Volume 19 April/May 2022

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PhotonicsViews

OPTICS • PHOTONICS • LASER TECHNOLOGY

COVER STORY

Driving the manufacturing and improvement of batteries

AKL'22 SPECIAL SECTION International Laser Technology Congress

LASER World of PHOTONICS

WILEY

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Are you looking for the next useful mission?

Improving sustainability thanks to Digital Photonic Production

For a viable and livable world, economic activity must become more sustainable – and photonics offers relevant advantages for the sustainable use of resources. The spectrum of photonic solutions ranges from energy-efficient optical communication technology and photovoltaics for energy generation to satellite-based lidar measurement systems for climate research and laser-based sensor technology for materials recycling. Digital photonic production also makes a decisive contribution to sustainable solutions for industrial applications by combining precision, efficiency, and effectiveness.

For example, the additive manufacturing process of selective laser melting enables the resource-efficient production of complex components by avoiding numerous assembled individual parts and thus unnecessary weight. This in turn is a decisive criterion in aircraft construction as it saves fuel and thus improves energy efficiency. Innovative coating processes such as extreme high-speed laser material deposition (EHLA) offer not only economical but also environmentally friendly solutions in offshore technology, mechanical engineering, or transportation. In battery technology, laser technology enables effective manufacturing processes that increase the quality and efficiency of energy sources. Whereas in the past the focus was on trial-and-error developments, with today's sensors and computing power, the representation of the real world in the virtual world – the digital twin – is more complete and conclusions can be drawn faster in process optimization. Benchmarking is still required, but fewer loops mean fewer resources consumed and a shorter time to market. In addition, machine learning supports finding the right parameters, improved process control, and learning from previous experience. Digital photonic production will reach its full potential when the goal of 'first time right' can be achieved for every new product and when the machine can be operated without special prior knowledge: the ease-of-use factor.

I am looking forward to the new approaches to tomorrow's sustainable and smart production as presented by users and system developers from industry and academia in this issue and at the AKL'22 International Laser Technology Congress organized by Fraunhofer ILT. I also look forward to a stimulating exchange with the participants of AKL'22 and the readers of PhotonicsViews.

Sincerely yours

Prof. Constantin Häfner

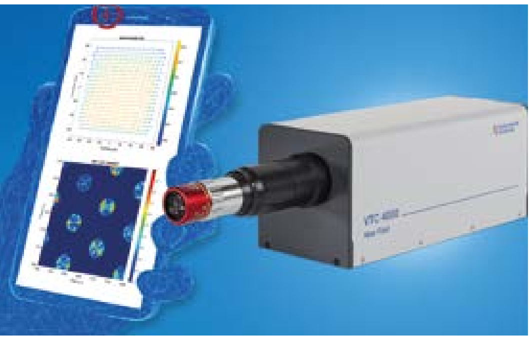
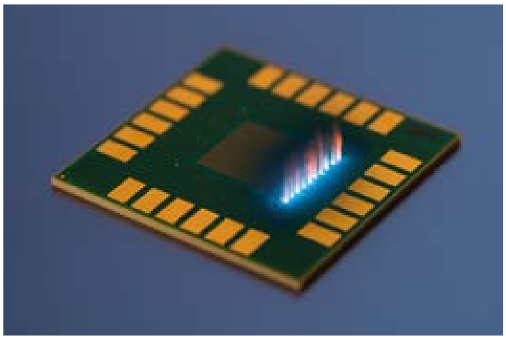
Source: Fraunhofer ILT, R. Baumgarten

Prof. Constantin Häfner
Director
Fraunhofer Institute for Laser Technology ILT

AKL'22
INTERNATIONAL LASER TECHNOLOGY CONGRESS

PhotonicsViews

OPTICS • PHOTONICS • LASER TECHNOLOGY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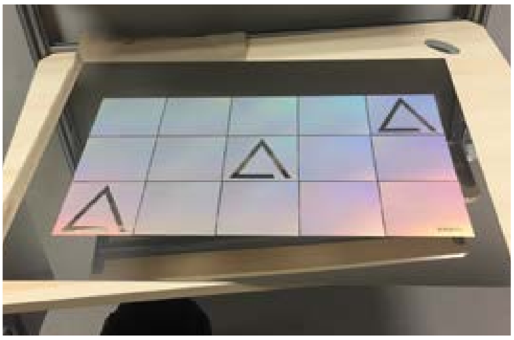
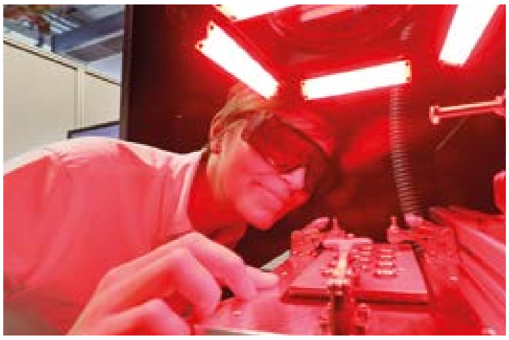




Focus section: AKL'22

Trumpf acquires majority stake in fiber laser specialists AFS, celebrates laser anniversary

High-tech company Trumpf has acquired an eighty percent stake in Active Fiber Systems GmbH (AFS), a company based in Jena, Germany, that specializes in fiber lasers. AFS develops and manufactures ultrashort-pulse laser systems and fiber-laser systems used primarily in science and research. In addition to basic research, its areas of application include the generation of extremely short-wavelength light with high coherence, biomedical imaging and material processing.


AFS Jena (Source: Active Fiber Systems)

As a majority stakeholder in AFS, the Ditzingen-based group – whose holding's managing company just changed its legal form and now operates under the name Trumpf SE + Co. KG – hopes to leverage synergies in the research and further development of its existing ultrashort-pulse laser portfolio and to expand its business in this growing field.

Founded in Jena in 2009, Active Fiber Systems has a workforce of 37 employees. Both parties have agreed not to disclose details about the transaction.

50th laser anniversary for Trumpf

The idea of using light as a tool was still in its infancy when the Schramberg engineers used laser systems to spot-weld watch springs. The facility in the Black Forest – the second-largest Trumpf location in Germany – now employs over 1,400 people including physicists, engineers and software architects. Together, they develop, manufacture and maintain laser systems that are used in numerous industries all over the world. "Schramberg is the hub of German industrial solid-state laser technology," says the site's managing director, Hagen Zimer. "We now supply state-of-the-art laser technology for global applications including e-mobility, display manufacturing, smartphones, and tablets."

From its humble origins in the Black Forest, when the Schramberg engineers came up with the idea of building laser systems to spot-weld watch springs, the introduction of laser-based processes for cathode ray tube manufacturing and pacemakers swiftly followed, culminating in the company's breakthrough use of solid-state laser technology in automotive production.

"Over the years, we have demonstrated time and again that we are an industry trendsetter that knows how to respond to change and meet its customers' needs," says Zimer. Development engineers in Schramberg played a key role in developing ultrashort-pulsed laser technology and ramping it up for industrial use. These systems are an efficient choice for processing hard materials such as glass and sapphire, as well as solar cells. In 2013, Trumpf received the prestigious German Future Prize together with representatives of Bosch and Friedrich Schiller University Jena.

www.trumpf.com

Materialise exercises option to buy Link3D

Globally active provider of 3D printing solutions, Materialise, has acquired 100 % of the equity interests of Link3D, an additive workflow and digital manufacturing software company, for 33.5 million US dollars.


Source: Materialise

Building on the success of its existing additive manufacturing (AM) software suite, Materialise has outlined an ambitious cloud-based platform strategy. Its software platform will offer companies cloud-based access to a continuously growing set of digital tools, enabling users to personalize and manage their 3D printing processes and streamline their workflows. The acquisition of Link3D will strengthen and accelerate the creation of the platform, particularly for companies that are scaling up their additive manufacturing operations to volume production.

By integrating Link3D's additive MES (manufacturing execution system) solution with the Materialise Magics software suite into a unified, cloud-based software platform, manufacturers will be able to run and continuously improve the most efficient, repeatable, automated, and controlled processes to mass-produce identical or customized products. This process extends beyond the actual 3D printing operations and creates a closer alignment between 3D printing and conventional manufacturing.

www.materialise.com
https://am.link3d.co

Mercedes-Benz partners with Luminar

The two companies intend to accelerate the development of future automated driving technology for passenger cars. A central component of this is the optimal access to new technologies and global competencies.

The new partnership with Luminar underlines Mercedes-Benz's policy of continuously expanding its network of top-flight tech partners and suppliers for passenger cars. The intent of this partnership is to leverage the foundational lidar technology from Luminar with the aim to industrialize and integrate it into series production Mercedes vehicles. By shortening development cycles and strengthening technology partnerships, Mercedes-Benz seeks to ensure that its vehicles have the most up-to-date technology.

"Luminar is the perfect addition to our existing roster of first-class cooperations with leading and cutting-edge tech companies. Mercedes-Benz's achievement of SAE Level 3 already marked a huge milestone for automated driving and I am absolutely convinced that partnerships will increase our level of ambition for what is possible in future," says Markus Schäfer, member of the board of management of Daimler AG and Mercedes-Benz AG, the chief technology officer responsible for development and procurement.

"This partnership is a landmark moment in the industry, demonstrating how substantially increased safety and autonomous driving functions in consumer vehicles are going from sci-fi to mainstream," said Austin Russell, Luminar founder and CEO.

www.mercedes-benz.com
www.luminartech.com

Zebra Technologies to acquire Matrox Imaging for 875 million US dollars

Software, machine learning and deep learning – Zebra Technologies underlines its claim to gain further market share in industrial machine vision. The acquisition of Matrox Imaging is subject to customary closing conditions, including regulatory approval, and is expected to close in 2022. Matrox Imaging generates approximately 100 million US dollars in annual revenue and has a higher profit margin profile than Zebra.

The Matrox Video Division (Matrox Graphics Inc.) is not part of the transaction and will remain under the ownership of Matrox President and co-founder Lorne Trottier. In addition, both Matrox Video Division and Matrox Imaging Division headquarters will remain in Montreal.

Anders Gustafsson, CEO of Zebra Technologies, comments on the pending acquisition: "This acquisition enables us to meet our customers' evolving needs, regardless of where they are on their automation journey – from capturing and analyzing data to facilitate decision-making, to deploying physical automation solutions to accelerate the production and movement of goods and materials."

www.zebra.com
https://matrox.com/imaging

Bystronic completes acquisition of automation specialist Antil

Flexible manufacturing aligned with automated material handling and data flow is key to the productivity of Bystronic's customers in the sheet metal processing industry. In the summer of 2018, the Swiss had acquired seventy percent of the family-owned company Antil in San Giuliano Milanese in northern Italy. Since then, Bystronic has integrated Antil's operations, doubled sales to around 40 million swiss francs at good profitability and increased the number of employees from 110 to 200.

Since the beginning of 2021, the demand for automation solutions for laser cutting systems has grown well above average. Effective November 2021, Bystronic acquired the remaining minority stake of thirty percent for around 13 million swiss francs. CEO Alex Waser emphasizes: "Automation is one of the core drivers of growth for both our customers and our own business. With this acquisition, we are strengthening our portfolio in this crucial field and will be able to even more effectively address our customers' needs. Over the coming months, we will leverage Antil's know-how to develop additional solutions for the silver and entry-level segment in China."

www.bystronic.com

Fluence opens new facility in Poland

Intended to develop laser processes for future products and technologies that will forge new frontiers in micromachining for consumer electronics, medical devices, and other applications, the Ultrafast Laser Application Laboratory (ULAL) allows Polish laser manufacturer Fluence to test new processing strategies for industry, perform feasibility studies, and identify new applications. The new laboratory in Wrocław is equipped with a top-class, high-precision automated micromachining station based on high-power femtosecond lasers.

"The new facility will give our customers the hands-on technical experience they need to solve complex laser micromachining challenges in cutting, microdrilling, marking, structuring, welding, scribing, and more," said Bogusz Stępak, R&D director of laser microprocessing at Fluence.

Partnerships with Scanlab, ACS Motion Control, and Direct Machining Control allow for the machining of large samples with precise motion synchronization between scanner and linear stages.

The ULAL targets laser micromachining applications such as cutting glass, polymer, metal (including titanium, wolfram, and tungsten) and hard materials like diamond and sapphire, microdrilling, also surface structuring, surface functionalization, in-volume and surface marking, selective layer removal, semiconductor scribing, and transparent material welding.

The facility's higher harmonic generation enables greater precision and improved surface finishes thanks to a small beam spot, strong light absorption, and minimal heat accumulation on different materials.

https://fluence.technology

Leoni sells fiber optics and plasma units to Weinert Industries

The international automotive supplier Leoni is selling its subsidiaries Leoni Fiber Optics GmbH, Leoni Fiber Optics Inc., and J-Plasma GmbH to a consortium of buyers to pursue its focus in the automotive and commercial vehicle industries.

The portfolio of Leoni Fiber Optics and J-Plasma includes special fibers for optical metrology and industrial data transmission. Leoni AG intends to strategically focus on consolidating its leading position as a supplier and service provider of wiring systems for passenger cars and commercial vehicles – for example in the growing business of alternative powertrains. Against this backdrop, Leoni already sold several non-automotive units in 2021.

The sale is a management buy-out supported by investors: Weinert Industries consists of Andreas Weinert, Thüringer Industriebeteiligungs and Mittelständische Beteiligungsgesellschaft Thüringen. Andreas Weinert founded part of the now sold units himself in 2001 and currently serves as director technology management of the Leoni fiber optics business unit. He will head the company, which will operate under the name Weinert Group, with around 300 employees at six locations in Germany and one in the US.

www.leoni.com

Source: Leoni

Leoni Fiber Optics GmbH in Sonneberg

Acrotec Group unveils new headquarters

After 15 years in development, the new HQ was opened in Develier, establishing Acrotec's local roots in the Jura and its desire of federating companies to benefit its customers in the company's three main industrial sectors.

Founded in 2006 in Develier by François Billig, when Vardeco and KIF Parechoc were brought together under the same corporate entity, the Acrotec Group has continued to develop through acquisitions and organic growth.

"What a journey we have been on in the last fifteen years," says François Billig, CEO of the Acrotec Group. "When I set up Vardeco in Develier in 2001, the precursor of the foundation of Acrotec in 2006, I had no idea that this entrepreneurial adventure would take on such a human, economic, and industrial dimension."

Today, the Acrotec Group consists of twenty-four companies, located mainly in Switzerland but also in France and the United States, with an annual turnover of more than 300 million swiss francs. These companies employ more than 1,300 people skilled in high-precision micromechanics. They are based on some twenty sites and operate a total inventory of 1,400 machines.

https://acrotec.ch

Acrotec group's headquarters in Develier, Jura, Switzerland (Source: Acrotec)

Datalogic merges sensor division with acquired MD Micro Detectors

Datalogic is combining the Sensor & Safety and Machine Vision business unit and the sensor manufacturer M.D. Micro Detectors, which was acquired in March 2021, into a separate brand: Datasensing. As of January 1, 2022, sensors of various technologies, optoelectronic solutions for machine and plant safety, automated vehicle guidance, and machine vision will then be bundled.

Cosimo Capuzello, chief executive officer of Datasensing, explains, "Thanks to the merger with Datalogic, we are creating an industrial player with a total of one hundred years of experience." He anticipates sales of 76 million euros in 2021.

In March 2021, Datalogic bought Italian sensor manufacturer Micro Detectors for 37 million euros. It became part of the subsidiary Datalogic S.r.l. with its 200 employees. The previous owner was the industrial holding Finmasi Group.

www.datalogic.com

Laser Components stronger than ever after 40 years

After four decades in business, Laser Components is still well positioned for the future. Since 1982, entrepreneurial foresight and organic growth have created an internationally active group of companies, which at the same time has always remained true to the basic idea of an owner-managed family business.

The production facilities on both sides of the Atlantic have specialized in the manufacture of customized optical and optoelectronic components, which are developed in close cooperation with customers. This portfolio is supplemented by products from premium suppliers with whom the company has often been working for decades. This results in a broad range of products for an equally diverse customer base. This allows Laser Components to maintain its growth course even during short-term fluctuations in individual markets.

www.lasercomponents.com

MVTec celebrates 25th anniversary

The specialist for industrial machine vision software MVTec is 25 years old. The Munich-based company plans to celebrate this anniversary throughout 2022. It was founded in 1996 as a spin-off of the Technical University of Munich and the Bavarian Research Center for Knowledge-based Systems 'Forwiss'.

"Over the past 25 years, we have managed to grow faster than the market. This has allowed us to maintain our independence, while ensuring that we can continue to conduct intensive research into new technologies for our customers," comments Dr Olaf Munkelt, CEO and one of the three founders of MVTec Software.

The general economic conditions for MVTec's anniversary year are basically positive. "We do see certain obstacles to growth with the still strained supply chains and high energy prices, but we nevertheless expect further growth in the machine vision industry overall," explains Munkelt.

www.mvtec.com

Scottish laser center receives five-year funding boost

The Strathclyde-based Fraunhofer Centre for Applied Photonics (CAP) is to receive £6.5m over the next five years from the Scottish Government. Recognized as a world-class center of excellence, the CAP develops light-driven technologies for industry across a wide range of sectors: quantum tech, healthcare, life science, renewable energy, navigation, communication and space are just some of the fields in which Fraunhofer's world-leading scientists have been helping companies in Scotland, and beyond, to develop and bring products to market over the last nine years.

Such is the technological and economic contribution the center is making, not only to Scotland, but globally, that the Scottish Government and Scottish Enterprise, which is Scotland's national economic development agency, have committed to continuing to fund Fraunhofer's activities.

This core funding, announced in December 2021 by Ivan McKee MSP, Minister for Business, Trade, Tourism and Enterprise, will enable the purchase of cutting-edge equipment and doctorate level student training. The latter is a crucial part of the Fraunhofer model and both are essential components in delivering next generation products and processes.

Housed in Strathclyde's Technology and Innovation Centre, Fraunhofer's CAP is the first of its kind in the UK and has a close relationship with the University.

www.strath.ac.uk

New funding for TU/e spinoff MicroAlign

The Eindhoven-based start-up will use a new investment by PhotonDelta and the Smart Industries TTT Fund to optimize the quality of optical fiber-to-chip connections at packaging and start exploring the market opportunities.

The funding is indicative of the successful valorization strategy at the Eindhoven University of Technology. In a growing number of cases, scientific research results in new start-ups. This is especially the case around integrated photonics, as famous scale-ups like Smart Photonics and Effect Photonics have already shown.

With its solutions around packaging and assembly, MicroAlign fills another important part of the ecosystem, making it more robust and cost-effective for producers as well as customers. The company is developing a technology capable of manipulating multiple optical fibers individually, by means of a novel micro-electromechanical system, aiming to improve the quality of each optical fiber-to-chip connection, for tens of optical fibers and with submicron accuracy.

Source: PhotonDelta

Pieter Klinkert (PhotonDelta), Pleuni Hooijman (Innovation Industries), Simone Cardarelli (MicroAlign, clockwise from left)

https://microalign.nl
www.photondelta.com

Fraunhofer Center for Sensor Intelligence (ZSI) planned

A new Fraunhofer Center is to be established at Saarland University in Saarbrücken. Saarland's departing Minister President Tobias Hans and the president of the Fraunhofer-Gesellschaft Prof. Reimund Neugebauer signed an agreement to this effect. A new building is planned, which will cost 35 million euros and, after a five-year construction period, will be operated as a cooperative project between the Fraunhofer Institute for Biomedical Engineering IBMT and the Fraunhofer Institute for Nondestructive Testing IZFP.

It is planned to locate the Fraunhofer ZSI on the campus of Saarland University. The new building and its equipment, with a volume of around 35 million euros, is to be funded from federal, state and EU resources for structural fund support (EFRE). In addition, a personnel and project budget of around 29 million euros is expected for the five-year start-up phase of the ZSI, which is to be borne by the Fraunhofer-Gesellschaft, the state and other third-party donors.

After the five-year start-up phase, up to eighty jobs are to be created and the Fraunhofer ZSI is to operate sustainably in the proven Fraunhofer financing model of the federal and state governments in a 90:10 ratio.

The new center establishes an innovative research field, building on the core competencies of the two Fraunhofer institutes located in Saarland, the IZFP and the IBMT.

The application-oriented research of the center serves to demonstrate the potential of such sensor systems in the material, production and health sectors.

www.fraunhofer.de

14th annual Prism Awards celebrate innovative photonics technologies

This years' ceremony again showcased a dynamic range of companies – from Luxexcel, PlenOptika, and Lumotive, to SWIR, LightPath Technologies, and ColdQuanta – applying innovative and creative solutions to critical problems in areas such as augmented and virtual reality, biomedical devices, autonomous vehicles, quantum, and industrial lasers.

Source: SPIE

Each year, the Prism Awards reflect the latest exciting developments, exponential growth, and rich technical innovations across photonics and photonics-enabled industries. SPIE received 120 applications from eighteen countries for consideration in this year's awards.

Finalists and winners were selected by a panel of international judges who leveraged the knowledge and acumen of leaders from across the technology commercialization and funding sectors. The award categories and the winners in 2022 are: Augmented & Virtual Reality: Luxexcel, Autonomous Vehicles: Lumotive, Better Sensing: SWIR Vision Systems, Biomedical Devices: PlenOptika, Displays: Brelyon, Industrial Lasers: Civan Lasers, Manufacturing & Test: LightPath Technologies, Quantum: ColdQuanta, Scientific Lasers: Stuttgart Instruments, and Software: Zemax.

The distinguished judges' roster included MKS Instruments' Marc Himel, the FDA's Zane Arp, Femto Blanc's Uri Abrams, iFocus' Adi Diner, Berkeley Catalyst Fund's Laura Smoliar, Engender Technologies' Cather Simpson, Luminate Accelerator's Sujatha Ramanujan, Notal Vision's Nishant Mohan, Teledyne Princeton Instruments' Jason McClure, and Chromacity's Shahida Imani.

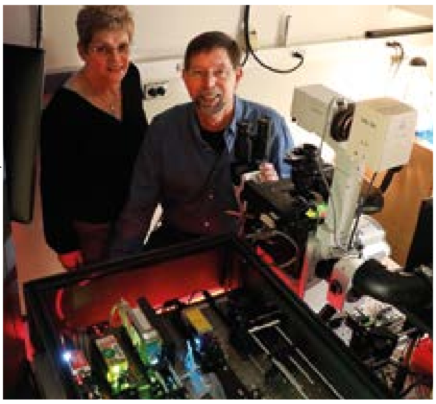
"We are particularly delighted to be celebrating our Prism Award winners in person this year," said SPIE CEO Kent Rochford. "These companies with their scientists and engineers – and I am including the award finalists as well – are ensuring that key technologies and products are reaching, energizing, and continually growing the photonics market. Their critical, innovative work is impacting lives across the globe."

"Each year, the Prism Awards singles out the very brightest innovations in a highly innovative industry and, despite a global pandemic, supply chain issues, and other challenges over the past year, the 2022 winners still found a way to advance the field of photonics in important and remarkable ways," said president and CEO of Photonics Media Tom Laurin.

https://spie.org

A microscope to explore how molecules make cells work

Oregon Health & Science University researchers are developing an entirely new approach to scientific imaging to learn how the seemingly random movements of molecules are actually a well-orchestrated operation. The W M Keck Foundation has awarded research duo Catherine Galbraith, PhD, and James Galbraith, PhD, one million dollars over three years to develop a one-of-a-kind imaging and computational system. Their system will seek to decode molecular aggregates – collections of proteins or ribonucleic acid that frequently rearrange inside cells and are involved in cellular information processing.



Source: OHSU, Christine Torres Hicks

Drs Catherine and Jim Galbraith with one of their microscopes

Many researchers are convinced that phase separations are part of a more general class of molecular aggregates that are key to cellular processes, such as reading DNA and making proteins, as well as immune responses and even the reproduction of SARS-CoV-2 virus. Improperly functioning phase separations may lead to protein accumulations that underlie diseases such as Lou Gehrig's, Alzheimer's, Parkinson's and some cancers.

Conventional imaging technologies cannot zoom in close enough to decipher individual molecules within aggregates, let alone track their rapid movements within cells.

ohsu.edu/knight-cancer-institute

Martin Dawson receives award for micro-LED research

The director of research at Strathclyde's Institute of Photonics and also head of the Strathclyde-hosted Fraunhofer Centre for Applied Photonics (cf. p. 7), Prof Martin Dawson, has been named as the 2021 winner of the Global SSL Award of Outstanding Achievement by the International SSL Alliance (ISA).

The award was announced at ISA's General Assembly and is the second international award Prof Dawson has received in 2021. Earlier that year, he was named as the recipient of Optica's (OSA) Nick Holonyak Jr Award.

He has won the ISA award jointly with Prof Hongxing Jiang of Texas Tech University. The award is presented to individuals or organisations "who stay at the forefront of solid -state lighting (SSL) development, whose outstanding contributions have changed our lives, and who lead the field with innovative applications impacting human society."

Source: U Strathclyde

Prof Martin Dawson

Dawson said: "I am particularly pleased that my co-honoree is Prof Hongxing Jiang, a close colleague for the past twenty years in the establishment and development of the micro-LED field."

Prof Dawson's career has focused on applied research in academia and industry in the UK and USA and he has been involved in the formation and technical development of a number of spinout businesses.

www.strath.ac.uk

Nuburu secures fresh funding, appoints CFO, COO, VP global sales, executive chairman

l.t.r.: Brian Knaley, Andrew Dodd, Brian Faircloth, Ron Nicol (Source: Nuburu)

The provider of high power and high brightness industrial blue lasers has raised additional growth capital at a valuation of approximately 350 million dollars. The company has also brought on experienced technology executive, Brian Faircloth, as chief operating officer, and promoted Andrew Dodd, a thirty-year veteran of laser development and material processing, to vice president of global sales to boost commercialization efforts for its revolutionary industrial blue laser technology. Nuburu already appointed Ron Nicol as executive chairman in December 2021. Coming from Boston Consulting Group, the graduate of the US Naval Academy with a degree in physics also sits on the Nuburu board of directors and brings over forty years of management experience to the company.

In March, Nuburu named Brian Knaley as CFO. The three-time public company CFO joins the company with deep experience in leading business transformation and optimization of financial processes on a global scale.

https://nuburu.net

Femtoprint is going 'Photonics'

Source: Femtoprint

Dr Rolando Ferrini

As of February 1st, 2022, under the management of Dr Rolando Ferrini, a new business unit will pursue the company's growth in photonics and specifically micro-optics.

