Volume 19 June/July 2022 3

PhotonicsViews

OPTICS • PHOTONICS • LASER TECHNOLOGY

COVER STORY

Multiphoton microscopy – ultrashort pulses make a difference

SLT

SPECIAL SECTION
Stuttgart Laser Technology Forum

LASYS

WILEY

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EPIC European Photonics Industry Consortium

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PHOTONICS GERMANY
DGaO

The universal laser machine

On the verge of a new era in laser technology

Thanks to the great progress in the development of ultrafast lasers, it is now technically possible to set up lasers that can switch between cw and (ultrashort) pulsed operation at kW average power levels. The technology is ready and will allow us to perform most of the known laser applications with one and the same device. The prospect of performing everything from micro to macro materials processing with the same laser on one and the same machine bears enormous potential for digital manufacturing and is particularly attractive for small and medium-sized enterprises.

There are already promising demonstrations that combine additive manufacturing with high-precision ablation on one machine for example, but it will still take some significant research effort to realize the universal laser machine on which one can carry out all or at least most of the currently-known laser-based manufacturing processes. The needs are well understood though, and require especially novel approaches to system engineering and the integration of powerful machine learning.

The vision of a universal laser machine is being strongly promoted by the Institut für Strahlwerkzeuge (IFSW) at the University of Stuttgart and is also being successfully pursued within the Innovation Campus 'Mobility of the Future' (ICM). This has been established as a joint initiative with the Karlsruhe Institute of Technology, funded by the Baden-Württemberg Ministry of Science, Research, and Arts. Thanks to these efforts, a new professorship on laser systems engineering has been established at the IFSW in order to intensify the research activities required for the realization of universal laser machines as one key technology for digital manufacturing. The new professor will present his vision and planned research in a keynote speech during the opening session of the Stuttgart Laser Technology Forum (SLT 2022).

Together with many other exciting contributions, the SLT 2022 will once again give us an outlook into the future of laser technology and will highlight the current developments and achievements. The latest developments in laser sources will be discussed along with the latest advances in fiber-based beam delivery, optical scanners, and real-time process control. The materials processing applications to be presented range from high-precision drilling to the fundamentals of additive manufacturing, welding, and cutting. Special emphasis will be given to the x-ray emission generated when processing metals with powerful ultrafast lasers, and the legal and practical consequences.

I wish you inspiring reading of the current issue of PhotonicsViews!

T. Graf

Source: Max Kovalenko

Prof. Dr. phil. nat. Thomas Graf
Director, Institut für Strahlwerkzeuge (IFSW)
University of Stuttgart

SLT 2022
21 June – 22 June
www.slt.uni-stuttgart.de

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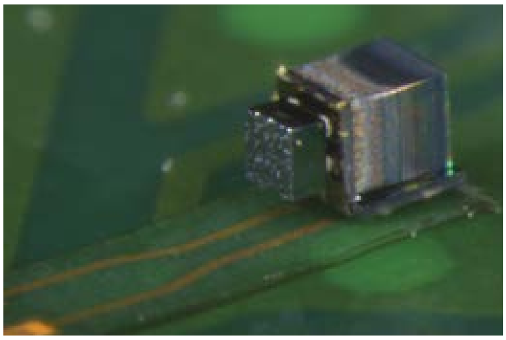

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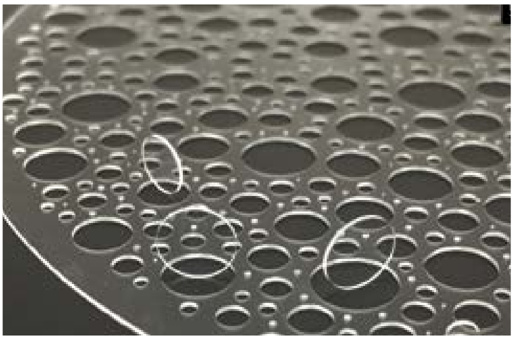
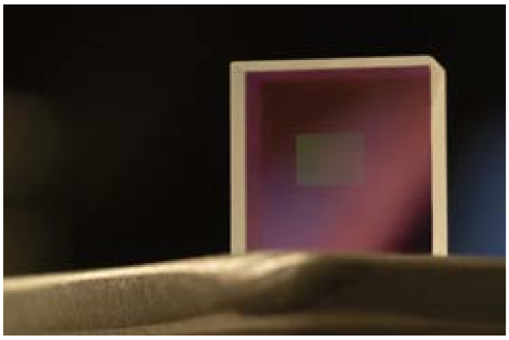


Cover:
The Valo series by Hübner Photonics provides a "market-unique short-pulse performance"
p. 26

"Dawning of a new era" study forecasts quantum systems sales of € 2.3 B in 2030

A new market report by Spectaris and Messe München shows the importance of photonics in the commercial age of quantum systems – a profound technological change is expected in industrial sectors such as medical technology and artificial intelligence.

Quantum systems are opening up a world of completely new possibilities for industry and society. Photonics plays a central role as a key technology for the commercialization of quantum systems and adds another field of application with enormous potential to the diverse and innovative industry. A new market report proves this: the global market for quantum systems is expected to grow sixfold by 2030, reaching a value of € 2.33 B p.a. These figures only include hardware, but also software and services, such as computing-as-a-service, could expand the market by a factor of three to four. It is expected that the manufacturers of basic photonics technology for quantum systems will generate additional sales of € 530 M p.a. by 2030. This does not include the fact that photonics also plays an important role in the production process for this technology.

These are the forecasts made in the market report "Photonics@Quantum: Basic Photonic Technologies for Quantum Systems" which was presented during the Laser World of Photonics fair in Munich. The report was commissioned by the German industry association Spectaris and Messe München and was compiled by the French technology consulting firm Tematys, which has already produced numerous studies on photonics and its important fields of application.

The market for quantum systems is divided into three fields: metrology and sensor technology, communication and computing. In these fields, quantum systems extend existing applications far beyond what is feasible today, for example in medical technology, communications, finance or transportation, or artificial intelligence. So-called quantum cryptography for communications (QKD) is important to protect sensitive communications. And quantum computing will significantly speed up computing processes compared to classical computers.

Managing director of Spectaris Jörg Mayer presents the new studies in cooperation with Messe München (Source: Wiley)

The new market report also makes it clear that many countries believe in the possibilities of this technology: a few years ago, government programs were launched worldwide to fund research into quantum systems, the value of which adds up to 20 billion US dollars over a ten-year period. The European Union is also participating in this race of nations with an amount of $ 1.1 B, and Germany is investing as much as $ 3 B in research into quantum systems. This does not take into account the research expenditures of companies and the investments of private capital providers.

www.spectaris.de
www.messe-muenchen.de

Best business prospects for additive technology

"The additive manufacturing industry is looking ahead with a good dose of optimism." This is how Dr Markus Heering, managing director of the additive manufacturing working group (AG AM) in the German mechanical engineering industry association VDMA summarizes the results of the current survey. Companies covering the entire process chain took part in the survey in March. Service providers and users of additive manufacturing (AM) were particularly well represented.

Heering is extremely pleased that more than eighty percent of the respondents assess their business prospects for the next twenty-four months positively and that none of the participants expects the business situation to deteriorate. Even the short-term forecast for the next twelve months is positive for 65 % of the companies. None of the participants expects a deterioration in business expectations for the current year either. Only 8 % of the participants are strongly affected by the Ukraine conflict.

The respondents underline their optimism through entrepreneurial action. "Every fourth company says it will increase its investments and another 54 % plan to invest at the same level," explains Heering. Only 5 % plan to invest less in technology over the course of the year.

www.vdma.org

German photonics industry logs record sales

The Photonics Germany survey of one thousand German photonics manufacturers after the 2021 annual financial statements showed sales of € 47.3 B. The total is almost 18 % higher than in 2020.

The high growth was supported by strong domestic business, which increased by around 15 %, and even stronger international business with a plus of 19 %. The great importance of international business is also reflected in the export rate of 73 %. Accordingly, € 34.4 B in sales were achieved abroad.

The number of employees rose by nine percent to around 176,300 due to this positive sales development. In the last year before Corona, 2019, the German photonics industry grew by about 16 %. The market research company Tematys expects average annual growth of around 6 % and total sales of almost € 60 B in Germany by 2025.

According to a new study by Spectaris and Messe München, the greatest potential for growth lies in the field of quantum technology. This predicts annual growth of 20 % up to 2030. Other fields of application for photonics are also growing rapidly, such as autonomous mobility. Others are about to be developed, for example precision farming as part of the digitization of agriculture.

Photonics Germany is an alliance between the German industry association Spectaris and Optecnet Germany.

www.spectaris.de

Amplitude acquires MW Technologies

The two companies have been working together for many years. The fiber laser maker from the Porto region has been a trusted manufacturing and R&D partner specializing in fiber laser and control electronics. With this acquisition, MW Technologies' name changes to Amplitude Portugal, becoming the company's fourth manufacturing site and R&D center worldwide.

"We are very pleased with this acquisition which will enable us to increase our production capacity and so offer a better response to our international customers," explains Pierre Rigail, VP, Amplitude head of operations.

"Our collaboration with general manager Miguel Melo and his team will also help us strengthen and consolidate our technical expertise," says Eric Mottay, Amplitude president and CEO.

"Having worked with Amplitude for several years, it is an honor now to be part of a company with the same core values. I am looking forward to sharing our common drive for engineering excellence and quality in laser design and manufacturing," declares Melo.

https://amplitude-laser.com


Source: Amplitude

Miguel Melo (l.), Eric Mottay

nLight acquires process monitoring expert

Plasmo Industrietechnik's assets strengthen nLight's position as a critical enabler of next generation manufacturing solutions.

The acquisition expands nLight's industrial solutions into automated quality assurance products and adds additional scale in Europe.

nLight, a provider of high-power semiconductor and fiber lasers used in the industrial, microfabrication, aerospace, and defense markets, has acquired the assets of Plasmo Industrietechnik, an Austrian-based provider of automated quality assurance and diagnostic solutions primarily for the welding and additive manufacturing markets.

Plasmo's innovative quality assurance solutions empower customers to implement robust, efficient, and cost-optimized production processes. Its products are driven by proprietary machine vision and analysis software that monitors and helps to automate a wide range of industrial welding and additive manufacturing processes. Complementing nLight's expanding laser portfolio, the acquisition of the Plasmo assets strengthens nLight's position as a critical enabler of next generation manufacturing solutions in these growth markets.

"Plasmo is a technology leader in process monitoring and quality assurance systems for laser-based manufacturing processes," said Jake Bell, general manager for industrial lasers. "Combining lasers with Plasmo's real-time process monitoring solutions provides customers with a significant advantage."

www.plasmo.eu
www.nlight.net

Pulsar Photonics and Scanlab join forces

The two German companies agree to collaborate on the development and distribution of higher-integrated laser scan systems. Besides collaborating on the development of the 'photonic drill engine' for laser microdrilling at a high throughput rate, Scanlab will now be able to supply a range of beam shaping systems and other customized solutions, expand its product range for micromaterial processing and offer users new solutions that will help them to improve their productivity and processing quality.

The two companies have already been collaborating on the design and development of scan solutions for microprocessing since 2019. This new project also means that Scanlab will take on joint responsibility for the distribution of highly integrated laser scan systems, allowing the organization to provide its own customer base with additional, integrated solutions from February 2022 onward.


Source: Scanlab

Integrated scan system for beam shaping

Over the course of their 'Photonics Drill Engine' (PDE) project, the partners will jointly develop an extremely dynamic, versatile multibeam tool for laser material processing.

www.pulsar-photonics.de
www.scanlab.de

Edmund Optics establishes new facility in Cherry Hill

The optical components manufacturer has opened a facility in New Jersey, USA. The building is less than three miles from the company's headquarters in Barrington, and will house the sales, marketing and compliance departments, as well as its business units.

"This new facility is an exciting expansion to our presence in New Jersey," says Marisa Edmund, chief sales and marketing officer and vice chairman of the board. "It has been great to see the new office abuzz with activity and is an important step in realizing our ability to better and more quickly service customers as part of our continuous growth."

For the past 74 years, Edmund Optics has operated in New Jersey from its headquarters in Barrington. During this time, the company has established itself as a provider in many markets, including industrial inspection, semiconductors, biomedical and R&D.


Source: Edmund Optics

The newly opened Edmund Optics office in Cherry Hill, New Jersey.

www.edmundoptics.com

Ligentec opens R&D center in France

Originating from western Switzerland, Ligentec has established its first foreign subsidiary in Corbeil-Essonnes near Paris.

The newly formed company, Ligentec France SAS,

Source: Ligentec

Ligentec France SAS, Corbeil-Essonnes

will primarily act as a R&D center to advance the Ligentec base technology as well as to expand it with new functionalities. The center's expertise will cover the whole chain in PIC development, from design, wafer processing to characterization and is equipped with state-of-the-art equipment.

The center is located in a new development area in Corbeil-Essonnes south of Paris, hosting a range of highly innovative high tech semiconductor companies. This local density of semiconductor technology, the great support by the tenant and the flexible options for expansion were key criteria for the selection of the location.

"This center allows us to perform research and development very close to our strategic partner and will increase our efficiency," says Ligentec's co-founder Michalis Zervas, president of the new entity.

The newly-formed company has already built a core team in Corbeil-Essonnes and plans to expand further in the next few months.

Jolt Capital, has recently joined Ligentec's board to support the management team in the scaling phase of the company and in the setup of its French subsidiary.

www.ligentec.com

Zygo broadens European presence

Optical metrology and optical component manufacturer Zygo Corporation – a business unit of Ametek, Inc. – has established an office in Italy, building upon its extensive network of offices and partnerships throughout Europe.

Source: Zygo

Ametek, Peschiera Borromeo

The Italian office will be led by two new additions to the Zygo team – Marco Pagano as senior field engineer and Luca Grisoni as sales manager – helping the company to service its growing customer-base in continental Europe and positioning Zygo as the preeminent metrology and optics supplier in Europe.

Zygo provides highly precise, cutting-edge, 3D optical metrology solutions and exacting optical components. The opening of its Italian office is in addition to its German office – opened in 1999 – and growing partner network throughout the United Kingdom, France, the Czech Republic, Turkey, and Romania.

Zygo has a 50-year heritage in the precision metrology and optics manufacturing sectors. Over 750 patents have been issued to Zygo scientists and engineers.

www.zygo.com

Luna Innovations acquires Lios Sensing

NKT Photonics has divested its Lios Sensing business to the American company Luna Innovations for a total consideration of € 20 M.

NKT Photonics will now fully focus on its core business within lasers and fiber optic solutions to the medical and life science, quantum and nano technology, industrial, and aerospace and defense markets. The activities comprise sales, development and production including the main site in Cologne, Germany, and the sales office in Portland, USA, and covers 66 employees. The divestment became effective as of March 10, 2022.

Luna is well-known for optical technology, providing unique capabilities in high-performance, fiber optic-based test products for telecommunications and distributed fiber optic-based sensing for the aerospace and automotive industries.

Scott Graeff, president and CEO of Luna said: "Combining Lios' market-leading position in temperature and strain sensing with Luna's broad fiber optic offerings, allows us to capitalize on significant technology advancements and enhanced market opportunities."

Lios will become a fully-owned subsidiary of Luna, while continuing to operate under its existing brand for the foreseeable future. Its employees will remain within the company, with offices in Germany and the US.

www.nktphotonics.com
https://lunainc.com

Technotrans completes merger and renaming of its companies

It is a key milestone for the implementation of the group's Future Ready 2025 strategy: the one-brand strategy was successfully implemented. All the Technotrans SE companies, with the exception of GDS GmbH which specializes in technical documentation, now operate under the name of the Technotrans umbrella brand.

The technology supplier has also completed the merger of Technotrans SE and KLH Kältetechnik GmbH as well as Technotrans Solutions GmbH and Reisner Cooling Solutions GmbH. From now on, Termotek GmbH will be operating under the name of Technotrans Systems GmbH.

The current product and technology portfolio will be maintained and is to be systematically expanded in future. The full organizational integration of the individual companies into the group is to be completed in the first half of 2022. These measures will strengthen the

Source: Technotrans

The podium at the Technotrans annual general meeting

group's position as a leading innovator in the field of thermal management. The group is consolidating its knowledge and skills to enable it to operate even more efficiently, flexibly and effectively in its major markets.

www.technotrans.com

'Lasers for hydrogen technology' opened

The researchers of the Fraunhofer Institute for Laser Technology ILT have set up a hydrogen laboratory in more than three hundred square meters of laboratory space. A wide range of laser technology test facilities will offer public projects and industrial cooperation a research platform here that is unique in Germany. On May 5, the new Hydrogen Lab opened its doors for the first time to participants of the International Laser Technology Congress AKL'22 in Aachen as part of ILT's biannual Laser Technology Live event (cf. p. 66).

To ensure that the energy transition succeeds, scientists not only at Fraunhofer ILT but throughout Germany are developing new technology for energy generation and use that is sustainable, efficient and economical, and hydrogen plays a prominent role in this.

The activities in the ILT's new Hydrogen Lab are embedded in the institute's business strategy. For example, the researchers are working on laser processes for the production of bipolar plates used in fuel cells. Researchers can significantly improve the efficiency and functionality of bipolar plates by selectively structuring and coating them.The new Hydrogen Lab gives researchers at both Fraunhofer ILT and their partners from science and industry new opportunities to link process results from manufacturing technology with the performance and functionality targets they have set.

www.ilt.fraunhofer.de

Endowed chair in the US named after Robert M. Edmund

An endowed chair at the Wyant College of Optical Sciences at the University of Arizona (UA) has been newly created and named after Robert M. Edmund, Edmund Optics' CEO and chairman of the board of directors.

As Dean Thomas L. Koch announced earlier this year, the university received a financial commitment for the Robert M. Edmund Endowed Chair in Optical Sciences. The gift was proposed by UA president emeritus John P. Schaefer and funded by the Frederick Gardner Cottrell Foundation, a nonprofit organization established by Research Corporation Technologies Inc.

The Edmund Chair was part of an ambitious fundraising campaign by the college in 2018, funded by an initial $ 20 M donation from James C. Wyant and his family. The gift from the Wyant family was contributed to the fund to match a gift from a donor three to one.

www.edmundoptics.com
www.optics.arizona.edu

Source: Edmund Optics

During Photonics West, Robert Edmund was honored with the Edmund Endowed Chair in Optical Sciences in a ceremony attended by family, friends and several EO employees.

PhotonDelta lands € 1.1 B investment

Source: Smart Photonics

Smart Photonics' CTO Luc Augustin holding a wafer that contains photonic chips

The cross-border ecosystem of photonic chip technology organizations PhotonDelta has, subject to conditions, secured € 1.1 B in public and private investment to transform the Netherlands into the leader of the next generation of semiconductors. The investment includes € 470 M of funding obtained through the National Growth Fund, while the rest is co-invested by various partners and stakeholders. It is part of the Dutch Government's national plan to cement and expand the country's position as a world leader in integrated photonics.

The programme will run for six years and will enable PhotonDelta and its partners to further invest in photonic startups and scale-ups, expand production and research facilities, attract and train talent, drive adoption, and develop a world-class design library. By 2030, PhotonDelta aims to have created an ecosystem with hundreds of companies, serving customers worldwide and a wafer production capacity of 100,000+ per year.

Ewit Roos, CEO at PhotonDelta, said: "The ongoing chip shortage highlights the pressing need for Europe to create its own production capabilities for strategic technologies. We will now be able to support hundreds of startups, researchers, producers and innovators to boost this industry that will be as impactful as the introduction of microelectronics a few decades ago."

The proposal has been submitted by the Dutch Ministry of Economic Affairs and Climate Policy in close collaboration with Eindhoven University of Technology (TU/e), University of Twente (UT), Delft University of Technology (TUD), Holst Centre, TNO, Imec, PITC, CITC, OnePlanet, Smart Photonics, Lionix International, Effect Photonics, MantiSpectra, PhotonFirst, Phix, and Bright Photonics.

www.photondelta.com

Tübingen student wins EMVA Young Professional Award 2022

Source: EMVA

Karsten Roth (left), EMVA president Dr Chris Yates

Karsten Roth, a doctoral student in the explainable machine learning group at the University of Tübingen was able to convince the jury with his work on the subject of automated industrial anomaly detection. As part of his research work, a novel automated visual anomaly detection method – PatchCore – was developed that meets all the key criteria.

The location of the EMVA Business Conference 2023 was also announced at the ceremony. It will be held in Seville, Spain, to celebrate the federation's 20th anniversary.

www.emva.org

Christoph Leyens appointed to Acatech executive board

Effective March 25, Prof Leyens became a presidium member of Germany's National Academy of Science and Engineering. He completes the body in which Reinhard Ploss, CEO Infineon, succeeds former president Karl-Heinz Streibich.

Leyens, director of the Fraunhofer Institute for Material and Beam Technology IWS, Dresden, and director of the Institute for Materials Science at Technical University of Dresden, was newly appointed to the presidium. The materials scientist had already contributed to working groups on the topics of competence monitoring, additive manufacturing and framework conditions for materials research. He was spokesman for the Acatech thematic network of materials science and engineering for many years.


Source: Fh. IWS

Prof Dr-Ing Christoph Leyens

His term of office is set to last four years. The presidium is responsible for the scientific management of the academy and its external representation.

At the same time, a change takes place at the very top of Acatech. Infineon CEO Reinhard Ploss assumes the office of president from Karl-Heinz Streibich. The outgoing president will remain actively associated with the academy.

www.iws.fraunhofer.de
www.acatech.de

Automation Technology gets new managing director

The co-founder of camera manufacturer Automation Technology, Michael Wandelt, handed over his duties as CEO to Daniel Seiler, the former CEO of IDS, on March 1, 2022. Among other things, he plans to expand the US business.


Spurce: Automation Technology

Managing director Daniel Seiler, technical managing director André Kasper, founder Michael Wandelt

Daniel Seiler, 43, will lead the company as CEO together with CTO and founder Dr. André Kasper. He thus takes over the operational responsibilities of the previous CEO and founder Michael Wandelt.

Seiler studied electrical engineering in Darmstadt, specializing in communications engineering, and later completed an Executive MBA in Frankfurt while working. He has been working in the machine vision industry for many years: starting as an applications engineer at IDS Imaging Development Systems in Obersulm in 2005. Seiler led the US site in Boston to success within four years at the same company.

He then returned to the company's headquarters to take over as CEO. This was followed by two years as CEO at the laser technology startup Cycle, during which he already supported AT as a member of the advisory board.

www.automationtechnology.de

Annette Rinck appointed president of Leica Microsystems

Leica Microsystems, a leading manufacturer of microscopes and other scientific instruments, has announced the appointment of Dr Annette Rinck as its president, with effect from 1 April 2022. She succeeds Markus Lusser, who was promoted to a new life sciences position within Danaher Corporation, Leica's parent company.

"I am very excited to join Leica Microsystems and to lead our company into the future, enabling customer value and global growth expansion. Our highly engaged teams at Leica are focused on offering innovation breakthroughs with the highest quality and the most useful applications to our customers," says Annette.

She joins Leica from Honeywell where she has spent the past seven years, most recently as general manager of global brands and companies within the building management systems division. Previously Annette built her career in commercial, portfolio management and marketing leadership roles at Eaton, Caterpillar, and BMW. She holds a PhD in applied economics / communication science.


Source: Leica Microsystems

Dr Annette Rinck

www.leica-microsystems.com

Isorg appoints Dieter May as new CEO

Isorg, a pioneer in organic photodetectors (OPDs) and large-area image sensors, appointed Dieter May as CEO to transform the company from an SME into a major corporation. He takes over from Isorg founder Jean-Yves Gomez, who has successfully led the technological and industrial development since its creation in 2010. Mr Gomez will now devote his time to driving future generations of technology as chief innovation officer.

Mr May joins Isorg from Osram Opto Semiconductors in Munich, where he was chairman of the board and CEO for three years. With a distinguished career in hi-tech, he brings his extensive experience of top-level industrial business management in semiconductors, software, automotive and mobile communications to Isorg. Mr May has over thirty years of experience in international organizations, driving transformational change and product innovation in optoelectronics and digital products and services, with Osram OS, BMW, Nokia and Infineon.


Source: Isorg

Dieter May

His appointment comes at a time when Isorg is about to begin its commercial ramp-up. Mr May's aim is to build a company with a scalable footprint. He will ensure that Isorg's industrial scale-up is ready to meet the required mass production for consumer markets and drive business success.

www.isorg.fr

Schulz-Electronic with new investor and managing director

Haspa Beteiligungsgesellschaft für den Mittelstand (Haspa BGM), together with long-time sales manager Stefan Dehn, is taking a majority stake in the Baden-Baden-based distributor of professional power supplies, which was founded in 1975, as part of a succession plan. Schulz-Electronic GmbH supplies, among other things, laser diode drivers and capacitor chargers for photonics.

Haspa BGM is a subsidiary of Hamburger Sparkasse. It focuses on equity investments in the form of silent and open participations in medium-sized companies in Germany with sales of ten million euros or more. The declared common goal of the new shareholders is to continue the successful development of recent years and to exploit the market potential, particularly in the application areas of electromobility, renewable energies and laser technology.


Source: Schulz-Electronic

Stefan Dehn

Hubert Maier, the previous managing partner, has been with the company since 1998. He took over responsibility as part of a management buyout, too. Since then, Schulz-Electronic has developed into a market-leading, manufacturer-independent supplier of professional power supplies for industrial customers in the Germany-Austria-Switzerland region.

www.schulz-electronic.de

Changes in Sick's executive

Dr Martin Krämer is leaving sensor manufacturer Sick on September 30. Nicole Kurek will join the executive board on July 1, 2022 and will be responsible for people and culture.

Dr Krämer has been a member of the executive board since July 2012, responsible for HR and legal & compliance. He holds a doctorate in law, and has devoted particular attention to the topics of continuing education and organizational development. He is now leaving the company after 23 years.

Nicole Kurek will take over as executive board member. The qualified educational scientist has a Master's degree from Saarland University and an MBA. Most recently, she headed global talent and transformation management at the BMW Group.

Sick's fiscal year 2021 recorded significant growth overall. The company achieved sales of just under 2 billion euros and incoming orders of 2.3 billion euros. Ebit amounted to 202 million euros and increased by 44 percent compared to the previous year.


Source: Sick

Nicole Kurek

In the major economies of the USA and China, Sick recorded sales growth of around 15 percent and 30 percent respectively. The number of employees increased by 5.6 percent to 11,022 at year-end 2021.

www.sick.de

Viscom appoints new head of central service

As of May 1, 2022, Viscom has a new head of central service in Christian Schweizer (40). He holds a degree in engineering and an MBA. In his career to date, he has been involved in project and product management as well as process automation and production management and drives forward the digital networking of Viscom's service products.

Henning Obloch, who was previously responsible for the field service, is moving into the release phase of his semi-retirement after participating in the international trade fair SMT Connect.

Viscom founded the service division in 2008, and Obloch has headed it since then. Central service employs around thirty people who are responsible for Europe and who work closely with colleagues in Viscom's customer care teams which were created in 2020. In order to make the handover smooth, Schweizer has already been working for the company since the beginning of 2022.


Source: Viscom

Christian Schweizer (l.), Henning Obloch (r.)

www.viscom.com

Aalen University: new president, new professor for optical engineering

On January 1, 2022, Prof Dr Harald Riegel took office as the new president of Aalen University. The physicist succeeded in the application process for the highest management position at the university and was elected by a large majority of the Senate and University Council last April. Before that, Riegel, who has been teaching at Aalen since 2009, was vice-president for teaching, communication and international relations for seven years.

As a passionate researcher who has raised around 6.5 million euros so far for research activities and has successfully established the Laser Application Center (LAZ) at Aalen University, it is important to him not to neglect basic research.

The university's research center for optical engineering and applied photonics welcomes Anne Harth as newly appointed professor. The native of Frankfurt grew up in Lower Saxony and when studying physics, joined a young professor in Hanover who was setting up laser physics at the university.

After her PhD dealing with XUV lasers, she received an offer to work in Sweden through the research group she knew, before changing to the Max Planck Institute for Nuclear Physics.

www.hs-aalen.de

Professors Harald Riegel, Anne Harth (Source: HS Aalen)

UpNano strengthens position in US market

Based on strong interest from the US market and a solid financial position, UpNano, a commercial-stage technology company and expert in 2-photon polymerization (2PP) 3D-printing, announced it will extend operations to the United States, adding Erika Bechtold as vice president of US operations.


Source: UpNano

Dr Erika Bechtold

The company manufactures and sells the well-known NanoOne series of laser-powered 2PP 3D-printing systems that are able to build structures across twelve orders of magnitude at an unprecedented speed. The company's expansion follows a year of strong business growth, seeing its sales triple and market interest rising strongly.

Parallel to establishing a global sales division, staff and floor space at the Viennese headquarters have been expanded significantly. Now the company is responding to increasing interest from the US by appointing Erika Bechtold to its leadership team as the incoming VP for the US operations in Boston, Massachusetts.

Dr Bechtold served as the director of technology commercialization at Harvard's office for technology development, supporting the Wyss Institute for Biologically Inspired Engineering, at Harvard. She brings over ten years of business development and commercial strategy experience from both academia and industry.

In addition to leading UpNano's US operations, Bechtold will also be involved in supporting ImageBiopsy Lab. With offices in Austria and the US, ImageBiopsy Lab develops and deploys medical-AI software in the field of musculoskeletal imaging intelligence. Both companies are supported, in part, by the same investment group.

www.upnano.at

Framos adds global chief marketing and sales officer to its management team

In February Daniel Otto was appointed chief revenue officer at the machine vision provider Framos, responsible for all marketing and sales tasks worldwide.


Source: Framos

Daniel Otto (r.), Dr Andreas Franz

In his career, Otto has held management positions for well-known manufacturers, primarily in the areas of sales and support, including IDS, Cognex and Rockwell Automation. He thus has extensive management experience in German and American companies as well as extensive and deep market knowledge on an international level.

CEO Dr Andreas Franz is pleased that Otto has chosen Framos: "With Daniel on board, he will lead us to work more collaboratively and strategically on our marketing, sales and technical support."

www.framos.de

Sensopart expands management

Marius Westermann became managing director marketing and sales for Sensopart. With this appointment, the management team grows to three members.


Source: Sensopart

Marius Westermann

With Marius Westermann's promotion from head of sales and marketing to managing director, Thorsten Wanner can now focus on operations. Company founder Dr Theodor Wanner will also remain on the management board, but will concentrate on the company's advisory board activities.

Westermann has around thirty years of professional experience in industrial machine vision and automation and has already held management positions in relevant companies in Europe, Asia and the USA. He joined Sensopart in November 2020 as marketing and sales director.

www.sensopart.com

McElhinney appointed as CEO of PowerPhotonic

A manufacturer of wafer scale micro-optics for laser beam shaping and other corrector optics, PowerPhotonic from Dalgety Bay, Scotland, has appointed Mark McElhinney as CEO of its US subsidiary. His initial focus will be quickly establishing US engineering and manufacturing operations that will directly serve the North American defense market.

Mark has strong current expertise in leading the development and manufacture of laser products for directed energy markets and delivering high-tech solutions for mission-critical defense applications. He also has a strong background in government contracting.

Mark was president of Lasertel from 2003 to 2020, during which time it was acquired by Leonardo Electronics USA. Prior to Lasertel, Mark was a founder and technical director of Spectracom, which was bought by ADC Telecommunications in 2000. Mark went on to become director of engineering at ADC and further enhanced that business by successfully developing and launching a range of fiber products for the telecom market. Mark started his professional career as a device engineer at Motorola Semiconductors, before moving on to Pirelli in Milan, where he helped establish DWDM amplifier and pump laser manufacturing.


Source: PowerPhotonic

Dr Mark McElhinney

Mark has a PhD in electrical and electronic engineering from the University of Glasgow.

PowerPhotonic founder and CEO Roy McBride commented, "Mark's knowledge and experience of advanced photonic systems and the US defense market will be invaluable in our growth and success in America."

www.powerphotonic.com

PhotonFirst appoints Nick Singh CTO


Source: PhotonFirst

Dr Nick Singh

The Dutch photonics scale-up has appointed Fiji-born, Toulouse-educated, and Bristol-based Nick Singh as its chief technology officer to succeed founder and CTO Pim Kat who retired in December.

Singh, born in 1970, brings over 25 years of experience and track record of consistently delivering innovative and commercially successful new technology products and services to customers in the UK, Europe, China, South Korea and the USA. Nick is a Fellow of the Institute of Engineering & Technology (IET) with a PhD in plasma physics from University Paul Sabatier in Toulouse. He gained extensive expertise in multidisciplinary engineering and new product introduction in high-tech market segments like semiconductors, photonics, flexible electronics, analytical instrumentation, water and energy. Nick has worked internationally with very talented and diverse teams based in Europe, the US and Asia for companies like Scienta Scientific and Oxford Instruments.

"We are proud and grateful to have found an excellent candidate to follow in the footsteps of our founder Pim Kat per February 1st," said PhotonFirst CEO Daan Kersten.

www.photonfirst.com

Innovavent expands management


Sources: Innovavent

Drs Denis Bolshukhin, Sebastian Geburt, Hans-Juergen Kahlert (left to right)

The company's founder and managing director Hans-Juergen Kahlert transfers duties in 2022. Innovavent Laser Optics develops and manufactures line-beam and homogenizer optics for annealing and laser lift-off applications used in the display and semiconductor industry. The company was founded 2003 in Goettingen, Germany. The Korean system integrator EO Technics, Anyang, has been shareholder and the key integrator of Innovavent optics systems since 2011.

