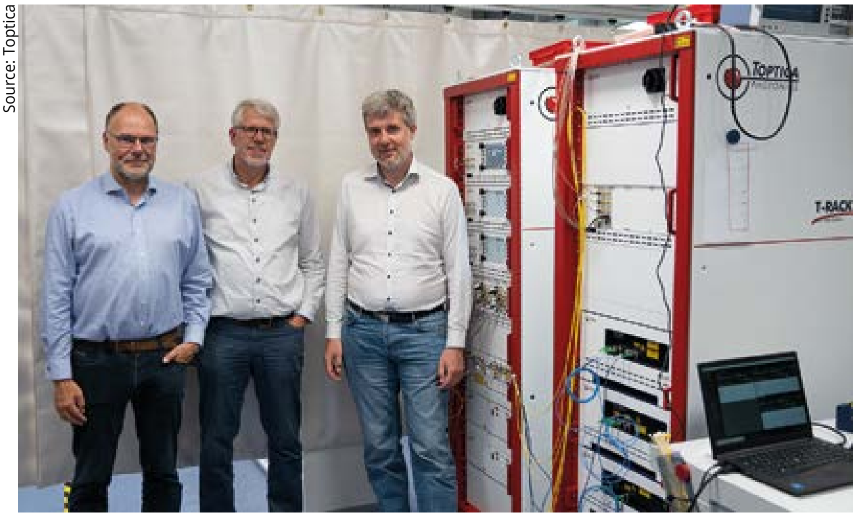
Renner: I would like to contradict you there. Most methods of quantum computing are optically controlled, but it is simply a fact that the companies that back superconductors are more prominent in the media at the moment. It remains to be seen who will win the race. There are at least four very promising technologies that use photonics intensively: ion-based and neutral atom-based approaches, photonic quantum computers and the method based on color centers in diamond. Companies like IonQ, Pasqal, Alpine Quantum Technologies (AQT), Coldquanta, and Honeywell Quantum Solutions have outstanding concepts. In many cases, only the number of qubits is considered when comparing their methods, but their coherence time, gatter fidelity and connectivity – known as quantum volume in professional circles – are also important. And optically controlled systems currently have a clear advantage here.

Bloch: The necessary cooling of the equipment alone makes scaling difficult. With millions of qubits, this would require enormous cryostats, which simply don't exist. This illustrates the challenges and the current state of the art to some extent. Scaling requires optimized process control – and it is completely unclear which of the described technology paths will produce the best result. But one thing is clear: the optical approaches (especially with ions and atoms) are pursued primarily in Europe and we have a very good technological basis with a strong photonics industry and good research. We can certainly set the trend.

Renner: I agree. No matter whether we are talking about lasers, frequency combs and detectors or the wide range of user industries, Europe has the best prerequisites to shape the market. Here we have users, such as chemical and pharmaceutical companies, insurance companies and banks but also the increasingly networked mobility sector on rail and road, who want to carry out highly complex simulations and computing operations with the help of quantum computing.

Bloch: Apart from computers, we have quantum metrology and sensors and in there is a high level of demand from the quantum communications industries that are based here. Large markets for photonics are opening up here too: atomic clocks, gravimeters, navigation systems, for example. In many cases, the driver is currently the vision of quantum computing, but I am convinced that every advance that we make in this area will stimulate all other applications and markets, with better clocks, more precise trace gas analyses, or more sensitive measuring instruments, and, of course, more accurate, more efficient, and lower-noise lasers. The beauty is that the areas of application are linked with each other technologically. When you have built an atomic clock, you already have half the stretch to quantum computers behind you. In other words, on the road to quantum computers, many potential products are created for which there is already a market and, consequently, potential sources of income …

… that take laypeople to the limit of their mental capacity. Demands for precision are enormous where atoms are cooled by laser and individual photons are counted



Source: Toptica

Member of Parliament Dieter Janecek (right) in conversation with the two board members Dr Wilhelm Kaenders (center) and Dr Thomas Renner (left) during a visit to the Graefelfing-based laser manufacturer Toptica Photonics.

and manipulated. How can your processes that are implemented in many-body systems be measured and controlled?
Bloch: Currently, we can typically position, control, and move about a thousand atoms perfectly with defined distances in space. With the current systems, we can also control their states as well. In quantum simulation, we are mainly interested in the interactions between these atoms. We can specifically adjust them and then photograph the atoms directly and analyze the photos precisely by reading the position of every single atom.

Seriously: 'photos'?
Bloch: Yes, we can determine the distances of laser-cooled atoms relatively freely with laser tweezers or with the help of diffraction gratings and are working here in the micrometer range. This can be shown optically very well. We are not concerned about the absolute length scales but rather the relationship between physical length scales. Rather than taking a look into a material and its atoms with an x-ray microscope, we pull the atoms apart randomly and more or less 'enlarge the material' and then look at how it reacts to external influences.

A frequently heard complaint is that the gap between research and application is too large. How is Toptica able to keep pace with scientific research and derive practical products from it?
Renner: We are able to do this because we work so closely with research. I already mentioned the high number of our employees with a doctor's degree – on average they are between thirty and forty years old, have usually carried out experiments with photonic instruments during their studies and, as a result, know what matters. Through them alone, we maintain close contact to current research, and about 10,000 of our lasers are currently being used in scientific quantum optics applications. Many meetings are held before a laser is sold: consultation, specification, or planning the laboratory setup. This exchange of experiences in both directions helps us to keep on top of things and offer solutions that really help the users. Other driving forces come from funded projects that we take part in. In quantum technology alone, we are currently cooperating in about a dozen projects.

Professor Bloch, if you were to write a wishlist of photonic innovations for your research, what would be your three most important wishes?
Bloch: I would like not having to bother about the lasers. And if something breaks down, I would like to be able to replace the respective module and continue working. That is where we want to be. How these systems are designed in detail, whether with many lasers or with beam multiplexing with modulators, is unimportant to us. What is important are functionality and performance, systems that can switch lasers quickly with a high contrast ratio and that can use the required wavelengths without complications – low-noise systems with stable frequencies and minimum linewidth. We always need the best to keep pushing the boundaries of what is feasible. Perhaps I will see the rack with a thousand beams from one laser that we talked about earlier before the end of my career.
Renner: We'll manage that before you retire (laughs).

Sounds interesting. Are there physical and technical obstacles that you would have liked to have overcome already to pave new ways for quantum research?
Renner: Prof Bloch's wishlist includes the challenging problems that have to be solved. In some cases, we can use solutions from other areas. For example in confocal microscopy, it is state of the art that lasers with different wavelengths have wandered from the side table into the device. These days, you can find the corresponding modules with half a dozen lasers that are activated and coupled with a mouse click. We are also striving to achieve this state of the art in quantum systems. The challenges are that the required linewidths are very narrow and the stability requirements are very high. In addition, the preferred difficult wavelengths – often in the UV range – increase development effort and costs. We will not be short of work in laser development, electronic control, material development or photonic integrated circuits (PICs) for a long time. Our industry has some exciting times ahead of it during this second quantum revolution.

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New light sources for the second quantum revolution

Project DigiQuant develops new laser diodes at AMS-Osram, which are suitable for hybrid integration of photonic waveguides and digital control electronics at Toptica

Diode-laser-based technology is a key enabler for quantum optics. Within the DigiQuant project, the miniaturization of electronics in integrated circuits for digitized operation of any material class laser diodes from diverse manufacturers will also be investigated with the Fraunhofer Institute for Integrated Circuits IIS and Toptica.

The miniaturized and digitized subsystem will be tested in two different applications, a quantum computer application and in an industrial application to read out a digital code with a handheld scanner.

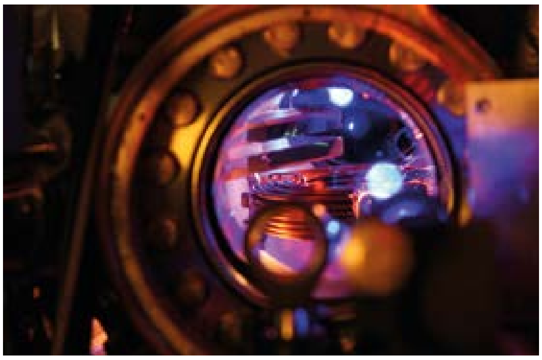
Bringing quantum computers to market

These combined developments will enable the implementation of complex laboratory technology in portable and robust devices with high wall plug efficiency for industrial use and help to scale up quantum computers and take them from the basic research stage to market maturity.

AMS-Osram is a global player in optical solutions. It has a unique product and technology portfolio for sensing, illumination, and visualization: from prime-quality light emitters and optical components to micro-modules, light sensors, ICs and related software.

The Fraunhofer Institute for Integrated Circuits IIS conducts research on microelectronic and IT system solutions and services. Today, it is the largest institute of the Fraunhofer Gesellschaft.

Toptica develops and manufactures high-end laser systems for scientific and industrial applications. The portfolio includes diode lasers, ultrafast fiber lasers, terahertz systems and frequency combs.



Blue fluorescing cloud of atoms that have been laser-cooled to milli-Kelvin temperatures in the PTB's strontium lattice clock. (Source: PTB)

www.toptica.com

Quantum keys fiber-linked over 75 kilometers

First successful exchange of quantum keys between Erfurt and Jena via optical fiber enables new QKD experiments

The Thuringian Ministry of Science has provided eleven million euros in funding to develop an infrastructure for quantum communication networks in the Free State of Thuringia, Germany. This includes a fiber-based test route between Jena and Erfurt. Partners of the Fraunhofer Institute for Applied Optics and Precision Engineering IOF have now successfully exchanged quantum keys on the 75 km route for the first time.

On a test route between Jena and Erfurt, quantum keys have been successfully exchanged via optical fiber. More than 300,000 quantum keys were sent between the Thuringian cities over a test period of ten days.

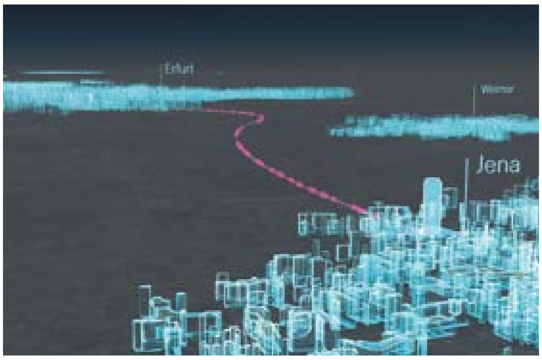
The test route, funded by the state, was already completed in the spring of this year. It connects Fraunhofer IOF in Jena with the Fraunhofer Center for Microelectronic and Optical Systems for Biomedicine (MEOS) in Erfurt. It uses conventional optical fiber and therefore can act as the basis for the nationwide implementation of quantum systems in the future. About six kilometers of the test route run above ground, allowing scenarios of already existing networks to be simulated.

The first company that has now successfully exchanged quantum keys on the fiber test route with the support of Fraunhofer IOF is Quantum Optics Jena GmbH. The young start-up was spun off in 2020 from the Fraunhofer Institute and has since been developing plug-in solutions for quantum communications. “We see that the system works differently in the field than in the laboratory,” says CEO Kevin Füchsel.

“In the lab, we transmit at about 300 bits per second with comparable losses. That gives us one encryption key per second. In the field, we are at about 200 bits, so a little less. A key is 256 bits long and can therefore be renewed almost every second for cryptographic protection, i.e., encryption and decryption, of the transmitted information. It is precisely this fast, tap-proof and automated key renewal that distinguishes quantum key distribution from established methods,” Füchsel continues.

Quantum Optics Jena is planning a second test run in the near future to further deepen the results obtained from the first test run and to develop further solutions.

www.iof.fraunhofer.de



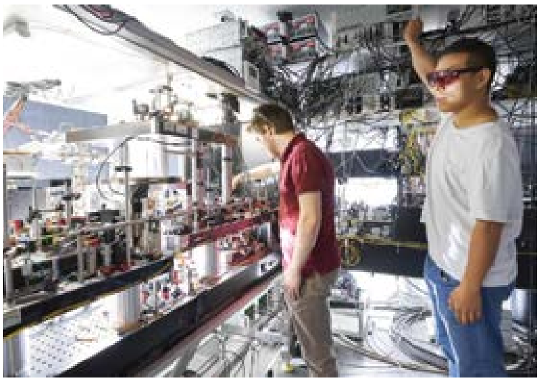
The quantum fiber link between Jena and Erfurt extends over 75 kilometers. (Source: Fh. IOF)

The Quantum Optics Jena GmbH team has successfully exchanged quantum keys on the test link for the first time (Source: Fh. IOF)

Record entanglement of quantum memories

An important step toward a future quantum internet

German researchers have entangled two quantum memories over a 33-kilometer long fiber optic connection. A team led by Harald Weinfurter from the University of Munich (LMU) and Christoph Becher from Saarland University have now coupled two atomic quantum memories over a 33-kilometer long fiber optic connection. This is the longest distance so far that anyone has ever managed entanglement via a telecom fiber. The quantum mechanical entanglement is mediated via photons emitted by the two quantum memories. A decisive step was the researchers' shifting of the wavelength of the emitted light particles to a value that is used for conventional telecommunications. "By doing this, we were able to significantly reduce the loss of photons and create entangled quantum memories even over long distances of fiber optic cable," says Weinfurter.



The researchers use a system comprised of two optically trapped rubidium atoms in two laboratories on the Munich campus. (Source: J. Greune, LMU)

Generally speaking, quantum networks consist of nodes of individual quantum memories – such as atoms, ions, or defects in crystal lattices. These nodes are able to receive, store, and transmit quantum states. Mediation between the nodes can be accomplished using light particles that are exchanged either over the air or in a targeted manner over a fiber optic connection. For their experiment, the researchers use a system comprised of two optically trapped rubidium atoms in two laboratories on the LMU campus. The two locations are connected via a 700-meter-long fiber optic cable. By adding extra fibers on coils, connections of up to 33 kilometers in length can be achieved.

However, most quantum memories emit light with wavelengths in the visible or near-infrared range. "In fiber optics, these photons make it just a few kilometers before they are lost," explains Christoph Becher. For this reason, his team optimized the wavelength of the photons for their journey in the cable. Using two quantum frequency converters, they increased the original wavelength from 780 nanometers to a wavelength of 1,517 nanometers. "This is close to the so-called telecom wavelength of around 1,550 nanometers," says Becher. The telecom band is the frequency range in which the transmission of light in fiber optics has the lowest losses. Becher's team accomplished the conversion with an unprecedented efficiency of 57 percent.

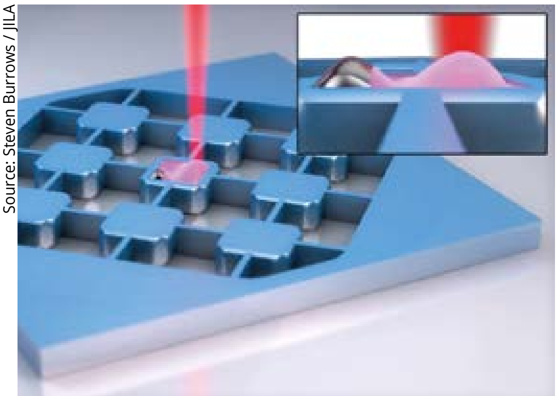
Reference: *T. van Leent* et al.: Entangling single atoms over 33 km telecom fibre, Nature **607**, 69 (2022); DOI: 10.1038/s41586-022-04764-4

www.mcqst.de

Reading out superconducting qubits with laser light

New results could be a major step toward building a quantum internet

Source: Steven Burrows / JILA



Artist's depiction of the electro-optic transducer, the ultrathin device that can capture and transform the signals coming from a superconducting qubit.

A team of physicists from the University of Colorado Boulder and the National Institute of Standards and Technology (NIST) demonstrated that it could read out the signals from a superconducting qubit using laser light, and without destroying the qubit at the same time.

The group's results could be a major step toward building a quantum internet, the researchers say. Such a network would link up dozens or even hundreds of quantum chips, allowing engineers to solve problems that are beyond the reach of even the fastest supercomputers around today. They could also, theoretically, use a similar set of tools to send unbreakable codes over long distances, explains Robert Delaney, lead author of the study and a former graduate student at the Colorado joint research institute JILA.

In the new study, Delaney and his colleagues showed that they could get around that fragility. The team uses a wafer-thin piece of silicon and nitrogen to transform the signal coming out of a superconducting qubit into visible light – the same sort of light that already carries digital signals from city to city through fiber-optic cables. "Researchers have done experiments to extract optical light from a qubit, but not disrupting the qubit in the process is a challenge," said Cindy Regal, associate professor of physics at CU Boulder.

Under the right circumstances, superconductors will emit quantum signals in the form of photons that oscillate at microwave frequencies. To send those over long distances, one would first need to convert the microwaves into optical photons. But when it comes to quantum computers, achieving that transformation is tricky.

The team used a thin piece of an electro-optic transducer and tested it using a real superconducting qubit. They discovered that the thin material could effectively keep qubits and photons isolated from each other. The team is now working to improve the microwave-optical conversion rate. (Source: UC Boulder)

Reference: *R. D. Delaney* et al.: Superconducting-qubit readout via low-backaction electro-optic transduction, Nature **606**, 489 (2022); DOI: 10.1038/s41586-022-04720-2

https://jila.colorado.edu

Twin photons from unequal sources

Producing identical photons with different quantum dots

Many technologies that make use of quantum effects are based on exactly equal photons. Producing such photons, however, is extremely difficult. Not only do they need to have precisely the same wavelength, but their shape and polarization also have to match. A team of researchers led by Richard Warburton at the University of Basel, in collaboration with colleagues at the University of Bochum, has now succeeded in creating identical photons originating from different and widely-separated sources.

In their experiments, the physicists used quantum dots, in which a laser pulse can trigger the emission of a single photon at the push of a button.

Previously, researchers had to select those photons that were the most similar from a huge number of photons by using optical filters. In that way only very few usable photons remained. Warburton and his collaborators chose a different, more ambitious approach. First, the specialists in Bochum produced extremely pure gallium arsenide from which the quantum dots were made. The natural variations between different quantum dots could thus be kept to a minimum. The physicists in Basel then used electrodes to expose two quantum dots to precisely tuned electric fields which modified the energy levels of the quantum dots in such a way that the photons emitted by the quantum dots had precisely the same wavelength.

To demonstrate that the photons were actually indistinguishable, the researchers sent them onto a half-silvered mirror. They observed that, almost every time, the light particles either passed through the mirror as a pair or else were reflected as a pair. From that they could conclude that the photons were 93 % identical.

Moreover, the researchers were able to realize an important building block of quantum computers, a controlled NOT gate or CNOT gate. (Source: U. Basel)

Reference: L. *Zhai* et al.: Quantum interference of identical photons from remote GaAs quantum dots, Nat. Nanotech., online 19 May 2022; DOI: 10.1038/s41565-022-01131-2

https://nano-photonics.unibas.ch

Trapping photons in a quantum flute

New forms for error correction in quantum computers

University of Chicago physicists have invented a quantum flute that can coerce particles of light to move together in a way that has never been seen before. This approach could point the way towards realizing quantum memories or new forms of error correction in quantum computers. David Schuster's lab works on quantum bits which tap the properties of particles at the atomic and subatomic level. In this experiment, they were working with photons in the microwave spectrum.

The system they devised consists of a long cavity made in a single block of metal, designed to trap photons at microwave frequencies. The cavity is made by drilling offset holes – like holes in a flute. "Just like in the musical instrument," Schuster said, "you can send one or several wavelengths of photons across the whole thing, and each wavelength creates a 'note' that can be used to encode quantum information." The researchers can then control the interactions of the notes using a master quantum bit, a superconducting electrical circuit.

But their oddest discovery was the way the photons behaved together. In nature, photons hardly ever interact – they simply pass through each other. With painstaking preparation, scientists can sometimes prompt two photons to react to each other's presence. Schuster said: "At first the photons don't interact at all, but when the total energy in the system reaches a tipping point, all of a sudden, they all talk to each other."

The researchers are also excited about the behavior itself. No one has observed anything like these interactions in nature, so the researchers also hope the discovery can be useful for simulating complex physical phenomena. (Source: U. Chicago)

Reference: S. *Chakram* et al.: Multimode photon blockade, Nat. Phys. **18**, 879 (2022); DOI: 10.1038/s41567-022-01630-y

http://schusterlab.uchicago.edu

Quantum effects improve lidar

Creating a detailed 3D map of a 20-pence coin with 7-micron depth resolution

Scottish researchers have shown that a quantum-inspired technique can be used to perform lidar imaging with a much higher depth resolution than is possible with conventional approaches.

Source: A. Lyons, U. Glasgow

Researchers developed a quantum-inspired technique that can be used to perform lidar with a depth resolution that is much higher than conventional approaches.

Lidar, which uses laser pulses to acquire 3D information about a scene or object, is usually best suited for imaging large objects such as topographical features or built structures due to its limited depth resolution. "Although lidar can be used to image the overall shape of a person, it typically doesn't capture finer details such as facial features," said research team leader Ashley Lyons from the University of Glasgow. "By adding extra depth resolution, our approach could capture enough detail to not only see facial features but even someone's fingerprints."

Lyons and Robbie Murray call the new technique 'imaging two-photon interference lidar'. They show that it can distinguish reflective surfaces less than two millimeters apart and create high-resolution 3D images with micron-scale resolution. "This work could lead to much higher resolution 3D imaging than is possible now, which could be useful for facial recognition and tracking applications that involve small features," said Lyons. "For practical use, conventional lidar could be used to get a rough idea of where an object might be and then the object could be carefully measured with our method."

The new technique uses quantum inspired interferometry, which extracts information from the way that two light beams interfere with each other. Entangled pairs of photons are often used for this type of interferometry, but approaches based on photon entanglement tend to perform poorly in situations with high levels of light loss, which is almost always the case for lidar. To overcome this problem, the researchers applied what they have learned from quantum sensing to classical light. "With quantum entangled photons, only so many photon pairs per unit time can be generated before the setup becomes very technically demanding," said Lyons. "These problems don't exist with classical light, and it is possible to get around the high losses by turning up the laser power."

Two-photon interference lidar also works very well at the single-photon level, which could enhance more complex imaging approaches used for non-line-of-sight imaging or imaging through highly scattering media.

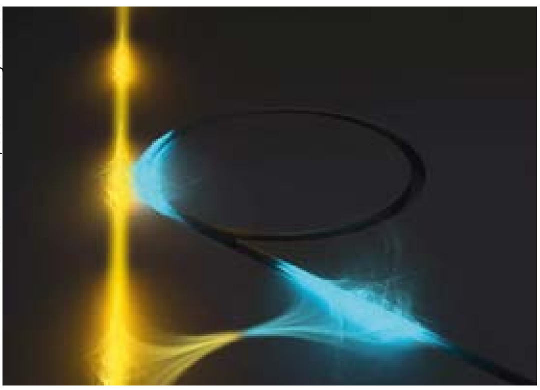
Reference: *R. Murray* & *A. Lyons*: Two-photon interference LiDAR imaging, Opt. Exp. 30, 27164 (2022); DOI: 10.1364/OE.461248

www.gla.ac.uk/schools/physics

Combining free electrons and photons

Creating electron-photon pairs in a controlled way in an electron microscope

Researchers from Germany and Switzerland teamed up to develop a new method that simultaneously generates two individual particles in the form of a pair. The findings of the study expand the toolbox of quantum technology.



Source: R. Allen, Second Bay Studios

An illustration of the generation of coupled eletron-photon pairs with a ring-shaped resonator.

The international team from the Max Planck Institute (MPI) for Multidisciplinary Sciences, the University of Göttingen, and the Swiss Federal Institute of Technology in Lausanne (EPFL) succeeded in coupling single free electrons and photons in an electron microscope. In the experiment, the beam from an electron microscope passes through an integrated optical chip, fabricated by the Swiss team. The chip consists of a fiber-optic coupling and a ring-shaped resonator that stores light by keeping moving photons on a circular path.

"When an electron scatters at the initially empty resonator, a photon is generated," explains Armin Feist, scientist at the MPI. "In the process, the electron loses exactly the amount of energy that the photon requires to be created virtually from nothing in the resonator. As a result, the two particles are coupled through their interaction and form a pair." With an improved measurement method, the physicists could precisely detect the individual particles involved and their simultaneous manifestation.

This way, the presence of one quantum particle can be confirmed by detecting the other particle, in a heralding scheme. Such a feature is necessary for many applications in quantum technology.

MPI director Claus Ropers sees electron-photon pairs as a new opportunity for quantum research: "The method opens up fascinating new possibilities in electron microscopy. In quantum optics, entangled photon pairs already improve imaging." Tobias Kippenberg, professor at EPFL adds, "For the first time, we are bringing free electrons into the toolbox of quantum information science. More broadly, coupling free electrons and light using integrated photonics could open the way to a new class of hybrid quantum technologies." (Source: MPG)

Reference: *A. Feist* et al.: Cavity-mediated electron-photon pairs, Science 377, 777 (2022); DOI: 10.1126/science.abo5037

www.mpinat.mpg.de/ropers

Spiraling lasers decrypt topological insulators

New method reveals how topological insulators lose their ability to conduct current on their surface

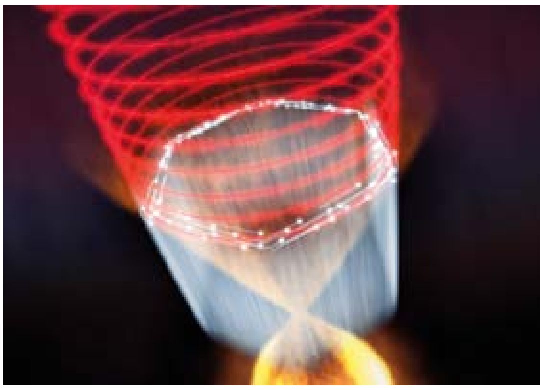
Topological insulators, or TIs, have two faces: electrons flow freely along their surface edges but cannot flow through the interior of the material at all. It takes a special set of conditions to create this unique quantum state – part electrical conductor, part insulator – which researchers hope to someday exploit for things like spintronics, quantum computing and quantum sensing. For now, they are just trying to understand what makes TIs tick. In the latest advance along those lines, researchers at the Department of Energy's SLAC National Accelerator Laboratory and Stanford University systematically probed the phase transition in which a TI loses its quantum properties and becomes just another ordinary insulator.

They did this by using spiraling beams of laser light to generate harmonics from the material they were examining. Those harmonics make it easy to distinguish what is happening in the superhighway layer from what is happening in the interior and see how one state gives way to the other. "The harmonics generated by the material amplify the effects we want to measure, making this a very sensitive way to see what is going on in a TI," said Christian Heide, a postdoctoral researcher with the Stanford PULSE Institute at SLAC. "And since this light-based approach can be done in a lab with tabletop equipment, it makes exploring these materials easier and more accessible than some previous methods."

These results are exciting, added PULSE principal investigator Shambhu Ghimire, because they show the new method has potential for watching TIs flip back and forth between superhighway and insulating states as it happens and in fine detail – much like using a camera with a very fast shutter speed.

In the current study, they set out to demonstrate what the new method could do by varying the composition of their TI material, bismuth selenide, and the properties of the ultrashort pulses of laser light they hit it with to see how each combination affected the harmonics the material generated.

They discovered that circularly polarized pulses, especially the ones that spiraled clockwise, were much more efficient at producing high harmonics from superhighway surfaces than from insulating parts of the material. "The difference between the two was huge," Heide said, so the team could easily tell the two states apart. (Source: SLAC)


Source: G. Stewart, SLAC

In a topological insulator, electrons flow freely on its surface but not through its interior.

Reference: *C. Heide* et al.: Probing topological phase transitions using high-harmonic generation, Nat. Phot. **16**, 620 (2022); DOI: 10.1038/s41566-022-01050-7

https://ultrafast.stanford.edu

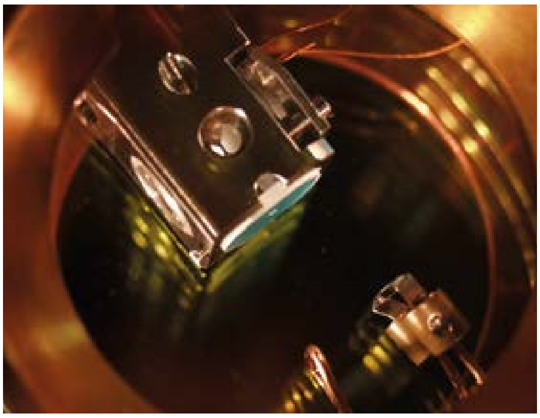
Entangled photons tailor-made

More than a dozen photons efficiently entangled in a defined way

A large number of entangled basic building blocks are needed to carry out computational operations in order to effectively use a quantum computer. A team of physicists at the Max Planck Institute of Quantum Optics in Garching has demonstrated this task for the first time with photons emitted by a single atom. Using a novel technique with an optical resonator, the researchers generated up to 14 entangled photons that can be prepared into specific quantum physical states in a targeted and very efficient manner. The new method could facilitate the construction of powerful and robust quantum computers, and serve the secure transmission of data.

"Photons are particularly well suited for this because they are robust by nature and easy to manipulate," says doctoral student Philip Thomas. Together with colleagues from the quantum dynamics division led by Gerhard Rempe, he has now succeeded in taking an important step toward making photons usable for technological applications such as quantum computing. For the first time, the team generated up to fourteen entangled photons in a defined way and with high efficiency. "The trick to this experiment was that we used a single atom to emit the photons and interweave them in a very specific way," says Thomas. To do this, the researchers placed a rubidium atom at the center of an optical cavity. The state of the atom could be precisely addressed with light of a certain frequency. The researchers also specifically triggered the emission of a photon that is entangled with the quantum state of the atom by using an additional control pulse.

"We were able to prove an efficiency of almost fifty percent by measuring the resulting photon chain," says Thomas. This means: almost every second push of a button on the rubidium atom delivered a usable light particle – far more than has been achieved in previous experiments. "All in all, our work removes a long-standing obstacle on the path to scalable, measurement-based quantum computing," Gerhard Rempe said in summary. (Source: MPQ)



Setup of an optical resonator in a vacuum. A single rubidium atom is trapped between the conically shaped mirrors inside the holder. (Source: MPQ)

Reference: *P. Thomas* et al.: Efficient generation of entangled multiphoton graph states from a single atom, Nature **608**, 677 (2022); DOI: 10.1038/s41586-022-04987-5

www.mpq.mpg.de/quantumdynamics

Silicon nanopillars for quantum communication

Silicon-based sources generate photons at the right wavelength to proliferate in optical fibers

New photon sources are required that emit single light quanta in a controlled fashion and on demand. Only recently has it been discovered that silicon can host sources of single-photons with properties suitable for quantum communication. So far, however, no-one has known how to integrate the sources into modern photonic circuits. For the first time, a team led by the Helmholtz-Zentrum Dresden-Rossendorf (HZDR) has now presented an appropriate production technology using silicon nanopillars: a chemical etching method followed by ion bombardment.

Source: J. Baratech, HZDR

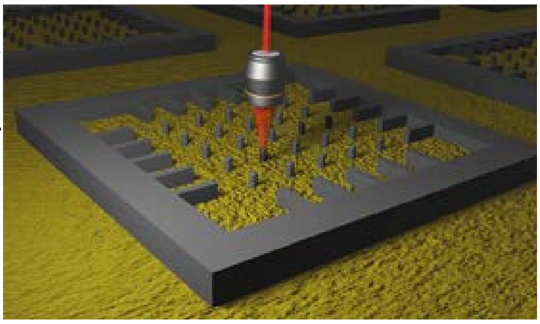


Illustration of an objective lens to test the light output from an array of silicon nanopillars on a chip.

"Silicon and single-photon sources in telecom have long been the missing link in speeding up the development of quantum communication by optical fibers. Now we have created the necessary preconditions for it," explains Yonder Berencén of HZDR's Institute of Ion Beam Physics and Materials Research who led the study. Although single-photon sources have been fabricated in materials like diamonds, only silicon-based sources generate light particles at the right wavelength to proliferate in optical fibers – a considerable advantage for practical purposes.

The researchers achieved this technical breakthrough by choosing a wet etching technique to process the silicon on a chip rather than the conventional dry etching techniques. Using this MacEtch method, researchers initially fabricated the simplest form of a potential light wave-guiding structure: silicon nanopillars on a chip. They then bombarded the finished nanopillars with carbon ions, just as they would with a massive silicon block, and thus generated photon sources embedded in the pillars. Employing the new etching technique means the size, spacing, and surface density of the nanopillars can be precisely controlled and adjusted to be compatible with modern photonic circuits. Per square millimeter chip, thousands of silicon nanopillars conduct and bundle the light from the sources by directing it vertically through the pillars.

"My dream is to integrate all the elementary building blocks, from a single photon source via photonic elements through to a single photon detector, on one single chip and then connect lots of chips via commercial optical fibers," says Berencén. (Source: HZDR)

Reference: *M. Hollenbach* et al.: Metal-assisted chemically etched silicon nanopillars hosting telecom photon emitters, J. Appl. Phys. **132**, 033101 (2022); DOI: 10.1063/5.0094715

www.hzdr.de

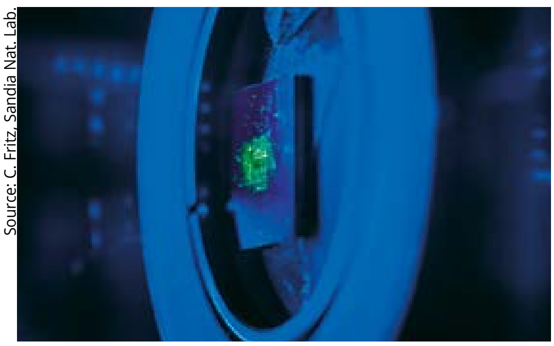
Metasurfaces generate complex quantum states

Nonlinear devices essentially achieve multi-entanglement in one sample only

Scientists at Sandia National Laboratories and the Max Planck Institute for the Science of Light have created a device that could replace a roomful of equipment to produce entangled photon-pairs. An ultrathin metasurface paves the way for entangling photons in complex ways that have not been possible with compact technologies.

"It scrambles all the optical fields," said Sandia senior scientist Igal Brener. Occasionally, he said, a pair of entangled photons at different wavelengths emerge from the sample in the same direction as the incoming laser beam. Brener said he is excited about this device because it is designed to produce complex webs of entangled photons – not just one pair at a time, but several pairs all entangled together, and some that can be indistinguishable from each other.

Source: C. Fritz, Sandia Nat. Lab.



Green laser light illuminates a very thin metasurface to produce entangled photon-pairs.

Until now, the only way to produce such results was with multiple tables full of lasers, specialized crystals and other optical equipment. Brener said: "These nonlinear metasurfaces essentially achieve this task in one sample when before it would have required incredibly complex optical setups."

For this result, the team tuned their metasurface to produce entangled photons with varying wavelengths, a critical precursor to generating several pairs of intricately entangled photons simultaneously. However, the efficiency of the device is lower than that of other techniques and needs to be improved.

Commercial industries, said Brener, are busy developing metasurfaces because they take up less space and can do more with light than, for instance, a traditional lens.