Founded in 2013 in Ticino, Switzerland, and employing thirty highly skilled professionals, Femtoprint is a high-tech contract manufacturing and development organization specialized in high-precision 3D printing for glass microdevices. With the new BU in Neuchâtel, the company can offer cutting edge high-precision micromachining in glass for photonics and micro-optics applications.

Dr Rolando Ferrini joined CSEM in 2011 where he is group leader micronano optics and head of the focus area photonics. He has coordinated the H2020 Phabulous project since 2020 and is managing director of the corresponding pilot line for the manufacturing of freeform micro-optical components.

www.femtoprint.ch

3D-Micromac with two changes in the management board

Sources: 3D-Micromac

Marko Gerlach, Hartmut Schubert

Marko Gerlach was appointed by the management board of the Chemnitz, Germany, company for laser micromachining and roll-to-roll laser systems for the semiconductor, photovoltaic, medical device and electronics markets, to the role of CFO effective December 1, 2021. The previous interim CFO, Frank Jäger, will remain for a transition period before leaving the company.

Hartmut Schubert was appointed to the position of CTO effective January 2022. After successfully completing his studies in control engineering in Darmstadt, Germany, Schubert worked for Vitronic Dr.-Ing. Stein Bildverarbeitungssysteme GmbH for many years. During this time, he also completed his MBA studies in Mannheim, Germany, and Paris, France. Since 2012, Schubert has held various technical and managerial positions at Dr. Heinrich Schneider Messtechnik GmbH.

https://3d-micromac.de

Atik Cameras introduces new managers

The scientific and industrial imaging company is preparing for growth in the UK and Portugal and has promoted Dr Panos Kapetanopoulos and Pedro Matos as director of Atik Cameras Norwich, and general manager of the production facilities in Lisbon, respectively.

Source: Atik Cameras

Panos Kapetanopoulos, PhD (l.), Pedro Matos

Panos brings over 15 years of research and development experience with a proven track record in imaging and engineering, having spent the first few years of his career as an R&D Engineer, before becoming an engineering manager in production and development at Photek Ltd. Since then, Panos moved into a commercial role with focus on growth, distribution management and exportation, dealing with space science, life science, high energy physics, defense, academic research and OEM applications in domestic, European, US and Asian markets.

The appointment of Pedro Matos was also made due to the considerable growth the company has seen in the last two years and the subsequent scaling up of production volume to meet the needs of the expanding customer base, particularly into the scientific and OEM markets. He will oversee production and logistics operations at the Portuguese production facility. Pedro spent twenty years serving the automotive industry as a purchasing manager.

www.atik-cameras.com

Trioptics changes its management board

After 30 years, Eugen Dumitrescu has left the management of the Wedel-based company and handed over to a new, extended management team.

Source: Trioptics

(l.t.r.) Kristin Holzhey, Simon Zilian, Dr Stefan Krey, Jörn Lüthje, Eugen Dumitrescu

As of January 1st, 2022, Kristin Holzhey (CEO) and Simon Zilian (CSO) complete the board in addition to the earlier-appointed managing directors Dr Stefan Krey (CTO) and Jörn Lüthje (CFO). Dumitrescu, who founded the company in 1991, remained with the company as an active managing director until March 31st and now continues as an advisory board member.

Trioptics has been part of the Jenoptik Group since September 2019. Kristin Holzhey held various positions there, including as an advisor to the CEO, and was managing director of Otto Vision Technology, and in charge of the integration of Trioptics into the Jenoptik Group.

The physical engineer Simon Zilian has been with Trioptics since 2005 after gaining initial professional experience at Eurolaser, also in Northern Germany. He has been a member of the management board since 2019.

www.trioptics.com

Kiran Ramakrishnan new CEO at Z-Laser

Effective December 20th, 2021, the Freiburg native has assumed the position of CEO at Z-Laser, the German manufacturer of laser sources for innovative customer applications. Ramakrishnan, 50, takes over the position from Hans Ebinger, who successfully ran the company since 2018. Ramakrishnan has more than 25 years of experience in senior management positions with global players in the semiconductor industry. He joined Z-Laser in spring 2021 to elevate sales and marketing activities to an international level. This gave him the opportunity to learn the company's capabilities and earn the respect of the leadership team. When the position of CEO needed to be filled, Kiran was the candidate of choice for both the management team and the Exaktera Group, of which Z-Laser is a part.

Dr Hans Ebinger (l.), Kiran Ramakrishnan

Source: Z-Laser

www.z-laser.com

Scanlab expands management

At the beginning of 2022, laser scanner manufacturer Scanlab added two new members to its management team. In addition to long-time managing director Georg Hofner, the management board now includes Dirk Thomas and Christian Sonner.

The two new additions to the management team are to help develop and implement the company's digitization strategy. The previous managing director operations, Christian Huttenloher, has left the company.

Dirk Thomas, previously commercial director of Scanlab, has been part of the staff for over twenty years. As a new director, he will be responsible for administration, controlling and human resources, as well as IT.

In addition, Christian Sonner, former head of development, has been appointed a managing director. He has been with the company for nine years and, in his new role, will continue to drive forward the digitization of the product portfolio and the development of more highly integrated scanning systems.

Source: Scanlab

(from left): Dirk Thomas, Georg Hofner, and Christian Sonner

www.scanlab.de

Ametek subsidiary Spectro appoints new managing director

Spectro Analytical Instruments appointed Michael Privik as managing director with effect from January 1, 2022. He succeeds Dr Christoph Mätzig, who has taken over the management of the ultraprecision technologies division within the Ametek group.

Source: Spectro

Michael Privik

Privik has been a member of Spectro's management team since 2016 and moved to the top at the turn of the year. Born in Duisburg, he started working for the company back in 1991. After his beginnings in the customer center, he played a key role in setting up the x-ray fluorescence analysis (XRF) division and headed the applications laboratory there. He finally switched to sales, where he held various positions up to EMEA sales management. In 2016, Privik became managing director global sales and marketing.

"Over the course of my thirty years at Spectro, I have experienced all the ups and downs. Today, Spectro is in an excellent position – we have qualified employees, state-of-the-art technologies and market-leading products," Privik explained. "However," he added, "there are also challenges to overcome. In particular, rising inflation and the global shortage of materials." But he is sure that he will find the right answers.

www.spectro.com

Okke Ottenlinger to head Evosys China

Since 1 November, Okke Ottenlinger is the new managing director of the German laser systems producer's Chinese subsidiary Evosys Suzhou Laser System Co Ltd.

Ottenlinger has been working in mechanical and plant engineering for almost a decade and brings with him a high level of technological competence and internationality. As new managing director, he is to foster the further development of the Chinese subsidiary, which is currently responsible for sales and service in Asia but also runs a laser welding system which is available for sampling in an in-house technical center.

Source: Evosys

Okke Ottenlinger

Holger Aldebert, managing director of the parent company Evosys Laser GmbH: "We want our subsidiary to continue to be as successful as it has been in recent years. We see Mr Ottenlinger as an experienced specialist in the market and, thanks to his strong commitment, as an ideal manager."

Okke Ottenlinger succeeds Frank Sun, who had most recently managed and built up the subsidiary and is now moving to the joint venture partner as planned. In particular, Ottenlinger is to further expand the sales network in China and further increase the level of awareness of the Evosys group in Asia.

www.evosys-laser.com

Balanced photoreceivers up to 500 MHz

Manufacturer: FEMTO Messtechnik.
Product: Low-noise balanced photoreceivers of the “HBPR” series that enable the differential measurement of optical signals with wavelengths from 320 nm to 1700 nm and bandwidths up to 500 MHz. The optical inputs are optionally free space or fiber-coupled to ensure maximum compatibility with common optical accessories. These photoreceivers are ideally suited for highly sensitive and precise acquisition of laser pulses, even with high repetition rates and rapidly changing signal shapes, e.g. as required in quantum state tomography.
Features: The photoreceivers use two photodiodes selected in pairs, which are connected in anti-parallel, and a subsequent low-noise transimpedance amplifier to detect the differential signal. The series is characterized by a very low input noise (NEP) down to 3.7 pW/√Hz and a high common mode rejection (CMRR) of up to 55 dB. Various models with Si or InGaAs photodiodes and bandwidths from 100 MHz to 500 MHz are available. The output coupling is switchable (AC/DC), the gain can be set in two stages and the bandwidth can be limited to 20 MHz. Two monitor outputs with 10 MHz bandwidth enable fast, separate acquisition of the individual input signals.

Applications: Optical spectroscopy, coherent heterodyne detection, homodyne detection of optical quantum states, optical coherence tomography (OCT), differential optical front end for oscilloscopes, spectrum analyzers, A/D converters and lock-in amplifiers.

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Detectors for pulsed light sources and lasers

Manufacturer: Gigahertz-Optik.
Product: Measurement solutions to perform complete temporal and radiometric characterizations (peak power, pulse shape, pulse width) of pulsed light sources and lasers as VCSELs, with pulse width down to the nanosecond range and varying pulse peak powers and pulse shapes.
Features: The temporal resolution extends down to the nanosecond range (up to 0.1 GHz) and typical measurement wavelengths are 532 nm, 905 nm, 940 nm, 1064 nm and 1550 nm. For such a setup, the manufacturer has introduced the so-called 'two diode technology' for different kinds of integrating sphere detectors (sphere diameter and measurement port). These can be combined with well-established optometers. The product portfolio also covers detectors, e.g. for cw laser measurements with a measurement range from nanowatts (nW) to kilowatts, covering the wavelength range from 200 nm to 1800 nm.
All detectors are calibrated according to ISO 17025 in the company’s own accredited calibration laboratory with the highest reliability, precision and traceability to NMIs.

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LASER World of PHOTONICS,
Hall A6, Booth 500

Autocollimator for intricate measurements in optical metrology

Manufacturer: Duma Optronics.
Product: “Total Station” Autocollimator for intricate industrial measurements, including optics, lasers, alignment, as well as projecting virtual objects over a wide range of distances.
Features: The new autocollimator is designed as a multitool device to work in multiple applications. It is suited for use, for example, as a system for AR/VR, cameras for autonomous driving, or projection screens. An upgraded device based on already mature technology for testing and adjusting fully integrated systems including mechanics, optics, and lasers as well as interalignment and testing of lasers, optics, mechanics and electronic sensors. Angular accurate optical measurements come with a resolution of 0.01 arcsec or better, implementing fusion of several wavelengths including NIR into one system. The device allows the measurement of remote mechanical dimensions, centering and alignment of measurements of multilaser arrays such as VCSEL with respect to other optical sensors. The autocollimator is easily interfaced with existing factory software standards, allowing the system to follow external inputs and to meet manufacturing assembly line requirements.

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LASER World of PHOTONICS,
Hall A6, Booth 420

Large aperture and high resolution beam profiler

Manufacturer: Duma Optronics.
Product: New beam profiling sensor "BeamOn HR 1". This revolutionary beam profiling camera features a 1" detector with 20 MP resolution for better serving the Photonics industry with some automatic testing of VCSELs and multiple beams analysis capability. It was recently introduced to support new lasers and VCSEL chip components.

Features: This classical camera look-alike beam profiler is a GT interface camera with a large spectral response from deep UV to 1350 nm and beyond. Due to its relatively small pixel size of 2.4 × 2.4 μm, it offers large beam size measurement over a wide spectral range from ø 30 μm to ø 8 mm, with 16 bit digital depth and independent gain and shutter control. This feature allows intricate measurements by combining the functionality of different currently available beam profilers into one system.
Applications: The new device is designed for use in the photonics and laser industry.

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LASER World of PHOTONICS,
Hall A6, Booth 420

High-precision laser-based microassembly and fine cutting systems

Manufacturer: nanosystec.
Product: High-precision laser-based production stations for microassembly and fine cutting with laser energy. The production systems work as a single station or can be integrated into production lines. They will be presented at the LASER 2022 show in Munich.

Features: With up to six degrees of freedom and long-travel linear motor axes with encoders for position readout in the submicron range, the precision laser stations cope easily with complex geometries. As an additional option, an XY scanner deviates the laser beam to any position in a field of 100 × 100 mm within milliseconds.

Modern fiber laser sources offer up to 500 W cw power and create weld seams down to 20 μm width. In pulsed mode, such lasers provide high peak powers that enable fine cutting. Diode laser modules provide the required power for selective laser soldering while lamp-pumped Nd:YAG lasers with multiple outputs serve for low shift spot and seam welding.
Automated machine vision utilizes the images from the process optics and external cameras for motion control purposes, such as seam tracking and the recognition of difficult shapes, e. g. rotor blades. Device-specific machine vision algorithms reduce the processing time to a minimum.

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LASER World of PHOTONICS,
Hall B5, Booth 428

New laser cutting optics

Manufacturer: Scansonic.
Product: High-power laser cutting optics in the "SCut" series. In addition to the "SCut 360" for lasers with a large divergence angle and the "SCut Pro" for laser power up to 12 kW, the new "SCut MAX" provides a version for higher laser power of up to 30 kW. It will be presented for the first time at the Laser World of Photonics trade fair in Munich.
Features: Higher laser power allows laser cutting of sheet metal at higher speeds and processing of thicker materials. Low-drift distance control and an autofocus function ensure high cutting quality. The unit is easy to set up, with horizontal adjustment between laser beam and nozzle regulated by two front-mounted rotary controls. The cutting gas flow was adjusted to the laser power levels and now permits a significantly higher volume flow. The cooling design for the cutting optics was also refined to accommodate the greater heat generation. Larger cooling water conduits and additional cooling elements prevent excessive temperatures from causing damage to the cutting optics. The optics' autofocus range was also adapted to allow cutting of significantly thicker material. The optics uses an FCH-16 fiber connector for coupling. This connector is suitable for commercially available fiber and disc lasers, and can easily transmit power levels up to 30 kW. The manufacturer has also further enhanced the design of the monitoring sensors for the laser cutting optics. Malfunctions are reported immediately to ensure greater overall process safety. All these measures produce extremely high-quality cutting results. In future, all laser cutting optics will be equipped with a fast fieldbus connection, which will simplify integration into the controller technology used for laser cutting systems.

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Hall A5, Booth 311

Review of Photonics West

At this year's Photonic West fair in San Francisco in January, Toptica Eagleyard presented, amongst others, a tapered amplifier in a standard butterfly package, and the "µMOPA", a DBR laser and tapered amplifier monolithically integrated on a chip.

Based on the already proven tapered amplifier product portfolio, two new variants were introduced with a new package solution that brings multiple advantages. They offer 2 W @ 852 nm or 3 W @ 780 nm with very good SMSR (typ. >50 dB). This simple pluggable solution is easily usable for industry purposes as the tapered amplifier is integrated into a hermetically sealed butterfly package and is therefore very robust. It is very easy to use as no further adjustment is needed. Moreover, the circular beam profile is beneficial for fiber coupling and focusing. These new variants of the tapered amplifier will mainly be used in spectroscopy and atomic clocks and will also be relevant in quantum technology.
The "µMOPA" was designed to bridge the gap between science and industry: for the first time, a DBR laser and tapered amplifier are monolithically integrated on a chip with a standard 14 pin butterfly package, including integrated thermal management by thermoelectric cooler and thermistor. The complexity for usage is reduced significantly. In addition, the product is easily mountable due to the use of standard sockets while the circular beam profile is especially beneficial for fiber coupling and focusing. The device delivers 2 W @ 1064 nm with a typical spectral width of 3 pm. The "µMOPA" will mainly be used in Raman spectroscopy and interferometry.

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Hall B5, Booth 331

Primary mirror segment of the James Webb Space Telescope at LASER Show 2022

The James Webb Space Telescope which was parked in January on its position in Lagrange point L2 is the largest optical instrument ever launched into space. Its powerful optics promise to reveal the earliest galaxies to form in the universe. At the heart of the telescope is a 6.5 m diameter primary mirror, which is actually composed of 18 hexagonal segments, each of which is 1.32 meters in diameter. Each of these segments is an aspheric 'freeform', meaning that it is not rotationally symmetric. This primary mirror folds up small enough to fit into a launch vehicle, and then deploys to full size once in space. Once completely opened, the positioning and surface shape of the mirror

segments is accurate enough – to within tens of nanometers – to enable the assembly to deliver the optical performance of a single 6.5 meter mirror.
The primary mirror segments themselves are the result of contributions from several different organizations. Surface shaping and polishing of the beryllium mirror blanks was performed by Coherent Tinsley, one of just a few organizations in the world with this expertise and equipment. Now the company will perform polishing and hexing of 231 of the 492 freeform, aspheric, 1.52 meter diameter mirror segments for the ground-based Thirty Meter Telescope.

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Hall A5, Booth 321

Eight partners from research and industry start the BMBF project FluoResYst

Rapid detection system for multidrug resistance in tuberculosis infections

Ending the tuberculosis epidemic by 2030 is one of the goals of the United Nations. In 2020, around ten million cases were registered worldwide, around 1.5 million people died as a result of the disease. This makes tuberculosis the second deadliest infectious disease worldwide after Covid-19. Multiresistant variants of the bacterium Mycobacterium tuberculosis are an increasing problem in diagnosis and thus in successful treatment, mainly due to a lack of laboratory infrastructure in developing countries. A national network of eight companies and non-university research institutions wants to counter this with the help of photonics and had its solution approaches presented at the kick-off meeting of the three-year project. The aim is to develop a compact detection system for multiresistance in tuberculosis infections for rapid diagnosis and efficient treatment of those affected.

Source: IC-Haus

Photonic point-of-care detection system

In order to counter multiresistance from tuberculosis bacteria, suspected cases must be tested daily and, if the laboratory results are positive, treated and isolated quickly. As a rule, however, there is a lack of the necessary laboratory infrastructure and logistics, because 95 percent of tuberculosis diseases occur in developing and emerging countries. In the "Time-resolved fluorescence detection for the integrated multiparameter analysis of multiresistances, for example in tuberculosis" project, FluoResYst for short, the partners will develop an innovative method for accelerated diagnosis of multiresistances of bacterial pathogens using the example of tuberculosis. The goal is a compact and cost-effective photonic point-of-care detection system.

Combination of fast fluorescence effects with fast detectors

The detection is based on a fluorescence quenching effect. The glow of a fluorescent dye that is coupled to a DNA fragment is suppressed by the binding of an antibody. If a sample with the gene segment you are looking for is added, this bond is broken and the DNA lights up.

In order to be able to detect fluorescence, the corresponding fluorescent dyes are excited with a specific picosecond laser and then emit light of a different wavelength, which is measured.The image sensor is realized with new single photon avalanche diodes (SPAD).

Network partners are Lionex (network coordinator), IMMS Institute for Microelectronic and Mechatronic Systems, iC-Haus, X-Fab, Ditabis Digital Biomedical Imaging Systems, Fraunhofer Institute for Cell Therapy and Immunology, Department of Bioanalytics & Bioprocesses IZI-BB, Microfluidic ChipShop and the Institute for Molecular Diagnostics and Bioanalysis (IMDB).

www.ichaus.de

World's smallest projection display

Trixel 3 – powered by Infineon's 2D MEMS mirror

Trilite has presented Trixel 3, the world's smallest laser beam scanner at the SPIE Photonics West exhibition in San Francisco, California.

Trixel 3 is Trilite's first laser beam scanner light engine based on Infineon's 2D MEMS mirror, and is targeting augmented reality (AR) glasses. Together the two companies created the smallest projector system so far. The tiny module is the key component for AR smart glasses that offers comfortable all-day wear. With no relay optics required, the overall module size is shrunk to a volume of less than a cubic centimeter with an ultralight weight of 1.5 gram.

Peter Weigand, CEO at Trilite, said: "We're proud to present the first laser beam scanner demonstrator powered by Infineon's unique 2D MEMS mirror. This is the first step in the collaboration between our companies focusing on a light engine with the very smallest form factor. We are very proud where we stand today and very excited about where our technology roadmaps are going to bring us soon."

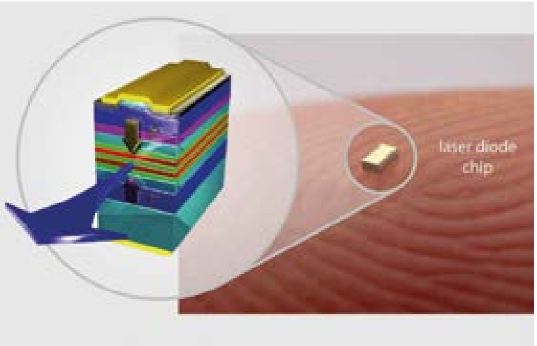
Source: Trilite

Infineon brings decades of experience in MEMS devices design and manufacturing into the augmented reality market with its 2D MEMS mirror. The powerful Trilite Calibration Module (TCM) software simplifies system integration by providing real-time correction of lens errors, distortions, and color shifts (true tone).

www.trilite-tech.com
www.infineon.com

Mathematics meets semiconductor technology

Development of new and compact UVC lasers for medicine and biotechnology



Structure of an edge-emitting UVC laser diode (Source: TU Berlin, Kremzow / FBH, schurian.com)

The Leibniz Association will fund the joint project UV Lasers – From Modeling and Simulation to Technology (UVSimTech) for three years with nearly 1 million euros within the Leibniz Competition. It is coordinated by the Weierstrass Institute for Applied Analysis and Stochastics, Berlin.

Lasers in the high-frequency UVC ultraviolet range have broad application potential, for example in medical diagnostics or cancer research. However, current UVC laser systems are very bulky, short-lived and require high maintenance. A novel concept for the development of robust UVC laser diodes in a compact design is now expected to bring about a paradigm shift. This will be beneficial to important areas of life sciences and medicine such as high-resolution microscopy or fast optical analysis.

Through a combination of mathematical modeling, simulation and experiments, problems of such UVC laser diodes will be identified and their technological maturity advanced. The goal is to develop an electrically pumped semiconductor laser diode based on aluminum gallium nitride (AlGaN) for coherent emission in the UVC spectral region.

The UVSimTech consortium combines the multidisciplinary expertise of the Berlin Weierstrass Institute (WIAS) in mathematical modeling and simulation of complex semiconductor lasers and of the Institute of Electromagnetic Fields of the Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU) with materials science know-how coming from the Berlin Leibniz-Institut für Kristallzüchtung (IKZ) and the Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik (FBH, also in Berlin), as well as from the experts in UV photonics at the TU Berlin.

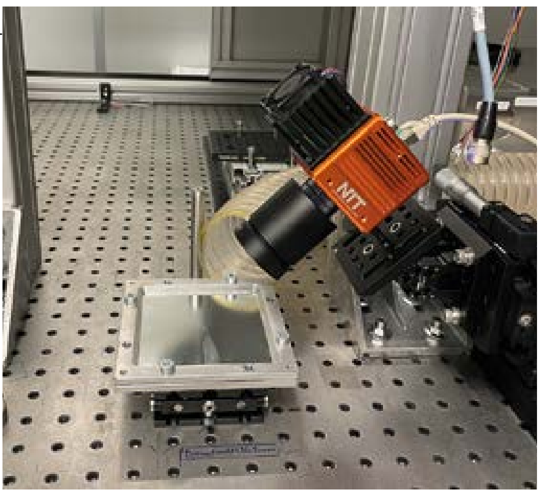
In addition to the importance of the project goals, the reviewers particularly recognized the outstanding composition of the consortium as well as the scientific strength of the participating partners in their respective fields. Project coordinator Dr Thomas Koprucki (WIAS) emphasizes: "With UVSimTec we want to create a collaborative interdisciplinary network to master the challenges of UVC laser diodes by pooling complementary expertise."

www.fv-berlin.de

A high-speed IR camera to monitor laser surface structuring

System combines infrared imaging and real-time fast Fourier transform

Within the framework of the EU-funded LAMpAS project, New Infrared Technologies (NIT) has developed an uncooled high-speed IR camera specifically adapted to the project's requirements. The camera is able to detect inline the heat accumulated during laser surface structuring processes. It will be one of the two sensors/techniques integrated in the LAMpAS inline monitoring system.



Source: LAMpAS

The high speed IR camera setup used for measuring the heat accumulated during a texturing test

The IR camera is an upgraded version of the NIT Tachyon 16K. The unique sensor technology of the company enables processing focal plane arrays with outstanding sensitivity in the MWIR spectral range (1 – 5 µm) to be operated without cooling. The upgraded version of the detector developed for LAMpAS enables the capture of more than four thousand images per second at full resolution (128 × 128) in snapshot configuration. New features such as flexible selection of ROIs (regions of interest), new AR coatings for optics and windows, and integrated NUC (non-uniformity correction) were implemented.

Laser structuring processes are extremely dynamic processes combining very high scan velocities and high-frequency ultrashort laser pulses. Inline measurement of the heat accumulated on the treated surface during texturing provides useful information about the process itself. Studies carried out in the LAMpAS project by researchers of the Technische Universität Dresden and NIT have demonstrated a strong correlation between the heat accumulated and the quality of the texture.

As part of the monitoring system, the high-speed IR camera will supply real-time information about the laser structuring process stability and the quality of a new range of functionalized surfaces such as easy-to-clean finishes for ovens, fridges, and other home appliances.

It is remarkable that this monitoring system will combine two independent techniques, high-speed IR imaging, and real-time FFT (fast Fourier transform), for inline monitoring of laser structuring processes. This innovative strategy aims to to provide early detection of instabilities and malfunction during microstructure processes using the direct laser interference patterning method.

www.lampas.eu

Scanning and 3D-printing NASA rocket engines

Hexagon's manufacturing intelligence division collaborates with printer manufacturers Pro-beam, Sciaky, DM3D, Gefertec and Meltio

Applicable to a broad range of part sizes, directed energy deposition is attractive for the cost-effective production of large parts – from one to six or more meters – that may be impossible to manufacture using powder bed fusion (PBF) technology. SmarTech Analysis estimates revenues from large-format metal additive technologies and related areas will reach 739 million US dollars in 2026.

Sharing core technologies with mature coating and welding processes, DED is rapidly gaining traction for military and aerospace maintenance, repair and operations (MRO) because it can repair or rebuild high-end equipment, such as turbine blades. It also offers innovation potential within hybrid manufacturing processes where it can add material and features to workpieces finished with wire EDM or milling processes.

Driven by interest from the aerospace and defence industries, parts are often made from high-performance metal alloys such as titanium and high-temperature and stainless steels. Hexagon is working with printer OEMs, customers and service providers to help predict how these materials behave when subjected to the thermal-mechanical stresses of DED processes, which are compounded in large structures.

"We see significant demand for the use of our technologies in tandem to creating customized, cost-effective solutions that meet the needs of specific additive manufacturing technologies in a variety of applications," said Hexagon's global business development director for AM, Mathieu Pérennou. "Optimizing deposition production processes may entail taking advantage of powerful simulation tools, state-of-the-art scanning technology, robust reverse-engineering and analysis software, or a combination of all of these to achieve the required quality and repeatability."