On January 1, 2022, Dr Sebastian Geburt, was appointed managing director. He was with Innovavent since 2013, most recently as head of research and development. Together with Dr Denis Bolshukhin, head of manufacturing and operations and EVP since 2020, Geburt will organize the management transfer in 2022 with the founder and managing director Dr Hans-Juergen Kahlert.

The company's optics are developed for solid-state lasers from infrared to ultraviolet, cw, ns and sub-ps. The Innovavent application lab offers process feasibility testing. The company currently counts 17 employees.

www.innovavent.com
www.eotechnics.com

Scan lenses for stereolithography

Manufacturer: Sill Optics
Product: Non-telecentric lens S4LFT1655/328 stereolithography applications in the infrared wavelength range
Background: Stereolithography is an additive manufacturing process that is particularly suitable for the production of especially filigree components due to its high precision. In this process, the component is created by laser curing of a liquid plastic, layer by layer. A scan lens is required to focus the laser at specific positions, resulting in curing at the corresponding location. In order to be able to manufacture large components, the lens must have an extended scan field, so non-telecentric lenses are most suitable for such applications. The larger the free input beam diameter, the smaller the minimum achievable focus diameter and the more accurate the manufacturing in the end. A focus diameter of less than 80 μm is ideal for creating very fine structures.
Features: The lens has a scan field of 410 mm × 410 mm, which enables the production of very large components. With a free input beam diameter of 20 mm, focus sizes in the range of 64 to 72 μm are achievable, depending on the scan field position. The objective is suitable for high power laser applications thanks to the fused silica lens. The low absorption of material and coating results in a slight heating of the lens during operation, and therefore in a stable process with a minimum thermal focus shift. If contamination or defects occur on the protective window, it can be easily replaced by the customer.

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e-mail: info@silloptics.de
Web: www.silloptics.de

Laser diode module for machine vision applications

Manufacturer: IMM Photonics
Product: Laser diode modules of the ilumVISION industrial series for machine vision applications
Features: The laser diode modules are set to a fixed focal distance, which can be adjusted to customer requirements by the manufacturer. The lasers boast either homogeneous line optics or DOEs (diffractive optical element). The DOEs can be used to map patterns such as multi-lines, crosses, dot matrices, viewfinders or concentric circles. The laser diode module may be digitally modulated from DC to 500 kHz. Positive or negative analogue modulation is offered upon request. The modules are currently available with a wavelength of 660 nm and an output power of up to 85 mW with the homogeneous line and up to 65 mW when using the DOEs. The durable design and integrated electronic protection circuitry enable their use in harsh industrial environments. Construction and electronic protection measures protect the sensitive components from damage caused by ESD up to level 4 in accordance with IEC 61000-4-2. Its drag chain-compatible cable makes it a reliable component in mobile systems.

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e-mail: sales@imm-photonics.de
Web: www.imm-photonics.de

Photoreceiver/optical power meter for femtowatt to milliwatt

Manufacturer: FEMTO Messtechnik
Product: Ultra-low noise photoreceiver series OE-200 with variable gain from 10^3 to 10^{11} V/W. The device has a compact and user-friendly design for easy integration into optical measurement systems. Both fiber optic and free space input are available. The product line covers optical wavelengths from 190 nm to 1700 nm and includes models with calibration at 850, 1310 or 1550 nm.
Features: The outstanding feature of the series is the combination of high speed, ultra-low noise and wide gain range. The high bandwidth of up to 500 kHz allows measurement speeds of up to one million readings per second and supports the precise measurement of dynamic and modulated signals. The ±10 V output signal can be easily read using standard voltmeters, oscilloscopes or AD converters,

which can also be used to set up a fast and highly sensitive optical power meter. The sophisticated circuit design with an input noise (NEP) down to 6 fW/√Hz enables the low-noise measurement of optical signals from femtowatt to milliwatt range. Due to its robust, compact and high-quality design, the photoreceiver can also work without problems in environments with strong electromagnetic interference. It is easy to operate and can be controlled either completely manually or via a digital interface (USB optional).
Applications: The device is suitable for a wide range of applications such as spectroscopy, characterization of light sources, fast optical power monitoring, time-resolved pulse measurements and much more.

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

Innovation award for Primes ScanFieldMonitor

The Primes ScanFieldMonitor (SFM) won first place after being nominated finalist for the Innovation Award Laser Technology 2022 in Aachen (Aix-La-Chapelle), which put the SFM ahead of twenty other innovations in 2022.

The novel and patented measurement principle in the SFM enables the measurement of laser beam parameters during the movement of a scanned vector. The resulting laser-scanner characterization provides all geometrical and laser-related parameters relevant for remote applications. Additionally, beam position and movement of the laser scanner unit in its scanning field are determined in the same operation.

The measurement principle is based on a defined scattering structure engraved by an ultra-short pulse laser into a transparent material. When the laser beam passes over this structure, the light is scattered by means of the engraved stray elements. The characteristic SFM scattering signal is detected by a photodiode. It allows the calculation of the vector location within the scan field, vector start and end point as well as the scanning speed. Besides all these parameters, the beam diameter is calculated based on the generated 1D-integrated signal at the same time. Without any further optics included, the SFM provides a wide incidence angle of ±20° to enable measurements on the entire scan field. Among other things, this also allows the stitching of overlapping scanner areas with an accuracy of less than 10 µm.

The European science and technology prize is awarded every two years by the Arbeitskreis Lasertechnik and the European Laser Institute ELI. The award is aimed at laser manufacturers and laser users as well as researchers and developers who have shaped a laser technology innovation from the stage of application-oriented research to successful industrial implementation.

Primes GmbH
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64319 Pfungstadt, Germany
phone: +49 6157 9878
e-mail: info@primes.de
Web: www.primes.de

Product of the Month

Stabilization of optical frequencies with frequency comb solutions

Manufacturer: Toptica
Product: Complete laser system solutions for quantum applications, all from a single source. They include an optical difference frequency comb with outstanding stability and accuracy, any desired wavelength extension, beat units, stabilization electronics, wavelength meters, and multiple laser systems locked to the comb.
Features: The 200 MHz variant of the manufacturer's difference frequency comb, the DFC CORE 200+ is a 19-inch compatible, optical frequency comb based on erbium fiber technology and has proven to be robust and reliable. It is the core system for applications such as optical clocks, microwave generation or phase-locking of cw-lasers and can be equipped with additional wavelength extensions and options. Its unique stabilization is based on difference frequency generation (DFG) and leads to improved stability with a simpler and more reliable, all-passive frequency offset stabilization. Further advantages are high robustness and ultralow phase noise. The comb is free from fluctuations of the offset phase and offset frequency due to the common mode suppression of the two parts of the original spectrum. The manufacturers offer a technical tutorial entitled "Phase and Frequency Locking of Diode Lasers" on their website.

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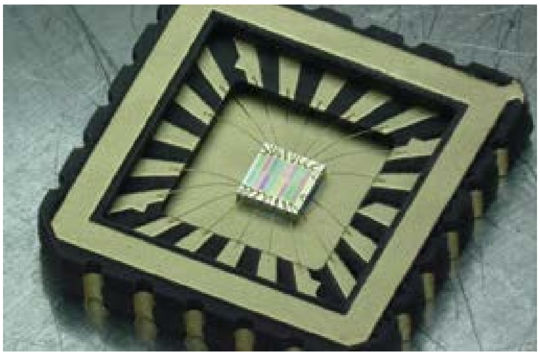
Web: www.toptica.com

A new tiny, near-infrared sensor

New device could be used for personalized health care, precision agriculture and lab-on-chip testing

A research group at TU Eindhoven has developed a near-infrared sensor that is easy to make, and is comparable in size to sensors in smartphones.



The new, miniaturized near-infrared sensor could fit in a smartphone. (Source: MantiSpectra)

While the human eye is impressive, it is far from being the most advanced natural light sensor out there. "The eyes of the Mantis shrimp have sixteen different types of cells, which are sensitive to ultraviolet light, visible, and near-infrared light," says Kaylee Hakkel, a member of the TU Eindhoven Photonics and Semiconductor Nanophysics group. "And measuring the spectrum in the infrared is most interesting for applications in industry and agriculture, but there is one major issue – current near-infrared spectrometers are just too big and expensive." Hakkel and her collaborators have solved this issue by developing a near-infrared sensor that fits onto a small chip.

Just like the eye of the Mantis shrimp, it has got 16 different sensors – but they are all sensitive in the near-infrared. "Miniaturization of the sensors while keeping costs low was a major challenge, so we designed a new wafer-scale fabrication process to achieve this. It is low-cost because we can produce multiple sensors at the same time, and it is ready, right now, for use in practical applications in the real world," Hakkel adds. "The sensor chip is small and could even be embedded in future smartphones."

With the sensor in hand, the researchers then tested it in a number of experiments, as explained by Maurangelo Petruzzella, who is also working at the startup company MantiSpectra: "We used the sensor to measure the nutritional properties of many materials, including milk. Our sensor provided comparable accuracy in the prediction of fat content in milk as conventional spectrometers. And then we used the sensor to classify different types of plastic."

"Besides these applications, we anticipate that the sensor could be used for personalized health care, precision agriculture (monitoring the ripeness of fruit and vegetables for instance), process control, and lab-on-chip testing. We now have a full development kit available based on this technology, the SpectraPod, that companies and research institutes are using to build their applications," adds Petruzzella.

And things are just starting to get exciting for Hakkel. Soon, she will be joining Petruzzella at the startup company MantiSpectra where they will strive to advance the sensor for more practical applications.

www.mantispectra.com
www.tue.nl

Web-based laser cutting simplifies high-end manufacturing

Machine is producing between 4 and 1000+ parts per hour

Clean surfaces on laser-cut parts due to an innovative laser process (Source: Snijlab)

Snijlab is partnering with laser manufacturer Luxinar to provide engineers and creative entrepreneurs with a simple and accessible online cutting service for their production parts.

The SR 15i CO_2 laser source from Luxinar is integrated in Snijlab's fully automatic system to cut and mark a variety of plastic and wooden parts.

Established in 2010, Snijlab has clients across Europe in high-end manufacturing, including medical devices, industrial machinery, lighting, and electronics, who need precision-cut parts to successfully bring their own products to market. The SR 15i is used mainlyto cut flat parts that vary between approximately 5 – 500 mm, an example being plastic face shields that were needed during the first phase of Covid-19.

Jiskar Schmitz of Snijlab explains why the company selected a Luxinar CO_2 laser source, "High reliability, good beam quality and also power stability. As our system is automated it needs to be able to produce exactly the same part for days on end. A drop in power means a scrapped product and, since no operator is present, it is hard to detect. We used glass lasers in other machines, but in our experience they are not reliable enough for an application like this." Schmitz continues, "…approachability was a factor as well. We are new in the industry and found it is pretty hard to get good documentation or even price information if you are less experienced and a small buyer."

SR 15i is from Luxinar's well-established SR series of sealed CO_2 laser sources with powers of up to 250 watts. The laser is based on a diffusion-cooled slab principle that gives a high-quality, round, and symmetrical beam and, in addition to cutting, the SR series is used for drilling, engraving, marking, perforating, scribing and welding in a variety of industries. The 175W-rated SR 15i laser installed in Snijlab's machine produces between 4 and 1000+ parts per hour, depending on the material and part size.

www.luxinar.com
https://snijlab.nl

Seeing through blood with a microscope

Research network develops technology to fight bacterial contamination

The new collaborative 'BetterView' project is working on a special surgical microscope to detect cholesteatomas – an aggressive form of chronic otitis media – and bacterial biofilms and to remove them safely.

The project's SWIR microscope system uses short-wave infrared light. The aim is to illuminate blood, bacterial biofilms, cartilage, and soft tissue, display them spatially, and make them distinguishable from each other. The research is coordinated by the medical technology company Munich Surgical Imaging.

"An advanced generation of image sensors now makes it possible to equip surgical microscopes with a new function: to process and display images in the short-wave infrared light spectrum in real time," says Thomas Huser from the faculty of physics at Bielefeld University. The professor is a specialist in biomedical photonics.

To enable the surgical microscope to distinguish the short-wave infrared signals, Huser and his team are developing their own software that filters out light outside the short-wave infrared spectrum and calculates a three-dimensional view of the image. "In addition, the software needs to produce color contrasts. Such colored markings make it easy to distinguish between, for example, nerves and soft tissue," Huser explains. The software has to display the video image in real time so that surgeons in the operating theater can work precisely and face no delay in seeing what their intervention is doing to the surgical field.

Compared to conventional microscopes, the future SWIR microscope will also be able to see through soft tissue. This will make it possible to examine optically hidden areas as well. Surgeons will then be able to see whether bone material in the inner ear has been colonized or damaged by bacteria. In addition, the microscope should increase patient safety. If surgeons can see and distinguish the inner ear precisely, there is less risk of damaging sensitive structures such as the facial nerve or the labyrinths of the inner ear.

Development of the short-wave infrared microscope in the project is based on the Arriscope surgical microscope. (Source: Munich Surgical Imaging)

Alongside Bielefeld University and Klinikum Bielefeld, other members of the cooperation project are the Helmholtz Pioneer Campus at Helmholtz Zentrum München, Leibniz University Hanover, the camera system manufacturer PCO, and the laser manufacturer Omicron-Laserage Laserprodukte. (Source: U. Bielefeld)

www.munichimaging.de
www.uni-bielefeld.de

Improving fringe projection 3D shape measurement

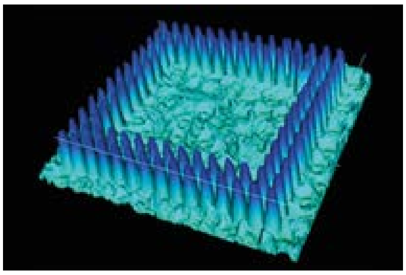
Scientists leverage Mikrotron CoaXPress camera to develop telecentric system

Based on a novel measurement algorithm and the Mikrotron EoSens 12CXP+ area scan camera, scientists in Taiwan have developed a system to reconstruct a 3D model in a continuous scan mode instead of the conventional approach of taking three full-field fringe images sequentially in pause mode.

Optical 3D shape measurement is rapidly gaining importance in metrology applications thanks to its capability to accurately measure and reconstruct 3D moving objects such as silicon wafers, PCBs, or flat panel displays. Several production-worthy 3D measurement methods are available today, all offering varying tradeoffs between speed and accuracy. Two of the most commonly deployed methods are triangulation and fringe projection, which encodes depth via the deformation of a known fringe pattern projection.

To improve the performance of fringe projection 3D shape measurement, scientists at the Industrial Technology Research Institute in Taiwan recently developed a system based on a novel measurement algorithm and the Mikrotron EoSens 12CXP+ area scan camera. The scientists flexibly programmed the camera's region of interest (ROI) to contain selectable rows to simultaneously acquire three fringe images with 120° phase shifts. Because only the pixel information within the ROI was stored in the memory, this approach reduced the data volume and processing, therefore greatly accelerating area scan acquisition.

This 3D measurement system features three segments: optical imaging, projection, and object space. The optical imaging system consists of a telecentric lens (Net-Gmbh L-VS-LTC) with selectable magnification, and the Mikrotron camera offering a resolution of 4096 (H) × 3072 (V) pixels, an image field with a diagonal of 32.6 mm, and 4.5 × 4.5 µm pixels, which correspond



Reconstructed topography of the 3D BGA sample (courtesy of Industrial Technology Research Institute)

to the lateral sampling for the selectable magnification. If needed, the camera can be set to a smaller ROI so that only the pixel information within the ROI is stored in the memory, and the frame rate can be bumped up to a staggering 10,100 fps with an active sensing area of 4096 (H) × 50 (V) pixels, made possible by the CoaXPress high-speed interface. The projection system has a telecentric lens and 250 W metal halide light source.

www.mikrotron.de

Trumpf and Metalenz illuminate with stable polarization

Consumer electronic devices need less than half components for illumination applications

High-technology company Trumpf and Boston-based optics innovator Metalenz held live demonstrations of illumination for smartphone applications at Photonics West.

At the clean room facility in Ulm, Germany, Trumpf manufactures VCSELs and photodiodes. (Source: Trumpf)

Trumpf has developed the patented technology of VCSELs with stable polarization, which is locked by a surface grating that is directly etched into the GaAs. Polarized VCSELs achieve almost 100 percent efficiency compared to standard VCSELs, which translates to a slope efficiency of 1 W/A. The high quality is based on Trumpf own designs and processes to realize extremely low losses. The design of the VCSEL can come with a single mesa or as an array. "With our development of polarized VCSELs we are addressing demanding 3D illumination applications not only in smartphones but also in OLED screens or in virtual reality and augmented reality applications. Market release of our next generation, advanced polarized VCSEL is intended to be in 2023", says Berthold Schmidt, CEO at Trumpf Photonic Components. "Working together with Metalenz enables us to visualize the promising solution for illumination in smartphone devices", says Schmidt. Not only the form factor and the optical system complexity can be reduced by the next generation of VCSELs in combination with the right optics, but the illumination quality is also improved by the controlled light. The resolution is increased because the laser light is only projected to where it is needed, even for longer distances, and overall power savings can be achieved. The laser components in a smartphone can be used for illumination applications such as face recognition, 3D mapping or camera autofocus.

"Together with the VCSEL from Trumpf we show how two leading edge technologies can revolutionize the technical standards in smartphones for light illumination", says Carlos Calvo, vice president of product at Metalenz. "We are happy to demonstrate the high quality in illumination together with Trumpf. The laser diodes and our meta-optic technology complement each other perfectly", Calvo adds.

www.trumpf.com/s/VCSEL-solutions

www.metalenz.com

Meet us at LASYS, Hall 4, Booth 4B32

Precisely coat complex-shaped optics

Developed by Finnish company Beneq in collaboration with LZH

The new Spatial ALD system can uniformly coat complex-shaped optics and deliver higher deposition rates than previously possible. It is of interest, among others, for applications in the automotive lighting or VR/AR sectors.

Source: LZH

The plasma-based Spatial ALD system

Atomic layer deposition (ALD) can produce very thin, high-quality coatings. So far, the ALD process has been used primarily to produce thin functional layers in the semiconductor industry, for example. The new Spatial ALD system of the LZH (Laser Zentrum Hanover), which was developed in cooperation with Beneq, now makes another application that is in high demand in industry economically viable. The scientists in the optics integration group at the LZH can use it to produce layers of uniform thickness much faster than before, for example on tightly curved and structured optics.

The Spatial ALD system achieves high deposition rates in the production of ultrathin coating systems for optics and enables the uniform coating of complex surfaces. This is of interest, for example, for automotive lighting or augmented reality / virtual reality, where three-dimensionally shaped lighting elements are essential. As the system is plasma-based, it can operate at low temperatures below one hundred degrees – making it particularly suitable for coating the temperature-sensitive polymer optics that are often used for displays.

The ALD process is based on self-limiting chemical reactions between gaseous precursors and substrate surfaces. The process reactions are carried out one after the other in most currently-used systems, which necessitates a time-consuming gas exchange of the entire reaction chamber.

This is different in the Spatial ALD system at the LZH where the process cycles take place spatially separated. The system has four individual process chambers separated by pressure and nitrogen and an ALD reaction step is completed in each one. The substrates then rotate into the next chamber. In this way, the scientists achieve deposition rates that were previously only possible with other coating processes. This makes the process particularly economical and at the same time enables high throughput in optical coating.

www.lzh.de

https://beneq.com

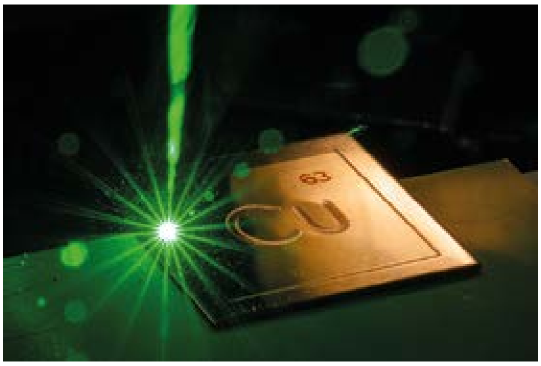
Meet LZH at LASYS, Hall 4, Booth 4A19

Laser processing unit for highly reflective materials

Green laser radiation in electric vehicle production

A consortium of four partners sees the 'GreenPls' project as a great opportunity for Germany as a manufacturing location. The results are intended to give small and medium-sized companies in particular access to new product fields and sales markets in the changing automotive industry.

for machine tools and production engineering (WZL) at the RWTH Aachen University. A high degree of maturity of the research results will be achieved through the full consideration of process development up to a complete plant layout, which will ensure rapid industrial use of the research contents.



Laser materials processing of copper with a green laser (Source: BLZ, Cvecek, Kaufmann)

One of the most relevant joining technologies for electromobility components is laser beam welding. High precision, non-contact welding joints and flexible process design options make it possible to meet high quality requirements. Materials such as copper and aluminum are frequently used due to their good electrical and thermal conductivities.

However, conventionally used infrared (IR) lasers are only absorbed to a small extent by these highly reflective materials at room temperature. One solution for joining these materials is the use of green laser radiation, which is absorbed more strongly in copper by a factor of about five compared to infrared.

In order to improve the performance of the green laser for the production of electric vehicle components, a comprehensive concept for a modular laser processing unit with green laser radiation is being developed and compared with conventional infrared lasers as part of the WZL GreenPls research project. Simultaneous work is currently being carried out on process optimization and monitoring, fixture and safety technology, and a system layout adapted to the application environment of electric vehicle components.

The research work is being done in a practise welding cell at the laboratory

The digital kick-off of the GreenPls research project took place under the leadership of the consortium leader Bayerisches Laserzentrum (BLZ) and the Laboratory for Machine Tools and Production Engineering (WZL) of RWTH Aachen University in August 2020, ushering in the project duration of two years. Initial system and fixture concepts were developed and welding tests with battery components were carried out during two consortium meetings at the RWTH Aachen campus and at the BLZ technical center in Erlangen.

The project partners are: Bavarian Laser Center GmbH, Haimerl Lasertechnik GmbH, HST H. Steinhardt GmbH, and the Chair of Production Systems Engineering of the Laboratory for Machine Tools and Production Engineering (WZL) of RWTH Aachen University.

www.wzl.rwth-aachen.de
www.blz.org

Meet BLZ at LASYS, Hall 4, Booth 4D34

Photonics Germany exhibited at the Laser World of Photonics 2022

The alliance of Spectaris and OptecNet Deutschland was represented twice

The optical and quantum technology capabilities of more than 500 member companies and institutes were demonstrated by the association.

After a three-year break, the international photonics industry was finally reunited at the Laser World of Photonics trade fair in Munich from April 26 – 29, 2022. In total, nine hundred exhibitors from more than thirty countries had the opportunity to present high-tech trends and establish new collaborations.

Source: OptecNet Deutschland

Joint booth of OptecNet Deutschland with 18 co-exhibitors

Photonics Germany, the alliance of Spectaris and OptecNet Deutschland, was represented twice: OptecNet Deutschland was once again exhibiting at its large and well-known joint booth with 18 co-exhibitors, including companies, research institutions, and start-ups. Spectaris took part in the new World of Quantum theme area with an information booth and also represented Photonics Germany. The new exhibition area provides a platform for the professional exchange of researchers, manufacturers, and users in the field of quantum technology. The World of Quantum highlighted initial use cases and current research results of this future technology.

Information booth of Spectaris at the 'World of Quantum' (Source: Spectaris)

Photonics Germany represented the innovative strength of its more than five hundred members in the field of optical and quantum technology at the trade fair. Photonics Germany strengthens the position of the German high-tech industry at both a national and a European level – the alliance initiates activities to strengthen the competitiveness of companies and research institutions. In particular, the framework conditions for photonics and quantum technology are to be further improved and funding opportunities are to be developed in a targeted manner. Photonics Germany offers its services to the political community as a representative point of contact, especially on the topics of funding policy, legislation and securing skilled workers. It also acts as a central dialog partner for international associations.

www.photonics-germany.de

Open call for LBAAM technology in production

Pulsate – application deadline: 29 July 2022, 5 pm CEST

On 2 May 2022, the EU-funded Pulsate project launched the Technology Transfer Experiments (TTE) open call for LBAAM technology in production environments.

The Pulsate network, which is designed and dedicated to boosting the adoption of laser-based advanced and additive manufacturing (LBAAM) technology that will empower the European manufacturing industry digitalization, has launched its second open call for technology transfer experiments (TTE).

The TTE is an end-user-relevant case study applicable to laser-based equipment for the Advanced and Additive Manufacturing markets, within one of the following areas of experimentation: laser equipment integration, interoperability, and robust automation; technology for cost-effective laser-based manufacturing; first part right and zero-defect laser-based production; flexible technology for small to large batches; and from CAD to PLM: data integration and flow.

To participate, a consortium of a minimum of two companies acting as technology provider (system integrator) and adopter / end user (manufacturing company) can apply, where SME or slightly bigger legal status of all consortium partners is required. Companies must be legally established in the EU member state or associated country, and their experiments should have a minimum TRL level between 5 and 7.

Proposals should be submitted by July 29, 2022 at 17:00 CEST (Brussels Time) through pulsate-tte.fundingbox.com.

The coordinators have prepared a number of useful documents that will support the participants in writing the winning proposal. All the resources including webinars can be found at pulsate-tte.fundingbox.com/pages/OCdocuments.

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

IVAM: new chairwoman and new board members

Network's changes following board elections

Dominique Bouwes from Micronit is the new chairwoman of the board of IVAM. The new president of Germany's Microtechnology Network succeeds Dr Lutz Aschke from Mahr GmbH in Göttingen, who resigned from his position after fifteen years on the board.

Martin Hovestadt from Jüke Systemtechnik in Altenberge and Dr Albert Hasper from the Dutch company Phix in Enschede were also newly elected to the IVAM board. The previous board member Dr Hans van den Vlekkert, LioniX International BV, is also retiring after 14 years on the IVAM board. The other board members were confirmed in their positions.

The five members of the board are now Dominique Bouwes as chairwoman, Matthias Lorenz of AEMtec GmbH as deputy chairman, Bärbel Schilling of Plan Optik AG, Martin Hovestadt and Dr Albert Hasper. The elections took place on May 5, 2022, during the IVAM General Meeting at 'Dortmunder U'.

www.ivam.de

New board of 2022 (l. to r.): Bärbel Schilling, Matthias Lorenz, Dominique Bouwes, Martin Hovestadt and Dr Albert Hasper (Source: IVAM)

Chairman of the European Executive Forum for AM

Matthias Bölke: committed to a modern, digital and more sustainable manufacturing industry

The new Executive Forum for Advanced Manufacturing, EFAM, has a chair: Dr. Matthias Bölke, vice president strategy industrial automation at Schneider Electric, is taking over the leadership of the forum set up by the European industry association Orgalim.

The goal of EFAM is to bring international suppliers and users of advanced technology solutions for the manufacturing industry together in a regular format in order to develop common impulses for European industrial policy. The Committee, which first met in December 2021, also serves as an advisory body to the Orgalim board of directors.

As an experienced expert in the fields of industrial automation and energy management, Bölke has held various management positions for many years. In addition to his function as VP at Schneider Electric, the new chairman is involved in various committees and associations specializing in digitization topics.

As the sponsor of the EFAM, the international industry association Orgalim not only represents a large number of European companies from the mechanical engineering, electrical engineering, electronics and metal technology sectors, but is also co-curator of the so-called Task Force 5 of the EU Industry Forum. The specific task of this Task Force 5 is to accelerate the development and use of advanced technology solutions for the manufacturing industry across the EU. The main focus is on the rapid implementation of a digital transformation, which not least aims to establish more sustainable and environmentally friendly manufacturing processes. The Executive Forum for Advanced Manufacturing will support Task Force 5 with its work.

Source: Schneider Electric

Dr Matthias Bölke

www.schneider-electric.de

Change in the management of ASAM e.V.

Marius Dupuis took over as CEO from Klaus Estenfeld, Benjamin Engel promoted to CTO

Starting May 1, 2022, the standardization organization ASAM e.V. is led by a new management team. Marius Dupuis takes on the role of chief executive officer and Benjamin Engel the newly created position of chief technology officer.

Dupuis took over as CEO from Dr Klaus Estenfeld, who has held the position of managing director on an interim basis since February 2022. Before joining ASAM, Dupuis was owner and managing director of Vires Simulationstechnologie for more than twenty years and most recently worked as managing director of the Vires business unit within the Hexagon group.

Simultaneously, Benjamin Engel has been appointed chief technology officer. In this newly created position, he is responsible for the technical development and alignment of the ASAM standards as well as for the technical team at ASAM.

www.asam.net

Source: ASAM

From left: Marius Dupuis, CEO, Dr Klaus Estenfeld, interim managing director, Benjamin Engel, CTO

EPIC is on the road again

Lithuanian photonics community welcomes EPIC members and strengthens bonds

Ingrida Šimonytė, Prime Minister of Lithuania during the welcome speech at the EPIC AGM in Vilnius (Source: EPIC)

Spring has been busy for the European Photonics Industry Consortium: the association was finally able to meet in Vilnius, Lithuania for the EPIC Annual General Meeting 2022 (AGM), after three years of planning due to the traveling restrictions imposed by the pandemic. The event gathered more than 150 c-level attendees, members of the consortium, who enjoyed interesting market and technology discussions as well as a fruitful time for networking, together with the warm welcome of all the Lithuanian companies. It was an honor to have the support of the Prime Minister of Lithuania, Ingrida Šimonytė and the Mayor of Vilnius, Remigijus Simasius, who delivered the welcome speech at the event, raising the bar for future events with the support of public authorities.

The Annual General Meeting (AGM) was a unique opportunity to strengthen relations between the EPIC members. During our stay, we visited the facilities of some Lithuanian companies such as 3photon, Altechma, the Center for Physical Sciences and Technology, Eksma Optics, Ekspla, Light Conversion, Lidaris, Litilit, Optoman, QS Lasers and Workshop of Photonics. It was a great opportunity to see how the Lithuanian photonics community is so powerful and fast-growing.

After a successful AGM, the EPIC team gathered again at the end of April in Munich for Laser World of Photonics, the largest photonics show in Europe. Everyone was so happy to meet again on the show floor, which this year had many more industrial attendees due to the fact that there was no academic program. EPIC had a full program of activities during Laser World of Photonics, including six Technology Meetings,

Upcoming EPIC events:

- 7 July 2022, 09:00 – 10:00 CEST
  EPIC VIP Networking Breakfast at W3+Fair 2022, Wetzlar, Germany
- 7 July 2022, 10:30 – 12:00 CEST
  EPIC TechWatch at W3+Fair 2022, Wetzlar, Germany
- 7-8 September 2022, Leuven, Belgium
  EPIC Meeting on CMOS Compatible Integrated Photonics at Imec
- 7-8 September 2022, Glasgow, United Kingdom
  EPIC Industrial Quantum Photonics Technology Summit at the University of Glasgow
- 8 September 2022, Shenzhen, China
  EPIC TechWatch at CIOE on Precision Optics
- 12 September 2022, 15:00 – 17:00 CEST
  EPIC Online Technology Meeting on Emerging Trends in Laser Micromachining
- 13-14 September 2022, Noordwijk, The Netherlands
  EPIC Meeting on Photonics at the Final Frontier at European Space Agency (ESA)
- 19 September 2022, Basel, Switzerland
  EPIC VIP Networking Reception at ECOC
- 21 September 2022, Basel, Switzerland
  EPIC Members Run at ECOC
- 26 September 2022, 15:00 – 17:00 CEST
  EPIC Online Technology Meeting on Photonics for Aesthetics and Cosmetics
- 17 October 2022, 15:00 – 17:00 CEST
  EPIC Online Technology Meeting on Photonics for the Mobility of the Future
- 24 October 2022, 15:00 – 17:00 CEST
  EPIC Online Technology Meeting on Satellite Quantum Communication
- 7 November 2022, 15:00 – 17:00 CET
  EPIC Online Technology Meeting on Optical Fiber Sensing for Monitoring

www.epic-assoc.com/epic-events

the traditional EPIC CEO Exhibitors Breakfast, and an investors session. The exhibition was a tremendous success, and the association had its biggest presence ever.

After the success of these two events, we were all looking forward to continuing business as usual. We visited the Nanoscribe facilities in Germany in May to take a closer look at advanced micro-optics, and at the beginning of June we were in Paris to organize the EPIC Roundtable at Optro, which this year was focused on smart optronic detectors for challenging targets.

Even though the physical meetings are restarting, we will not give up our traditional online meetings. EPIC is planning further Online Technology Meetings over the next few months, now co-hosted by EPIC tech specialists. There will also be physical events at EPIC member facilities, such as the EPIC Meeting on CMOS Compatible Integrated Photonics at Imec, the EPIC Industrial Quantum Photonics Technology Summit at the University of Glasgow or the EPIC Meeting on Photonics at the Final Frontier at the European Space Agency (ESA).

EPIC booth at Laser World of Photonics 2022 (Source: EPIC)

EPIC is looking forward to continuing our services to promote the sustainable development of organizations working in the field of photonics. For an overview of all 800 members, please go to

www.epic-assoc.com/membership/epic-members

Nicoletta Casanova joins EPIC Board of Directors

CEO and president of Femtoprint succeeds Jan Meise, CEO of AMS Technologies

During the annual general meeting 2022 in Vilnius, Lithuania, the European Photonics Industry Consortium announced its new board member: Nicoletta Casanova, CEO and president of Femtoprint, a Swiss high-tech company that uses light as a powerful ink source to manufacture 3D printed microdevices in glass and other transparent materials. Benno Oderkerk, president of EPIC, said that "we are excited to welcome Nicoletta Casanova to the EPIC board of directors and look forward to benefit from her energy, enthusiasm and entrepreneurial spirit to the board."