The device made of gallium arsenide was designed, fabricated and tested through a partnership between Sandia and a research group led by physicist Maria Chekhova, an expert in the quantum entanglement of photons at the Max Planck Institute for the Science of Light, MPL, in Germany.

Brener, who has studied metamaterials for more than a decade, said this newest research could possibly spark a second revolution – one that sees these materials developed not just as a new kind of lens, but as a technology for quantum information processing and other new applications. (Source: Sandia Nat. Lab)

Reference: *T. Santiago-Cruz* et al.: Resonant metasurfaces for generating complex quantum states, Science **377**, 991 (2022); DOI: 10.1126/science.abq8684

https://cint.sandia.gov

Twisty photons for quantum communication

New approach opens the door to even faster and more powerful quantum communication tools

Quantum researchers at Stevens Institute of Technology have demonstrated a method for encoding vastly more information into a single photon, opening the door to even faster and more powerful quantum communication tools.

Typically, quantum communication systems write information onto a photon's spin angular momentum. In this case, photons carry out either a right or left circular rotation, or form a quantum superposition of the two as a two-dimensional qubit. It is also possible to encode information onto a photon's orbital angular momentum. When the spin and angular momentum interlock, it forms a high-dimensional qudit – enabling any of a theoretically infinite range of values to be encoded into and propagated by a single photon.

These flying qubits and qudits are used to propagate information stored in photons from one point to another. The main difference is that qudits can carry much more information over the same distance than qubits, providing the foundation for turbocharging next generation quantum communication. The researchers led by Stefan Strauf, head of the NanoPhotonics Lab at Stevens, show that they can create and control individual flying qudits, or twisty photons, on demand. That could dramatically expand the capabilities of quantum communication tools. "Normally the spin angular momentum and the orbital angular momentum are independent properties of a photon. Our device is the first to demonstrate simultaneous control of both properties via the controlled coupling between the two," explained Yichen Ma, a graduate student in Strauf's NanoPhotonics Lab, who led the research in collaboration with Liang Feng at the University of Pennsylvania, and Jim Hone at Columbia University.

"What makes it a big deal is that we have shown we can do this with single photons rather than classical light beams, which is the basic requirement for any kind of quantum communication application," Ma said.

Further work is needed to create a device that can create twisted photons with rigorously consistent quantum properties, i.e., indistinguishable photons – a key requirement to enable the quantum internet. Such challenges affect everyone working in quantum photonics and could require new breakthroughs in material science to solve. (Source: Stevens)

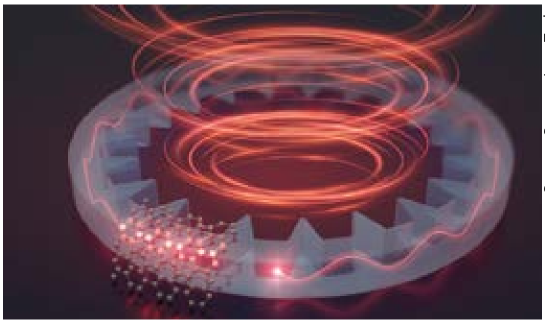

Source: Stevens Inst. Tech.

Illustration of a quantum emitter of single photons integrated with a gear-shaped resonator.

Reference: *Y. Ma* et al.: On-chip spin-orbit locking of quantum emitters in 2D materials for chiral emission, Optica **9**, 953 (2022); DOI: 10.1364/optica.463481

www.stevens.edu

The first programmable optical quantum memory

New approach to generate multiphoton entangled states is faster than any previous method

Entangled systems containing multiple quantum particles offer significant benefits in implementing quantum algorithms, which have the potential to be used in communications, data security or quantum computing. Researchers from Paderborn University have been working with colleagues from Ulm University to develop the first programmable optical quantum memory.

The Integrated Quantum Optics group led by Christine Silberhorn from the Department of Physics and Institute for Photonic Quantum Systems (PhoQS) at Paderborn University is using photons as quantum systems. The researchers are seeking to entangle as many as possible in large states. Previously, attempts to entangle more than two particles only resulted in very inefficient entanglement generation. If researchers wanted to link two particles with others, in some cases this involved a long wait as the interconnections that promote this entanglement only operate with limited probability rather than at the touch of a button. This meant that the photons were no longer a part of the experiment once the next suitable particle arrived – as storing qubit states represents a major challenge.

"We have now developed a programmable, optical, buffer quantum memory that can switch dynamically back and forth between different modes – storage mode, interference mode and the final release", the quantum physicist explains. In the experimental setup, a small quantum state can be stored until another state is generated, and then the two can be entangled. This enables a large, entangled quantum state to grow particle by particle. Silberhorn's team has already used this method to entangle six particles, making it much more efficient than any previous experiments. By comparison, the largest ever entanglement of photon pairs, performed by Chinese researchers, consisted of twelve individual particles, but took significantly more time to create.

Silberhorn states: "Our system allows entangled states of increasing size to be gradually built up – which is much more reliable, faster, and more efficient than any previous method." The new approach can be combined with all common photon-pair sources. (Source: UPb)


Source: B. Mazhiqi, U. Paderborn

Researchers from Paderborn University use entangled photons for a programmable optical quantum memory.

Reference: *E. Meyer-Scott* et al.: Scalable Generation of Multiphoton Entangled States by Active Feed-Forward and Multiplexing, Phys. Rev. Lett. **129**, 150501 (2022); DOI: 10.1103/PhysRevLett.129.150501

https://physik.uni-paderborn.de

Processing photons in picoseconds

Another step toward advancing quantum information processing

Using a time lens, Columbia Engineers resolve single photons seventy times faster than other techniques. "Just like an ordinary magnifying glass can zoom in on some spatial phenomena you would not otherwise be able to see, a time lens lets you resolve details on a temporal scale," said Chaitali Joshi, a former PhD student in Alexander Gaeta's lab at Columbia University.

The team's time lens lets them pick out photons faster than ever before. The experimental set-up consists of two laser beams that mix with a signal photon to create another packet of light at a different frequency. With their time lens, Joshi and her colleagues were able to identify single photons from a larger beam with picosecond resolution. That is about 70 times faster than has been observed with other single-photon detectors said Joshi, now a postdoc at Caltech. Such a time lens enables temporally resolving individual photons with a precision that cannot be achieved with current photon detectors.

In addition to seeing single photons, the team can also manipulate their spectra, reshaping the path along which they traveled. This is an important step for building quantum information networks. "In such a network, all the nodes need to be able to talk to each other. When those nodes are photons, you need their spectral and temporal bandwidths to match, which we can achieve with a time lens," said Joshi.

With future tweaks, the Gaeta lab hopes to further reduce the time resolution by more than a factor of three and will continue exploring how they can control individual photons. "With our time lens, the bandwidth is tunable to whatever application you have in mind: you just need to adjust the magnification," said Joshi. Potential applications include information processing, quantum key distribution, quantum sensing, and more. For now the work is done with optical fibers, though the lab hopes to one day incorporate time lenses into integrated photonic chips, like electronic chips, and scale the system to many devices on a chip to enable many photons to be processed simultaneously. (Source: Columbia U.)

Like a magnifying glass zooming in on an object, a time lens can zoom in on time. (Source: N. Barolini)

Reference: *C. Joshi* et al.: Picosecond-resolution single-photon time lens for temporal mode quantum processing, Optica **9**, 364 (2022); DOI: 10.1364/optica.439827

https://gaeta.apam.columbia.edu

More control over captured light

New approach to create and control quantum states of light in a three-dimensional cavity

Researchers in quantum technology at Chalmers University of Technology have succeeded in developing a technique to control quantum states of light in a three-dimensional cavity. In addition to creating previously known states, the researchers are the first ever to demonstrate the long-sought cubic phase state. The breakthrough is an important step toward efficient error correction in quantum computers. "We have shown that our technology is on par with the best in the world," says Simone Gasparinetti, who is head of a research group in experimental quantum physics at Chalmers.

A major obstacle to the realization of a practically useful quantum computer is that the quantum systems used to encode the information are prone to noise and interference, which causes errors. Correcting these errors is key to their development.

A promising approach is to replace qubits with resonators – quantum systems which, instead of having just two defined states, have a very large number of them. These states may be compared to a guitar string, which can vibrate in many different ways. This continuous variable quantum computing makes it possible to encode the values 1 and 0 in several quantum mechanical states of a resonator. However, controlling the states of a resonator is a challenge with which quantum researchers all over the world are grappling. And the results from Chalmers provide a way of doing so. The new technique allows researchers to generate virtually all previously demonstrated quantum states of light, such as Gottesman-Kitaev-Preskill (GKP) states, and the cubic phase state, a state previously described only in theory.

"The cubic phase state is something that many quantum researchers have been trying to create in practice for twenty years. The fact that we have now managed to do this for the first time is a demonstration of how well our technique works, but the most important advance is that there are so many states of varying complexity and we have found a technique that can create any of them," says doctoral student Marina Kudra. The resonator is a three-dimensional superconducting cavity made of aluminium. Complex superpositions of photons trapped inside the resonator are generated by interaction with a secondary superconducting circuit.

The quantum mechanical properties of the photons are controlled by applying a set of electromagnetic pulses via gates. The researchers first succeeded in using an algorithm to optimize a specific sequence of simple displacement gates and complex SNAP-gates to generate the state of the photons. When the complex gates proved to be too long, the researchers found a way of making them shorter using optimum control methods to optimize the electromagnetic pulses.

The electronics that apply the electromagnetic gates to the cavity were developed in collaboration with the Swedish company Intermodulation Products. (Source: Chalmers)

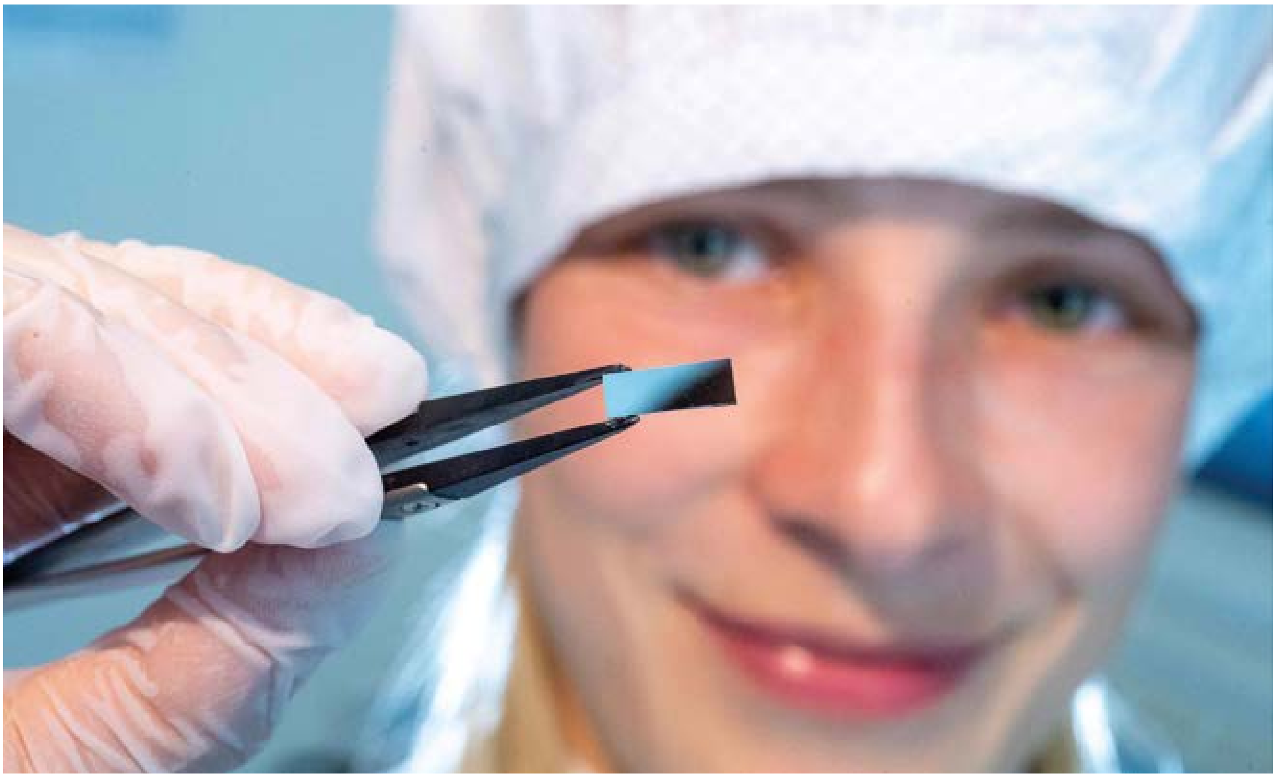
Reference: *T. Hu, X. Feng, Z. Yang, M. Zhao*: Design of scalable metalens array for optical addressing. Front. Optoelectron. **15**, 32 (2022). https://doi.org/10.1007/s12200-022-00035-2

www.chalmers.se/en/centres/wacqt

Quantum computing – the photonic approach

A pure photonics approach to quantum computing needs no cooling and makes use of semiconductor technology

Michael Förtsch & Tobias M. Wintermantel



▲ **Fig. 1** A 'Qantie' presenting a photonic chip (Source all images: Qant)

More than thirty billion dollars has gone into funding quantum technologies, and much of this money has been allocated to quantum computing projects. Accordingly, a large number of different realizations for quantum computing are being developed. The photonic approach is one of the most promising of these ideas because it is based on well-known materials, established production processes, and operation at room temperature.

Quantum computing is a fascinating technology: it promises to solve certain computational problems that cannot be executed within a reasonable time by conventional computers. A quantum computer may accomplish such an astonishing achievement based on an architecture that differs substantially from the bit-wise calculating processors that have been used since the days of Konrad Zuse and Alan Turing.

Their computers have done little more than counting integer numbers, comparing, adding, and storing them. A quantum computer exploits quantum mechanical effects and uses superposition, interference, and entanglement to come to a result. It is therefore very difficult to compare the two systems. It is very likely that both systems will support each other in the future by calculating different problems.

For simplicity, some analogies have been drawn between the current and the new systems. One of them is the qubit, as an analogue to the normal bit. Such a qubit is the simplest quantum state and can have, for example, the states 1 and 0 plus their superpositions. The quantum effect is that all superpositions are possible, although a measurement yields only 1 or 0.

On the way to commercial quantum computers, many corporates and start-ups have begun to engineer qubits based on various physical systems, ranging from superconducting circuits, to ions, to cold atoms and photonics. The enormous potential of quantum computers, or more generally quantum information processing using photons

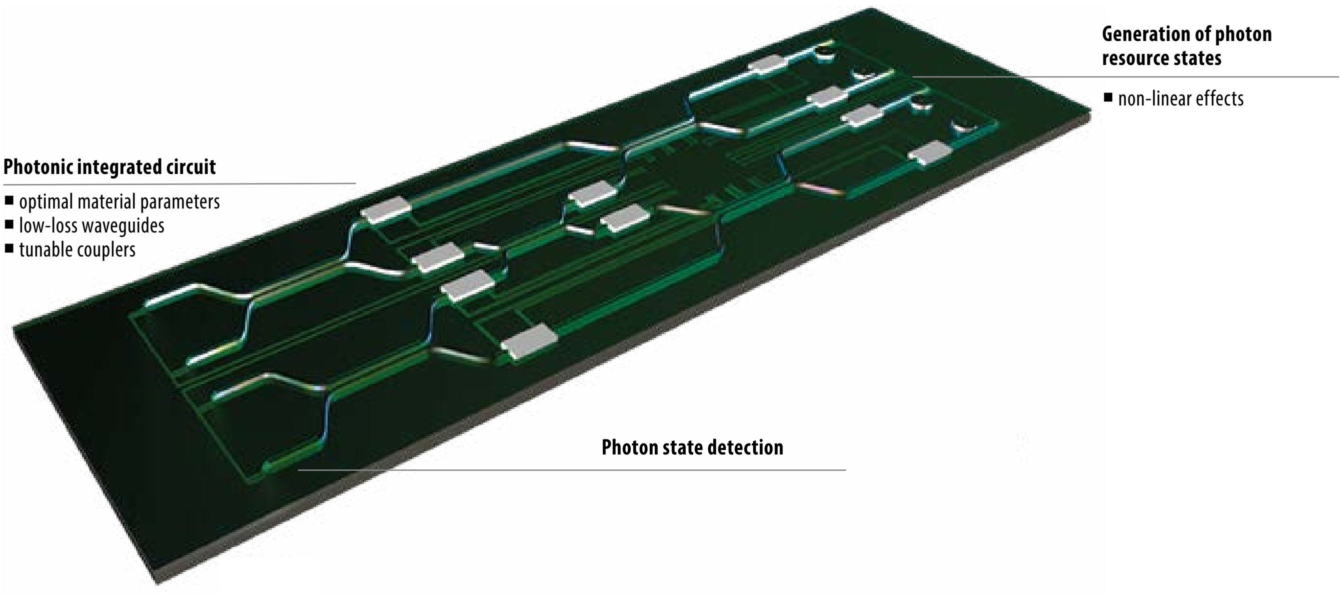


Fig. 2 Photonic integrated circuit for quantum computation with ring laser sources, low-loss waveguides and tunable retarders.

as a resource for qubits, was highlighted by the award of the Physics Nobel Price 2022 to Alain Aspect, John Clauser and Anton Zeilinger for their groundbreaking experiments with entangled photons. These opened the path to advanced quantum technologies.

Among all known forms of qubits, photons have inherent unique features. Photons are extremely robust against environmental impact. This results in very long coherence times, the time that allows for quantum operations. The fact that photons are flying qubits enables a high connectivity within individual and even across multiple quantum computers. This opens up the potential for quantum communication by sending them to distant photonic quantum computers.

Realizing a photonic quantum computer and how it works

The team at Qant has developed a photonic integrated platform for photonic quantum computing. The basic idea is to shrink bulk, free-space optical elements down to photonic integrated circuits using microfabrication processes. This enables a direct combination of the optical world with the electronic world. For the optical components, Qant relies on lithium niobate wafers, which are bonded onto silicon wafers (Figs. 3). Out of the possible material choices, lithium niobate was selected for its optimal properties with regard to quantum photonics: it has low losses, good non-linear and electro-optical properties and allows for the monolithic integration of all optical elements. In addition, this lithium niobate photonic platform has demonstrated the shortest gate operation times across all qubit platforms. These outstanding material proprieties are the key to achieve highly efficient qubit generation combined with very fast gate operations via electro-optical phase retardation.

Lithium niobate is a common material in telecom components, so there is an established technology to make phase retarders or wave guides and it can be produced in the form of wafers. To use it for photonic quantum computing, however, Qant researchers had to further improve semiconductor production techniques, which resulted in a proprietary process design kit (PDK). These improvements allow them to work with lithographically monolithically-produced waveguides with extremely low losses, microscopic ring resonators, and fast switching phase retarders (Fig. 2).

The starting point of each photonic quantum computing chip are the microscopic ring resonators. They are unique; through applied bias voltage they can be tuned to deliver single-mode radiation of a defined wavelength and bandwidth [1]. They act as tunable sources for indistinguishable special quantum states, like squeezed states of light.

The actual photonic circuit is built up on a few building blocks: tunable wave retarders, waveguides and coupling regions. If two waveguides A and B come close enough, then a light from waveguide A can either stay in A or switch to B. This is the function of a beam splitter. In a quantum mechanical sense, the beam splitter produces a superposition, as it remains unclear whether the mode goes into the one or the other channel. In fact, the beam splitter produces a mix of the two possible states.

If one optical quantum state comes through waveguide A and another one through waveguide B, they may interfere at the proximity point, or entangle for more suitable quantum states. The interference can be controlled through a retarder in one of the waveguides. This is the second important function of a quantum computer: interference.

A Mach-Zehnder interferometer can be easily built with these building blocks: two optical quantum states are sent through waveguides A and B, and interfere at a first beam splitter. After this beam splitter, the two waveguides act as two arms of an interferometer. Both arms meet at a second beam splitter where interference happens once more. To make the interferometer tunable, one arm contains a retarder, which controls the overlap on the second beam splitter.

Company

Q.ANT

Q.ANT develops quantum sensors and quantum computing chips based on their photonic quantum framework. The company was founded in 2018 as a spin-off from Trumpf SE + Co KG and employs more than sixty people (October 2022). It participates in several German projects for the research and development of quantum technology. These include the PhoQuant project with € 50 M funding, where Q.ANT takes the lead.

www.qant.de

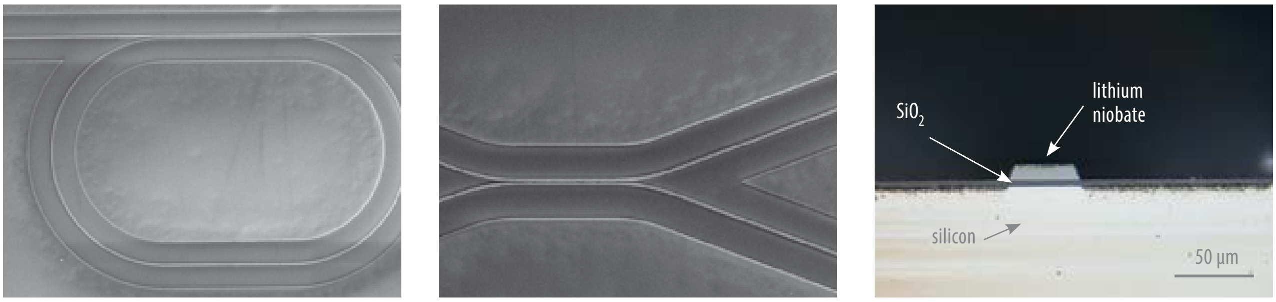


Fig. 3 Electron microscope images of photonic integrated circuit structures: ring resonator, coupling zone of waveguides and waveguide cross-section (from left to right)

A photonic integrated quantum computer then assembles a two-dimensional array of such interferometric nodes. They can be coupled in such a way that neighboring nodes influence the interference of each other. Fig. 2 shows such a setup where the silver squares represent phase retarders. After one calculation stage, signals can be fed into a next stage of coupled interferometers. The output is recorded with low-noise photon detectors at the end of each waveguide.

Of course, this is a simplified description. In reality, more components for beam or signal handling are included. The combination of optical components may also vary according to the actual task of the chip.

Photonic quantum chips put relevant applications on the horizon

Although there is still substantial development necessary on the way towards universal photonic quantum computers, intermediate steps already show their potential to solve specific problems. Such application-specific photonic quantum accelerators are likely to be applied in quantum neural networks or for quantum sampling problems.

As an example, in 2020 a team led by Jian-Wei Pan and Chao-Yang Lu at the University of Science and Technology of China in Hefei claimed to have reached quantum supremacy on a photonic quantum computer. They carried out a procedure called boson sampling where several photonic quantum states are interfered and the output is measured. The combination of input and output data was used to calculate the 'permanent' of a matrix, a number that is calculated similarly to its determinant, just without alternating signs. For large matrices, this process becomes too much of an effort for conventional computers. The Chinese team claimed that their quantum computer with 100 input and output channels was a hundred trillion times faster than a supercomputer [2].

The developments at Qant will now allow this static, free-space experiment filling a whole lab to be scaled down into a small, reprogrammable quantum photonic chip. Gaussian boson sampling can then be used for tough mathematical problems such as dense subgraphs, graph isomorphism or max clique. In chemistry it will help to calculate complex molecular properties, such as Franck-Condon factors or vibrational spectra.

The development of photonic quantum computers has just begun. Large projects, such as the Qant-led PhoQuant project funded by the German Federal Ministry of Education and Research with about fifty million euros, target systems with a hundred qubits and beyond within the next five years. In parallel, the ecosystem is growing: algorithms are being developed, a cloud access of existing systems will allow external users to test the hardware for their own problems. Although quantum supremacy has been shown already, it will be the proliferation of the quantum computer by a broader ecosystem that enables its transfer into widespread industrial applications.

DOI: 10.1002/phvs.202200051

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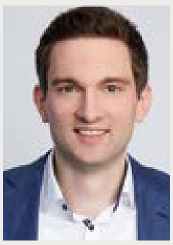
Authors



Michael Förtsch is the founder and CEO of Qant. He studied mathematics and physics, and earned his doctorate at the Max Planck Institute for the Physics of Light in Erlangen. A research stay at the National Institute for Standards and Technology in Boulder was followed by positions as strategy consultant and personal assistant to the CTO at Trumpf in Stuttgart. From this position, he founded Qant in 2018.

Tobias Martin Wintermantel is senior quantum architect at Qant. He studied physics at the Ruprecht Karls University in Heidelberg as well as at the University of Strasbourg, with stays at the University of Connecticut. After his PhD studies on quantum simulation with ultracold atoms, he joined Qant in late 2020.

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How the hidden quantum realm reveals the invisible

Tunable quantum dots offer a sought-after breakthrough in SWIR sensing and imaging

Stuart Stubbs

Source all images: Quantum Science

Current infrared (IR) sensing and imaging technology is at its practical limit. Siliconbased CMOS solutions are cost-effective but spectrally limited, while InGaAs sensors offer excellent photon conversion efficiency, but are too complex and costly. As the world experiences both a second quantum revolution and an increasing proliferation of machine sensing technology, using quantum dots to gather detailed IR data is the next frontier for sensing and imaging technology.

There are currently very few technologies that offer the short-wave infrared (SWIR) sensitivity required to truly start the machine sensing revolution. Today's products all suffer from significant challenges that prevent them from being deployed in mass markets where cost and performance are critical factors.

Indium-gallium-arsenide (InGaAs) sensors are currently the most mature compared to other SWIR imaging technologies. Camera technology based on InGaAs photodiodes operating within the 0.9 – 1.7 µm SWIR region can demonstrate high detection performance thanks to its high quantum efficiency, low dark current, fast response speed, and excellent reliability. The technology offers scope for wavelengths of light up to 2.6 µm to be detected with extended InGaAs alloys using higher InAs composition.

Despite the high performance, it is the complex manufacturing process that limits the use of InGaAs detector arrays to applications that are less sensitive to cost. Furthermore, the high fabrication cost and low throughput of InGaAs sensors, along with their low pixel resolution and relatively bulky design, make the technology impractical to use in consumer electronics.

▲ Infiq quantum dot inks can be printed in a single, thin layer, making for more compact device stacks.

During fabrication, InGaAs is epitaxially grown on indium phosphide (InP) wafers, then diced into chips before the individual pixels are indium bonded with silicon readout circuits (ROIC) via 'flip-chip' hybridization. This is a complex and expensive process that practically limits the pixel pitch and resolution, and leads to a high rate

Fig. 1 Quantum dots can be fabricated using a relatively simple benchtop wet chemistry process.

of defects and low yields. The complex 'flip-chip' fabrication method also makes the scale-up process for large InP wafers more challenging – the fragile nature of InP makes manufacturing large wafers difficult.

More advanced InGaAs sensors using copper-copper (Cu-Cu) hybrid wafer bonding technology can deliver pixel pitch scaling (the center-to-center distance between two pixels) down to 5 µm. However, they are susceptible to higher levels of noise due to the high dark current present at room temperature. Dark current refers to the current that exists in a photosensitive device even when no light is incident upon it. As most sensing applications need very small pixel sizes, a low dark current is necessary to ensure a sharp, crisp image with minimal image noise.

To address this, InGaAs sensors must be intensely cooled to achieve adequate image quality. The need for a cooling system adds more bulk to what are already usually larger chip sizes. InGaAs technology, therefore, is only appropriate for niche markets such as military, aerospace, and inspection equipment applications, where high performance is required at the cost of every other factor.

An alternative to InGaAs is SiGe (silicon-germanium) technology which is based on the direct integration of germanium photodiodes onto silicon wafers [1]. SiGe technology enables high-speed, low-cost IR image sensors. However, the high dark currents and limited light detection range (typically up to 1.6 µm) reduce their application to space and special market use cases.

SiGe technology is further impeded by the thick active layer needed to absorb longer wavelengths, necessary for the integration of SiGe photodiodes into ROICs. SiGe technology is more appropriate for surveillance, industrial automation, and diagnostics applications where a compromise between device performance and cost is acceptable.

Both are useful for certain applications, but neither has all the qualities needed to herald the next generation of photonics. It is unsurprising that a Yole Développement report into SWIR imaging claims that a more complete solution could bring about what it calls a "paradigm shift" in the sector [2]. The same report also predicts that high performance solutions will begin to replace legacy technology by 2027, with the main trend being the emergence of quantum dot solutions.

Photon detection and conversion

Quantum technology – and, specifically, quantum dots – could solve many of the problems outlined above at a stroke. Quantum dots are nanoscale semiconductors that can absorb and emit different wavelengths of light. The exact wavelengths of light to which the dot is sensitive are directly correlated to its size – larger quantum dots are sensitive to longer, lower-energy wavelengths of light, while smaller dots are sensitive to shorter, higher-energy wavelengths. By controlling the size of the quantum dots during fabrication, it is possible to precisely tune the wavelengths of light absorbed.

The technology is already widely used in consumer TVs and other displays as the quantum dots can be tuned to emit visible light in an array of colors. However, they can also be tuned to emit and absorb light in invisible frequencies, such as infrared (IR), which is where the real value to the sensing and imaging space can be seen.

Monolithic integration of quantum dots onto complementary metal oxide semiconductor (CMOS) ROICs is possible through solution processing. These quantum dot solutions can be spin coated and inkjet printed onto a variety of substrates, making them an ideal technology for low-cost manufacturing. This method combines all the benefits of CMOS technology with the SWIR sensitivity enabled by quantum dots. CMOS is the current mass market NIR sensing solution of choice due to its low cost and high throughput manufacturing process. However, it has reached the limits of its usefulness – it cannot be used in SWIR sensing at all, as SWIR light is not absorbed by the silicon on a CMOS chip.

A quantum solution could bring low cost, high resolution, scalable production and 300-mm wafer scale processing, all with the SWIR sensitivity required to chart a new frontier for sensing and imaging technology. Perhaps most importantly, it could provide all of this while eliminating the drawbacks of InGaAs and SiGe solutions.

Quantum dots allow the sensitivity range of a sensor to be precisely tuned and, owing to the nature of quantum

Company

Quantum Science

QS is a leading British materials innovation company that focuses on developing and commercializing QDs, nanomaterials, and technologies for imaging and sensing markets. QS has a team of experts in QD synthesis and scaleup, nanocrystal and nanoparticle surface engineering, ink formulation, thin-film processing and QD semiconductor device engineering.

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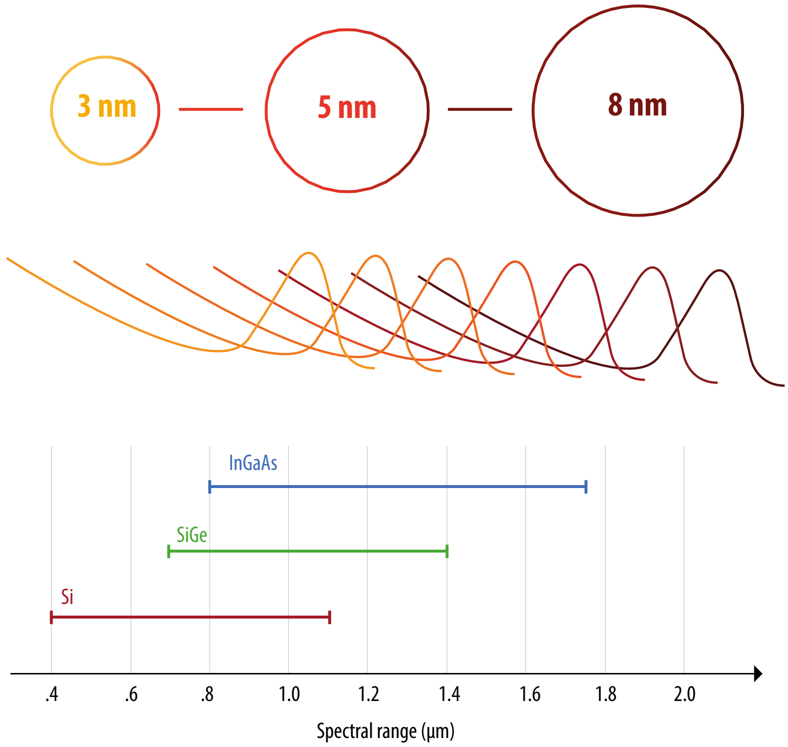

Fig. 2 Wavelength tuneability of quantum dots

mechanics, they are not limited by the fundamental properties of traditional semiconductor materials. At the same time, the high absorption coefficient means that quantum dots absorb light more efficiently than silicon. The photon absorbing layer in a quantum dot photodiode can therefore be made much thinner than silicon, which must be several thousand nanometers thick. Fabrication is also much simpler than with incumbent materials. For all their confounding physical properties, quantum dots can be made using a simple benchtop wet chemistry process. Unlike SiGe or InGaAs materials, they do not require high temperature, foundry-based processes to make.

Despite the rapid advance in QD sensing technology, there remain several key hurdles that must be overcome to ensure the technology is ready for commercialization.

Developing quantum dot solutions

Current attempts to commercialize this technology rely upon a spin coating method whereby up to fourteen thin quantum dot layers are deposited sequentially to build up the absorbing layer thickness. A chemical treatment step is conducted upon each consecutive QD layer in which the long-chain insulating ligands of each quantum dot are replaced with shorter, conductive ligands to improve electronic coupling between the nanoparticles when deposited as a solid film. Large volumes of solvent are wasted in this multistep process, adding cost and complexity to fabrication. Naturally, a protracted fabrication process means batch-to-batch consistency is low. This is one of the major barriers that has held back quantum dot SWIR sensing from the mass market.

To solve this problem, Quantum Science carries out the ligand exchange process in solution and formulates stable colloidal inks. This enables a single layer deposition process for image sensor manufacturers, removing the need for further chemical processing, reducing waste and minimizing the chance of defect formation.

A leading indicator for the performance of quantum dot image sensors is found in the optical properties of the quantum dot materials themselves. Designing high quality materials that can demonstrate superior performance even prior to integration into sensors is a certain way to improve the output of the final image sensor product. The critical metrics indicating the quality and performance of materials are the full width at half maximum, and the peak-to-valley ratio of the optical absorption peak.

In Fig. 2, the uniformly spherical shape and homogenous size distribution of the quantum dots are easily identified using transmission electron microscopy (TEM). After ligand exchange and ink formulation, the individual quantum dots can be seen in close proximity to each other, with a high degree of necking, and arrangement into highly-ordered and closely-packed structures. These features contribute to quantum dot solids with high charge mobility and high absorbance.