Hexagon's Simufact Welding was used to create a robust DED simulation model that accounts for vacuum conditions, clamping locations, and power adjustments to predict stresses, strains, and distortions while in the innovative vacuum chamber by Pro-beam. The new printer successfully produced the part from 35 layers of titanium wire. The printed part was scanned using Hexagon's state-of-the-art AS1 Absolute scanner and REcreate reverse engineering software, then compared to the final part geometry predicted by the simulation using geometry analysis software from Volume Graphics.

This part is scanned inside the DM3D printer using Hexagon's StereoScan Neo R16 structured light scanning technology. (Source: Hexagon)

DM3D, a DED service bureau and machine builder, used Hexagon measurement technology to prove that it could meet NASA's tolerance requirements in producing a full-scale Nasa RS-25 nozzle liner, 111 inches (app. 2.8 meters) in height and 96 inches (app. 2.4 meters) in diameter, as part of the agency's Rapid Analysis and Manufacturing Propulsion Technology (RAMPT) project.

Meltio, a laser metal deposition technology manufacturer, has added Hexagon's ESPRIT CAM computer-aided manufacturing software to its technology ecosystem, offering machine shops a single interface to prepare and program high-quality hybrid DED production and machining.

www.hexagonmi.com

Trumpf boosts 3D cutting speed

BrightLine Speed technology makes laser cutting even more efficient, up to 60 % faster

The German high-tech company has developed a new technology that increases the speed and efficiency of sheet-metal cutting. Known as BrightLine Speed, this innovative solution offers particularly striking benefits for the 3D cutting of hot-formed parts – for example, those used to produce B-pillars and door frames in auto manufacturing.

"It allows us to increase cutting speed by up to sixty percent for sheets up to four millimeters thick," says Trumpf product manager Ralf Kohllöffel. But that's not all: BrightLine Speed also consumes around fifty percent less cutting gas per part than conventional laser cutting. What's more, it makes the cutting process up to fifteen percent more productive with the same laser power, so each part requires correspondingly less energy to fabricate. "Our new cutting technology is faster and uses less gas – and that translates into tangible cost savings and a real boost in productivity for our customers," says Kohllöffel.


3D laser-cutting of hot-formed parts benefits, for example for B-pillars and door frames in auto manufacturing. (Source: Trumpf)

At the heart of BrightLine Speed is a new, Trumpf patented laser light cable (LLK), a special '2-in-1' innovation with an inner and an outer fiber core. A TruDisk disk laser couples the laser light into the LLK and distributes the laser power to the inner and outer cores using a device known as a wedge switch. This allows users to adapt the laser power and beam profile more precisely and flexibly to the thickness of the sheet currently being processed.

www.trumpf.com

Meet us at LASYS, Hall 4, Booth B32

A million times brighter than the sun

Application of a special white-light laser for semiconductor industry and microbiology

A new high-performance white-light laser is expected to speed up quality control in the semiconductor industry and provide closer monitoring of toxicity tests in microbiology. In one step, this laser enables the two-sided characterization of surfaces and can be integrated into production chains. The technology has been developed at the Fraunhofer Application Center for Optical Metrology and Surface Technologies (AZOM) and Westsächsische Hochschule Zwickau (WHZ) as part of a PhD thesis.

Source: Fh. IWS


The new white-light laser source enables scientist Tobias Baselt to detect cell changes in real time.

In his research, Dr Tobias Baselt focused on enhancing the optical performance of white-light lasers in metrology. The aim was to minimize costs, time and errors, for example in chip production or microbiology. To this end, the scientist investigated the application of white-light laser sources in two different measurement processes. The result was a new light source that is million times brighter than the sun and can be easily integrated into manufacturing processes without having to stop them or segregate samples.

Today, Baselt heads the Optical Fiber Technology group at Fraunhofer AZOM and is a research associate at the faculty of physical engineering at WHZ. "In my PhD thesis, I researched the application of specially-developed laser sources with white laser light, which are particularly high-performing compared to the current state-of-the art methods, and therefore very promising for microbiological and industrial measurement," he explains.

Particularly in high-cost manufacturing processes in the semiconductor industry such as chip production, significant potential savings could be achieved. Baselt demonstrated that the white-light laser process can perform quality control of semiconductor elements more quickly.

For example, the intensity of the light source can be used to characterize the surface profile, deeper structures and even the reverse side of microchips in a single process. Microbiology could also benefit from the new light source, for example in cell culture studies. The white light laser used in this process, also known as a supercontinuum source in technical jargon, is focused on the cell for a brief moment. The intensity of this light source permits the imaging of the smallest cell structures without destroying them.

Therefore cells can be monitored in real time, allowing early detection of cell changes as well as cell damage.

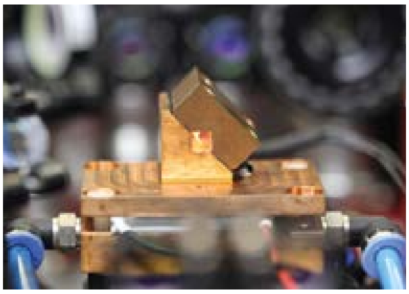
www.iws.fraunhofer.de

Meet us at LASYS, Hall 4, Booth C40

A femtosecond laser at 2 microns

LZH and partners develop innovative high-energy laser

Femtosecond lasers have gained enormous importance in industry and are used, for example, for glass cutting of cell phone displays. They are also used for the micromachining of metals or ceramics. Femtosecond lasers usually emit in the wavelength range around one micrometer. For many applications, however, lasers that emit wavelengths around two microns are optimal – for plastics and organic materials, for example, which absorb energy particularly well in this wavelength range.



Source: LZH

The scientists of the ultrafast photonics group of the LZH want to realize such an fs laser at two micrometers with more than 250 µJ pulse energy together with Neolase from Hannover and their Belgian partners Optec, Lasea and Multitel ASBL. The project partners will also develop a complete system for material processing. The high-energy laser systems could be used for applications such as the manufacture of miniaturized, biocompatible medical components such as low-cost stents or catheters.

The DISRUPT project – Development of ultrafast Infrared Sources for Realizing Unprecedented materials Processes at Two micrometers – deals with the development of ultrafast infrared sources to realize unprecedented material handling processes at 2 µm.

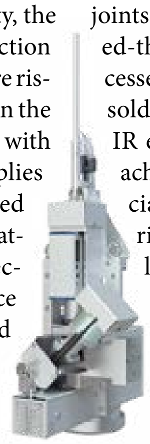
www.lzh.de

Meet LZH at LASYS, Hall 4, Booth A19

Eutect and Jenoptik cooperate in optimized laser soldering

Precise alignment of the laser avoids solder bridges

Due to increasing miniaturization and ever higher packaging density, the demands on the individual production steps in the electronics industry are rising. "We usually get the projects on the table that cannot be implemented with standard solutions. This also applies to cases where a laser is considered for melting the solder," explains Matthias Fehrenbach, managing director of Eutect. It makes no difference whether the solder wire is conveyed via a wire feeder or via the sustained ring soldering (SRS) process. The SRS module produces solder rings from common solder wires, which enable a new cycle time-optimized, highly accurate and economical assembly soldering process.



Using the newly developed SRS module, pre-assembled solder rings can be produced on the fly and placed on and around THT pins. The automatically reproducible solder rings can be positioned manually or automatically by means of special, highly dynamic pick-and-place handling on the solder joints to be processed or over the plated-through pins. These are then processed using laser, piston or induction soldering processes, as well as using IR emitters or hot air. "In order to achieve highly accurate results, especially when processing the solder ring with lasers, the vision-assisted laser tool JENvelt from Jenoptik is ideal," Fehrenbach continues.

"It is easy to integrate into machines and meets the requirements of current and future laser material processing," explains Steffen Reinl, key account manager at Jenoptik Optical Systems. System integrators benefit from the complete solution with a short set-up time and an intelligent software package. This software is the core of the system, which combines scanner and laser control as well as image recognition.

https://eutect.de ■ www.jenoptik.com

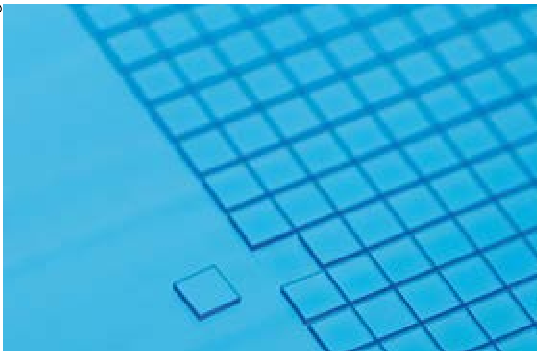
Meet Jenoptik at LASYS, Hall 4, Bth. A18

New technology for laser glass wafer dicing

Collaboration between Corning Laser Technologies and Dynatex enables opportunities

Corning has launched a dicing technology that will allow the company's laser technologies business to enter the semiconductor application space to further focus on microfabrication processes.

Source: Corning



Fully diced and separated glass panel on stretch tape

Corning Laser Technologies (CLT) advanced its patented nanoperforation process and paired it with a well-established breaking technology from Dynatex International, an industry leader in mechanical breaking of crystalline wafers, to create a new glass wafer dicing technology.

The new technology will allow customers to drive lower cost through significantly higher throughput as well as achieve lower, near-zero kerf loss and high edge strength through an inherently clean process that will eliminate subsequent cleaning steps.

Additionally, the glass wafer dicing technology for up to 300 mm diameter glass wafers achieves superior results on yield, enabling unprecedented die aspect ratios and a sidewall quality that meets the highest demands of the semiconductor industry. The innovation was developed for use in industries such as microfluidics and micro-optics. It can also be applied for meta-surfaces on glass and other glass wafer-based semiconductor applications, as well as dicing of other brittle and transparent materials.

"We are looking forward to leveraging our 20-plus years of experience in precision laser machining along with Dynatex's expertise in breaking tools and supporting equipment," said Michael Mueller, business director, Precision Glass Solutions and Corning Laser Technologies. "This novel wafer dicing method will help Corning continue to grow in the semiconductor industry and innovate to meet current and future demands."

With decreasing die sizes and increasing wafer diameters, material utilization becomes significantly more important for high-yield semiconductor applications. When comparing to a kerf-removing technology such as blade dicing (calculated with a kerf loss of 0.2 mm), CLT's new laser dicing method can increase utilization of a wafer with small dies of 5 × 5 mm by 8 % and even smaller dies of 2 × 2 mm by 17 %. Enabled by the near-zero kerf loss, a fully populated 300 mm diameter and 0.7 mm thick wafer can provide a wafer utilization of 96 % calculated with an edge exclusion of 5 mm.

Small dies on large glass wafers require a high-quality and high-speed dicing process. With the die size of 5 × 5 mm, a 300 mm wafer can be fully diced in less than ten minutes – significantly faster than classical blade dicing, which requires multiple hours to cut.

Additionally, when using Corning HPFS fused silica, results demonstrate the exceptional performance for chipping and edge quality. HPFS wafers allow for low chipping that is better than 50 µm with very precise edges and die corners.

www.corning.com

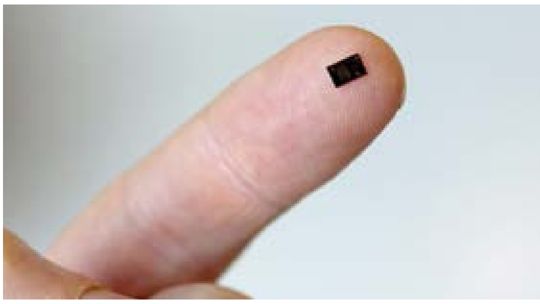
A laser light engine for augmented reality headsets

Novel wafer-level processes enable commercial production

At Photonics West, Lionix International presented an integrated RGB laser light engine for retinal projection augmented reality (AR) headsets. The millimeter-scale light engine excels not only in the brightness and quality of the images projected but also in terms of compactness.

The AR hardware market promises tens of billions of dollars of growth in the next few years. But issues with the integration of light sources threaten progress for headset developers. Currently, AR manufacturers looking for the brightest light sources are limited to bulky separate laser diodes. This makes for inelegant headsets and makes production scaling difficult. Lionix International have integrated the highest performing laser diodes on a chip to create a tiny RGB light source that can be scaled to very high production volumes.

Source: Lionix Int'l



Laser sources integrated on a small chip for AR headsets

With immense potential, the laser engine is a complete modular solution – it combines all the optical and electronic interfaces required for direct integration into a headset. "This is an amazing opportunity for a disruptive AR company to be the first to market with really slim and fashionable glasses and leading imaging quality," says Dr Douwe Geuzebroek, Lionix' vice president marketing and sales.

"Whilst we are ready to hit production right now and scale to the desired volumes, we also specialize in co-developing our solutions to meet our customers' needs. So we are a best-of-both-worlds combination of high standardization with the option to further customize the development for lead customers."

The new RGB light engine benefits from the company's twenty year track record in the design and assembly of photonic integrated circuit technology, especially for visible light. Equally important is Lionix's use of novel wafer-level processes that enable production at volumes required by commercial customers.

Douwe Geuzebroek, Ronald Dekker, Paul van Dijk: Photonics Packaging Made Visible – Scalable assembly and packaging of photonic integrated circuits for emerging applications, Optik Photonik **12**(5), December 2017; DOI: 10.1002/opph.201700033

www.lionix-international.com

Pushing the boundaries of AM

Beam forming greatly boosts quality of laser powder bed fusion

The pace of innovation in additive manufacturing is accelerating all the time. The use of cutting-edge laser technology has been part of this trend for years. As a trailblazer in manufacturing, the ring-mode laser has made a name for itself in all things welding. But even more is needed for the LBPF (laser powder bed fusion) process in 3D printing. In this arena, a new laser that can toggle flexibly between single mode and ring mode offers a range of beam qualities from narrow to wide. And it has recently been joined by a new fellow player in the field of laser material processing in additive manufacturing. The way these two lasers work together is so unique and so full of potential that the results are causing something of a sensation in AM.

Katrin Wudy, professor of laser-based additive manufacturing (LBAM) at the Technical University of Munich, is currently studying the unique combination of the AFX-1000 fiber laser from nLight and the AM Module Next Gen optical deflection unit from Raylase. Her research focuses on the influence of the beam profile on microstructure formation. "We cut apart the workpieces that this process produces, before examining the grain structure in the microsections under the microscope," says Wudy. "Due to the altered geometries of the melt tracks when using alternative beam profiles, temperature regulation is also changed. We're seeing different grain sizes and different grain textures in the initial microscopy findings. However, the grain size and texture are essential to the behaviour of the components – for example, their ultimate tensile strength or ultimate strain. "So if we can strategically control grain growth by selecting specific process parameters and beam profiles, the resulting component properties can be fine-tuned – for example, we can make particular parts of a component especially stiff or pliable without any additional post-processing. Properties can also be varied within a single component using sophisticated exposure strategies," explains Prof Wudy, emphasizing the huge benefits offered by laser beam forming based on a fiber laser and deflection unit.

"TUM, Optoprim – the German distributor of US laser manufacturer nLight – and Raylase have joined forces to overcome the critical process limitations of laser LPBF applications, such as a lack of homogeneity in the melt pool and reduced production speed," says Wolfgang Lehmann, product manager at Raylase. A range of defects can occur with conventional AM processes using a single mode laser, such as keyhole formation due to overheating, inadequate melt track depth, a powder denudation zone (powder-free zone) around the solidified melt power or balling in the melt pool. These problems are a thing of the past with the product combination comprising the programmable AFX-1000 fiber laser from nLight and the AM Module Next Gen deflection unit with zoom axis from Raylase.

It is important to note that the intensity distribution of the beam sources of the AFX 1000 that consist of a single-mode center beam and a ring beam can be switched instantaneously from a typical Gauss profile to six different ring-shaped profiles. The various powder outputs of the two overlying laser beams generate an extremely attractive, homogeneous energy input while avoiding spatter and heat cracks. This is crucial for 'hatching', i.e., the movement of the laser in a meander pattern based on the geometries to be exposed in additive manufacturing.

www.raylase.de

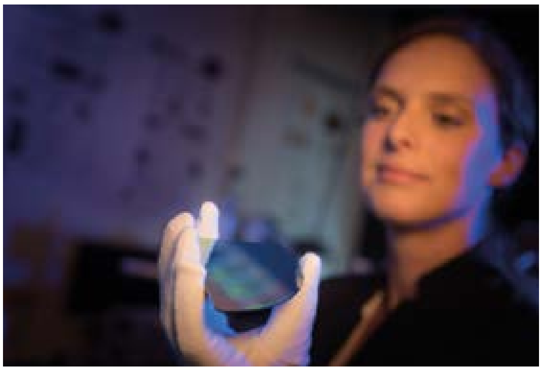
Source: Raylase

L. t. r.: Wolfgang Lehmann (Raylase), Christian Schröter (Optoprim), Philipp Schön, Marc Schinkel and Jan Bernd Habedank (Raylase), Katrin Wudy and Jonas Grünewald (TUM)

16 million euros for photonic quantum processors

Seven universities and research institutions as well as Vanguard Automation employ a measurement-based quantum computing approach in the BMBF project PhotonQ

Quantum computers will one day be able to solve problems at high speed that cannot be handled by classical computer cores. However, in order for these computers to become practical, they must process a significantly higher number of qubits and have lower error rates. A research project led by Prof Stefanie Barz from the University of Stuttgart is now developing a photonic quantum processor for this purpose, which allows the realization of quantum algorithms with only a few qubits and, in the future, should enable rapid scaling to qubit numbers that are relevant for practical applications.



Prof Stefanie Barz (Source: U Stuttgart, Uli Regenscheit)

There are many different approaches to researching new, scalable quantum processors: atom and ion traps, superconductors, semiconductors or entangled photons. In PhotonQ, funded by the Federal Ministry of Education and Research (BMBF) with 16 million euros, the universities of Stuttgart, Würzburg, Mainz and Ulm, the Technical University of Munich, the Institute for Microelectronics Stuttgart and Vanguard Automation will develop a photonic quantum processor. The heart of the quantum processor is an integrated photonic chip.

The starting point for a measurement-based quantum processor is a highly entangled quantum state. Entanglement means that a measurement on one particle can change the state of another particle regardless of distance. To perform universal quantum computations, (adaptive) measurements are made on a large entangled state adapted to the computational problem at hand. “The challenge here is to produce and process such a state in a photonic system with high efficiency and quality. The development of integrated optical components and circuits plays a central role here. Very importantly, optical losses in the system must be kept as low as possible. At the same time, there must be a high level of efficiency in the generation and detection of photons. This requires the development of new or significantly improved components in all subsystems,” explains project coordinator Stefanie Barz from the Institute for Functional Matter and Quantum Technologies (FMQ) at the University of Stuttgart. Accordingly, deterministic photon sources, scalable silicon photonic circuits, better interconnection technology and novel single photon detectors will be realized in the PhotonQ project.

The overall system of the quantum processor will be built at the University of Stuttgart to demonstrate quantum information processing with eight qubits and prove the fundamental suitability of the measurement-based principle for photonic quantum computing.

www.uni-stuttgart.de

United to champion quantum internet

Fraunhofer-Gesellschaft and research center QuTech signed a memorandum of understanding

QuTech – a collaboration of TU Delft and TNO – is joining forces with Fraunhofer Institute for Laser Technology ILT to cooperate on quantum communication and quantum information networks.

In a long-term, strategic partnership, the Fraunhofer-Gesellschaft and QuTech will work together structurally on the development and knowledge transfer of the quantum internet. The partners aim to initiate and promote a wider scientific collaboration, to roll out new prototypes and testbeds, and to make better joint use of know-how in application-oriented research and transfer to industry.

”To ensure reliable and secure communication and to strengthen European sovereignty in the field of new quantum technologies, we are committed to the goal of establishing a multinational quantum network in the EU,” explains Paul de Krom, CEO of the Netherlands Organization for Applied Scientific Research, TNO. The network will be made available to industry and science as a testbed to develop new products and applications and to unlock the full potential of distributed quantum computing. To this end, the participants will jointly establish technology and interface standards in the areas of quantum communication and quantum information networks and to contribute in a coordinated manner to European agenda setting in these areas.

For example, QuTech and Fraunhofer have agreed to collaborate on the deployment of complex quantum key distribution (QKD) networks across borders or around hubs in Germany and The Netherlands. They will also collaborate to develop integrated photonics solutions for such networks.

“To become a world leader in the implementation and application of new quantum technologies and to remain competitive against the market powers USA and China, immense joint transnational efforts of European science, industry and society are necessary,” says Prof Reimund Neugebauer, president of the Fraunhofer-Gesellschaft.

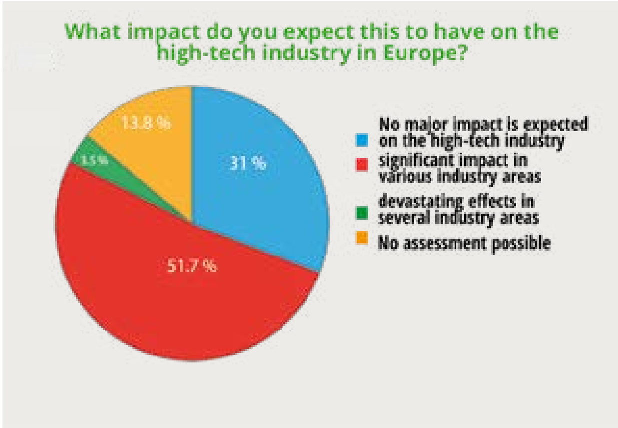
“These collaboration infrastructures require a cross-border strategy between leading countries and actors for the development of the various technologies and a clear understanding of the different positions, roles, and interests,” explains Dr Kees Eijkel, director of business development at QuTech.

The Fraunhofer ILT and QuTech have been working closely together as part of an ICON project since 2019.

www.ilt.fraunhofer.de
https://qutech.nl

IVAM: companies think sanctions against Russia are right

War in Ukraine affects numerous high-tech companies



Two questions surveyed by the IVAM Executive Panel in the second half of February 2022 (Source: IVAM)

The Russian attack on Ukraine will not remain without consequences for the hightech industry in Europe. As part of its Executive Panel, the IVAM Microtechnology Network has surveyed the current mood regarding the Ukraine crisis among selected executives in the micro and nanotechnology industry.

The majority of respondents anticipate significant, in some cases even devastating, effects on the high-tech industry. 48 % of IVAM Microtechnology Network's members have reported to be directly or indirectly affected by the war in Ukraine in the recent survey. For 3 % of the companies, the situation is even highly critical. 49 % of the respondents stated that their own company is not currently affected.

With regard to the general impact on the entire European high-tech industry, the majority (52 %) of respondents expect to see significant effects. 3 % even expect devastating effects in various areas of the high-tech industry. Furthermore, 14 % of the experts were still unsure at the time of the survey whether effects of the war will be felt in Europe, 31 % were confident and do not expect any further effects on the industry.

Regarding the sanctions imposed on Russia, the industry experts were united: the sanctions are at least appropriate, if not too weak. None of the respondents stated that the sanctions were too drastic or that no sanctions should be imposed.

www.ivam.de

Milestones for Photonics Finland

100 members mark reached, new employee in project management

In autumn 2021, Photonics Finland reached the magical number of 100 company and societal members! The 100th member is KxS Technologies Oy that provides digital measuring devices for process industry optimization. The company designs, manufactures, and distributes monitors that use refractive indices to measure liquid concentrations in the processing industry.

The history of Photonics Finland started in the year 1996, when the Finnish Optics Society was first established. In 2014 Photonics Finland was re-launched as a cluster together with 19 members to provide better service and visibility for industry and academia members.

On December 1, 2021, Caroline Amiot started as a project manager. She will work closely with Dr Ana Gebejes on the ongoing projects and with Tuukka Pakarinen on the organization of future Photonics Finland events. Dr Amiot is from Besançon, France where she studied Photonics at the University of Bourgogne Franche-Comté. During her studies, she visited Newcastle, UK and Tampere, Finland where she did her master thesis on the generation of broadband sources.

She continued her studies with a co-supervised PhD between France and Finland and got her double doctorate in 2018 from Tampere University of Technology and the University of Bourgogne Franche-Comté. Her doctoral dissertation was on "Novel Supercontinuum Sensing and Imaging Techniques in the Infrared". After three years as a postdoc researcher in Tampere University and EPFL in Lausanne, Switzerland, Caroline decided to change career and join the team of Photonics Finland.

Dr Caroline Amiot (Source: Photonics Finland)

Ana Gebejes will continue as a head of projects at Photonics Finland part-time; she will also be working as a post-doctoral researcher at the University of Eastern Finland (UEF).

www.photonics.fi

German photonics industry with a strong presence at SPIE Photonics West

Companies and associations from Germany celebrate award winners, outstanding booth participation and networking events

Joint Booth German Pavilion at the Photonics West Exhibition 2022 (Source: OptecBB)

The German photonics industry was again strongly represented at this year's Photonics West in San Francisco, the leading photonics trade show including a technical conference in North America. From January 24 to 27, 2022, about one hundred German companies and research institutions presented their innovations in the entire field of photonics, especially in the miniaturization of optical components and systems, laser technology and photonics in life sciences.

Photonics Germany – the alliance of OptecNet Deutschland and Spectaris – supported the organization of the always noticeable German Pavilion again, funded by the German Ministry for Economic Affairs and Climate Action. This year, it offered 41 companies and research institutes an ideal platform for their presentations and the acquisition of new customers.

Photonics Germany congratulates all the winners of the renowned Prism Awards and especially the young and innovative Stuttgart Instruments company from Germany in the scientific lasers category. In addition to the German Pavilion, the highly appreciated German Evening – from this year on organized and hosted by Photonics Germany – took place in the prestigious Leica Store as a special networking and international customer relationship event. More than a hundred guests were welcomed by Dr Wenko Süptitz from Spectaris and Dr Frank Lerch from OptecNet Deutschland. The German Consul General Oliver Schramm gave a welcome speech and pointed out the great business opportunities, especially in California and Silicon Valley. The Consul General was very impressed by the innovative strength and the technological potential of the photonics industry as well as the personal commitment of the German participants to meet business partners in person at this uncertain time.

Photonics Germany will support the German Pavilion and the exhibitors at Photonics West again next year and hopes to welcome many new companies and research institutes as well.

The next German Evening is already planned as the corresponding networking event for the German exhibitors and their customers, partners, and suppliers.

www.photonics-germany.de

Germany and Québec start joint expert talks in the field of quantum technologies

Representatives of the photonics communities of the Canadian province Québec and Germany in lively exchange

On February 16, about one hundred participants from numerous countries gained insights into ecosystems and research institutes operating in the field of quantum technology in Germany and Québec.