"My story is studded with collaborations: Femtoprint is the result of a European collaborative project and is an example of how working together synergistically leads to success. I am therefore very happy to support EPIC's strategy and to contribute with my enthusiasm and passion for innovation at this very challenging historical moment," said Casanova.

The EPIC board of directors composition as of April 2022: Adam Piotrowski, CEO of Vigo Photonics, Basil Garabet, president and CEO of NKT Photonics, Benno Oderkerk, Berthold Schmidt, managing director of Trumpf Photonic Components, Christian Bosshard, managing director of Swissphotonics, Nicoletta Casanova, CEO and president of Femtoprint and Samuel Bucourt, CEO of Imagine Optic.

Source: EPIC

Nicoletta Casanova

Departing board member Jan Meise, CEO of AMS Technologies, stated: "I am especially happy that after six years on the board of directors I was able to pass on the baton to Nicoletta Casanova, a terrific addition to the EPIC BoD team."

www.epic-assoc.com

EPIC hires Antonio Castelo as Program Manager

Laser specialist to provide research and industry experience

To address all the needs of its members, EPIC has strengthened its team by recruiting Antonio Castelo as photonics technologies program manager, succeeding Dr Francesca Moglia.

Antonio (pictured right) has a PhD from the department of applied physics of Universidad de Santiago de Compostela in laser processing of glassy samples. After 2010, he worked as a sales engineer in the photonics department of the company Acal BFi, a job that he continued in the Spanish company Grupo Álava since 2012. In 2021 he became US sales manager for the company Fyla, a manufacturer of supercontinuum and ultrafast fiber lasers.

www.epic-assoc.com


Source: EPIC

EPIC Award goes to Reinhard Völkel

A celebration of sustainable growth focused on the excellence of micro-optics

The European Photonics Industry Consortium named Reinhard Völkel, CEO of Suss MicroOptics, winner of the EPIC CEO Award 2022.

Völkel started his career at the Institute of Microtechnology, University of Neuchatel. He worked on micro-optics for biosensors, optical interconnects, photolithography systems and miniaturized imaging and camera systems for five years, technologies that he would later exploit with Suss MicroOptics.

According to EPIC director general Carlos Lee, the success of Völkel and his enterprise relies on the explosion of light sources and related applications that made it possible to break into so many new markets and their sustainable and realistic growth with a focus on investing in excellence.

And in fact, in 2019, Suss MicroOptics set up an imprint excellence center for the manufacturing of wafer-level optics with the aim of using a new generation of Suss MicroTec's manufacturing equipment to prove the pilot production and thus the possibility of volume production of high-quality freeform micro-optics for applications such as microlens arrays for automotive, sensors and cameras. This technology is being tested at the EU funded project Phabulous pilot line services to help bring the whole European micro-optics manufacturing imprint to 2.0, i.e. from a lab state to a fully industrialized state.

Dr Reinhard Völkel, Suss MicroOptics, with the EPIC CEO Award (Source: EPIC)

www.epic-assoc.com
www.suss-microoptics.com

Innovation Awards Laser Technology 2020 and 2022

Primes and Trumpf teams win 10.000 euros each

Outstanding innovations in laser technology were presented and honored in the Coronation Hall of Aachen's city hall on May 4, 2022, in front of around three hundred guests. This year's winners of the 10,000 euro award are Dr Boris Regaard of Trumpf (2020) and Stefan Wolf of Primes (2022).

The Innovation Award for Laser Technology is presented every two years and had to be postponed in 2020. Dr Alexander Olowinsky, chairman of the board of the European Laser Institute ELI eV, and Ulrich Berners, chairman of the board of AKL eV, describe the context of their organization's award: "With the presentation of the Innovation Award for Laser Technology, we want to honor precisely those innovators who have spearheaded an invention in the field of production-oriented laser technology from research through development to market launch." The award-winning projects were met with enthusiasm: "Each of the finalist teams has made a significant contribution to the advancement of science and technology through their innovative achievements."

The topic of the 2020 award-winning project was 'Active Speed Control – camera-based sensor system for closed-loop feed regulation in laser cutting'. At the heart of Active Speed Control, developed by Dr Boris Regaard and his team at Trumpf, Ditzingen, Germany, is a camera-based sensor system in the cutting head, whereby real-time image processing analyses the camera data. Based on the data analysis, the feed rate is constantly monitored for optimal results.

The 2022 award-winning project is called ScanFieldMonitor (SFM). It was developed by Stefan Wolf, head of research and development at Primes, Pfungstadt, Germany, and his team as a tool for laser scanner characterization. The development was prompted by many new applications in additive manufacturing and regarding electromobility.

Other finalists for 2020 and 2022 were Blackbird Robotics and Scanlab, and Fusion Bionic, Laser on Demand together with the Laser Zentrum Hannover and the explosive ordnance disposal service of the Hamburg Fire Department, and Neolase, all from Germany.

www.ilt.fraunhofer.de
www.akl-ev.de


Source: AKL eV / A. Steindl

Innovation Award Laser Technology 2020 (left) and 2022 winners – Trumpf, Laser on Demand, Neolase, and Primes, Fusion Bionics, Blackbird / Scanlab, framed by moderator Kristina zur Mühlen, Prof Constantin Häfner, Dr Alexander Olowinsky, and Ulrich Berners

EPIC

European Photonics Industry Consortium

EPIC PROMOTES THE DEVELOPMENT AND COMPETITIVENESS OF THE EUROPEAN PHOTONICS INDUSTRY AND ITS MEMBERS

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"Believe in yourself and your skills"

EPIC interview of Lynred's CTO, Pierre Jenouvrier


Source all images: Lynred

Jose Pozo, EPIC's former director of technology, portraits Pierre Jenouvrier, CTO of Lynred, a manufacturer of detectors covering the entire infrared spectrum from short to very-long wavelength IR.

After graduating with an MSc in physics from the Grenoble Institute of Technology in 2000, Pierre went on to pursue a PhD in optoelectronics that involved conducting research at the French National Center for Scientific Research (CNRS). He worked on reducing the cost of optical fiber amplifiers. While the topic was interesting, upon completion of his doctoral degree, he opted to leave academia and move into industry where he thought he could make more of an impact.

Accordingly, in 2004, he joined Paris-based Sagem – now called Safran – a major French company involved in defense electronics, consumer electronics and communication systems, and for the next year, he worked as an R&D engineer in Sagem's hemispherical resonator gyroscope unit. With sights on a new technical challenge, Pierre started working on gyroscope sensors, and within a year he became a process manager providing support for ramping up production and in the transfer of R&D lab processes to production. The basic aim was to reduce the cost of the gyroscopes by reducing the number of parts while maintaining high performance.

In 2007, Pierre moved back to Grenoble where he joined Sofradir, a designer and manufacturer of infrared detectors for military, space and commercial applications, as an R&D engineer. He worked in the cryogenics division where he was responsible for liaising with suppliers and customers to develop custom packaging design for optics and optical filters. This was an exciting time as the job involved travelling to Germany, Japan and the UK and provided very useful cross-cultural experience.

After three years, he successfully applied for a management position and became product development team manager at the company, responsible for managing teams of technicians and engineers for the product development of customized infrared detectors. In 2013 he was promoted to head the technology and product development team responsible for back-end development, and in 2015 he headed the design development team in charge of mechanical cryogenics, microelectronics, electronics and optronics, and product prototyping as well as the development of external partners, and Sofradir's investment portfolio.

Lynred

In 2018, Pierre received a promotion to chief technical officer of Sofradir and its Ulis subsidiary, two companies that merged in 2019 to become Lynred, upon which he was designated CTO. In this position, he now leads a team of more than two hundred skilled engineers and technicians with expertise in mechanics, electronics, optics, microelectronics, materials, software, and testing.

As he explains, Sofradir and Ulis were both at the forefront in the production of infrared sensors for broadly the same markets. But with increasing competition there was a need to combine and rationalize resources to create a single company with greater punch in R&D, a shorter time-to-market for new products, and increased visibility within the IR ecosystem.

Today, Lynred designs and manufactures a range of infrared imaging sensors that cover the entire infrared spectrum (SWIR, MWIR, LWIR, and VLWIR) through a variety of technologies (MCT, InGaAs, microbolometer) and in a range of resolutions: QQVGA, QVGA, VGA, XGA, SXGA, and 80 × 80.

The company has just over a thousand employees and addresses seven main application fields: defence, space, security and surveillance, industry, smart buildings, and automotive. To ensure that Lynred stays at the leading edge of innovation, the company allocates more than 15 % of its annual revenue to R&D.

Over the last three years, from a CTO perspective, Pierre has developed an inclusive management approach. Rather than 'tell' people what to do, he prefers to allow people to understand what the problems are and discover for themselves how they can use their skills to find solutions. As he says, people are different, and a manager has to adapt to the personality of each employee in order to bring out the best in each individual.

As regards the technology, an important aim has been to make it more accessible and easier to use by newcomers who are used to dealing with visible imagers. A case in point is Lynred's new ATI320, an advanced thermal imager with embedded image correction and shutterless imaging, which has been designed as a compact, flexible, easy-to-use device especially for high volume integration and automatic handling. But however good a device may be, Pierre is always careful to fully understand a customer's problems before coming up with a particular solution or a range of options to meet the customer's needs.

The future

Lynred's goal is to continue to develop next generation IR detectors to address trends in autonomous systems for smart buildings, road safety and the in-cabin comfort of vehicles. Other developments include the very large dimension IR detectors needed for space and astronomy observations as well as compact and light IR detectors for portable devices and on drones.

The company will continue to enlarge its product catalogue, strengthen its R&D investments and hire more talent to support its activities. In this context, being based in the Grenoble Alps has an enormous advantage for recruiting talent: not only is the area the French hub for microelectronics, it is also home to an exceptional set of companies involved in imaging, such as INRIA, CEA-Leti, Apple, STMicroelectronics, LE2V/Teledyne, Xenocs and Trixell.

For Pierre, an important growth area will be sensors such as the company's Thermeye, an innovative thermal imaging sensor for smart buildings. This sensor can be used for detection, tracking, people counting, and posture classification and can work in any lighting conditions with an 80 × 80 pixel resolution to create reliable images and avoid false alarms or counting errors.

Another anticipated growth area is sensors for automotive applications, particularly advanced driver assistance systems and collision avoidance systems such as forward collision warning (FCW) and active emergency braking (AEB). As Pierre points out, while current visual systems like lidar and/or radar can provide information about the vehicle's surroundings, if there is not enough light, obstacle detection and recognition distances become too small to keep the vehicle and its surroundings safe. Under these conditions, thermal imaging can complement existing systems by helping to detect and recognize an environment in even the most extreme conditions, such as at night with fog and rain.

Lynred will also continue to develop and manufacture space-grade infrared detectors from the near-IR region to the VLWIR band. These detectors have already been used in several space programs and scientific studies such as Venus Express (to observe the atmosphere on Venus), Hayabusa 2 (to analyse samples from the asteroid Ryugu), ExoMars (to explore Mars) and the Indian Space Research Organization's Chandrayaan mission (to explore the moon).

Underlying these developments is Lynred's drive for innovation: for example, size, weight, power and cost reduction in thermal image sensors has become key to enable high-volume applications. To address these issues, Lynred has developed a prototype IR image processor (ISP) to achieve the highest level of thermal imager integration. The ISP is a dedicated ASIC built to apply a pipeline of image processing algorithms to the raw sensor data that corrects for pixel defects and non-uniformities in the sensor, without the need for an external mechanical shutter. With this approach, Lynred can provide an easy-to-use, plug-and-play solution which, for example, can be combined with an uncooled bolometer detector for a new generation of long-wave infrared (LWIR) camera modules.

Similarly, the trend in cooled IR detector development for defense applications in the mid-wave infrared (MWIR) domain is the design of very small pixels, large formats and higher operating temperatures while maintaining high image quality. In this context, Lynred is developing a digital readout integrated circuit (ROIC) for a small pixel pitch, cooled IR detector to achieve improved performance in terms of readout noise, linearity, power consumption and frame rate.

As regards specific applications, Lynred are working on a new generation of short-wave infrared (SWIR) detectors for machine vision systems that are capable of resolving new industrial problems by collecting light outside of the visible spectrum. In particular, the use of SWIR offers significant advantages for numerous applications in the food, semiconductor, and recycling industries. Compared with other technologies, Lynred's InGaAs technology with a frame rate of up to 300 Hz guarantees a higher level of performance in terms of sensitivity, noise, and operability.

If you started again, what would you do differently?

The subject I chose for my PhD was new and exciting, but it lacked connection to the industry. If I started again, I would choose a PhD with a stronger relevance to industry.

What advice do you have for the next generation of entrepreneurs?

My general advice is what I say to the people in my team:

First, be yourself and don't act like someone else.

Second, believe in yourself and your skills.

Third, say what you want to do and do not wait for someone to give you the okay. If you express yourself and say what you want to do, people will usually listen to your arguments and, if you have an interesting idea, you will not necessarily get 100 % but maybe they will meet you halfway.

Fourth, listen to your customers and understand exactly what they need before trying to sell them a solution.

Author

Jose Pozo was the former director of technology at EPIC, and as such he represented more than seven hundred leading corporate members active in the field of photonics. His work consisted of actively engaging with them and providing them with the tools to strengthen their position in the supply chain. He has twenty years' background in photonics technology, market knowledge, and a large network within the industrial and academic photonics landscape. Jose holds a PhD in electrical engineering from the University of Bristol, UK, and an MSc and a BEng in telecom engineering from Spain and Belgium.

Dr. Jose Pozo, formerly: European Photonics Industry Consortium EPIC, 17 Rue Hamelin, Paris, France; e-mail: info@epic-assoc.com, Web: www.epic-assoc.com

Multiphoton microscopy – improved signal efficiency and better contrast with <50 fs pulses

Femtosecond fiber lasers get ready to shine as Hübner Photonics eyes ultrafast markets

Comprehensive, it seems, just got more comprehensive. That is the key take-away following the acquisition of Valo Innovations, a German start-up specializing in ultrashort-pulse fiber lasers, by Hübner Photonics, one of the optics industry's leading lights and home to an already broad portfolio of compact single-frequency cw lasers, diode-laser modules and nanosecond pulsed lasers across the full UV, visible and near-IR spectrum.

Dr Oliver Prochnow (Source: Hübner Photonics)

For its part, Hannover-based Valo Innovations represents an intriguing diversification opportunity, with proprietary fiber-laser technology and "market-unique short-pulse performance" (pulse lengths <50 fs, up to peak powers >2 MW) opening up – indeed underpinning – new ultrafast applications in bioimaging, spectroscopy and optogenetics. Oliver Prochnow, CEO of Valo Innovations, explains why his team's customer-centric approach to product development and a complementary offering in the ultrashort-pulse regime represent the perfect addition to the Hübner Photonics portfolio.

What are the anticipated upsides following the acquisition of Valo?

During our exploratory conversations last summer, both parties quickly realized that the acquisition was a win-win. From the Hübner Photonics side, Valo Innovations represents a compelling technology fit, complementing its established portfolio of high-performance laser products for advanced imaging and analysis applications, including the Cobolt lines of single-frequency cw nanosecond pulsed lasers, the C-FLEX laser combiners and the widely tunable, single-frequency C-WAVE cw laser. Put simply: ultrafast lasers represent a natural complement to the Hübner Photonics portfolio and Valo Innovations provides the ideal vehicle to fast-track that ambition.

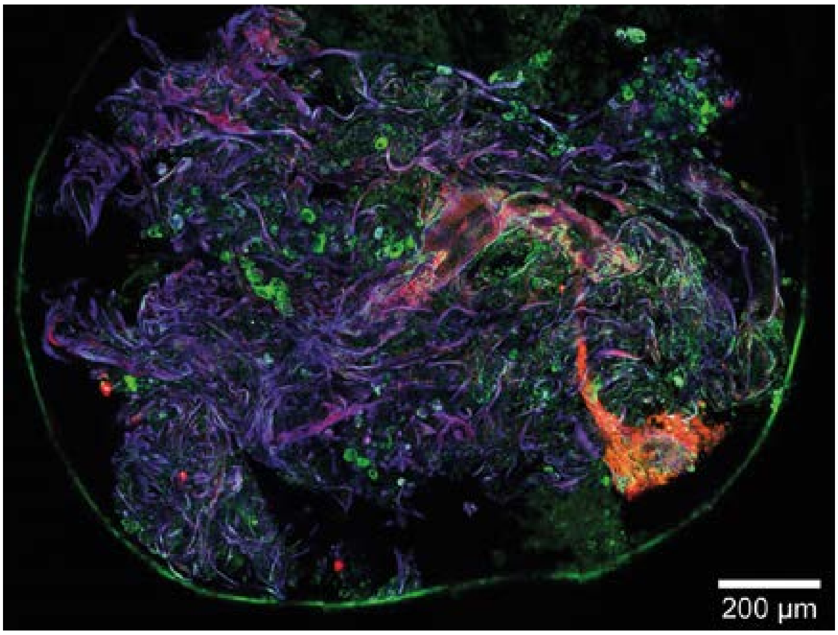
For the Valo Innovations team meanwhile, we are now positioned to develop and scale our femtosecond fiber-laser range within an established innovation and manufacturing ecosystem. That means full integration with the in-house R&D and product development functions at the parent company, plus the ability to benefit from economies of scale when it comes to component/subcomponent purchasing. It is worth adding that Valo Innovations and Hübner Photonics are also an excellent fit on a personal level, with a commonality of approach when it comes to our customer orientation, product development and commercial strategy.

How has your role evolved within Hübner Photonics?

As CEO of Valo Innovations, which is now a wholly-owned subsidiary of Hübner Photonics, I am responsible for the parent group's ultrafast fiber-laser market segment. That means owning and articulating the technology roadmap for the femtosecond product line while delivering our commercial growth targets in research and industry applications. Operationally, we are in the process of extending the office and laboratory space of the Valo Innovations division here in Hannover. We are also building up the team, recruiting talented scientists, engineers and product managers with specialist capabilities in ultrafast fiber-laser technologies and applications.

What differentiates Valo series fiber lasers from the competition?

Our fiber-laser technology is based on the interaction between linear and nonlinear optical effects. In broad terms, we have found a way to control all phase contributions that affect pulse quality, a capability that enables us to generate very clean and extremely short pulse durations without any additional nonlinear broadening after the laser. As such, Valo Series lasers are compact and stable turnkey systems – including integrated group-velocity dispersion, precompensation control – which enable



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

us to scale the energy of ultrashort laser pulses while yielding the same clean pulses in the sub-50 fs regime.

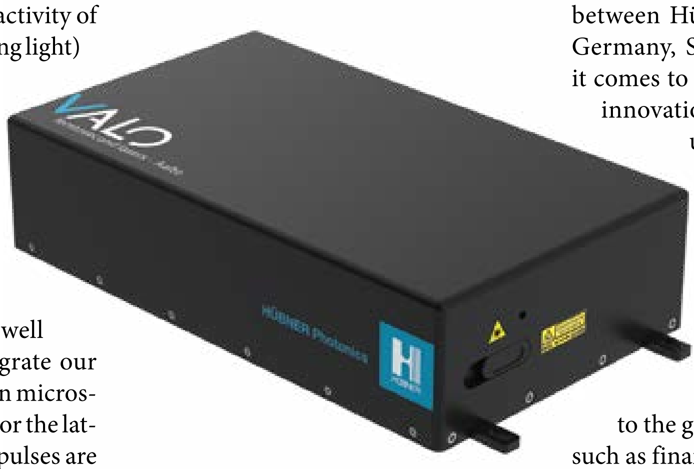
How are commercial applications shaping up for the Valo series?

We are making inroads with a range of ultrafast imaging applications, including multiphoton microscopy (to study complex and dynamic biological processes deep within living tissue), optogenetics (which controls the activity of neurons or other cell types using light) and with amplifier seeding (in which femtosecond pulses increase the energy of selected laser pulses by several orders of magnitude).

It is very much a mixed customer base, comprising research laboratories as well as industry OEMs who integrate our sources into their multiphoton microscopy/spectroscopy systems. For the latter, the benefits of ultrashort pulses are clear: a 40 fs pulse, for example, yields a five times higher peak power versus a 200 fs pulse. That, in turn, means greater signal efficiency, enhanced penetration depth in tissue, better contrast and reduced photothermal damage.

What's coming next on the development roadmap?

In the near term, we want to 'industrialize' the femtosecond product line by transferring best-practice production models from the wider Hübner Photonics laser portfolio. Right now, the emphasis is on continuous improvement and internal benchmarking along a number of key coordinates, including manufacturability, device testing and quality control, long-term reliability, packaging and after-sales service. Looking ahead, we also want the Valo Series to be a scalable technology platform – both in terms of power levels and wavelengths – to broaden our access to emerging applications in life sciences and microscopy.



How important is customer engagement in shaping product innovation for the Valo series?

We have an ongoing dialogue with our early-stage customers and R&D partners, figuring out what needs are not being met and how our lasers can help end-users to do their jobs better. Up until now, it has been mainly me initiating these conversations, though in future much of the responsibility for requirements-gathering and prioritization will switch to our product managers.

It is still early days, but what are the main operational benefits that you are seeing since the acquisition?

Joining forces with Hübner Photonics feels like a once-in-a-lifetime opportunity to embed the Valo Innovations start-up model within an established laser manufacturing operation. We are already benefiting from the open, collaborative, and supportive environment here, with very close engagement between Hübner Photonics teams in Germany, Sweden and the US when it comes to product development and innovation. Another benefit is the uptick in lead generation given that Valo Innovations is now integrated with an experienced in-house sales team and global distributor network, while we also benefit significantly from our direct access to the group's other core functions such as finance, legal, and HR.

*

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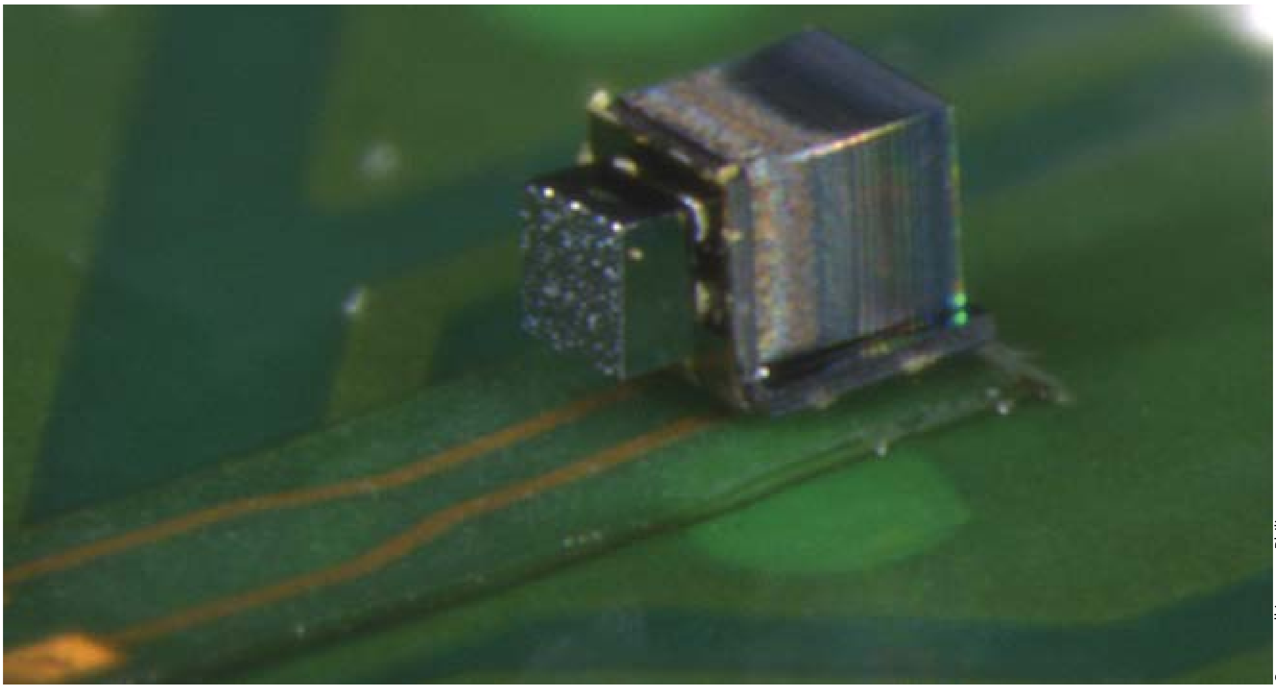
A photonic MEMS interposer to solve electronic and optical assembly challenges

Scalable production, enabling miniaturization and function combination

Jian Li, Andrzej Sielecki, and Elena Beletkaia



Source all images: Philips

Photonic applications often face industry-specific assembly requirements that can be challenging to overcome. There is a need for micron-accurate alignment, device miniaturization and integration in challenging form factors. Special materials and packaging must be developed for the best performance of the devices in exacting environmental conditions. In the medical field, these requirements are additionally complicated by the demanding ISO 13485 regulations. The article demonstrates how solutions are found in a combination of new and existing technology in microelectronics packaging and now made suitable for photonics.

The possibility to fold or roll electronic modules in a tightly confined form factor using flexible interconnects is already widely exploited in the electronics industry, in mobile phones for example. It enables the integration of multiple cameras while keeping a slim design; it allows a tighter density of functionality while maintaining a high level of reliability and more form factor degrees of freedom; it makes the next generation of foldable or deformable phones possible. And this fold or roll approach can be adopted and extended to provide benefits in photonic innovations such as opto-acoustic or spectroscopic imaging integration on the tip of a catheter or a guidewire.

Philips MEMS Foundry-developed flex-to-rigid (F2R) technology allows multiple silicon elements to be flexibly combined that can be folded [2] or rolled [3] as a result. But for the successful integration of electronics in a guidewire, size is not the only concern; the quality and the speed of data transfer requirements must be considered too. In addition, consideration must be given to minimizing the effect of cabling on the mechanical properties of the guidewire, the ease of integration during the assembly process and the direct electrical connection to other components.

The solution to this complex challenge involved the combination of F2R technology and an optical data link that removes interference issues and is able to transfer high speed digital data in a very small diameter. The microelectromechanical system (MEMS) building block based on the Philips MEMS Foundry F2R platform allowed the miniaturization of an optical data link module (ODLM), resolving form factor requirements to fit into the tip of a guidewire [1]. This MEMS interposer enabled the integration challenges to be overcome while simplifying the assembly and maintaining the high performance of the ODLM. In this way, high-speed and disturbance-free communication between, for example, an ultrasound imaging head and the analysis electronics can be realized.

MEMS interposer design to manufacture an ODLM in a miniaturized form factor

In order to align with the overall standard guidewire assembly protocol, the optical link should be mass-producible, designed for high speed and high yield assembly steps, and preferably on wafer level. It must also be a stand-alone device that can be easily connected to other parts in the guidewire. To accomplish this, the optical link design comprised three parts: a microfabricated F2R silicon interposer; a commercially available vertical cavity surface emitting laser (VCSEL) with its electrical contacts and laser emitting spot on the same surface; a 125 µm diameter optical fiber. The F2R silicon interposer incorporated flexible interconnects to reroute the VCSEL electrical contacts to a plane perpendicular to the surface of the VCSEL. This design enabled the optical link module to be mounted on a flex-PCB within the limited space available in the catheter or guidewire. At the same time, the VCSEL is optically self-aligned and connected to a fiber (Fig. 1c) that can be mounted in the catheter shaft leading up to the proximal end of the catheter. This design allows the interposer to be made using high-volume, compatible assembly processes.

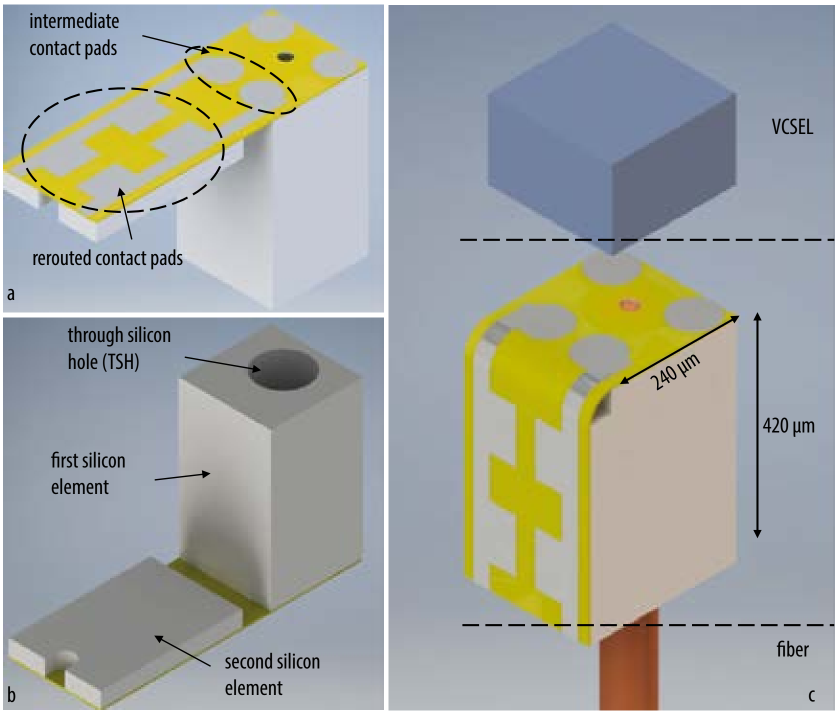


Fig. 1 ODLM design: (a) unassembled F2R interposer, (b) rear view of unassembled F2R interposer, (c) assembled F2R interposer with flip-chipped VCSEL and inserted optical fiber

Interposer fabrication and assembly into the ODLM

The silicon interposer fabrication was based on the F2R process module available from Philips MEMS Foundry and described in detail elsewhere [4]. Some critical points of the F2R process include tight control over the etching process, leading to the required alignment accuracy, and well controlled deposition of the polyimide layers containing the electrical tracks. Importantly, the metal layer in the flexible interconnect is in the stress-neutral plane, and as a result can achieve a very small bending radius of 10 µm that allows tight packaging.

For the first assembly step of the interposer into the ODLM, solder spheres can be placed on the contact pads of the ODLMs at a wafer/die level and the VCSEL can be flip-chipped on top of four reflowed solder spheres. The use of four solder spheres provided two electrical contacts, with the other two being used for mechanical support to prevent tilting during the second reflow step. While all assembly steps were executed piece by piece for the prototype, for high volume assembly solder ball application and reflow on wafer level,

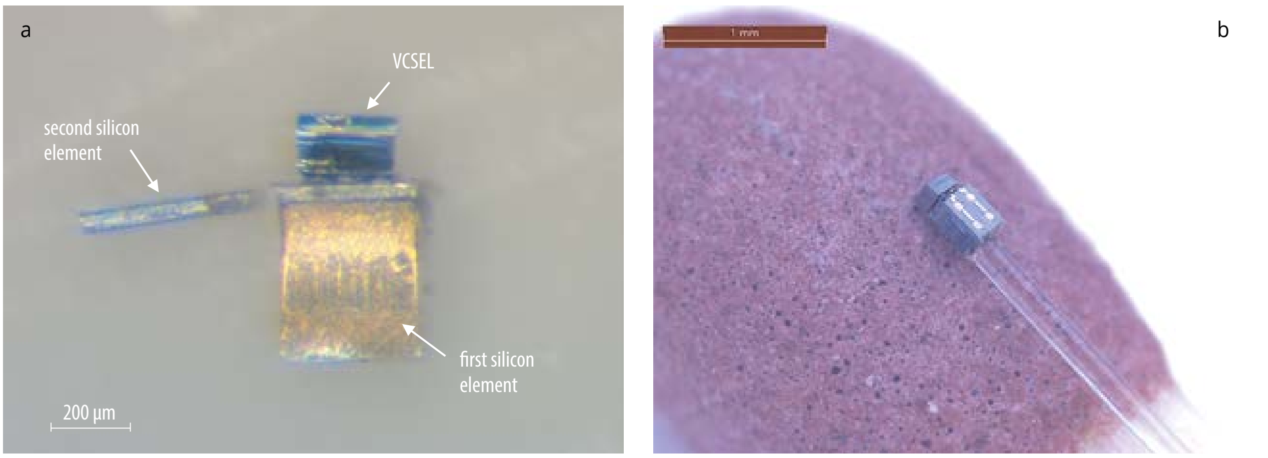


Fig. 2 (a) Side view of an ODLM F2R interposer with assembled VCSEL, released from the Si frame. The two silicon elements are connected by flexible interconnects. (b) An assembled ODLM, with the VCSEL and an inserted 125 µm diameter optical fiber, placed on a match head. The optical fiber was fixed with biocompatible glue.

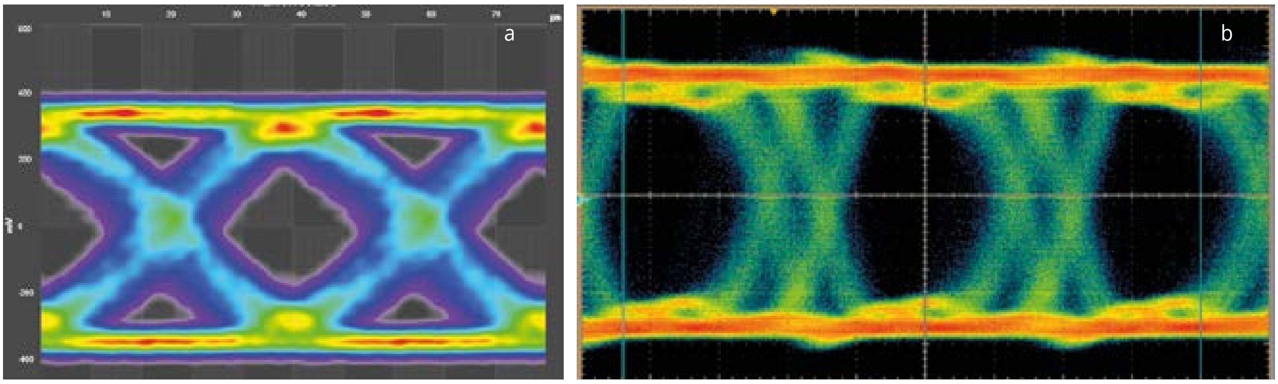


Fig. 3 Eye diagrams of (a) standalone ODLM with 25.8 Gb/s and (b) ODLM and laser driving testing board with 7 Gb/s

automatic flip-chip and wafer level soldering techniques would be possible to use, confirming a design for high-volume manufacturing.