Seeing beyond the visible

Should Infiq technology continue to mature rapidly, it will unlock SWIR sensing, which aids a host of photonics applications. The medical imaging sector, as one example, would benefit from enhanced biometric and vital

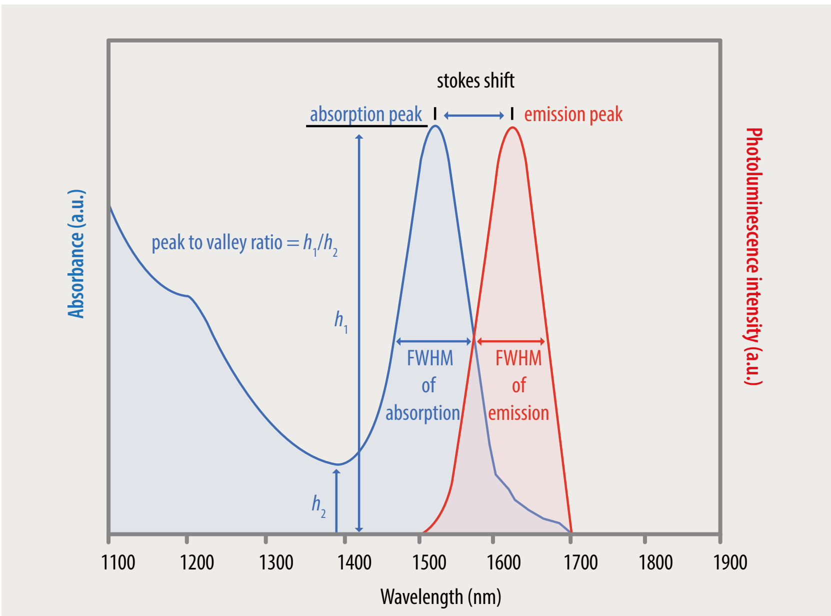

Fig. 3 Important optical parameters in characterizing quantum dot materials

signs monitoring. SWIR light penetrates deeper into the chromophore-rich dermis than the NIR light used in current applications. SWIR wavelengths also improve medical diagnostics, such as optical coherence tomography. This non-contact 3D imaging technique is used to image the retina in the eye and would benefit from the improved penetration depth of SWIR.

The automotive industry is another sector that will see breakthroughs due to quantum dot-based imaging and sensing. In-cabin driver monitoring systems (DMS) that collect visual data on a driver will benefit as SWIR performs better in conditions with sun-glare, specular reflection, and shade patterns, meaning accurate data will always be provided to onboard AI. It could offer a long-sought-after breakthrough in autonomous control too, as part of light detection and ranging (lidar) systems. This in turn could boost advanced driver-assistance systems (ADAS) by giving self-driving cars the visual data they need to process decisions on the road.

For the consumer sector, cost-effective and compact SWIR sensing technology unlocks a host of opportunities. As SWIR light can pass through OLED screens, facial recognition systems can be mounted behind a phone screen, enabling attractive, notch-free smartphone screens.

Other consumer electronics applications such as VR headsets will enjoy SWIR-powered eye tracking, allowing users to wear their headsets for prolonged periods without suffering eye damage. Fitness trackers will be able to provide wearers with detailed information on blood oxygen levels, glucose levels, alcohol, or other important biomarkers. Earbuds can use minute proximity sensors to accurately detect when they are inserted into the ear rather than when stored in a pocket or case.

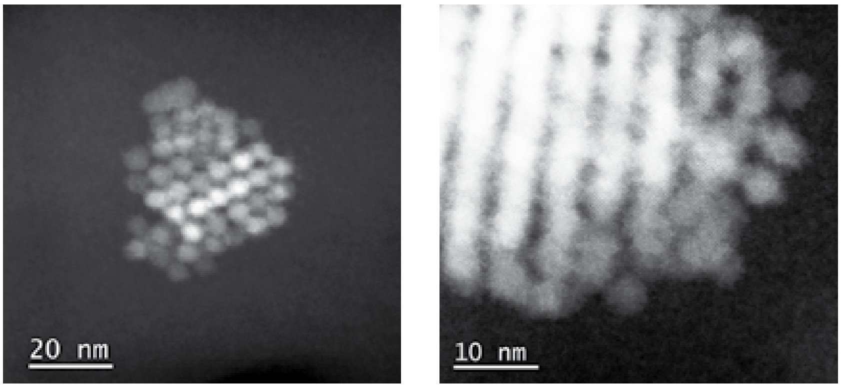

Fig. 4 TEM images of quantum dot inks shown in closely-packed and highly-ordered arrangements

The enhanced machine vision systems of the future could boost manufacturing by using SWIR cameras operating between the 1.7 and 2.2 µm wavelengths to distinguish between different types of plastic, regardless of their color. Silicon's transparency under SWIR light can be exploited in quality control applications by using SWIR sensors to see through silicon wafers to check for otherwise invisible defects.

It is fitting that it is possible to see beyond the visible by utilizing the hidden quantum realm. The potential of this technology is what drives businesses like Quantum Science to overcome the last few hurdles to commercialization to bring the quantum revolution into the lives of billions of people around the world.

DOI: 10.1002/phvs.202200046

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Stuart Stubbs, PhD, is product director at Quantum Science. He has over ten years of experience in managing optoelectronic devices from proof-of-concept through commercialization. Dr Stubbs has 25 patents in quantum dot materials, technology and optoelectronic devices.

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Ultrastable, ultraprecise, portable

How commercial ultrastable laser systems enable high-end optical clock applications

Patrizia Krok & Malcolm Simpson

Source all images: Menlo Systems

In quantum applications such as optical clocks ultrastable laser sources address extremely narrow atomic transitions without introducing noise to the system. This level of stability and precision has historically only been achieved under controlled laboratory conditions. Novel commercial solutions combined with new approaches are now meeting the high demands for field applications of emerging quantum technologies.

▲ Highest stability of the spacer length and lowest losses at the end mirrors are key to ultimate performance of an ultrastable laser optical reference cavity.

The need for laser stabilization

The ability to address ultranarrow linewidth transitions in trapped atomic systems has led to an explosion of scientific research in optical clocks, metrology, and quantum science. Laser sources are readily used to perform complex trapping operations, for example in optical lattice clocks, to cool systems to temperatures close to the quantum mechanical limit in the microkelvin range, to close cooling cycles by repumping out of other states, and to address the narrow clock transitions of interest. While most cooling and repumping transitions may be adequately accessed by kilohertz light sources, the narrow clock transitions with long excited state lifetimes of the order of one second require linewidths less than one Hertz of the interrogating laser. Therefore, an ultrastable light source arguably constitutes one of the most important components of the light-atom system.

The typical linewidth of a stable free running laser system is of the order of a few hundred kilohertz, so reaching the criteria for high-precision spectroscopy requires some method of active frequency stabilization. One way of achieving this is to compare the laser output frequency to a reference and to convert the resulting offset between the two into an electrical signal, which then serves as feedback to the laser control parameters. In more detail, the frequency comparison may be performed by means of a chosen resonance frequency of a stable reference cavity. When modulating the laser frequency across this resonance, a photodiode registers dips (or peaks) in the reflection (or transmission) signal. This gives rise to an error signal slope with a zero crossing at the resonance frequency serving as the locking point of the laser control parameters.

Historically, such cavity stabilized laser systems have been solely employed in controlled laboratory environments and were designed to accommodate standard optical tables. As applications of high precision spectroscopy have proceeded to encompass local systems synchronization, measurements of the gravitational potential in different locations, turnkey quantum computing systems, or positioning systems, the apparatus needs to become much more portable. Recent commercial solutions successfully address this requirement. A careful choice of system components pushes the system performance to the limit, and at the same time ensures a fully portable package.

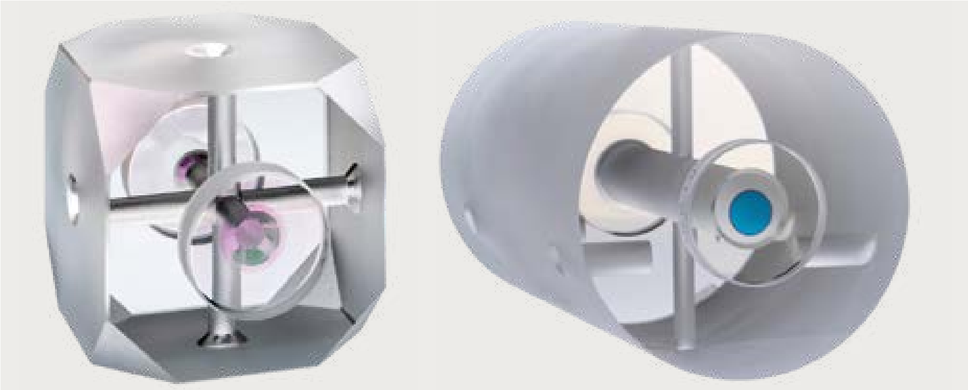

Fig. 1 5-cm cubic Fabry-Pérot cavity (left) and 12.1 cm cylindrical cavity (right), each comprising an ultralow expansion (ULE) glass spacer with optically contacted highly reflective mirrors (external faces antireflection coated).

Commercial ultrastable laser systems

Developing and designing commercial ultrastable lasers bears the challenge of combining several different disciplines, such as laser technology, stabilization electronics, vacuum technology, vibrational and acoustic isolation, software, and even material science. Manufacturer Menlo Systems, Germany, focuses on highest performance in a compact form factor in their cavity-based, ultrastable laser product line.

The optical part of the cavity-based, ultrastable reference laser system comprises a single-mode laser source, the optical reference cavity, and the associated optics and electronics for the implementation of feedback control. A Fabry-Pérot cavity serves as the optical reference and represents the central part of the system. This comprises two mirrors with highly reflective coatings, which are optically contacted onto a spacer. The spacer and the mirror substrate are manufactured from ultralow-expansion (ULE) glass. Its property of vanishing thermal expansion around the so-called zero-crossing temperature prevents changes of the cavity length due to external temperature drift at this working point. The specific case of the zero crossing at room temperature minimizes the effort of thermal stabilization as complex thermal management such as cooling becomes unnecessary. Fused silica mirror substrates, resulting in an even lower thermal noise floor, are combined with ULE compensation rings to ensure the overall zero crossing is still at room temperature. The cavity construction enables the laser light to pass in an ultrahigh vacuum, thereby avoiding disturbing effects on the laser stability from light matter interaction.

Fig. 1 shows the realization of the resonator cavity in two different spacer geometries with end mirrors and recesses for mounting and evacuation. While the shape enables mechanical stability to be optimized, the resonator length has an effect on the bandwidth and the spectral resolution, as expressed in the free spectral range, which describes the frequency separation between neighboring resonant modes:

$$\Delta \nu = \frac{c}{2L}$$

with c being the speed of light in a vacuum and L the cavity length. A longer resonator thus increases the spectral mode density. A measure to maintain sharp lines for unique line separation is the cavity finesse

$$F = \frac{\pi \sqrt{R}}{1 - R}.$$

It is directly related to the reflectivity R of the mirrors and characterizes the overall performance of the cavity. A typical reflectivity of the order of 0.99999 yields a finesse value of >300,000.

The light source of the ultrastable laser system is a single-mode continuous wave (cw) laser, which is actively stabilized to a transmission mode of the reference cavity by using a Pound-Drever-Hall (PDH) locking scheme. Fig. 2 depicts the principle of the PDH feedback loop. An electro-optic modulator (EOM) modulates the phase of the laser light by adding sidebands in the frequency domain. A photodiode (PD) detects the fraction of light reflected

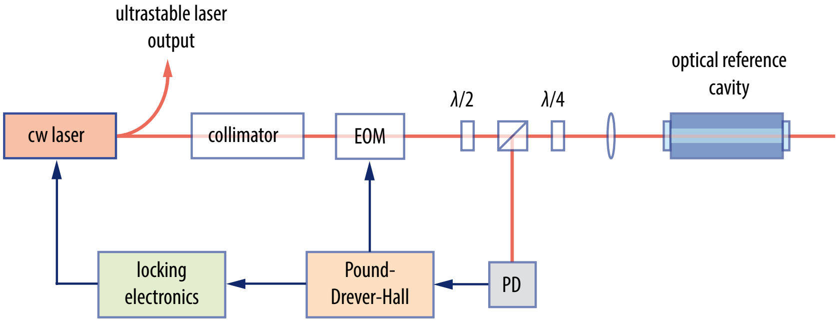

Fig. 2 Principle of operation of an ultrastable laser system. A small fraction of the single mode laser light passes the reference cavity. The reflection off the cavity mirror is measured by photodiode (PD) and the resultant electrical signal converted to an error signal by the Pound-Drever-Hall method for feedback to the single-mode laser.

Company

Menlo Systems

Menlo Systems GmbH is a developer and global supplier of instrumentation for high-precision metrology, providing solutions for science and industry. The company with its headquarters in the west of Munich is known for its Nobel Prize-winning optical frequency comb technology. The main product lines are optical frequency combs, time and frequency distribution, terahertz systems, ultrafast and ultrastable lasers, and control electronics.

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Fig. 3 Vacuum chamber containing the Fabry-Pérot cavity, with ion getter pump and incoupling viewport

from the cavity, delivering a signal that changes with the EOM modulation frequency. Down-mixing with the modulation frequency converts it into a direct current (DC) signal, which serves as fast feedback for the laser current control and slow feedback for the temperature control of the laser.

The fractional frequency stability of the laser locked to the cavity is dominated by the length fluctuations of the cavity. The resonator material and geometry of the cavity are therefore carefully chosen, and the cavity is well isolated from fluctuating ambient conditions, such as changing temperature and pressure. To eliminate mechanical vibrations and acoustic noise, the entire vacuum system containing the cavity and the ion getter pump (Fig. 3) is mounted on an active vibration isolation platform and acoustically shielded by an MDF casing.

Fig. 4 shows Menlo Systems' rack-mounted ORS-Mini, a complete ultrastable laser system including cw laser, optical reference, PDH locking, vacuum system, system stabilization, and system control electronics with touch screen operation. The control unit uses an automated procedure to reach and maintain optimal operation mode, even upon initial system setup.

Ultrastable laser systems provide single-mode laser light with <1 Hz spectral linewidth and fractional stability better than 7×10^{-16} at 1 s sampling time (modified Allan deviation, MADEV). Ageing of the ULE glass substrate, manifesting itself in a slow linear drift of the frequency, is removed by data post processing.

This high level of stability in a commercial ultrastable laser system competes with setups that have been built in research laboratories with a high investment of workforce. It is hardly surprising that the advent of commercial systems restructures those habits since it enables the focus of the research subject to be shifted and propels project advancement. The systems are ideal sources of stable laser light that is capable of addressing ultranarrow resonant atomic transitions, and that is also often used to stabilize other laser systems within a laboratory environment. The latter is achieved by locking an optical frequency comb to the stabilized wavelength, thereby stabilizing each of the comb lines. The comb lines, in turn, serve as a reference for other lasers involved in the specific experiment. Since the technology of both ultrastable lasers and optical frequency combs has matured significantly, it has enabled the combination of the two into complete commercial quantum laser systems. Likewise, as the full range of laser wavelengths required for an atomic physics experiment can be commercially sourced, the significant reduction of R&D effort proves to be a catalyst to the prospering quantum technology sector.

Optical atomic clocks

One of the principal applications of precision spectroscopy is optical lattice clocks. An optical lattice (Fig. 5) is a periodic electromagnetic potential within a standing wave pattern produced by interference between two counter propagating laser beams. In the case of lattice lasers propagating along two orthogonal directions, the lattice can resemble an egg carton in which neutral atoms are confined by the dipole force within the potential. The force is a consequence of the potential gradient that the atom experiences when the laser frequency is detuned from the atom's resonant optical transition. The most promising optical lattice clocks currently operate on the basis of trapped ytterbium or strontium atomic ensembles. For each trapped species, there is a magic wavelength at which the trapping light does not perturb the resonance frequency of the clock transition. Besides optical clocks, such lattice-confined atoms provide the platform for quantum simulations and computation.

The superiority of optical lattice clocks over other trapping schemes is due to the tight confinement of the atoms within the individual lattice sites, leading to a highly efficient suppression of noise induced by the atomic

Fig. 4 Complete rack-mounted, compact ORS ultrastable laser system by Menlo Systems, providing sub-Hertz laser linewidth.

motion. Optical lattice clocks based on strontium have recently been reported to have reduced the instability to 2.1×10^{-18} [1]. However, such highly precise measurements typically require complex laser systems involving cryogenically cooled monocrystalline reference cavities. These devices stabilize the laser linewidth to only a few millihertz, thus increasing the coherence time of the laser-atom system and allowing for long interrogation time of the atoms.

Portable optical clocks

Many quantum applications require the comparison between two or more optical clocks, among them the measurement of minute effects of general relativity such as time dilation between spatially separated clocks, and gravitational wave detection. It is therefore desirable for such clock experiments to maintain their cutting-edge level of performance whilst becoming more mobile and thereby enabling field deployment.

Recently, the comparison between two separate clocks located within one single optical lattice has become one of the most accurate reported to date [2]. Notably, this accomplishment was achieved with a commercially available ORS ultrastable reference. The work presents a milestone that opens the door for field applications of such high precision measurements. The authors of the study loaded atoms into different sites of a vertically oriented one-dimensional optical lattice, with the lattice sites displaced from each other by a distance of about 1 cm. The vertical displacement adds gravity to lift the degeneracy between each neighboring lattice site, thereby eliminating redistribution of the atoms due to quantum tunneling effects. Each atom ensemble contained in the lattice represents a single clock. This is possible since sources of noise common to all ensembles confined within the same optical lattice are eliminated. In particular, due to the high stability of the optical reference, there is no contribution of noise induced by the interrogating clock laser, and only the intrinsic noise due to the atomic motion within the lattice remains. A comparison between the two atomic ensembles yielded a coherence time of 26 s and a relative instability of 8.9×10^{-20} which is among the lowest instabilities ever reported. Such a small instability is equivalent to the two clocks being out of synchronization by just one second in three hundred billion years.

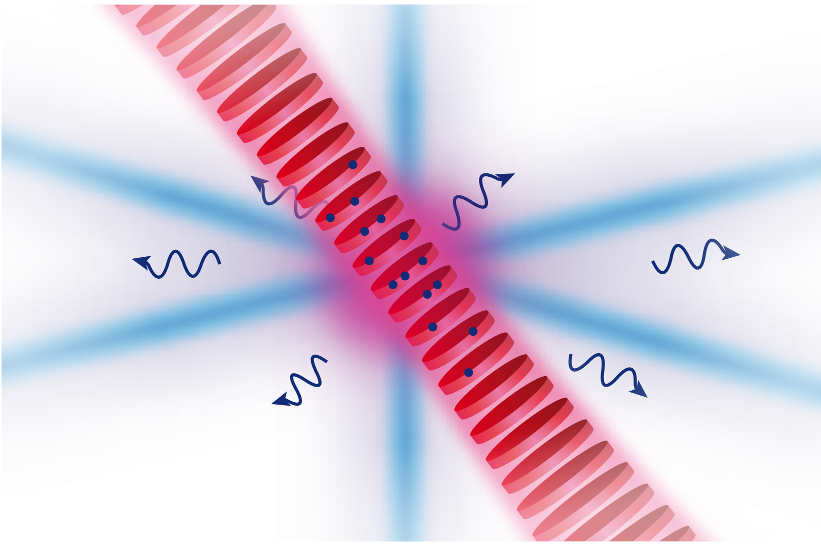

Fig. 5 Artist's impression of atom laser cooling and trapping within a one-dimensional optical lattice.

The fact that such precise measurements can be achieved using a commercially available laser system with sub-Hz linewidth is unprecedented and enables much more compact experimental setups without a loss in performance. Commercial ultrastable laser systems have become true partners in the race to develop new optical clock applications, and also for the dawning quantum age in which numerous startups are pushing to bring turnkey quantum computers to market. The expertise honed in the development of portable ultrastable laser systems is key to pushing forward in this field.

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Laser technology for precise material machining applications

"A trenchant edge" for processing of brittle and hard materials – solid-state picosecond laser technology

Nan Zhang, Lynn Li, and Alexus Yu

Source all images: JPT

▲ Shenzhen JPT Opto-electronics focuses on the development of various laser sources, such as MOPA fiber lasers, DPSS lasers, ultrafast lasers or cw fiber lasers.

In recent years, driven by the need for energy conservation and pollution reduction to develop a sustainable society, the building-integrated photovoltaics (BIPV), centralized photovoltaic power stations and new energy vehicle markets have grown significantly and with that increased the demand for glass that requires more precise micromachining methods.

Transparent and brittle materials, such as glass and sapphire, have been widely used in architecture, consumer electronic products, automobile, solar panel, and others due to their properties of good optical transparency, chemical stability, strong physical strength and electromagnetic interference immunity. Conventional machining methods for brittle materials use a polycrystalline diamond cutter, a grinding wheel or chemicals, which easily introduce external stress that produces surface and sub-surface microcracks, fragmentations, or environmental pollution. Moreover, glass is becoming thinner and thinner, and this in turn adds more difficulties in machining using conventional methods. To overcome this problem, picosecond laser technology that can generate high peak power pulses has attracted a lot of attention.

Laser processing technology focuses the laser beam on the surface of objects, and utilizes the high energy density of the focused spot to gasify or melt the material to be processed. It has the following advantages: (1) non-contact processing, and therefore no reintroduced pollution or damage (2) a small heat-affected area (3) high accuracy, suitable for automation integration (4) good processing flexibility, it can be applied to cut or drill irregular shapes/patterns. With the development of ultrashort pulse and high peak power laser technology in recent years, ultrafast laser processing technology represented by the picosecond laser has shown great potential in improving the glass manufacturing process and improving product properties. This paper will make a systematic introduction about the development of the picosecond laser and the laser machining technology for brittle materials.

Picosecond laser technology

High power picosecond lasers usually consists of a seed source, pre-amplifier and main amplifier modules, which is a master oscillator power amplifier (MOPA) structure. Short wavelength laser output can be generated by a non-linear frequency converting mechanism with crystals.

Firstly, the wavelength of picosecond seed lasers used in industry is usually at 1,064 nm or 1,030 nm. The seed laser source can be realized by the following methods: ytterbium-doped fiber-based mode-locking technology, all-solid crystal mode-locking technology and direct semiconductor laser modulation technology. In recent years, as the passive mode-locking technology has proved its reliability and stability through long-term running, it has become the main technical route for picosecond seed lasers in the market. Commercial passively mode-locked fiber lasers mainly use a semiconductor-saturable absorber mirror (SESAM) [1] or nonlinear loop mirror [2] to serve as a saturable absorber. Seed lasers with a SESAM-based linear cavity have the advantage of high consistency, high reliability and good self-starting probability, but it has the problem of a short single-point lifetime. A long lifetime can be received by automatic point change on the SESAM-based plate. There are no vulnerable devices in the nonlinear loop cavity so that its lifetime can be guaranteed, but the realization of 100 % self-starting will need the help of special circuit design.

Secondly, there are a few ways to build the main amplifier of industrial high-power picosecond lasers, such as with rod crystals, disks, Innoslab, and photonic crystal fibers. It has been reported that the laser output power amplified with fiber-based coherent combination [3], disk [4] and Innoslab [5] has exceeded one kilowatt. At present, the mainstream high power, infrared, picosecond lasers have an output power in the range of 100 – 400 W, but usually working in burst mode (pulse string within an envelope), and the maximum single pulse energy is between hundreds of microjoules and one millijoule. It is a great challenge to further improve the power.

The picosecond laser with a disk amplifier structure has the capability of generating high average power and good beam quality output. However, since the gain length of a single pass through the thin disk is too short, a complicated multi-pass cavity is needed, and the stability of the laser output therefore relies

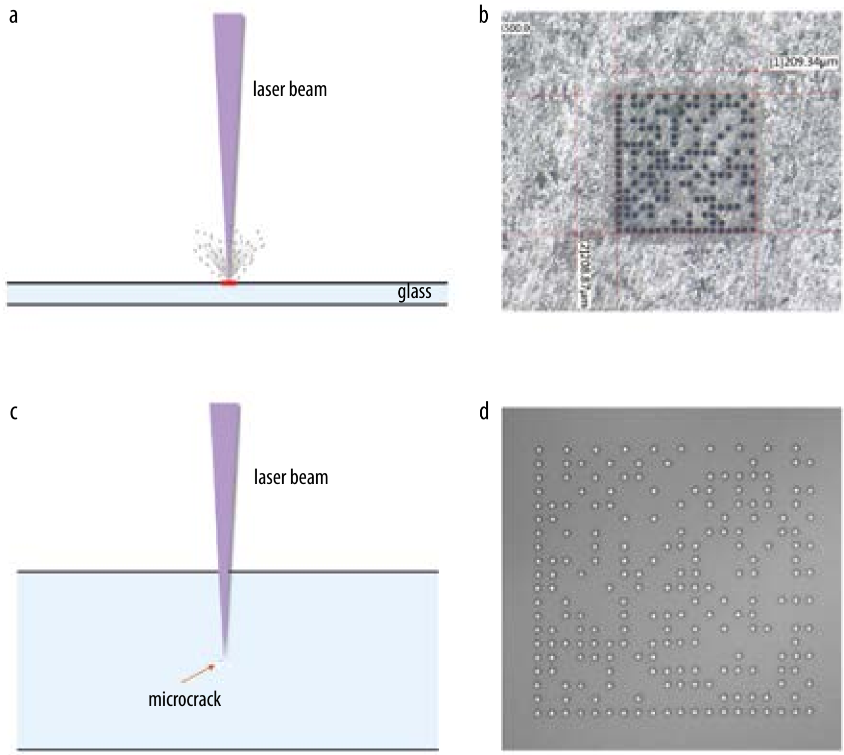

Fig. 1 (a) laser focused on the surface of the material, (b) QR code marked on the glass surface, (c) laser focused on the inner layer of glass, (d) microscopic image of sub-surface laser marking.

highly on its mechanical robustness and, unavoidably, it is easily affected by circumstantial vibration.

The picosecond lasers with an Innoslab amplifier also show high power and good beam quality output capabilities because of their large cooling surface. Good reliability of 100–200 W average power output has been demonstrated in the industrial field, but long-term operation at higher power output (e.g. 500–1000 W) is full of challenges.

As for the photonic crystal fiber amplifier, as the output power increases, the heat accumulates, which will result in degradation of the beam quality, and the long-term operation reliability of the high power output remains to be verified. Above all, the ultrahigh average power, good performance and high reliability picosecond laser still needs further technical research.

Thirdly, for short wavelengths such as ultraviolet picosecond lasers, output frequency converting technology is used to convert the near-infrared output beam to a green or ultraviolet beam. The ultraviolet picosecond laser with high-efficiency and a long lifetime depends greatly on the advanced growth and surface treatment technology of non-linear optical crystals. Due to the design requirements of walk-off angle and module, the commercial laser mostly uses lithium triborate crystal (LBO). A few institutes/companies are involved in research on LBO crystal such as CrystaLaser in the US, the physics and chemical institute of the Chinese Academy of Science, the Fujian Institute of Research on the structure and Castech in China. Research on increasing the laser damage threshold of optical thin films on crystals is being done by Sandia National Labs and Gamdan Optics in the US, the Laser Zentrum Hannover in Germany, the Shanghai

Company

Shenzhen JPT Opto-Electronics

Registered in 2006, JPT concentrates on the R&D, production, sales, and technology service of optical fiber devices, lasers and laser intelligent equipment.

Based on laser technology, JPT integrates leading technologies such as laser and optics, test and measurement, motion control and automation, and machine vision. The company highly valued intellectual property and has applied for more than 600 patents.

JPT ranks: top 1 of MOPA pulsed fiber lasers globally, top 3 of fiber laser manufacturers in China.

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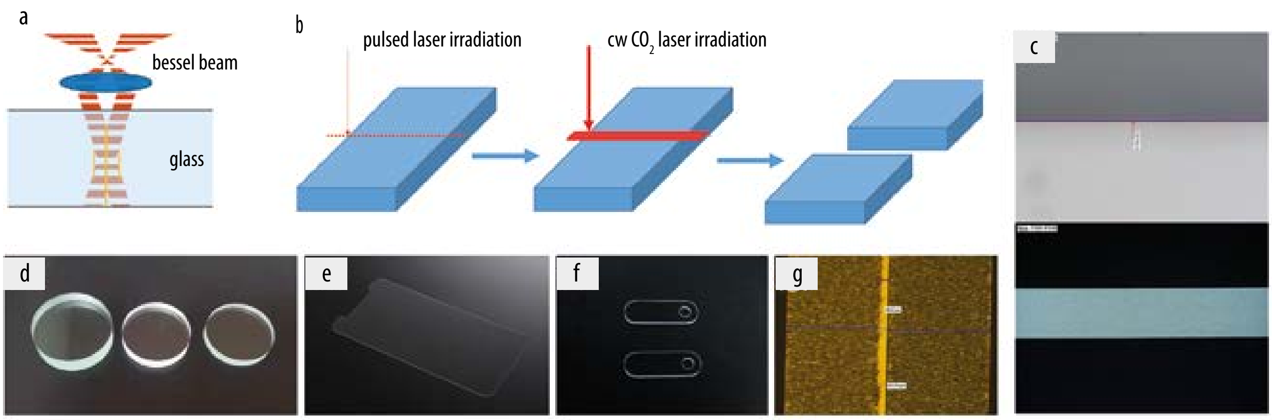

Fig. 2 (a) Schematic diagram of a Bessel beam, (b) schematic diagram of the cutting and splitting process of brittle material by an ultrafast laser, (c) cross-sectional microscopic images, (d) circular cutting of thick glass, (e, f) special-shaped cutting of cover glass and camera, (g) laser cutting of double laminated glass

Institute of Optics and Fine Mechanics, the Changchun Institute of Optics and Fine Mechanics and others, of which the Shanghai Institute of Optics and Fine Mechanics used atomic layer deposition technology to produce an HfO_2/SiO_2 antireflection layer for 355 nm wavelength. The measured reflectivity of the film layer at 355 nm is lower than 0.2 %, and the laser damage threshold reaches 24.4 J / cm^2 (at a pulse width of 7.8 ns) [6].

Picosecond laser for processing of brittle and hard materials

The application of picosecond laser technology in the processing of brittle materials covers QR code marking for information tracing, cutting, drilling, and surface layer removal.

1. QR code marking for information tracing

There are mainly two kinds of laser marking: surface engraving and subsurface laser marking. Surface engraving focuses the laser beam on the glass surface as shown in Fig. 1a. When the laser energy density exceeds the material damage threshold, the surface material instantly gasifies, and the target pattern is formed by controlling the movement path of the laser beam. Surface marking using a picosecond laser can not only avoid thermal deformation of the material, but can also greatly reduce the interior stress because of the small heat accumulation during processing. The pattern engraved using a laser beam has the advantages of (1) abrasion resistance: it does not fade when exposed to environmental influences (touch, temperature, etc.); (2) anticounterfeiting: the engraved pattern is not easy to imitate or change, so it is capable of being used for anticounterfeiting. For example, when we mark the QR code in a way that even without any obvious touch feeling, we can still observe the code points very clearly under a microscope as shown in Fig. 1b. Picosecond lasers have also been widely used for information tracing on semiconductor chips.

Glass subsurface marking is shown in Fig. 1c, d: When the laser beam is focused on the inner layer of glass, the laser pulse with high energy density produces microcracks in the order of micrometers to millimeters, which appear a different color compared to unprocessed areas due to the scattering of light. The ideal pattern is marked/engraved similarly by controlling the laser path in the interior of the glass.

2. Laser cutting

Laser processing technology has been used in the cutting and separation of transparent brittle materials. Depending on the different cutting mechanisms, laser cutting methods for brittle materials can be divided into laser scribing and breaking method, laser thermal stress cutting method, laser filamentation method and the Bessel beam cutting method, and so on.

The laser scribing and breaking method is similar to the traditional mechanical method, which separates the object with the help of external force following laser scribing on the material, so the cutting quality is not fine enough, and the sharp edge still needs to be polished. The laser thermal stress cutting method relies mainly on the heating effect of laser beam, then a proper temperature gradient formed on or within the material surface with a cooling system. This will result in hot tensile stress, and when it exceeds the proper tensile strength threshold, microcracks will appear on or under the material surface and expand along the direction of laser movement, so the glass is cut.

The laser filamentation method is mainly applied with ultrafast lasers. When the laser energy density is larger than a certain threshold, it can achieve a dynamic balance between the nonlinear self-focusing effect and plasma defocusing effect, and the light beam will not obviously diverge and will spread several times longer than the distance of the Rayleigh length, keeping almost the same beam diameter in the medium. If using this effect for glass separation, the application scenario is limited and difficult to control.

Bessel beams, known as 'non-diffracting beams', have a transverse light field distribution that does not vary along the propagation of the beam, and the main lobe diameter can be as small as a few micrometers, but the focal depth can reach several millimeters, as shown in Fig. 2a. Taking advantage of the characteristic of Bessel beam, it is easy to separate the glass at the laser-modified section by adding only a slight external force or thermal stress gradient (as shown in Fig. 2b). For example, for laser cutting of high aluminum cover glass we use a solid infrared picosecond laser with a Bessel cutting head to achieve glass cutting. The Bessel laser head moves along the cutting line and pulses are controlled in position-synchronized output (PSO) mode. After cutting, a CO_2 laser beam (thermal stress) or mechanical stress is applied to the cutting line to separate the brit-

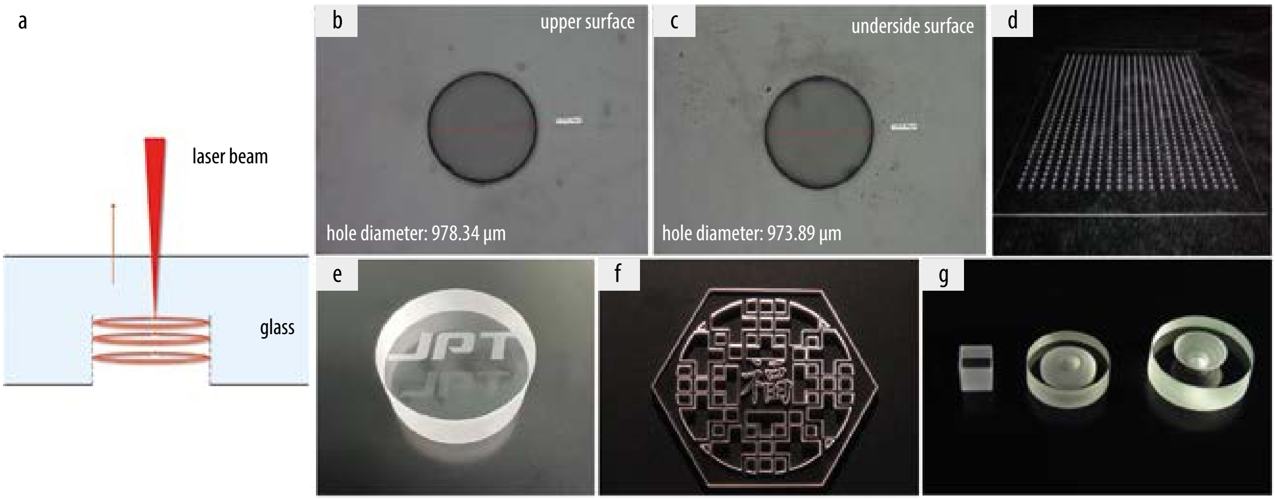

Fig. 3 (a) Schematic diagram of drilling with laser from bottom to up, the thin red arrow indicates the moving direction of the laser beam scanning route. (b, c) Microscopic images of 1-mm aperture hole drilled by laser on the substrate glass; (d – g) are the images of laser drilling samples, including through-holes and blind holes.

tle object. In this method, the cutting positioning can be of high accuracy, and whole process can be time-saving. As shown in Fig. 2c, the cover glass has a smooth cutting edge, and the chipping area can be controlled within 10 μm without debris. At present, this cutting technology is widely used in glass substrate, glass cover, display panel, camera and precision cutting of other electronic glass products (Figs. 2d – f), and this can be extended into photovoltaic glass and other industries. Bessel beam cutting is the most widely used cutting method with high precision, high quality and high efficiency.