The virtual event was jointly organized by Photonics Germany, the Délégation Générale du Québec à Munich and the Ministère de l'Économie et de l'Innovation du Québec. The aim of the event was the exchange and networking on an international level at the interface of quantum technologies, optics, and photonics to promote mutual understanding, to establish contacts and to prepare joint scientific and commercial projects.

Elisa Valentin, general delegate of the Government of Québec, and Dr Andreas Ehrhardt, managing director of Photonics BW and member of the board of OptecNet Deutschland, welcomed the participants and speakers. Dr Peter Freier, attaché for economy, science and technology at the Délégation Générale du Québec à Munich, and Dr Andreas Ehrhardt jointly moderated the event, which is based on an initiative of Dr Horst Sickinger, managing

Wenko Süptitz greeting the participants of the virtual Germany-Quebec quantum technology event (Source: Photonics Germany)

director of Bayern Photonics. Prof Dr Sébastien Francoeur from Polytechnique Montréal introduced Photonique Quantique Québec. This quantum photonics hub organizes, structures, and financially supports research and innovation activities in quantum photonics. Subsequently, Dr Wenko Süptitz, head of photonics at Spectaris, provided insights into past and upcoming activities of Photonics Germany, the alliance of Spectaris and OptecNet Deutschland. He also illustrated the importance of the photonics industry in Germany.

Anke Odouli gave the first insights into the new trade fair "World of Quantum" as part of the Laser World of Photonics in Munich from 26 to 29 April 2022. It is worth noting that the new "QT Expo" exhibition is planned to take place in Stuttgart on September 29 and 30, 2022.

The virtual event continued with key activities and current projects of MCQST – the Munich Center for Quantum Science and Technology, presented by Dr Tatjana Wilk. Afterwards, the participants thematically switched to Québec by listening to Olivier Gagnon-Gordillo who introduced Québec Quantique. The overall aim of the interest group is to promote the adoption of quantum technology by Québecian companies and organizations to ultimately enable the Québec quantum ecosystem.

Prof Dr Jens Anders, University of Stuttgart, then introduced the current activities on the miniaturization and industrialization of quantum sensors. Finally, André Fougères provided insights into the Institut National d'Optique (INO) Québec which is an enabling partner for the development and commercialization of quantum and photonics technology.

Following the presentations, the participants had the opportunity to interact in smaller groups at virtual coffee tables and to discuss all the topics in greater detail. The organizers thank all participants and speakers for the inspiring exchange and the numerous new insights into quantum technology. Various starting points for further exchange and possible cooperation were identified during the event. Photonics Germany is looking forward to the next event on quantum technology.

www.photonics-germany.de

Photonics Germany supports Ukraine

Given the current situation in Ukraine, Photonics Germany, the alliance of Spectaris and OptecNet Deutschland, is offering various information and support services. OptecNet Deutschland supports refugees from Ukraine in their job search with a job portal containing numerous current job advertisements from companies and research institutions throughout Germany: https://optecnet.de/jobs/. In addition, Spectaris provides comprehensive information on current developments and numerous offers of support: www.spectaris.de/verband/aussenwirtschaft-exportfoerderung/ukraine/

www.photonics-germany.de

Perseverance and sustainable growth

EPIC strengthens its managing team by appointing Helfferich as COO, to implement business operations and align them with the organisation strategy

During the first quarter of 2022, EPIC consolidated its structure by appointing Ulrike Helfferich as chief operating officer to supervise daily business operations, lead key initiatives, and implement organization-wide strategies (cf. next page). Helfferich has a diploma in engineering physics and extensive sales and business development experience with a wide knowledge of optics, photonics, semiconductors, and the machine-building market that is based on business relationships with large scale and medium-sized enterprises. The association has also reinforced its technical expertise with the hiring of Dr Jérémy Picot-Clémente, specialized in photonics systems integration, who will focus on optics and micro-optics fields and their related technologies and applications. Also appointed was Dr Ivan Nikistki with his strong background in optoelectronics and semiconductors, who will be responsible for the photonic integrated circuits, imaging, and sensing sectors (cf. next page).

As travel restrictions eased at the beginning of 2022, EPIC was finally able to take part in several international photonics exhibitions again, such as Photonics West and OFC, which were a great opportunity to bring together EPIC members, decision-makers, and technology experts.

After the success of these events, we were all looking forward to restarting business as usual and the European Chips Act promoted by the European Commission on 8 February was a great starting point, but at the end of February, Russia started the invasion of Ukraine, an aggression that EPIC condemns.

At Laser World of Photonics in April, EPIC will be exhibiting and organizing several meetings on topics such as single-photon sources and detectors, industrial process monitoring, laser-based advanced and additive manufacturing, laser surface functionalization, laser optics and sensors for medical devices, diffractive optics or FMC lidar systems. In May we will visit Nanoscribe facilities in Germany to take a closer look at advanced micro-optics, and at the beginning of June we will discuss 3D printing of metal at a Siemens plant in Sweden.

Some members of the team at the EPIC booth at Photonics West 2022

This will be followed a few days later by a visit to Paris to celebrate the EPIC round table at Optro, which this year is focused on smart optronic detectors for challenging targets.

Some of our events include the popular EPIC Online Technology Meetings, now co-hosted by EPIC tech specialists, and in the upcoming months we will address topics such as hybrid photonic integrated circuits, medical fiber sensing, lidar miniaturization, micro and nano-satellites, and co-packaged optics for hyperscale datacenters.

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

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

Upcoming EPIC events:

- 9 May 2022, 15:00 – 17:00 CEST
  EPIC Online Technology Meeting on LiDAR Miniaturization
- 11 – 12 May 2022
  EPIC Meeting on Advanced Micro-optics: Simulation, Fabrication & Characterization at Nanoscribe
- 16 May 2022, 15:00 – 17:00 CEST
  EPIC Online Technology Meeting on Micro and Nano-satellites in the New Space
- 23 May 2022, 15:00 – 17:00 CEST
  EPIC Online Technology Meeting on Co-packaged Optics for Hyperscale Datacenters
- 30 May 2022, 15:00 – 17:00 CEST
  EPIC Online Technology Meeting on Photonics for Woodworking
- 8 – 9 June 2022
  EPIC Meeting on 3D Printing of Metal at Siemens
- 10 June 2022, 14:00 - 16:00 CEST
  EPIC RoundTable at OPTRO: Smart Optronic Detectors for Challenging Targets, Paris, France
- 13 June 2022, 15:00 – 17:00 CEST
  EPIC Online Technology Meeting on VCSELs Technology and Applications
- 20 June 2022, 15:00 – 17:00 CEST
  EPIC Online Technology Meeting on Plastic Sorting, Recycling and Waste Management
- 22 June 2022
  EPIC Meeting on Beam Shaping for Industrial Applications at LASYS, Stuttgart, Germany
- 27 June 2022, 15:00 – 17:00 CEST
  EPIC Online Technology Meeting on Quantum Communication and QKD
- 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

www.epic-assoc.com/epic-events

Ulrike Helfferich joins EPIC as COO

Management, leadership, and vision, to further strengthen the society's structure

EPIC has strengthened its team by appointing Helfferich as chief operating officer, to supervise daily business operations, lead key initiatives, and implement organization-wide strategies. She brings over thirty years of experience and deep knowledge of the photonic market, which will reinforce the robust systems and processes of the organization. "What I found most compelling about EPIC was its undisputed influence in the photonics sector," said Helfferich. "EPIC brings together the entire value chain to enable new business opportunities and creates collaborative bonds to facilitate technological innovation, something that is truly mission-critical for the members and European industry. I'm looking forward to helping take the organization to the next level in its leadership."


Ulrike Helfferich (Source: EPIC)

Helfferich has a diploma in engineering physics and extensive sales and business development experience with wide knowledge in optics, photonics, semiconductor, and machine-building markets, that is based on business relationships to large scale and medium-sized enterprises. "With Ulrike joining me as COO, I feel confident we are building a sustainable organization for EPIC," said Carlos Lee, director general of EPIC. "She has thirty years of industry experience. Ulrike will run the operations, and all eleven staff will report directly to her: six technology and market experts, and five events and marketing managers."

Helfferich worked among others with applications related to spectroscopy, distance sensors, optical measurement, and image sensors, and from 2006 to 2007, was an official member of the DIN standardization committee on light engineering photometry and LED systems.

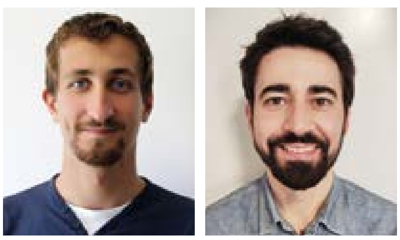
www.epic-assoc.com

EPIC hires photonics technologies program managers

Drs Nikitski and Picot-Clémente join the European Photonics Industry Consortium

To address the needs of its members, EPIC has strengthened its team by recruiting Dr Ivan Nikitski and Dr Jérémy Picot-Clémente to support the technical needs of the growing membership as well as the EU-funded initiatives. Ivan and Jérémy started in January 2022.

Ivan has an MSc in physics and a PhD in photonics. He has a strong technical profile built by his experience in both academia and industry of new materials, optoelectronics, and semiconducting.


Dr Ivan Nikitski (left), Dr Jérémy Picot-Clémente (Source: EPIC)

Jérémy has an MSc in physics, a PhD in optics, and also an MBA. During his PhD, Jeremy developed deep knowledge in nonlinear optics, free-space optics, optical experiments, optical fiber fabrication and characterization, spectroscopy analysis and experiments, and presented his findings in international conferences. To supplement this technical knowledge, the MBA brought him insights into management, economy, marketing, and strategy – crucial tools to understand the expectations and issues of the industrial world.

www.epic-assoc.com

Not going dotty

EPIC CEO interview of Igor Nakonechnyi, founder, director and CPO of QustomDot

Jose Pozo

Source all images: QustomDot

Jose Pozo, EPIC's former CTO, portraits Igor Nakonechnyi who is a founder of QustomDot, a Belgium based developer of on-chip grade, RoHS compliant quantum dot (QD) technology for future applications in color conversion.

▲ QustomDot team at the lab in Zwijnaarde at TechLane Science Park

Early career

In 2004, in keeping with the family tradition (both of his parents were chemists), Igor started a BSc in chemistry at Yuriy Fedkovych Chernivtsi National University in Western Ukraine. This was followed by an MSc in chemistry and in 2009, he enrolled on a PhD in solid-state chemistry. In 2014, after a year as a teaching assistant, he moved to Ghent University in Belgium where he worked as an Erasmus Mundus Postdoctoral Researcher on the growth and characterization of QD core/shell structures based mainly on cadmium selenide (CdSe) and zinc selenide (ZnSe).

A year later, thanks to an IWT Vlaio Innovation Mandate grant from the Flemish government, he was invited to take up a full-time post as a post-doctoral researcher at Ghent University. In collaboration with NovoPolymers, a Belgian company involved in the development and production of encapsulant solutions for the photovoltaic industry, the research focused on QD stability issues for future QD applications and the development of large-scale production processes for making QD foils.

QustomDot – developing the technology

By 2017, Igor and his fellow researchers had become aware of the enormous potential of QDs, and they began preparatory work to set up a spin-off from Ghent University to commercialize the technology. The work focused on four main areas: developing the technology, talking to potential customers, securing investment and building the team.

Quantum dot displays use semiconductor nanocrystals – called quantum dots, QDs – to produce pure monochromatic red, green, and blue light. Photoluminescent QDs are photo-emissive and glow a particular color after being illuminated by UV or blue light, with the colors depending on the size of the quantum dot: larger ones emit reds while smaller ones emit blues.

When used as a display technology, quantum dots of just a few nanometers in size have excellent optical properties and can be used to make LED and LCD technology more efficient. Specifically, QD displays have better color accuracy, higher color saturation, wider contrast ratio, and higher peak brightness.

Additionally, in comparison with OLED displays, QD technology has a longer lifespan, uses 20 % less power and QD systems are cheaper to produce as they can be processed very easily by

Igor Nakonechnyi

printing and coating. Most importantly, the fact that QD technology can be integrated with other display technologies makes it ideal for producing displays capable of ultrahigh definition applications, such as new-generation televisions, computer monitors, laptop displays, smartphones, other mobile devices, and consumer electronic devices such as wearables.

Notwithstanding these advantages, QDs have suffered from two main problems until now: firstly, degradation at high temperatures and light flux; and secondly, the fact that the only commercially available QD technology used cadmium-based LED chips, a material restricted by the Restriction of Hazardous Substances directive (RoHS) of the European Commission.

To overcome these challenges and to meet a gap in the market, Igor and his colleagues began in 2017 to develop a novel QD technology operating on non-restricted cadmium-free QDs and stable enough for on-chip usage that could not only be used for traditional LED lighting and LCD displays, but also in both mini and micro-LED applications.

Talking to potential customers

Conscious of the danger of developing technology without industry feedback, QustomDot started taking with potential customers right at the start of the incubation period. In this way, they were able to understand exactly what needed to be developed. From these discussions and also conscious of the need for a small company to specialize, they decided to focus solely on the microLED market. The advantage of this market segment was that there were a lot of applications that only required a small fab to manufacture them, for example, small microLED displays for wearables, which is a huge and growing market.

The idea was to have several tracks running in parallel with a core R&D working towards a kind of generic microLED application with a size of 10 × 10 microns using red and green QDs for conversion. But at the same time, the company would run parallel customization projects, for example, for customers who might want to do conversion for blue light from violet microLEDs, or those who wanted four instead of three primary colors, where having green, red and orange would be useful, for example.

Securing investment: Fortunately for QustomDot, there were a number of investors who shared their vision and ambition to explore the full potential of QDs for next-generation applications. This was exemplified by the fact that shortly after being founded in 2020, the company raised an impressive 3 million euros in a seed round led by the Belgian Qbic Fund, a multisector fund supporting spinoff companies in Flanders. Funding was also provided by PMV, a Flanders government fund and Vigo Ventures, a Polish fund specializing in photonics.

In addition to the money, along with the tech transfer office from Ghent University and individuals from industry who were eager to help, these investors provided much needed business advice.

Building the team: Planning in the incubation period was overseen by Igor as chief product officer responsible for aligning QustomDot's internal R&D with customer needs, along with the two other co-founders from the Ghent University research team: Kim De Nolf (currently CEO) and Willem Walravens (currently CTO). As Belgium has a rich pool of chemists and experts in nanotechnology, QDs and polymers, it has been relatively easy to add to the team and the company now has a workforce of nine, most of them PhD-qualified. And since QustomDot is still growing, be sure to check out their website or send a spontaneous application if you think that you can help them.

The future

QustomDot's work is based on five pillars: QD synthesis; QD surface modification; incorporation of QDs with a modified surface into a resin to create an ink or a photoresist; patterning; the production of a QD device on, for example, a microLED. But as Igor explains, their goal is not to become a QD supplier.

Instead, they are looking to bring application expertise to microLED companies to help them create the colors they need through customization and then to set up partnerships with larger chemical companies and companies already in the display business, either through licensing or outsourcing for the production.

And, as he points out, the fact that microLEDs are a disruptive technology means there will be a lot of reshuffling of the market, which will open up opportunities for companies who are not currently in the display field but interested in trying something new. These include chemical companies and those making equipment for patterning, such as new kinds of inkjet printers. Similarly, there will be opportunities for companies wanting to break into the wearables market.

Because there are so many potential applications, Igor sees a lot of opportunities where the value chain has not yet been established. QustomDot's mission is to be an integral part of this value chain by understanding what each customer wants and determining where they can bring the most value.

To make this a reality, QustomDot is also aware of the need for scalability and for this reason they've taken reproducibility seriously right from the start – in relation to both new methods, patterning and the more conventional methods employed by existing fabs.

If you started again, what would you do differently?

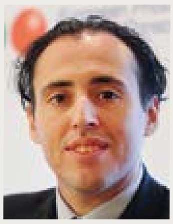
"I would definitely try to spend a bit more time learning about entrepreneurship. In this context, being a scientist has helped a lot because I think it is much easier for a scientist to become an entrepreneur than the other way round. With modern day entrepreneurship, it is possible to apply scientific methods: first, you set up your experiment, which is your business hypothesis, then you try it out, analyze customer feedback, correct it, and then implement it. This is quite an easy process if you're a scientist but much harder if you have never studied the subject."

What are your words of wisdom for the next generation of entrepreneurs?

"First, be ambitious and don't be afraid to experiment, which is really the key. Whatever the outcome of the experiment, just learn from it and it will help you. There is no such thing as failure these days; everything that does not work just adds value to your experience.

Second, talk to your potential customers as early as possible. Loving the technology helps but it can also be a problem because it's easy to fall into a trap and come up with a product that no one needs. Before we launched QustomDot, we went outside and talked to the industry. We listened to customers about what they needed and discussed prices, and by using this approach we were able to come up with a robust and feasible business plan and attract investment at a very early stage."

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.

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Polarization-controlled VCSEL characterization

Novel one-shot method enables the full performance efficiency of the VCSELs to be exploited while assuring safe operation

Frank Münchow & Karthik Iyer

Source all images: Instrument Systems

Most VCSELs are not designed to emit in a single polarization state and often there is no control over the polarization angle. A novel one-shot method measures the spatial polarization of each single emitter and allows to correct the polarization dependency of the setup. This process minimizes the error budget of the VCSEL testing system and measures accurate values for laser eye safety calculations.

Although VCSELs are intrinsically single-longitudinal mode devices, they usually show complex polarization characteristics. Most VCSELs are not designed to emit in a single polarization state and often there is no control over the polarization angle. Typically, the light emitted by the VCSEL is linearly polarized along one of two orthogonal directions and abrupt polarization switching can be observed when temperature or bias current is changed. A typical measurement system shows a polarization dependency; hence it is essential that the polarization of VCSEL emitters be accounted for whilst measuring quantities like absolute power. It is noteworthy that if the polarization of VCSEL emitters is not considered, there is a definite chance of computing incorrect results. Also, quantities like absolute power are crucial to evaluate accessible emission limits (AEL) for laser eye safety classifications. Here we show a method how to measure spatially resolved polarization characteristics of VCSELs using a combination of polarization filtered microscope optics and a CMOS camera. This also ensures correct intensity measurements independent of any polarization effects.

CMOS cameras are designed in such a way that the output is not dependent upon polarization. The same is true for simple lenses in the optical path. Nevertheless, measurements in a system consisting of a microscope lens and CMOS camera show a dependency of the pixel counts on a polarized light source (**Fig. 1**). In this simple experiment, we measured a fully linear polarized light source in front of the camera optics and repeated the measurement with a rotated source with respect to the optical setup. The sum of the pixel counts varied by approximately ten percent. This means that the sensitivity of the whole setup varies and is therefore not suitable for an absolute calibration, where the pixel counts are correlated to the input power in watts. For absolute measurements, the influence of the polarization cannot be neglected. Since VCSEL typically consist of many emitters where each emitter can have a different polarization, even relative measurements within the VCSEL will have this measurement error contribution to the full error budget.

For absolute power measurements of the emitter power of the VCSEL, for example for eye safety, it is important to take these effects into account, otherwise the read-out value is incorrect.

Our approach is to measure the spatially-resolved polarization and correct the read-out values of the camera for correct absolute power readings. As a plus, the polarization angle and degree for each pixel are also measured. All these measurements can be made using the near-field camera setup VTC 4000 [1].

System overview

It is imperative to identify the functionality and quality of a VCSEL array on a single emitter level with a near-field characterization system. Our system consists of a CMOS camera and microscope optics and measures the spatial distribution of the light (intensity and linear polarization) from a VCSEL array with a single shot image [2]. The information enables the analysis of each single emitter in terms of absolute power within a very short time-frame, enabling defect detection even during production. The system is optionally equipped with a translation stage, moving only the optical parts without the need to reposition the DUT during the measurement. The complete beam analysis can be performed by moving the camera in the z direction, thereby measuring the beam waist in focus, the numerical aperture and M^2 value. An additional high resolution spectroradiometer in combination with an xy translation stage enables the analysis of the spectrum for each single emitter on the array.

One of the unique features of this measurement setup is its ability to measure polarization at each pixel position and correct the power readings for the known imperfections of the optics. Since the polarization of each emitter can vary across the array, it is essential to determine the correct polarization even for relative measurements. The calibration concept of this setup is based on flat-field and polarization correction. This guarantees a minimum error budget in power measurement and results in high measurement accuracy, especially important for determining laser eye safety where high intensities are desired but the manufacturer needs to be within the safety limits to protect users of the device.

Measurement principle

Besides standard microscope optics consisting of a microscope objective and a tube lens, we use a CMOS camera with a polarizer pattern in front to obtain spatially resolved polarization information, similar to the technique used in RGB cameras for color information. This approach allows the polarization to be measured in one-shot without needing any movable parts inside the device, delivering very fast results and a robust device design.

The measurement principle of the camera is shown in Fig. 2.

The camera pixel will (in the ideal case) behave like this with incoming linear polarized light:

$$I = E_{\mathrm{light}} \cdot S(\lambda) \cdot \cos^2(\alpha_{\mathrm{light}} - \alpha_{\mathrm{pol}})$$

Here, E_{light} is the energy of the light, $S(\lambda)$ is the sensitivity of the camera chip, α_{light} the polarization of the incoming light and α_{pol} is the polarization of the filter in

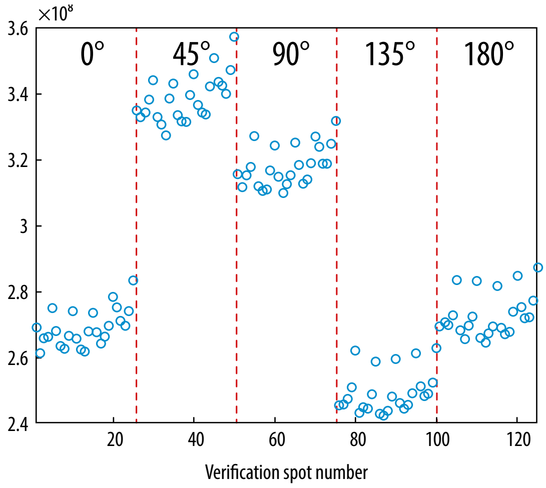

Fig. 1 Comparison of total power measurement with different polarizations: each dot represents one measurement position. Measurement made by rotating the source in 45° steps.

front of the pixel. All four polarizations show the same intensity for completely unpolarized light. In reality, partially polarized light is emitted most of the time.

The angle and the degree of polarization can be calculated using these formulas with I_x being the intensity for each polarization:

$$\alpha_{\mathrm{light}} = \frac{1}{2}\,\mathrm{atan}\left(\frac{I_{45°} - I_{135°}}{I_{0°} - I_{90°}}\right)$$

$$\mathrm{DoP} = \sqrt{\frac{(I_{0°} - I_{90°})^2 + (I_{45°} - I_{135°})^2}{I_{0°} + I_{90°} + I_{45°} + I_{135°}}}$$

The degree of polarization varies from 0 (completely unpolarized) to 1 (completely polarized). A typical VCSEL light source only has partially polarized light, which can be split up into completely unpolarized light and polarized light:

$$I_{\mathrm{total}} = I_{\mathrm{polarized}} + I_{\mathrm{unpolarized}}$$

Note that these formulas are only true for an ideal camera and ideal optics.

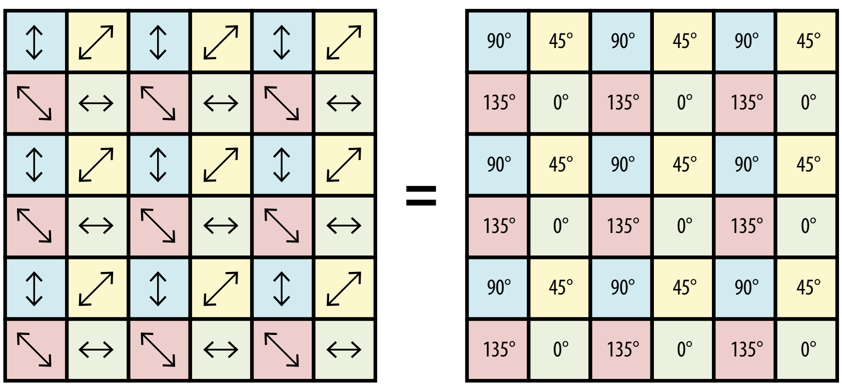

Fig. 2 Polarization filter in front of the camera chip consisting of four different polarization filters in 2 × 2 pixel blocks.

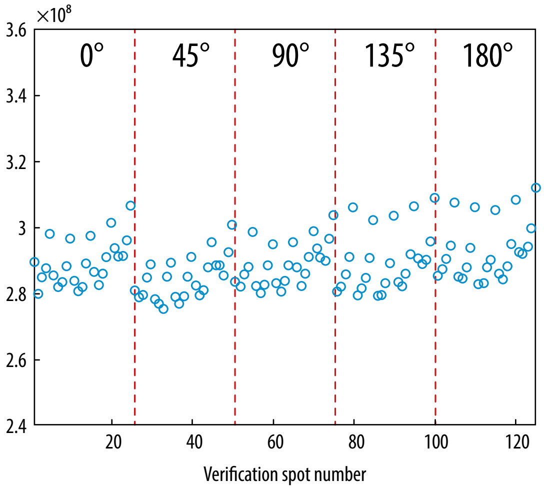

Fig. 3 The same measurement as shown in Fig. 1, but corrected for polarization effects as described. The intensity does not show any polarization effects anymore and can be calculated back to watts, independent of the polarization of the incoming light.

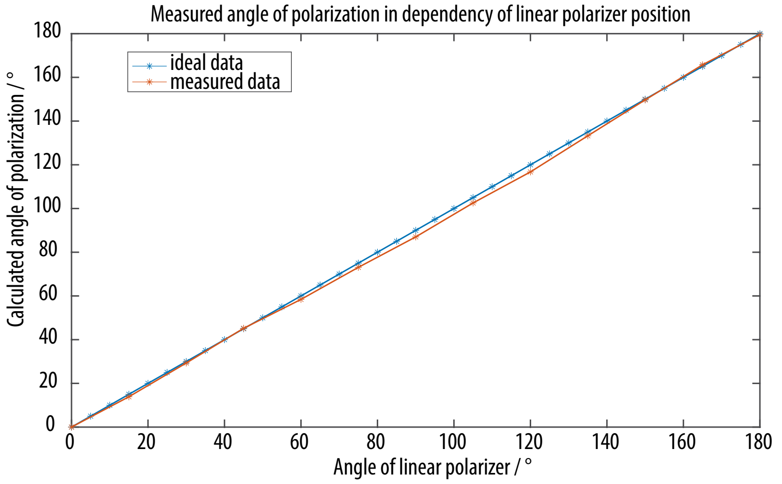

Fig. 4 Polarization measurement with the help of a linear polarizer that is rotated with respect to the camera.