After the electrical integration of the VCSEL on the F2R interposer, the interposer was released from the Si wafer and the free-hanging second thin silicon element was connected to the first silicon element by the flexible interconnect (Fig. 2a). The second thin silicon element was folded by ninety degrees and fixed to the side of the first element with a transparent, biocompatible, UV-cured glue. Subsequently, a 125 µm diameter OM1 multimode optical fiber was stripped and dipped in the same glue, inserted into the 135 µm diameter through-silicon hole, and pushed into the assembled VCSEL on the other side. Fig. 2b shows the final assembled standalone ODLM, including the VCSEL, the F2R interposer, and an inserted 125 µm diameter optical fiber. The interposer geometries attained match the designed geometries shown in Fig. 1. This is strong evidence that the Philips MEMS Foundry F2R processing has reached a maturity level that allows accurate fabrication according to the design with good process control, and creates a good basis for solving assembly challenges in the development of custom devices for different applications.

ODLM performance testing

Miniaturization often comes at the cost of performance. The assembled ODLM was characterized by high-speed data transmission measurements with an external laser driver through high speed probes using a time-domain analyzer and tested to a maximum speed of 25.8 Gb/s. This speed was limited by the analysis system used, not by the ODLM.

A bias voltage of 1.91 V was applied to obtain the best performance of the VCSEL. An optical output power P_{opt} = 1.1 mW was detected at the end of the 1 m long optical fiber. Compared with the specifications of the VCSEL where P_{opt} = 1.45 mW is achieved at 1.91 V bias voltage, the ODLM delivers over 75 % of the optical intensity generated by the VCSEL. This optical intensity was satisfactory for the application and could still be optimized by improving VCSEL positioning.

A 25.8 Gb/s differential signal with PRBS 2^{31}-1 sequence was fed into the ODLM device through high-speed probes. The eye diagram without clock data recovery (CDR) in Fig. 3a proves the capability of the stand-alone ODLM to support data rates up to 25.8 Gb/s. The ODLM was also tested with a custom laser driver with a power dissipation below 10 mW in order to prevent a temperature increase in the tip of the catheter to over 40 °C. The result was a maximum data rate of 7 Gb/s, well above the data rate of 1.6 Gb/s required for the application. Using the low power miniaturized laser driver, 7 Gb/s differential signals with 2^{15}-1 sequence were fed into the ODLM with the resulting eye diagram shown in Fig. 3b.

Both eye diagrams show a big opening, indicating room for a speed increase in both the stand-alone and the integrated case with the low power laser driver. This also means that the 75 % optical intensity transmission through the MEMS interposer is not a limiting factor to the optical link performance.

Photonic MEMS interposer beyond ODLM

The photonic MEMS interposer was also adjusted to be compatible with a four-fold VCSEL component (Fig. 4a), showing the potential to further increase the data transmission density with this technology. It also shows that further miniaturization, scale-up and acceleration in assembly is possible. Using the same F2R technology to redirect the electrical connections to the side of the module, the assembled module can be directly flip-chipped on an ASIC or flex PCB to reduce the length of the interconnect. The example assembly with four fibers in one larger interposer on a flexible PCB is shown in Fig. 4b.

The integrated electronic connection points in the photonics MEMS interposer can also be extended to include mounting pads for ASICs, passive components, or cables. The big benefit of the MEMS interposer is the ability to make a flip chip connection to these ASIC or PIC chips, allowing a route to high volume manufacturing.

In addition, the combination of the passive alignment of optical components and integrated electronics in the MEMS interposer can also be extended with other processing modules from the Philips MEMS Foundry, like the capacitive ultrasound transducers in different frequency ranges and apertures. Furthermore, this technology building block can be combined with the technology and capability of other research and industry partners of MedPhab. Europe's first pilot line for photonics-based med-

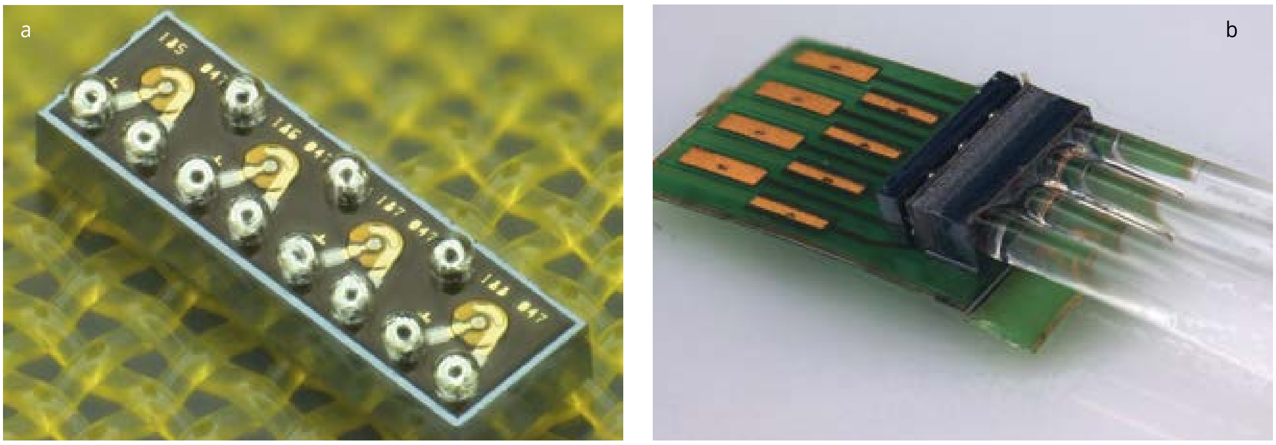


Fig. 4 Four-fold VCSEL a) as a bare chip package with re-flowed solder balls and b) 1 × 4 version of an ODLM with VCSEL interfaced to four fibers and electrically connected to a flexible PCB board using the MEMS interposer

ical devices, MedPhab is dedicated to accelerating their development and commercialization by improving the technology transfer from research and technology organizations to high(er) volume medical applications.

The extremely small form factor and integration of electrical interconnects brings new assembly opportunities to integrated photonics devices with the promise of a high volume manufacturing capability using standard microelectronics assembly methods. As an example, an F2R-based optical data link module (ODLM) with dimensions of 240 µm × 280 µm × 420 µm was designed, fabricated, assembled, and characterized, showing 7 and 25 Gb/s data rate performance. The technology platform described is already offered as a manufacturing service by Philips MEMS Foundry under ISO 13485, complementing customers' own innovations, potentially amplified with solutions from MedPhab partners.

*

We would like to thank all Philips Engineering Solutions colleagues that supported the design, fabrication and assembly of the devices, and TU/e for its characterization and optical measurements. This work was partly funded by the EU ECSEL JU POSITION project, grant no. Ecsel-783132-Position-II-2017-IA

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MedPhab
Photonic Medical Devices
Funded by:

https://medphab.eu

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Gravur.de breaks new ground in laser technology

New system to mark and engrave 3D surfaces in a single operation

Source all images: Optogon

Each of us has consciously or unconsciously had contact with the products of Bornemann: the VW emblem on your car, the Lindt lettering on the chocolate praline or the prancing horse on the gearshift gate of the Ferrari – the manufacturers of these products and brands trust the company in Wermelskirchen, which specializes in precise engraving. Bornemann is investing in the future in 2021, and in the latest laser technology from Optogon.

▲ The M-Series from Optogon as an open system – NC rotary axis and OptoSkop with dual-lens color camera system

Bornemann GmbH was founded just over sixty years ago by Karl Heinz Bornemann in Remscheid, Germany, and dedicated itself to the production of steel stamps and the traditional, handcrafted creation of engravings. In the 1980s, the company entered the computer age and the associated CNC milling technology. Its clientele is international and comes from all sectors of industry.

The company started using laser technology in the 1990s while the demand for lettering, marking and signage increased steadily. Bornemann continued to expand its range of products and invested in a large number of hand-operated and CNC-controlled, lamp-pumped laser marking systems until the 2000s. Among them was one of the first 3D laser engraving systems.

“Everyone has had something in their hands that has been refined by us,” says Bornemann’s commercial manager Ralf Berger. Bornemann’s core business is the production of high-precision embossing tools for companies that could not be more different. The double embossing tools for the brewery logo with lettering for the beer keg, embossing rollers for the flower embossing of sanitary towels, or complex tools for the BMW sill trims – the thirty employees at Bornemann have a very varied range of tasks.

Flexibility and foresight run like a thread through the history of the company, which secured the website domain ‘gravur.de’ in the early years of the Internet. “We were convinced of the laser technology from the very beginning,” Berger says.

No clamping, contactless and fast – these are only the most important advantages of laser technology, and why Bornemann has given this tech-

From left: Ralf Berger (l.) commercial manager, and Roland Wilhelm, laser specialist and protection officer at Bornemann GmbH, with Andreas Plauschin, sales engineer, and Thilo von Grafenstein, marketing, at Optogon GmbH

nology preference over other marking and labeling processes. The company has operated its own laser department, marking and engraving materials and workpieces of all kinds according to customer specifications, since 1996.

"The laser is almost without alternative, especially for complex and more expensive molds. The laser can introduce inscriptions and engravings in very inaccessible places," is how laser specialist and protection officer Roland Wilhelm describes it. Serial numbers, logos and inscriptions are lasered onto the workpieces quickly and with high contrast. This is usually done by hand.

"We like new ideas!"

Ralf Berger
commercial management

After the move to the new 1,600 square meters company building, the laser department was also expanded, and a realignment planned. "The need to develop continued, and the laser technology also continued to develop," says Wilhelm. Then, at the end of 2020 and in the middle of the pandemic, the decision was made to invest in new laser technology. "We wrote extensive specifications for the new laser system," Berger says. "We placed great emphasis on versatility of the laser system and software, as well as automated processing." This relates specifically to the automated processing of a wide variety of 2D codes, such as the UDI code (GS1) for the medical industry, and all common QR and bar codes. Laser engraving and laser marking on the circumference of rotationally symmetrical components without a seam is also a major activity.

The search then began for a partner in the laser sector who on the one hand, was up to this technical challenge, but who was also in the ring as a 'sparring partner' in the long term. Roland Wilhelm sums up: "The contact with Optogon came about quite early. We had known Mr. Plauschin for a long time, and we quickly got down to details" Andreas Plauschin, sales engineer at Optogon, comments: "Since Bornemann already has decades of experience in the field of laser technology, we didn't have to start with Adam and Eve. We were able to concentrate right away on the essential topics, laser and software automation, as well as the flexible bandwidth that the new laser system had to cover." Optogon received a range of data in its laser laboratory in Erlau for a wide variety of applications on many different materials such as various plastics, deep marking of brass housings, cylinders and many other workpieces.

Programming times are a very important factor at Bornemann. "What about the handling of the data? How long does it take for the file to be lasered onto the component? Working together, it was possible to get a live picture of the laser system at PPW Handel in Gummersbach. We were immediately convinced by the simplicity and speed of the human machine interface," recounts Wilhelm. Contract negotiations began in March 2021 and were concluded in June.

Bornemann opted for an open laser system. "From experience, we are more flexible and faster with an open system. We are set up for laser processing according to laser protection class 4," says Wilhelm, who is the company's designated laser protection officer.

Due to the pandemic, the chip shortage delayed the delivery of the system by several weeks until November 2021. An important assembly and an essential requirement for Bornemann, the third optical axis (Opto3D) was subsequently installed in January 2022. This enables the laser system to mark and engrave three-dimensional surfaces in a single operation. The focus point of the laser is automatically adjusted to the surface and delivers a perfect result.

Unfortunately, Optogon's service team discovered hidden transport damage that made life a bit difficult at the beginning, where a defective mechanical component in the control system caused a sporadic error. "The search was tough, as the error was difficult to narrow down. However, Optogon's service solved the problem without further ado,"

The M-Series from Optogon as an open system

Laser marking of an individual UDI code on a plastic housing for the medical industry

Berger reported. Since the installation of automatic focus interpolation in January 2022, the system has been in full operation performing a variety of different tasks. "One of the first orders that made use of the system was for the medical industry. We laser components that are used in the cardio area," Wilhelm said. Automatic UDI code processing, sequential numbers and text typesetting are the challenges that the system automatically handles.

"With this system, everything is actually possible for us: single part processing, or automated processing on pallets," said Roland Wilhelm. "The camera is the dream of anyone who works with a laser." This refers to the 'OptoSkop', a color image preview of the laser system that shows the work area. The operator sees his components on the screen and can place the layout on them – the laser marks and engraves exactly at this point. "The beam quality of the system is better than anything we've had before. The edges are sharper and simply clean," said Wilhelm.

When asked where the journey should go, Berger answered: "The experience after a quarter of a century of laser technology tells us – be prepared! We now have a very flexible system with which a lot is possible. We also like to be surprised ourselves. With the close partnership with Optogon, we are constantly learning and looking forward to new things."

Andreas Plauschin concludes: "We are very happy about this partnership and learn a lot from each other. This is on the application side, on the machine side and also on the product side. We are currently working with Bornemann on new, precise 3D laser engraving and surface structuring, among other things for the automotive industry."

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Preview Full article online and in PhotonicsViews issue 4/2022

Electrifying lasers for the transformer industry

How CO_2 laser sources are being used for paper cutting

BR Technologies is enabling a transformer manufacturer to cut its insulation paper in a unique way by using lasers integrated into its machines. The SR 15i CO_2 laser sources from Luxinar are cutting crepe paper, which is used as an insulation layer inside the electrical transformers that are sold to power grid suppliers.

The uniqueness of this application is twofold: first, insulation in most power transformers is made from oil and cellulose (paper/pressboard), not crepe paper, and second, these materials are usually cut mechanically using blades, not by laser. Additional requirements were for the laser system to automate a process that had previously been done by hand, and that it should produce a clean cutting edge.

BR Technologies has been supplying high-quality winding equipment since 1948 and is a market leader in the transformer winding industry with innovative new projects and research focusing on increasing the automation of the machine to increase the quality, production time and efficiency of the product.

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Close-up of laser cutting crepe paper for the electrical transformer industry (Source: BR Technologies)

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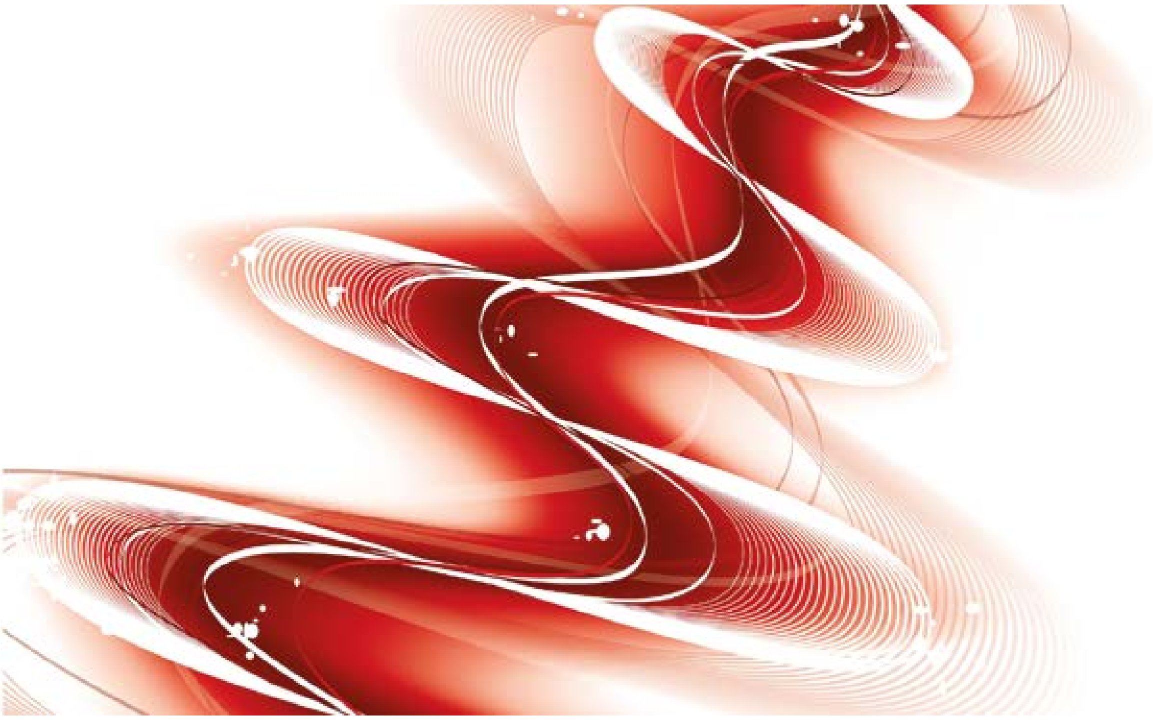
Taming an articulated laser

Beam delivery over a wide spectral range is enabled by articulated arms that direct beams from the laser exit point to the end point, preserving the beam quality

Oren Aharon



Source: marinakoven / 123RF.com

Articulated arms are a well-established method for laser beam delivery, with superior characteristics for diversified spectral wavelengths. Recent innovative applications, especially in the dentistry industry, benefit from improved performance, including user-friendly beam delivery directly to the treatment position. The preferred technology relies on mounting mirrors in hollow members, rotating with respect to each other. The beam is delivered by a train of mirrors to the end point.

Different types of beam delivery systems are available, and essentially serve the purpose of directing a light beam from a laser source to a working area. Frequently we find applications in the medical industry, laser material processing, industrial lasers and academia. For example, emerging areas of applications are in dentist cavity treatment areas, eye surgery and general surgery. In those applications, the most important function is to deliver a high-quality beam with accurate location with respect to the output aperture, regardless of the articulated arms manipulations.

To preserve the laser beam qualities, the best solution is a free space beam delivery using mirrors to direct the beam through articulated hollow members that are connected together. Very high reflectance is achieved using special mirrors such as dielectric mirrors, which minimize the output power loss relative to input power even if multiple mirrors are used along the articulated arm.

Several applications, such as material processing, require a very accurate beam delivery system with little sensitivity to temperature differences. It is beneficial to place the laser source in a protected area for such applications, while the laser beam delivery is moveable outside this protected area. The ability to ensure a focused laser beam is dependent on the stability of angular direction, and hitting the output aperture.

A typical articulated beam delivery arm comprises a series of hollow tubes connected to rotational mirror knuckles. The beam travels through the tubes and is directed by the reflecting mirrors along the tube axis. Connecting several knuckles and tubes allows multiple degrees of freedom, achieved by rotating each tube with respect to the others. This multiple-degrees-of-freedom articulated arm can deliver the beam to the target by moving the end-tip of the arm. Building a robot-like beam delivery arm is a very challenging task due to the alignment problems of the rotating knuckle mirrors. Slight misalignment of laser placement on each knuckle will inherently cause the laser beam to wander inside the free space delivery system with the potential to hit the tubular surfaces or cause the beam to wander within the delivery aperture. To prevent this adverse situation, each knuckle should be perfectly placed and have the exact required angles, preserving the laser direction regardless of knuckle rotation. A special instrument was designed to achieve this, rightfully called AlignMeter, which solves alignment problems when assembling an articulated arm. The alignment process follows the alignment of each knuckle from the first (closest one to the laser) to the last, and is performed by replacing the downstream mirrors with the AlignMeter system to align the non-replaced mirrors. Alignment is done by simultaneously observing the deviation of the laser beam angle and lateral position as a function of knuckle rotation.

Hollow articulated arm technology

Articulated arms are a well-established technology. However, recent applications for delivering laser beam energy require higher accuracy. New system manufacturers want to benefit from this convenient beam delivery system that can be used most lasers' wavelengths on the one hand, while preserving the initial laser characteristics throughout the beam's propagation on the other.

Fig. 2 describes the beam path in a schematic way showing hollow members where the beam transits and is manipulated by rotational movement of mirrors along the propagation direction. This provides a working area of two or more meters by holding the end-tip and directing it towards the treatment area. The multiple mirrors create a situation where any misalignment can move the beam relative to the end-tip center by many millimeters. For example, for a given articulated arm of one meter covering a two meter enclosed area, the specification of center beam deviation of ±0.5 millimeters will require a total angular accuracy of all mirrors to be better than:

$1000\ [\text{mm}]\ \cdot 7 \cdot 2x = 0.5\ [\text{mm}]$

(distance · 7 knuckles · 2 mirror deviations = total deviation), $x \approx 35\ \mu\text{rad}$

This is a very challenging number by any means, especially keeping in mind that the arm is constantly moving with respect to the input laser direction. To achieve this precision, the rigid tube articulated arm, preferably made of aluminum or carbon fiber and equipped with rotating knuckles (six or seven) needs to be pre-aligned in the factory. Even after factory alignment, when mounting the system relative to the laser, the mounting should be perfectly perpendicular to the incoming laser beam and needs accurate alignment as well.

A unique instrument, the AlignMeter, offered off-the-shelf, serves as an accurate and simple device for the alignment routine of robotic arms or articulated arms. The instrument is conceived to measure both the positional and angular beam runout of the articulated arms, enabling the accurate alignment of each knuckle.

Fig. 1 AlignMeter mounted on an articulated arm (Source: Duma Optronics)

Alignment in practice

The method involves mounting the AlignMeter by replacing one mirror along the laser propagation and rotating the previous knuckle. The laser hitting the AlignMeter aperture will move on the detector surface and leave its trajectory clearly displayed on a computer screen. If the trajectory is displayed as a stable dot, it means that

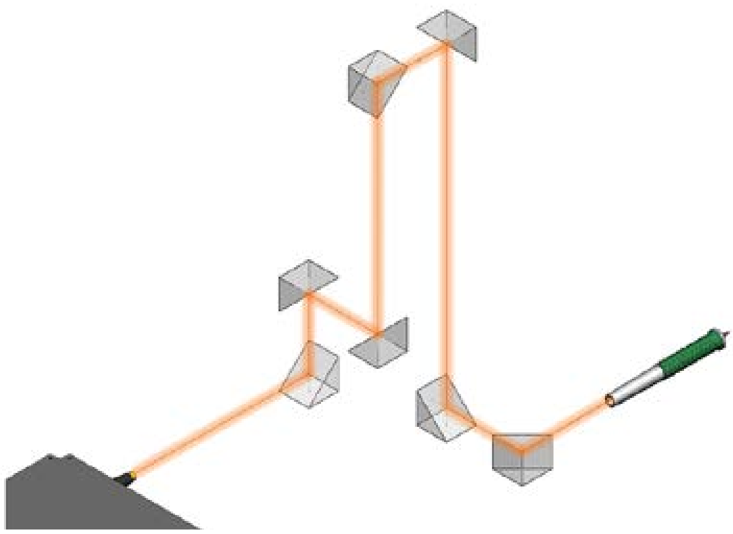


Fig. 2 Laser ray trace within a hollow articulated arm (Source: Duma Optronics)

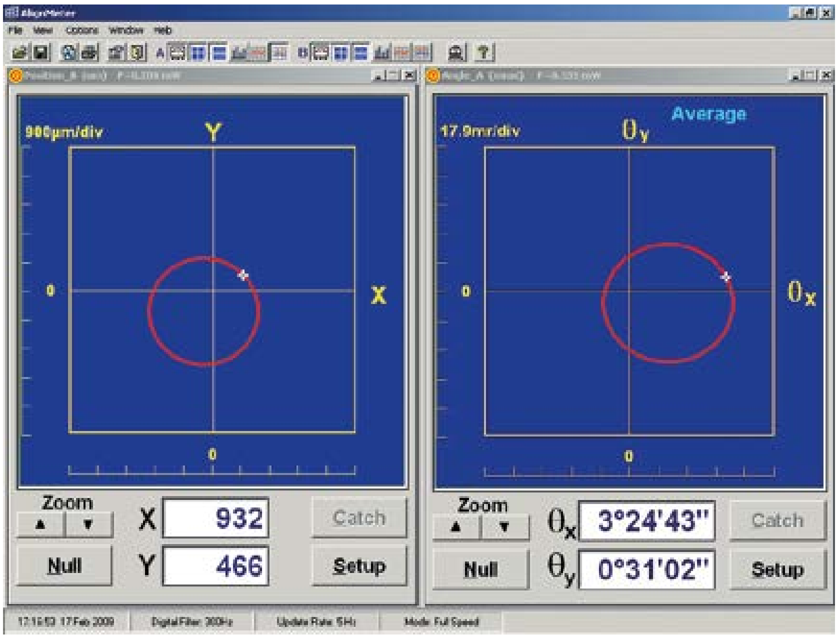


Fig. 3 Beam trace describing non-concentricity effect (Source: Duma Optronics)

the knuckle under examination is perfectly mounted. On the other hand, if the trajectory on the screen shows a circular trace, then the knuckle should be adjusted. The instrument displays both the angular and positional deviation.

A typical screenshot showing the circular movement caused by a combination of position and angular deviation is also displayed in Fig. 3. The left-hand side shows the linear concentricity while the right-hand side shows the angular deviation. Both figures are displayed in parallel, and the technician can follow relevant instructions that are displayed in the software to correct alignment until any further rotation yields a point-like circle.

Measurement layout

Solution 1 – static: a calibrated AlignMeter assembly can be easily mounted on an articulated arm by using the adapting nut. If the mechanical datum is accurately aligned relative to the optical axis of the robotic arm, then the AlignMeter will provide the centralization deviation and angular deviation instantaneously.

Solution 2 – dynamic: if the mechanical datum is not accurate enough for the application, the AlignMeter can be mounted at the elbow as in the previous case and then the usual rotation of the arm performed. The beam deviation will be recorded by the AlignMeter as a circle. The user must then align the previous elbow so that the 'circle' becomes one point.

Summary

Many laser system providers are realizing that incorporating articulated arms into their products results in an accurate, reliable and optically superior solution. The main obstacles to the wide acceptance of this technology lie in the accuracy of the output beam. This obstacle can be removed by using the AlignMeter, accurately mounting the knuckle and increasing the total rigidity of the system. Popular new applications are in medical devices such as dentistry, for example for treating cavities with CO_2 lasers via articulated arms. Many other applications exist, including those using high power. Another potential application would be coupling the articulated arm to an industrial robot that directs the end-piece to the work area.

Combining the advantages of an articulated arm with the alignment procedure offered by the AlignMeter will yield a better beam delivery system in terms of performance, and the proliferation of various laser wavelengths used in day-to-day material processing and laser delivery. This creates an alternative method of delivering flexibility as well as extreme accuracy.

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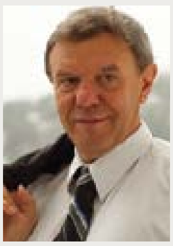
Author



Oren Aharon has several decades of experience in the electro-optical field, including start-up initiations based on his own patents. He founded Duma Optronics 25 years ago to offer advanced enabling technologies for the industry. He owns thirty patents and graduated from Technion with a BSc in nuclear engineering and an MSc in industrial engineering. He has written numerous articles and has served as a technical assistant to the Israeli Minister of Energy. He is the inventor of the CKET technology.

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SLT Program: Tuesday, 21 June 2022

ROOM C1.2.2: Plenary Session

09:00 SLT 2022 OPENING AND INFORMATION
Heidi-Maria Götz, IFSW, University of Stuttgart, Germany

09:10 WELCOME TO THE SLT 2022
Thomas Graf, IFSW, University of Stuttgart, Germany

09:30 TOWARDS AUTOMATED SELF-LEARNING PROCESS OPTIMIZATION
Andreas Michalowski, Bosch Research, Renningen, Germany

10:00 INDUSTRIAL LASER PROCESSING: WHAT'S NEXT?
Christian Schmitz, TRUMPF SE + Co. KG, Ditzingen, Germany

10:30 COFFEE BREAK

ROOM C1.2.1, SLT Topic 1:
FUNDAMENTALS AND APPLICATIONS OF CW LASER PROCESSING

1.1 PROCESS IMPROVEMENT WITH SHAPED LASER BEAMS, Chair R. Weber

see article p. 52

11:15 Latest Technology Leaps due to Beam Shaping in Laser Materials Processing
T. Hesse, TRUMPF Laser- und Systemtechnik GmbH, Ditzingen, Germany

11:40 Laser Processing with Arbitrary Beam Patterns
J. Wagner, IFSW, University of Stuttgart, Germany

12:05 Fast Beam Oscillations Improve Laser Cutting of Thick Materials
A. Wetzig, Fraunhofer IWS, Dresden, Germany

ROOM C1.2.2, SLT Topic 2:
ULTRAFAST LASER SOURCES AND OPTICS

2.1 HIGH POWER AND HIGH ENERGY ULTRAFAST LASERS Chair M. Abdou Ahmed

11:15 Industrial High Power Lasers Covering ns to fs Regime
A. Killi, TRUMPF Laser GmbH, Schramberg, Germany

11:40 Generation of Visible and UV Ultra-Short Laser Pulses at High Average Power, C. Röcker, IFSW, University of Stuttgart, Germany

12:05 High Beam Quality Thin-Disk PERLA Platform for Multibeam Micromachining
M. Smrž, HiLASE Centre, Dolní Břežany, Czech Republic

12:30 LUNCH AND LASYS VISIT

1.2 PROCESS CONTROL FOR ADDITVE MANUFACTURING AND WELDING, Chair C. Hagenlocher

14:15 OCT in Additive Manufacturing – New Approaches in System and Sensor Technology for DED with Powder and Wire
M. Kogel-Hollacher, Precitec GmbH & Co. KG, Gaggenau, Germany

14:40 Advanced Process Monitoring Approaches for Additive Manufacturing of Metals
T. Seefeld, BIAS GmbH, Bremen, Germany

15:05 Process Monitoring of Laser Welding Processes with a Multi-Sensoric Approach
C. Franz, 4D Photonics GmbH, Isernhagen, Germany

2.2 NOVEL LASER AND BEAM DELIVERY CONCEPTS Chair M. Abdou Ahmed

14:15 Innovative Lasers and Beam Transportation with Microstructured Optical Fibers
E. Audouard, Amplitude, Pessac, France

14:40 Design, Production, and Characterization of Specialty Optical Fibers at the IFSW
C. Röhrer, IFSW, University of Stuttgart, Germany

see article p. 47

15:05 Thulium-Based, Ultrafast Fiber Lasers: From a Laboratory Curiosity to a Top-Performer
M. Kumkar, TRUMPF Laser GmbH, Schramberg, Germany

15:30 COFFEE BREAK

1.3 PROCESS FUNDAMENTALS OF ADDITIVE MANUFACTURING AND WELDING, Chair T. Graf

16:10 Experimental Advances in Dynamic Laser Coupling Measurements on Metals – From Solids to Powders
B. J. Simonds, National Institute of Standards and Technology, Boulder, USA

16:35 Numerical Simulation of Laser Powder Bed Fusion
A. Otto, TU Vienna, Research Unit for Photonic Technologies, Austria

17:00 Looking Back – Process Fundamentals for Laser Beam Welding over the Years
P. Berger, IFSW, University of Stuttgart, Germany

2.3 HOLISTIC APPROACH TO ULTRAFAST LASER PROCESSING SYSTEMS, Chair V. Onuseit

16:10 kW-Class Picoseconds Thin-Disk Laser for High-Throughput Manufacturing
A. Loescher, IFSW, University of Stuttgart, Germany

16:35 Automated Free-Space Beam Delivery System for Ultrafast Laser Beams in the kW Regime
A. Peter, IFSW, University of Stuttgart, Germany

17:00 kW-Class Ultrafast Laser Applications: From Drilling and Cutting to Surface Structuring and Micromilling
D. Holder, IFSW, University of Stuttgart, Germany

see article p. 40

17:30 INDIVIDUAL TRANSFER TO THE IFSW

18:30 SLT 2022 EVENING WELCOME
Thomas Graf, Director of the IFSW

18:45 PRESENTATION OF LASER APPLICATION BASICS LIVE
Staff of the IFSW

19:30 NETWORKING AND DINNER IN THE INNER COURTYARD
Swabian Evening at the IFSW

SLT Program: Wednesday, 22 June 2022

ROOM C1.2.2: Plenary Session

09:00 SLT 2022 OPENING AND INFORMATION
Heidi-Maria Götz, IFSW, University of Stuttgart, Germany

09:05 ADDITIVE MANUFACTURING UNDER SPACE CONDITIONS USING THE EINSTEIN-ELEVATOR
Ludger Overmeyer, Leibniz University Hannover, Germany

09:30 THE (R)EVOLUTION OF LITHOGRAPHY OPTICS: EUV ENABLES THE CONTINUATION OF MOORE´S LAW
Thomas Stammler, Carl Zeiss SMT GmbH, Oberkochen, Germany

10:00 ON THE WAY TO THE UNIVERSAL LASER MACHINE
Thomas Graf, IFSW, University of Stuttgart, Germany

10:30 COFFEE BREAK

ROOM C1.2.1, SLT Topic 3:
FUNDAMENTALS AND APPLICATIONS OF ULTRAFAST LASER PROCESSING

3.1 SPATIAL AND TEMPORAL OPTIMIZATION OF ULTRAFAST LASER PROCESSES, Chair D. Holder

11:15 System Technology for Processing with High-Power Ultrafast Lasers, B. Neuenschwander, Bern University of Applied Sciences, Burgdorf, Switzerland

11:40 Optimized Airy-Beams for Round Glass Edge Cutting
J. U. Thomas, SCHOTT AG, Mainz, Germany

12:05 Latest Progress in Precise and Efficient Materials Processing with Ultrashort Laserpulses
A. Gillner, Fraunhofer ILT, Aachen, Germany

ROOM C1.2.2, SLT Topic 4:
HIGH AVERAGE POWER CW LASER SOURCES AND OPTICS

4.1 DYNAMIC PATH PLANNING FOR LASER MACHINING Chair S. Boley

11:15 Iterative Path Planning for Laser Metal Deposition with Online Control
M. Wolf, ISW, University of Stuttgart, Germany

11:40 Toolpath Generation in Laser Metal Deposition for Complex 3D Geometries, R. Beccard, LUNOVU GmbH, Herzogenrath, Germany

12:05 Closed-Loop Control of Ultrafast Laser Ablation
M. Buser, IFSW, University of Stuttgart, Germany

12:30 LUNCH AND LASYS VISIT

3.2 SPECIAL SYSTEMS FOR HIGH-PRECISION LASER DRILLING, Chair V. Onuseit

14:15 High-Speed Rotary Optics for Ultra-Short Pulse Lasers with High Average Powers and Short Laser Pulses
R. Holtz, University of Applied Sciences and Arts Northwestern Switzerland, Windisch, Switzerland

14:40 5-Axis Scan Head for High Precision Drilling
H. Schlüter, SCANLAB GmbH, Puchheim, Germany

15:05 Optic Concept for High Power Helical Drilling
D. Brinkmeier, IFSW, University of Stuttgart, Germany

4.2 LASER BEAM TAILORING Chair M. Abdou Ahmed

14:15 Nonlinear Optics in Multipass Cells
M. Hanna, Laboratoire Charles Fabry, Université Paris-Saclay, Palaiseau, France

14:40 MPLC Systems for High-Power CW and fs Laser Beams
G. Pallier, Cailabs, Rennes, France

15:05 Latest Results on Grating Waveguide Structures for Pulsed Laser Systems
M. Rumpel, MarTec Photonics, Stuttgart, Germany

see article p. 56

15:30 COFFEE BREAK

3.3 FOCUS ON X-RAYS FROM ULTRAFAST LASER PROCESSING, Chair C. Hagenlocher

16:00 Introduction to the USP-X-Ray Session
R. Weber, IFSW, University of Stuttgart, Germany

16:10 The Current Legal Situation for Operating Ultrashort-Pulsed Laser Material Processing Stations, M. Rothmund, Regierungspräsidium Stuttgart, Referat 54.6, Heilbronn, Germany

16:25 X-Ray Protection in an Industrial Production Environment
C. Freitag, LightPulse LASER PRECISION, Stuttgart, Germany

16:40 X-Ray Emissions during Laser Turning with Ultra-Short Laser Pulses, R. Giedl-Wagner, GFH GmbH, Deggendorf, Germany

see article p. 55

16:55 X-Ray Emission from Industrial Applications with Ultra-Short Laser Pulses
G. Kunz, Robert Bosch GmbH, Renningen, Germany

4.3 INTELLIGENT LASER AND PROCESSING SYSTEMS Chair V. Onuseit

16:00 Lasers that Learn
B. Mills, Optoelectronics Research Centre, University of Southampton, United Kingdom

16:25 Optimization of the Laser Beam Welding Process using Combination of Physical Based and Data Driven AI Models
A. Ilin, Robert Bosch GmbH, Renningen, Germany

16:50 Application of Machine Learning for Quality Assessment of Laser Powder Bed Fusion Process
A. Molotnikov, RMIT University, Melbourne, Australia

17:15 SLT 2022 CLOSING NOTE

17:15 R. Weber, IFSW, University of Stuttgart, Germany

V. Onuseit, IFSW, University of Stuttgart, Germany

Ultrafast laser applications in the kW-class

From drilling and cutting to surface structuring and micromilling

Daniel Holder, Manuel Henn, Alexander Peter, Sebastian Faas, Anne Feuer, Christian Freitag, Rudolf Weber, Volkher Onuseit, and Thomas Graf

Source: Max Kovalenko / U Stuttgart. Source all other images: IFSW, U Stuttgart

Ultrafast lasers are an excellent tool for processing almost all materials and for micromachining structures and geometries with sizes ranging from nanometers to millimeters. Their only weakness, the low average power of the beam source and therefore the lack of potential for high throughput, disappeared with the development of ultrafast lasers with average powers exceeding 1 kW. With the high average power, a new challenge has emerged for systems engineering and process development: achieving high throughput micromachining with high average power ultrafast lasers while maintaining high quality.