3. Laser drilling

Laser through-hole drilling is shown in Fig. 3a. The laser beam focuses on the underside of the surface of the material through the glass, and the material is gasified. Then the laser beam rises in spirals, scanning layer by layer from the bottom up to the upper surface of the glass. As for the opaque material can only be drilled from top to bottom, the gasified material flowing on the surface easily absorbs the laser energy to generate plasma, thus reducing the processing efficiency and producing a tapered through-hole with a large entrance and a small exit. The bottom-up drilling method for transparent glass avoids the surface plasma masking effect, and achieves high processing efficiency and a small through-hole taper.

Compared with mechanical drilling, laser glass drilling has the advantages of being contactless, using no consumables, with an arbitrary shape cutting capability, and no pollution. For example, using an infrared picosecond laser to drill a 1 mm aperture hole on the substrate glass, the glass chipping edge is observed to be within 30 μm with a microscope, as shown in Figs. 3b, c. Other laser drilling samples are shown in Figs. 3d – g.

In addition to the glass used in 3C products, the market demand for glass back for solar panels is dramatically increasing, parallel to the development of the photovoltaic industry. The back glass generally needs to have three holes, some of them may be irregularly-shaped, which is not easily achieved by the traditional mechanical punch drilling method due to low efficiency and poor quality. At present, fiber lasers are being used to drill photovoltaic glass. Picosecond lasers combined with chemical wet etching can also produce microholes with a large deep-width ratio without cracks.

4. Surface layer removal

Laser surface layer removal mainly uses a high-energy laser beam to quickly gasify or strip the surface layer. Normally, we would select a laser wavelength which shows a higher absorption rate for the layer to be removed than that of the base substrate. Meanwhile, the laser energy density is adjusted to be above the damage threshold of removal layer but avoiding causing damage to the substrate under the layer. The traditional methods of film removal include mechanical grinding, chemical corrosion and others, which have inevitable shortcomings such as poor accuracy, easy damage to the glass substrate or causing environmental issues. For example, driven by the demand of energy saving and emission reduction, low-e glass shows a high growth trend in China, and lasers are also being introduced to remove the dielectric film layer or heat insulation films in specific areas on windshields or sunroof, as shown in Fig. 4b. Also, it is used for the selective removal of passivation/insulation layers on semiconductor materials.

In addition to the above applications, industrial-grade picosecond lasers have also been widely used in semiconductor wafer processing, display panel cutting, perovskite film scribing and other industries. With the further improvement of laser pulse energy, average power and stability, they will make further progress to realize high-precision and high-efficiency laser processing in new energy lithium batteries, the photovoltaic silicon industry, the military, and aerospace science and technology.

Shenzhen JPT Opto-electronics focuses on the development of laser sources, its JPT-PS-IR series industrial grade infrared picosecond laser, based on MOPA structure and rubidium-doped yttrium vanadate crystal, can achieve 2 mJ pulse energy output. JPT's industrial grade green picosecond laser can achieve 50 W output average power, and the UV picosecond laser can achieve an average power output of more than 30 W, and these parameters can meet the above-mentioned processing requirements. JPT has accumulated rich experience in the application fields of brittle materials processing, FPC circuit board cutting, medical stainless steel surface modification and others. In addition, the company engages in

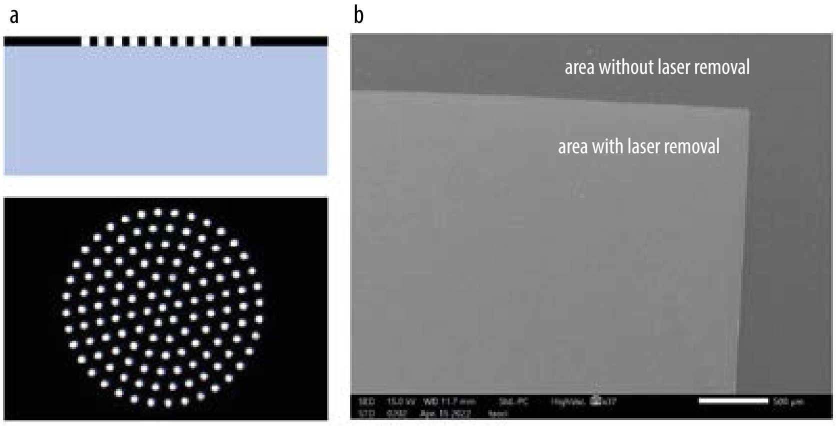

Fig. 4 (a) Glass deco removal with UV picosecond laser, black color indicates the deco layer. (b) Scanning electron microscope image of functional thin film removal on glasses

large R&D investment for picosecond, femtosecond mode-locking technology, femtosecond chirp pulse amplification technology and high power, high energy density laser products, which are expected to create new laser application fields under the premise of meeting high-precision processing requirements, and promote the further improvement of laser processing efficiency.

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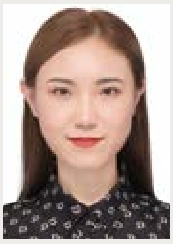
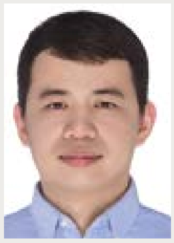


Lynn Li is a senior project assistant at Shenzhen JPT Opto-electronics. She obtained her master degree from Huazhong University of Science and Technology in China. Her research focus lies on developing laser processing technology for silicon solar panels, perovskite film solar cells, and brittle materials.



Alexus Yu, chief engineer at Shenzhen JPT Opto-electronics, received his PhD degree from Nanyang Technological University in Singapore. He is in charge of the research and development of solid-state picosecond lasers and optical parameter amplifiers.

Dr. Nan Zhang, Lynn Li, Dr. Alexus Yu, Shenzhen JPT Opto-electronics Co. Ltd., 1201, Bldg. A, Kemron S&T Park, Guanlan Hi-tech Industrial Area, Longhua Dist., Shenzhen, China, 518110; phone: +86 15737838036, fax: +86 755 29528-185; e-mail: zhangnan@jptoe.com, sales@jptoe.com, Web: www.jptoe.com

CAPABILITIES GUIDE

CUSTOM MANUFACTURING from PROTOTYPE to PRODUCTION

Global Design & Manufacturing Facilities
page 3

Manufacturing Capabilities for Custom & Off-the-Shelf Optics
pages 4-15

Design, Rapid Prototyping, Volume Support & Other Services
pages 16-22

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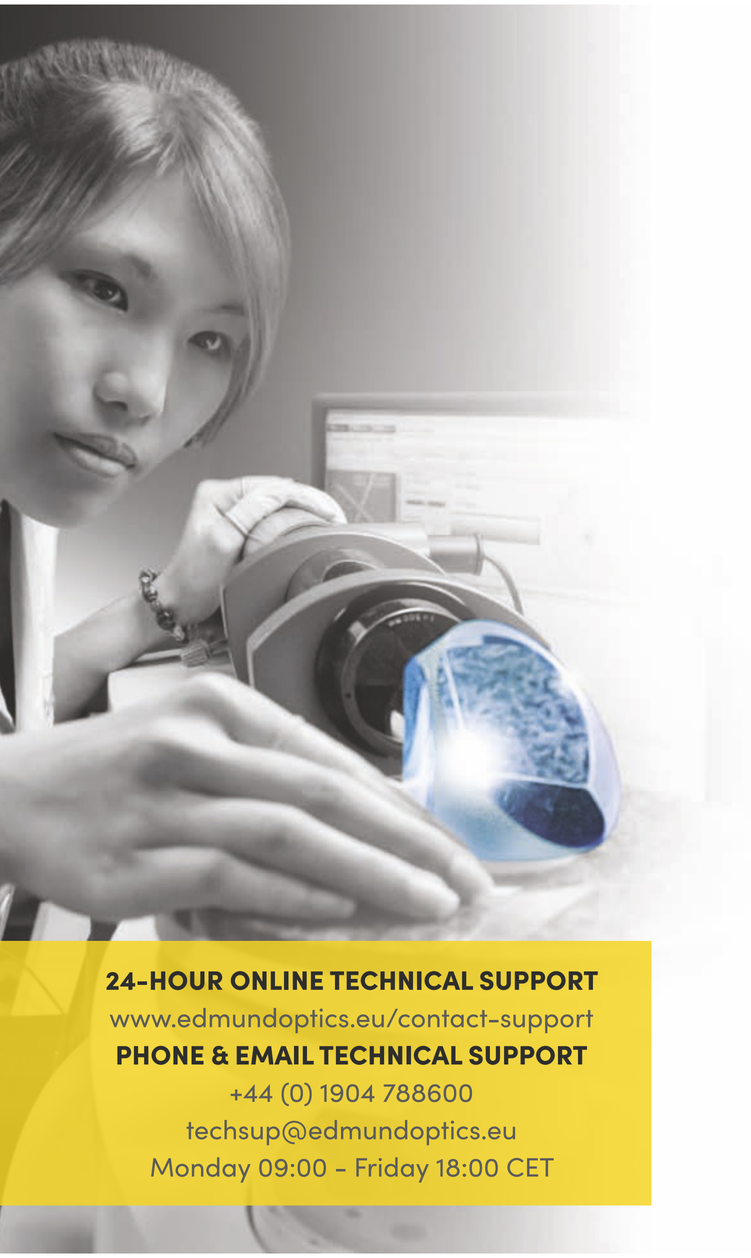

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VOTED **#1**
PREFERRED SUPPLIER
of optical components
13 years in a row.

Also ranked best in industry
Technical Support | **Product Variety**
Customer Service | **Competitive Pricing**
Lead Times | **Product Performance**

- October 2020 Readex Research Survey

WHO IS EDMUND OPTICS®?

The Future Depends on Optics® and the world-changing innovations they enable. Edmund Optics® (EO) has contributed to this innovation by manufacturing and suppling industries across the globe with precision optical components and subassemblies for more than **80 years**.

Whether you need off-the-shelf optics for rapid prototyping or cost-effective custom components for volume production, we have the capabilities and engineering expertise to meet your specifications, timelines, and budgets. Our engineers create tailored solutions for unique optical challenges through expert application support, both build-to-print and completely-custom design, and a world-class quality and metrology program. Every step of the way, Edmund Optics® is committed to ensuring product and procedural quality.

We are a family-owned business with over 1.200 employees in 12 countries around the world, and we look forward to working with you!

Warm regards,

Marisa Edmund, Chairman of the Board and Chief Marketing & Sales Officer

Contact Us for Confidential Application Support!

- Phone, Email, and Online Chat Contact Methods – Get Engineering Assistance Your Way!
- Dedicated Global Technical Support Team
- Quick Non-Disclosure Agreement (NDA) and Confidential Disclosure Agreement (CDA) Process

Leverage the Wealth of Technical Content on our Website!

- Over 157.000 Downloadable Documents and Drawings
  - 2D & 3D Drawings
  - Prescription Files
  - Coating Curves and More!
- Over 1.400 videos, Tech Tools, Application Notes, Articles, and FAQs in Our Online Knowledge Center

WHY EDMUND OPTICS®?

With over **80 years in business** and **8 global manufacturing facilities**, EO's promise to customers is:

MORE OPTICS, MORE TECHNOLOGY,
AND MORE SERVICE.

Optical Manufacturing

- Custom and volume manufacturer of quality optical and imaging products

Engineering Services

- Provider of prototyping services, optical consulting, and design

Marketplace

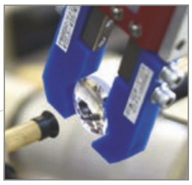
- One-stop-shop for the best brands and products in optics and photonics

GLOBAL MANUFACTURING FACILITIES

Edmund Optics® manufactures and supplies customers around the glo with millions of precision optical components and optical assembli Whether stock, modified standard, or custom, we have the expertise a resources necessary to manufacture optical products based on your pr ect's specific requirements. Our dedicated and skilled team members w ensure that you receive the optimal solution for your application, while c quality assurance teams guarantee the best final products. In the last fe years, we have added three new global manufacturing facilities.

SCAN HERE
to watch a video about our
key manufacturing facilities.

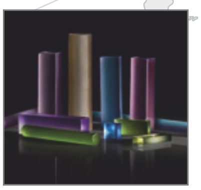
GLOBAL DESIGN & MANUFACTURING



Akita, Japan
80.000 sq. ft. (7.430 m²) of manufacturing space. High precision spherical lenses, prisms, and other coated optics with over 50 years of experience

Shenzhen, China
16.140 sq. ft. (1.500 m²) of manufacturing space. On-site design, assembly, and testing of high volume optomechanical and imaging assemblies

Arizona, USA
Tucson Design & Manufacturing Centers
21.225 sq. ft. (1.972 m²) of combined facilities for advanced, high-volume assembly of optical systems, along with a separate Tucson design center

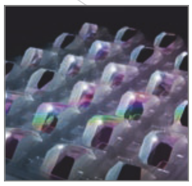


Florida, USA
34.000 sq. ft. (3.159 m²) facility manufacturing high laser damage coatings, laser crystals, and other high-precision laser optics

New Jersey, USA
Corporate Headquarters
120.000 sq. ft. (11.150 m²); 20.000 sq. ft. (1.860 m²) of dedicated manufacturing space. High precision fabrication, coating, assembly, and testing cells

Mainz, Germany
EO Germany Design & Manufacturing
7.060 sq. ft. (660 m²) European manufacturing base for polarizers and colored filter glass and home for European Optical Design service

Singapore
77.000 sq. ft. (7.150 m²) of manufacturing space. Highly vertically integrated facility for volume production of spherical and aspheric lenses, prisms, and other coated and mounted optics



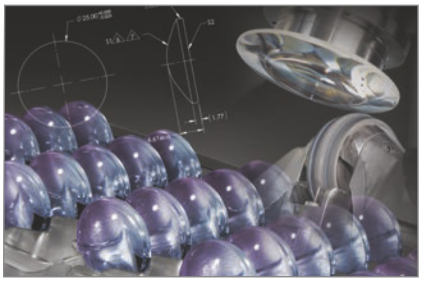
Malaysia
16.140 sq. ft. (1.500 m²) of manufacturing space. Supports Singapore facility in volume production of spherical lenses and prisms

For more detailed **MANUFACTURING CAPABILITIES**, visit **www.edmundoptics.eu/manufacturing**

DID YOU KNOW?

Manufacturing by the Numbers
2.000.000 Optical Components Each Year
170.000 Optical Assemblies Each Year

OVERVIEW OF **MANUFACTURING** CAPABILITIES



CUSTOM COMPONENTS

Edmund Optics® takes customers from prototype to volume production and specialize in creating cost-effective solutions that meet their specifications, timelines, and budgets.

- Lenses, Mirrors, Prisms, Beamsplitters, Filters, and More
- Build-to-Print Manufacturing
- Competitive Volume Pricing
- Global Manufacturing Facilities

CUSTOM ASSEMBLIES

The expert team of Edmund Optics® optical and optomechanical designers, project managers, and manufacturing engineers create a wide variety of different types of optomechanical assemblies.

- Imaging Lenses, Laser Beam Expanders, Microscope Objectives, and More
- Environmental Ruggedization for Shock & Vibration, Moisture, and Athermalization
- Global Assembly Facilities

QUALITY CONTROL AND METROLOGY

Every step of the way, Edmund Optics® is committed to ensuring product and procedural quality and has a proven track record of tailored testing for optical assemblies customized to project requirements.

- State-of-the-Art In-Process Metrology And Quality Management
- ISO 9001 Certified and ISO 10110 Compliant with MIL-SPEC Quality Programs
- Thorough Preventative and Corrective Action Procedures

POLISHED ASPHERIC LENSES

- Manufacturing in US and Singapore
- Stock and Custom, from Design and Prototype to Volume Production
- Build-to-Print Capabilities
- Over 700 Aspheric Lens Designs Available for Delivery
- MRF Fine Finishing Consistently Exceeding λ/40 Surface Accuracy and State-of-the-Art Metrology

Edmund Optics® is a recognized leader in aspheric lens manufacturing, with extensive experience producing polished aspheres for a broad variety of applications ranging from life science systems such as ophthalmic instruments and surgical devices, to industrial laser equipment, to metrology and analytical instruments, to defense applications. Edmund Optics®' high volume aspheric lens manufacturing cell operates 24 hours a day to produce thousands of precision aspheric lenses per month. Our manufacturing cells feature state-of-the-art production and metrology equipment, which complements our expert knowledge in aspheric lens design and manufacturing.

Whether your application calls for a standard component from our vast inventory, a build-to-print lens, or a fully customized design effort, our expert optical design and manufacturing engineers can develop solutions to meet your needs.

Aspheric Manufacturing Capabilities — *1/10th wave at 632,8 nm, limited by design and/or metrology

	Commercial	Precision	High Precision
Diameter:	10 - 200 mm	10 - 200 mm	10 - 150 mm
Diameter Tolerance:	+0/-0,100 mm	+0/-0,025	+0/-0,010
Asphere Figure Error (P - V):	3 µm	1 µm	<0,06 µm
Sag:	25 mm max	25 mm max	25 mm max
Typical Slope Error:	1 µm per 1mm window	0,35 µm per 1 mm window	0,15 µm per 1 mm window
Centering (Beam Deviation):	3 arcmin	1 arcmin	0,5 arcmin
Center Thickness Tolerance:	±0,100 mm	±0,050 mm	±0,010 mm
Surface Quality (Scratch Dig):	80-50	40-20	10-5
Aspheric Surface Metrology:	Profilometry (2D)	Profilometry (2D & 3D)	Interferometry

MANUFACTURING EQUIPMENT

- 5-Axis CNC Grinding Machines
- 5-Axis CNC Polishing Machines
- QED MRF Finishing Machines for Fine Finishing
- Centering Machines

METROLOGY

- Talysurf PGI 1240 Profilometers
- QED ASI™ Aspheric Stitching Interferometers
- Zygo® NewView White Light Interferometers
- OptiPro UltraSurf 4X 100 Non-Contact Profilometers
- TRIOPTICS Opticentric® Centration Measurement Machines
- Zeiss Contura G2 CMMs
- Design-Specific Computer Generated Holograms (CGH)
- LUPHOScan 260 HD

For more information on **ASPHERIC LENSES**, visit **www.edmundoptics.eu/capabilities/aspheric-manufacturing**

SPHERICAL LENSES

SCAN HERE
to compare the **performance of different lens geometries**.

- Manufacturing Redundancy in Multiple Factories Across US, Singapore, and Japan
- Prototype Through High Volume Production Capabilities
- Large Variety of SCHOTT, Ohara, and CDGM Glass Types in Stock
- Build-to-Print Capabilities
- Standard and Custom Coating Options Available

Spherical Manufacturing Capabilities

	Commercial	Precision	High Precision
Diameter:	4 - 200 mm	4 - 200 mm	4 - 200 mm
Diameter Tolerance:	+0/-0,100 mm	+0/-0,025 mm	+0/-0,010 mm
Thickness:	±0,100 mm	±0,050 mm	±0,010 mm
Sag Height:	±0,050 mm	±0,025 mm	±0,010 mm
Clear Aperture:	80%	90%	90%
Radius:	±0,3%	±0,1%	Fix to Test Plate
Power (P - V):	3,0 λ	1,5 λ	λ/2
Irregularity (P - V):	1,0 λ	λ/4	λ/40
Centering (Beam Deviation):	3 arcmin	1 arcmin	0,5 arcmin
Bevel (Face Width @ 45°):	<1,0 mm	<0,5 mm	<0,25 mm
Surface Quality:	80-50	40-20	10-5

OPTICAL PRISMS

SCAN HERE
to learn about **different prism types and applications**.

- Stock or Custom, from Design and Prototype to Volume Production
- Wide Assortment of Prism Shapes In Stock
- Build-to-Print Capabilities
- Available in Many Glass Types with a Variety of Standard and Custom Coatings

Optical Prism Manufacturing Capabilities

	Commercial	Precision	High Precision
Dimensions:	2 - 200 mm	2 - 150 mm	2 - 75 mm
Dimensional Tolerance:	+0/-0,2 mm	+0/-0,1 mm	+0/-0,01 mm
V-Height:	±0,25 mm	±0,1 mm	±0,03 mm
Irregularity:	1,0λ	λ/4	λ/20
Prism Physical Angle Tolerance:	±3 arcmin	±1 arcmin	45° & 90° ±0,5 arcsec
Penta Prism Deviation:	±5 arcmin	±3 arcmin	±0,5 arcsec
Max Bevel (Face Width @ 45°):	±0,5 mm	±0,3 mm	±0,05 mm
Surface Quality (Scratch Dig):	80-50	40-20	10-5
Bonded Prism Assembly Beam Deviation:	5 arcmin	3 arcmin	0,5 arcmin
Pyramid Tolerance:	±5 arcmin	±3 arcmin	±0,5 arcmin

HARD-COATED OPTICAL FILTERS

- Wavelength Ranges from 193 nm to 12,4 µm
- 960 Standard Filter Coating Designs
- Custom Design, Manufacturing, and Testing Offered
- Laser-Line Designs Available for Ultrafast and Other Laser Systems

Hard-Coated Optical Filter Capabilities

	Filters for Fluorescence / Life Science Applications		Hard Coated Bandpass Filters			High-Precision Edge Filters		
Types of Filters:	Fluorescence Bandpass Filters	Fluorescence Dichroic Filters	Narrow Bandpass Filters	Medium Bandpass Filters	Broad Bandpass Filters	Shortpass Filters	Longpass Filters	Dichroic Filters
Typical Specifications:	Transmission ≥95%		Transmission ≥95%			Transmission ≥95%		
	Blocking ≥OD6,0	Reflection ≥98%	Blocking ≥OD4,0			Blocking ≥OD4,0		Reflection ≥98%
	Bandwidths between 10 - 80 nm	Transmitted Wavefront Distortion (TWD) ≤λ/4	Bandwidths between 5 and 20 nm	Bandwidths between 25 and 50 nm	Bandwidths ≥50 nm	Slope Factor ≤1%		Transmitted Wavefront Distortion (TWD) ≤λ/4
	Environmental Durability per MIL-STD-810H		Environmental Durability per MIL-STD-810H			Environmental Durability per MIL-STD-810H		
	Physical Durability per MIL-C-48497A		Physical Durability per MIL-C-48497A			Physical Durability per MIL-C-48497A		

*Capabilities for notch filters, neutral density filters, and machine vision filters available online at **www.edmundoptics.eu/filter-coatings**

ABSORPTIVE OPTICAL FILTER GLASS

- >60 SCHOTT Optical Filter Glass Types in Stock
- Online Tool for Quick Quotes of Custom Filter Glass at **www.edmundoptics.eu/tools/opticalfilterglass**
- Build-to-Print Manufacturing and Full-Custom Design
- Rapid Turnaround for Prototypes

Optical Filter Glass Manufacturing Capabilities

	Commercial	High Precision
Dimensions:	5 - 50 mm	3 - 160 mm
Dimensional Tolerances:	±0,2 mm	±0,05 mm
Thickness:	1, 2 , or 3 mm	0,5 - 4,0 mm
Thickness Tolerances:	±0,1 mm	±0,05 mm
Surface Finish*:	P2	P2 - P3
Surface Quality (Scratch-Dig):	80-50	20-10
Flatness:	2-3 λ	λ/4
Neutral Density:	0,15 - 5,0 OD	
Geometry:	Round, Elliptical, and Rectangular	
Filter Glass Type:	Longpass, Shortpass, Bandpass, Neutral Density, and Combinations of Multiple Glasses	

* Specifications per DIN ISO 10110. Manufacturing specifications per MIL-PRF-13830B also available.

BEAMSPLITTERS

SCAN HERE
to watch a recorded webinar about **different types of beamsplitters** and **tips for maximizing your application's performance**.

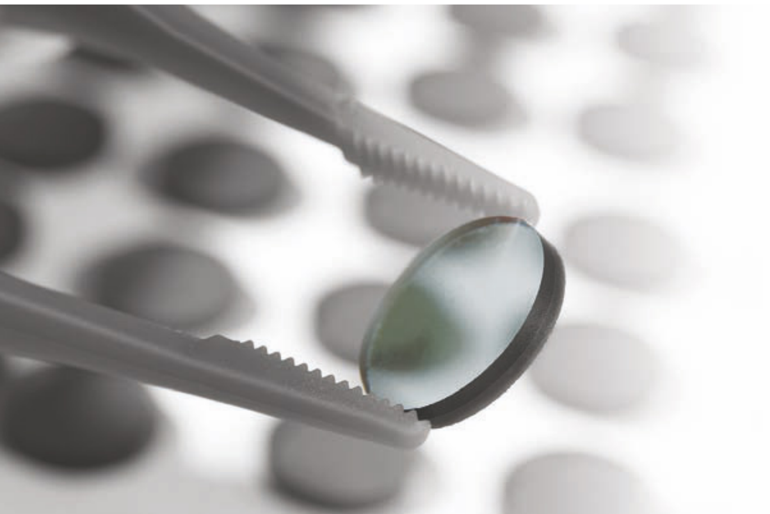
- Wide Variety of Beamsplitter Types Including Polarizing, Non-Polarizing, and Laser Line
- Customized Solutions for Prototype to Volume Production
- Design & Application Expertise for Complex Coating and Geometry Needs

Beamsplitter Manufacturing Capabilities

	Commercial	Precision	High Precision
Dimensional Tolerance:	±0,15 mm	±0,08	±0,04
Dimensions:	5 - 75 mm	5 - 75 mm	5 - 75 mm
Irregularity (or Flatness):	1,0 λ	λ/8	λ/20
Surface Quality (Scratch Dig):	80-50	40-20	10-5
Max Bevel (Face Width @ 45°):	±0,5 mm	±0,3 mm	±0,05 mm
Beam Deviation:	±5 arcmin	±3 arcmin	±0,5 arcmin
|Ts - Tp| (Broadband Non-Polarizing):	<10%	<8%	<6%
|Ts - Tp| (Laser Line Non-Polarizing):	<6%	<3%	<2%
R/T Splitting Ratios (Non-Polarizing):	30/70 to 90/10	30/70 to 90/10	30/70 to 90/10
R/T Splitting Ratio Tolerance:	±15%	±10%	±5%
Extinction Ratio (Polarizing):	100:1	500:1	> 1000:1
Wavelength Range:	400 - 1620 nm	400 - 1620 nm	350 - 1620 nm

* Some values may depend on material and the other required specifications

POLYMER POLARIZERS



SCAN HERE
to learn about **polarization** and **how to manipulate it for different applications**.

- Wide Range of Polymer Polarizers for Visible Applications
- Custom Sizes and Shapes for Linear and Circular Polarizers, and Retarders
- Lamination on Glass or Plastic Substrates for Improved Stability
- Online Tool for Quick Quotes of Custom Polarizers and Retarders at **www.edmundoptics.eu/tools/polarizers**

Linear Polarizer Manufacturing Capabilities*

Specifications:	Linear Polarizing Film	PMMA Laminated	Glass Laminated	Wire-Grid Polarizing Film
Dimensions:	3 x 3 mm - 600 x 1000 mm	3 x 3 mm - 600 x 900 mm	6 x 6 mm - 250 x 250 mm	3 x 3 mm - 240 x 80 mm
Diameter:	3 - 600 mm	3 - 600 mm	6 - 250 mm	3 - 80 mm
Dimensional Tolerance:	According to DIN ISO 2768-1m/c			
Thickness:	0,18 - 1,00 mm	1,00 - 3,00 mm	2,00 - 3,50 mm	0,08 mm
Transmission:	Up to 44%			85%
Extinction Ratio:	Up to 1:30.000			1:4.250

*For specifications for circular polarizers and retarders, visit **www.edmundoptics.eu/capabilities/polarizers**

MIRRORS

- Wide Variety of Metallic and Dielectric Coatings
- High Laser Damage Threshold (LDT) and Ultra-High Reflectivity Options
- Standard or Custom, from Design and Prototype to Volume Production
- Superpolishing Capabilities for Surface Roughness Down to 0,5Å

SCAN HERE
to learn about
metallic mirror coatings.

Mirror Manufacturing Capabilities			
	Commercial	Precision	High Precision
Dimensions:	2,5 - 406,4 mm		
Dimensional Tolerance:	±0,25 mm	±0,1 mm	±0,05
Flatness:	4-6 λ	λ/10	λ/20
Surface Quality (Scratch Dig):	80-50	40-20	10-5
Coating Options:	Metallic, Broadband Dielectric, and Dielectric Laser V-Coats		
Reflectivity (Non-Laser):	85-99,98%		
Wavelength Range Covered:	13,5 nm - >40 µm		
Group Delay Dispersion (GDD) Range:	-4000 - 5000 fs^2		
Substrate Options:	Metals, Glass, and Ceramics		
Geometries:	Flat, Elliptical, Spherical, and Parabolic		

DIAMOND TURNING

- Metals, Crystalline Materials, and Plastics
- Off-Axis Parabolic, Elliptical, and Toroidal Mirrors, Aspheric and Spherical Lenses, and Flatwork
- Build-to-Print Manufacturing and Full-Custom Design
- Wide Range of Coating Options

SCAN HERE
to watch a video about
diamond turning
at Edmund Optics®.

Diamond Turning Capabilities	*Exact values are dependent on the specific material and size		
	Commercial	Precision	High Precision
Reflected Wavefront Error (P - V @ 632 nm):	λ	λ/2	λ/8
Surface Quality:	80-50	60-40	40-20
Surface Roughness (RMS) Metals*:	150 Å	100 Å	<30 Å
Surface Roughness (RMS): Crystalline Materials and Plastics	<50 Å for Diameters 6,25 - 200 mm		
Geometries:	Off-Axis Parabolas, Off-Axis Ellipses, Off-Axis Toroids, Spherical Surfaces, Aspheric Surfaces, and Planar Surfaces		
Angles:	0 - 90°		
Diameter (Off-Axis):	2 - 254 mm		
Diameter (On-Axis):	8 - 254 mm		
Coatings:	Uncoated, Aluminum, UV Enhanced Aluminum, Protected Gold, Bare Gold, Protected Silver, Anti-Reflection, and Custom (upon request)		
Materials:	Metals (Aluminum, Copper, Brass, and Nickel-Plated Surfaces), Crystalline Materials (Germanium, Silicon, Calcium Fluoride, and Zinc Selenide), and Plastic (Acrylic and Zeonex)		

SCAN HERE
to watch a video about
how an EO imaging lens is made.

- Full Custom Lens Design for Your Specific Needs
- Designs for Newest Technology Trends Including Stability Ruggedized Lenses, Integrated Liquid Lenses, and Ultra-High Resolutions (100+ MP)
- M12, C-Mount, Factory Automation, Telecentric Lenses, & More
- Global In-Region Engineering Support & Service
- Volume Manufacturing & Designs Optimized for Integration

The expert team of Edmund Optics® optical and optomechanical designers, project managers, and manufacturing engineers seamlessly support our customers from the ground-up and at each step of the project journey. From product design and prototyping, to scale-up and volume production, we are proud to deliver award-winning and innovative imaging lenses designed for the most demanding and cutting-edge applications.

Imaging Lens Assembly Capabilities

	Fixed Focal Length Lenses	Telecentric Measuring Lenses	Fixed Magnification Lenses
Sensor Sizes:	Up to 43,3 mm	Up to 43,3 mm	Up to 90 mm
Resolution:	Up to 120 MegaPixels	Up to 32 MegaPixels	Up to 16k Line Scan
Field of View:	>105°	Up to 242 mm	0,2 mm - 186 mm
Lens Mounts:	C-Mount, TFL-Mount, TFL-II Mount, F-Mount, S-Mount, M42	C-Mount, F-Mount, M42	C-Mount, F-Mount, M42, M72

RUGGEDIZED IMAGING LENSES FOR HARSH ENVIRONMENTS

- Stability Ruggedized Lenses with Streamlined Mechanics and Lens Elements Glued in Place to Protect from Shock and Vibration
- Ingress Protected Lenses Sealed from Moisture that Meet IEC Ratings of IPX7 and IPX9K
- Athermal Lenses that Maintain Performance Over Wide Temperature Ranges
- Industrial Ruggedized Lenses with Streamlined Mechanics for OEM Integration

METROLOGY

- MTF & Resolution Testing
- Zygo® VeriFire™, QED ASI, & Other Interferometers
- Coordinate Measurement Machines (CMM)
- Zygo® NewView™ Optical Profiler
- OptiPro UltraSurf 4X 100 Metrology Systems
- Bespoke Testbeds
- T-Number
- Telecentricity & Distortion
- Relative Illumination

EDMUND OPTICS® Innovation Summits

SCAN HERE
Learn all about **building better imaging systems** in our Edmund Optics® Innovation Summit virtual event series.

For more information on **IMAGING ASSEMBLIES**, visit **www.edmundoptics.eu/capabilities/imaging-lens-assemblies**

- Internal Volume Coating Capabilities from 248 nm to >40 µm
- Custom Coating Design from UV to LWIR Spectral Ranges
- Well-Established Partners Covering Selective UV Ranges From 4,1 nm to 157 nm
- Anti-Reflective, Highly-Reflective, Filter, Polarizing, Beamsplitter, and Metallic Designs
- High Laser Damage Threshold (LDT) and Ultrafast Laser Coatings

Optical coatings are a critical portion of the finished optical component or assembly. Accurate optical coating design and production can mean the difference between the component failing in the field or lasting for the intended lifetime of the project. Edmund Optics® has extensive coating capabilities, and expertise in producing coatings for life science applications and medical devices, harsh environment imaging assemblies, and applications throughout the ultraviolet (UV), visible (VIS), and infrared (IR) spectral regions. All optics are meticulously cleaned, coated, and inspected in a clean room environment, and subjected to the environmental, thermal, and durability requirements specified by our customers.

ION BEAM SPUTTERED (IBS) COATINGS

- Highly-Repeatable Coatings Offering Sharp Spectral Transitions
- Less Affected by Environmental Factors, Including Temperature and Humidity
- Ideal for Hard-Coated Optical Filters and High-Precision Laser Optics

Optical Coating Capabilities	
Dimensions (Diameter or Square):	2 - 1000 mm
Reflectivity:	0,1 - 99,98%
Anti-Reflective Wavelength Range:	248 - 12.000 nm
Highly-Reflective Wavelength Range:	13,5 - >40.000 nm
Group Delay Dispersion (GDD) Range:	-4000 - 1600 fs²
Longpass Filter Cut-On Wavelength:	240 - 7300 nm
Bandpass Filter CWL, OD, and Bandwidth:	193 - 10.600 nm, >OD 7, 1 nm - Broadband
Notch Filter CWL:	355 - 1064 nm
Reflective ND Filter OD:	OD 0,1 - OD 3
Filter Center Wavelength (CWL) Tolerance:	±1 nm
Filter Edge Tolerance:	<1% Deviation, <0,2% Special Cases
Beamsplitter (BS) Wavelength Range:	240 - 20.000 nm
BS Polarization Extinction Ratio (S:P):	10.000:1
Laser-Induced Damage Threshold (LIDT):	>40 J/cm² @ 1064 nm @ 20 ns @ 20 Hz Pulses, Measured
Durability:	MIL-PRF-13830B APP C, PARA C.3.8.4, PARA C.3.8.5, MIL-C-48497A

MANUFACTURING EQUIPMENT

- E-Beam Deposition
- Ion-Assisted Deposition
- Advanced Plasma Source (APS)
- Ion Beam Sputtering (IBS)
- Thermal Evaporation
- High-Precision Optical Monitoring
- Hard Coatings for Stringent Environments and Durability
- Automated Ultrasonic Cleaning

METROLOGY

- Spectrophotometers - Agilent Cary, Hitachi, PerkinElmer LAMBDA, PerkinElmer FTIR, Varian, Essent Optics, and Photo RT
- In-House Laser Damage Threshold Testing (LDT)
- UltraFast Innovations White Light Interferometers for Group Delay Dispersion Testing
- Olympus MX51 DIC Microscopes
- Filmetrics F20 Thin Film Analyzer
- ZYGO NewView 9000 for Surface Roughness Metrology
- Cavity Ring-Down Spectroscopy for High Reflectivities
- Environmental Test Chambers: Temperature, Humidity, Salt Spray
- Automated Abrasion Tester for Durability
- Atomic Force Microscopy (AFM)
- Photothermal Common-Path Interferometry

For more information on **OPTICAL COATINGS**, visit **www.edmundoptics.eu/coatings**

SCAN HERE
to watch a video about **metrology for laser optics manufacturing**.