Imperfections of the optics or filters or the camera sensitivity will lead to different results that need to be corrected.

Calibration of camera sensor

Quite a few imperfections occur in a real camera setup. Standard corrections for bad pixel, dark current and flat field calibration are needed. These effects also have to be accounted for when measuring polarization.

The filters in front of each camera pixel are not perfect – the extinction ratio is quite low. This means that even perfectly polarized light will appear as if it is a little unpolarized. The extinction ratio appears as an Offset_x in the measured values and needs to be corrected afterwards.

The extinction ratio is different for each polarization channel and therefore also affects the calculation of the polarization angle and appears as on offset φ_x in the measured data.

Both effects are dependent on each polarization filter and each position on the camera sensor. The final measured intensity is calculated to be

$$I_x(\alpha) = A_x \cdot S(\lambda) \cdot \cos^2(\alpha - \varphi_x) + \mathrm{Offset}_x$$

This needs to be back calculated in order to get the corrected intensity A_x for each pixel position of the camera. All parameters are position-dependent on the camera. The calibration measurements in the complete setup will take imperfections of the optics like intensity deviations due to shadowing or polarization deviations due to reflection/transmission changes at optical surfaces (Fresnel formulas) into account. The final calibration files consist of several matrix files that correct for imperfections at each pixel position of the camera sensor. The final image consists of a three-channel image with intensity, angle and degree of polarization for each (x, y) pixel position.

With all these corrections, we performed the same measurement as already shown in Fig. 1. The polarization effect is not visible anymore and the intensity values can be calculated back to watts of the incoming light, which is a vital element for traceable, absolute results (Fig. 3). The spatial information about polarization angle and degree is also provided.

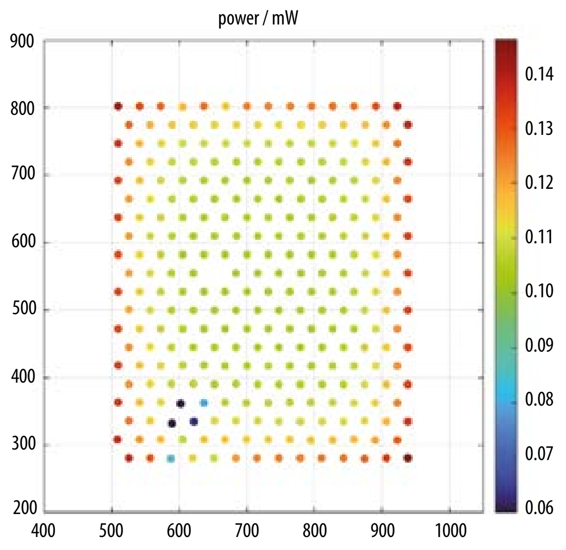

Fig. 5 Intensity map of a typical VCSEL array. Shown here is the intensity per emitter in mW.

Measurement results

In a first experiment, we used an unpolarized light source with a linear polarizer that was rotated in order to obtain different linear polarizations. In Fig. 4 we show the mean measured polarization of that source compared to the position of the linear polarizer. The measured absolute deviation is smaller than 4°.

Our camera has 10× magnification, resulting in a pixel resolution of 0.35 µm/pixel. A typical VCSEL array measurement is shown in Fig. 5. It shows the intensity map for the VCSEL array, already absolutely calibrated.

In Fig. 6 we show a few examples of single emitters showing different polarization patterns in angle and degree, taken at the focus position of the VCSEL array surface. The intensity maps (left column) show the typical donut structure of VCSEL emitters, where not much difference between the maps is observed. In contrast, the polarization analyses (middle column) show significant differences between the emitters. Different modes inside the emitter are observed: the upper example shows a VCSEL where one polarization angle is emitted while the middle one shows two different modes with a roughly 90° difference in polarization angle and the lower one shows an even more complicated structure with three different polarization modes at 0°, 45°, and 90°.

Calculations

The measurement results can now be used to determine different properties of VCSELs. For example, we can calculate the projection to a polarization angle – comparable as if a linear polarizer is used.

In Fig. 7d and 7e there are two examples showing one VCSEL emitter with a calculation of the polarization angle. One can clearly see the structure of the VCSEL with some structure at the polarization switch. We can also calculate the mean intensity measured over the whole emitter with respect to the polarization angle showing the dominant polarization of the emitter as seen in Fig. 7f.

These two measurements can also be achieved with a linear polarizer in front of the sample and images taken at different rotational positions of the polarizer, but here we obtain all the information in just one shot.

Many more calculations can be made; there are no limits here as we have all the information (intensity, polarization angle, polarization degree) for each pixel of the camera.

Summary

In conclusion we have demonstrated, using our near-field camera system, the ability to measure the intensity, polar-

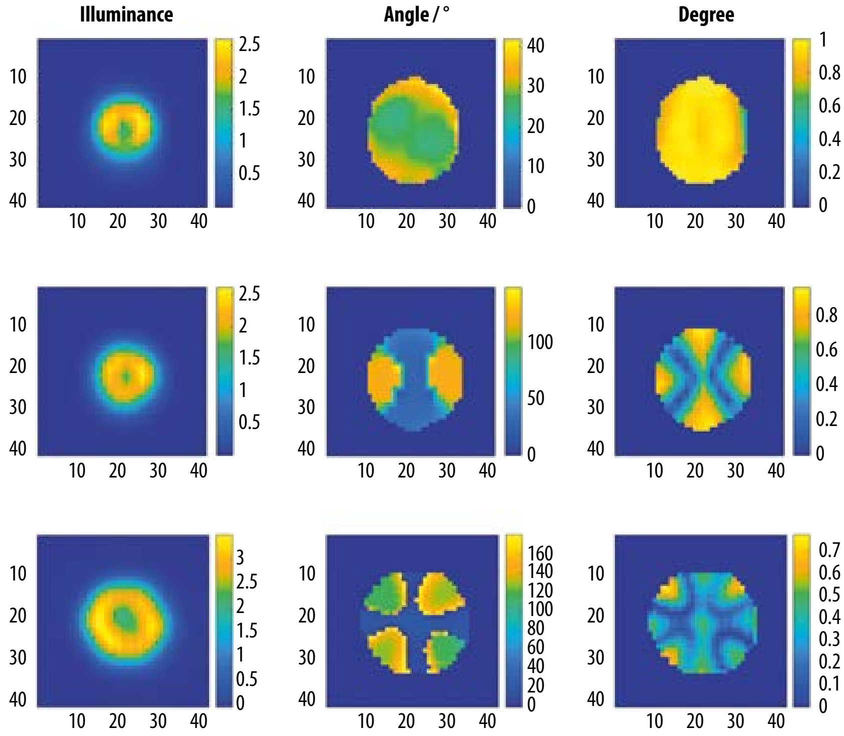

Fig. 6 Examples of single emitter intensity (left column), polarization angle (middle) and degree of polarization (right). The pixel resolution is 0.35 µm/px.

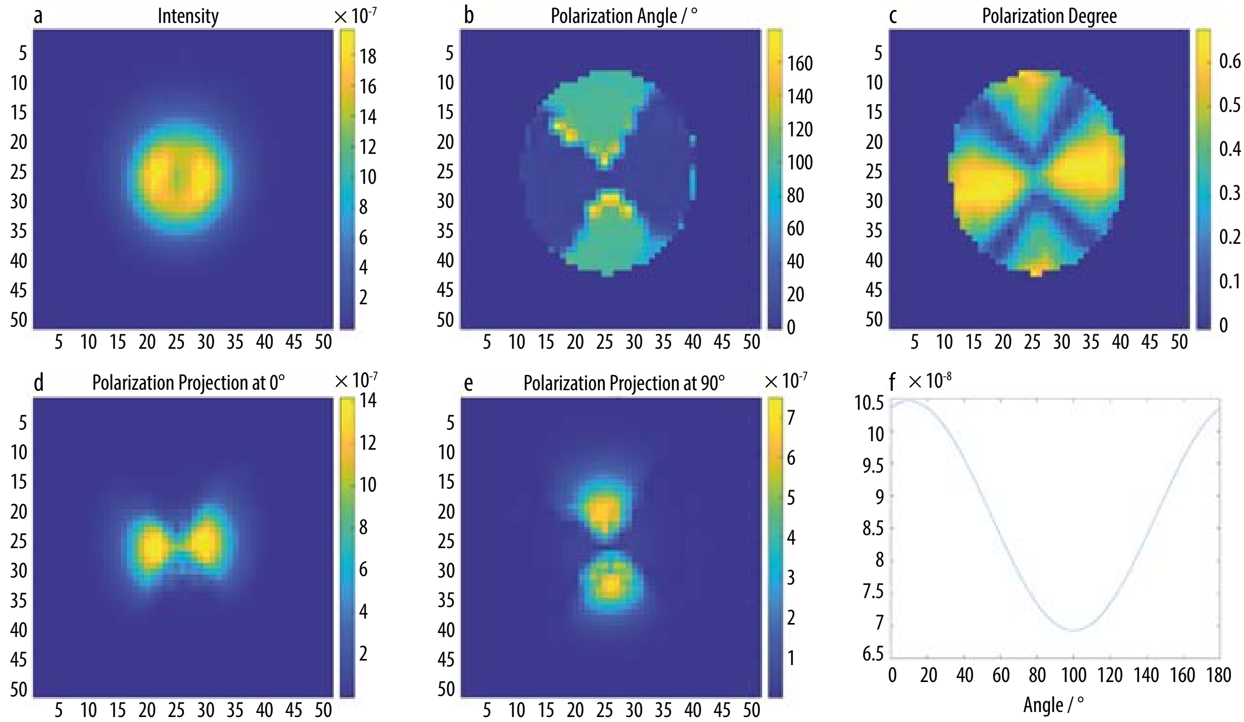

Fig. 7 Example image: intensity image (a), polarization angle (b), polarization degree (c), intensity projection to 0° (d), intensity projection to 90° (e), mean polarization curve (f)

ization angle and polarization degree with a one-shot image of each individual emitter of a VCSEL array without needing any movable parts inside the device, providing very fast results and a robust device design. Furthermore we have shown that a polarization dependency is seen in the results with standard microscope systems , showing the necessity of correcting the polarization effects to measure the absolute and relative power of a VCSEL array to minimize the error budget of the system, and delivering the best values for laser eye safety calculations according to IEC 60825.

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[1] https://www.instrumentsystems.com/en/products/imaging-colorimeters-ir-testing-cameras/vtc-4000

[2] "Spatially-resolved polarization characterization of VCSEL arrays", Dr. Frank Münchow and Dr. Karthik Iyer, Conference presentation at SPIE.PhotonicsWest 2022

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Frank Münchow has been working as an application project manager, specialized in the field of VCSEL and IR applications, at Instrument Systems since the beginning of 2019. He obtained a PhD from the University of Düsseldorf in quantum optics and laser spectroscopy in 2012.

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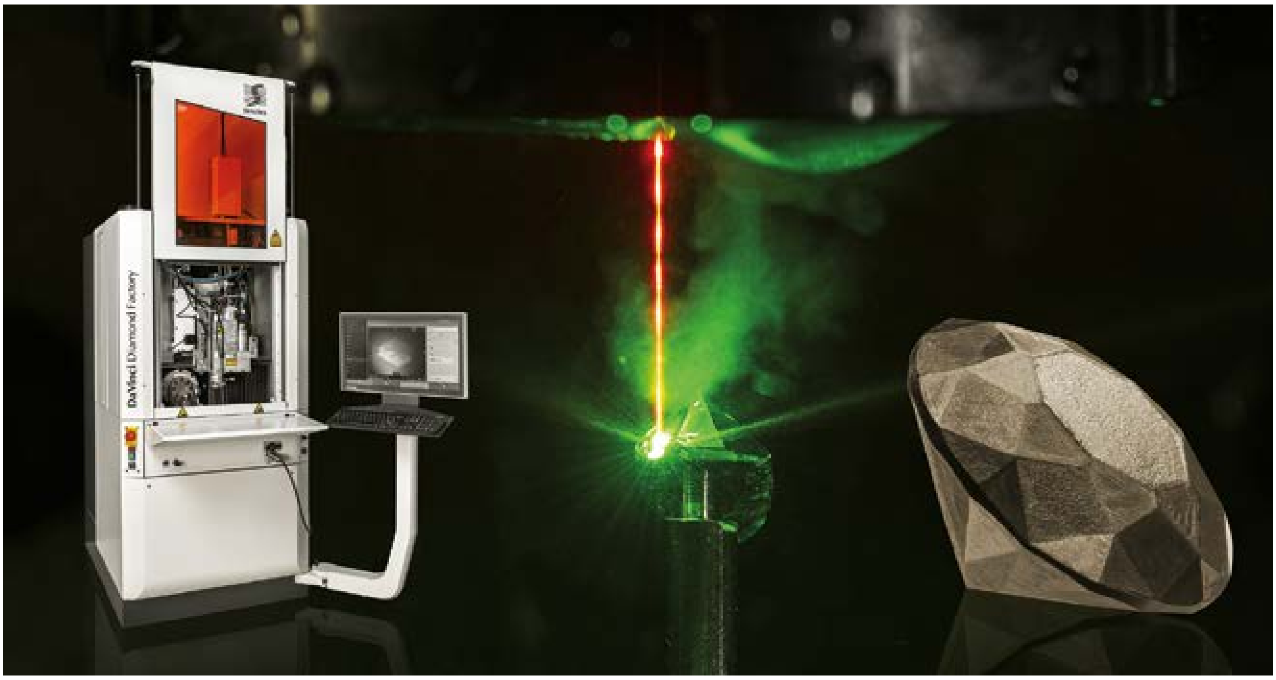
Gentle to the material, precise, and fast

Precision processing of high-tech materials using a water laser



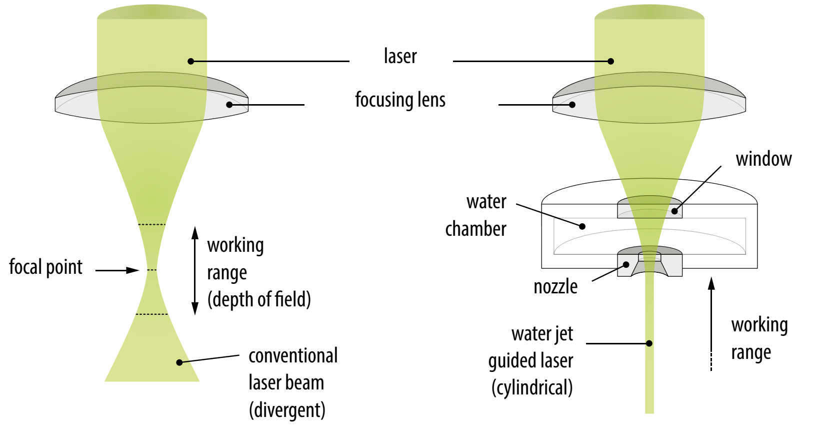
In the patented LMJ technique, the processing is carried out by a water jet as thin as a hair through which high-energy laser impulses are directed. The water cools the workpiece in the process and prevents damage to the material. This method is being used in ever more applications, and in particular for materials that are hard to process, such as hard metals, cubic boron nitride (CBN) or diamond as well as all types of ceramics. It is also just as suitable for fiber-reinforced composites, titanium, cobalt and superalloys or semiconductor materials. Here are some current applications.

"The fundamental difference between our Laser MicroJet (LMJ) method and other laser techniques is the guiding of the laser beam down the inside of an inherently stable water jet as thin as a hair," says Dr Amédée Zryd, director of applications, research, and development at Synova in Duillier/Nyon, Switzerland. The high-energy nanosecond laser pulses are coupled into the water jet, which is only a few dozens of micrometers wide, with the help of a sophisticated optical head. The water has exactly the same purpose as the optical fibers in communications cables whereby the laser light is internally totally reflected at the boundary of the water to the air. In contrast, the working range of a conventional laser system is very short because of the focusing that is done by lenses. This characteristic of LMJ lasers enables very deep cuts with true vertical, very smooth surfaces. The medium pressure water jet – up to 500 bar – prevents thermal damage and at the same time washes away any reaction residue from the workpiece. The result is clean surfaces as well as material characteristics that correspond to those of the material before processing. The thin water jet permits extremely narrow and absolutely parallel clearances of 25 – 80 µm with only minimal roughness.

▲ The DaVinci Diamond Factory is a complete turnkey solution for the faceting of diamonds (Source: Synova)

Applications: tools, metal sheets and special alloys ...

"An application of growing commercial interest is the processing of tungsten carbide and cutting ceramics such as CBN, SiC, aluminium nitride or alumina," says Dr Zryd. It is not only about the basic geometry, but ever more often about achieving five-axis geometries, such as the required cutting angle and the sharpness of edges in cutting tools.



While a water jet guided LMJ laser remains focused over a long distance, the intensity of a conventional laser beam drops off quickly beyond the point of focus (Source: Synova)

A further promising application has arisen from the manufacture of permanent magnet materials such as NdFeB, which can only be processed with difficulty because of their hardness and brittleness. Synova can help here because the technique also allows thick materials to be processed. In addition, there is virtually no effect on the magnetic properties of the material because of the excellent cooling provided by the water jet. Further interesting applications of the LMJ technique include the drilling of cooling holes in ceramic-coated turbine blades as well as in large silicon components that are used in wafer reactors as consumables.

In this last case, specially constructed systems were developed for a large customer. According to Dr Zryd, a number of these systems are now in use there almost the whole year round in three-shift operation and have reached an uptime of 98 %. This confirms the maturity of the LMJ technology to carry out work that meets the highest requirements of quality and reliability while meeting strict safety standards.

> The focusing of the laser light within a stable water jet enables very deep cuts with vertical and very smooth surfaces
>
> Dr Amédée Zryd

… diamonds …

“Although clear diamonds hardly absorb our green laser light, we are still able to process diamond materials,” discloses Dr Zryd. The reason is simple: black graphite is formed on the surface of the diamond as soon as the first laser beam hits it, which absorbs the following laser impulses very well. The thin graphite layer can be easily polished away afterwards. One of the important advantages of the Synova technology here is the narrow cutting width because only very little of the expensive stone volume is lost. There are special solutions for the jewellery industry, such as the DaVinci Diamond Factory which machines rough diamonds into fully facetted brilliants.

Artificial diamond stones made by the CVD process are a growing application where such lab grown crystals are cut by laser into monocrystalline slices. The depth of the cut is continually increasing: the standard currently lies at about 10 mm, although 20 mm has already been achieved. As the workpieces can be turned and worked on from the rear, slices with a depth of up to 40 mm can be created. Other industrially-produced diamond materials like MCD, PCD or metal-matrix diamond composites can also be easily machined.

… as well as fiber-reinforced composites and ceramics

“We are also able to process almost any type of ceramics or ceramic-composite, as long as it is not transparent to green light,” says Dr Zryd. There are currently some interesting developments on the subject of non-oxide (such as SiC-SiC) or oxide-oxide ceramic matrix composites

Company

Synova

Synova SA, headquartered in Duillier, Switzerland, develops and manufactures advanced laser cutting systems that incorporate its proprietary water jet guided laser technology (Laser MicroJet) in a true industrial CNC platform. Customers benefit from significant yield and improved cutting quality as well as enhanced capabilities for precision machining a wide range of materials. The company has supplied over 400 machines designed for applications such as drilling coolant holes in turbine blades, faceting rough diamond stones and processing semiconductor materials.

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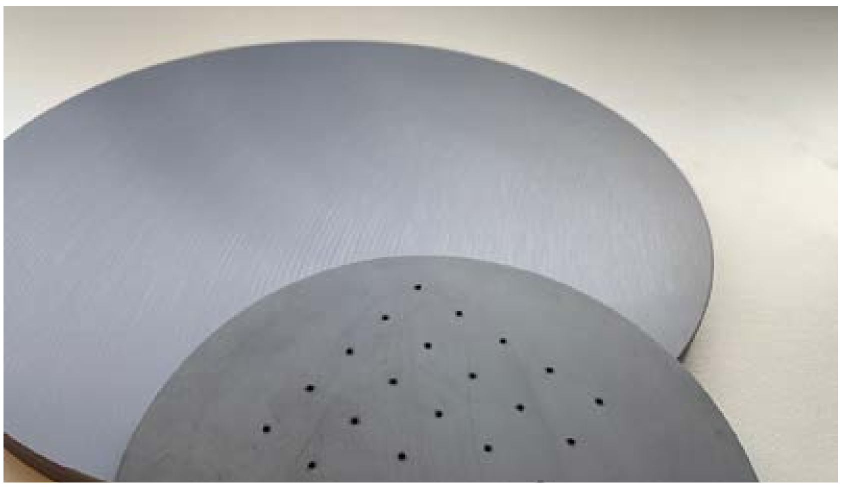
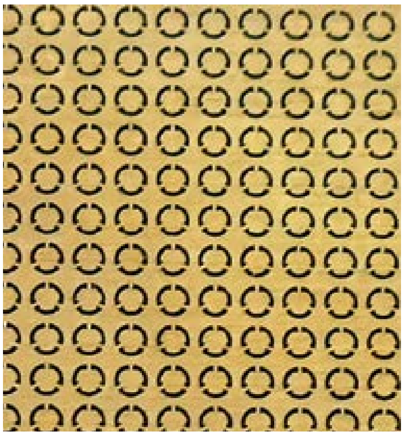


Holes are made in these discs of high purity silicon using the LMJ technique to let gas through during the production of wafers (Source: Synova)

Numerous openings to the hollow interior of the blades in modern gas turbines provide cooling for the blade surface (Source: Synova)



A spinneret structure in a thin metal sheet (Source: K. Vollrath)

(OxOx-CMCs). These materials consist of high-grade ceramic fibers embedded in a ceramic matrix. They are primarily used in aerospace because of their excellent thermal resistance with good high temperature strength and low weight, and compete with titanium materials and other high-temperature alloys. Equally easy to process are carbon fiber composites as well as numerous other ceramic materials, some of a particularly complicated composition, that are used in the production of power semiconductors or sensors, as well as diamond grained composites. These consist of diamond grains embedded in a metal or ceramic matrix and are used in contoured grinding wheels or watch cases that display high resistance to scratches and other damage through the diamond grains. The semimetal silicon and the ceramic silicon carbide are also of growing interest. An example of an application is for solid silicon discs up to 10 mm thick. These are drilled with precisely placed and dimensioned holes for the production of silicon chips. An exact amount of an aggressively reactant gas is fed through these holes onto the wafer.

Micro and macro-processing

"A further advantage of our cutting technique is the ability to create high-precision microstructures", says Dr Zryd. An example of these are so-called spinnerets, which are spinning nozzles for the production of textile fibers. These structures consist of arrangements of very small openings through which thin strands of liquid plastic are extruded.

The plastic polymerises as it exits and forms the required textile fiber. Whole bundles of thin fibers can be created through the appropriate layout of such spinnerets that are then combined into a thread. The LMJ process is ideal for creating these structures as the openings and holes have very clean edges and smooth, exactly vertical sides. This is important to ensure the faultless quality of the fibers. On the other hand, the LMJ technique can also be used to create large structures with extremely thin, sometimes only 30 µm wide poles e.g. for vibration sensors. With regard to the area of the workpiece, there are no real limits for the LMJ method. For example, it would be in principle possible to fit an optical head onto a robot arm for remote machining.

Highly reliable process technology

"We have to monitor numerous parameters during long periods of operation and keep them stable to ensure reproducible results," adds Dr Zryd. The workpieces are, after all, often very expensive. So Synova has developed a number of solutions over the years and, thanks to this perfecting of the technique, LMJ systems can maintain high uptime levels even under continuous operation.

There are standard systems available in three or five-axis versions with a working volume of 50 × 50 × 50 mm up to 690 × 630 × 100 mm. Larger gantry systems are also possible. To handle the variety of usage scenarios, there are numerous specialized versions for particular applications, such as diamond machining, the shaping and grinding of cutting edges, the drilling of cooling holes in turbine blades or the processing of semiconductor materials for computer chip manufacture.

As with every other groundbreaking development, the LMJ technology is also being illegally copied ever more often. Synova's fundamental developments are patented and well protected by around twenty patent families with a total of some one hundred individual patents. "We are following developments in the market very closely and will act rigourously against any infringement of our intellectual rights," confirms Dr Zryd.

These filigree structures were cut from a thick sheet of silicon carbide using the LMJ technique (Source: Synova)

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Text: Redaktionsbüro Klaus Vollrath, Aarwangen, Switzerland, b2dcomm.ch

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Driving the manufacturing and improvement of batteries

JPT's advanced laser technology promotes innovation and advances electrode slitting and laser welding

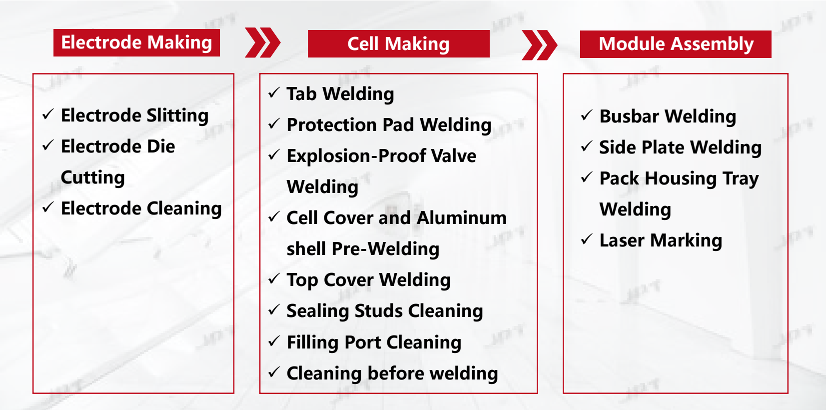
Lulu Wang, Lulu Song, and Xueqing Wang

In recent years, more and more attention has been paid to the application of laser technology in the lithium battery industry, which deeply affects all production processes of lithium batteries, accelerates the improvement of the performance and quality of lithium battery products, and promotes the evolution of the lithium battery industry chain from the era of quantity to the era of quality. The innovative technology of JPT lasers drives the manufacturing and upgrading of lithium batteries, which makes the quality of lithium battery products move towards the high end.