The outstanding precision, flexibility, and versatility of processing with ultrafast lasers has opened up the development of many new industrial applications in recent years. Drilling of precise microholes in metals [1], cutting of holes in carbon fiber-reinforced plastics (CFRP) [2], separation of glass by inducing elongated modifications [3], surface functionalization with periodic micro and nanostructures [4, 5] or high-quality micromilling of copper [6] and additively manufactured aluminum parts [7] are only some of the various possibilities enabled by ultrafast laser processing.

In the past, a limiting factor in processing with ultrafast lasers was the low average power of the beam sources of up to a few tens of watts at a high cost per watt, which often prevented the use of this promising technology for large-area processing or high-throughput manufacturing. This situation changed with the demonstrations of ultrafast lasers in the range of kW [8, 9, 10] and multi-kW [11] average laser power. New challenges have emerged in systems engineering and process development for machining with high average laser power due to this development, such as the avoidance of air breakdown and maintaining the optimum fluence at high pulse energy as well as minimizing heat accumulation effects of processing with multiple pulses at high repetition rates [12]. Technical approaches for processing in the range of 100 W to 210 W average laser power have been demonstrated using polygon-scanners and high repetition rates [13, 14] or beam splitting

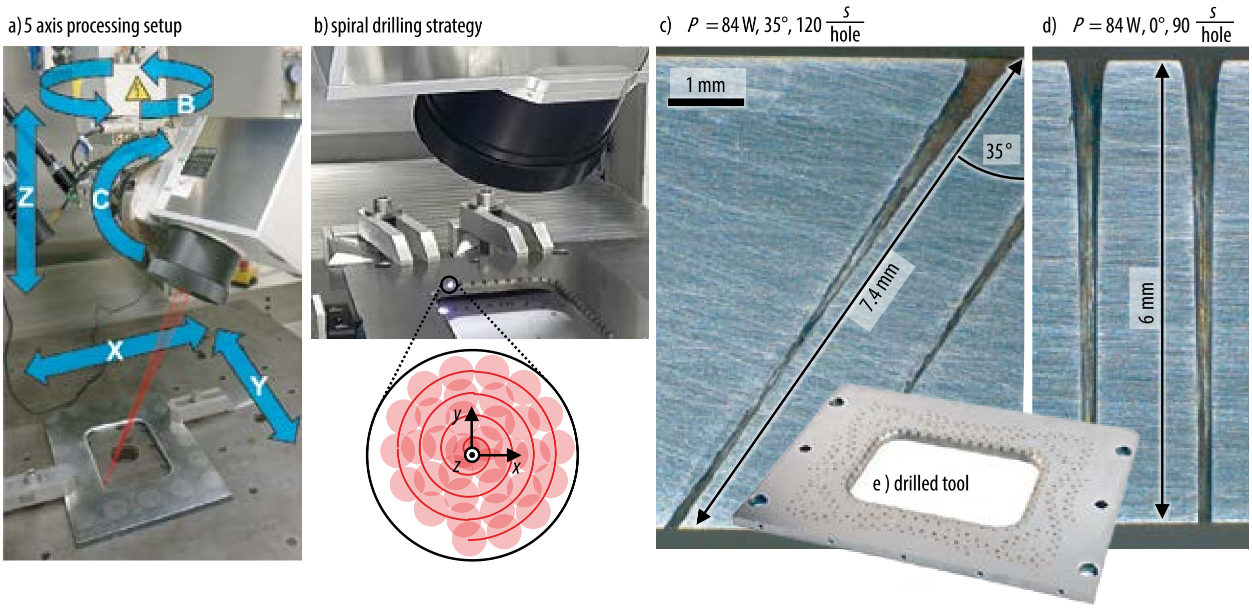

Fig. 1 Five-axis processing setup in combination with a galvanometer scanner used for laser drilling of the forming tool (a). Spiral drilling strategy for an adapted hole geometry (b). Cross sections of holes drilled through 6 mm thick hardened steel plates with P = 84 W and with a 35°-inclined drilling axis, resulting in 120 s drilling time per hole (c). Vertical drilling axis resulting in 90 s drilling time per hole (d). Dry metal forming tool made from hardened tool steel after deep drilling of 336 holes (e).

by diffractive optical elements and high pulse energies [15, 16].

In the following, we present the results of high-quality, high-throughput, ultrafast laser micromachining with over 1 kW achieved at the IFSW, from drilling and cutting to surface structuring and micromilling.

Deep drilling of dry metal forming tools

Dry metal forming using volatile lubricants is a recently developed approach to avoid the usage of synthetic and mineral oils in deep drawing processes. Instead, liquid carbon dioxide is introduced through microholes in the tool as a volatile lubricant under high pressure directly into the friction zones between the deep-drawing tool and the sheet metal [17, 18]. The great challenge is to drill several hundred microholes into one deep drawing tool in a reasonable amount of time through hardened tool steel several millimeters thick without softening the surrounding material, while also achieving microholes with a conical shape.

This home-built ultrafast laser system emits laser pulses at a wavelength of λ = 1030 nm with a pulse duration of τ = 8 ps. Although an average laser power of up to P = 570 W was available, the power used for the drilling process was limited to P = 84 W by setting the repetition rate to f = 30 kHz. As explained in [19], it is not possible to drill a high-quality microhole with an average power >100 W due to thermal defects. Drilling of multiple holes at the same time by means of parallelization as shown for 10 µm thin foils in [16] could be a potential solution for using kW average power for deep holes as well, if a high-energy beam source as demonstrated in [9] is used.

A five-axis processing setup was used to introduce vertical and inclined microholes all over the fixed tool (Fig. 1a). The drilling strategy is described in detail in [18]. In short, a galvanometer scanner was used for spiral drilling in order to adapt the inlet diameter (Fig. 1b). An energy-ramp from 0.1 mJ to 2.8 mJ was used to minimize surface damage typically observed at the beginning of the drilling process. The focus position was shifted into the workpiece with increasing hole depth in order to maintain a high fluence in the tip of the hole and thus maintain high depth progress [20].

With P = 84 W and for a drilling axis inclined by 35°, which corresponds to a depth of 7.4 mm at a sample thickness of t = 6 mm, the desired hole geometry with its tapered shape was achieved after 120 s drilling time (Fig. 1c). A shorter drilling time of only 90 s per hole was demonstrated for the vertical drilling axis and a depth of 6 mm (Fig. 1d). As a result, the 336 deep microholes required in the hardened steel tool could be drilled within approximately ten hours (Fig. 1e).

High-quality cutting of CFRP

CFRP is a material that is frequently used for structural components in aviation due to its excellent mechanical properties and low weight. These structural components typically have a thickness of a few millimeters and require the insertion of geometries such as holes up to few tens of millimeters in diameter in order to join different parts by screws or rivets. The challenge is to fully cut through CFRP plates of several millimeters thickness with a high effective cutting speed v_{eff} without significantly damaging the adjacent material. The presence of delamination and the extent of the matrix evaporation zone

Institute

Institut für Strahlwerkzeuge (IFSW)

The IFSW of the University of Stuttgart, founded in 1986, has a reputation as one of the leading laser research centers worldwide. Its strength is based on a holistic research approach covering every aspect from laser sources to their applications, and ranging from fundamental investigations to industrial technology transfer. The main emphasis at the IFSW is in the fields of laser beam sources (especially the thin-disk laser), optical elements and components for beam delivery and beam shaping as well as fundamental investigations into the light-matter interaction with the subsequent process development of macro and micro applications for industrial manufacturing.

www.ifsw.uni-stuttgart.de

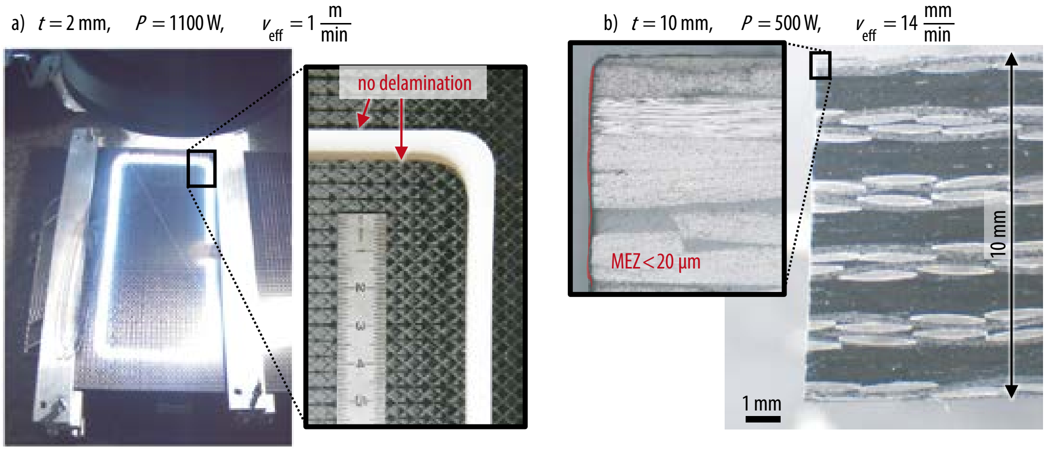

Fig. 2 Camera image taken during the cutting process of 2 mm thick CFRP plate with P = 1100 W average laser power and an effective cutting speed of v_{eff} = 1 m/min. The magnification of the top right corner of the cut plate demonstrates the high cutting quality without any delamination on the cutting edges (a). Microscope images of cross sections of a full cut through a 10 mm thick CFRP plate performed with P = 500 W and v_{eff} = 14 mm/min. The MEZ was <20 µm along the entire cutting edge (b).

are typically considered as damage in CFRP-processing.

The home-built ultrafast laser system emitted laser pulses at $\lambda = 1030$ nm and with $\tau = 8$ ps. Using a maximum average power of $P = 1100$ W at $f = 300$ kHz led to a maximum pulse energy $E_P = 3.7$ mJ. The laser beam was guided into a galvanometer scanner when moving the beam over the workpiece.

Heat accumulation between subsequent pulses or multiple scans has to be avoided when cutting CFRP to minimize the extent of the MEZ. A promising strategy was demonstrated in [21], where heat accumulation between pulses was minimized by using high scanning speeds in the range of $v = 30$ m/s in order to achieve a low pulse overlap. Heat accumulation between scans can be avoided by pauses after a critical number of scans, the cutting of long contours or parallel processing. As a result, a full cut at an average laser power of $P = 1100$ W through CFRP plates with a thickness of $t = 2$ mm was achieved with an effective cutting speed (without considering pauses) of v_{eff} = 1 m/min and without delamination on the sample's surface (Fig. 2a) [21]. A full cut through thick CFRP plates (t = 10 mm) at a reduced power level of P = 500 W could be demonstrated with an effective cutting speed of v_{eff} = 14 mm/min and with a MEZ < 20 µm along the entire cutting edge (Fig. 2b).

Single-pass separation of thick glass

Shielded but still transparent areas are required in aviation and safety applications. Glass panels with a thickness of up to tens of millimeters are typically used to maintain their functionality even under high loads. These glass panels have to be cut into their final shape to fit the respective application. The challenge is to fully modify the thick glass panels along the separation contour with a high feed rate and still achieve a smooth cutting face after cleaving.

The home-built ultrafast laser system used for the experiments emitted laser pulses at λ = 1030 nm and with τ = 8 ps. Using a maximum average power of P = 760 W at f = 300 kHz resulted in a maximum pulse energy E_P = 2.6 mJ. A promising strategy for inducing modifications of several millimeter lengths was demonstrated in [22]. The laser beam was transmitted through an axicon to generate a Gaussian-Bessel beam (Fig. 3a) and the glass

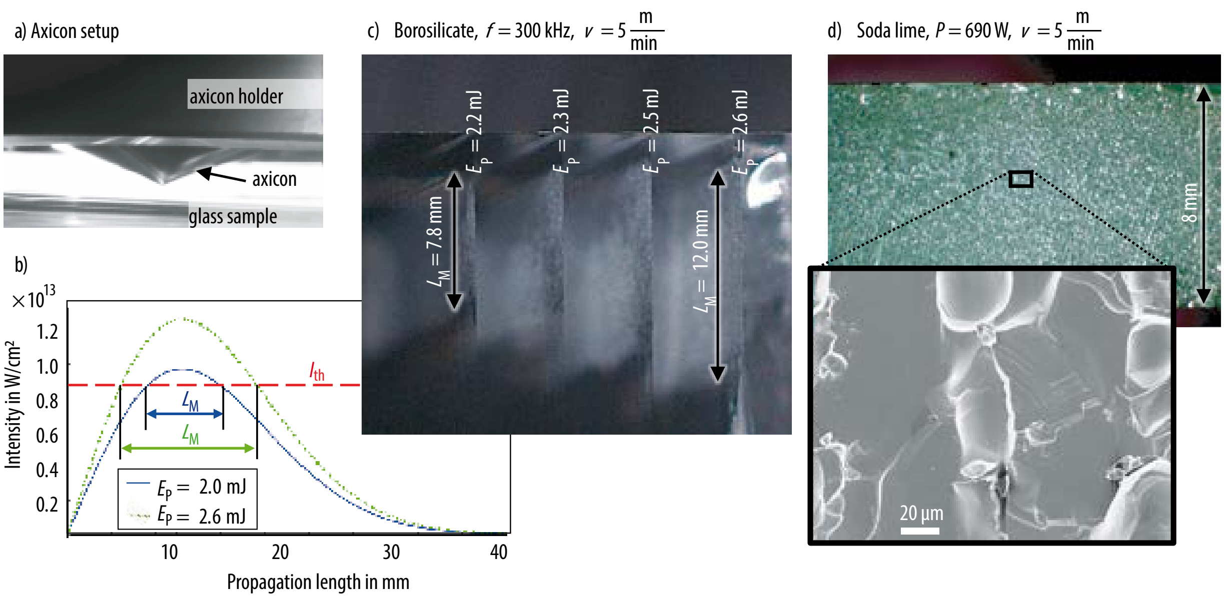

Fig. 3 Axicon setup used for the generation of a Gaussian-Bessel beam (a). Calculated peak intensity of an axicon-generated zeroth-order Gaussian-Bessel beam along the propagation direction for two pulse energies, 2.0 mJ (blue line) and 2.6 mJ (green line). The intersections with the modification threshold I_{th} determine the resulting modification length L_M (b). Cross section of the borosilicate ingot with lines inscribed at different pulse energies up to E_P = 2.6 mJ (P = 780 W), resulting in modification lengths up to L_M = 12 mm (c). Cleaved surface of a soda lime glass with thickness t = 8 mm after inscribing with E_P = 2.3 mJ (P = 690 W) at a feed rate of v = 5 m/min in a single pass (d).

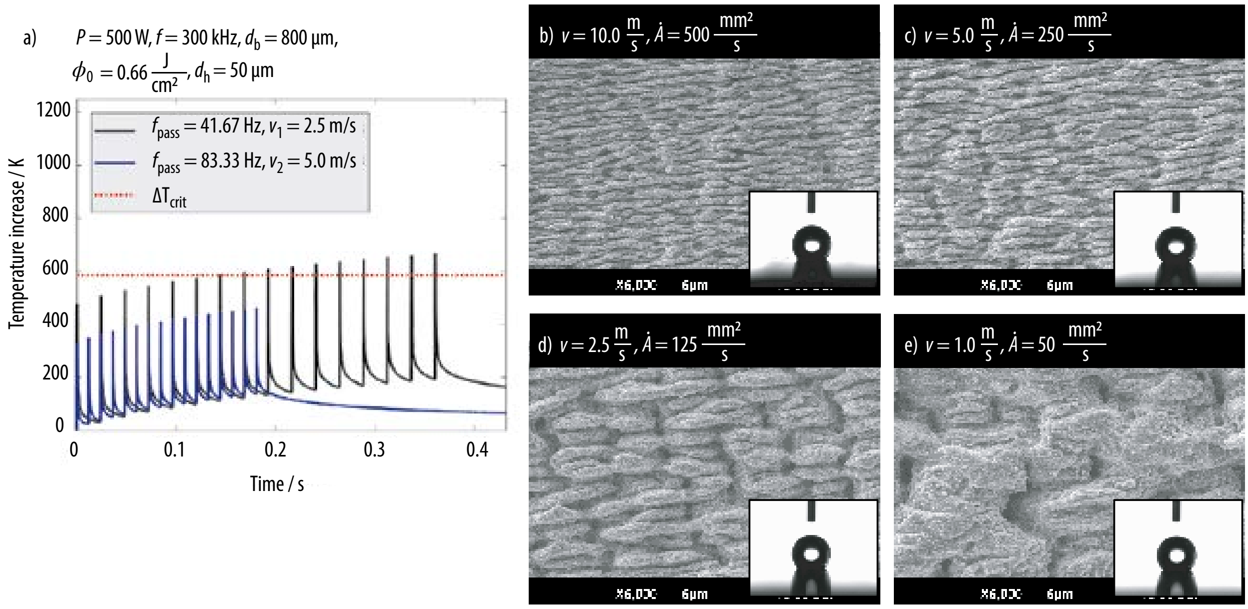

Fig. 4 Calculated temperature increase caused by heat accumulation of multiple scans over the sample surface with P = 500 W, f = 300 kHz, ϕ_0 = 0.66 J/cm², d_b = 800 µm, d_h = 50 µm for the two scanning speeds v_1 = 2.5 m/s and v_2 = 5.0 m/s. SEM images of surface structures resulting from scanning with aforementioned parameters and different scanning speeds, resulting in different structuring rates (a): v_s = 10.0 m/s, $\dot{A}$ = 500 mm²/s (b), v_s = 5.0 m/s, $\dot{A}$ = 250 mm²/s (c), v_s = 2.5 m/s, $\dot{A}$ = 125 mm²/s (d), v_s = 1.0 m/s, $\dot{A}$ = 50 mm²/s (e). The insets show the measured hydrophobic behavior of deionized water on the respective surface.

samples were moved below the axicon with translation stages at a feed rate of v = 5 m/min. With increasing pulse energy E_P, the modification length L_M increases due to the longer distance in which the local intensity exceeds the intensity threshold I_{th} (Fig. 3b).

As a result, modification lengths in borosilicate glass up to L_M = 12 mm were achieved at E_P = 2.6 mJ and P = 760 W in a single pass (Fig. 3c). At P = 690 W, a complete modification along the separation contour of soda lime glass with a thickness t = 8 mm could be demonstrated at v = 5 m/min (Fig. 3d). After cleaving, the roughness of the cutting face was measured to S_a = 7 µm, which can be reduced in future work by using translation stages with higher feed rates in order to avoid melt formation resulting from heat accumulation effects [22].

Surface functionalization of stainless steel plates

Functionalized surfaces with properties such as self-cleaning or antibacterial behavior have a high potential to be commonly used in industrial production or medical technology. However, metal parts typically exhibit a hydrophilic surface with a contact angle in the range of 50° to 80°. For water-repellant, hydrophobic surfaces (contact angle >90°), the surface topography and surface chemistry have to be adjusted accordingly, which can be achieved with laser-induced surface structures in the micrometer and nanometer range. The challenge is to induce the appropriate surface structure with a high structuring rate for economic production in large-scale applications.

The home-built ultrafast laser system emitted laser pulses at λ = 1030 nm and with a pulse duration of τ = 8 ps. Using a maximum average power of

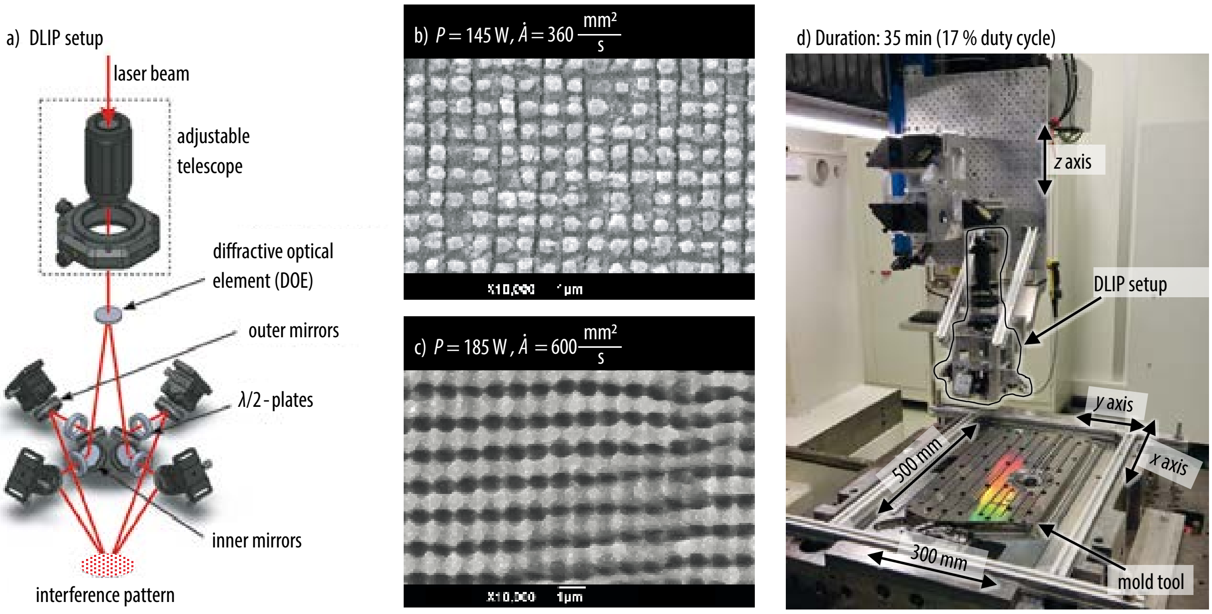

Fig. 5 Scheme of the setup used for direct laser interference patterning (DLIP). SEM images of exemplary surface structures generated by DLIP on a steel sample (a): SEM images of cones structured with P = 145 W and $\dot{A}$ = 360 mm²/s (b) and holes structured with P = 185 W and $\dot{A}$ = 600 mm²/s (c). Large-area injection mold steel tool after structuring with the DLIP setup. The steel tool was moved using the numerically controlled axes, resulting in a duty cycle of 17 % and total structuring time of 35 min. The colors on the tool are created by the diffraction effect caused by the periodic structures (d).

P = 500 W with a pulse repetition rate of f = 300 kHz resulted in a maximum pulse energy E_P = 1.67 mJ. The beam was guided into a galvanometer scanner when moving the beam over the workpiece at different scanning speeds. The focus position was shifted above the sample's surface in order to increase the beam diameter to d_b = 800 µm and therefore maintain a moderate peak fluence of ϕ_0 = 0.66 J/cm².

The heat accumulation resulting from multiple scans influences the surface temperature, which in turn affects the resulting surface structure on the workpiece. The heat accumulation model presented in [23] was used to calculate the temperature increase due to multiple scans (Fig. 4a) at different scanning speeds. A laser-wavelength-sized ripple structure (Fig. 4b, c) was induced on stainless steel when the temperature increase remained below the critical temperature increase of about 600 K, which corresponds to scanning speeds of $v \geq 5.0$ m/s. A bumpy structure (Fig. 4d, e) was generated when exceeding ≈600 K with scanning speeds of $v \leq 2.5$ m/s.

The structuring rates $\dot{A}$ are directly correlated with the scanning speed, whereas ripple structures could be demonstrated on stainless steel with very high structuring rates of up to $\dot{A}$ = 500 mm²/s at an average power of P = 500 W and a scanning speed of v = 10.0 m/s. The contact angle was measured 107 days after structuring. All investigated surface structures were hydrophobic with contact angles in the range of 140°. Even higher structuring rates of up to $\dot{A}$ = 1250 mm²/s and contact angles up to 173° were achieved by adjusting the processing parameters accordingly [24].

Surface structuring of large-area injection mold steel tools

A promising approach for the economic generation of functionalized surfaces on injection-molded plastics is to induce the negative surface geometry onto the mold steel tool and to replicate the structure during the injection mold process. The challenge is to induce the appropriate surface structure with a high area rate onto the desired areas for an economic structuring process in large-scale applications.

The home-built ultrafast laser system emitted laser pulses at λ = 1030 nm and f = 300 kHz with τ = 8 ps. The beam was guided into the home-built direct laser interference patterning (DLIP) setup (Fig. 5a) and transmitted through a diffractive optical element to split the beam into four beams. The polarization of each beam was adjusted with the respective $\lambda/2$ plate. Different interference patterns can be generated on the sample surface depending on the angle of incidence and polarization of each beam [25]. The tool steel samples were moved below the DLIP setup with numerically controlled axes at a feed rate of approximately v = 0.5 m/s.

Small cones with a diameter of 600 nm and a period of 850 nm could be generated on tool steel by cross hatching with P = 145 W and a structuring rate of $\dot{A}$ = 360 mm²/s (Fig. 5b). Holes with a diameter of 600 nm and a period of 1 µm could be generated on tool steel by conventional hatching with P = 185 W and a structuring rate of $\dot{A}$ = 600 mm²/s (Fig. 5c). Finally, the interference patterns were structured on an injection mold steel tool with a weight of 500 kg, a length of 500 mm and a width of 300 mm. Considering the duty cycle of 17 %, the injection mold steel tool was structured within a duration of only 35 minutes. The generated surface structures could be successfully replicated by injection molding onto the molded polypropylene parts [26].

Micromilling of silicon wafers and metal parts

Laser micromilling is a promising technique for advanced applications such as the manufacturing of optics for THz radiation and dry etching of microelectro-mechanical systems (MEMS). These demanding applications require high surface quality and minimized surface damage after processing to provide their targeted functionality. The great challenge in micromilling with high

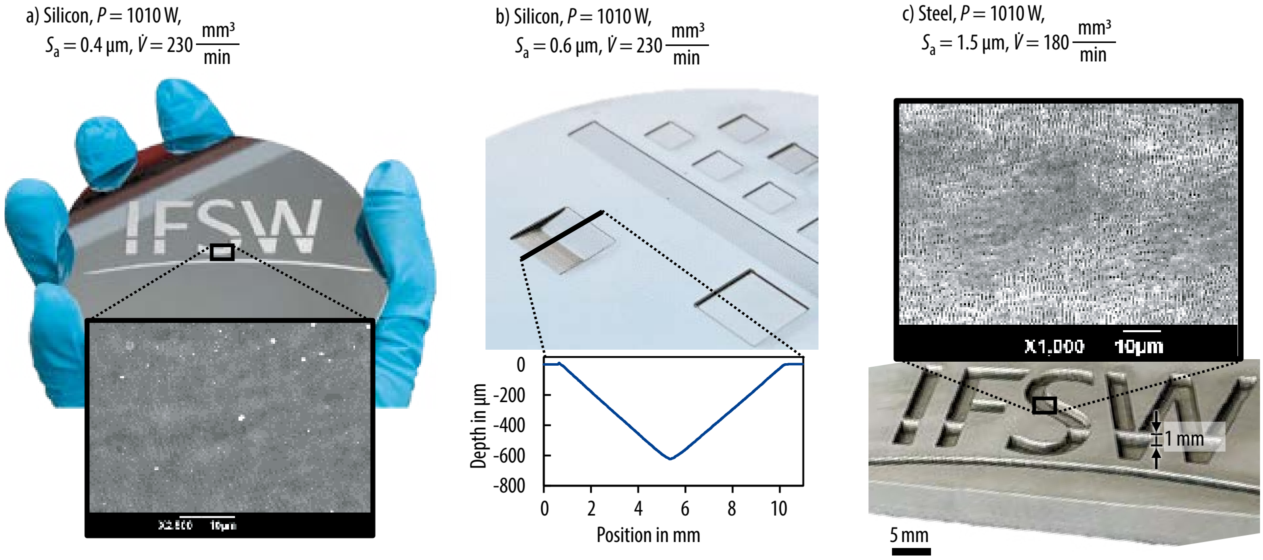

Fig. 6 Camera image and SEM image of a silicon wafer after laser milling with P = 1010 W, resulting in a depth of 30 µm, roughness S_a = 0.4 µm and material removal rate $\dot{V}$ = 230 mm³/min (a). Camera image of a chamfer geometry laser-milled with P = 1010 W in a silicon wafer with a maximum depth of 625 µm, S_a = 0.6 µm and material removal rate $\dot{V}$ = 230 mm³/min (b). SEM image and camera image of a steel sample after laser milling with P = 1010 W, resulting in a depth of 1 mm, roughness S_a = 1.5 µm and material removal rate $\dot{V}$ = 180 mm³/min (c).

average powers is to achieve high material removal rates while at the same time maintaining high surface quality with low roughness $S_a < 1$ µm and without inducing surface defects such as cracks.

The home-built ultrafast laser system emitted laser pulses at $\lambda = 1030$ nm and with a pulse duration $\tau < 600$ fs. The laser was operated in burst mode with five pulses in each burst at the maximum available average power of $P = 1010$ W at $f = 500$ kHz. The laser beam was guided into a galvanometer scanner when moving the beam over the workpiece with a high scanning speed $v = 24$ m/s and multiple passes in order to avoid melt formation and nanocracks due to heat accumulation of subsequent pulses [27]. The focus position was shifted below the sample's surface in order to increase the beam diameter to $d_b = 372$ µm and thus maintain a moderate peak fluence of $\phi_0 = 0.74$ J/cm² [28].