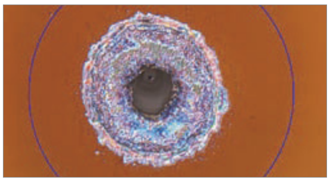
- In-House Manufacturing of Laser Optics Components and Assemblies
- State-of-the-Art Metrology Utilized to Consistently Meet Specifications
- Standard Off-the-Shelf Components Ready to Ship Today
- Fully Custom Design and Manufacturing for Prototyping through Volume Production

Edmund Optics® high-precision laser optics manufacturing is supported by a host of in-house metrology including a laser damage threshold (LDT) testing lab. Whether you need high LDT coatings, tightly-toleranced laser optics substrates, optical components, or laser assemblies, we have the expertise and state-of-the-art equipment to make and measure the laser optics required for your application.

METROLOGY: IF YOU CAN'T MEASURE IT, YOU CAN'T MAKE IT

Spectrophotometry
Used to characterize reflective and transmissive spectral performance. Large spectral measurement range of 120 nm - 20 μm.

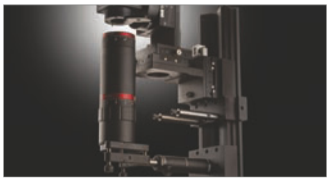
Interferometry
Highest accuracy transmitted and reflected wavefront measurements down to <λ/20



LDT Testing
Testing both in-house and outsourced for guaranteed laser damage threshold (LDT) or laser-induced damage threshold (LIDT)

Cavity Ring-Down Spectroscopy
Loss measurement sensitive enough for reflectivities of 99,9xxx% at 1064, 532, and 355 nm

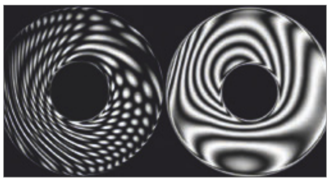
White Light Interferometry
Accurately measure group delay dispersion (GDD) of multilayer ultrafast optics from 250 nm to 2400 nm



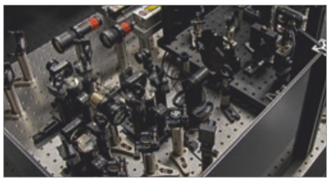
Shack-Hartmann Wavefront Sensors
Transmitted and reflected wavefront measurements down to λ/10 from 266 nm to 1100 nm

Differential Interference Contrast (DIC) Microscopy
High sensitivity defect detection in transmissive materials up to magnifications of 100X

Atomic Force Microscopy (AFM)
High accuracy characterizations of surface roughness and feature sizes and locations

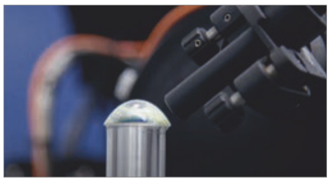


Short Coherence Length Interferometry
Special LED source used to measure parallel, flat surfaces while minimizing reflections from back surfaces



Photothermal Common-Path Interferometry
Accurately measure absorption for better characterization of the spectral properties of optical coatings and substrates

Coordinate Measuring Machines (CMMs)
Measure mechanical dimensions of optical components

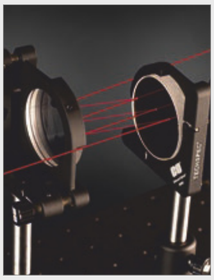


Non-Contact 3D Profilometry
Verify surface profile of precision aspheric lenses

For more information on **LASER OPTICS**, visit **www.edmundoptics.eu/LO**

- Laser Mirrors, Windows, Lenses, Filters, Crystals, Beamsplitters, and Prisms
- Complex E-Beam Coatings: High LDT, Multi-Band Anti-Reflective or Highly-Reflective
- Ion Beam Sputtered (IBS) Coatings for Low Loss
- UV, Visible, NIR, SWIR, MWIR, and LWIR Spectral Ranges
- Designs for Common Laser Sources as Well as Uncommon Tunable Lasers
- Ultrafast Coatings for Group Delay Dispersion Values from -4000 – 5000 fs^2

ULTRAFAST LASER OPTICS



- Highly-Dispersive Mirrors, Low Group Delay Dispersion (GDD) Optics, and Beam Expanders
- White Light Interferometry and Cavity Ring Down Spectroscopy for Guaranteed GDD and Reflectivity
- Internal Manufacturing and Strategic Partners Including UltraFast Innovations GmbH

SUPERPOLISHING

- Minimize Scatter with Ultra-Low RMS Surface Roughness <1Å
- Parts-per-Million Level Scattering
- Supported by State-of-the-Art Metrology Including Atomic Force Microscopy and White Light Interferometry

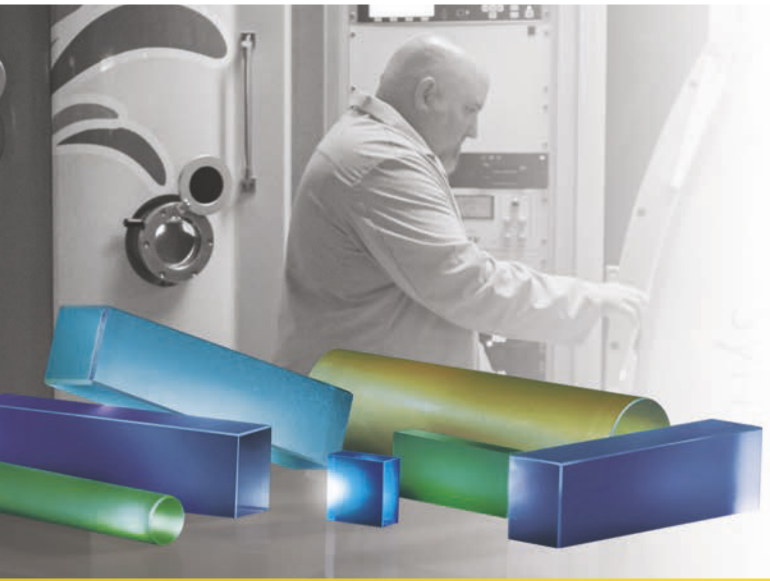
LASER OPTICS ASSEMBLIES

- Beam Expanders, Focusing Objectives, and Other Laser Optics Assemblies
- Laser Line and Broadband Coatings from 257 nm to 3 µm
- Low Group Delay Dispersion (GDD) Designs for Ultrafast Systems, Including Reflective Designs
- High-Power Assemblies with No Issues from Internally-Focusing Ghost Images
- Build-to-Print Capabilities

Beam Expander Capabilities	
Expansion Power:	1X - 20X
Design Wavelengths:	Common Laser Lines Including Nd:YAG, Yb:YAG, Ti:sapphire, and Tm/Ho-Doped Fiber Lasers, Broadband
Mounts:	C-Mount, M22, M30, Custom
Focusing Mechanisms Available:	Sliding Optics, Rotating Optics, Fixed Focus
Ruggedization Available:	Athermalization, Shock and Vibration, Sealing from Contaminants
Testing/Design Specifications:	Transmitted Wavefront Error, Power in the Bucket / Energy on Target, Focused Spot Size
Assembly Size:	From Handheld, to Vehicle-Mounted, to Large Stationary Systems

SCAN HERE
to learn about
laser beam expanders.

For more information on **LASER OPTICS**, visit **www.edmundoptics.eu/LO**



SCAN HERE
to watch **how laser crystals are polished and coated** in the Florida Laser Optics Center.

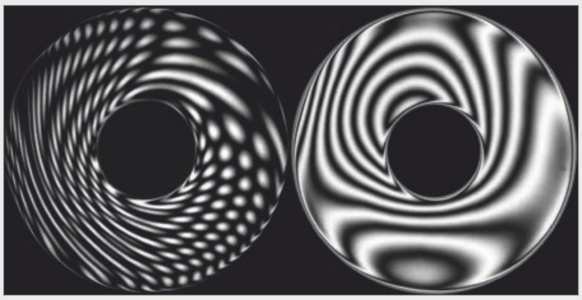
EDMUND OPTICS® FLORIDA LASER OPTICS CENTER

- Dedicated Laser Optics Manufacturing Center of Excellence
- High Laser Damage Threshold (LDT) Coating Options Covering 248 nm to 12 μm
- Laser Crystal Cutting, Polishing, and Coating

Edmund Optics® has acquired Quality Thin Films (QTF), a leader in the industry offering a wide range of optical components with high laser damage threshold (LDT) and laser crystal coatings from the ultraviolet to the far infrared. This acquisition allows Edmund Optics to expand its laser optics manufacturing capabilities across crystal and glass fabrication, polishing, metrology, high laser damage threshold and diamond-like carbon coatings, inspection, and testing. The Florida Laser Optics Center's 34.000 sq. ft ($3.159\ m^2$) facility, located outside of Tampa, FL, is home to approximately 30 employees, many of whom are laser optics experts.

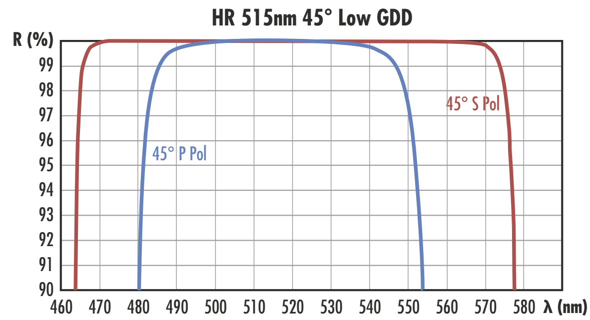
FEATURED METROLOGY: SHORT COHERENCE LENGTH INTERFEROMETRY

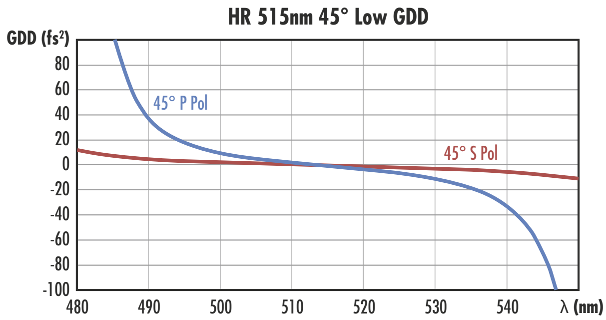
Short coherence length interferometers using specialized LEDs as their light source are able to measure parallel, flat surfaces without noise from light reflecting off of the back surface (*right*), while conventional laser-based interferometers will be affected by this noise (*left*). This is particularly useful for thin substrates with stress compensating coatings on the backside. Image from InterOptics LLC.



COMPLEX OPTICAL COATINGS

- Design and Deposition of Optical Coatings for Both Catalog and Custom Laser Optics
- Complex Coatings Including Multi-Band Anti-Reflective or Highly-Reflective E-beam Coatings
- High LDTs and Control of Group Delay Dispersion (GDD) for Ultrafast Applications



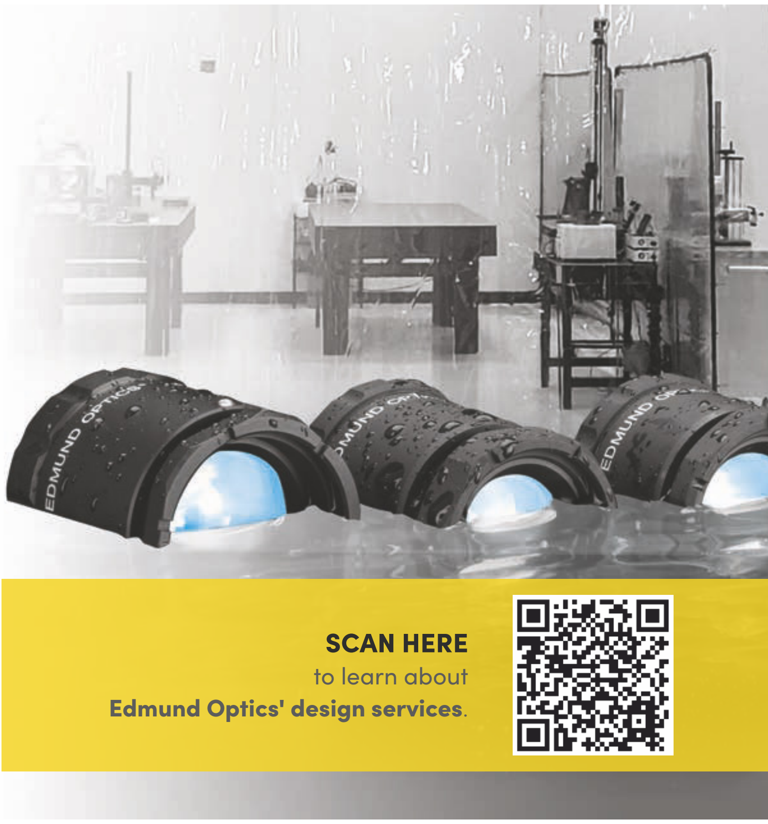


For more information on **THIS FACILITY**, visit **www.edmundoptics.eu/QTF**

EDMUND OPTICS® TUCSON ASSEMBLY AND ADVANCED DESIGN FACILITY

- Advanced Design and High-Volume Manufacturing Services
- Commercial and ITAR-Compliant Facility
- Cleanroom Assembly and Advanced Testing for MTF, Stray Light, Thermal Cycling, Shock and Vibration, and More
- Advanced Assemblies Requiring Active Alignment, Electronics Integration, and/or Environmental Ruggedization

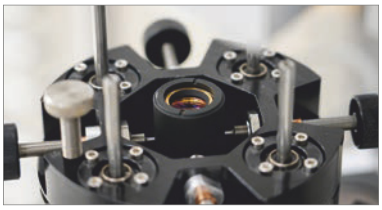
Edmund Optics® now operates a second facility in Tucson, Arizona. This location offers Assembly and Advanced Design services. The 22.284 sq. ft (2.070 m²) facility includes ISO Class 6 cleanrooms for assembly, ISO Class 7 cleanrooms for incoming inspection, and numerous testing capabilities such as modulation transfer function (MTF), straylight, laser beam profiling, thermal cycle, shock, and vibration. Our skilled team of optical assembly technicians has extensive experience with high-performance systems in cleanroom facilities. Customers now have access to more sophisticated commercial and ITAR compliant offerings at a new location on the US West Coast. With this new facility, Edmund Optics strengthens a globally diversified supply chain that lowers risk for customers.



SCAN HERE
to learn about
Edmund Optics' design services.

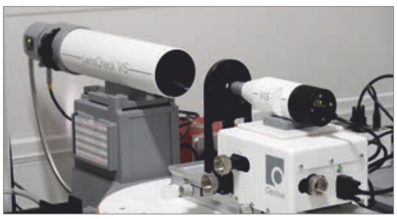
PRECISION OPTICAL ASSEMBLIES AND SYSTEMS

- Imaging Lens Assemblies
- Beam Delivery Systems
- Telescopes
- Microscopes



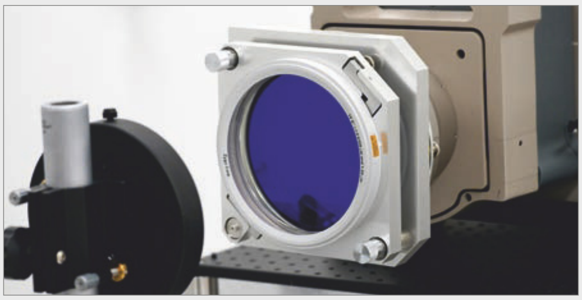
AREAS OF EXPERTISE

- Transfer from Concept to Volume Manufacturing
- Rapid Prototyping
- Cleanroom Assembly
- Testing and Certification

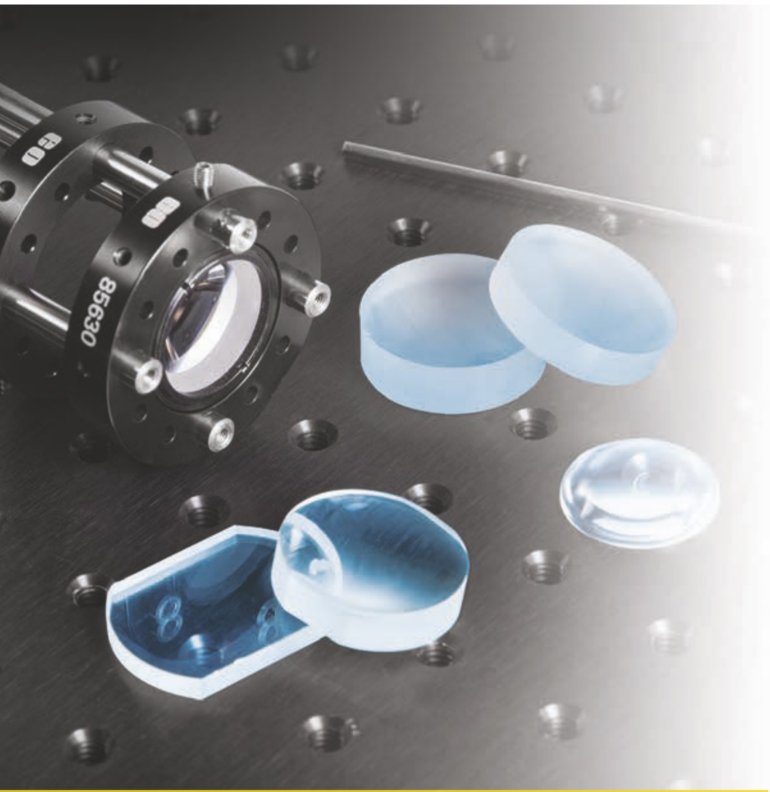


SPECIALIZED TESTING INCLUDES:

- Modulation Transfer Function (MTF)
- Wavefront
- Environmental Ruggedization
- Stray Light
- Laser Beam Profiling
- High-Precision Mechanical Tolerances
- Development of Application-Specific Tests



For more information on **THIS FACILITY**, visit **www.edmundoptics.eu/tucson-assembly**



SCAN HERE
to learn more about our
modified standard program.

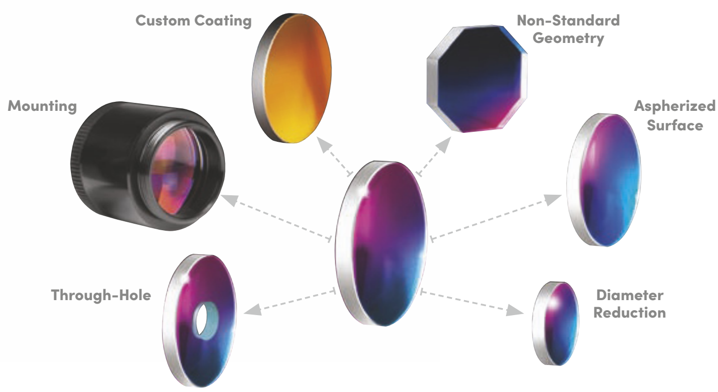
CUSTOMIZED OPTICS IN **2-3 WEEKS**

When developing a product, being able to quickly and easily iterate your prototypes is critical.

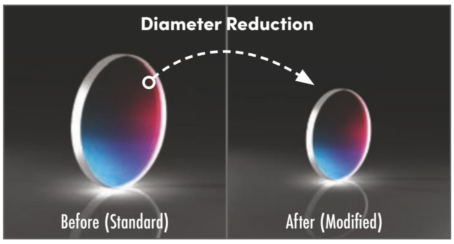
In addition to our immediately available inventory of over 34.000 standard optics, quick "modified standard" customizations are available in just **2-3 weeks**, simplifying the path to production.

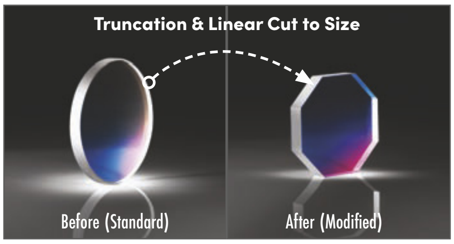
Our modification services include: customizing the size, shape, and edges of standard optics; improving the surface figure or accuracy of the optical surface; sorting; mounting; kitting; inspection; and more! Find an achromat that has everything you need, but it's just a little too big? We can edge it down for you. What about that mirror that you need in a non-standard size? We can cut it for you. Looking for a customized inspection report? We can measure it for you.

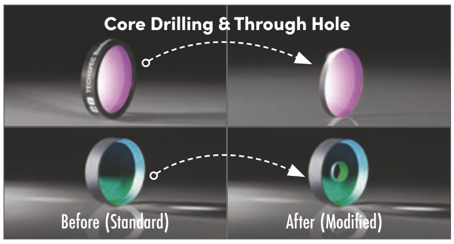
One Standard Optic = Infinite Possibilities

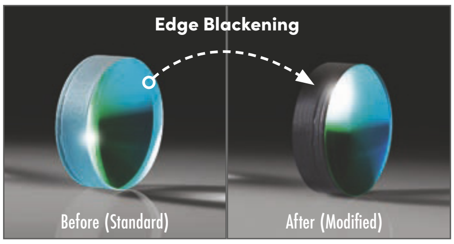


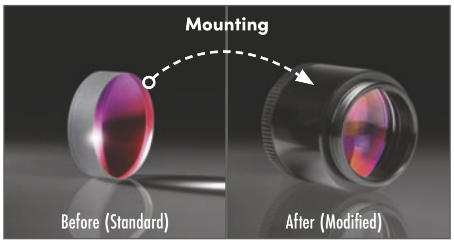
MODIFICATION SERVICES OFFERED

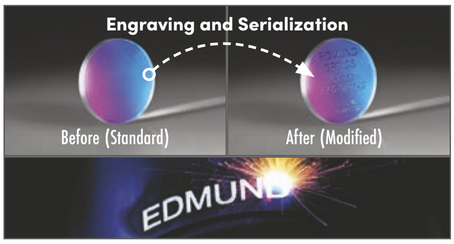












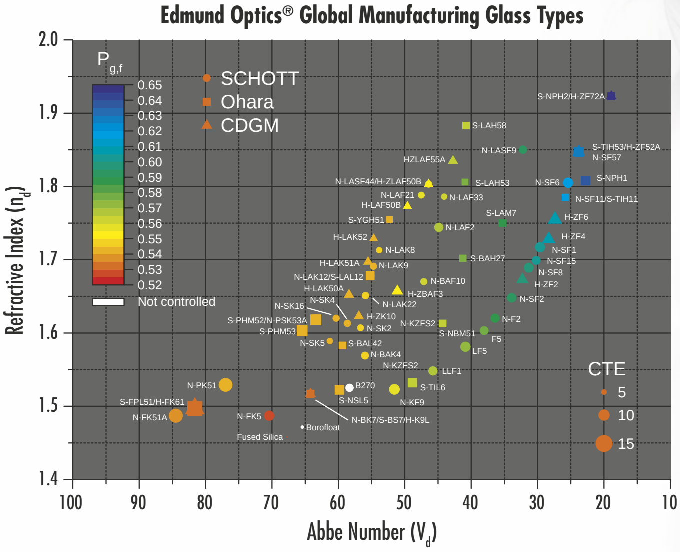
WHAT CAN WE MAKE FOR YOU? Learn more at **www.edmundoptics.eu/modify**

FULL CUSTOM FAST!

If off-the-shelf or modified standard components do not meet your prototyping needs, you can utilize our fully-custom prototyping capabilities to obtain custom glass components in a matter of days to a maximum of a few weeks.

Edmund Optics® maintains an inventory of over 70 of the most common optical glass types at all manufacturing sites. Using these materials reduces lead time of raw materials and facilitates quick prototyping.

Edmund Optics® Global Manufacturing Glass Types



Glass map indicating the Refractive Index (n_d), Abbe Number (V_d), Coefficient of Thermal Expansion (CTE), and Relative Partial Dispersion ($P_{g,f}$).

SCAN HERE
to download **Edmund Optics' global manufacturing glass types chart**.

13 CREATIVE "HACKS" FOR **RAPID PROTOTYPING**

While every application has its own timelines, credentials, and specifications, there are several techniques that may be commonly utilized to decrease the amount of time required for prototyping. Below are several of the 13 creative “hacks” that can be used to quickly and efficiently make prototypes of optical sub-systems:

#1 – Go monochromatic to reduce element count and complexity

#2 – Approximate custom "best-form" elements with available standard singlets

#3 – Flip imaging lenses to use them as objectives

#4 – Customize compound assemblies with standard optics

#5 – Utilize inner diameter threaded prototyping tubes

SCAN HERE
to watch
our video.

For **FULL GLASS and ZEMAX GLASS CATALOGS**, visit **www.edmundoptics.eu/preferred-glass**

VOLUME AND OEM SUPPORT

Edmund Optics® manufactures and supplies customers around the globe with millions of precision optical components and optical assemblies. Whether standard, modified standard, or custom, we have the expertise and resources necessary to manufacture optical products based on your project's specific requirements. Our dedicated and skilled team members ensure that you receive the optimal solution for your application, while our quality assurance teams guarantee the best final products.

Additional Requirements? We've Got You Covered!

- Highly Flexible Volume Order Servicing
- Support Blanket Orders and Other Stocking Agreements
- Competitive Volume Discounts
- Well Versed in Configuration Control, Change Control, and Copy Exact Requirements
- Seamless Federal Acquisition Regulation (FAR), Defense Federal Acquisition Regulation (DFAR), Quality Assurance Provision (QAP), and Testing Requirement Flow-Downs
- ITAR Registered and Compliant; Defense Priorities and Allocations System (DPAS) Servicing and Support
- Global Supply Chain Network with Global Warehousing – Quickly and Easily Supporting Your Projects Wherever You Prefer
- Comprehensive First Article Inspection Reports (FAIR) for Product Qualification

DID YOU KNOW?

Edmund Optics® manufactures **over 2 million optical components** and **170.000 optical assemblies every year** at our global facilities.

DEDICATED **SUPPORT TEAMS** FOR YOUR NEEDS

All customers with volume orders receive a dedicated support team to ensure their products are manufactured and specified to meet their needs, deadlines are kept, and a specified point of contact for general or technical questions is assigned. The support team consists of a project manager, solutions engineer, OEM sales representative, and regional sales manager.

SAMPLE DEDICATED SUPPORT TEAM

Engineering Team

Your assistance for questions along our standard and customized products including imaging, components, assemblies, and more, bringing your project to success.

Solutions Engineer

Your technical resource for your custom optics requirements provides suggestions on cost-effective and manufacturable optics specifications.

Sales & Applications Engineers

Dedicated to your region the Sales & Applications Engineer gives technical support and helps with general services like order status and delivery schedules.

Regional Sales Manager

Your dedicated account manager provides on-site support and capability knowledge to develop and grow our relationship with you.

SCAN HERE
to meet the team!

For more information on **VOLUME and OEM SERVICES**, visit **www.edmundoptics.eu/volume**

6 WEEK
VOLUME PRODUCTION TIME

Edmund Optics® is proud to offer industry-leading **6 week production times** for **volume orders** of **custom optical components** at no premium!*

In addition to our quality and customer service, we pride ourselves on speed and accuracy. We understand that ever-shrinking development and product cycles make short lead times crucial to many of our customers. For this reason, we offer quick turnaround solutions to get you the optics you need within your specified timelines. Our continued partnerships with glass and crystal suppliers allow us to get raw materials as quickly as possible, but exact lead times are dependent on global glass and crystal availability.

**Dependent on quantity, specifications, and glass availability. Exact lead time to be acknowledged at the time of order.*

SCAN HERE
to contact us now!

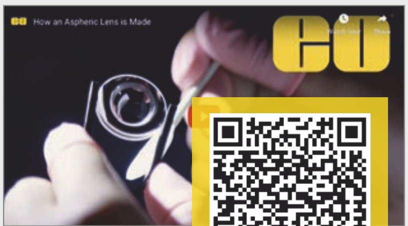
ENGAGE WITH US
EARLY AND OFTEN

Speaking with our experts during your proof-of-concept phase can help significantly expedite custom manufacturing. We can help provide feedback on specifications to choose for your components and review your design for manufacturability, while assisting with possible cost reduction measures once your project moves from prototype to production.

BEHIND THE SCENES IN OPTICAL MANUFACTURING

Watch the following two videos to see the manufacturing processes of both **aspheric lenses**, **imaging lens assemblies** and **laser crystals** in Edmund Optics' global manufacturing facilities.

How an Aspheric Lens is Made

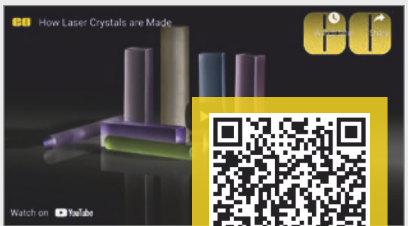


SCAN HERE

How an EO Imaging Lens is Made

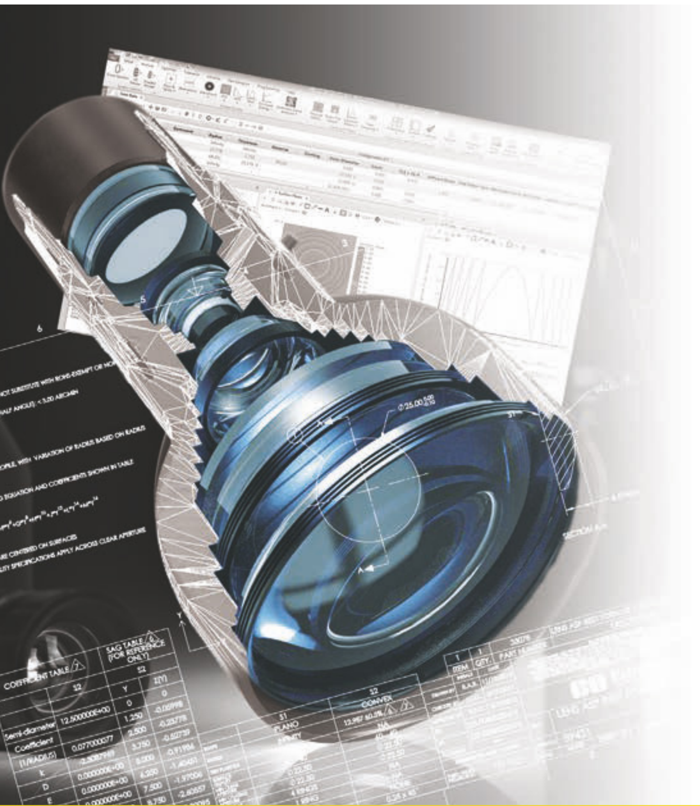
SCAN HERE

How Laser Crystals are Made



SCAN HERE

For a **FREE QUOTE**, contact us at **www.edmundoptics.eu/contact-support**



- Over 30 Years of Experience Designing Optical Components and Optomechanical Assemblies
- Analysis Expertise Spans Zemax, Code V®, FRED™, Solidworks, Matlab®, Abaqus, and More
- Regional Engineering Support & Service Across the Globe
- Designs Optimized for Integration and High Production Yields

Edmund Optics® offers a variety of design services in order to meet the specialized needs of our customers. We excel at designing optical and optomechanical systems from components to assemblies and imaging to laser optics, spanning from the UV to IR. Our design engineers are well versed in tolerancing and complex optical and mechanical analysis.

Whether standard or custom, we have found that approaching the design and proof-of-concept stage with an eye towards manufacturability at the onset yields the fastest, most affordable, and most effective results. EO engineers are prepared to take your project from design to prototype to volume production.

Zemax codeV FRED Optimum SolidWorks




DID YOU KNOW?

EO has over 230 engineers on staff, located at each of our global sales offices and manufacturing facilities, as well as our four dedicated design service locations in **Arizona, New Jersey, Germany,** and **China**.

For more **DESIGN ASSISTANCE**, visit **www.edmundoptics.eu/design**

TIPS FOR DESIGNING **MANUFACTURABLE LENSES** AND **ASSEMBLIES**

A successful lens design succeeds not only in the creation of a working model but also in manufacturing, assembly, testing, and implementation.

Visit this online resource to learn the nuances of designing manufacturable lens assemblies including:

- Geometry Considerations
- Tolerancing Methods and Assumptions
- Modeling Surface Irregularity
- Stack-ups of Assembled Systems

SCAN HERE for tips on **designing manufacturable lenses and assemblies**.

QUALITY AND METROLOGY

- Robust Global Compliance Systems
- Thorough Preventative and Corrective Action Procedures
- Commitment to Continuous Improvement
- ISO 9001:2015 Certified and ITAR Compliant

Edmund Optics® is committed to ensuring product and procedural quality. Guided by ISO 9001 certification standards, we employ a strict global quality program that is monitored by experienced staff and supported by the most innovative optical testing available. EO-manufactured products undergo rigorous and thorough testing as part of our quality program and in compliance with EO's global quality procedures, as well as a host of ISO and mil-spec standards.

Additionally, Edmund Optics® has documented plans for improving resource efficiency and waste reduction through the Environmental Management System (EMS) ISO 14001. We hope our initiative will develop and sustain both supply and demand for greener goods, services and products, and reduce waste both in and outside of the company.