▲ JPT's advanced laser technology drives manufacturing improvements within the battery industry. (Source all images: Shenzhen JPT Opto-Electronics)

Due to the numerous and complex production processes in battery production, batteries are prone to suffer various defects such as scratches, exposed foils, bubbles, folds, dark spots, bright spots and falling materials in various links, such as the battery materials, the cells and the pack packaging. These defects will seriously affect the performance and quality of the battery. Therefore, strict requirements are put forward for the safety, accuracy and controllability of battery manufacturing technology and production equipment.

On the one hand, high-quality lithium batteries require a manufacturing process that can improve the energy conversion efficiency and energy density of lithium batteries. At the same time, it is necessary to adopt appropriate lithium battery processing methods that improve the performance of lithium batteries so as to reduce the energy consumption of automobiles



Laser technology in battery industry

and achieve energy conservation and emission reduction. On the other hand, it is required that lithium batteries can be manufactured on a large scale using mass-production methods, with costs reduced and quality improved so as to achieve efficient production.

The best solution for lithium battery processing

Compared with traditional machining methods, laser processing technology has the characteristics of no consumables, no pollution, no contact stress, high processing quality and precision, and can be automated. Laser processing technology with its multiple performance advantages is therefore widely used in the production processes of the battery industry. At present, it is employed in the electrode making process, in cell marking and the assembly process, as well as the module/pack assembly process on battery production lines. The laser processes include cutting, welding, cleaning and marking. The specific processes are as follows:

- Laser cutting: used in the electrode making process, including electrode slitting / die cutting, separator slitting, tab forming process;
- Laser welding: used in the cell making and assembly process and module / pack assembly process, including tab welding, protection pad welding, cell cover pre-welding;
- Laser cleaning: used in electrode cleaning, part cleaning before welding;
- Laser marking: used to mark the battery surface with a code, character, production date, anti-counterfeiting code and other information to trace the source.

Laser technology has greatly improved the safety and reliability of batteries and further improved the performance of new energy vehicles. We believe that laser technology will bring more innovation to lithium batteries.

In the following, interesting applications with JPT laser will be introduced.

Lasers for electrode slitting

Electrode slitting is an essential process for electrode manufacturing. The problem of tool wear is common in the traditional way of cutting battery electrodes with a metal mold, which can easily affect the stability, seriously reduce the cutting quality of pole pieces, and lead to the degradation of battery performance. Laser processing has obvious advantages for lithium battery electrode slitting by virtue of its characteristics of high efficiency, being a stable process, with non-contact processing and easy automation.

The edge quality (burr, thermal effect, flatness, etc.), processing accuracy and pollution during the process will have serious impacts on the performance and quality of the battery:

1) burr and impurity problems: the burr generated by electrode processing is extremely harmful to the battery, especially the large metal burr, which will directly pierce the diaphragm, resulting in a short circuit between the positive and negative electrodes, self-discharge, thermal runaway and other hazards;

2) Thermal damage to the material and peeling of the electrode coating can lead to decreased activity or failure of the material, which in turn reduces battery performance.

3) The deviation of the size of the processed pole pieces will cause the negative electrode not to completely wrap the positive electrode and the diaphragm

JPT MOPA pulsed fiber laser

cannot completely isolate the positive and negative electrodes, resulting in safety problems of the battery.

In view of the requirements and problems of electrode slitting, JPT, as a laser source supplier, has conducted extensive research and experiments on the quality and efficiency of laser processing of various electrodes (negative / positive, with / without coating) and has developed the customized MOPA pulse fiber laser for electrode slitting. JPT MOPA pulse fiber lasers have the advantages of an independently controllable pulse width and frequency, high efficiency of energy conversion, good and stable quality of the output beam, and an integrated all-fiber design. Compared with the traditional laser series, this MOPA pulse fiber laser can not only reduce the thermal effects and burrs during the process, but also has a higher product processing efficiency, which enables it to match the production line speed of up to 120 m/min. In addition, with the further innovation of laser technology, JPT takes the lead in realizing the technical innovation of electrode slitting without burrs.

The HAZ (heat affect zone) by JPT MOPA lasers can be controlled to within 60 µm. Positive electrode slitting enables the technical innovation of burr-free cutting, which greatly improves the processing quality of pole cutting and thereby also improves the performance of the battery. Compared with the solid-state ultrafast laser, this laser has a better process effect, higher processing efficiency, higher stability and reliability, a longer service life and extremely low cost. In addition, the JPT MOPA laser also has outstanding performance in electrode cleaning and busbar cleaning. Its processing technology improves the quality and safety of customers' products, and its high cost performance greatly reduces the cost of customers' equipment. It is an ideal light source favored by customers.

Lasers for welding

Laser welding is an efficient and precise welding method that uses a laser beam with a high energy density as the heat source. During this process, the laser beam is focused on a small working range through the optical system, and the location where the welding is required forms a highly concentrated heat source in a very short time. This causes the welding zone to melt and subsequently solidify to form solid solder joints and welds. Compared with traditional welding methods, laser beam welding has the advantages of high efficiency, high precision, high quality and high flexibility.

JPT has developed lots of customized products to meet strict welding requirements. The JPT AOB (adjustable output beam) fiber laser has one output beam with two coaxial beams, which can be controlled independently. The power of the central spot and the annular spot can be adjusted independently. During the welding process, the annular laser beam is used for pre-heating and the central beam is used for instant welding, which largely reduces spatter and bubbles and improves the welding efficiency.

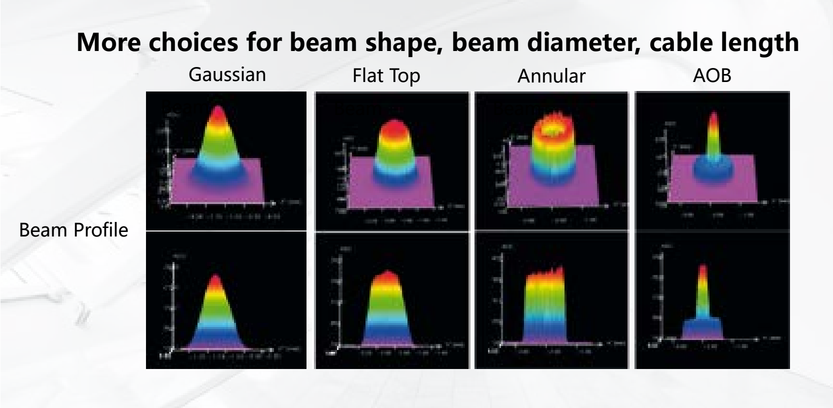
Company

Shenzhen JPT Opto-Electronics

Registered in 2006, JPT concentrates on the R&D, production, sales, and technology service of optical fiber devices, lasers and laser intelligent equipment.
Based on laser technology, JPT integrates leading technologies such as laser and optics, test and measurement, motion control and automation, and machine vision.
The company highly values intellectual property and has applied for more than 600 patents.
JPT ranks: top 1 of MOPA pulsed fiber lasers globally, top 3 of fiber laser manufacturers in China.

www.jptoe.com

JPT AOB fiber laser



Beam profile portfolio for JPT cw fiber lasers

JPT also offers flexible customizations for cw fiber laser sources, including fiber core, cable length, beam diameter etc., which could satisfy the requirements of different processes in the battery industry.

Using the correct laser leads to a higher success rate for specific applications. JPT has a specialized application lab with highly trained engineers and various types of equipment used for different applications (marking, cutting, welding, etc.), which helps customers to evaluate the processing characteristics before choosing the appropriate laser. We believe that the continuously innovative technology of JPT laser technology will drive the production and upgrade of the battery industry. You are welcome to contact us for any question.

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Lulu Song is very experienced in laser technology, from the laser principle to laser applications. After obtaining her Master of Science degree, she joined JPT as a sales engineer and has worked for many famous customers in the laser industry. As a bridge between laser source provider and laser manufacturer, a deep understanding of laser technology, good communication skills and excellent teamwork ability enables her to offer quick and professional support.

Xueqing Wang is senior project assistant for Shenzhen JPT Opto-Electronics. She received her master's degree from Huazhong University of Science and Technology in 2021. She has completed more than three years of academic research in optical technology. She has participated in the research of optical applications in key national research and development projects. At present, she mainly focuses on laser application research in the new energy industry.

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Monitoring the condition of a laser tool in production

Source all images: Primes

Fig. 1 The new FocusTracker

With its new FocusTracker FT, Primes has developed a flexible and cost-efficient measuring system to reliably monitor the focus position in real time, and with this also the quality of a laser-based process in production.

With respect to the ongoing discussion about sustainable and modern mobility concepts, 'conventional engines' such as combustion engines will be substituted by alternative drive systems. Of course, this requires different hardware and production processes, and whether for cutting, welding, cleaning, or coating, none of it works without the laser. Because of this, about half of the costs are incurred in the battery and drive production.

Hydrogen fuel cells require leak-proof welding seams, which are comparatively long. The bonding within battery cells must be performed at a constant high level, as variations would have a direct impact on the performance of the battery. And last but not least, one of the most complex components of the electric motor is the stator: hairpins that need to be prepared and positioned accurately to be welded in high quantities require not only a stable process but also high throughput. To reduce cycle times, laser power is increasing while new laser sources, such as ring mode lasers, are being introduced.

Dr Thomas Umschlag, managing director of Primes, summarizes: "Laser processes are becoming more and more complex. At the same time, efficiency and throughput requirements are increasing in order to maximize profitability. So better utilization of the process window is essential and, in order to achieve this, real-time quality assurance will be key to success."

Optimizing the laser process in cutting or welding applications

Ideally the laser beam cuts or welds as long as a defined power density reaches the process surface. Since the focal position of a laser is not constant, the power density on the workpiece varies over time. This variation is acceptable and can be handled as long as it stays within the process window. However, any contamination of the protective window can instantly force the laser focus position to leave this 'sweet spot'. Apart from the loss in laser power, the change in focus position will result in changes, for instance, of the welding depth or the heat-affected zone and can happen due to increased absorption within the glass, which leads to thermal lensing effects and will shift the focus position towards the focusing lens. As a consequence, the risk of production losses is increased if no countermeasures are taken to avoid focus shift.

One internal system parameter that is not regularly monitored and can cause spontaneous failures in production is the shift of the laser focus over time. The effects of focus shift are well known; just a quantitative evaluation was missing until now. Only strict process control tells the user when maintenance measures are necessary, so that the process runs within the respective process window.

Contamination alone causes what is shown in Fig. 2. Within the first twenty seconds, the focus position is 'relatively' stable. Triggered by spontaneous contamination of the protective window,

Company

PRIMES

PRIMES develops and produces systems for laser beam characterization in industrial applications. For thirty years, its spectrum of high-precision, durable products finds application in numerous branches, such as the automotive industry, industrial machinery, additive manufacturing, R&D and laser manufacturing. The systems are easy to integrate in production processes due to their standardized interfaces. The company is located in the Rhine-Main area and has about 130 employees.

www.primes.de

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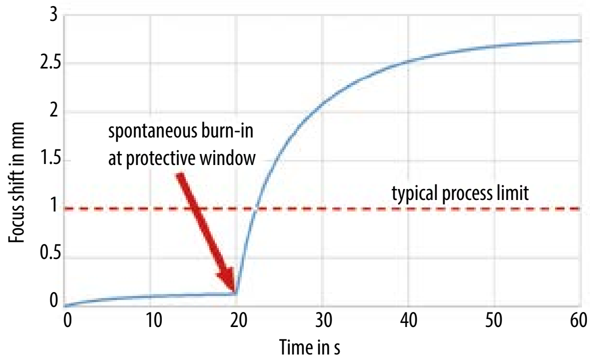

Fig. 2 Relevance of focus shift in production

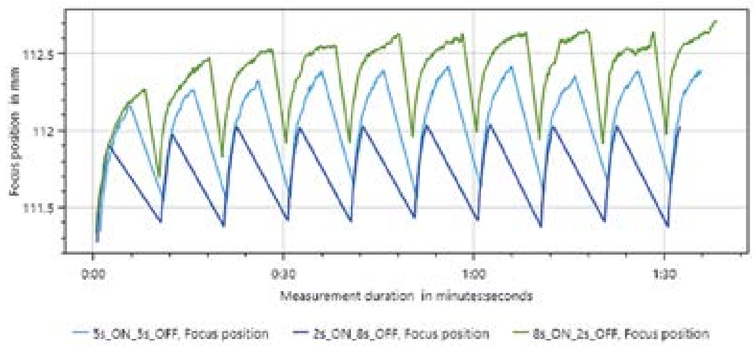

Fig. 3 Focus shift depends on absorption of optics, laser power, laser on time and off time

however, the focus shift increases significantly from 20 s onwards. The dashed line corresponds to a threshold of the process window. The process thus leaves its sweet spot immediately after contamination. By constant monitoring of the focus shift, immediate measures can be taken.

Tracking the focus shift in production

The new FocusTracker FT measures the focus position with a high time resolution at process-relevant power levels. The shift of the focus position, and therefore the condition of the processing head, can be monitored in real time. The wear of the protective window and the aging of the optics can be tracked and analyzed, which makes it easier to plan preventive maintenance cycles. Unscheduled downtimes or process interruptions can be minimized.

The measuring device is placed in the process area, about 90 mm below the focus. A small fraction of the laser light is coupled into the measuring device, while the majority passes through. The analyzed beam is further attenuated internally and the laser power is dumped in either a water-cooled or an air-cooled absorber, selected depending on the laser power and the measuring time. This enables the FocusTracker FT to be used in vastly different applications from the lowest to the highest laser power.

The new system measures the angular distribution of a divergent laser. Measuring a defined section of the angular spectrum, the focus position can be determined with a resolution of below 50 µm in the *z* position. This highly accurate measurement of the focus position enables the user to define the machine TCP (tool center point). This accuracy is achieved by two internal optical setups, which can be selected depending on the actual divergence of the laser. The system provides a measuring range from 30 to 180 mrad (full angle), which will cover nearly all addressed laser applications regardless of whether they are using fixed optical setups or scanners in remote applications.

Since the measurement principle can be adapted to various wavelengths, a pre-production series of the FocusTracker FT has been setup for NIR and green lasers. The optical configuration will allow an average power of up to 12 kW at 1 – 1.1 µm and up to 4 kW at 510 – 540 nm. The design is flexible and allows for even higher powers and different wavelengths on demand.

Benefits of the high temporal resolution

"The highlight: the measurement is so fast that the focus shift can be measured not only in continuous laser operation, but also during changing cycle times, i.e. under real production conditions," says Umschlag. **Fig. 3** shows such a process.

The screenshot from the Laser Diagnostics Software shows three different measurements. The chosen laser power was 3 kW over all three measurements, but the duty cycle was changed (dark blue: 20 %, light blue: 50 %, green: 80 %). This is a very typical process in serial production, with short weld seams or even spot welds that are continuously repeated.

The obvious conclusion is that an increased optical load leads to an increased focal shift. One can also see the accumulation of focus shift in the green graph where the optics cannot fully cool down between each measurement. But the data provided from the FocusTracker enables a much closer look into the process parameters. **Fig. 4** shows a typical focus shift measurement using the FT. The time constants of the

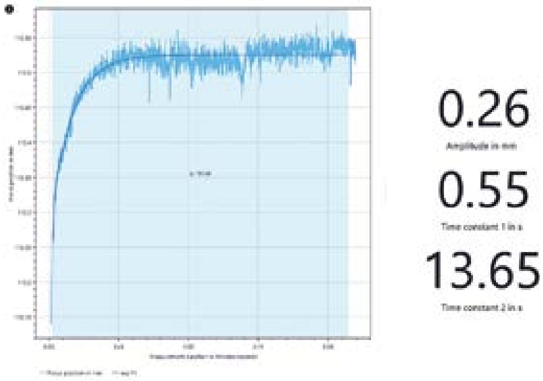

Fig. 4 Tracking the focus shift enables qualification of processing heads and characterization of focus shift

exponential fit line can be easily determined within its evaluation tool. Based on these values, the behavior of an optical setup, for example a focusing head at different power levels and loads, can be predicted. As a result, long test sessions with different beam sources and power levels can be shortened to a minimum.

"With the new FocusTracker FT, Primes has developed an ideal tool to track and characterize the focus position in real time. With its unique design, it can be used under real production conditions and allows to identify even small deviations from the ideal focus position with maximum performance. It can significantly contribute to process optimization and increasing productivity in various fields of application," Umschlag concludes.

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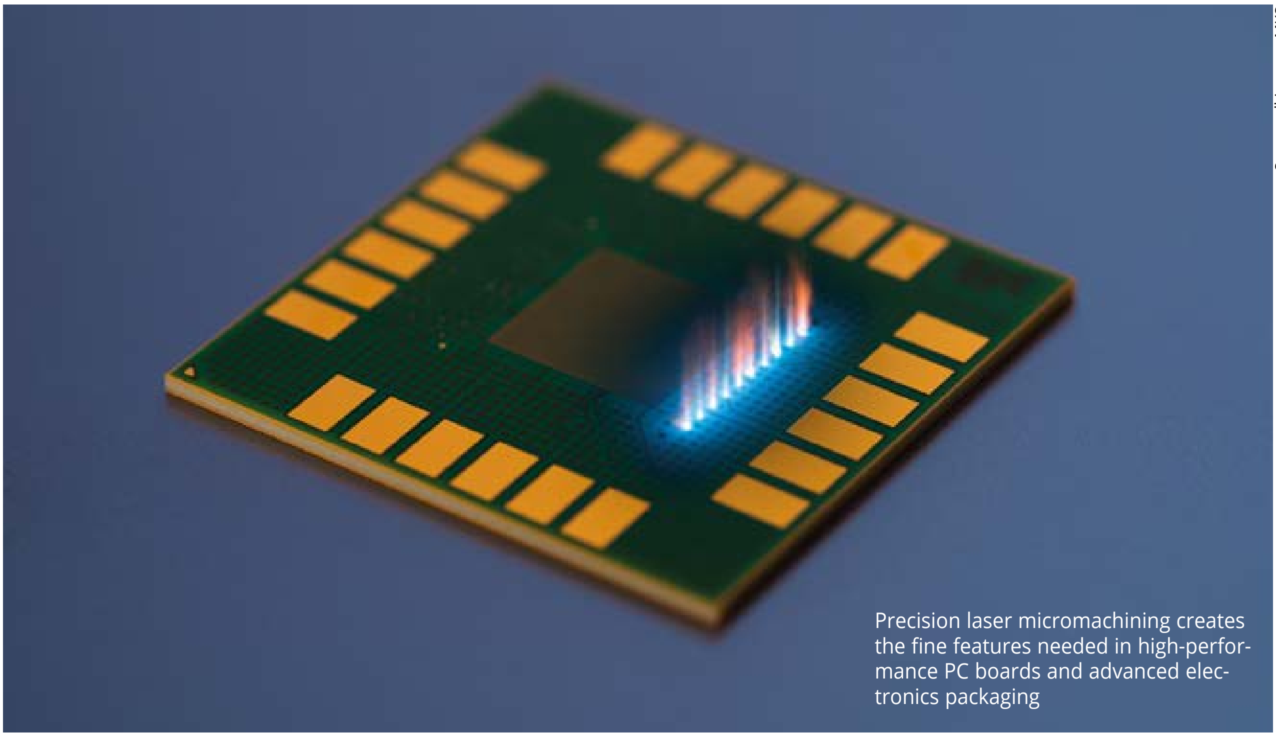
Sustainable and efficient micro-machining solutions

Cutting 5G flex PCB materials with a high energy, high power, nano-second UV laser

Jim Bovatsek



Source all images: MKS

Precision laser micromachining creates the fine features needed in high-performance PC boards and advanced electronics packaging

The global shortage of semiconductor chips is not only leading to new perspectives on how to organize global supply chains, but it also pinpoints the need to further enhance quality and efficiency in production processes. By exploring new options on how to use and measure ultrashort-pulse lasers, MKS Instruments is highlighting ways on how to optimize production processes.

Laser technology has significantly improved micromachining applications and continues to have a strong impact on advanced electronics packaging and printed circuit board (PCB) manufacturing, helping to drive the development of devices with improved performance and lower power consumption. Pulsed ultraviolet laser technology in particular has paved the way to high-volume manufacturing applications with more consistent and environmentally friendly processes. At the same time, there is a strong need for the measurement industry to keep pace with the latest laser developments. Synchronized research and innovation in both areas are therefore essential for the further improvement of the process chain and the evaluation of how to use sensitive materials.

New materials to enable 5G mobile communications

The mobile device market is one of the drivers in the development of advanced electronics packaging and printed circuit board (PCB) manufacturing, with laser technology playing a key role. A highly diverse set of materials – from thick fiber composites like FR4 to thin flexible laminates (flexible PCB or FPCB) – are now processed in a variety of ways using a range of laser sources. One such development is in 5G mobile communications, which enables significantly increased wireless data rates. Unsurprisingly, new materials are required to receive, manipulate, and transmit data at dramatically higher speeds, and the conventional polyimide dielectric layer has to be replaced with advanced materials such as modified polyimide (MPI) and liquid crystal polymer (LCP), both of which provide superior dielectric performance at 5G frequencies. For various reasons and including its suitability for much higher frequencies as well as for antenna related components, LCP is seen as a preferred material for 5G. In terms of laser processing, full-depth profile cutting/routing is carried out in FPCB manufacturing in which the final designed shape of a device or component is cut from the material sheet or web.

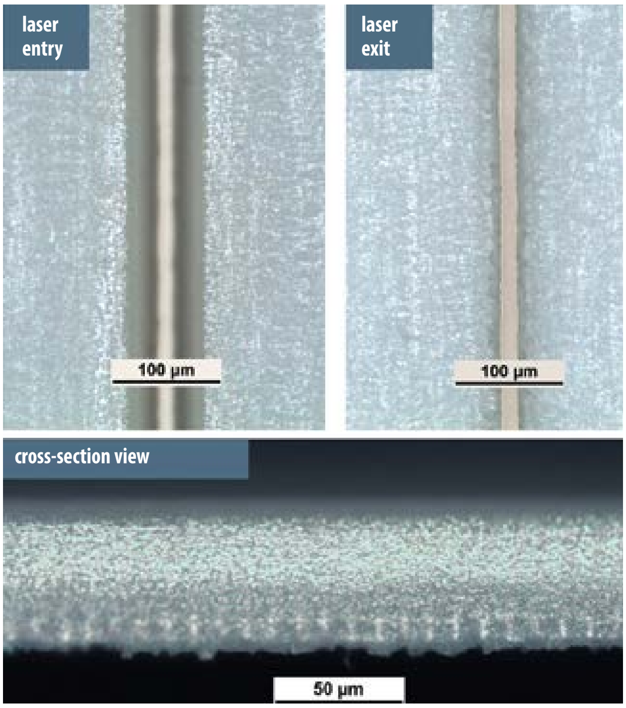


Fig. 1 Bare 50 µm thick LCP cut with Quasar UV80 laser. Entry (top left), exit (top right), and cross-section (bottom) views indicate excellent quality and minimal excess heating.

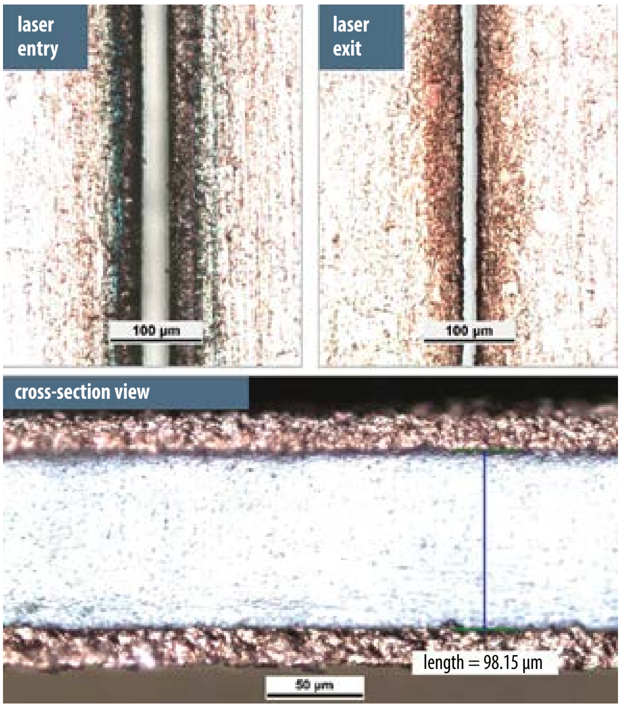


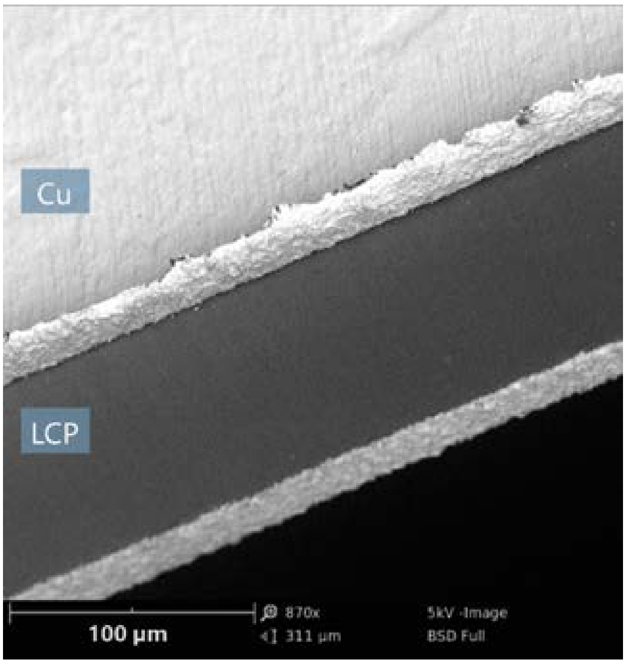
Fig. 2 Thick copper-clad LCP cut with Quasar UV80 laser. Entry (top left), exit (top right), and cross-section (bottom) views demonstrate clean, high quality cuts realized with temporally-tailored ns pulses.

High-power UV lasers for full-depth cutting

High-power ultraviolet (UV) hybrid fiber lasers are ideally suited for full-depth cutting in FPCB manufacturing. MKS industrial laser application researchers took a closer look to the quality of the cuts: they performed a series of cutting experiments with a Spectra-Physics Quasar laser with 80 W average UV power and up to 400 µJ per pulse. LCP-based FPCB materials, including bare LCP sheet and copper-clad LCP laminates were tested. The Quasar laser offers the flexibility of TimeShift programmable-pulse technology, which allows a range of temporally tailored pulse outputs (pulse widths, burst mode, pulse shaping) to be explored at a wide range of pulse repetition frequencies (PRFs), from single-shot to 3.5 MHz. All tests were performed using a 2-axis scanning galvanometer for high-speed, multipass processing, and an f-theta objective (f = 330 mm) was combined with a variable beam expansion telescope to explore a range of focal diameters (20 – 35 µm, $1/e^2$ diameter).