Micromilling of various geometries into silicon wafers with a high surface quality $S_a = 0.4$ µm and very high removal rates of $\dot{V} = 230$ mm³/min could be demonstrated, even at an average power $P = 1010$ W on the workpiece (Fig. 6a). The surface roughness only increased slightly in micromilling of deep structures of >600 µm depth (Fig. 6b), proving the high potential of this technique for the manufacturing of high-quality silicon surfaces. The processing strategy developed for high-quality and high-throughput also works for metals, as shown in [10] for copper, aluminum and stainless steel. For demonstration purposes, the logo of the IFSW was micromilled into a thick steel plate at $P = 1010$ W with a resulting depth of 1 mm at a high removal rate of $\dot{V} = 180$ mm³/min (Fig. 6c).

Conclusion

In summary, the results presented here show the great potential of high average power ultrafast lasers for high-quality and high-throughput micromachining, from drilling and cutting to surface structuring and micromilling. We were able to show that an average laser power of over 1 kW can be transferred into highly productive processes that still exhibit the high precision and high quality for which processing with ultrafast lasers is known.

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Design, production, and characterization of specialty optical fibers at the IFSW

Hollow-core fibers for the delivery of high-brightness beams from ultrafast lasers

Christian Röhrer, Tim Kühlthau, Bowen Chen, Götz Kleem, Thomas Graf, and Marwan Abdou Ahmed

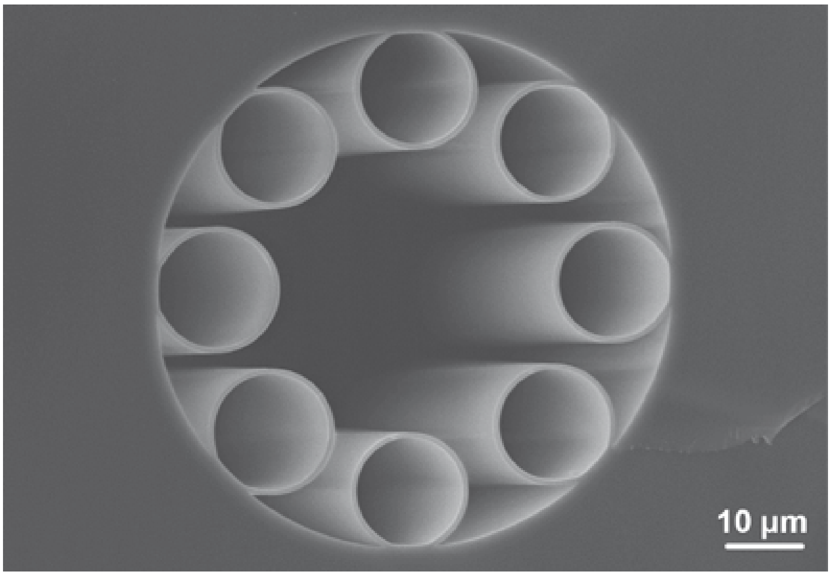

Fig. 1 Scanning electron microscope image of the fiber facet of an inhibited-coupling, hollow-core, photonic crystal fiber (IC HC-PCF) fabricated at the IFSW. (Source all images: IFSW, U Stuttgart)

Over the past few years, the IFSW has strengthened its activities in the development of hollow-core fibers for the delivery of high-brightness beams from ultrafast lasers. The full chain from design to fabrication and characterization is covered. The first promising results were achieved with the production of a single-mode fiber that exhibits low losses. This fiber is therefore very suitable for the delivery of high-brightness laser beams emitted from common high-power solid-state lasers.

One major advantage of solid-state lasers for industrial manufacturing is the possibility of flexible fiber-based beam delivery since, for laser wavelengths around 1 µm, the material of choice – fused silica – exhibits very low losses. In contrast to free-space propagation, fiber-based beam delivery offers a variety of advantages not only in terms of manufacturing but also with economic aspects. These include the elimination of additional steering optics, easy integration into robot systems and thus more versatile processing possibilities, increased safety due to the prevention of free-space beam propagation, as well as flexible control and use of processes and equipment.

The fiber-based beam delivery of continuous-wave multimode beams in macro materials processing (such as welding or cutting) has been the state-of-the-art for many years. The delivery of ultrashort laser pulses with high peak power and high pulse energy has already been shown experimentally [1]. The application of this technology in an industrial environment has also been demonstrated and tremendous progress is ongoing [2]. The fabrication as well as the implementation of such fibers is, however, still challenging.

The fibers used for the delivery of high-brightness laser beams for micromachining applications must provide low transmission losses, a high damage threshold, support good beam quality as well as provide the ability to maintain the polarization state. Since ultrashort laser pulses exhibit high peak power and high pulse energy, which would inevitably destroy a solid core [2], a hollow fiber core of air or a vacuum has to be used.

Types of microstructured hollow-core fibers

Total internal reflection – as used in classical solid-core fibers – cannot be exploited as a guiding mechanism when using a hollow core (HC) that has a lower refractive index than the surrounding silica. In so-called photonic crystal fibers (PCF), which consist of a periodically arranged array of dielectric

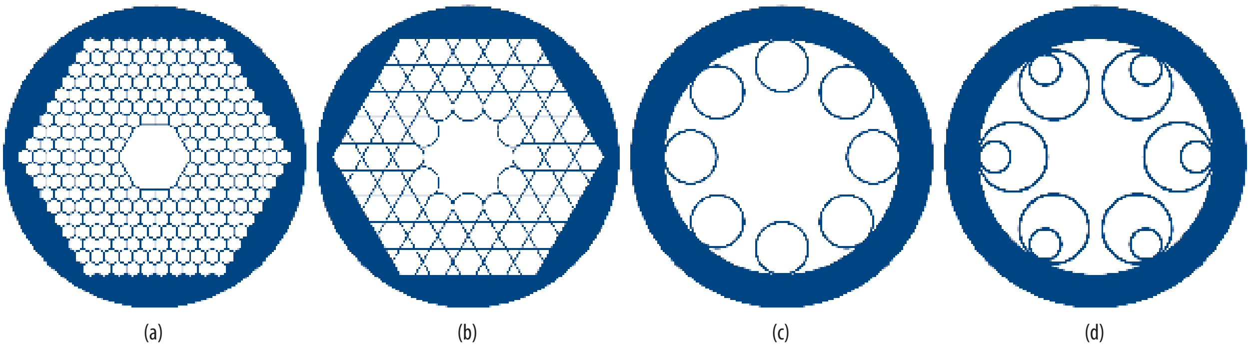

Fig. 2 Schematic representation of different types of HC-PCFs. PBG HC-PCF consisting of a hexagonal lattice in the cladding (a). IC HC-PCF consisting of a Kagome lattice in the cladding with a hypocycloid core contour (b). IC HC-PCF with a tubular structure (c). IC HC-PCF with a nested tubular structure (d).

layers, two alternative guiding mechanisms exist – either by exploiting a photonic bandgap (PBG) or by 'inhibited coupling' (IC) [1].

Analogous to semiconductors, which exhibit an electronic bandgap where no electronic states can exist, PBG HC-PCFs (see Fig. 2a) have a microstructure in their cladding that exhibits a photonic bandgap in which light cannot propagate. The light is therefore confined within the core. Even though low losses could be demonstrated, the limiting factor for the beam transport at high power and with high-energy pulses are not the losses themselves, but the overlap between the light guided in the core of the fiber and the modes in the surrounding cladding [1]. This overlap is directly related to the damage threshold of the fiber, which is lowered with decreasing overlap. For PBG HC-PCFs, the overlap of the guided mode with the modes in the cladding is typically in the order of 10^{-2} to 10^{-3} [1].

Institute

Parallel to the developments of hollow-core fibers with a photonic bandgap, the discovery was made that beam delivery can be achieved even in absence of a bandgap in a fiber with a Kagome lattice in its cladding [3]. This is possible when there is a strong transverse phase mismatch between the modes guided in the core and the ones in the cladding. This mismatch reduces the interaction between the modes of the core with those in the cladding and hence diminishes their coupling. The resulting guiding mechanism is therefore known as 'inhibited coupling' [3]. The mismatch can be increased by further reducing the spatial overlap of the modes in the core with those of the cladding by implementing a hypocycloidal contour of the fiber's core in conjunction with the Kagome lattice (see Fig. 2b) [4]. Since the node between two capillaries has a crucial influence on the confinement losses, an alternative fiber design consisting of only a single ring of capillaries in the cladding (see Fig. 2c) was proposed [5]. Losses similar to those of PBG HC-PCFs could be demonstrated, while the overlap can be lowered by several orders of magnitude to values between 10^{-4} to 10^{-6} [1].

To reduce the overlap even further, the most recent major improvement of the fiber properties originates from the implementation of additional nested capillaries (see Fig. 2d) [6]. For these so-called nested antiresonant nodeless fibers, the confinement of the core mode is further enhanced and the overlap with the cladding modes is reduced to values below 10^{-8} [6]. Losses lower than those of state-of-the-art, solid-core fibers could be achieved by optimizing this structure. This was possible since hollow-core fibers are not restrained by the limits of Rayleigh scattering, which is the fundamental limit for glass-guiding fibers.

Besides having an influence on the damage threshold and hence the high-power capabilities, a low overlap also has advantages concerning the polarization-maintaining properties of such fibers. A low overlap not only means that energy barely couples from the core to the cladding, it also works the other way around and efficiently decouples the core mode from external perturbations. In such IC fibers, the core-guided modes can propagate without any perturbation from the outside. IC HC-PCFs can therefore inherently exhibit strong polarization-maintaining behavior without being specifically designed for this purpose [7].

In conclusion, a low overlap of the modes in the core with those of the cladding, combined with large core diameters, led to the breakthrough of IC HC-PCFs for the delivery of high-brightness beams from ultrafast lasers [1]. In this context, the capability of these fibers to guide high-brightness laser beams was demonstrated for wavelengths around 1 µm. This was shown both for picosecond and femtosecond pulse durations, with peak power in the gigawatt range and average power of a few hundred watts with transmission efficiencies of more than ninety percent [2].

Fabrication

While their guiding properties differ substantially, the manufacturing process of all kinds of microstructured fibers is quite similar and pretty much unchanged since the first realization of a photonic crystal fiber in the late 1990s [1]. The production method by means of a two-step drawing process from preforms, assembled using the well-known stack-and-draw method, is illustrated schematically in Fig. 3. This two-stage process allows for higher

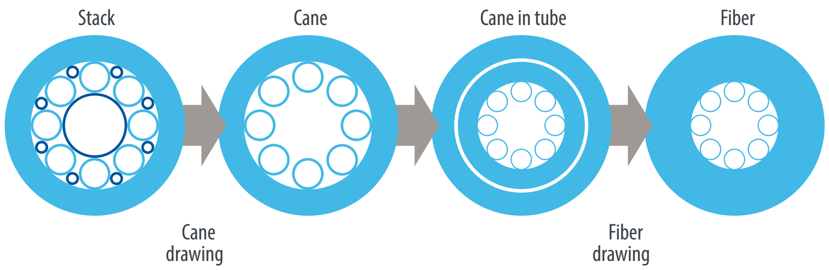

Fig. 3 Schematic of the stack-and-draw technique for the production of micro-structured fibers, here exemplarily illustrated for a tubular structure where additional supporting capillaries are shown in dark blue.

design flexibility, is less material consuming, and reduces the draw-down ratio, which results in smaller deviations from the initial design in the final fiber.

In a first step, dozens of capillaries are drawn from a high purity fused silica tube. Active pressurization is applied to obtain the desired diameter of typically a few millimeters. The wall thickness of the capillaries during the drawing is adjusted by adapting the feeding and drawing speeds. During this first production step it is already extremely important to ensure constant dimensions, not only from capillary to capillary but also over the complete length of each capillary. Inconsistencies cannot be rectified during subsequent production steps and rather accumulate with each drawing step.

The capillaries are tightly stacked inside another fused silica tube with a diameter of one to a few centimeters, depending on the structure and type of fiber. In general, more cladding elements such as those used in photonic-bandgap or Kagome fibers lead to larger preforms. Additional capillaries to stabilize the geometry support the stack only at both ends of the tube (leftmost image in Fig. 3 in dark blue), whereas all capillaries that are needed in the final fiber (right image in Fig. 3 in light blue) will go through the complete length of the tube.

The stack is drawn down to a so-called cane, which represents a more or less scaled-up version of the final fiber with a diameter of several millimeters, where the capillaries and the outer tube are fused together. Since typically no active pressurization is applied, it is important to realize a cold drawing to mitigate any temperature-sensitive irregularities as well as to avoid the collapsing of the capillary structure.

In the last step, the cane is placed inside another fused silica tube. This preform with an outer diameter of a few centimeters is drawn to a fiber with an outer diameter of a few hundred micrometers. In this step the draw-down ratio amounts to about 30 to 50 and represents the largest shrinkage in the whole production chain, as the drawing of the capillaries and the canes occurs with a draw-down ratio of approximately only 5 to 30 and 4 to 10, respectively.

Active pressurization is applied during the fiber drawing to fuse the cane with the outer tube and to allow for an adaptation of size and shape of the cladding. The gas pressure is needed to counteract the collapsing of the capillaries, which results from the pressure induced by surface tension. While the applied gas pressure is dominant in the upper part of the neck-down area of the preform, the surface tension is dominant in the lower part, since it scales inversely proportional to the capillary diameter [8]. Their interplay depends significantly on the viscosity of the glass and is therefore directly influenced by the drawing tension.

For fibers with a closed lattice such as fibers with a hexagonal (see Fig. 2a) or Kagome cladding structure (see Fig. 2b) the cladding's microstructure is self-stabilizing. However, for fibers with an open lattice such as fibers with a tubular (see Fig. 2c) or a nested tubular structure in their cladding (see Fig. 2d) this is not the case. The drawing tension therefore plays an important role and precise control is needed to achieve a stable cladding geometry over the whole fiber length.

In order to understand all involved mechanisms and the dynamics during the drawing process, we used numerical simulations based on the work of Jasion et al. [8] to determine the required drawing parameters as well as to predict the geometry of the resulting fiber. We implemented different characterization tools to track any deviation from the ideal geometry and to observe the fabrication process. These include the optical characterization of capillaries, canes, and fibers using optical or scanning electron microscopy as well as the constant measurement and recording of all parameters during the drawing process. New methods were also implemented that enable direct monitoring of the microstructure during fiber drawing, such as the method proposed by Frosz et al. [9] to measure the capillary size in tubular fibers using whispering-gallery mode spectroscopy.

Design and numerical modeling

The fiber described in this work is based on the design of Debord et al. [10]. This tubular type was chosen due to the low complexity of its lattice structure and since such IC HC-PCFs are perfectly

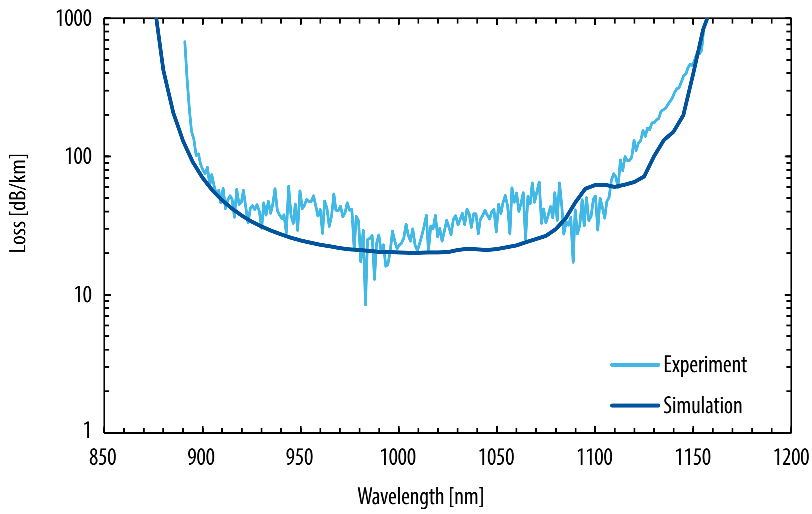

Fig. 4 Recorded transmission spectrum of the fiber including the results of numerical simulations using the FEM-based model.

suitable for the delivery of high-brightness beams from ultrafast lasers. This means that they offer low transmission losses, a high damage threshold, and maintain good beam quality as well as the polarization state.

Numerical simulations using the commercially available Comsol Multiphysics software were performed to model the fiber properties. The numerical model is based on the finite element method (FEM) where the cross-section of the fiber was discretized and the resulting set of differential equations was solved numerically to find the electromagnetic eigenmodes of the system. Suitable boundary conditions were defined and a circular, perfectly matched layer was implemented to obtain exact solutions. The losses of each fiber mode were determined by retrieving the imaginary part of the eigenvalues.

The fiber considered has a tubular cladding consisting of eight evenly spaced capillaries with a diameter of 15.08 µm, while the core has a diameter of 40 µm. In contrast to the work of Debord et al. [10] where the fundamental transmission band was used, the capillary's strut thickness was set to 736 nm such that the fiber makes use of the second transmission band with an operating wavelength of 1030 nm. The increased strut thickness makes the fiber less susceptible to manufacturing tolerances and increases the damage threshold. Additionally, the coupling of an incident Gaussian beam to the fundamental mode of the fiber is improved in comparison to fibers using the first transmission band. The excitation of higher-order modes by the incident Gaussian beam is therefore reduced.

Measurement of the fiber structure and optical characterization

The fiber shown in Fig. 1 was manufactured completely at the IFSW using the methods presented in the previous sections and using our in-house manufacturing facilities, which consist of a preform lathe and a fiber drawing tower. A fiber with a length of several hundred meters was drawn, which is long enough for most industrial and scientific applications.

The structure of the fiber was analyzed using a scanning electron microscope. The diameter of the core, the diameter of the capillaries, and their strut thickness were measured to be 36.19 µm ± 0.32 µm, 16.18 µm ± 0.26 µm, and 672 nm ± 13 nm, respectively. This measurement revealed that the capillaries of this produced fiber are larger than designed and that the diameter of the core and the thickness of the struts were therefore reduced. Especially the strut thickness can be critical since this defines the position of the low-loss transmission window. The transmission spectrum was recorded to analyze this (see Fig. 4) using the cutback-technique to determine the propagation losses.

For the cutback experiment, the light of a supercontinuum source was launched into the fiber, which was loosely spooled on a reel with a diameter of one meter. The fiber was cut back from an initial length of 93.5 m to a length of 6 m without changing the input conditions. The first 6 m of fiber were tightly coiled to filter out unwanted higher-order modes and to determine the losses of the fundamental mode only. The results show a low-loss region ranging from a wavelength of 900 to 1100 nm, where the losses amount to approximately 50 dB/km (see Fig. 4). The low-loss region is slightly shifted to the shorter wavelength side, which is attributed to the reduced strut thickness of the fiber's capillaries. Nevertheless, the fiber is still able to efficiently guide radiation with wavelengths around 1 µm. The numerical simulations were adapted according to the measured geometry and the resulting losses are in good agreement with the experimental results.

The single-mode behavior of the fiber was confirmed by an optical characterization with respect to the beam quality factor M^2 (see Fig. 5) and by a spatially and spectrally resolved measurement (see Fig. 6) known as S^2 imaging [11]. Free-space launching was used for both measurements and the focus diameter of the incident Gaussian beam with a wave-

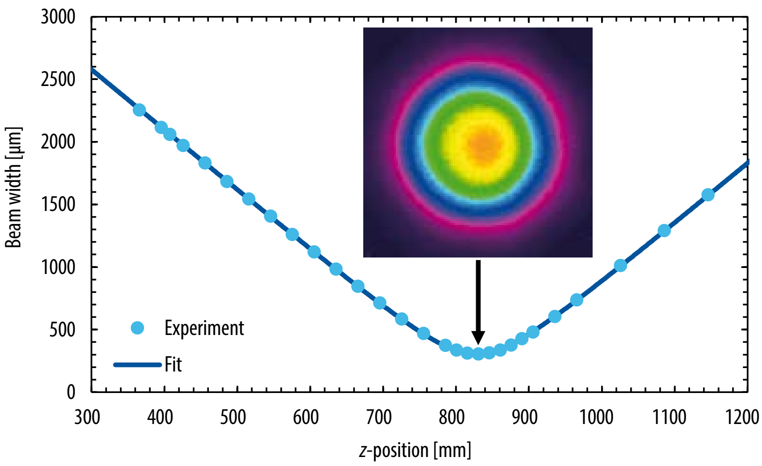

Fig. 5 Caustic of the beam recorded after propagation through the fiber, including the intensity distribution in the focal plane.

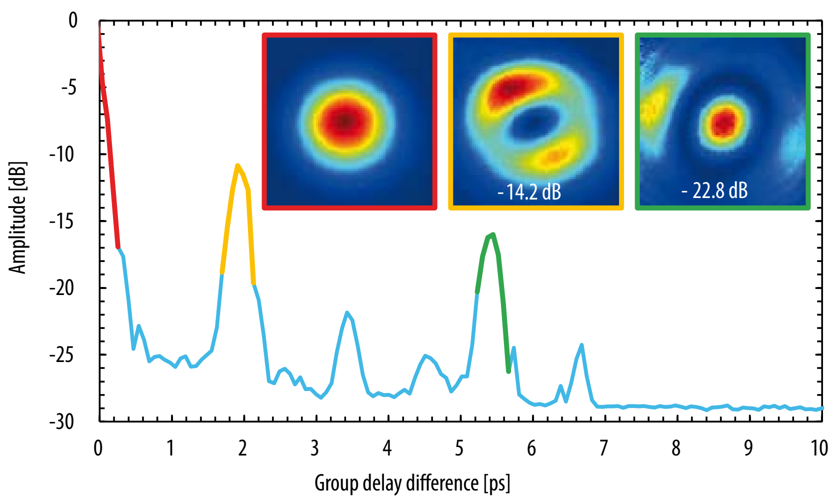

Fig. 6 Results of the spatially and spectrally resolved measurement recorded after propagation through the fiber, including the intensity distribution of the retrieved fiber modes

length of 1050 nm was matched to the mode field diameter of the fundamental mode of the fiber. The fiber itself had a length of approximately two meters and was loosely coiled on the table.

The measured caustic of the transmitted beam is shown in Fig. 5, where the beam quality factor M^2 was measured to be 1.11 in both axes. The good beam quality is also illustrated by the intensity profile that was measured in the focal plane (see inset in Fig. 5). In order to resolve the low content of higher-order modes, an S^2 measurement was performed under the same input conditions and the results are shown in Fig. 6. This confirmed a low content of higher-order modes of only -14.2 dB and -22.8 dB for the LP_{11} and LP_{02}-mode, respectively, which were excited when launching the Gaussian beam into the fiber and which are eventually filtered out with increasing propagation distance in the fiber.

Conclusion

IC HC-PCFs are currently the only possible solution for the flexible fiber-based beam delivery of laser pulses with high peak power and high pulse energy. The IFSW has therefore strengthened its activities in the development of such IC HC-PCFs. The presented fiber exhibits low propagation losses in the spectral range of the most common high-power solid-state lasers with a wavelength of about 1 µm and exhibits a single-mode behavior, i.e. maintaining a nearly diffraction-limited beam with a low content of higher-order modes. Further optimization of all the production steps mentioned here will be implemented to further improve the fiber's performance.

*

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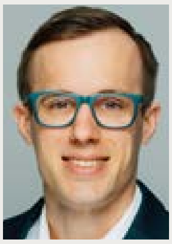

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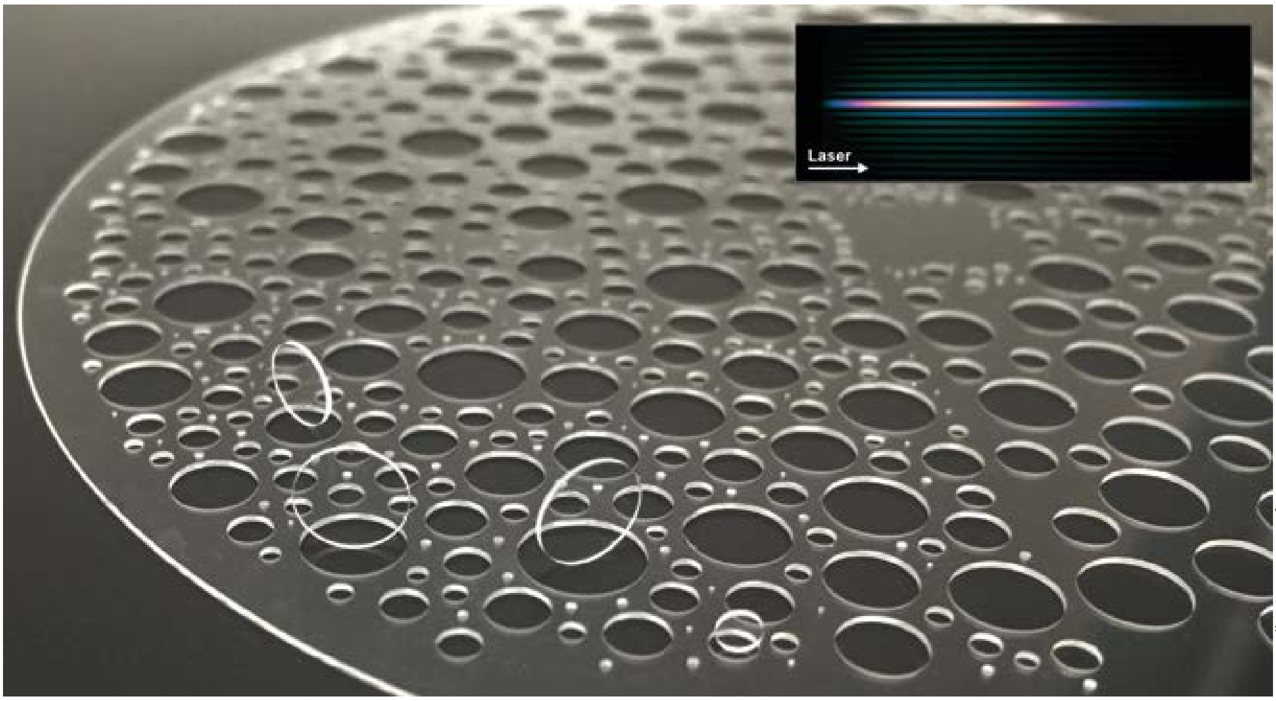
Cutting glass with photons

Latest technology leaps due to beam shaping in laser materials processing

Max Kahmann, Myriam Kaiser, Jonas Kleiner, Tim Hesse, and Daniel Flamm



Source all images: Trumpf

A comprehensive report is provided here about the state of the art and recent advances in cutting glass with ultrashort pulsed lasers. Several optical concepts are discussed that enable single-pass, full thickness modification of transparent articles in the most diverse geometries, such as architectural glass or glass tubes. We also highlight the trend towards tailored glass edges for substrate protection with laser-fabricated chamfers. A completely new beam-shaping concept is used here, in which a large number of focus copies are distributed along any edge shape in order to combine cutting and chamfering within a single laser process.

▲**Fig. 1** Inner contours cleaved by a TruMicro 2030 ultrafast laser beam shaped to a Bessel-like intensity distribution with Trumpf TOP Cleave-2 optics (inset) [4]

We use glass to decorate the façades of our buildings or the interior of our cars and touch it almost every minute when we control our smartphones. In addition to the obvious transparency, its frequent use is due to the outstanding mechanical and chemical properties – to name but two. Conventional processing of glass using the scribe and break method is a cost-effective solution but has several disadvantages, such as the occurrence of internal cracks, chipping or time-consuming post-processing steps. This is exactly where the laser shows its strength as a subtle tool for efficient processing on a micro or nanometer scale. The extreme photon densities provided by ultrashort pulsed lasers allow energy to be selectively deposited in the volume of the transparent workpiece via non-linear absorption effects [1]. If suitable intensities are selected, the material can be specifically weakened and separated in a second processing step, for example by applying thermal or mechanical stress. Considering the laser modification process, reliable ultrafast laser platforms are equally available as adapted processing optics providing customized non-diffracting beams for single-pass operations with meters-per-second feed rates. The use of non-diffracting beams to process transparent materials can therefore be considered state-of-the-art. For more details see [2] and Fig. 1.

In this paper, we discuss recent advances in cutting glass in different geometries, highlighting the beneficial use of adapted focus distributions. The presented beam shapes will go far beyond the conventional Bessel-Gaussian beam,

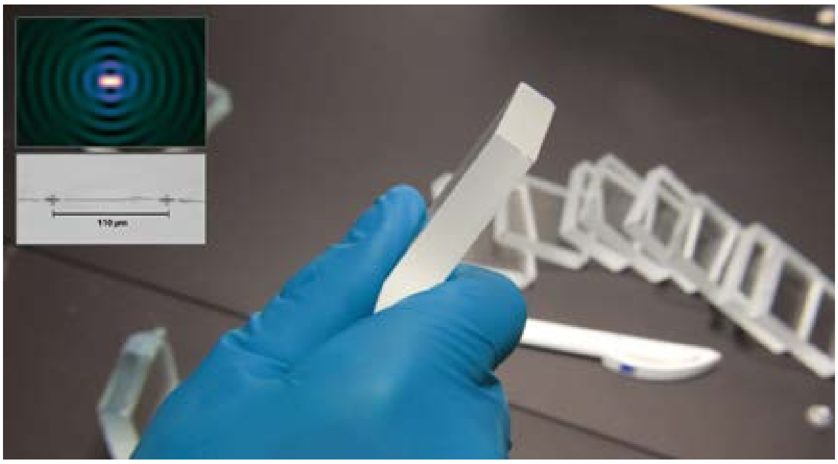


Fig. 2 Architectural glass with a thickness of 12 mm separated by multiple non-diffracting beams. The samples have been realized by TruMicro series ultrafast lasers, providing mJ-range pulse energies. The top inset shows the lateral intensity distribution for multiple Bessel-like beams. The lower inset is a reflecting light microscope picture top view of two laser modifications. The resulting intensity distribution enables the modification distance to be increased up to 110 µm [4].

enabling the cutting of glass tubes as well as glass edge chamfering.

Facilitating glass separation

As mentioned in the introduction, after having induced laser-created modifications inside the volume of the glass article, actual separation is achieved in a second processing step. If the substrates are particularly thick (>2 mm) or thin (<0.1 mm), difficulties such as chipping or uncontrolled crack formation [3] often arise during controlled separation. To counteract this, multiple non-diffracting beams are used to generate asymmetric material modifications. If the modifications are aligned with each other during processing, a controlled crack discharge is triggered, resulting in the separation of the material.

Fig. 2 shows the process results with multispot Bessel-like beam shape processing, enabling the mechanical separation of glass with extreme dimensions. Fig. 2 further shows a lateral intensity distribution of a non-diffracting beam [top inset] generated by beam splitting. For profiles with cracks aligned along the cleaving path, a continuous crack can be detected independently of the applied spatial pulse distance. Hence by increasing the distinctive pulse distance which is still capable of achieving a proper cleaving process, the feed rate and thus the throughput can be improved significantly. The maximum spot distance that was demonstrated was >100 µm [4] (for symmetric Bessel-like beams the typical distance is <10 µm). The bottom inset in Fig. 2 shows a reflected light microscope image of a top view modified glass, demonstrating a continuous crack for spatial pulse distances of 110 µm.

A microscope image of the entrance surface of ultrathin glass (~50 µm) of a laser-modified glass sample, in contrast to the previously mentioned material thicknesses, is shown in the inset of Fig. 3. This demonstrates the capability of this optical approach to cleave glass of several orders of magnitude thickness with a m/s feed rate. Here the crack orientation clearly follows the rotation of the Trumpf TOP Cleave-2 optics that have created a multispot Bessel-like beam. So in addition to the improved quality, the theoretical feed rate can be improved to the next level. For more details see [3, 4].

Phase correction for curved surfaces

However, if non-diffracting beams are applied to a surface which is curved (e.g. tubes) the resulting energy distribution prevents proper material processing. This negative effect can be overcome by a correction which can in a way be compared to equipping myopic eyes with glasses. In our case, the ideal on-axis constructive interference is disturbed in a way that causes strong intensity modulations to appear. Fig. 4 upper inset shows the disturbed transversal intensity distribution as well as mechanical separated microscope images of the resulting laser-induced material modifications in the cross-section of the glass. As can be seen, the elongated modifications are too short due to the disturbed interference and only reach from the curved surface entrance to approximately half the wall thickness.

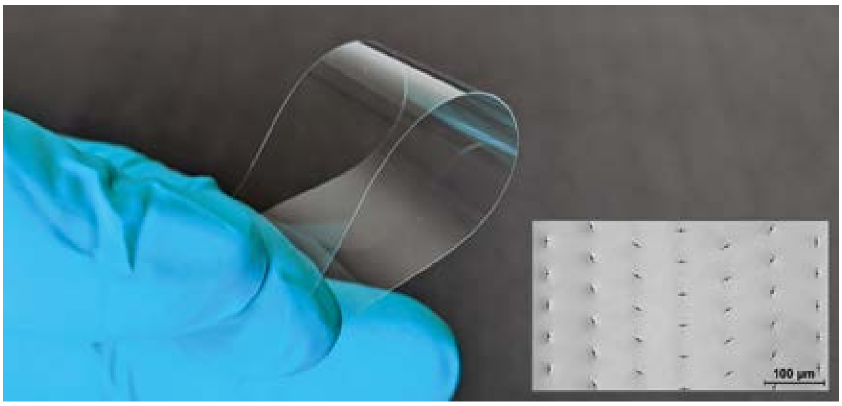


Fig. 3 Ultrathin glass separated by an optic generating multiple Bessel-like beams. The inset shows a reflective light microscope picture top view of laser-induced modifications/cracks. From left to right, the orientation of the optic was changed in 30° steps. It shows that the orientation of the applied cracks can be controlled by the orientation of a twin-spot Bessel-like beam [3].