EDMUND OPTICS® IS COMPLIANT WITH:

- ISO 9001:2015
- ISO 14001:2015
- ISO 13485:2016
- ANSI / ASME Y14.5
- ISO 10110
- MIL-C-48497A
- MIL-STD-810
- MIL-PRF-13830B
- MIL-C-675C

STATE-OF-THE-ART **METROLOGY**

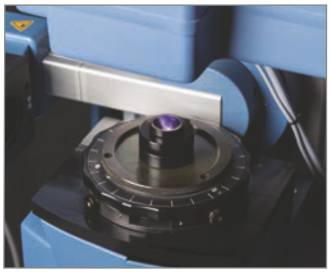
OPTICAL METROLOGY CAPABILITIES

- Interferometers, Profilometers, Coordinate Measurement Machines (CMM), and a host of Optical and Mechanical Metrology
- Radiometrics: Stray Light, Veiling Glare, and More
- Semi-Automated MTF Measurement Equipment
- UV/VIS/NIR/IR Coating Characterization through Varian and PerkinElmer Spectrophotometers and Fourier Transform Infrared (FTIR) Spectroscopy
- Laser-Induced Damage Threshold (LIDT) and Beam Quality (M^2) Measurement
- Environmental Testing Equipment such as Vibration, Humidity, Immersion, and Thermal Cycling
- Calibration of Equipment in Accordance with FDA 21 CFR Part 11, ISO 9001, ISO 13485, and AS9100 via GageTrak by Cybermetrics
- Over 50 Employees in Quality Control Functions Across the Company
- Product Testing and Certification Reports Available Upon Request

IN-HOUSE OPTICAL ASSEMBLY TESTING

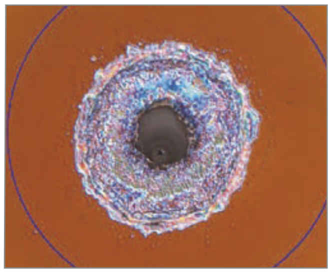
- Modulation Transfer Function (MTF)
- Stray Light
- Telecentricity
- Wavefront Distortion
- White Light Interferometry
- Mechanical Profilometry
- Laser Beam Profiling
- Athermalization and Ruggedization
- Much More!

QED ASI Aspheric Stitching Interferometer



Trioptics ImageMaster® MTF Test Station

Zygo® Interferometer



Laser-Induced Damage Threshold (LIDT) Testing

To learn more about our **STATE-OF-THE-ART METROLOGY**, visit **www.edmundoptics.eu/metrology**

TIPS FOR DESIGNING MANUFACTURABLE LENSES & ASSEMBLIES

A successful lens design succeeds not only in the creation of a working model but also in manufacturing, assembly, testing, and implementation. Occasionally, a lens may appear to succeed in conception but fail in one of the subsequent phases of manufacturing, assembly, or testing. Designers must consider the individual lens element geometry, the assembly setup, and the tolerancing models when creating an optic from scratch.

GEOMETRY CONSIDERATIONS

- Oversize lenses to ensure that the edge thickness is not too small and not too sharp, such that the edge would be prone to damage.
- It is suggested to keep the edge thickness above ~0.7 mm, at a diameter 1 mm larger than the intended final diameter of the lens.
- The Karow or Z-factor, which measures the ability for a lens to center itself automatically between bell chucks, also known as bell clamps, is given by:

$$Z = \left[\frac{D_1}{R_1} + \frac{D_2}{R_2}\right]$$

- D_1, D_2 are the bell chuck diameters (commonly equal to the lens clear aperture diameter). R_1, R_2 are the radii of curvature for the first and second surfaces. Convex and concave surfaces respectively have positive and negative radii (*Figure 1*).

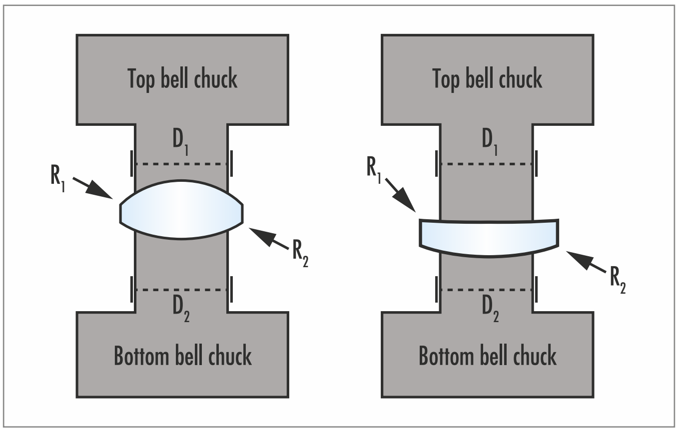


Figure 1: The left lens Karow factor (Z = 2.5) is greater than the right lens (Z = 0.4). As such, the left lens would be easier to center via automated bell-chucking while the right would be more difficult.

- Lenses with a Karow factor greater than 0.56 will automatically center well via automated bell-chucking.
- Those with a Karow factor less than 0.56 may not automatically center and will need to be centered manually. To ensure that a lens can be centered, concentricity (Δr) should be greater than 2 mm as a rule of thumb:

$$|\Delta r| = |R_1| - |R_2| - |CT|$$

STACK-UPS OF ASSEMBLED SYSTEMS

- Stack-up models should attempt to accumulate tilt and decenter effects while keeping elements anchored to the optical axis.
- To model a system, ensure each Monte Carlo or simulation based on random sampling from the probability distributions of all tolerances iteration, is configured with the correct stack-up of element tilts according to the element arrangement in the assembly (*Figure 2*).

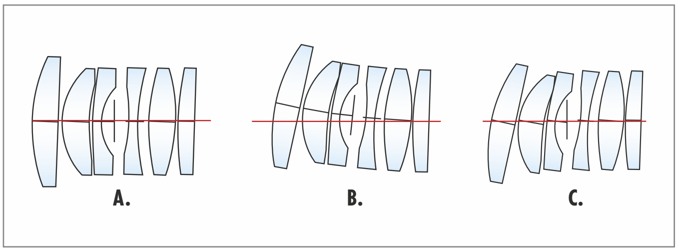


Figure 2: Three approaches to lens element tilt in a drop-together assembly. All elements are tilted by 2° in the same direction to illustrate the differences. **A.** Tilts are modeled independently. **B.** Tilts and decentration are accumulated in the order of assembly. **C.** Tilts are accumulated in the order of assembly, with no additional decentration; this motion is called shearing.

- Roll and decenter of an element can affect subsequent elements in the barrel.
- Connected elements will be "coupled" to a single rolling element and will move together.
- Only elements with convex rear surfaces contacting spacers have a coupled decenter.
- Elements with annuli or flat surfaces resting against a spacer can move independently (not coupled) from an initially decentered element (*Figure 3*).

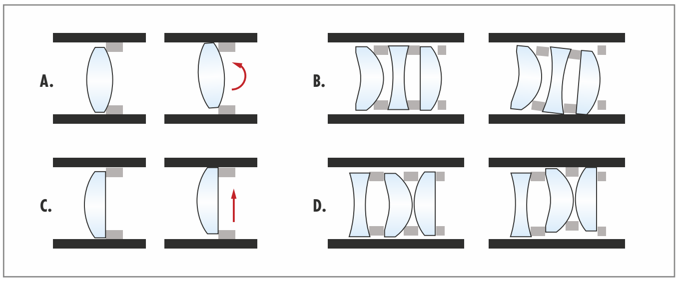


Figure 3: **A.** Roll motion of a lens element. **B.** Coupled roll motion. **C.** Decenter motion of a lens element. **D.** Coupled decenter motion.

- Oversimplifying tolerance models and designs can overlook possible manufacturing issues, and doing so increases the chances that designs will need revisions or additional iterations with increased levels of complexity.
- Increasing system model accuracy and using high-fidelity tolerancing methods early in design will require additional effort up front but will reduce expensive mistakes and save time in the end.

For more **OPTICS APPLICATION NOTES**, visit **www.edmundoptics.eu/appnotes**

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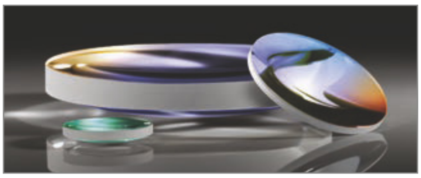
ASPHERIC LENSES

- 600+ Standard Aspheres Ready for Purchase
- Edmund Optics® is One of the Largest Aspheric Lens Manufacturers in the World

Aspheric Manufacturing Capabilities	Commercial	Precision	High Precision
Diameter:	10 - 200 mm	10 - 200 mm	10 - 200 mm
Diameter Tolerance:	+0/-0,100 mm	+0/-0,025 mm	+0/-0,010 mm
Asphere Figure Error (P - V):	3 µm	1 µm	<0,06 µm
Sag:	25 mm max	25 mm max	25 mm max
Typical Slope Error:	1 µm per 1 mm window	0,35 µm per 1 mm window	0,15 µm per 1 mm window
Centering (Beam Deviation):	3 arcmin	1 arcmin	0,5 arcmin
Center Thickness Tolerance:	±0,100 mm	±0,050 mm	±0,010 mm
Surface Quality (Scratch Dig):	80-50	40-20	10-5
Aspheric Surface Metrology:	Profilometry (2D)	Profilometry (2D & 3D)	Interferometry

SPHERICAL LENSES



- 6.300+ Standard Spherical Lenses Ready for Purchase
- Available in Glass and Crystalline Materials with a Variety of Standard and Custom Coatings

Spherical Manufacturing Capabilities	Commercial	Precision	High Precision
Diameter:	4 - 200 mm	4 - 200 mm	4 - 150 mm
Diameter Tolerance:	+0/-0,100 mm	+0/-0,025 mm	+0/-0,010 mm
Thickness:	±0,100 mm	±0,050 mm	±0,010 mm
Sag Height:	±0,050 mm	±0,025 mm	±0,010 mm
Clear Aperture:	80%	90%	90%
Radius:	±0,3%	±0,1%	Fix to Test Plate
Power (P - V):	3,0λ	1,5λ	λ/2
Irregularity (P - V):	1,0λ	λ/4	λ/40
Centering (Beam Deviation):	3 arcmin	1 arcmin	0,5 arcmin
Bevel (Face width @45 degrees):	<1,0 mm	<0,5 mm	<0,25 mm
Surface Quality:	80-50	40-20	10-5

PRISMS

- Custom Prisms in a Wide Variety of Geometries
- Angle Tolerances Down to 0,5 arcsec and Irregularity Down to λ/20

Prism Manufacturing Capabilities	Commercial	Precision	High Precision
Dimensions:	2 - 200 mm	2 - 150 mm	2 - 75 mm
Dimensional Tolerance:	+0/-0,2 mm	+0/-0,1 mm	+0/-0,01 mm
V-Height:	±0,25 mm	±0,1 mm	±0,03 mm
Irregularity:	1,0λ	λ/4	λ/20
Prism Physical Angle Tolerance:	±3 arcmin	±1 arcmin	45° & 90° ±0,5 arcsec
Penta Prism Deviation:	±5 arcmin	±3 arcmin	±0,5 arcsec
Max Bevel (Face Width @ 45°):	±0,5 mm	±0,3 mm	±0,05 mm
Surface Quality (Scratch Dig):	80-50	40-20	10-5
Bonded Prism Assembly Beam Deviation:	5 arcmin	3 arcmin	0,5 arcmin
Pyramid Tolerance:	±5 arcmin	±3 arcmin	±0,5 arcmin

BEAMSPLITTERS

- Cube, Plate, Polarizing, Non-Polarizing, and Laser Line Capabilities
- Design and Application Expertise for Complex Coating and Geometry Needs

Beamsplitter Manufacturing Capabilities	Commercial	Precision	High Precision
Dimensional Tolerance:	±0,15 mm	±0,08	±0,04
Dimensions:	5 - 75 mm	5 - 75 mm	5 - 75 mm
Irregularity (or Flatness):	1,0λ	λ/8	λ/20
Surface Quality (Scratch Dig):	80-50	40-20	10-5
Max Bevel (Face Width @ 45°):	±0,5 mm	±0,3 mm	±0,05 mm
Beam Deviation:	±5 arcmin	±3 arcmin	±0,5 arcmin
|Ts – Tp| (Broadband Non-Polarizing):	<10%	<8%	<6%
|Ts – Tp| (Laser Line Non-Polarizing):	<6%	<3%	<2%
R/T Splitting Ratios (Non-Polarizing):	30/70 to 90/10	30/70 to 90/10	30/70 to 90/10
R/T Splitting Ratio Tolerance:	±15%	±10%	±5%
Extinction Ratio (Polarizing):	100:1	500:1	>1000:1
Wavelength Range:	400 - 1620 nm	400 - 1620 nm	350 - 1620 nm

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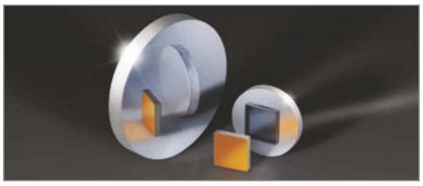
MIRRORS

Mirror Manufacturing Capabilities	Commercial	Precision	High Precision
Dimensions:	2,5 - 406,4 mm		
Dimensional Tolerance:	±0,25 mm	±0,1 mm	±0,05
Flatness:	4-6λ	λ/10	λ/20
Surface Quality (Scratch Dig):	80-50	40-20	10-5
Coating Options:	Metallic, Broadband Dielectric, and Dielectric Laser Line		
Reflectivity (Non-Laser):	85 - 99,98%		
Wavelength Range Covered:	13,5 nm - >40 µm		
Group Delay Dispersion (GDD) Range:	-4000 - 5000 fs²		
Substrate Options:	Metals, Glass, and Ceramics		
Geometries:	Flat, Elliptical, Spherical, and Parabolic		



- 2.000+ Standard Mirrors Ready for Purchase
- High Laser Damage Threshold (LDT) and Ultra-High Reflectivity Options

OPTICAL COATINGS

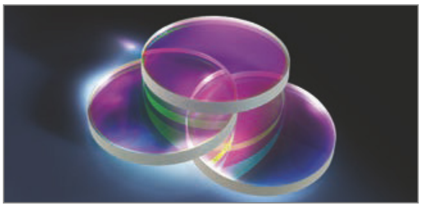
Optical Coating Capabilities	
Dimensions (Diameter or Square):	2 - 1000 mm
Reflectivity:	0,1 - 99,98%
Anti-Reflective Wavelength Range:	248 - 12.000 nm
Highly-Reflective Wavelength Range:	13,5 - >40.000 nm
Group Delay Dispersion (GDD) Range:	-4000 - 5000 fs²
Shortpass Filter Cut-Off Wavelength:	400 - 1600 nm
Longpass Filter Cut-On Wavelength:	240 - 7300 nm
Bandpass Filter CWL, OD, and Bandwidth:	193 - 10.600 nm, >OD 7, 1 nm - Broadband
Notch Filter CWL:	355 - 1064 nm
Reflective ND Filter OD:	OD 0,1 - OD 3
Filter Center Wavelength (CWL) Tolerance:	±1 nm
Filter Edge Tolerance:	<1% Deviation, <0,2% Special Cases
Beamsplitter (BS) Wavelength Range:	240 - 20.000 nm
BS Polarization Extinction Ratio (S:P):	10.000:1
Laser Damage Threshold (LDT):	>40 J/cm² @ 1064 nm @ 20 ns @ 20 Hz Pulses, Measured
Durability:	MIL-PRF-13830B APP C, PARA C.3.8.4, PARA C.3.8.5, MIL-C-48497A

- In-House Custom Coating Design
- Anti-Reflective, Highly-Reflective, Filter, Polarizing, Beamsplitter, and Metallic Designs

LASER OPTICS COMPONENTS

Laser Optics Components Capabilities

Component Types	Coating Types	Ultrafast Laser Optics	Superpolishing
Laser Mirrors, Windows, Lenses, Filters, Crystals, Beamsplitters, and Prisms	Complex E-Beam Coatings: High LDT, Multi-Band Anti-Reflective or Highly-Reflective; Ion Beam Sputtered (IBS) Coatings for Low Loss	Highly-Dispersive Mirrors, Low Group Delay Dispersion (GDD) Optics, Reflective Focusing Optics, and Beam Expanders	Minimize Scatter with Ultra-Low RMS Surface Roughness <1 Å for Parts-per-Million Level Scattering



- Designs for Common Laser Sources as Well as Uncommon Tunable Lasers

LASER OPTICS ASSEMBLIES

Beam Expander Capabilities	
Expansion Power:	1X - 20X
Design Wavelengths:	Common Laser Lines Including Nd:YAG, Yb:YAG, Ti:sapphire, and Tm/Ho-Doped Fiber Lasers, Broadband
Mounts:	C-Mount, M22, M30, Custom
Focusing Mechanisms Available:	Sliding Optics, Rotating Optics, Fixed Focus
Ruggedization Available:	Athermalization, Shock and Vibration, Sealing from Contaminants
Testing/Design Specifications:	Transmitted Wavefront Error, Power in the Bucket / Energy on Target, Focused Spot Size
Assembly Size:	From Handheld, to Vehicle-Mounted, to Large Stationary Systems

- Beam Expanders, Focusing Objectives, and Other Laser Optics Assemblies
- Laser Line and Broadband Coatings from 257 nm - 3 µm

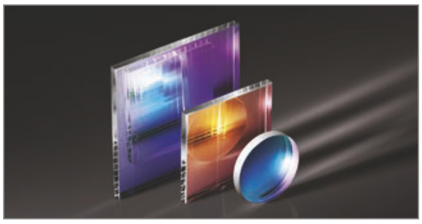
IMAGING ASSEMBLIES

- Over 1,5 Million Imaging Lenses Sold
- Global In-Region Engineering Support & Service

Imaging Lens Assembly Capabilities

	Fixed Focal Length Lenses	Telecentric Measuring Lenses	Fixed Magnification Lenses
Sensor Sizes:	Up to 43,3 mm	Up to 43,3 mm	Up to 90 mm
Resolution:	Up to 120 MegaPixels	Up to 32 MegaPixels	Up to 16k Line Scan
Field of View:	>105°	Up to 242 mm	0,2 mm - 186 mm
Lens Mounts:	C-Mount, TFL-Mount, F-Mount, S-Mount, M42	C-Mount, F-Mount, M42	C-Mount, F-Mount, M42, M72

OPTICAL FILTER GLASS



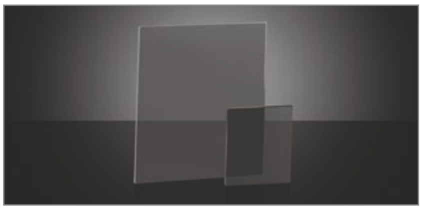
- >60 SCHOTT Optical Filter Glass Types in Stock
- No Minimum Order Quantity

Optical Filter Glass Manufacturing Capabilities

	Commercial	High Precision
Dimensions:	5 - 50 mm	3 - 160 mm
Dimensional Tolerances:	±0,2 mm	±0,05 mm
Thickness:	1, 2 , or 3 mm	0,5 - 4,0 mm
Thickness Tolerances:	±0,1 mm	±0,05 mm
Surface Finish*:	P2	P2 - P3
Surface Quality (Scratch-Dig):	80-50	20-10
Flatness:	2-3 λ	λ/4
Neutral Density:	0,15 - 5,0 OD	
Geometry:	Round, Elliptical, and Rectangular	
Filter Glass Type:	Longpass, Shortpass, Bandpass, Neutral Density, and Combinations of Multiple Glasses	

* Specifications per DIN ISO 10110. Manufacturing specifications per MIL-PRF-13830B also available.

POLYMER POLARIZERS



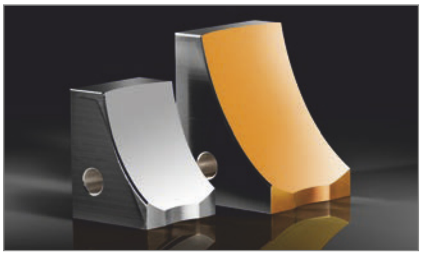
- Custom Polarizers Manufactured at our German Manufacturing Facility
- No Minimum Order Quantity

Linear Polarizer Manufacturing Capabilities*

	Linear Polarizing Film	PMMA Laminated	Glass Laminated	Wire-Grid Polarizing Film
Dimensions:	3 x 3 mm - 600 x 1000 mm	3 x 3 mm - 600 x 900 mm	6 x 6 mm - 250 x 250 mm	3 x 3 mm - 240 x 80 mm
Diameter:	3 - 600 mm	3 - 600 mm	6 - 250 mm	3 - 80 mm
Dimensional Tolerance:	±0,20 mm		±0,10 mm	
Thickness:	0,18 - 0,75 mm	1,00 - 3,00 mm	2,00 - 3,50 mm	0,08 mm
Transmission:	Up to 44%			85%
Extinction Ratio:	Up to 1:30.000			1:4.250

*For specifications for circular polarizers and retarders, visit **www.edmundoptics.eu/capabilities/polarizers**

DIAMOND TURNING



- In-House Experts with 10+ Years' Experience
- Precision Diamond Turning of Metals, Crystalline Materials, and Plastics

Diamond Turning Capabilities *Exact values are dependent on the specific material and size

	Commercial	Precision	High Precision
Reflected Wavefront Error (P - V @ 632 nm):	λ	λ/2	λ/8
Surface Quality:	80-50	60-40	40-20
Surface Roughness (RMS) Metals*:	150 Å	100 Å	<30 Å
Surface Roughness (RMS): Crystalline Materials and Plastics	<50 Å for Diameters 6,25 - 200 mm		
Geometries:	Off-Axis Parabolas, Off-Axis Ellipses, Off-Axis Toroids, Spherical Surfaces, Aspheric Surfaces, and Planar Surfaces		
Angles:	0 - 90°		
Diameter (Off-Axis):	2 - 254 mm		
Diameter (On-Axis):	8 - 254 mm		
Coatings:	Uncoated, Aluminum, UV Enhanced Aluminum, Protected Gold, Bare Gold, Protected Silver, Anti-Reflection, and Custom (upon request)		
Materials:	Metals (Aluminum, Copper, Brass, and Nickel-Plated Surfaces), Crystalline Materials (Germanium, Silicon, Calcium Fluoride, and Zinc Selenide), and Plastic (Acrylic and Zeonex)		

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Understanding laser protective eyewear requirements

Meeting user and regulatory needs for a safe work environment

Donald Tibbitt

Source: iStockPhoto / all other images: Epolin

Laser-protective eyewear formulations should match the laser requirements

Regardless of the type of laser, all can produce biological effects on the human body if protective eyewear is not used. Many lasers produce a beam of light in the UV or infrared spectrum that our eyes are not able to detect. To qualify as laser-protective eyewear, independent laboratory tests validate and certify the protective capabilities and optical density (OD) against the standard, using the actual laser, including performing destructive testing. This certification is required to meet standards like European norm CE EN207 and American National Standard for Safe Use of Lasers ANSI Z136.

Lasers are a tool used in a wide range of applications, such as medical, military, industrial, entertainment, education, farming, and research. Monochromatic light is emitted at a single wavelength while white light is a combination of many different wavelengths. Laser light is monochromatic, directional, and coherent.

Depending on the wavelength of laser emission, it is either visible or invisible. Laser light is emitted as a relatively narrow beam that follows a single direction and creates a high power density when it falls on a material. It is also coherent, which means the photons of the laser light are in the same phase and frequency.

Lasers can be combined into a system that produces multiple wavelengths of light designed for a specific application. Many of these systems are combined with incoherent light sources like UV, or broad-spectrum flash systems such as intense pulsed light for targeted medical or welding applications. Without proper protection, radiation from laser systems can lead to serious biological effects on the eye and skin. The intensity and types of light used within a given application must be considered when designing laser eye protection to meet user needs while conforming to regulations, which are key to creating a safe work environment.

Types of lasers

There are five main types of lasers found on the market today. They are grouped by the gain medium or material within

Expanding use of novel laser systems continues to drive reformulation of protective eyewear design

the laser that is used to produce excitation and lasing. The five types are:

- gas
- liquid
- semiconductor
- solid-state
- fiber

Gas lasers use a glass or ceramic tube that is filled with a gas or gas mixture. Gas lasers tend to have very narrow bandwidths and defined wavelengths. There are lasers that cover the spectrum from UV through visible and into the near infrared. Although gas lasers have been superseded by newer technologies, some, like CO_2 lasers, are still very popular for cutting and welding operations.

Company

Epolin

Since 1983, Epolin has produced the highest quality materials to meet laser protective eyewear manufacturer needs, with Epolight dyes and Luminate thermoplastic pellets. Epolin develops and manufactures near-infrared absorbing dyes and thermoplastic compounds. Our materials provide premium performance for laser and welding eyewear, light filters, touchscreens, night vision products, sensors, lidar, and security inks. Epolin is a subsidiary of the Chroma Color Corporation, and manufactures and ships products from our headquarters in Newark, New Jersey, USA. Epolin regional distributors include AAKO BV (Europe), SN Consultant (Japan), and Sun & Bright Industrial Ltd (China).

www.epolin.com

Liquid lasers use a range of organic dyes dissolved into solvents that are excited with either a flashlamp or other lasers. The dyes will absorb and then radiate energy that can be tuned and focused to produce the desired lasing effect. Due to their extensive maintenance requirements, these lasers have been largely replaced by newer technologies.

Semiconductor lasers are often referred to as diode lasers because they operate in the same fashion as a light-emitting diode, an LED. Power is driven through the diode junction, which in turn achieves lasing. Most common semicon lasers operate in the near infrared (NIR) region of the spectrum, which enables their use in a wide range of modern applications.

Solid-state lasers are based on glass or crystal mediums that are doped with rare earth elements. One of the most common types is the neodymium-doped yttrium aluminum garnet (Nd:YAG) laser. These lasers achieve some of the highest power and energy levels possible today. The wide range of possible wavelengths, power outputs, and flexibility offered by solid-state lasers has enabled their use in everything from material processing and measurement to weapon systems and autonomous vehicles.

Fiber lasers are built from doped optical fibers with an integrated resonator. As a flexible medium, it is easy to position these optical fibers and focus the laser light. The fibers can be bent or coiled over a substantial length, creating high optical gain while at the same time providing a substantial cooling surface. Fiber lasers tend to be very efficient and long lasting, even at the high-power levels used in cutting or welding. These systems excel in pulsed laser applications.

Laser modes of operation

Within these laser types, there are various modes of operation, such as continuous wave, pulsed, or mode-locked.

Continuous wave (cw) produces a constant wave of energy with a consistent power output. Because many of the laser systems are excited by pulsed energy, continuous wave lasers are defined as having a pulsed length of greater than 0.25 seconds, given a 'D' designation.

Pulsed lasers have a single short burst of energy or a repetitive periodic emission. These lasers will have a short pulse length of 1 microsecond to 0.25 seconds. They have been further divided into pulsed lasers and giant pulsed lasers which are designated with an 'I' or an 'R' respectively.

Mode-locked lasers generate ultrashort pulses from the laser. These systems will have a component that will only allow the pulse of energy to be released when it achieves certain parameters. This can be done either through active or passive means. Because these lasers are selectively releasing an incredibly short pulse they are often referred to as femto or picosecond lasers. Mode-locked lasers will have an 'M' designator.

Biological effects

Regardless of the type of laser, they are all capable of producing biological effects on the human body if protection is not used. It is important to note that many lasers produce a beam of light in the UV or infrared spectrum that our eyes are not able to detect. Some lasers are powerful enough that the even reflected light is sufficient to damage the eye. Pulsed lasers are also of particular concern because calculations will show a lower average energy level than the peak pulse is actually achieving.

The lens in our eye will pass light in the 400 – 1,400 nm range and can focus the radiated energy, concentrating it onto a small area of our retina. Concentrated light will quickly heat the area and destroy those cells. This typically happens faster than our blink reflex can shield our eyes. With an infrared laser system, the hazards are even more severe because our eyes will not react to the invisible light. The retinal area of the human eye lacks pain receptors and so there are no initial indications of damage until vision is lost.

Laser hazard classification

To help with identification, a laser hazard classification was established with International Standard IEC 60825-1 and then adopted by the American National Standard for Safe Use of Lasers as ANSI Z136. A system of four classes identifies the hazard level and laser exposure limit. A laser user needs to answer two important questions prior to using the device:

- Is laser eye protection required?
- Are there alternate sources of light that I should take into consideration (like welding or IPL, intense pulsed light).

Class	Safety
Class 1	Safe under normal use
Class 1M	Safe for all conditions except when passed through telescopic optics
Class 2	Safe due to the human blink reflex
Class 2M	Safe due to the human blink reflex when not viewed through telescopic optics
Class 3R	Careful handing is required with restricted beam viewing
Class 3B	Hazardous if the eye is exposed directly, but safe when viewing as a diffuse reflection on a surface
Class 4	Devastating and permanent eye damage through direct or indirect viewing of the beam. Powerful enough to burn skin

Table Laser safety classes and potential hazards

More formally, these questions are answered and monitored by an appointed laser safety officer (LSO). In the US, all Class 3B and 4 laser environments are required to have an LSO. Depending on the application, LSOs may also be required for Class 1M and 2M lasers.

A laser safety officer typically constructs and reviews a standard operating procedure to ensure a safe environment for the user and to comply with applicable regulations. They consider maximum permissible exposure (MPE) and nominal hazard zone (NHZ) calculations to prevent excess radiation exposure. There are software tools on the market that can calculate MPE and NHZ values and limits by considering the characteristics and properties of the laser. Laser-protective eyewear should be considered when the user would be outside the MPE and NHZ requirements or is exposed to other light systems within their work environment.

Eye protection standards and certification

Standards such as ANSI Z136.7, CE 60825-4, and CE 12254 also govern the manufacture of laser safety equipment. Laser-protective eyewear should never be considered the first line of defense, so the use of engineering control measures, standard operating procedures, and adequate user training are key to ensuring a safe environment. Eye protection must also to allow wearers to safely perform essential job functions, providing high visible light transmittance during the day along and high scotopic visible light transmittance for the early evening.

Optical density (OD) is a logarithmic ratio of the energy of light entering the lens divided by the energy of the light leaving the lens. An optical density of zero allows 100 % transmission of the energy through the lens. Stepping up to an OD of 1.0 would only allow 10 % of the energy through and an OD of 2.0 would only allow 1 %. Optical density is achieved using absorbing dyes that are specific to the wavelength and energy produced by the laser. These are chemical structures that absorb photons of light and dissipate their energy through emission or heat. In addition to the MPE and NHZ values, there are several other design considerations to take into account when designing a laser-protective lens. In most cases, computer modelling of the dye formulation can help to build target specifications prior to the costly expense of certification testing.

Formulation of laser-protective lenses

Design considerations for lenses or filters include

- What is the wearer trying to see?
- Laser requirements – optical density (OD)
- Laser requirements – frequency (nm)
- Lens or filter thickness
- UV requirements
- Visible light transmission (VLT) requirements
- Scotopic light transmission (SLT) requirements

During the development process, dyes are modelled, synthesized and mixed to absorb specific wavelengths of laser radiation. They can be added to a thermoplastic polymer, typically polycarbonate, via a compound extrusion process to create a ready-to-mold pellet built for a specified thickness and optical density ready for injection molding. Lenses are then analyzed on a spectrophotometer, which reads the optical density, absorbance, attenuation, and transmission from 200 to 3,300 nm, from ultraviolet through visible light and into the near infrared.

Although laser eye protection seems complex, there is an established industry that has grown to support the ever-expanding market, and industry experts who can guide you through the regulations and safety concerns. If you are a manufacturer of laser protective eyewear and you are looking for dyes or polycarbonate pellets for your applications, Epolin's technical team can discuss your specific laser-absorbing requirements.

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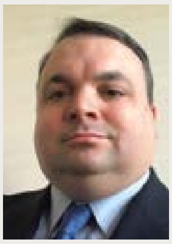
Author



Donald Tibbitt is an organic chemist with over twenty years of experience in synthesizing, formulating, and compounding UV, visible, and infrared dyes. After holding positions at Dupont and AstraZeneca, he joined Epolin where he serves as technical marketing director. Epolin is a global leader in optimizing near-infrared and visible light transmittance in plastic parts, films, adhesives, and coatings.

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Chillers get quieter, greener, and smaller

Miniature compressors enable compact, low-noise integrated cooling solutions without hydrofluorocarbons

Konrad Laufs

Source: AMS Technologies

▲ Lightweight and compact compressor-based recirculating chillers with pressurized coolant circuit provide high cooling capacity and temperature stability down to ±0.05 K.

Diode lasers, even those of low to medium power, need to be cooled – not only to avoid thermal damage, but also to keep their temperature-dependent output wavelength as constant as possible. Compressor-based cooling systems are well suited for medium to high-power lasers, but they are usually large, loud, and generate vibrations. However, there are also compact, quiet, and low-vibration solutions.

Some recirculating chiller models for laser cooling have been on the market for more than twenty years without an update. So, are there no interesting new aspects to laser cooling? Well, lasers are being used in ever more applications, and these applications might, for example, require integrated cooling of a laser that is transported on a motorbike to home visits for aesthetic treatments. Or the recirculating chiller might need to operate as quietly as possible in an operating theater. Other requirements could be greener solutions with the switch from hydrofluorocarbons to hydrocarbons, recirculating chillers with automatic filling and draining that go on an airplane or simply under the arm of a sales representative, or a maintenance-free cooling solution based on the direct evaporation of refrigerant that completely eliminates the water cycle.

Peltier or compressor?

Common cooling systems for diode lasers are either based on Peltier elements (thermoelectric cooling) or

Fig. 1 Solutions for direct Peltier cooling require no liquids – but large heat sinks and potentially noisy fans that can be challenging in some applications.

work with liquid cooling (mostly water). Cooling systems integrated into the laser system have so far been the domain of Peltier direct coolers, which do not require water and thus reduce the complexity of the cooling system as well as the amount of maintenance required (Fig. 1). A tool to configure such Peltier cooling systems is accessible online [1].

However, for the temperature control of even low to medium-power laser diodes, Peltier cooling systems already require large-format heat sinks and usually a forced airflow over these heat sinks using fans. If a laser diode is to be cooled to temperatures below the ambient temperature, Peltier cooling systems can only be used for very low-level cooling capacities and are not very efficient under these circumstances.

In liquid-based cooling systems, the laser diodes are usually mounted on thermally highly conductive blocks (usually made of metal) through which temperature-controlled liquid flows. Recirculating chillers with a closed circuit and a heat exchanger are used to cool this liquid circuit. The primary circuit of these chillers is in turn cooled with the help of Peltier elements or compressors.

Depending on the ambient temperature and the required water temperature, a Peltier-based chiller the size of a shoebox can provide up to about 200 W of cooling power (Fig. 2). The integrated compressor-based cooling solutions of a number of manufacturers of miniature rotary compressors are becoming popular, as they can be as compact as 20 × 20 × 20 cm, with cooling capacities of 400 W to 500 W (Fig. 3). The compressors operate at rotation speeds of up to 100 rps or even 120 rps, are 24 V_{DC} inverter-driven, and some can adjust the rotation speed in a range as wide as 20 to 100 % of the maximum value. Chillers based on these compressors can cool the water loop well below ambient temperature with very high efficiency.

Compared to Peltier-based chillers, two challenges remain: how to operate the compressor at zero load condition (e.g. with the laser temporarily disabled) without the risk of condensation or icing of the sensitive laser, and how to deal with vibrations when the compressor speed increases. The first can be solved with a heater in the coolant circuit that compensates the compressor's cooling capacity at minimum speed – enabling precise temperature control within ±0.05 K – or utilizing bigger tanks, this way increasing the thermal capacity of the cooling liquid and thus the time constant of the entire system's temperature control, allowing to switch the compressor off during the phases when the laser is idle. The vibration issue is best solved by using double pump / twin type compressors. As they are dynamically balanced by having two pump parts operating 180 degrees out of sync, vibration is about ten percent less than with a single-pump compressor.