Challenges in measuring the beams

The cutting depth of the laser depends greatly on the energy applied to the material. It is essential to keep the pulse energy of the beam exactly in spec, but



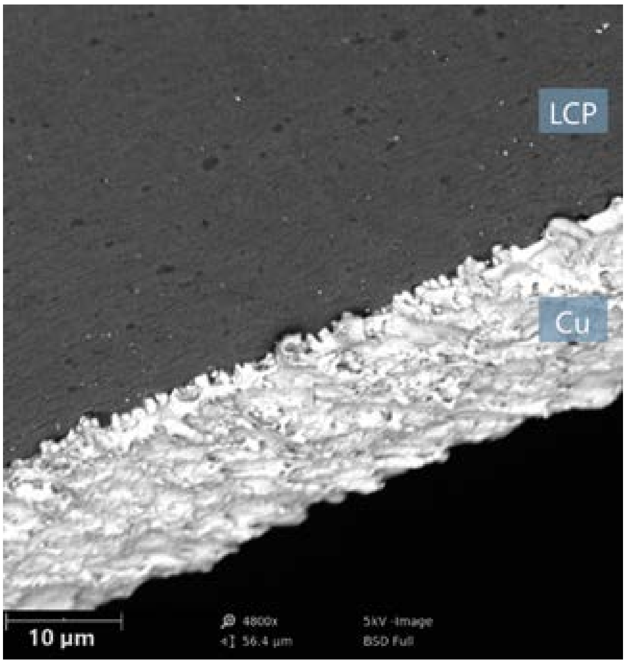


Fig. 3 SEM imaging reveals smooth material surfaces and crisp geometries of the copper-clad LCP cut with Quasar UV80 laser.

Fig. 4 Close-up SEM view shows Cu-LCP is fully intact after laser cutting with no LCP pull-back from the copper cut edge.

measuring the laser beam is no easy task because the peak power of the beam is high due to the high pulse energies and short pulses. Measuring the average or intermittent power of the beam is only possible with dedicated sensors that are able to withstand higher power densities. By using a newly-developed coating, thermal sensors like the Ophir F80 (120) A-CM-17 enable the measurement of the nanosecond pulsed UV laser in the application described above. Due to its unique absorber, the sensor will not suffer from the ablation usually caused by very short pulses and can withstand high power densities up to 7 kW/cm^2 at 80 W.

Achieving optimal cutting results with LCP sheet material

In addition to the energy applied to the material, there are many other parameters that influence the quality of the cuts. The first tests in the series were performed on bare LCP sheet material with a thickness of 50 µm. Preliminary tests indicated that, similar to polyimide, the material has a relatively low ablation threshold with the UV light. Unlike polyimide, however, LCP is sensitive to excessive heating, and careful process optimization is required to avoid melting and charring. The optimal cutting results were found using short laser pulse widths (~2 – 3 ns) and modest pulse energies delivered at high PRFs (>750 kHz). Optical microscope images in Fig. 1 show entry, exit, and cross-section views of the resulting cut.

The images demonstrate the excellent quality achieved with the ns UV pulses, showing little or no evidence of melting and charring. The cross-section view shows a finely textured machined surface that is free of thermal melt reflow (i.e. surface 'smoothing'). The cross-section view does reveal some 'channeling' towards the exit side of the cut. This is due to the high speed / low pulse overlap nature of the process and the diminishing ablation diameter that occurs with increasing depth, which results in nearly separated ablation 'dots' towards the exit side of the cut. In practice, this effect can be reduced or eliminated by reducing the beam scanning speed as the cut progresses deeper. The cut was achieved using thirteen overlapping scans at 8 m/s scanning speed resulting in a net cutting speed of ~615 mm/s.

High pulse energy for copper-clad LCP laminates

Cutting of copper-clad LCP laminates was also undertaken, with two different thicknesses of Cu / LCP / Cu-layered stacks available for our tests: 18 / 100 / 18 µm and 9 / 25 / 9 µm. The thicker material is particularly challenging, and higher pulse energies are helpful to avoid widening the cutting kerf width (such as by implementing a parallel line/raster scan process). With the Quasar laser's high pulse energy of up to 400 µJ however, such measures were not required. The laser's TimeShift pulse tailoring capability was exploited to study a variety of conditions, including short vs. long pulse widths and burst mode output. With longer (10 ns) pulses, cutting speeds were at the higher end at 100 – 120 mm/s, and quality tended towards smaller edge burrs but larger oxidation zones. Shorter (2.5 ns) pulses on the other hand were slower (~90 mm/s) and had taller edge burrs but exhibited significantly less oxidation. The best overall result was generated using a burst of short (2 ns) pulses, which gave the highest cutting speed of 130 mm/s and with quality characterized as moderate in both burr height and amount of oxidation.

The optical microscope images in Fig. 2 show such a cut from the entry and exit sides as well as a cross-section perspective. The microscope images show the overall good quality that can be achieved by careful process optimization and temporal tailoring of pulse intensity output. The excellent LCP cutting shown previously is preserved even when cut in tandem with copper cladding. In addition, since copper peel strength with LCP is generally much lower compared to that of polyimide, it is important to note that there is no evidence of delamination at the Cu-LCP interfaces. For the thinner 9 / 25 / 9 µm layered stack, similar results were observed but with a significantly higher net cutting speed of >350 mm/s.

Optical microscopy clearly highlights any oxide growth and areas of molten copper such as burrs, rough edges, etc. that occur when machining copper with ns pulse lasers. Scanning electron microscopy (SEM) is a preferred alternative for the very close-up imaging of fine surface structures and the modulation thereof, and was applied for further analysis of the cut samples. Fig. 3 shows a macro perspective of the 18 / 100 / 18 µm stack as viewed through an SEM.

Viewed with electron vs. light microscopy, the optical effects of thin oxides and scattering/reflective nature of previously molten copper are not as strongly apparent, allowing one to focus on the true dimensional aspects of the surfaces such as modulations, edge straightness, and the like. Here, the SEM image reveals a clean and precisely machined feature with high-quality surfaces.

Of particular note are the smoothness and verticality of the LCP cut edge, with no apparent 'barreling' or pull back from the cut edges of the copper layers. A highly magnified SEM view of the interface is shown in Fig. 4 and confirms that the bond between the LCP and Cu layers is nicely preserved. Greater detail also shows a smooth and flat LCP surface, without any pull-back from the edge of the cut copper.

UV laser approved for high quality cutting processes

New materials are often ushered in with new technologies, and manufacturing methods and measurement equipment must adapt accordingly. For 5G mobile devices, the high data rates and high-speed electronics require the replacement of traditional polyimide dielectrics in FPCBs, in many cases with LCP films and laminates. To optimize the manufacturing process of those materials, it is essential to choose the best-suited laser technology, fine tune the parameter set and – when using the laser – check the energy of the laser beam regularly with suitable devices. The experiments performed in the MKS lab showed excellent cutting results with a high power and high pulse energy Spectra-Physics Quasar UV laser. The flexibility inherent in TimeShift programmable-pulse technology was beneficial in addressing the widely varying thermal and optical properties presented by the materials, allowing for the development of a high quality and high throughput precision laser cutting process.

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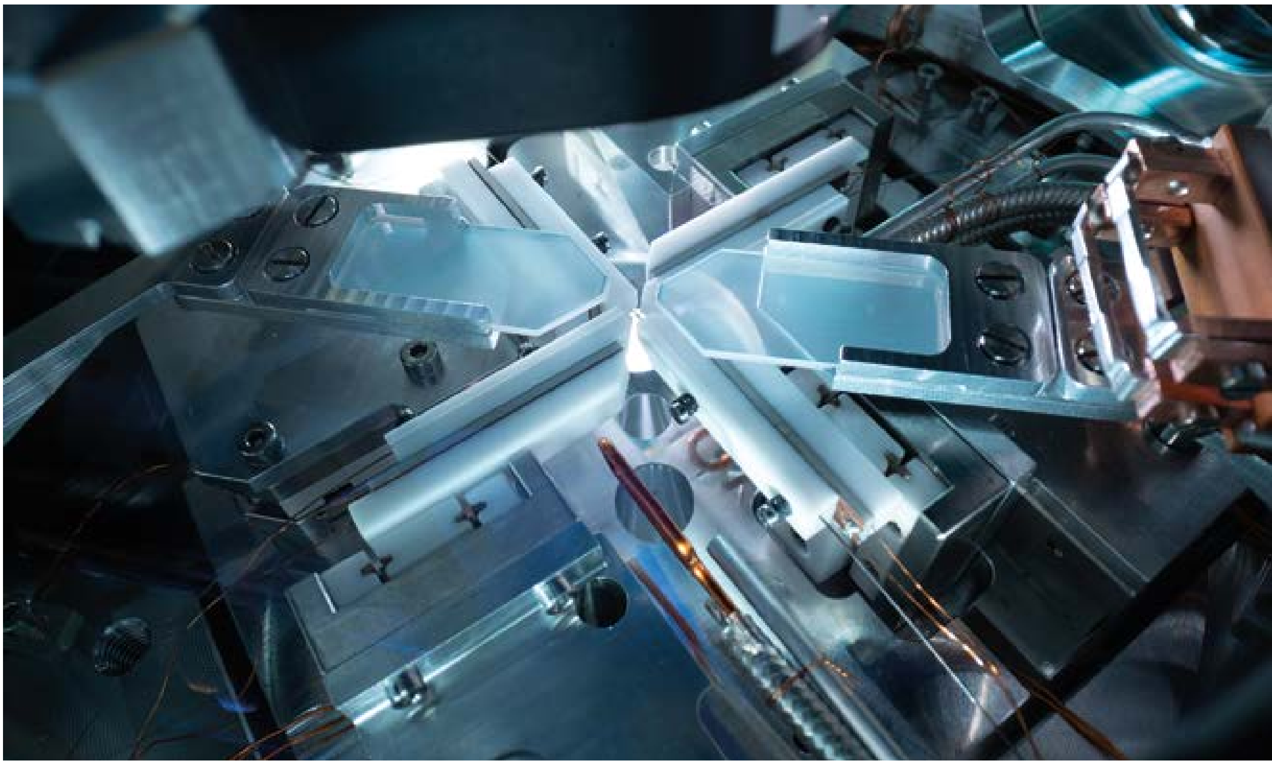
High-precision positioning technology for high-performance quantum networks

How piezo-controlled, crossed optical fiber cavities coupled to one atom are used for high-fidelity quantum nodes and qubit detectors

Kolja Kolata


Source: Christoph Hohmann, MCQST

A team led by Gerhard Rempe at the Max Planck Institute of Quantum Optics uses SmarAct's nano-precise, stick-slip piezo stages to enter the uncharted territory of quantum communications. In order to make this happen, they couple-crossed optical fiber cavities to one atom. This setup essentially forms a quantum network node that connects to two quantum channels, one provided by each cavity. It features passive, heralded and high-fidelity quantum memory that is not dependent on any amplitude and phase-critical control fields or error-prone feedback loops. Slight modification to the crossed optical fiber cavity setup provides non-destructive qubit detection within quantum networks. Both the highly reliable quantum memory system and the nondestructive qubit detection represent breakthroughs that pave the way for fully functional, large-scale quantum networks with multiple connected nodes [1, 2].

▲ **Fig. 1** Two optical fibers mounted on SmarActs high-precision positioners are crossed to form two resonators to trap an atom inside.

Quantum computers and quantum cryptography promise game-changing performance for a wide field of applications, tap-proof data traffic being one of the most sought after. Quantum-encrypted communications require undisturbed exchange of qubits – the smallest unit of quantum information – over long distances to be practical although, up until now, this exchange has been far too complex to be applied to everyday life applications such as e-mail or wire transfers.

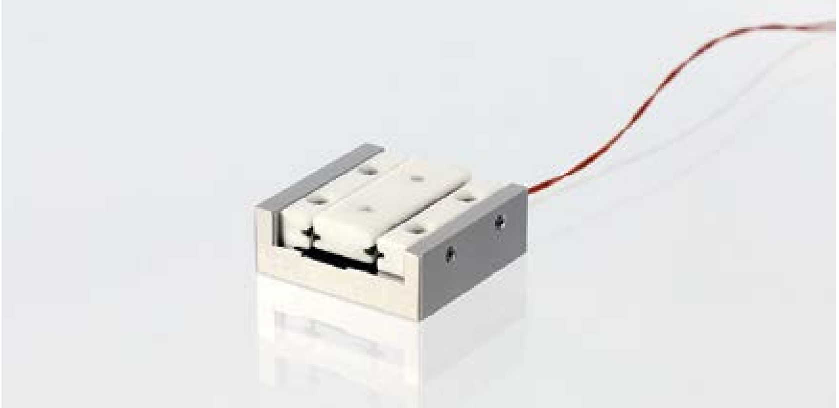


Fig. 2 High-precision non-magnetic linear stages like this one were utilized in the setup shown in Fig. 1.

Qubit carrying photons in particular are one of the biggest challenges: photons get lost due to scattering and absorption events within the network's fibers, and with them the encoded quantum information. As a result, thousands of photons would have to be transmitted in order to directly transmit only a single qubit over a distance of 100 km. Accordingly, transfer of quantum information can be quite 'time-consuming' despite speed-of-light transmission [3].

Gerhard Rempe and his group at the Max Planck Institute of Quantum Optics (MPQ) in Garching near Munich, Germany, have developed two key components that drastically improve the performance of quantum network schemes with web-like structures: heralded and high-fidelity quantum memory nodes that are the building blocks of the network and non-destructive qubit detectors that monitor transmission between quantum nodes. Quantum nodes are essential for every quantum network; they must serve as a quantum memory device that receives, stores and releases an unknown and potentially entangled quantum state better than any classical memory. Non-destructive qubit detectors on the other hand drastically increase the performance of the network since they can detect whether qubits are lost during transfer or not, at any given point within the network, and initiate a retransmission whenever a lost qubit is detected.

Both techniques utilize crossed optical fiber cavities coupled to one Rubidium-atom which is trapped with an optical grid right at the crossing point of both fiber cavities.

To realize this setup used at the MPQ, the cavity fibers are mounted on stacks of high-precision, stick-slip positioners from SmarAct that enable adjustment of the cavity lengths, mode matching between cavity mode and fiber mode at the out-coupling mirrors and overlap of the modes of the two cavities in an ultrahigh vacuum [1].

The SmarAct stick-slip positioners must meet high requirements. They are based on piezo-electric drives, which provide the highest position-resolution of sub-1 nm while still being able to cover macroscopic distances of up to 12 mm. In addition, purely non-magnetic materials are used: ball-bearing guideways are made of zirconium dioxide with balls made of silicon nitride. The titanium base thermally matches with the ceramic bearing, ensuring reduced thermal expansion and strain. Non-magnetic materials are key to prevent any magnetic disturbances of the quantum states, which would lead to an increased decoherence rate and therefore an increased loss rate of the quantum information. Other advantages of the stick-slip positioners are their compact dimensions in combination with their market-leading high blocking forces of more than 5 N. Both factors are beneficial for the rigidity of the setup and essential to keep vibrations to a minimum. Finally, although not so importantly, the stages are completely ultrahigh vacuum compatible down to 10^{-11} mbar and, in order to achieve these low pressures, they are bakeable up to 150 °C.

In the quantum memory nodes, one cavity is connected to the qubit channel and the other cavity is connected to the herald photon channel. The trapped Rb atom essentially stores the qubit and 'reports' successful storage by coupling both channels. During a writing process, two events occur: the qubit carrying photon excites the Rb atom which emits a photon into the herald channel. Subsequently, the herald photon is detected, 'reporting' successful storage. The ingenious part is that qubit storage is only successful when a herald photon is emitted. The reading process works in the reverse way: a herald photon excites the Rb atom, which as a result reemits the stored qubit with a photon into the qubit channel. Again, this process can only happen when a qubit was stored in the Rb atom beforehand [1].

The non-destructive qubit detector works with a similar crossed cavity setup coupled to one Rb atom. One cavity is connected to the quantum network so that a qubit-carrying photon can reach it once it travels along that path. The second cavity is connected to the detection channel. In order to detect the photon without destroying its qubit information, the atom inside the cavity is first prepared in a superposition of two atomic states with a microwave pulse. One atomic state is strongly coupled to the qubit microcavity mode, the other state is not. The qubit photon can then only enter the cavity in the latter case in which it acquires a π phase shift upon reflection. As a result, the phase of the superposition state is also flipped by the reflected qubit photon. After the last microwave pulse, the state of the atom is read out by additionally exciting it from the side with a laser beam. If no qubit was reflected at the first cavity, the atom is in a state resonant to the laser beam after the last microwave pulse and therefore often excited so that fluorescent light – i.e. many photons – are emitted that couple to the second cavity, signaling that no qubit was seen.

If a qubit was reflected at the first cavity, the atom is in a non-resonant state to the laser beam after the last microwave pulse and therefore cannot be excited. No photons can couple to the second cavity. Therefore it is signaled that the qubit has been seen. In this way it can be determined whether a qubit photon has passed the detector, preserving the qubit state and causing only a phase shift [2].

Model calculations show that the detection of qubit carrying photons increases the performance of quantum communication by minimizing the loss of information. Accordingly, this detector would already accelerate the transmission of quantum information at a greater distance than fourteen kilometers. An efficiency gain is also possible for shorter distances. This would require an improvement of the fabrication quality of the resonators as the current setup reflects only about one third of the incoming photons. Since this is 'only' a technical challenge and not a fundamental limit of the measurement scheme, doubling the detection efficiency will be possible in the near future [3].

Parallel to this, high-tech companies like SmarAct are already able to provide the necessary positioning technology and are constantly improving it. The conditions for a quantum internet are evolving in all areas, making it more and more realistic for many promising and game-changing applications to be developed.

*

We sincerely thank Prof. Rempe and his working group, both in former and current composition, for the inspiration and are very grateful that we are allowed to be involved in such mind-blowing projects – at least to a small extent with our positioning technology. In particular, we would also like to thank Tobias Frank, who helped us to realize this article.

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[1] *M. Brekenfeld, D. Niemietz, J. D. Christesen & G. Rempe:* A quantum network node with crossed optical fibre cavities, Nat. Phys. **16** (2020) 647–651.
[2] *D. Niemietz, P. Farrera, S. Langenfeld, & G. Rempe:* Nondestructive detection of photonic qubits, Nature **591** (2021) 570–574.
[3] https://www.mpq.mpg.de/6456061/04-tracking-for-quantum-post

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Kolja Kolata has supervised the setup for Prof Dr Rempe's working group as an experienced sales engineer at SmarAct.

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Preview

Full article online and in PhotonicsViews issue 3 / 2022

Taming an articulated laser

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

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. 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.

Combining the advantages of an articulated arm with the alignment procedure yield a better beam delivery system in terms of performance, and the proliferation of various laser wavelengths.

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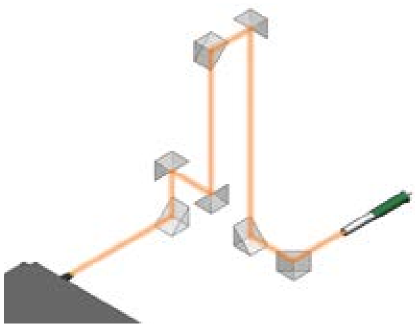

Laser ray trace within a hollow articulated arm (Source: Duma Optronics)

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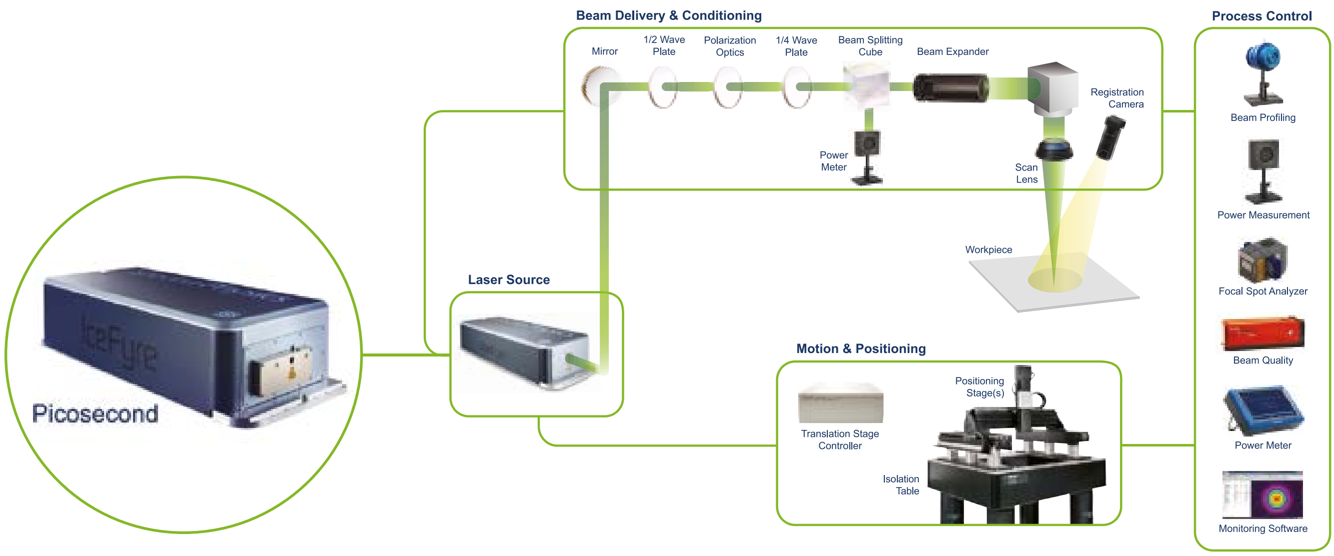

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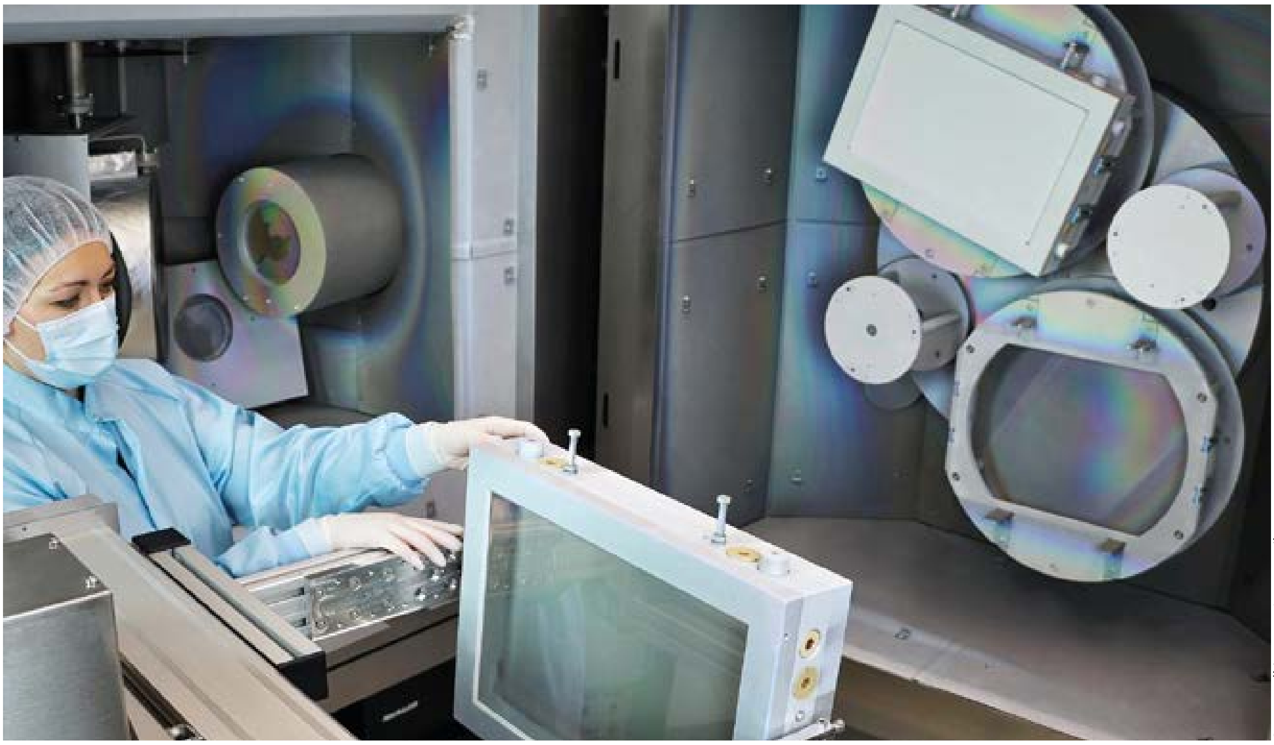
New IBS coatings boost performance of petawatt laser mirrors

Transporting HAPLS, the world's highest average power PW laser of ELI Beamlines

Thomas Willemsen, Uddhab Chaulagain, Stefan Borneis, and Wolfgang Ebert



Source all images: Laseroptik

Simply put, the performance of a laser is just as high as the quality of its optics. Latest advances in petawatt laser technology have stimulated the development of large surface area, dielectrically coated mirrors to guide these demanding ultrashort pulse laser beams. We describe major achievements during the development and fabrication of ion beam sputtered 440 × 290 × 75 mm^3 beam transport mirrors for the HAPLS laser at ELI Beamlines. A laser damage threshold greater than 0.9 J/cm^2 was measured.

The history of modern optical coating starts somewhere in the early part of the last century with the advent of high vacuum technology, one basic necessity for the rapid progress in thin film deposition. Thin silver films for Fabry Perot interferometers could first be produced using this technique. However, the ongoing breakthrough of the laser and increased sophistication of optical instruments enforced the search for high-quality optical coatings.

Evaporated coatings soon became the state-of-the-art to produce high-quality laser mirrors. These coatings are deposited in a heated high vacuum chamber (>250 °C), mainly by using electron beam guns. Each gun emits a high-voltage, accelerated electron beam that is directed into a water-cooled rotating crucible containing the coating material. The beam melts and evaporates the material at temperatures as high as ~2000 °C (Fig. 1, left). The high deposition rate and large available coated area lead to a good cost-performance ratio. As a drawback, evaporated layers are more porous, which results in a spectral shift and wavefront change depending on the humidity of the surrounding medium (thermal drift, vacuum-air shift). Ultrasonic cleaning is usually prohibitive for e-beam coatings.