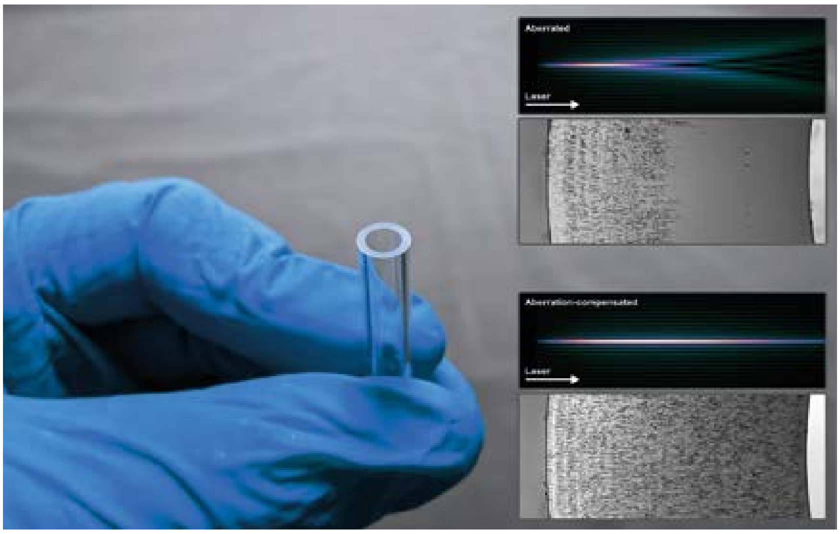


Fig. 4 Glass tube cleaved by an aberration-corrected laser beam. Upper inset: longitudinal intensity distribution aberrated by the curved surface and corresponding material modification. Lower inset: longitudinal intensity distribution with corrected aberration and corresponding material modification. For more details regarding laser cleaving of glass tubes see [5].

To correct these aberrations, it can be assumed that the surface acts as a cylindrical lens. The first approach to correct this is by inverting an additional cylindrical lens. In a metaphoric picture, we add glasses to diffractive optics. The resultant aberration-compensated, elongated intensity profile is close to an ideal Bessel-like beam shape in the case of a flat surface. The corresponding laser-induced material modification in the cross-section of the glass (also Fig. 4 lower inset) now covers the entire material thickness and allows a proper cleaving process. Fig. 4 shows a glass tube cleaved by such an aberration-corrected beam.

Tailored edges

All modifications and separations so far were realized by non-diffracting beams propagating straight through the transparent materials, allowing only plane cleaving edges.

We have to break new ground to make use of the laser literally as a universal shaping tool. So instead of shaping a single beam, the goal is to distribute copies of nearly ideal focus along an arbitrary trajectory or, even more enhanced, in a well-defined three-dimensional volume. Diffractive beam splitters are well established for material processing today to parallelize processing and scale throughput. The foci are usually placed in a single plane, hence in two dimensions. The expansion into the third dimension is already in use, for example for optical data storage. Here we transfer this 3D holographic approach into laser glass processing for a fully flexible, single pass, three-dimensional modification in transparent material. After separation, this enables almost freely-configurable edge geometry of cleaved glass samples.

Such an exemplary distribution of several tens of nearly ideal single foci is shown in Fig. 5 inset. They are aligned in a manner to form a 45° chamfered edge on both sides with constant spot distances. The overall height of this geometry is adjusted to the thickness (and optical density) of the glass sample.

The holographic approach enables almost any imaginable edge geometry to be created in a single-pass laser process that cannot be realized by conventional mechanical approaches. It therefore paves the way to a broad bandwidth of novel, laser-based material processing applications from the improved impact resistance of displays to new mounting concepts for optical components. For more details see [6, 7].

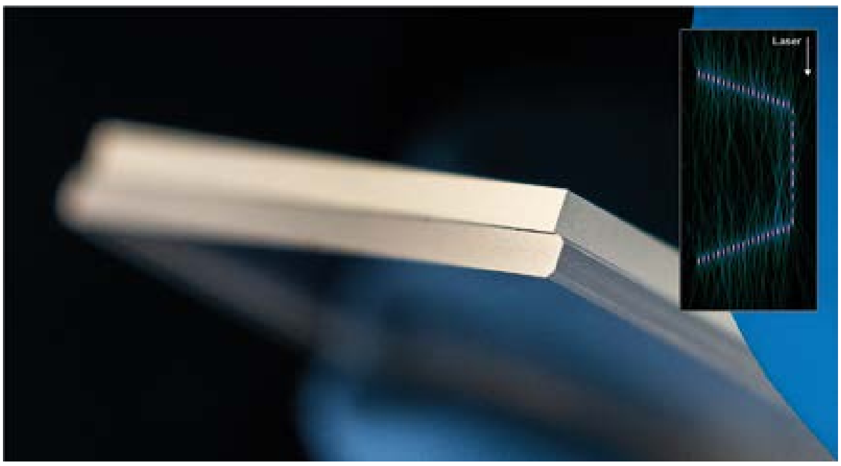


Fig. 5 550 µm Gorilla glass single pass modified 45° chamfer edge geometry. Inset: Corresponding holographic intensity distribution of several tens of near ideal single spots in a plane perpendicular to the glass surface and feed direction [6].

Conclusion

Using various selected process results, we have demonstrated how the laser can replace established tools in the machining of glass, or even enable completely new processing strategies. While the demonstrated applications for controlled crack orientation and glass tubes are available or close to available industrial systems (TruMicro series lasers and TOP Cleave optics), the example of holography for tailored edges heralds a paradigm shift for ultrafast laser processing and is still under development. Ultrafast lasers then pave the way toward new applications and approaches, for example in the display industry. Its potential as a universal photonic shaping tool is obviously far from being exhausted.

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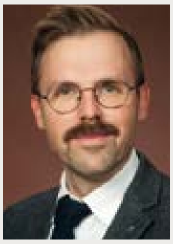

Max Kahmann finished school in 2002. After two years of military service he started his physics studies at the University of Tübingen with a focus on nano and atomic physics. In 2010 he graduated and went to PTB in Braunschweig for research on optical clocks. He received his PhD (topic: optical Feshbach resonances) in 2014 at the University of Hannover and joined Trumpf. Here he held several positions as senior product manager for ultrafast laser and executive assistant to the managing partner and CTO before he became head of advanced development, laser applications, responsible for next-generation laser applications.

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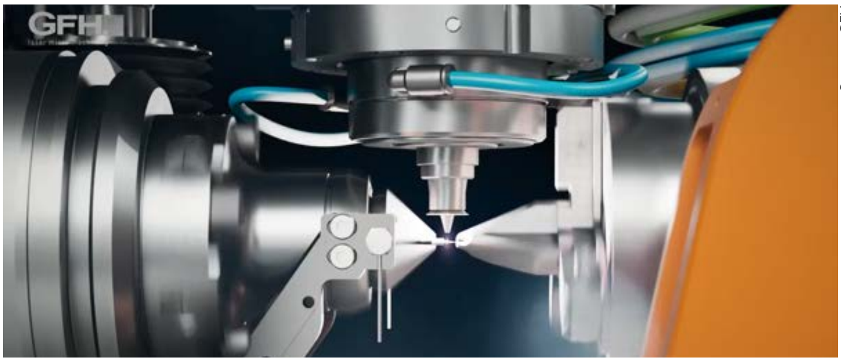
Full article in PhotonicsViews issue 4/2022 — **Preview**

X-ray emissions during laser machining of cylindrical microcomponents

Roswitha Giedl-Wagner and Thomas Lang

Ultrashort pulse lasers are the perfect tool for micromachining of components for a wide range of applications. Even hard and brittle materials may be processed with high precision in state-of-the-art machines like the GL.smart from GFH. With pulse lengths in the pico- and femtosecond range, an irradiation > 10^{12} W/cm^2 is incident on the work piece with the potential to generate ionizing radiation. This article deals with the x-ray emissions recorded during laser turning operations and the corresponding safety measures.



Source: GFH

The advantages of laser micromachining with ultrashort pulse lasers are numerous. The technology is contactless, generates a low heat impact and allows for high precision.

Since laser machines have been classified as "systems for the generation of ionizing radiation" according to the German Radiation Protection Act, laser machine tool builders have to consider the legal implications in the layout and safety architecture of the laser machining systems and the operating company may need to notify the authorities.

Industrial applications often require moderate irradiation below the threshold for the onset of x-ray emissions for a high quality and efficient processing result. Some laser applications like drilling and cutting provide inherent shielding from potential ionizing radiation. In laser turning operations, irradiations above 10^{13} W/cm^2 may be applied to implement roughing and smoothing operations and, as a consequence, ionizing radiation may occur depending on the used laser, optics and process parameters and the machined material. These emissions were recorded during laser turning, cutting, ablation and drilling of cylindrical work pieces in the GL.smart with interesting findings.

*

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Design of grating waveguide structures for pulsed laser systems

Strategy to maximize the production yield given special characteristics of the production process

Martin Rumpel, Frieder Beirow, Thomas Graf, and Marwan Abdou Ahmed

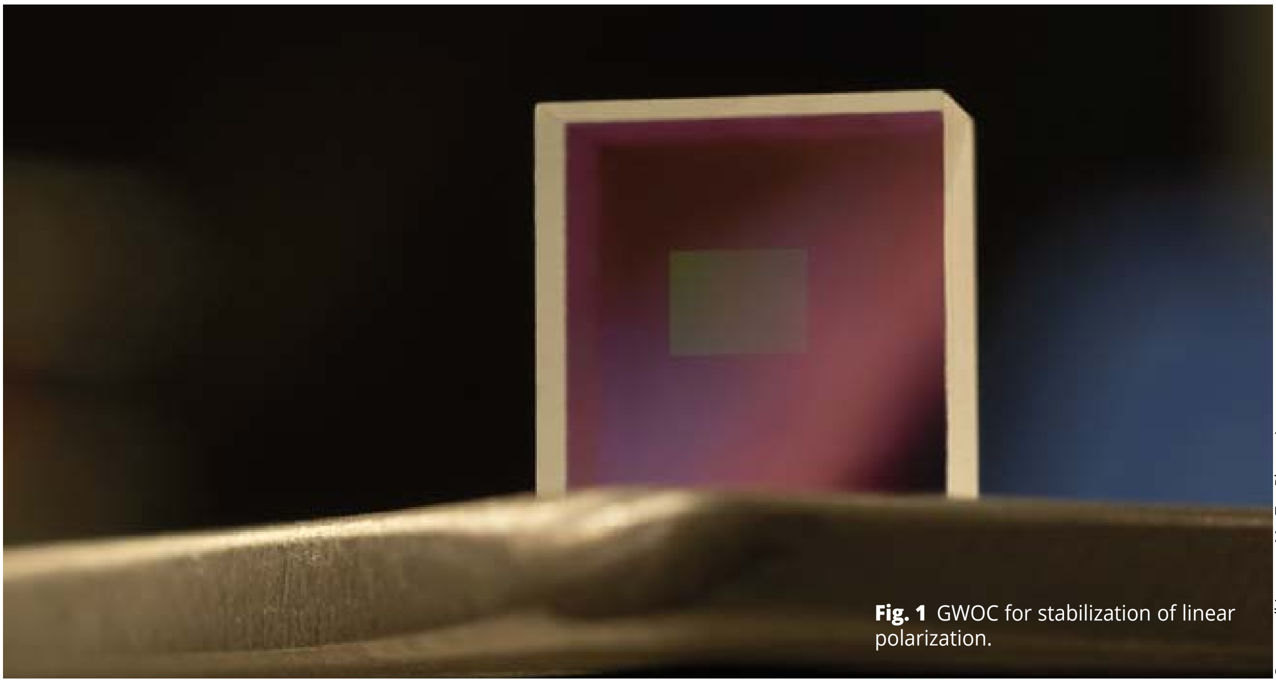

Fig. 1 GWOC for stabilization of linear polarization.

Source all images: MarTec Photonics

Grating waveguide structures (GWS) offer great variety in design for generating different states of polarization in laser resonators. The polarization-selective properties are achieved by one or more dielectric layers in combination with sub-wavelength microstructures. The resonant nature and resultant enhancement of the electromagnetic field in the dielectric layers used to limit the application of GWS in pulsed operation. However, thanks to robust design and fabrication methods, GWS can now be applied here without problems.

Over the past few years, GWS have repeatedly proven to be innovative devices, especially in the design of laser resonators that need to be stabilized to a defined state of polarization. In [1], a GWS served as a reflective diffraction grating that was used as the end-mirror of a resonator of a Yb:LuAG thin-disk laser. The GWS allowed linear polarization to be stabilized and, at the same time, beam pointing caused by thermally induced air convection in front of the laser disk to be passively compensated for. In [2], a GWS was used as an output coupler for the generation of axially symmetric polarized (e.g. radially and azimuthally polarized) laser beams. This 'grating waveguide output coupler' GWOC made it possible to realize a radially-polarized Yb:YAG thin-disk laser that was passively mode-locked. Since unwanted diffraction losses to the $\pm 1^{st}$ order in transmission of the GWOC reduced the overall laser efficiency, improvements to its design were discussed in [3] or, alternatively, different resonator concepts based on GWS to replace the GWOC were discussed in [4]. Here, GWS were investigated that serve as a cavity end-mirror combined with a saturable absorber used as an output coupler. The aim was to increase the overall laser efficiency for the generation of radially-polarized beams from a passively mode-locked thin-disk laser. In a similar way to [3], we will discuss design considerations of the GWOC, but focus mostly on the optimization of the polarization function in reflectivity and how to maximize the production yield, given known production tolerances and characteristics of the production equipment in use. We then briefly present results obtained from a commercial laser system with our GWOC (Fig. 1). The aim was the generation of laser beams with linear polarization from a passively q-switched Nd:YAG rod laser.

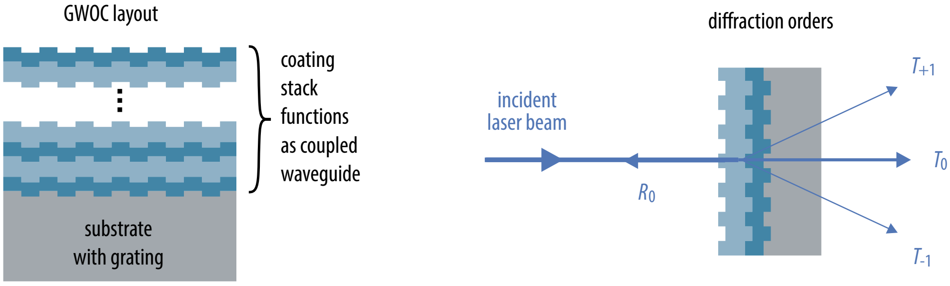

Fig. 3 Schematic of the cross-section of the GWOC-type GWS (left) and definition of different beams generated by the GWOC from an incident light beam (right)

Design of a GWOC by its modal content

The design process of a GWS can be based on the knowledge of the modal content of the underlying planar waveguide, either a single or a coupled waveguide [5]. The modes supported by a planar waveguide can be divided into two orthogonal states of polarization with regard to linear grating lines: TE-polarization, where the electric field of the mode is parallel to the grating lines and TM-polarization, where it is orthogonal (Fig. 2). Every TE or TM mode (either guided or leaky mode [5]) of a GWS can be excited from an incident beam of light due to the coupling mechanisms provided by the grating. The excitation of the modes is restricted to a certain bandwidth in angle of incidence and wavelength of the incident light. The spectral polarization function of a GWS can therefore be engineered by selecting a (coupled) waveguide that supports suitable planar waveguide modes to meet the required spectral bandwidth of polarization. The requirements in bandwidth are defined in our case by the laser gain media to be used, Nd:YAG. Designing such a GWS can be done with simulation software that implements modal theories for planar-waveguides [6].

Target parameters of the GWOC

In our example, we want to realize a polarization-selective output-coupler (GWOC) used at normal incidence, which has a reflectivity of 40 – 50 % for one state of polarization, which will become the state of polarization that is lasing (in the following we will call it the 'lasing polarization'), and a reflectivity of <5 % for the orthogonal state of polarization. A stack of coating layers with a reflectivity of 40 – 50 % at a wavelength of 1064 nm serves as a coupled waveguide, which translates to five to nine alternating layers of high and low refractive index. The exact number of layers depends on the materials used for the dielectrics (e.g. HfO_2, Ta_2O_5, SiO_2, Nb_2O_5 or TiO_2) and their refractive indices, which also depend on the coating technology used, such as ion beam sputtering (IBS) or atomic layer deposition (ALD). A good starting value for the layer thicknesses is typically a value close to a 'quarter-wave layer', i.e. the thickness is one quarter of the optical thickness ($w \cdot n$) for the given angle of incidence. Here w is the thickness of a particular layer an n its refractive index. In our case, we used thicknesses between 100 – 300 nm. Because of constraints given by our manufacturing tools available at the time, we needed to introduce the grating to the substrate and add the coating layers on top of the resulting corrugation. The modulation given by the grating will therefore be more or less replicated across all the subsequently added coating layers, as schematically shown in Fig. 3, left.

Our GWS will be used in transmission. The grating period is chosen to be slightly less than the central wavelength of the Nd:YAG emission spectra, i.e. <1064 nm. With the design criteria given, this device will create the ±1st diffraction orders in transmission. The target of diffraction efficiencies of these 'losses' was required to be <10 %, related to the total power in transmission, each, i.e. $\eta_{T\pm1} = T_{\pm1}/T_0$ (Fig. 3, right).

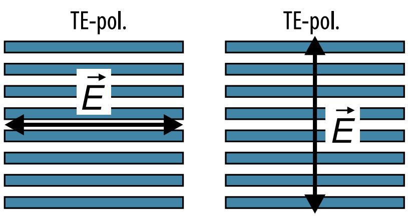

Fig. 2 Definition of polarization states on linear grating lines. *E* denotes the orientation of the electrical field.

Limitations of the coating process

As mentioned before, the polarization function of the GWS is tied to its modal content and its mode of operation, which means the bandwidth of angular and spectral excitation of the waveguide modes it will experience by the laser beam inside the cavity. The planar waveguide modes and their excitation conditions are very sensitive to changes in the opto-geometrical parameter of the GWS (grating profile, refractive indices, layer thicknesses). One therefore needs to use expensive manufacturing equipment to control the tight production tolerances and stay within simple waveguide shapes that can be reproduced from one production run to the next.

As mentioned, the available production tools required us to introduce the grating to the substrate and we therefore had to deal with inhomogeneous waveguide layers. Furthermore, the coating machine available was not optimized to reproduce an initial grating pattern. We also knew from our coating machine that for our five to nine layers of required dielectric coating (corresponding to a total thickness of ≈1 µm), the refractive index of each subsequently deposited layer would vary slightly, which further complicated the design process.

Hence, several characterization samples were fabricated in order to understand the development and characteristics of the various interfaces formed by subsequently adding dielectric layers. An SEM picture of the cross-section of the deposited sequence of dielectric layers is shown for one of the samples

Company

MarTec Photonics

MarTec Photonics is a spin-off of the Institut für Strahlwerkzeuge (IFSW) at the University of Stuttgart, Germany, and founded through the university's technology transfer program. We bundle the knowledge gathered over more than 15 years in the development of specialty optics for high-power laser sources, mostly based on RWG. We have the tools and facilities available to design and optimize RWGs for your applications and produce them to your requirements.

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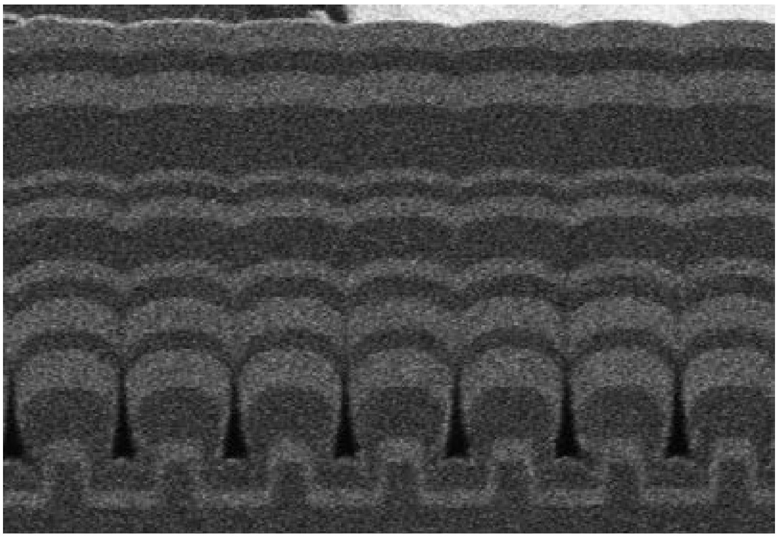

Fig. 4 SEM image of a sample to characterize the over-coating process of the initial grating in the substrate

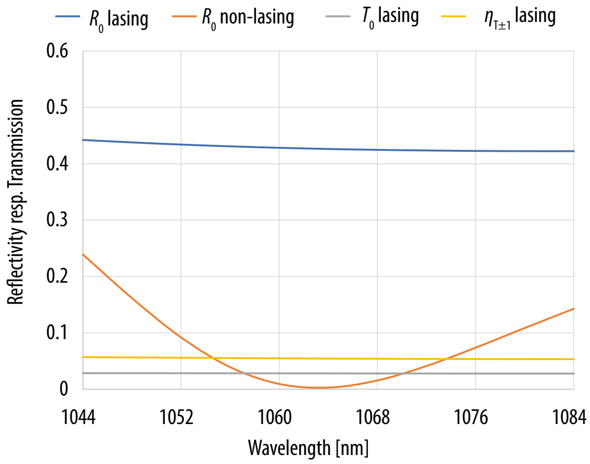

Fig. 5 Design for GWOC obtained by the genetic algorithm. Targets were reflectivity of 40 – 50 % and <5 % for one state of polarization and the orthogonal state, respectively, as well as diffraction losses $\eta_{T\pm1}$ < 10 % (yellow line).

in Fig. 4. Here one can clearly see that compared to the starting grating, the second layer did not reproduce the grating profile but created additional hollow cavities along the grating lines.

Optimization of GWOC design by genetic algorithm

It was then clear that the design of the GWS had to be started by considering the 'artefacts' of our production tools. We developed a genetic algorithm for this purpose that was fed with the target criteria in terms of reflectivity and losses, as mentioned previously. All the known characteristics of the coating process can be easily implemented in such a model (e.g. the evolution of the corrugation from each subsequent interface during the coating process and the refractive index change with each subsequent layer).

This way we could find several promising designs without having exact knowledge of the modal content of the coupled waveguides. Fig. 5 shows an example of the spectral polarization function of a design. At a wavelength of 1064 nm, the reflectivity R_0 for the lasing polarization is 43 % and close to zero for the non-lasing polarization. The absolute value $\eta_{T\pm1}$ of the losses is 5 % each.

Fabrication of the RWGs and experimental results

After the best design was identified, we produced a set of GWOCs. The grating was fabricated in a glass substrate by means of e-beam lithography and reactive ion etching (RIE). As the laser beam in the cavity at the position of the GWOC is <100 µm in diameter, a few mm² of grating area were sufficient, which can be produced economically by means of e-beam lithography. The IBS coating was then applied on top of the etched surface and an antireflective coating added to the opposite site of the substrate. Thanks to the design optimization with regard to the production tolerances, it was possible to obtain an economic yield from the first batch of GWOCs produced, even if the reflectivity R_0 for the 'lasing polarization' was close to 40 %, i.e. close to the lower limit at the target wavelength of 1064 nm, shown in Fig. 6, left. The losses $\eta_{T\pm1}$ at 1064 nm wavelength were also measured to be <10 %.

With the GWOC it was possible for our customer to generate fundamental-mode laser beams (M^2 close to 1) with a high-purity linear polarization (extinction ratio > 1:100). Pulses with a duration of ~700 ps were generated with

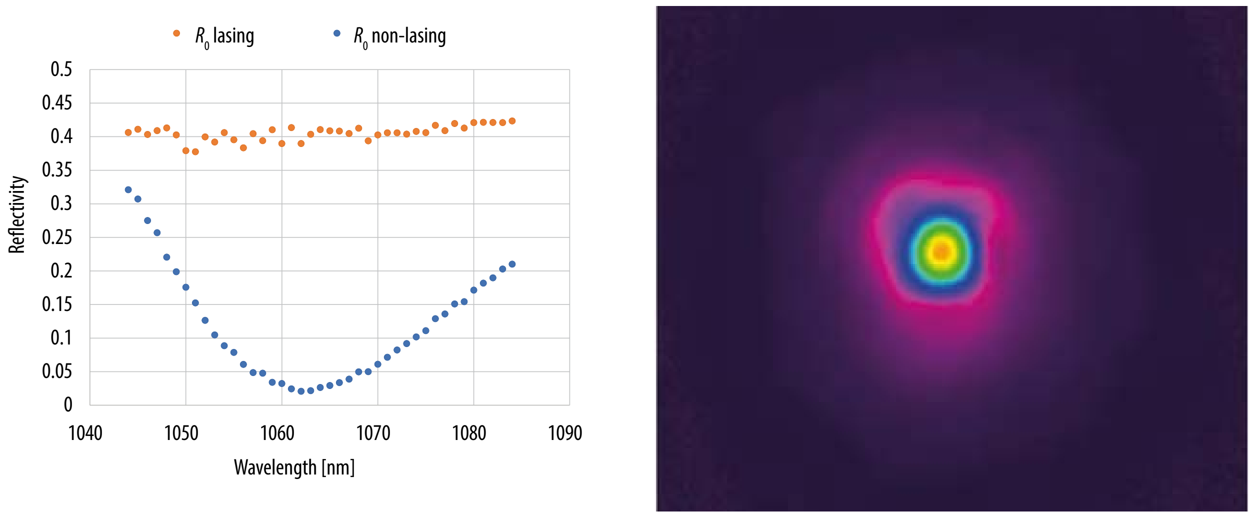

Fig. 6 Measurement of reflectivity of the GWOC used for the commercial laser system, left, and recorded intensity profile of the linearly polarized, close to fundamental-mode laser beam from the Nd:YAG rod-laser, right

pulse energies of >2 mJ. Given the beam diameter in the cavity at the position of the GWOC, this translates to energy densities of 5 – 10 J/cm² in its coupled waveguide.

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Martin Rumpel received his diploma degree in mechatronics from the University of Stuttgart in 2011 and his doctoral degree in engineering in 2019. He worked for more than five years as a scientist in the development of specialty optics for high-power laser systems and close to two years in the laser industry. He is now the CEO of MarTec Photonics, a spin-off of the Institut für Strahlwerkzeuge, founded in 2016. His company aims to bring the benefits and advantages of RWGs to global laser developers and the laser community.

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Full article online and in PhotonicsViews issue 4/2022

Preview

Bionic technology analyzed precisely

Ultrahigh-speed camera used in complex fundamental research analyzing bionic joints with 300,000 frames per second

Complex fundamental research is necessary to realize future visions such as robotic humanoids with artificial joints and muscles. The Max Plank Institute for Intelligent Systems (MPI-IS) in Stuttgart, Germany, has dedicated itself to this research using a Phantom ultrahigh-speed (UHS) camera for precise observation and versatile analysis of these complex processes.

In order to breathe life into bionic joints, small plastic bags filled with liquid (e.g. vegetable oil) are set in motion electrostatically. The strength and form of the electrical voltages applied determine the strength, type and form of movement. Several joints can be arranged in a geometric shape, one behind the other similar to a human finger, to imitate the complex mechanical processes of the human hand. This control is important as there is an enormous difference between grasping a raw egg and an object weighing several kilograms.

Equipped with the latest CMOS sensor technology, the Phantom v2640 camera offered by High Speed Vision provides the necessary ultrahigh-speed image sequences for precise motion analysis. This allows the quantitative and qualitative acceleration, speed, and movement behavior of an articulated arm to be followed very precisely – through slow-motion, high-resolution imaging.

Together with simultaneous tracking of the geometric deformation of these actuators, including the fluid flow occurring within them (flow behavior), researchers are able to analyze many important aspects and functional factors.

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Several joints can be arranged one behind the other like a finger – and combining multiples of them can form a hand. This can be used to lift a strawberry, an apple or a coffee cup.

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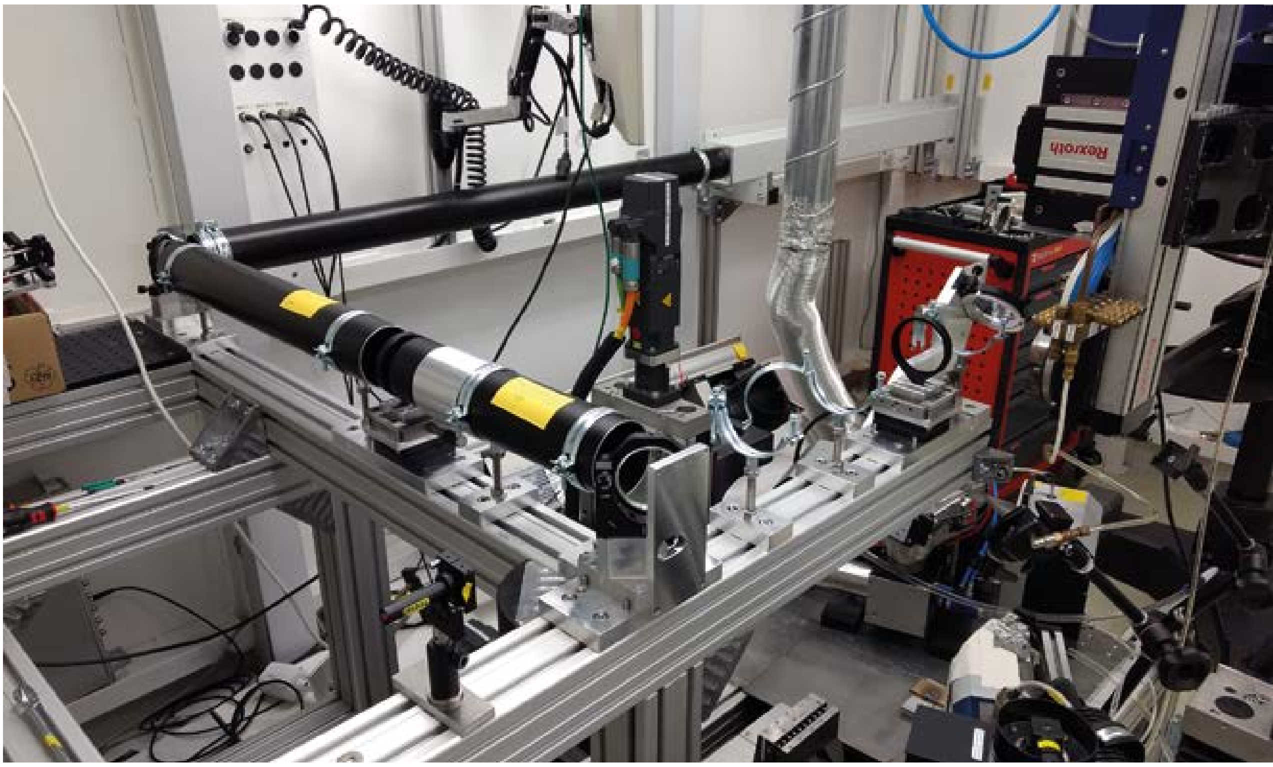
Coherent beam combining – unlimited flexibility in laser material processing

An analysis of the effects of CBC on the laser welding process

Jonas Wagner, Artur Leis, Nina Armon, Asaf Nissenbaum, Christian Hagenlocher, Julian Holland, Rudolf Weber, and Thomas Graf



Source all images: IFSW Stuttgart U

▲ Optical setup inside the x-ray facility

Civan's unique beam shaping technology enables the generation of beam patterns with an arbitrary variation of the intensity distribution within the laser beam. In addition, it is possible to switch between these patterns at MHz frequencies. This offers great potential to influence and control laser material processes.

The systematic use of this new technology first requires basic research to gain knowledge about the influence of this beam shaping technology on the energy input during laser material processing and the dynamics of the interaction. In order to investigate this, Civan's OPA6 laser source was integrated into the high-speed online x-ray facility at the IFSW (Institut für Strahlwerkzeuge) as part of a cooperation. 3D reconstructions of the keyholes can be generated from the x-ray images that enable subsequent ray tracing analysis of the energy input. This article shows for the first time the variation of the absorbed irradiance in a keyhole that results from Civan's beam shaping technology.

The intensity distribution in the laser beam determines the energy input into the workpiece. Consequently, high flexibility in adjusting the intensity distribution offers the potential to influence the entire process of laser material processing. Civan's OPA6 laser source provides coherent beam combining (CBC) of 32 parallel fiber amplifiers by means of optically phased arrays [1]. This enables beam shaping with almost arbitrary variations of the intensity distribution and switching between these intensity patterns at MHz frequencies. With laser powers up to 14 kW, this technology is now available for materials processing.