Fig. 2 Compact, benchtop recirculating chillers based on Peltier elements avoid the coolants required by compressor-based evaporation systems, but are less efficient – especially when cooling below ambient temperature is required. (Source: Solid State Cooling Systems)

Company

AMS Technologies

For more than 35 years, AMS Technologies has supported the European market with leading, innovative technologies, products, and solutions for optical, power, and thermal management applications. AMS Technologies delivers solutions into a variety of high-tech markets, including renewable energies, medical, defense and aerospace, research and scientific, and various other industrial segments. The company's pan-European customers are served from a network of local offices in Germany, the UK, France, Italy, Spain, and Sweden, with a focused operations and logistics center located in Munich, Germany.

www.amstechnologies.com

Fig. 3 Integrated cooling solutions based on a miniature 24 V_{DC} rotary compressor with inverter fit into a space as small as 20 × 20 × 20 cm and deliver 450 W of cooling capacity for laser cooling (Source: AMS Technologies)

Quiet and green chillers

Many recirculating chillers use on/off compressors and operate with hot gas bypass valves – a rather noisy technology that may disturb a surgeon in an operating theater. A solution here is to use compressors that are common in household appliances that produce less than 40 dB_A of noise, and are nowadays also inverter-driven and speed-controlled. A compressor with an inverter that fits into a space as small as 15 × 20 × 12 cm delivers 800 W of cooling capacity for laser cooling. 1,600 W can be reached in a 5U rackmount system with two compressors (**Fig. 4**).

Speaking of household appliances: household refrigerators switched to being filled with hydrocarbons (isobutane and propane) twenty years ago, refrigerated shelves in supermarkets are equipped with CO_2 nowadays, but recirculating chillers for laser cooling seem to be lagging behind in this soon to be mandatory switch to climate-friendly refrigerants. But change is underway – the first recirculating chillers are available with isobutane or propane, with the expectation that more of these will be launched soon.

Sometimes size does matter

When transporting a chiller and a laser on a small airplane, or just on a sales representative road tour, it is more convenient if the equipment is lightweight and compact. It is even better if it is equipped with an air pump and valve system that automatically checks for leaks, then fills, flushes, and pressurizes the system and, when done, drains the whole system from coolant, significantly simplifying system maintenance.

Based on an electronically speed-controlled miniature compressor, AMS Technologies has succeeded in realizing such a solution (see opening spread on p. 80), offering a high water-cooling capacity of up to 450 W (+25 °C ambient and +25 °C cooling water temperature) or 300 W (+45 °C ambient and +25 °C cooling water) in a very small space. The chiller's miniature compressor operates with efficient electronic speed control and provides very high temperature stability of ±0.05 K in a settled condition, with low vibration and a low noise level.

With its integrated electric air pump pressurizing the water circuit, the system manages with only 275 ml tank volume – without the risk of cavitation in the smooth-running centrifugal pumps. In addition, the overpressure in the cooling system prevents the ingress of bacteria and oxygen, thus keeping the coolant clean and extending the maintenance intervals. Thanks to its very compact (350 × 280 × 230 mm) and lightweight (13 kg) design and its wide-range V_{AC} power supply, the chiller can be operated anywhere in the world. The integrated Ethernet interface makes the device 'Internet of Things (IoT) Ready' and allows it to be remotely controlled, monitored and maintained from anywhere via an Internet browser.

An online recirculating chiller selection tool [2] enables selection by cooling capacity, ambient and coolant temperatures and preferences such as a wide power input of 100 to 240 V_{AC}, thermoelectric/compressor engine or form factor (benchtop, rack-mount, etc.).

Outlook: direct evaporation

The water circuit of a recirculating chiller requires regular maintenance. In addition, a water circuit carries a risk of leakage with potentially major consequential damage to optical and electronic components.

Some laser applications require maintenance-free operation, but do not need extra cooling for additional components such as crystals or optical couplers. If in such an application the laser is operated permanently without

Fig. 4 Two miniature, speed-controlled compressors in a 5U rackmount system can provide up to 1600 W of cooling capacity (Source: AMS Technologies)

switching off, continuously providing at least about one third of the maximum heat load, very good temperature stability can be achieved throughout the whole range of conditions even without the water circuit and its thermal capacity. So the water circuit can be eliminated for good and the laser is then cooled by one or several cold plates – which become evaporator plates – and a direct expansion refrigeration circuit.

With this 'direct evaporation' technology, the cooling process is not by means of water circulation, but the compressor circuit (Fig. 5) is directly connected with flexible refrigerant hoses and the refrigerant is evaporated in a cooling plate, (actually an evaporator plate), or directly in the macro or micro channels of laser diode stacks. This way, higher heat transfer coefficients can be achieved than with single-phase water flow. Tests have shown that a laser diode stack can be operated with about twenty percent higher output power at the same target temperature without further cooling channel optimization.

Also, the refrigerant used is inert, and the problems known from water cooling, such as erosion and corrosion, are avoided. To eliminate the entire water circuit it is necessary to place the compressor cooling in the immediate vicinity of the diode laser, as flexible refrigerant hoses should not be longer than two meters. New types of compressors that can be regulated quickly and within wide limits enable constant temperature control of the laser diodes, especially during load changes, without the thermal mass of cooling water.

Direct evaporation technology offers great potential, especially in combination with microchannel coolers, with significant savings possible in installation space, costs, and energy consumption. For example, two to three times higher COP values (coefficient of performance, a measure for the efficiency of refrigeration devices) can be achieved compared to a compressor-based recirculating chiller.

Fig. 5 Compressor unit for cooling solutions with the two refrigerant hoses leading to the left, directly connected to a cold plate or a laser diode stack where the refrigerant is evaporated – with no water loop required (Source: AMS Technologies)

Challenges still exist, mostly regarding practical application. For example, quick-connect couplings may only be operated by refrigeration technicians as long as commercially available R134a (hydrofluorocarbon) is used as refrigerant. An alternative would be the use of R600a (hydrocarbon), for which this restriction does not apply. In addition, for virtually every application, an expert must select and design a suitable evaporator and adapt the control system. The AMS Technologies team, with its many years of expertise, is happy to help.

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[1] http://selectatec.amstechnologies.com
[2] http://chillers.amstechnologies.com

Author

Konrad Laufs has more than two decades of experience in the development and sales of cooling solutions. He joined AMS Technologies in 1998 and has been promoted to business line manager for the company's thermal management solutions. He studied mechanical engineering and did his doctorate in thermodynamics and fluid dynamics in solar evaporator tubes at the Technical University Munich (TUM).

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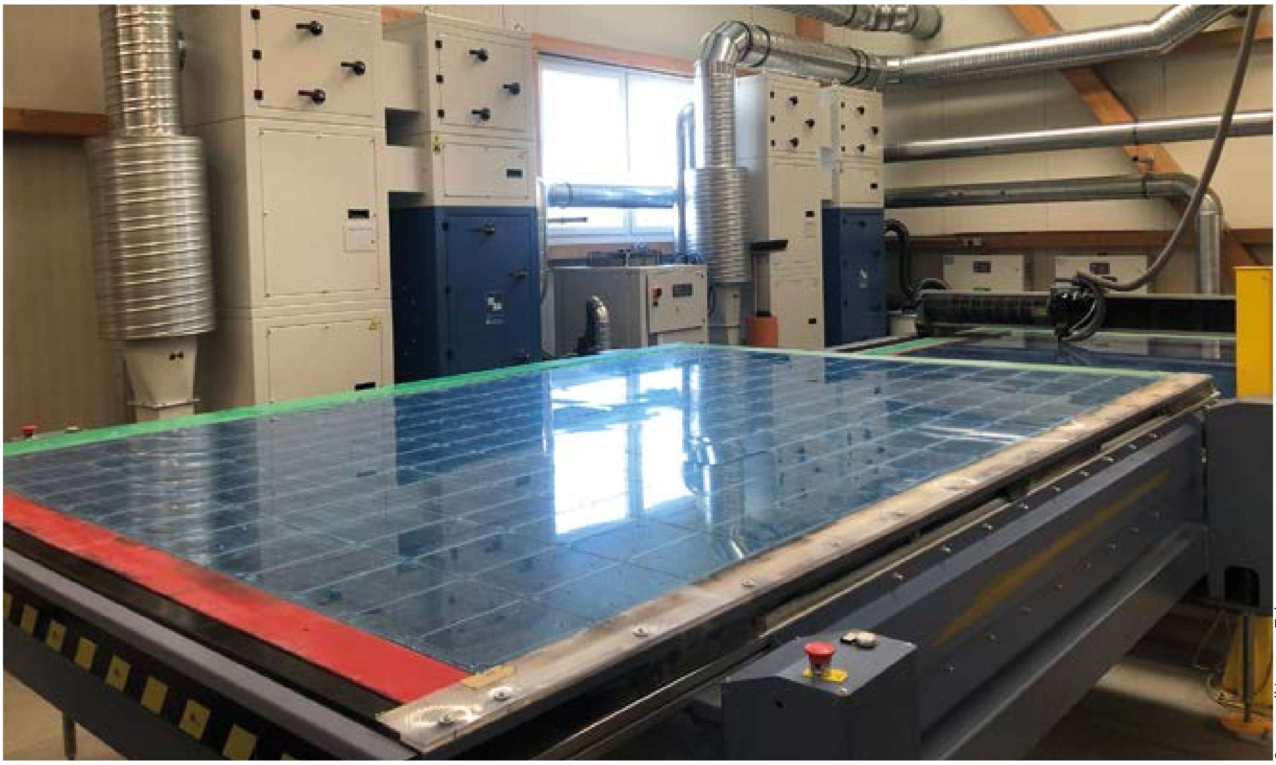
Smoke and dust-free laser use

Werba Plast relies on the Teka FilterCube in a trio



Source all images: Teka

"The filter lifetimes have increased enormously. For us, this means greatly reduced effort and, most importantly, costs," says Olaf Lehmann, head of production at Werba Plast.

Werba Plast is a dynamic medium-sized company, with its headquarters in Rosstal near Nuremberg. Since it was founded in 2003, this family-run business has become one of the leading manufacturers of industrial goods for the retail trade. The manufacturer is well known for its presentation displays, sales displays, product separators, fixtures and accessories for electronic price displays, product lifters and pushers, scanner rails and stands. The focus is always on ensuring the optimum presentation and price display for fruit and vegetables, meat, and books as well as pharmaceutical and drugstore products. The company's customers include the foodstuffs industry, bookstores, chemists or drugstores as well as other retailers. Its aim is to retain its position as a well-respected company for the attractive and functional presentation and identification of products. That is why it uses state-of-the-art technology in its production processes.

▲ At Werba Plast it was possible to install the Teka FilterCubes (backround) right next to the laser tables.

Companies

TEKA

For more than 25 years, TEKA Absaug- und Entsorgungstechnologie GmbH has been one of Europe's leading manufacturers of suction and filter equipment for industry, commerce, the trade sector and laboratories. As a reliable partner and expert in ensuring clean air at the workplace, Teka is an international supplier to mid-sized enterprises and groups in the metalworking and electronic engineering industries as well as the laboratory technology sector.

www.teka.eu

Werba Plast

Werba Plast GmbH is a dynamic medium-sized company, headquartered in Rosstal near Nuremberg. Founded in 2003, we have become one of the leading manufacturers of industrial goods for the retail trade.
Through long-lasting and satisfied customer relationships, we have managed to establish ourselves as a renowned company in the market. Quality, know-how, reliability and innovative ideas are the engine of our success.

https://werbaplast.com

▲ Michael Kneuer, member of the Teka field service team

▲ The FilterCubes are directly connected to the lasers and provide high-performance extraction at the very place where the dust and fumes are generated.

Werba Plast has long been using laser cutting and engraving technology during the processing of its materials. Wood and a variety of plastics in material thicknesses of between 1.8 mm and 15 mm are machined simultaneously at three workstations. Using different laser powers of 230, 690 and 850 W, the manufacturing materials can be cut or engraved exceptionally cleanly and precisely. This generates very large amounts of dust and fumes at the three 2 × 3 m laser cutting tables and it was necessary to change the filters of the extraction and filter system that was previously in use every week.

“When we decided to modernize our extraction and filter system, the most important thing was to have a system that would give the outstanding extraction performance necessary to cope with the volumes of dust and fumes coupled with very long filter lifetimes, because the previous solution was extremely labor-intensive and expensive,” explains Olaf Lehmann, head of production at Werba Plast. To provide an intelligent and particularly healthy solution, all three lasers were connected to a Teka FilterCube in order to reduce the dust and fume emissions directly at the place of production. A dual-module system equipped with a filter and activated carbon cartridges was chosen for this application.

Space-saving all-rounder

The Teka FilterCube is an extraction unit with a modular design that can be used for practically any fume and dust filtration application. As a stationary unit, it takes in the fumes and dust that are generated at Werba Plast through a pipe, cleans the contaminated air with an efficiency of almost 100 % and then guides it from the working area outside.

The contaminated particulate matter remains on the surface of the filter cartridges and falls into a dedicated container during the automatic filter cleaning operations. The Easy Clean Plus cartridges that are used in the FilterCube are made from a grooved polyester material with a nanofiber lining and were specially developed to remove particulate matter from the welding fumes and dusts that are generated by flame, plasma or laser cutting processes. Particles that are capable of entering the alveoli (<0.4 µm) in particular are filtered out very efficiently. The use of Easy Clean Plus cartridges greatly improves separation efficiency, meaning that a filtration level of nearly 100 % is very quickly achieved. As a result, under identical operating parameters, they offer considerably improved filtration performance with significantly lower pressure losses than conventional filter media made from polypropylene or PTFE. The unit is also equipped with activated carbon cartridges that absorb almost all the generated gases and consequently bind in any odors.

Preventing the filters from sticking

The cutting of Plexiglas, plastic and similar materials produces a sticky smoke that can soon clog up the filters. To prevent this, each of the extraction units at Werba Plast is equipped with a dispensing mechanism. A filter aid is applied to the filters after each cleaning operation and acts almost like a protective coating on the surface of the cartridges. The process dust binds with this and is deposited only superficially on the filter cartridge. This additional mechanism greatly extends the lifetime of the filter cartridges.

“The FilterCube is a compact all-rounder. The fact that it could be installed right next to the laser tables despite the limited space available made it the ideal solution for Werba Plast,” explains Michael Kneuer, the member of the Teka field service team who advised the company and ensured that the project was brought swiftly to fruition. Once the order had been awarded at the end of 2021, the FilterCube was installed as soon as February 2022.

A satisfied Olaf Lehmann sums things up: “Since the units were started up in February 2022, we have not yet had to change any filters.”

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Motion control: from component to system supplier

How a provider of automation systems transformed itself to offer holistic support for high-precision and industry-specific automation processes

Source all images: Aerotech & Peak Metrology

Successful implementation of a motion system involves more than just the purchase of modern positioning tables and control systems. The correct design of the machine structure, measuring system and mounting are all essential considerations. Environmental factors such as temperature, cleanliness, vibration, acoustics and EMI (electromagnetic interference) also have an influence.

▲**Fig. 1** Laser processing: Dentalpoint produces grinding utensils and precision tools for the manufacture of ceramic implants on Aerotech production systems with laser processing.

To meet the increasing demands of its customers, Aerotech not only supplies components suitable for particularly challenging operating conditions and mission-critical applications but also, drawing on knowledge and motion control expertise, increasingly acts as a builder of automation systems for industry-specific applications. Customers can choose between a component-only solution, a customized motion subsystem or a fully integrated system.

Aerotech has been providing standard product solutions such as motors, drives, controllers and positioning tables since 1970. Customized motion sub-systems include positioning systems on granite structures with underframe and vibration isolation as well as external measurement systems. The integrated systems are virtually turnkey machines developed in cooperation with customers to carry out an automated process. These include not only precision components manufactured in-house for motion control, but also full automation integration for parts handling, process instruments, safety elements and customized software.

Starting the process

"In recent years, we have worked closely with customers from a wide range of industries and have continued to advance into the field of process automation" explains Norbert Ludwig, managing director of Aerotech in Fürth, Germany. "As a builder of automation systems, we can now provide manufacturing companies with optimal process automation by utilizing the precision motion components we have historically been known for."

Fig. 2 Aerotech manufacturing system: A compact seven-axis system consisting of five swivel axes and two optical axes: the center of gravity is positioned exactly at the center of the machine, where a tool is lasered out with an integrated helix movement.

"This is particularly attractive for companies that are currently setting up, expanding or modernizing their production," he says. "Especially in the semiconductor and electronics market, many companies have neither the staff nor the vertical range of manufacture to develop mechanics and control systems in parallel," continues Norbert Ludwig. In addition, solutions are becoming smarter and more complex, so that a single company can no longer master all the implementation steps. As a result, the supplier's know-how is becoming increasingly important. "And this is where our work as a builder of automation systems begins: we offer extensive integration advice, which continues until either the delivery of individual components, a subsystem that can be seamlessly integrated or a complete automation solution. Application training, courses and services round off our service portfolio."

From electronics to medical devices and AM

Aerotech has a high level of vertical integration, especially when it comes to drive components and control elements. "We have grown with our customers over the years, gaining application knowledge from many industrial sectors. Accordingly, we can now recommend the ideal components for just about any application," explains Ludwig. "For example, if it is a laser welding process in which the laser beam must be deflected as quickly and precisely as possible, our experts can advise exactly which axes in combination with which galvo scanner are suitable. This level of support means that the customer only has to couple and control their laser. They can also use our own comprehensive control platform architecture, which enables them to complete, functionally test and deploy their laser welding system very rapidly."

Individual specifications can of course also be included into the subsystem, which go far beyond the component level. The Aerotech control electronics can be integrated into the customer's own control cabinet. Other elements that they need to control their laser when measuring parts can also be installed in the same cabinet.

On the mechanical side, Aerotech supplies partially integrated systems, which the customer simply completes. If an adjustment system on granite is required for the machine, Aerotech

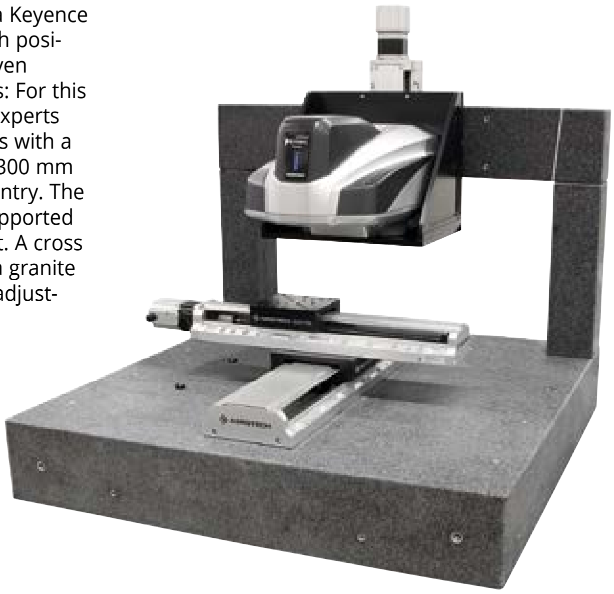

Fig. 3 Integration of a Keyence VR5000 in an Aerotech positioning systems for even larger travel distances: For this purpose, Aerotech's experts have mounted a z-axis with a travel range of up to 300 mm on a stable granite gantry. The measuring head is supported by an adapter bracket. A cross table is mounted on a granite base for component adjustment.

Company

Aerotech & Peak Metrology

Aerotech Inc., based in Pittsburgh, USA, is a privately held, family-owned company founded in 1970 by Stephen J. Botos with the vision of advancing the science of motion control and positioning systems for customers in industry, science and research. As a family business, the owners continue to build open and trusting relationships with customers, business partners and employees. Aerotech has full-service subsidiaries in Germany (Fürth), the United Kingdom (Ramsdell), China (Shanghai) and Taiwan (Taipei) and currently employs around 500 people worldwide. It has founded a subsidiary, Peak Metrology, to offer a wide range of products for surface metrology applications, including turnkey machines.

www.aerotech.co.uk ▪ www.peakmetrology.com

Fig. 4 Microscopy system with expanded working volume and industrial automation options

will prepare this individually for the customer. They can then integrate additional applications such as laser beam guidance or sensors themselves as required. “These are the sort of tasks that we are given here every day,” emphasizes Norbert Ludwig. “It is about offering the customer a freely expandable solution that is ready for use as quickly as possible without much effort and is versatile enough to adapt to other process requirements in the future.”

Flexible control systems for the medical market

Aerotech established a close collaboration with a well-known Swiss manufacturer of ceramic dental implants. They use a manufacturing system with an integrated galvo scanner to laser cut the microgrinding pins. The complete mechanical part with the linear drive, axes and the control software came from Aerotech, while the housing and remaining peripherals were assembled by the implant manufacturer’s own team. To process a workpiece, the manufacturing system is loaded by a handling robot which, together with the measuring system, is connected via Aerotech’s control software. The medical technology manufacturer had neither experience with laser technology, nor prior knowledge as to how it could be integrated with a manufacturing system, although they were aware there was no off-the-shelf system with an integrated laser. The company was therefore looking for a supplier who could cover as broad a spectrum as possible.

A suitable builder of automation systems was found in Aerotech, who realized a production system that matched the Swiss manufacturer’s needs. CNC control, linear drives, axes and galvo scanners for the laser: Aerotech was able to provide and integrate all components for the manufacturing system. The medical technology manufacturer also benefited from the fact that the same Aerotech control system is used across the entire process. The peripherals can also be expanded at any time without having to purchase any new control software, in the event that a Profibus or an additional piezo axis needs to be integrated for example.

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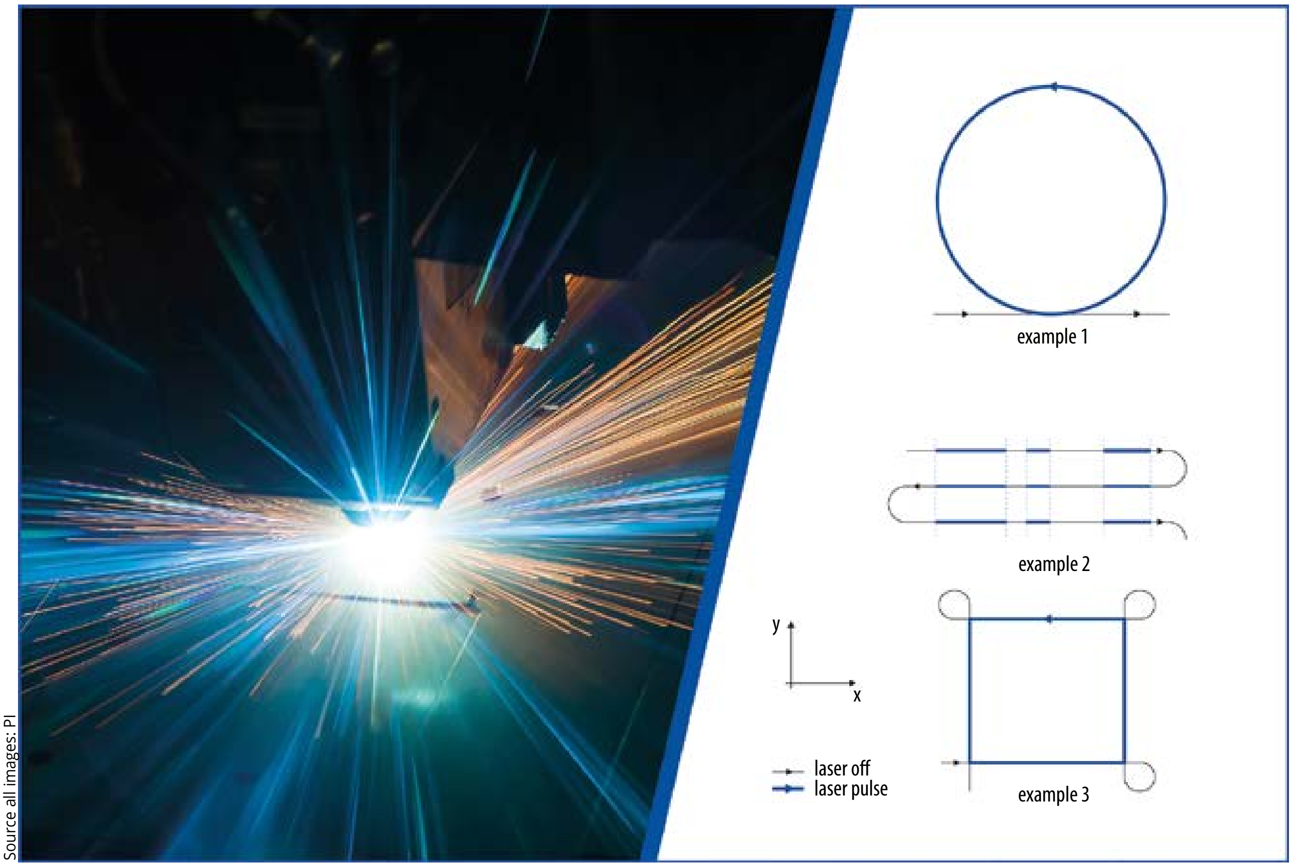
Simple, fast, accurate, and flexible control in laser materials processing

Linking laser control to speed and position – the challenges of controlling multiple axes

Cliff Jolliffe



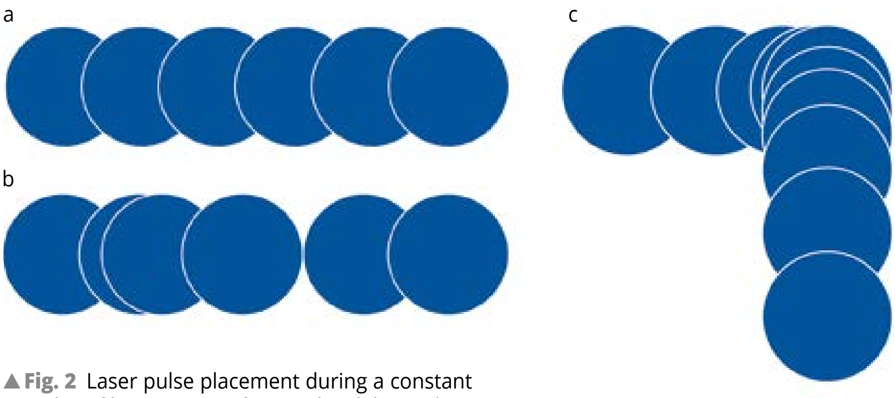
Source all images: PI

Until recently, controlling the motion path of lasers across multiple axes has come with certain limitations in performance, speed, practicalities and, on top, higher complexity and costs. With the development of new modular controllers, flexible solutions that enable a laser to be combined with multiaxis positioning are making it easier for system integrators to design and build advanced systems for a new era of laser applications.

▲ **Fig. 1** Turning the laser on/off at predefined positions along the path.

Lasers have been used for welding and cutting applications in materials processing for many years. However, laser technology has frequently been considered a specialist area, requiring complex control systems for accurate positioning, as well as significant investment and expertise. Recently, the cost of lasers has collapsed, opening this powerful technology up to new applications, even the latest extremely fast, ultrashort pulse lasers are now feasible options for machine builders who would typically have used less risky laser setups.

The commoditization of lasers means that system integrators must do more to gain and maintain an advantage, and that positioning and control – as integral parts of any laser system – are important elements of this. The newer technologies work in a slightly different way, so it makes sense that positioning and control also need to be different. The basic ability to fire the laser in the right place has become more challenging, and a simpler approach is even



▲ **Fig. 2** Laser pulse placement during a constant speed profile (a), non-uniform pulse delivery (b), pulses bunching up around corners (c).

more important than ever, especially for those who are completely new to the technology.

Novel solutions are now available that take a uniquely modular approach to laser control, making it far easier and faster for system integrators to design and build systems in the first place, whether or not they have previous experience of lasers. The use of industrial control networks such as EtherCAT makes this modular solution even more flexible because other items – such as sensors or non-motion devices – can be easily incorporated.

This paper looks at the positioning and control of lasers in detail, the challenges that system integrators face and, more importantly, the solutions that are available to them that simplify system builds.

Why choose laser processing?

There are many significant advantages to using lasers instead of traditional machining processes, not least their capacity for much higher throughput. Lasers are not susceptible to the same wear and tear that can lead to breakdown disruption and costs in mechanical components, and they are often efficient at processing materials that are otherwise notoriously difficult to deal with. The fine beams of lasers also give a level of elaborate detail and accuracy that is almost impossible to create using other methods, which is ideal for applications generating high aspect ratio holes or other features requiring similar high precision.

High intensity, short pulse lasers in particular are incredibly precise. The low thermal energy deposition around the beam of these lasers means there is negligible damage to the surrounding areas. Lasers can even process below the surface of a material, depending on where the beam focuses, examples of which can be commonly found in microelectronics devices, such as light-emitting diodes and flexible displays.

Striking the right balance of speed, power, and precision

Whatever the application, fast shuttering and accurate firing of laser pulses is essential to ensure consistent, high-quality processing. Precise placement and energy control are crucial for this and can be achieved by linking the automation and motion system directly to the laser output. It is extremely important to be able to make sure that the laser is focused on the right place, for the right amount of time, and delivering the right level of power in order to prevent damage to the material or the production of inaccurate parts.

One option is to link laser power to pulse rate and modulation. If the power is fixed, then the motion system will need to run at a constant speed to ensure that the correct level is delivered across the surface. This suits some operations, such as raster scans where the laser is fired following the motion in one direction, or during the constant velocity phase between acceleration and deceleration phases. However, cutting and welding applications may also need the laser pulses to overlap at a consistent ratio, even when the motion path speed is not constant, and laser pulses occur at a fixed frequency. Fig. 2 shows an example of this: Fig. 2a shows the laser pulse placement during a constant speed profile, and Fig. 2b when the velocity changes. This could result in non-uniform pulse delivery where too much energy to a particular area could create heat-affected zones (HAZs), and too little could cause weak regions or breaks in the cut or weld path.

The problem of HAZs occurs even more frequently with multiaxis systems, simply because of the nonlinear path of corners or arcs. The best analogy is that of a sports car driving around a racing track – when it gets to a corner, it must slow down, otherwise it wouldn't be able to follow the racing line and would probably run off the track; the same is true for an x-y table. However, if the motion path slows down too much but the laser pulsing rate remains constant, too much power is delivered into the corners as the laser pulses bunch up (Fig. 2c). Some G-code-capable CNC machines have look-ahead capabilities to address this, allowing the motion controller to look for changes in speed that exceed predetermined limits.

Linking laser control to speed and position

One of the simplest methods of controlling laser power is to link it to the velocity of the motion path. This can be simply achieved by linking an analog output in the controller to that of the vector speed of the motion path, and linking this to the laser power. The analog output is connected to the power input connection on the laser, for example, a 0 – 10 V_{DC} range.

Typically, the motion controller will allow you to define a scaling factor so that the maximum output is relative to the maximum power of the laser required for the process – a lower limit may also be set. It is important to remember that if the motion is badly tuned, jerks may result in bad processing. Poor placement accuracy could also create a bad quality part. This is a simple but effective process, for example in welding.

Another approach is to precisely control the laser by pulse placement along the motion path, regardless of

Company

Physik Instrumente (PI)

PI is a privately held, global-leading manufacturer of world-class precision motion and automation sub-systems, including gantry robots, hexapod 6-DOF micropositioners, nanopositioning stages, air bearings, and piezo motors. PI was founded 5 decades ago, currently employs 1400+ people worldwide and runs design, manufacturing and service centers in the USA, Europe, and Asia. PI's customers are leaders in high-tech industries and research institutes in fields such as photonics, life-sciences, semiconductors, and aerospace.

www.pi-usa.us

the vector velocity. It is also possible to combine these two methods to control the scaling of the power output, which overcomes undesired features of the laser electronics or optic path.

There are several technologies available in the industry that can generate such accurate, high-speed, position-based events linked to electronic outputs such as laser pulses. Although subtly different from each other, they essentially do the same thing for motion in a single axis. Some are better suited to galvo-technology, others are more aimed at motorized positioners. Now, with the development of a new modular controller from Physik Instrumente's (PI) subsidiary ACS Motion Control, the Position Event Generation (PEG) is emerging as an exciting and flexible solution to provide a laser with multiaxis positioning.

The challenges of controlling multiple axes

Paths that create three-dimensional trajectories can be created from three or more axes. Examples are simple dual vector tracking – generated from two axes and widely used for linear x-y table contouring, including circles or arcs and straight lines – a linear theta combination for processing tubing, or any combination of linear and rotary stages, producing helical motion for drilling for example. Controlling the motion path of lasers across multiple axes has, until recently, had some limitations in performance, speed and practicality along with higher complexity and costs.

Restricted application, performance, and speed

Many of the drives available for precision motion and laser processing have to be predefined, depending on the feedback device used on the stages or the table used in the motion system. 'Positional feedback' means a device that is capable of reading the stage's position, but also allows the controller to calculate the speed of such a device. Some motion stages do not use any feedback; they rely on the principle that the commanded motion request equals the actual response. Feedback systems are typically either incremental or absolute – incremental encoders require a reference point or known position when the system starts up, often provided by a homing switch. In comparison, an absolute encoder system has the positional data built into the feedback measurement scale. This positional data is available at startup and therefore removes the step of physically moving the system to a reference point.

Incremental feedback systems

There are two types of incremental encoders, square wave or sinusoidal (sin/cos wave).

Square wave encoders provide the system with discrete digital steps of a fixed distance. For example, a square wave encoder on a rotary motor may output 1,000 steps per revolution; if the rotary motor is driving a 1 mm pitch screw, the system resolution would be 1 mm/1,000, i.e. a 1 µm resolution. A potential problem with a square wave encoder is when it has a high count output to obtain resolution, and the system also requires high speed. The output frequency could potentially exceed the maximum frequency input of the controller's feedback circuit, resulting in position loss.

Sine wave encoders are able to provide much higher resolution with higher stage speeds because the controller inputs the data at the fundamental frequency of the encoder, which is much lower than the square wave equivalent. The controller feedback circuit internally subdivides the sine wave into digital steps; this process is called multiplication.

In practice, a square wave encoder may start out as a sinusoidal encoder, and the key difference is where the digitization or multiplication takes place – at the feedback device in the case of a square wave or in the controller.

However, many laser firing controllers unfortunately cannot use sinusoidal feedback to produce an output that will trigger the laser – their electronics require digital square wave signals – and this may restrict their usability to low-speed systems with high feedback resolution or to high-speed systems with low feedback resolution.

Multiple feedback in multiaxis systems

Laser synchronizing technologies use encoder data for single-axis path motion to trigger, for example, one-to-one firing so that there is a single laser pulse with every millimeter or micron moved. The same principle can be used for multiaxis motion, for example pulsing in a circle – data is taken from the individual encoders of each axis and fed into on-board electronics hardware where the combined vector output is calculated. This has been the accepted norm for many years and, in theory, its accuracy comes from the fact that it is based on real-time positional information from the encoders. In reality however, if the motion system is not adequate in performance, then this approach will produce poor results. For example, a constant speed circle on an x-y table is made up of sinusoidal changes in velocity for each axis. A change in velocity means there must be an acceleration associated with the motion. Acceleration is directly proportional to the following error (the difference between the commanded path and the actual path). The path will therefore always deviate from what was commanded, and it is the user's responsibility to ensure that the error is below the threshold for the required accuracy. The path may be longer or shorter because of the deviation, which would mean the laser pulsing could be activated at incorrect positions.

Additionally, the electronic circuitry used to process multiple feedback devices, and to create the output vector used for firing, can introduce a significant delay (latency) to the output; the more encoders that are tracked, the more dramatically the speed of the output reduces, and consequently the data input rate (tracking) of each feedback is reduced.