The use of the unprecedented potential of this beam source requires fundamental study on the relation between the variation of the beam profile and the process. Within the framework of a

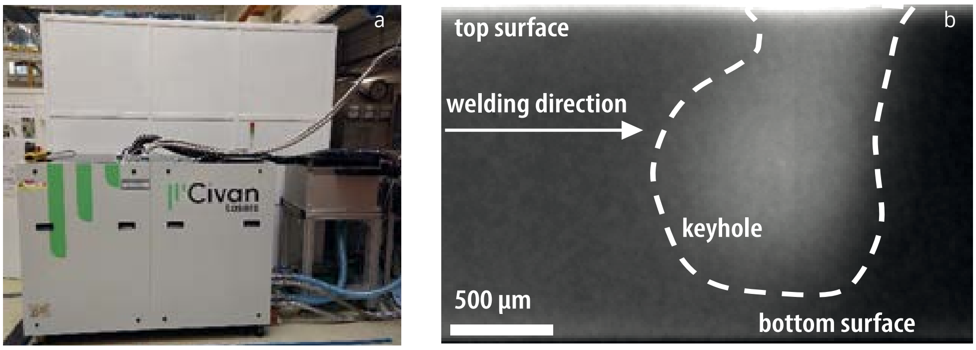


Fig. 1 OPA6 laser and IFSW x-ray facility (a). Example of an in-situ image of a keyhole formed during laser welding of the aluminium alloy AA6014, P = 5.3 kW, d_f = 600 µm, v = 6 m/min (b).

cooperation, an OPA6 laser from Civan was successfully installed at the x-ray facility of the Institut für Strahlwerkzeuge (IFSW) in Stuttgart [2]. The x-ray facility at the IFSW enables the capture of x-ray images of the process zone during the welding process at frequencies above 1 kHz [2, 3]. This provides valuable insight into the influence of the beam pattern on the keyhole geometry and its temporal change as well as on the melt flow inside the weld pool.

The image on the previous page depicts the optical setup within the x-ray facility, which guides the beam from the optical head to the processing area. Fig. 1a presents the setup at the IFSW with the OPA6 laser source on the left, the optical head on the right and the lead walls of the x-ray facility in the background. Fig. 1b is a representative example of an x-ray image of a keyhole during laser welding of the aluminum alloy AA6014.

Fig. 2 shows examples of different beam patterns generated with the OPA6 laser source. The color scale represents the local intensity I, which was measured by an HP-MSM device from Primes after the optical setup at the IFSW. The patterns shown are a) single spot, b) two spots, c) ring, d) ring with center spot, e) ring and center spot with reduced intensity in the ring (≈ 70:30 power distribution between center and ring), and f) a matrix of nine spots of equal intensity.

The measured intensity distributions illustrate the great variability in the choice of beam pattern that is possible with the OPA6. The investigations at the IFSW will show how these distributions affect the process and whether they can be beneficial for the avoidance of failures during the process, e.g. pores, spatters or cracks.

Deep penetration laser welding is characterized by the formation of a keyhole, as shown in Fig. 1b. The laser beam is reflected multiple times within this keyhole, which significantly increases the absorptance and the penetration depth of the weld seam. It is well known that many phenomena that deteriorate the quality of the weld are linked to the geometry and reduced stability of the keyhole. Examples for this are the formation of pores [4, 5], melt ejections [6], humping [7] and an insufficient connection between the joining partners. In order to investigate how the different beam patterns can be used to stabilize the keyhole, its 3D geometry is reconstructed from the x-ray images. This is determined from the intensity distribution of the transmitted radiation and the known attenuation of the corresponding x-rays in the weld sample, according to Beer-Lambert's law. A detailed description of the reconstruction algorithm is presented in [8]. The 3D-geometry of the keyhole that corresponds to the x-ray image in Fig. 1b is given in Fig. 3a (front view) and Fig. 3b (side view).

The shape of the keyhole in the process results from the interaction between the keyhole walls and the distribution of the absorbed irradiance from the laser beam: inhomogeneities in the absorbed irradiance lead to local changes of the keyhole geometry, which in turn alter the locally absorbed irradiance. Consequently, a direct correlation between the beam shape and the absorbed irradiance in the keyhole is not possible. IFSW's ray tracing algorithm, which is described in detail in [9], was used to calculate the absorbed irradiance. With this method, the laser beam is divided into more than 100,000 individual rays, whose intensities are individually assigned by the local intensity of the distribution within the investigated beam shape. The course of these individual rays is determined according to the beam parameters and their reflections within the capillary. For each interaction of an individual ray with the capillary wall, the proportion of power that is absorbed is calculated and summed up to the totally absorbed irradiance. Fig. 3c shows the results from the ray tracing calculations of a conventional laser beam with a top hat intensity distribution. The front right side of the keyhole is represented by its grid in order to visualize the course of the individual rays within the keyhole. The color scale indicates the resulting locally absorbed irradiance on a logarithmic scale.

The results show that the whole surface of the keyhole is irradiated by

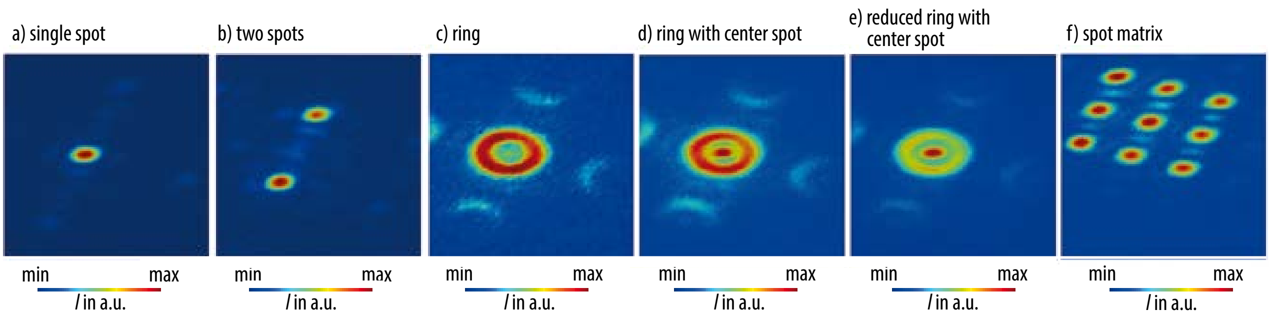


Fig. 2 Variation of the intensity patterns in the focal plane measured with an HP-MSM device from Primes

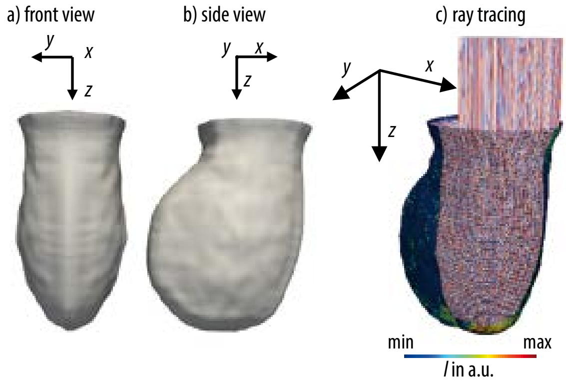


Fig. 3 Three-dimensional reconstruction from the x-ray image of the keyhole in Fig. 1b. a) front view, b) side view, c) with the absorbed irradiance determined by ray tracing and representations of the rays.

the multiple reflections. Local peaks of absorbed irradiance occur mainly at the front wall and the bottom of the keyhole, where the rays interact with the surface for the first time. The resulting total absorptance is $\eta_A = 0.69$.

The ray tracing software at the IFSW was enhanced with an interface to Civan's beam generator software to investigate the absorbed irradiance that results from Civan's unique beam patterns. Fig. 4 demonstrates the first results from this enhanced software and shows for the first time the absorbed irradiance from Civan's beam patterns in an arbitrary keyhole. Each subfigure a-f shows the absorbed irradiance in the previously introduced 3D reconstruction resulting from the application of the corresponding beam pattern in Fig. 2. As indicated by the coordinate system for each subfigure, the left image shows the front view of the keyhole and the right image shows the side view of the keyhole. The results show that the absorbed irradiance in the lower part of the keyhole varies significantly when the beam pattern is changed.

It has to be noted that all results describe the hypothetical absorbed irradiance in a keyhole that was experimentally determined from welding without beam shaping with a comparable beam diameter on the sample's surface. First x-ray imaging experiments at the IFSW will focus on the determination of the shapes of the keyhole that evolve when these beam patterns are applied.

As expected, the highest locally absorbed irradiances occur when a single spot pattern is chosen. The local maxima along the major axes of the beam pattern result in spots with increased absorbed irradiance at the center of the keyhole front and towards the side. Future work will include a comparison of simulations and experiments with and without these local maxima in order to determine their impact on the process. With two spots (Fig. 4b) in parallel orientation to the welding direction, see Fig. 2b, the intensity on the front of the keyhole is increased. The influence of additional local maxima in the beam pattern is reduced compared to the application of the single spot. By using a ring-shaped beam pattern, as shown in Fig. 4c, the area with high absorbed irradiance at the bottom is increased and the maximum absorbed irradiance is reduced.

The further regions with increased intensity in the beam pattern lead to additional areas with increased absorbed irradiance on the keyhole front and side wall. Compared to the application of the single spot pattern, these regions are more widely distributed with less distinct maxima. Compared to the single and two spot pattern more irradiance is absorbed at the backside of the keyhole and the irradiance is more evenly distributed in this region. As expected, a single spot in the center of the ring increases the peak of the absorbed irradiance but the distribution in the keyhole is mostly affected by the ring, as shown in Fig. 4d. When the intensity in the ring is reduced compared to the intensity in the center spot, the absorbed irradiance at the bottom of the keyhole is distributed less evenly, which is shown in Fig. 4e. The additional local areas with increased absorbed irradiance are reduced compared to the result from the ring shaped intensity pattern. Furthermore, less irradiance is absorbed at the back of the keyhole. Fig. 4f shows that the application of a beam pattern with a matrix of nine spots leads to a large area in the lower part of the keyhole with increased absorbed irradiance. The peaks resulting from the matrix can be clearly distinguished in the keyhole. The distribution of the absorbed irradiance on the back wall of the keyhole is similar to the distribution resulting from a ring shaped pattern.

Despite the different irradiance distribution on the capillary walls, the total absorptance varies only to a limited amount within a range from 66 to 72 %. This agrees well with the predictions from literature that the absorptance in a given material is mainly influenced by the geometry of the keyhole and the wavelength of the laser beam [10, 11]. The results indicate that Civan's beam shaping technology provides the potential to control the distribution of the absorbed irradiance in the keyhole and therefore the shape of the keyhole itself. The main influence was found to be in the region of the first impact, at the bottom of the keyhole and at the front wall. Consequently, a more even distribution of the intensity in the beam pattern leads to more evenly distributed

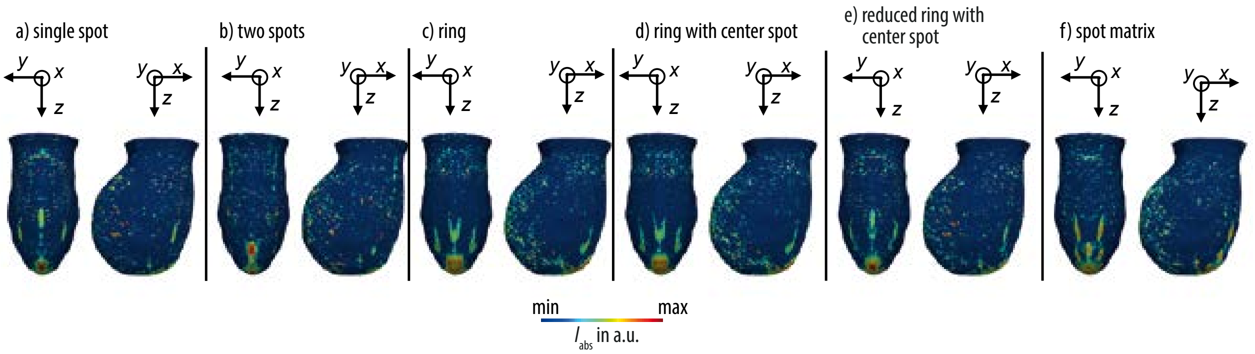


Fig. 4 Comparison of the absorbed irradiance of the beam patterns in Fig. 2 in the keyhole from Fig. 3c.

absorbed irradiance in this area of the keyhole. This enables the stabilization of the keyhole in order to generate defect free welds by the specific adjustment of beam patterns.

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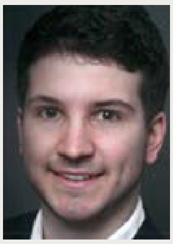
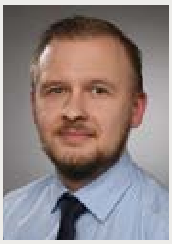


He has been a scientific employee at the Institut für Strahlwerkzeuge since then. His current PhD work is in the numerical modelling of the physical processes in laser beam welding. This includes in particular the process response on changing laser beam parameters, such as wobbling and power modulation.

Artur Leis achieved his MSc degree at the University of Stuttgart and is working on his PhD thesis



with the topic of the laser-materials interactions in laser-based powder bed fusion of AlSi10Mg and the influence of the processing parameters on the mechanical properties of the generated samples.

Nina Armon obtained her BSc in chemistry, specializing in materials science, and her MSc in chemis-

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Asaf Nissenbaum is a metallurgy researcher at Civan. He is focused primarily on the process development

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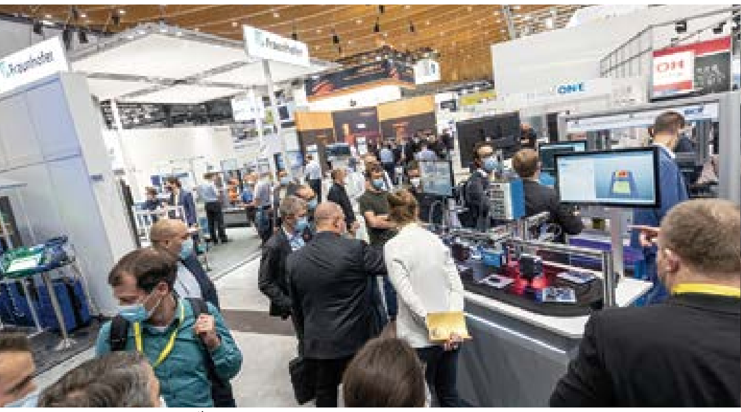

Source: Wiley


Source: Messe München

June 14 – 17, 2022
EPHJ
Geneva, Switzerland
https://ephj.ch/en

June 15 – 17, 2022 **NEW DATE**
SEMICON / FPD China
Shanghai, China
www.semiconchina.org

June 21 – 22, 2022
Stuttgarter Lasertage (SLT 2022)
Stuttgart, Germany
www.ifsw.uni-stuttgart.de

June 21 – 23, 2022
LASYS
Stuttgart, Germany
www.messe-stuttgart.de/lasys

July 06 – 07, 2022 **NEW DATE**
W3+ Fair
Wetzlar, Germany
https://w3-fair.com/wetzlar

July 13 – 15, 2022 **NEW DATE**
LASER World of PHOTONICS China
Shanghai, China
https://world-of-photonics-china.com

August 21 – 25, 2022
SPIE Optics + Photonics 2022
San Diego, CA, USA
https://spie.org/conferences-and-exhibitions/optics-and-photonics

August 28 – September 02, 2022
EUROPHOTON
Hanover, Germany
www.phoenixd.uni-hannover.de/de/ueber-uns/news-und-veranstaltungen/europhoton2022/

September 04 – 08, 2022
12th CIRP Conference on Photonic Technologies [LANE 2022]
Fürth, Germany
www.lane-conference.org

September 06 – 08, 2022
Optics and Photonics Days (OPD2022)
Tampere, Finland
www.photonics.fi/opd2022

September 07 – 09, 2022
24th China International Optoelectronic Exposition (CIOE 2022)
Shenzhen, China
www.cioe.cn/en/

September 12 – 16, 2022
EOS Annual Meeting (EOSAM) 2022
Porto, Portugal
www.europeanoptics.org/events/eos/eosam2022.html

October 18 – 20, 2022 **NEW DATE**
Optatec
Frankfurt, Germany
www.optatec-messe.de

The benefits of gathering in person

Review: SPIE Photonics Europe, 3 – 7 April 2022, Strasbourg, France

The biannual event was held in person for the first time since 2018, featuring over 1,000 presentations across 25 conferences and a 60-plus company exhibition. During the week, the more than 1,300 attendees were regularly reminded of the benefits of gathering in person, as numerous networking events complemented the strong technical program. The conference rooms, exhibition floor, and even the venue halls were abuzz all week with the smiling faces of researchers, engineers, and scientists, all happy to reunite with their colleagues and make new connections after the pandemic had caused the temporary hiatus of in-person scientific conferences.

In addition to the exhibition, there was an engaging industry program featuring presentations on European photonics funding, quantum technology, innovation, and entrepreneurship. The exhibit floor itself showcased an Innovation Village, where European startups competed for cash prizes.

The technical program spanned everything from fundamental to applied research, covering a wide range of topics that included biophotonics, nano and quantum sciences, optical imaging and sensing; lasers and nonlinear optics, and applications of photonic technologies. The plenary presentations did a wonderful job covering the breadth of the topics above and included:

- Enhancing optical contrast for cancer detection and therapy guidance, Brian W. Pogue (U. Wisconsin, Madison)
- Cell by lens: arguments and divagations for next visionary challenges in biophotonics and beyond, Pietro Ferraro, Institute of Applied Sciences and Intelligent Systems (ISASI-CNR)
- A sneak peek with light into opaque materials: from imaging to computing, Sylvain Gigan (Sorbonne U. and Lab. Kastler-Brossel, ENS)
- Active metasurfaces empowered by two-dimensional materials, Isabelle Staude (Friedrich Schiller U. Jena)
- Access to photonics innovation support for European researchers and companies through Actphast4R and PhotonHub Europe, Hugo Thienpont (Brussels Photonics; VUB)
- Quantum computing: prospects and challenges, Heike Riel (IBM Research Zurich)
- Einstein Telescope, the pioneer project for a third-generation GW observatory in Europe: science, technologies and perspectives, Michele Punturo (National Institute for Nuclear Physics)


Source: SPIE

Presentations from the event are included in the official proceedings in the SPIE Digital Library.

SPIE Photonics Europe will take place once again in Strasbourg France in the spring of 2024.

https://spie.org/conferences-and-exhibitions/photonics-europe

Strong response in challenging times

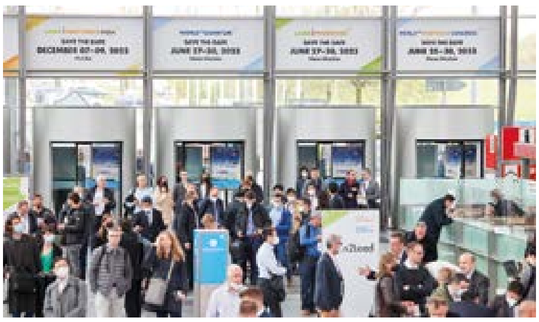
Review: Laser World of Photonics, 26 – 29 April 2022, Munich, Germany

Due to the coronavirus-related postponement, Laser World of Photonics took place without the parallel congress; the industry will meet again next year in Munich with the usual format. Dr Reinhard Pfeiffer, deputy CEO of Messe München, sums up: “The response has clearly exceeded our expectations: more than 15,000 trade fair visitors traveled to Munich. That is eighty percent of the level of the previous event in 2019, an outstanding result for a trade fair in the time of coronavirus. 39 percent of visitors came from abroad, with the US and Israel leading the way. We are also very pleased with the successful premiere of the World of Quantum, a platform for a future technology that is largely based on photonics and expected to be at least as promising.”

“The ‘Laser’ is alive and well again!” says Dr Wilhelm Kaenders, chairman of the exhibitor board and CEO of Toptica Photonics. “After three years and having successfully found its way through various crises, the industry can once again show its full innovative capacity.”

The show was an important milestone for an industry on the upswing. Over 900 exhibitors from more than 30 countries made an appearance (2019: 1,325 exhibitors from more than 40 countries), including 15 national and international joint stands. After Germany, the top ten exhibitor countries were the US, France, Great Britain and Northern Ireland, Switzerland, China, Lithuania, Netherlands, Canada, Finland and Japan. The top ten visiting countries from abroad included Switzerland, Italy, UK, Israel, France, US, Czech Republic, Austria, Netherlands, and Spain.

“There is immense growth potential for photonics,” explains Jörg Mayer, managing director of the industry association Spectaris. “For the German photonics industry alone, experts in 2020 forecast average annual growth of more than six percent and total sales of almost 60 billion euros by 2025. I am confident that this target will be met, if not exceeded, despite the current global challenges.”


Source: Messe München

Premiere: ‘World of Quantum’

Held for the first time in its own hall, the World of Quantum quickly won positive feedback: more than sixty percent of all trade fair participants visited this new area, and more than ninety percent of them were interested in the products at World of Quantum according to a survey carried out by the trade fair.

"The World of Quantum was an immense success," said a delighted Dr Lechner, executive director at Messe München. "Together with our partners, we are off to a great start, and we will continue down this path together." Dr Walter Riess, manager quantum technology at IBM Research Europe, added: "The World of Quantum more than exceeded my expectations. I am already looking forward to next year."

Award-winning innovations

The Innovation Award was presented for the second time in conjunction with Europa Science. A jury consisting of top experts from industry and science selected the most innovative products in a total of six categories; the SI Stuttgart Instruments was also honored as the overall winner. The winners in the individual categories are Hamamatsu Photonics Germany, Glassomer, SI Stuttgart Instruments, Qiova, ID Quantique and Xarion Laser Acoustics.

'Photonics for Ukraine'

On the last day of the trade fair, representatives of the major donors Coherent, Fraunhofer ILT, Jenoptik, Laser Components, Toptica, Trumpf, and deputy CEO of Messe München, Dr Reinhard Pfeiffer, presented a check for a total of 20,000 euros to Christine Kazenwadel, board representative of the Fritz Kreuzer Foundation. With this donation, the foundation supports children in Ukraine who have lost an arm or a leg. "This fundraising campaign is really a great thing," Dr Pfeiffer sums up. "The industry has sent a strong signal to Ukraine that it and its people are not alone."

The next Laser World of Photonics will be held at the Messe München exhibition center from June 27 – 30, 2023, and the next World of Photonics Congress from June 25 – 30, 2023.

https://world-of-photonics.com

"Laser: commodity or innovation driver?"

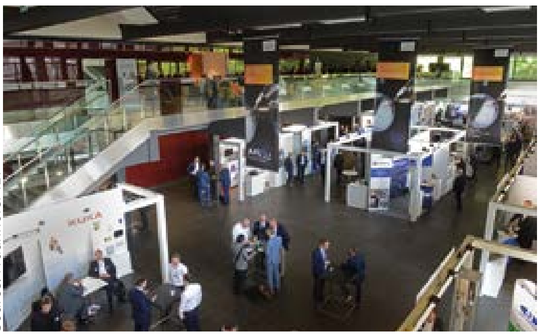
Review: International Laser Congress AKL'22, 4 – 6 May 2022, Aachen, Germany

Source: Fraunhofer ILT

After a pandemic break of four years, the industrial laser technology community met for AKL'22 in Aachen. The organizers counted 521 participants, 85 of whom gave a live presentation, and 44 sponsoring companies that exhibited their innovations in the Eurogress Aachen.

The general conclusion amongst the experts: the industry is doing well; the biggest trend is the extensive digitalization of processes. At the same time, however, common beam sources are being driven to ever new levels of peak performance.

New to the conference program was the Quantum Technology & Photonics Forum, where major German companies presented a range of topics.



Source: Fraunhofer ILT

"The mood in photonics is good, the prospects are very good," was how Constantin Häfner, director of the Fraunhofer Institute for Laser Technology ILT in Aachen, described the climate in the market. Drivers here are photonic production solutions for microelectronics, e-mobility and energy storage. "In competition with the rest of the world, the German industrial and research landscape can score points in process know-how, but it also became clearly visible that we still have to take a step forward in digitalization," Häfner summed up his impressions at the end of the conference..

If it were not for various supply chain problems, the industry would probably be talking about new records. In China, the world's largest laser market, there had been a massive increase of 18.3 % to almost \$ 13 B in market volume in 2021, Bo Gu (BOS Photonics) reported during the Technology Business Day. Jürgen Rumberger (Trumpf Laser- und Systemtechnik) was much more cautious in his assessment of the situation in Germany: On a short time scale he saw various trends in world laser markets: a decline in the automotive industry and growing figures in medical technology as well as in consumer electronics.

A highlight of the program this year was once again the Gerd Herziger session, named after the founder of the Fraunhofer ILT, during which institute director Constantin Häfner gave an overview of the major trends in industrial laser technology: sustainability and digitalization. Fittingly, he announced the opening of two new ILT laboratories for hydrogen and battery technology.

In the panel discussion that followed, Trumpf's laser technology CEO Christian Schmitz discussed the topic of 'lasers as commodities'. Mark Sobey, EVP, COO, Industrial Lasers and Systems, Coherent, provided an outlook on the opportunities Coherent sees in the automotive and semiconductor markets. Volker Krause, who was still advised by Gerd Herziger when he founded Laserline, looked at a core issue in beam sources: the scaling of individual laser diode emitters.

"It is already overwhelming to be together again in this way," Dieter Hoffmann from Fraunhofer ILT summarized his impressions. "When you meet again, you only realize all the things that were not possible in the home office." Many contacts were renewed or even newly established. The variety of topics and the mixture was particularly interesting: there is a spirit of optimism in the quantum field, and Infineon presented no fewer than three of its own approaches to the development of quantum computers. The challenges in today's manufacturing were discussed in parallel. Digitalization is the opportunity here; sustainability the requirement of the hour. The recruitment of qualified young people is increasingly emerging as a central challenge. In all this, the joy of the meeting dominated.

The next International Laser Technology Congress, AKL'24, will take place from April 17 – 19, 2024.

www.lasercongress.org

AM for sustainable structural transformation

Review: 18th Rapid.Tech 3D conference and trade fair, 17 – 19 May 2022, Erfurt, Germany

Over 2,500 people attended the 18th Rapid.Tech 3D. They heard about new products and services in additive manufacturing (AM) from 97 exhibitors representing 11 countries. 13 of the exhibitors in Thuringia came from outside Germany, including companies from the US, Great Britain, Austria and Switzerland. Visitors were delighted with the conference programme, and delegate numbers were higher than at the last live conference in 2019.

The inspiring programme for the last day of the event opened with a trailblazing keynote speech by Bernhard Randerath, highlighting a practical avenue for sustainable structural transformation. The managing director of the German Emirati Institute (GEI) invited his audience to imagine the CO_2-free factory of the future, where AM played a key role in the production of interiors for all kinds of vehicles. The concept is based on the fact that interiors – whether for cars, trains, planes or boats – all have similar designs and similarly constructed components. The factory is being developed jointly by Germany and the United Arab Emirates (UAE) and forms part of wide-ranging technological collaboration between the two states. The factory will be built in a structural transformation zone and is scheduled to start operations in 2025.

Speed and simplification were also the themes of the second keynote. Alexander Oster of Autodesk presented Machine Control Framework, open-source software that enables different hardware components to be combined quickly and easily in a finished SLM system, instantly producing product-quality metal and plastic components. The framework, which was the result of collaboration between Autodesk and Scanlab, allows every development organisation to integrate finished components rapidly into complete additive manufacturing systems – at a fraction of the usual cost.

Source: Messe Erfurt

As well as learning about the almost unlimited potential of additive manufacturing from the keynotes and specialist conference forums, visitors were able to experience them first-hand at the exhibitor stands.

Exhibitors almost unanimously reported that they had welcomed large numbers of sector experts – often with highly specific questions – representing all types of operation, from large corporations to very small businesses.

The next Rapid.Tech 3D will be held in Erfurt, 9 – 11 May 2023.

www.rapidtech-3d.de

"It's great to exhibit again!"

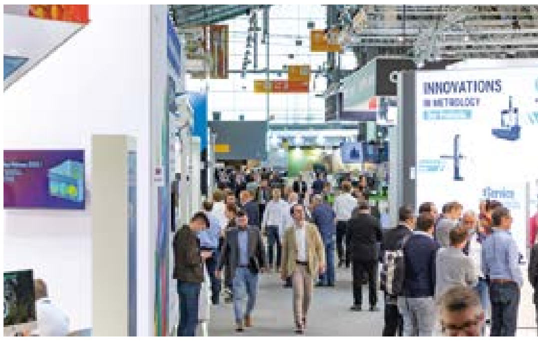
Review: 34th Control international trade fair for quality assurance, 3 – 6 May 2022, Stuttgart, Germany

After the two-year interruption due to the pandemic, more than 600 exhibitors finally experienced hands-on QA innovations live once again in Stuttgart. Current, forward-looking developments include artificial intelligence (AI) technology as well as inline production inspection processes.

18,531 expert visitors at Control 2022 finally experienced QA developments again in vision technology, image processing and sensor technology, as well as measuring and testing technology – up to date, live and on-site. 617 exhibitors presented innovative solutions and efficient, cutting-edge QA technology on nearly 23,000 square meters of floor space in six exhibition halls, making it the largest trade fair for quality assurance anywhere in the world. "It is great to exhibit at Control again after two years of abstinence," said Gerhard Mohr, managing director of Kapp Niles Metrology GmbH in Großostheim, Germany. "It is good to see that expert visitors are beginning to travel again, that on-site trade fairs are picking up and that we are getting a bit closer to the way things were done before." Georg Gutsch, area sales manager at Kapp Niles, corroborated this statement and adds: "The face-to-face exchange of ideas has a lot of significant benefits that are not possible at all with online formats."

Hubert Meintrup, New Technology Advisor at Matrix Automations GmbH in Ostfildern, Germany, also expressed his sense of relief at finally being available again to meet interested parties and users in the industry sector in person. "We are very pleased to be back again." Matthias Ruf, head of sales at the SKZ Plastics Center in Würzburg, was equally enthusiastic. "For us, Control was successful from the very first day with great interest shown by the visitors," explained Ruf. "We are happy to be able to exhibit here again as the SKZ."

31 % of the exhibitors at the 2022 industry highlight came from outside Germany – 6 % came from Switzerland, 4 % from Italy, 3 % from the USA and more than 2 % from the UK. Bettina Schall, managing director of trade fair



Source: Schall

promoters P. E. Schall, expressed her appreciation and satisfaction: "This event was awaited in advance with great anticipation, excitement and high spirits, because we all missed the personal exchange, technical discussion on an equal footing and the opportunity of experiencing QA solutions with all of our senses. Fortunately, this is now possible again!"

The next Control international trade fair for quality assurance will take place 9 – 12 May, 2023.

www.control-messe.de

Preview: LANE 2022

4 – 8 September 2022, Fürth, Germany

The Bayerisches Laserzentrum (BLZ) and the Institute of Photonic Technologies of the Friedrich-Alexander-Universität Erlangen-Nürnberg cordially invite all interested persons to participate in the 12th CIRP Conference on Photonic Technologies [LANE 2022]. Traditionally, this event has its focus on the interaction between science and commerce.

After a successful virtual edition of the conference in 2020, the organizers are really looking forward to holding an on-site event again. The LANE conference series deals with the latest developments in laser material processing. Emerging technology that will open up the capability of light is also examined to identify new manufacturing processes. LANE provides an international platform for the exchange of perspectives, results and solutions in photonic technology.

Participants can look forward to top-class keynote talks and about 200 informative and inspiring presentations from science and industry. The accompanying exhibition also offers companies a good opportunity to present their innovative products to an international audience of experts. The registration for participants and exhibitors is possible until August.

Traditionally, the organizers of the LANE conference also organize a diverse social program. Starting with the "Casual Reception" with food, drinks and some entertaining games, the Conference Banquet with the ennoblement of a new Knight of Laser Technology and the Lab-Tour & Cocktail Session at the organizers' labs in Erlangen work well for networking in a relaxed atmosphere too.

New in 2022: 'people@LANE lounge'

To stimulate the discussion on diversity and inclusion, there will be a so called 'people@LANE lounge' during the conference at the Stadthalle Fürth for the first time. Not only scientific work but also different aspects of the working environment of the participants will come under the spotlight. For this purpose, the LANE organizing team will provide a small exhibition on the topics of 'new work around the world' and 'science and social media' as a stimulus for discussion.

www.lane-conference.org

Preview: CIOE 2022

7 – 9 September 2022, Shenzhen, China

With 23 years of successful experience, CIOE is known as the world's largest optoelectronic event. Featuring the concurrent six subexpos, more than 3,000 optoelectronic exhibitors will showcase up-to-date optoelectronic technology and comprehensive solutions for various optoelectronic applications. This event will enable industry players to source optoelectronic products, gain the latest industry market insights, and network with key Chinese optoelectronic players.

Under China's 'Made in China 2025' and 'The 14th Five-year Plan' national policies, optoelectronic technologies, as the supporting cornerstone, will be sustainingly and continuously developing in product productivity, quality, and cost performance along China's industry upgrade.

In 2022, CIOE will expand to 240,000 m^2 (+50 % from 2021). There will be not only professionals from major optoelectronic application industries like optical communication/information processing and storage, consumer electronics, advanced manufacturing, defense and security, semiconductor processing, energy, sensing and measurement but also 'Displays' as one of the subexpos together with Photonics Innovation Expo, featuring the medical application of laser, 3D printing, etc.

This year, CIOE will also collaborate with world-class organizations like Yole, EPIC, and Epixfab to organize professional forums on different optoelectronic topics such as imaging, 3D sensing, lidar, and silicon photonics. All focus will be on the hottest issues in this industry, not only in China but the world. With over 80 forums and 550 speeches, industry professionals will certainly find a number of them to be of particular interest.

CIOE offers an exclusive services VIP Buyer Program for key buyers and senior decision makers to connect with manufacturers and suppliers. Considering the pandemic situation, the Year-Round Match-Making Service for international buyers is available.

Even under these tough conditions, CIOE has devoted itself to providing an even larger and more professional exhibition than the year before. As always, we would love to invite you all to attend this grand event!

www.cioe.cn

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