Fig. 3 Typical setup of x-y linear motor stages and vertical stage supporting a laser head.

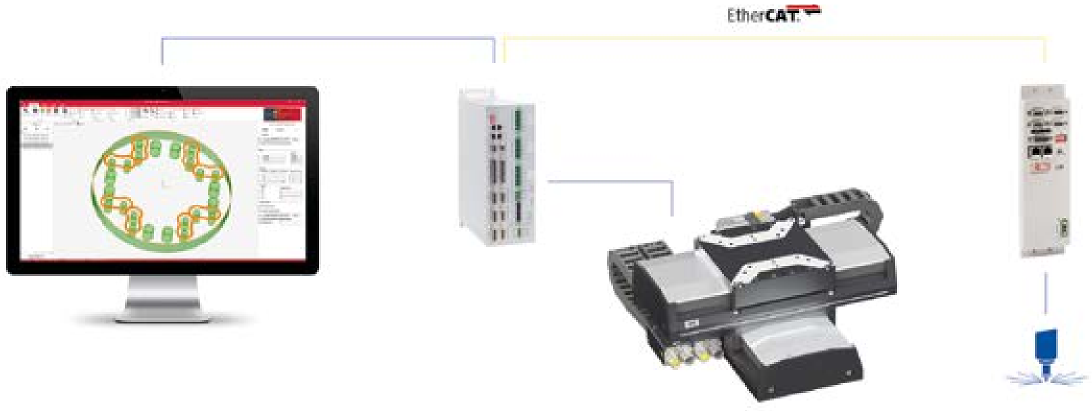


Fig. 4 Simple connectivity of an Ethernet cable

Non-incremental, non-direct, or non-feedback systems

Firing hardware that requires encoder data obviously cannot be used to generate events for motors that have no feedback, such as stepper motors. Similarly, they are not appropriate for serial communication-based absolute encoders. These encoders do not need to be homed when they start up, which can be a significant advantage with regard to safety and convenience for some advanced systems. Kinematic systems like hexapods are also challenging – the encoder data is not directly linked to the position or motion in a parallel direction, or it may be a combination of data from multiple axes that requires calculation, and so does not generate direct triggering for paths in Cartesian coordinates.

There are very few automation controllers on the market that can handle this level of complexity to ensure that the motion system not only has the correct motion performance, but also have the ability to read in and trigger out the encoders used in these applications. With this in mind, users should consider pulsing strategies that do not rely solely on direct feedback.

Whichever method is chosen, the machine builder should always consider the motion performance of the mechanics and controller. Motion systems have other system issues, such as resonances, low bandwidth, underpowered motors, or mechanical inadequacies (accuracy, roll, pitch, yaw, flatness, straightness, and stacking areas) that need to be appropriately matched to the system requirements so that the work piece or the laser head is in the right place when firing occurs.

The drawbacks of repurposing drive systems

Laser processing brings additional hardware requirements to an automation system and the system designer needs to be aware of the input and output needs of connecting a laser to a controller. In theory, every time a system integrator designs a new system with advanced laser control abilities, they must take the input/output capability of the master controller or the master drive unit into consideration. This is frustrating because the focus shifts from the servo performance required to the laser connection functionality. Typically, the machine builder has to completely rebuild the entire control system to take account of these additional requirements. This may involve replacing the first drive unit with a physically larger, much more complex, and more expensive drive that combines such capabilities. This can have a significant impact on cost, including the time required to redesign the system, additional hardware, stock of spare parts, and larger electrical cabinets.

The advantages of modular design

PI's ACS Laser Control Module (LCM) introduces a modular way to construct motion systems, based on the EtherCAT industrial network. It does not rely on encoder data and allows drives to select specified axes requirements. This new approach offers system integrators – particularly those who are new to the field – a far quicker and easier way to significantly expand their capabilities in laser control, and gives them the flexibility to add high-performance, multi-axis capabilities as and when they are needed, greatly simplifying the system architecture of the drives.

The LCM does not change the types of drive used for motion but simply connects to the existing network. The simple architecture of an add-on module is ideal for laser control. There is no need to change the drive types, which greatly

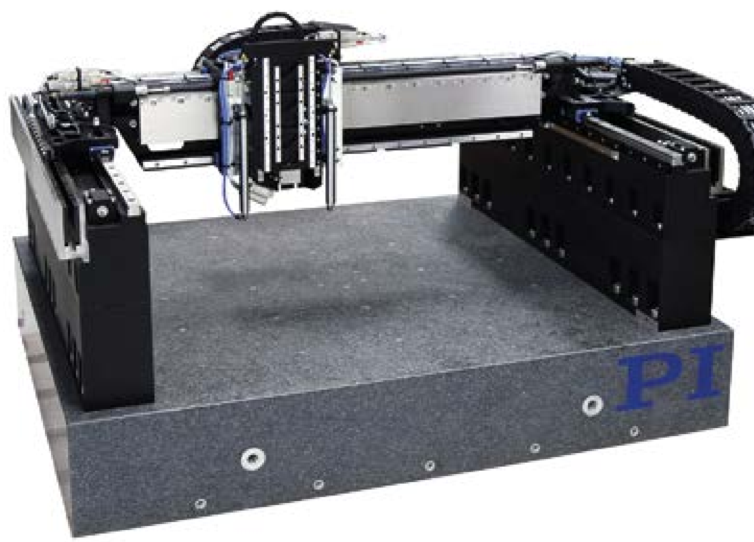


Fig. 5 PI moving gantry system employing two independent encoders for base motion.

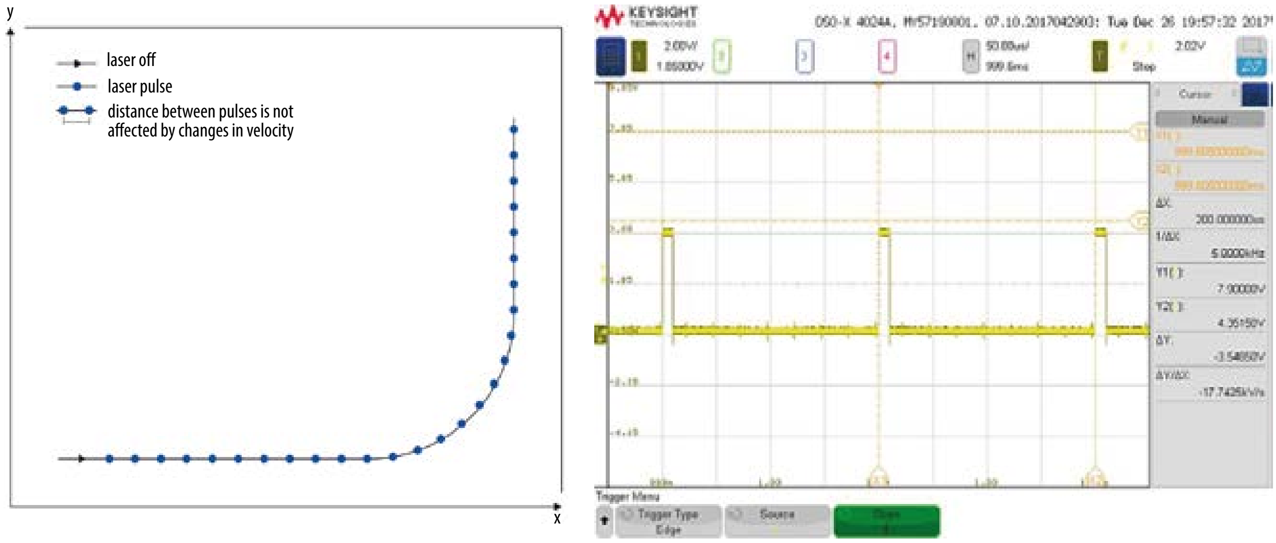


Fig. 6 LCM fixed-distance firing – defined by distance, not time.

simplifies the cabinet design. There are no changes to the existing hardware, which reduces stock requirements for spare parts. There is no additional wiring except a simple Ethernet cable. The time saved in design and build is also economically beneficial. This approach makes it really quick, easy, and extremely cost effective to construct a universal drive offering high performance that covers every eventuality.

Sharper performance

ACS' motion systems – combined with well-designed mechanical platforms that take into account the demands of laser processing (PI's V-41X stage series) – allow the user to simply add laser control using the LCM module to be able to fire along a highly accurate path. The ACS controller dynamically corrects disturbances and vibrations that occur in real time, ensuring minimal following errors.

The ability to use any type of feedback is hugely advantageous from a system integrator's point of view because it offers the potential to mix axes with or without encoder data, combine incremental and absolute encoders, or incorporate kinematic systems that cannot interpret direct output from encoders. This means that a total system solution that uses the right technology to solve the problem can be created.

Simple connectivity

Multiaxis control systems use output encoder pulses from each axis and feed these back to a central location by means of wiring. This sometimes involves complex encoder cables that split the signal between one axis drive and the central controller, adding complexity and wiring to the system build. In contrast, the new modular concept adds PEG to an entire drive system using the well-recognized EtherCAT industry standard (**Fig. 4**) – integrated by using a simple Ethernet cat5e cable – taking the individual path information directly from each motion device on the EtherCAT bus and linking the positional information from multiple axes to a single PEG output. This data is then used to generate laser control events along the combined vector path and to control the system's laser.

No feedback, absolute encoders, and kinematic transformation

Using stepper-motor-driven stages for laser control must be undertaken with caution. Open-loop positioning does not provide information when a motor has lost position due to a potential fault, but it does open up the method for lower cost and less demanding motion applications. In addition, there are certain situations where absolute encoders are ideal because they do not require referencing at machine power-up. This can help to avoid collisions of stages or parts with obstacles in the machine layout, allowing the system to intelligently create regions where the stages should not enter, or to provide additional flexibility when unusual or oversized parts need to be processed.

In systems where the three-dimensional coordinate system is made up from complex kinematics, or paths are created from nonlinear devices such as rotary stages, it is necessary to create motion path data that is not related directly to encoder feedback. The LCM can function without the use of encoder data, so it is ideal for either of these scenarios.

Gantry control

In general, gantries have two motors to move the bottom axes, guided by two encoders directing the base of the system. Other control signals also come from side encoders. However, these encoders may generate different readings and there is the potential for firing in the wrong place. The risk of this happening increases with wider gantry systems that have a long cross axis or high dynamics. The LCM combines the data from the two encoders in line with the carriage (laser) and effectively removes the effect of having two potentially conflicting feedback sources that could lead to inaccurate firing. ACS controllers provide PI gantries with additional controller algorithms thatenhance stability and positional accuracy across all travel ranges of the system in real time. These facilitate low following error and high disturbance rejection, which again ensure that the laser is fired at the right position.

Opening up control options for the new laser technology

Laser material processing is now a significant aspect of industrial manufacturing – used for tasks ranging from heating for hardening, melting for welding and cladding, and the removal of material by drilling and cutting – and many of the new technologies would benefit from a system that could synchronize laser pulse control with motion.

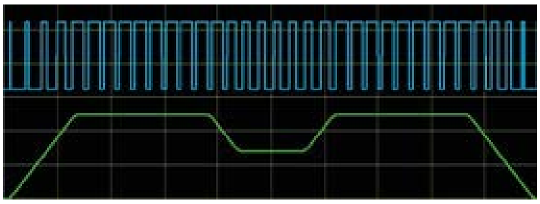


Fig. 7 Increasing duty cycle based on increased speed

For example, high-intensity, femtosecond laser processing, which is becoming more common as more industry-proven commercial lasers become available, is considered a cold process because the material being processed does not heat up during the interaction. This type of processing includes the texturing of surfaces to decrease reflectivity, provide hydrophobic surfaces, or create chemically reactive surfaces. It is of particular interest in the automotive industry where the push for improved efficiency is driving the reduction of friction of moving components, to lessen the use of lubricant consumables and to improve durability.

Another useful property of the 'cold' ablation of high intensity lasers is the ability to drill clean, small, deep holes in materials without damaging the surrounding material. This technology is now commonly used in the medical industry to fabricate vascular stents and it has been widely adopted to produce holes with diameters of microns and a large depth-to-diameter ratio.

Other applications include the dicing of glass that allows the back of a surface to be processed without damaging the front. This application is simply not possible using conventional mechanical, diamond blade dicing techniques.

Micromachining and welding are commonly carried out by nanosecond fiber lasers. Although the fiber laser has a longer pulse duration than femtosecond lasers, it can be used with careful control of pulses and processing parameters. In this type of laser processing, the energy is eventually converted into heat that dissipates out of the laser spot, beyond the duration of the laser pulse. Essentially, fiber lasers keep costs lower, so if the process is controlled and the results are suitable for the application, they make a lot of sense.

In all of these applications and others, controlling the pulse duration, frequency, and placement is key to changing the laser process capabilities, quality and intermolecular interactions.

Basic modes of operation

The simplest method of laser control is to define the switch-on and switch-off positions. The laser power control is set by the laser itself or by an additional analog input as described earlier for power related to speed.

The next method to consider is distance-based pulse control, which is when the laser expects to see a trigger at a fixed distance along the path. The user defines the switch-on and switch-off positions as before, but the firing signal is not continuously on. The controller may use this pulse to create a single shot from the laser or a combination of pulses for a particular laser processing recipe. Another method is based on the fact that the pulse trigger positions are not at a fixed distance but at user-specified points along the path. This is typically called 'random position pulsing' or 'array-based pulsing'. Some lasers have quite capable internal pulsing mechanisms and prefer simple gating or on/off commands; others require a pulse-width modulation (PWM) type of input. This is useful to control the laser power based on speed.

To improve application and process throughput, both the pulse and PWM inputs can be controlled by advanced laser control capabilities from the laser firing controller. The different methods can also be combined to offer even greater flexibility, precision, and throughput. The following section shows graphical examples of the different methods of control (Figs. 1, 6, 7).

User-specified output pulse generation

The combination of high resolution, multiple axes and high speed within one system can be problematic for a user to calculate the distance along the outputting vector path. Fortunately, laser firing modules like the LCM calculate the vector path for you. This makes it simple to define a fixed distance along the path, even when the path may be physically in one direction or a combination of multiple axes. In addition, modules like the LCM can subdivide the resolution of the encoder so that the firing position occurs below the natural resolution of the system, potentially improving placement accuracy.

It is also possible to define a series of pulses that occur after the initial pulse. This can be used where an event may require a series of pulses or a laser may expect an addition excitation pulse, or multiple pulses, to build an average power level from the laser.

Firing at defined positions along a path

Rather than telling the system to fire at fixed discrete positions, it is also possible to define an array of positions where firing occurs (array-based or random

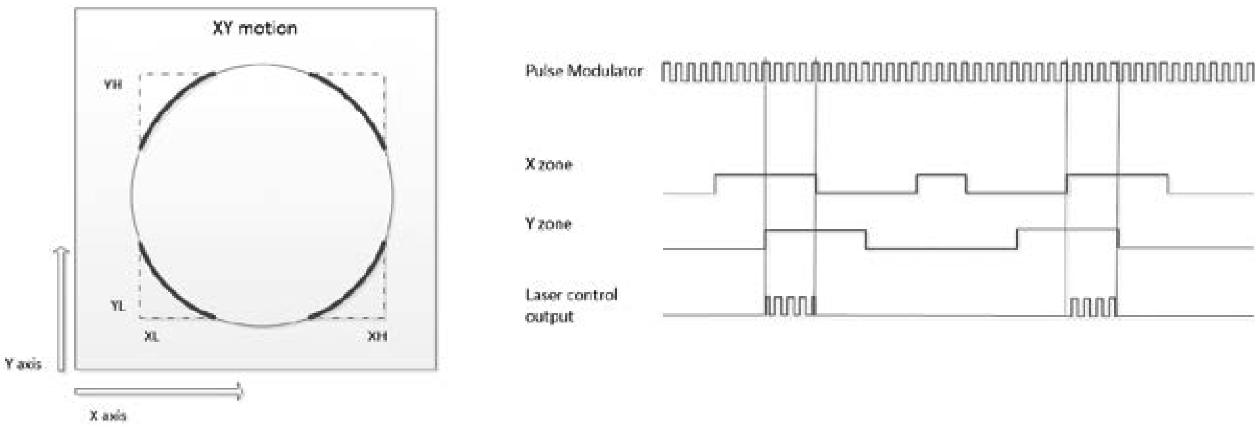


Fig. 8 Hybrid mode with PWM modulation and array gating (windowing)

firing). This can be used when an event may trigger a single shot or an alternative processing regime, for example, due to a material or process change (cutting versus welding).

Isolating an area of interest (windowing)

Some users may simply need to tell a laser where to turn itself on or off. The laser power may be controlled, for example, by an analog input (typically a 0 – 10 V signal). Alternatively, laser power can be controlled by a combination of modes, such as fixed-distance pulsing or PWM. Windowing can be overlaid with these methods to simplify the laser processing areas. This typically uses an array method to define the start and end of the window.

PWM mode

This method is very common in electronics, directly controlling laser power by using PWM to adjust the duty cycle. Hybrid modes are also available that combine PWM with pulsing at user-defined intervals, allowing nonlinear or varying firing events. In addition, zones of operation can be created, giving even tighter control over where firing or modulation takes place.

Fig. 8 shows when windowing and PWM are combined to provide discrete areas of laser firing.

Summary

The latest fast and ultrashort laser sources are now available at a reasonable cost, opening up many opportunities for system integrators to incorporate these innovative technologies into new applications. New tools offer faster solutions and the ability to process smaller features in a different way that was not previously possible with conventional methods.

However, for processes that require motion in the form of linear, rotary and nonlinear kinematics, it is essential that the laser firing is synchronized accurately with the motion path positioning. Electronics that allow this have been available in specialized motion controllers for some time, but now the industry is moving more towards networks such as EtherCAT that make it far simpler to add or to link laser pulsing hardware. The significant advantages for the system integrators and builders of electrical cabinets brought by this level of connectivity allow them to choose the appropriate motion amplifiers and controls for the motion and the right interfacing for the laser, giving them simple, fast, accurate and flexible control of their laser processing.

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Case study: power supply units

Fine-tunable switching power supplies as laser drivers

LaCoSys Laser Control Systems specializes in manufacturing optoelectronic products. The company's electronics experts have started integrating fine-tunable Cotek power supply units into their customers' laser test systems. Featuring technology much like that found in laboratories, these power supplies have a great advantage: they not only provide voltage, they can also a deliver a precisely calibrated amount of current.

Laser and laser diode manufacturers count on LaCoSys test systems to assure the quality of laser diodes installed on their production lines or test benches. Their objective is to minimize the failure rate and to rule out early failures altogether. After all, it is annoying when a service technician has to set out yet again to replace a faulty laser diode.

This is why manufacturers conduct burn-in tests. This method involves stress-testing laser diodes on a special burn-in board for up to 100 hours at or above their rated operating conditions to identify components that will fail prematurely, before their expected lifetime elapses. These operating conditions may include temperature, voltage/current, operating frequency and other parameters with specified thresholds.

The Cotek AEK-3000 power supply takes on the role of a laser driver in the new LaCoSys burn-in test system. (Source: Systemtechnik Leber)

DOI: 10.1002/phvs.202200053

Denny Vogel and Tino Becker

Systemtechnik Leber GmbH & Co. KG,
Schwaig, Germany

https://doi.org/10.1002/
phvs.202200053

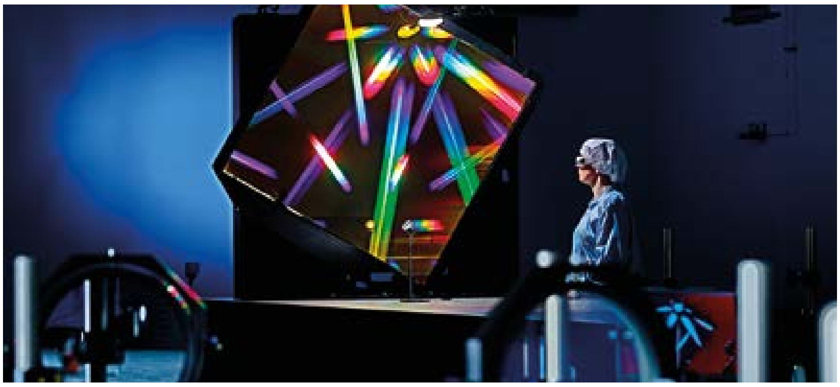
Resource-efficient generation of large-area micro and nanostructures

High-quality, large area diffraction gratings originated by diode laser-driven interference lithography

Lasers are widely used in various manufacturing processes. In order to achieve sustainable production, it is important to reduce the environmental impact caused by the laser operation. One major improvement is the step from gas lasers to diode lasers.

Replacing gas with diode lasers reduces the energy consumption of the light source by up to a factor of 1,000. Gas lasers usually also require substantial cooling, either wasting thousands of liters of water every operating day or increasing energy consumption when a closed cooling circuit is used. This article addresses large scale interference lithography as an important application, where gas lasers were the light source of choice until the arrival of solid-state lasers and novel diode laser solutions in recent years.

DOI: 10.1002/phvs.202200054



The large-scale interference lithography setup at the Fraunhofer Institute for Solar Energy Systems ISE (Source: Fh. ISE)

Benedikt Bläsi

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Martina Müller

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TOPTICA Photonics AG, Gräfelfing, Germany

https://doi.org/10.1002/
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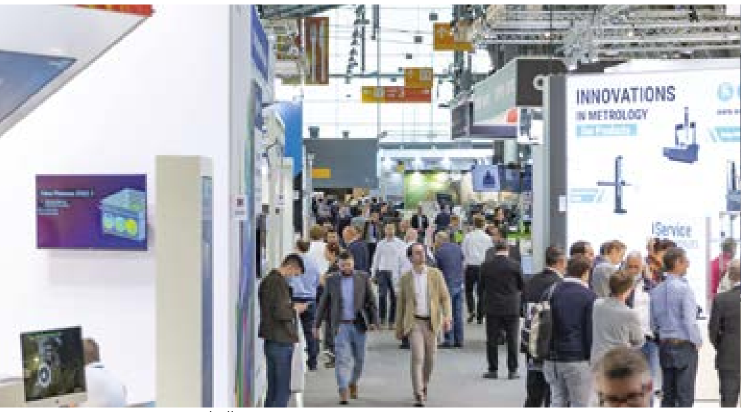

Source: P.E. Schall

Source: Palexpo / Tema

November 30 – December 1, 2022
W3+ Fair Rhine Valley
Dornbirn, Austria
https://w3-fair.com/en/rhine-valley

December 6 – 8, 2022
SPIE Photonex Conference & Exhibition
Birmingham, UK
https://spie.org

December 6 – 7, 2022
2nd International Conference on Applications of Quantum Technologies QuApps 2022
online
https://quapps-conference.com

January 28 – February 2, 2023
SPIE Photonics West
San Francisco, CA, USA
https://spie.org/photonics-west

February 22 – 24, 2023
PHOTOPTICS
Lisbon, Portugal
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March 7 – 8, 2023
LEF 2023
Fuerth, Germany
www.lef.info

March 22 – 24, 2023
LASER World of PHOTONICS CHINA
Shanghai, China
www.world-of-photonics-china.com

March 29 – 30, 2023
W3+ Fair
Wetzlar, Germany
https://w3-fair.com

April 17 – 21, 2023
Hannover Messe
Hanover, Germany
www.hannovermesse.de

May 7 – 12, 2023
CLEO
San Jose, CA, USA
www.cleoconference.org

May 9 – 11, 2023
Sensor + Test
Nuremberg, Germany
www.sensor-test.de

May 9 – 11, 2023
SMTconnect
Nuremberg, Germany
https://smt.mesago.com/nuremberg/en.html

May 9 – 11, 2023
Rapid.Tech 3D
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Re-Start in Autumn

After a 4-year interruption, the optotech and image processing sectors met once again at Optatec

Source: Schall

Optatec is a meeting place for experts, manufacturers and users of optotechnology and image processing

The 15th Optatec international trade fair for optical technologies, components and systems in Frankfurt was a resounding success from the 18th through the 20th of October, 2022. 255 exhibitors from 30 countries presented their global optotechnology products, stand-alone and system solutions as well as related software applications. These covered components, optomechanics, optoelectronics, fiber optics and cables, laser components and digital microscopy together with optics production machinery. Almost 3,500 visitors from 37 different countries - including some from China and the USA - viewed the exhibits in Hall 8 of the Frankfurter Messe.

It became plainly apparent right from the outset just how important face-to-face technical discussions can be – they can not be replaced by any other form of communication. This was confirmed by numerous enthusiastic voices. “We are always eager to participate at Optatec in Frankfurt in order to present new products and meet up with customers and partners,” said Dr. Christoph Seibel from Hamamatsu Photonics Germany. “It is important to be on hand and offline – it is indispensable.”

“We are thrilled – great event, interesting discussions,” said Axel Haunholter from Optosigma Europe in Munich in summing up his company’s second appearance at Optatec. And he added that Optatec is the right trade fair for anyone interested in optics.

Dr Jürgen Bode of Satisloh, a global supplier of eyeglass and precision optics, was very pleased with the high levels of visitor interest in, amongst other things, the new coating machine introduced by the company as a trade fair highlight this year.

The topics covered by Optatec are steadily gaining in importance in all industrial and non-industrial sectors. Optical technologies are being driven by ever-stricter quality requirements, as well as by expanding use of automation and digitalization. “After the trade fair had to be postponed several times and was at last being eagerly anticipated by the industry, these three days have once again underscored the global significance of the event,” sums up project manager Fabian Krüger from trade fair promoters P. E. Schall.

www.optatec-messe.de

Successful EuroBlech 2022 exhibition

The 26th International Sheet Metal Working Technology Exhibition had four days of flourishing business

A total of 38,076 trade visitors from around the world came to Hanover to shape the future of sheet metal working and defy current challenges. This year’s show hosted 1,300 companies from 39 countries on a net exhibition space of 86,136 square meters.

A closer look at this year’s visitor numbers reveals that 35,944 unique visitors came to the exhibition grounds in Germany. Practically matching the previous edition’s stats, this is a good result, especially given the difficult general conditions. Industry experts from all parts of the world came to the show for shorter but therefore more productive visits. “It is hard to describe how we are feeling after giving everything we had in the past four years to make this show possible. We are overwhelmed by the outcome and proud that EuroBlech continues its critical role in bringing the global sheet metal working industry together,” says Evelyn Warwick, exhibition director of EuroBlech, on behalf of the organizers Mack-Brooks Exhibitions. “This year’s edition was both special and hugely important for the whole sheet metal working industry. Judged by the exhibition space itself, you can tell as we came pretty close to the record numbers in 2018,” continues Evelyn Warwick.

Many exhibitors at this year’s show have already announced that they will exhibit again at the next EuroBlech in 2024, which will take place on 22 – 25 October 2024 at the Hanover exhibition grounds in Germany. (Source: Mack-Brooks)

www.euroblech.com

Source: Mack-Brooks

The hot topics this year were digitalization, sustainability and Industry 4.0

Vision 2022: machine vision fair exceeds expectations

The trade show recorded 6,505 trade visitors, making it the world's leading event for the machine vision industry.

Vision 2022 recorded a total of 6,505 trade visitors. (Source: Landesmesse Stuttgart)

"Vision 2022 was a complete success and far exceeded our expectations – both on the visitor and exhibitor side. It is also nice to see that the event was able to record a higher international participation again after the pandemic-related restrictions of the previous year. This means that the vision is also developing in the direction of familiar structures again in the context of changed information procurement," says Roland Bleinroth, managing director of Messe Stuttgart.

Visitors from around sixty countries were registered. The most strongly represented countries were Italy, Switzerland, the Netherlands, France, Austria, Belgium, Poland, Spain and Great Britain. Vision also welcomed a large number of trade visitors from South Korea, Japan and the USA.

In addition to the classic user industries such as electrical engineering/electronics, mechanical and plant engineering as well as the automotive and automotive supplier industries, there was also a large proportion of visitors from non-industrial sectors on site – including medical technology and the pharmaceutical industry, the agricultural industry, aerospace as well as transport and logistics. Accordingly, the interest in offers for non-industrial applications also increased compared to the previous year.

Turnkey machine vision systems also registered increased visitor interest. 55 % of the visitors stated that they were decisively or co-decisively involved in purchasing and procurement decisions in the company. 27 % came to the fair with firm investment or purchase intentions. Demand for machine vision components and systems developed more strongly than expected in 2021. Turnover in the German machine vision industry rose by 16 % to 3.1 billion euros. The European machine vision industry also recorded growth of 17 %.

At the opening of the trade fair, the VDMA's section for machine vision confirmed the positive basic mood in the industry: according to Mark Williamson, chairman of the association's board, "The machine vision industry continues to conquer new fields of application, also increasingly in the non-industrial sector." The positive developments in the machine vision industry were also reflected in the number of exhibiting companies at Vision.

378 exhibitors – 60 % of them from abroad

In addition to numerous first-time participants, the key players in the industry were on site. "Vision is the central platform for us to present innovations and communicate our repositioning as a solution provider. This year, too, many visitors approached us with concrete new projects. Initiatives such as the Vision Guided Tours for Food & Beverages, Intra-Logistics, Medical & Pharma created new incentives for visitors from applications outside factory automation," said Basler's CEO Dr Dietmar Ley. Technologically, Basler experienced a continuation of the trend themes from recent years at Vision 2022. "We saw further development in artificial intelligence, and we expect Industry 4.0 with cloud architecture and AI-based image processing on edge devices to become better established. 3D technology will also continue to mature and become more cost-effective," Ley said.

Jan Hartmann, managing director of IDS, also underlines the importance of Vision as the industry's leading technological trade fair: "Machine vision is a central technology for automation technology, especially in connection with 3D vision and artificial intelligence. At Vision, visitors learned how we facilitate access to these key technologies and help to initiate and optimize automation processes with easy-to-use components."

Vision Award 2022 for CAD Software

Kitov.ai was also present for the first time. The company from Israel won the Vision Award 2022 directly at its premiere for its CAD2SCAN software, which significantly simplifies the setup of robotic inspection systems by using CAD-based automated inspection planning. "Winning the Vision Award 2022 allows us to continue the development of this technology and optimize AI. This makes it easier for manufacturers to adopt automated visual inspection. We are immensely grateful to have been given the opportunity to address a wider professional audience. There is no greater appreciation for our work," said Corey Merchant, vice president Americas at Kitov.ai.

The next Vision will take place on 8 – 10 October 2024 in Stuttgart.

www.messe-stuttgart.de/vision

Source: Landesmesse Stuttgart

The Israeli company Kitov.ai won the Vision Award 2022 directly at its premiere for its CAD2SCAN software.

UV experts from all over the world met in Germany

Review: 3rd International UV Workshop took place at Laser Components HQ


Source: Laser Components

Participants of the 3rd International UV Workshop

On October 5 and 6, more than forty industry and research representatives met at Laser Components' premises in Olching near Munich for the 3rd International UV Workshop.

For two days, the experts exchanged information about the latest developments in the field of ultraviolet light. The second day of the event was completely dedicated to the growth market of UV-LEDs. For these sessions Laser Components and the industry association Advanced UV for Life had developed a program that focused on the short wavelength ranges UVC and deep UV. UVC applications for disinfection and sterilization are currently among the most important innovation drivers in the industry.

"Laser Components provided a perfect setting for the almost family-like exchange of experience, knowledge and ideas in a way that large conferences cannot offer," adds Klaus Jacobs of Advanced UV for Life. "I would particularly like to highlight the contributions on the current field of Far UVC, which enables UV disinfection without doing any harm to the human skin or eyes. The workshop gave an overview of the latest status from an industrial point of view."

www.lasercomponents.com
www.advanced-uv.de

Preview: SPIE Photonics West 2023

28 January – 2 February 2023 San Francisco, California

The largest annual conference and exhibition in optics and photonics, hosted by SPIE, will be bringing together researchers, innovators, engineers, and business leaders from across the globe for a dynamic and engaging week of networking and learning.

Photonics West will showcase the latest technologies and discoveries using optics and photonics, with four major application topics: BiOS, highlighting new research in biophotonics, biomedical optics, and imaging; LASE, with its focus on the laser industry and applications; OPTO, covering optoelectronics, photonic materials, and optical devices, and Quantum West, featuring technical conferences, a quantum-specific plenary session, and presentations from industry leaders who are moving quantum technologies to market. Overall, this year's Photonics West program includes more than 4,500 technical presentations.

Featuring over 1,000 companies with product launches, live demonstrations, and technologies on display, the BiOS Expo and Photonics West Exhibition showcase the diverse and healthy photonics industry. The BiOS Expo, featuring the latest technology in biomedical optics and healthcare applications, runs 28 – 29 January; the Photonics West Exhibition, 31 January – 2 February, showcases the latest from laser manufacturers and suppliers as well as other innovative optics and photonics devices, components, systems, and services. Both exhibitions are free to attend.

From the BiOS Hot Topics and conference plenary sessions, to the Prism Awards and the SPIE Startup Challenge, the event-filled week will showcase the latest technologies and industry developments across the optics and photonics spectrum. Confirmed hot topics and plenary speakers include Aydogan Ozcan, University of California, Los Angeles; Mark Anastasio, University of Illinois, Urbana-Champaign; Maryellen Giger, University of Chicago; Natan Shaked, Tel Aviv University; Chen Yang, Boston University; Vasilis Ntziachristos, Technical University of Munich; Srirang Manohar, University of Twente; Caroline Boudoux, Polytechnique Montréal; Jin U. Kang, Johns Hopkins University; Kirill Larin, University of Houston; YongKeun Park, KAIST; Eric Henderson, Dartmouth Hitchcock Medical Center; Rajeev J. Ram, MIT; Emily Warren, National Renewable Energy Laboratory; Nicolas Grandjean, EPFL; Arnan Mitchell, RMIT University; Eliana Fu, Trumpf North America; Jason Eichenholz, Luminar Technologies; and Jürgen Stuhler, Toptica Photonics.

An educational program of more than 50 technical courses complements numerous professional development workshops, a comprehensive job fair, and valuable networking opportunities for technical attendees, SPIE members, and exhibitors.

Included with full conference registration for Photonics West is access to the three-day SPIE AR-VR-MR event, which focuses on augmented, virtual, and mixed reality and the vital role that optics and photonics play in cross-reality (XR) hardware development. The program incorporates over thirty invited industry talks, keynotes, and panels, a two-day exhibition, and an XR-specific job fair. Invited speakers include experts from Avegant, Lynx, NewSight Reality, Mojo Vision, Schott, Magic Leap, Metalenz, and Sunny Optical.

"We are very excited to again be hosting Photonics West in person, kicking off the calendar year for the global photonics community," notes SPIE senior director of technical programs Marilyn Gorsuch. "Since our successful return to San Francisco last year, we have consistently heard from our community about the importance and value of reconnecting and having face-to-face conversations. Photonics West 2023 promises to be another engaging and thought-provoking week with many networking opportunities planned to complement the strong technical program. This year we will also offer an expanded Quantum West program and a new focus on artificial intelligence and machine learning for biomedical applications. Don't miss this opportunity to join your colleagues from around the world, engage with more than 1,000 photonics companies, and hear the latest research results that drive innovation."

https://spie.org/pw

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Windows, optical

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