Ion-assisted deposition (IAD) is based on electron beam evaporation (EBE) with an additional ion gun (Fig. 1, right). The plasma is directed onto the calotte and provides an ion bombardment of the growing layer which results in a denser microstructure and thereby minimizes the thermal and vacuum-air drift.

Both conventional coating techniques are well established in the industry but reach their limits when it comes to the deposition of most complex thin

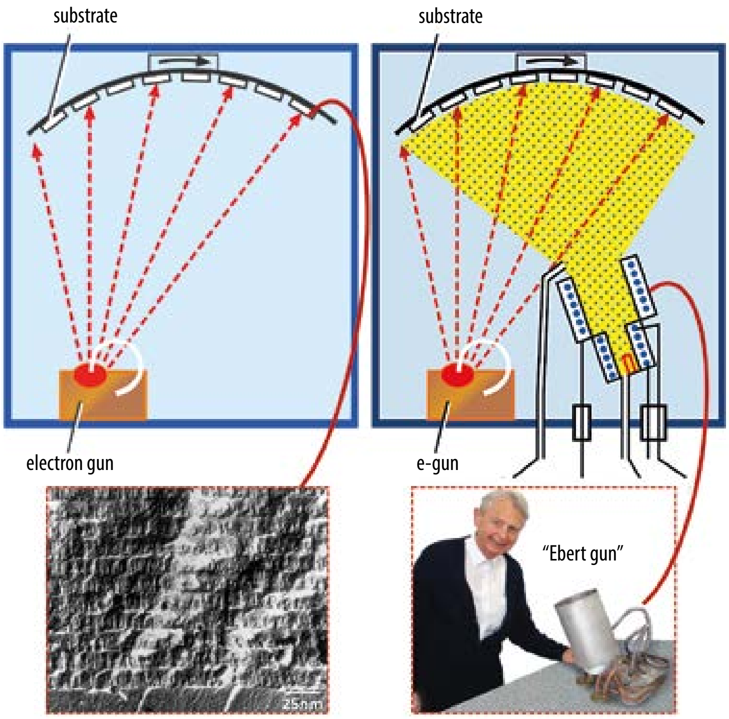


Fig. 1 Overview of conventional coating technologies for high quality laser optics. Left: electron beam evaporation chamber (EBE). Lower left: porous layer structure of evaporated thin films. Right: Ion-assisted deposition (IAD). Lower right: Dr Johannes Ebert, founder of Laseroptik, with his in-house developed ion gun.

films, e.g. the lowest losses or dispersive mirrors for ultrashort pulse applications.

These thin films require advanced deposition techniques like magnetron sputtering or ion beam sputtering, IBS (Fig. 2). In detail for an IBS process, an argon plasma is generated inside an ion source. The ions are accelerated by a grid assembly up to 1.5 keV energy towards the sputtering target with the desired coating material. The target assembly can be equipped with up to three different materials. In combination with a reactive gas (oxygen), compact dielectric layers are grown on the substrates. In general, the substrates need to rotate to achieve a sufficiently high layer uniformity. The dedicated IBS machine used at Laseroptik for the deposition of large-sized substrates is also equipped with a special planetary gear that improves the radial uniformity. The planetary gear consists of two planets, each of which can carry substrates up to a maximum diameter or diagonal of 550 mm (either round or rectangular) with a maximum weight of 50 kg. The layer variation on the full diameter of each planet is less than 0.5 %. The mirror blanks are handled with automatic lifting tools and are cleaned in automatic ultrasonic cleaning machines.

IBS-coated mirrors offer unique benefits for the beam transport of petawatt laser beams. The compact and dense layer structure prevents a thermal or vacuum-air spectral shift and a change of the wavefront when vacuum cycled. In addition, the layer structure enables the automatic cleaning of these sputtered optics in ultrasonic cleaning stages.

State-of-the-art, more porous e-beam coatings used for large-sized laser mirrors exhibit changing coating stress, depending on the humidity of the surrounding medium. This can lead to tensile stress-induced crazing of large-sized mirrors, especially on fused silica substrates. Furthermore,

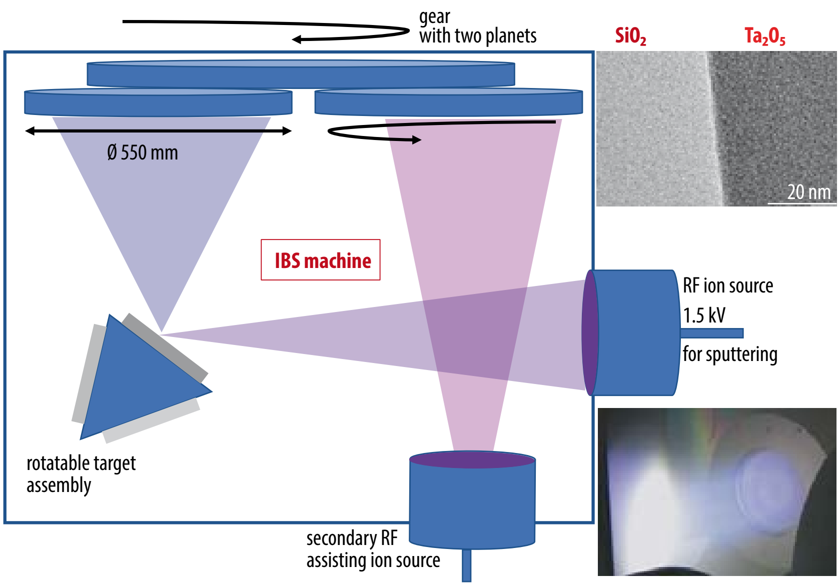


Fig. 2 Schematics of the large-sized IBS machine. Upper right: high density, low scatter layer structure of IBS films.

Company

LASEROPTIK

The company from Garbsen, northern Germany, is a manufacturer of high LIDT laser optics and coatings from VUV to IR and employs more than 38 coating machines with seven different coating methods, e.g. magnetron and ion beam sputtering. Products include mirrors, partial reflectors, AR coatings, thin film polarizers, complex filters, chirped mirrors and mirror pairs. Special IBS capabilities are available for coatings on large substrates. The main applications are for industry, medical technology and scientific research.

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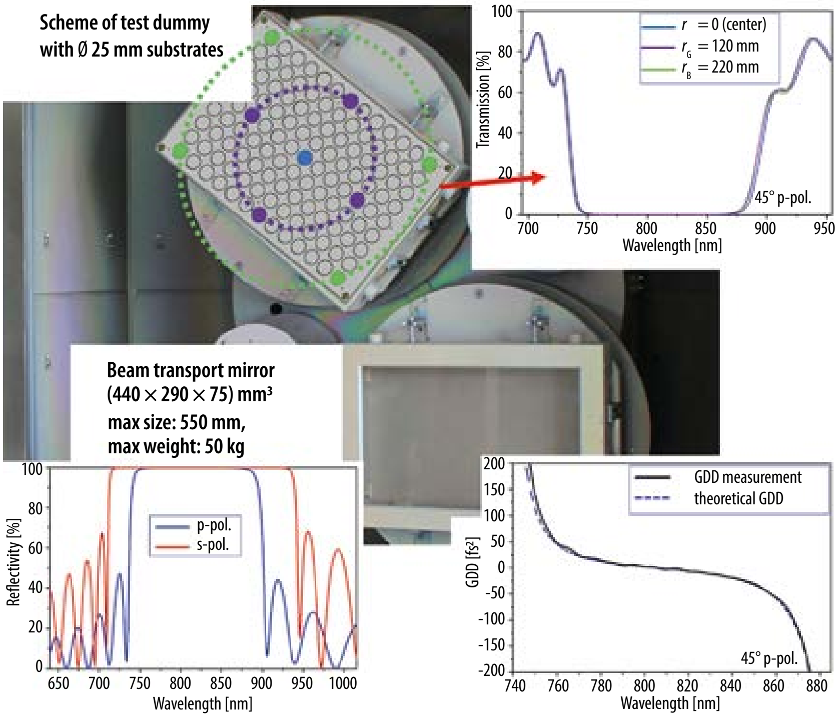

Fig. 3 View inside the IBS coating chamber with a mounted beam transport mirror substrate. Upper right: demonstrating the layer uniformity of the beam transport mirrors by spectral measurements of Ø 25 mm coating witness samples located on different radii.

the more porous layer stacks tend to absorb more contamination that can arise during handling and vacuum-air cycles. Ultrasonic cleaning could damage or even ablate such conventional coatings.

However, one major challenging performance parameter, the highest possible laser induced damage threshold (LIDT), cannot be addressed directly by the coating process. The damage mechanisms depend strongly on the pulse regime of the applied laser and have been a field of intensive research for more than thirty years. Within this article we will focus on optics for a PW laser beamline operating in the ultrashort pulse range – femtoseconds (fs) to low picoseconds (ps). In this time range, laser-induced damage is driven by electronic processes in the applied coating materials. Electrons of the respective coating material are excited into free states via multiphoton absorption and avalanche ionization. At some point a critical density is reached and a coulomb explosion introduces the damage. This damage behavior is strongly deterministic, and the expected damage threshold can be calculated very accurately depending on the well-known and characterized coating materials. Unfortunately, there is only a limited number of coating materials available in order to manufacture high-performance fs-laser mirrors with a sufficiently high reflectivity ($R > 99.8\,\%$) and negligible losses. At least two coating materials with a differing index of refraction are required for the design of optical components.

Because of the time-bandwidth relation, ultra-short pulses usually require the highest index of refraction coating materials to achieve a few 10 nm bandwidth. In general, such dielectric materials with a higher index of refraction are characterized by a weak, intrinsic laser-induced damage threshold in contrast to dielectric single layers with a low index of refraction. In an alternating layer stack of high and low refractive index materials, the LIDT of the complete layer stack is determined by the correlation of the electric field strength inside the stack and the intrinsic LIDT of the respective applied material. The highest LIDT values required for PW applications can therefore be achieved either by implementing new coating materials or by a manipulation of the electric field. Novel coating materials have been created in the last few years by sputtering ternary composites or quantized dielectric nanolaminates. The optical band gap can then be tuned and improve the intrinsic LIDT. Especially with the application of quantized nanolaminates, it is possible to tune the optical gap while maintaining a high index of refraction. The LIDT of most complex dielectric components for ultrashort pulse applications may be increased substantially in combination with numerical approaches to manipulate the electric field. Such design strategies are very sensitive to even the smallest deviations of the process parameters. The required high accuracy and repeatability can be met mainly by sputtering techniques like IBS.

As a short interim conclusion, sputtered mirror coatings for PW beamlines offer multiple advantages over conventional e-beam coatings:

- The dense layer structure eliminates the risk of crazing when exposed to a vacuum.
- The precision and reproducibility of an IBS process opens the door for the manufacturing of most complex designs, allowing a manipulation of the intrinsic electric field and consequently the LIDT. Such sophisticated designs cannot be realized with conventional evaporation techniques.

So far, IBS has rarely been used for large ultrafast laser mirror coatings. In the next sections we show the results of the large beam transport mirrors that were coated using the large IBS machine described above that was developed in-house by Laseroptik. A total of ten 440 × 290 × 75 mm^3 mirrors in batches of two substrates per coating run were manufactured and characterized for this study. These mirrors guide the compressed 30 J, 25 fs HAPLS laser beam at a repetition rate of 10 Hz and a center wavelength of 810 nm entirely in vacuum onto the target.

Beam transport mirrors for ELI beamlines

The ELI Beamlines user facility currently commissioned in Dolní Břežany, close to Prague in the Czech Republic, provides access to high average power petawatt laser technology for basic science and multidisciplinary applications. The high-repetition-rate, advanced petawatt laser system HAPLS is a Ti:Sa system and was built at Lawrence Livermore National Laboratory (LLNL). It is designed for a repetition rate of 10 Hz. It is the first diode-pumped petawatt laser system ever built, and with 300 W has the highest average power, with a beam normal fluence of roughly 70 mJ/cm^2 at the compressor exit.

The real beam develops modulations of increasing intensity during its free

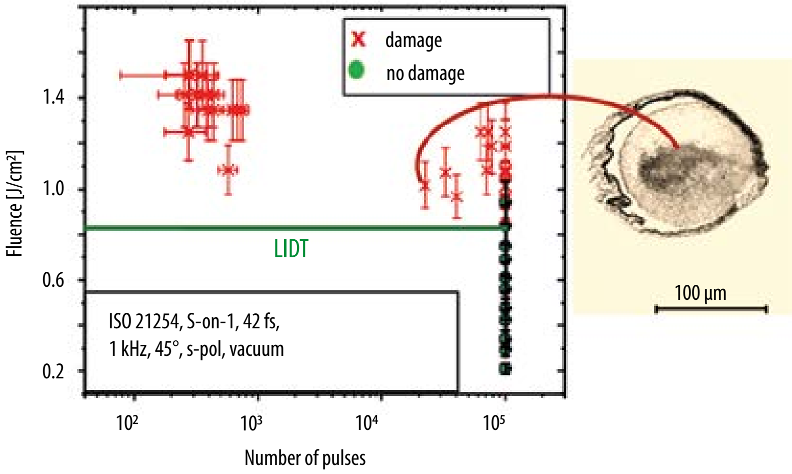

Fig. 4 Damage probability plot of a witness sample performed with the LIDT test bench of ELI Beamlines according to ISO 21254-2. The samples were irradiated with 100,000 pulses, if no damage occurred. The fluence values are calculated on the sample surface for s-polarized light.

space propagation (53 – 103 m), which originate from the phase to amplitude modulations of the phase errors of the non-ideal optics of the laser amplifier and compressor system as well as the beam transport up to the target. Consequently, the primary challenge of the HAPLS beam transport mirror coating design is to achieve the highest possible laser-induced damage threshold while meeting the reflectivity ($R_p \geq 99.8$ %), the group delay dispersion (GDD ≤ 50 fs^2) and bandwidth (80 nm for p-polarization) requirements at an angle of incidence (AOI) of 45°. The LIDT of the large-sized optics is expected to be decreased by target debris and local intensity spikes. The dielectric mirrors therefore require the highest possible LIDT margin to provide for a long lifetime and reliable operation. A major benefit of a high LIDT is the possibility to operate the beam transport without a complex and expensive reflective relay imaging system. Hereby, catastrophic optical damage due to intensity spikes during propagation can be avoided.

Evaluation of uniformity, GDD bandwidth, LIDT, wavefront and crazing risk

A design was developed and evaluated that applies an alternating quarter wave stack using a mixture of standard high and low refractive index materials, e.g. Ta_2O_5 and SiO_2. The spectral width ensures the specified reflectivity and a low GDD to preserve the 25 fs pulse width of HAPLS. The electric field intensity inside the layer stack was then optimized. A clear enhancement of the LIDT can be forecast with this design.

This coating has a bandwidth of more than 95 nm for p-polarized light while maintaining the GDD below 50 fs^2, centered at 810 nm (Fig. 3). Measurements of the GDD and the transmission or the reflection show no significant shift in the spectra for samples from different coating runs and prove the high reproducibility of our IBS process. In addition, a negligible vacuum to air shift could be confirmed with the spectrometer of the high resolution, optical broadband monitor for in situ thickness control within the IBS chamber.

Also, a tightly-specified layer uniformity needs to be ensured over the entire large aperture of the beam transport mirror. This is validated by placing various 25 mm diameter coating witness samples distributed over the full aperture of the turning mirror into a special sample mount as shown in Fig. 3. Again, the relative shift of the central wavelength of the mirror design can be compared depending on the position on the sample mount. A negligible relative shift of less than 0.25 % was measured over the full 440 × 290 mm^2 aperture of the HAPLS beam transport mirrors. This minimal shift is fully covered by the margin in the spectral width of the design.

Beside the spectral characteristics, it is important to measure and evaluate the LIDT of these mirrors. It was measured on 50 mm diameter witness samples that were included in every deposition run. The samples have the same surface finish as the full-size substrate and are LIDT tested in a vacuum. The LIDT tests were performed at ELI Beamlines according to the ISO 21254-2 S-on-1 test protocol with 42 fs pulses, a repetition rate of 1 kHz, an angle of incidence of 45° and s-polarized light. The number of pulses per site is set to

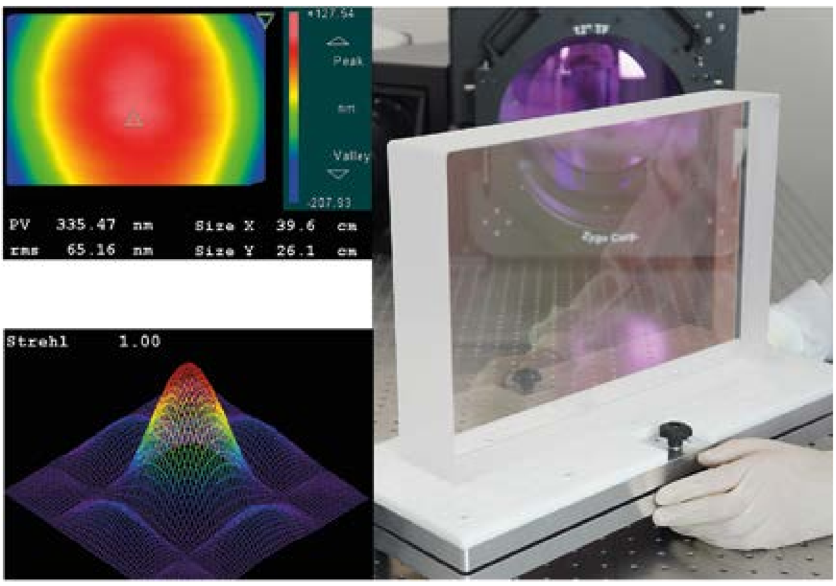

Fig. 5 IBS coated beam transport mirror during the wavefront measurement with a 12″ Zygo Verifire interferometer in the Laseroptik metrology clean room lab. Upper left: Typical wavefront after deposition for the 396 × 261 mm^2 clear aperture: 335 nm PV, 65 nm RMS. Lower left: Strehl after masking reflected wavefront error to 230 × 230 mm^2 and removal of power and astigmatism, resulting in 86 nm PV, 2.9 nm RMS

S = 100,000 pulses. A LIDT of 0.9 J/cm^2 (sample surface) could be demonstrated and the beam normal fluence is about 1.27 J/cm^2. The LIDT was measured for several samples from different coating runs and showed high reproducibility within the error bars of both the IBS process and the ELI Beamlines LIDT test bench (Fig. 4). Such a LIDT-optimized design with a spectral width of $\Delta\lambda$ = 95 nm in the case of p-polarized light and $\Delta\lambda$ = 170 nm for s-polarized light is a major advantage compared to conventional e-beam coated mirrors.

HAPLS is operated at 25 fs and a maximum of 10 Hz. The measured LIDT value at 42 fs can be extrapolated to 0.76 J/cm^2 at 25 fs on the coated surface (equal to 1.07 J/cm^2 beam normal). The peak fluence of HAPLS in the target chambers at 30 J operation should not exceed 0.2 J/cm^2. A safety factor of 5.4 (1.07 J/cm^2 vs. 0.2 J/cm^2) is expected to allow reliable routine operation.

In a next evaluation step, the large sputtered mirrors were exposed to multiple vacuum/air cycles in the beamline. The optical inspection after more than thirty vacuum to air cycles over a total period of two weeks showed no stress-induced crazing, as we expected for such compact IBS layers. Another important step was the analysis of the wavefront of all ten fabricated mirrors. Dielectric coatings introduce mechanical stress. Plane substrates become slightly convex due to the compressive stress of the sputtered HR coating. A radius of curvature (ROC) of >100 km is calculated for the coating on the 75 mm thick mirror substrates and is not critical for the application.

However, a more detailed analysis needs to be done for the impact of both the polish of the substrate and the induced stress of the coating on the reflected wavefront error (RWE). The RWE was evaluated and analyzed with a Zygo Verifire interferometer before and after coating. After coating, the peak-to-valley (PV) ranges from -214 nm up to -385 nm, depending on the surface figure (curvature) of the uncoated substrate. If required, the RWE can be significantly decreased by a well-calculated, stress compensation rear coating that is optimized for the specific front coating. The power and astigmatism term of the RWE may be compensated to a large extent by the adequate alignment of the focusing parabola in the target chamber.

These novel coatings have great potential to further advance the performance and the applications of petawatt laser technology. IBS coated components are expected to increase the up-time of PW laser facilities and to reduce operation costs significantly.

*

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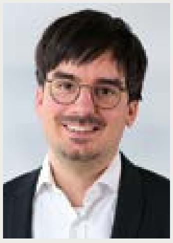
Authors



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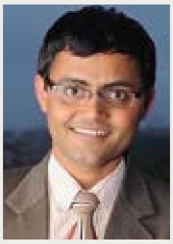

Uddhab Chaulagain works as an associate scientist at ELI beamlines. During his PhD at Pierre & Marie Curie University Paris, he worked on high energy density plasma physics research based on high-power lasers. He is currently leading the work on the development of laser-based ultrafast X-ray sources using state-of-the-art petawatt class lasers and their applications in plasma physics and fundamental science.

Stefan Borneis joined ELI Beamlines in late 2015 as senior consultant laser beam transport and is senior laser scientist at GSI Helmholtzzentrum für Schwerionenforschung. After receiving his PhD from Ruprecht-Karls-University in Heidelberg, Germany, in 1994, he worked on scientific and industrial lasers at Coherent Lambda Physik in Göttingen, Germany, and from 2001 to 2003 as manager laser product section at General Atomics in San Diego, USA. From 2003 to 2008 he was manager of the PHELIX petawatt laser program at GSI.

Wolfgang Ebert is the owner and CEO of Laseroptik. Starting work for the company in 1997, he learned the skills of a thin film engineer from scratch. After other positions in industry, he took over the general management from his father, Dr Johannes Ebert, in 2007. As CEO, he pushes new programs like the development of IBS, innovative coating concepts and other strategic and pragmatic advances. Technology management was the subject of his doctorate at the Leibniz University in Hanover, where he graduated from the faculty of economics.

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from 10:30 Check-in and Light Refreshments

Laser Markets in Europe, America and Asia
Chairman: *Prof. Peter Loosen*, Fraunhofer ILT, Aachen (D)

12:30 An Overview of the European Photonic Market and Industry article → page 68
Dr. Thierry Robin, TEMATYS, Paris (F)

13:00 Status Quo and Perspectives of the European and American Laser Market for Industrial Laser Processes
Jürgen Rumberger, TRUMPF Laser- und Systemtechnik GmbH, Ditzingen (D)

13:30 Status Quo and Perspectives of the Chinese Laser Market article → page 63
Dr. Bo Gu, BOS Photonics, Boston (USA)

14:00 Market Drivers and Perspectives of Laser Technology in Microelectronics
Dr. Dirk Müller, Coherent Inc., Santa Clara (USA)

14:30 Coffee Break – Visit of the Sponsors' Exhibition

Trends in Laser Processing

15:30 Challenges in Industrial Manufacturing of E-Drive Systems
René Schürer, GROB-WERKE GmbH & Co. KG, Mindelheim (D)

16:00 Room for Creativity – Shaping the Future with Additive Manufacturing
Christoph Hauck, toolcraft AG, Georgensgmünd (D)

16:30 Challenges and Opportunities in Industrial Femtosecond Laser Processing article → page 80
Eric Mottay, Amplitude Laser Group, Pessac (F)

17:00 LASER – The Tool for Digital Transformation
Dr. Christian Hinke, RWTH Aachen University – LLT, Aachen (D)

also **12:30 – 17:30**

SEMINAR – Laser Technology ABCs, Room K4-K5

Evening Event
19:00 – 23:00
Dinner with Presentation of the "Innovation Award Laser Technology" in the Coronation Hall of Aachen's Town Hall

FORUM – Process Control & Digitization, Room Brüssel

from 8:00 Check-in and Coffee Reception
Chairman: *Peter Abels*, Fraunhofer ILT, Aachen (D)

10:00 3D Geometry Recognition and Digital Process Chain for DED Processes
Dr. Oliver Steffens, Lunovu GmbH, Herzogenrath (D)

10:30 Process Monitoring for Additive Manufacturing using Sensor Fusion Approach
Emil Duong, Fraunhofer ILT, Aachen (D)

11:00 Automatic Monitoring of Laser Welding Processes with Robotic Guidance article → page 77
Charlotte Helzle, hema electronic GmbH, Aalen (D)

11:30 Online Detection of Defects during Laser Welding using AI
Dr. Michael Ungers, Scansonic MI GmbH, Berlin (D)

12:00 Lunch – Visit of the Sponsors' Exhibition

14:00 AI assisted In Situ Quality Inspection of Laser Welded Hairpin Joints
Johannes Gaigl, MAHLE International GmbH, Stuttgart (D)

14:30 Seeing the Unseen – Sensors with Sophisticated Data Models enable Higher Manufacturing Quality
Dr. Markus Kogel-Hollacher, Precitec GmbH & Co. KG, Gaggenau (D)

15:00 Challenges and Opportunities of Digitalization- and Sensor Concepts for Industrial Production
Frederic Schulze, Fraunhofer ILT, Aachen (D)

15:30 Coffee Break – Visit of the Sponsors' Exhibition

16:30 Convenience through Connectivity: OPC Unified Architecture for LPBF Systems
Thorsten Schreiner, AixPath GmbH, Aachen (D)

17:00 Acoustic Quality Monitoring in Laser Material Processing: An Overview
Dr. Wolfgang Rohringer, XARION Laser Acoustics GmbH, Vienna (AT)

also **10:00 – 17:30**

FORUM – Laser Additive Manufacturing, Room Europa

FORUM – Quantum Technology & Photonics, Room K2

Thursday, May 5, 2022

Gerd Herziger Session, Room Europa

Chairman: *Prof. Constantin Häfner*, Fraunhofer ILT, Aachen (D)

8:30 New Mission Areas for Photonics through Societal, Geospatial and Ecological Challenges
Prof. Constantin Häfner, Fraunhofer ILT, Aachen (D)

9:00 Perspectives for the Laser Source Development
- *Dr. Christian Schmitz*, CEO Laser Technology, Member of the Group Management Board, TRUMPF GmbH + Co. KG, Ditzingen (D)
- *Mark Sobey,* Executive Vice President and COO, Industrial Lasers and Systems, Coherent Inc., Santa Clara (USA)
- *Volker Krause*, Managing Director, Laserline GmbH, Mülheim-Kärlich (D)

10:00 Panel Discussion with the Speakers
10:40 Coffee Break – Visit of the Sponsors' Exhibition

Digitization in Photonic Production, Room Europa

Chairman: *Prof. Constantin Häfner,* Fraunhofer ILT, Aachen (D)

11:15 Digitization in Photonic Production
Dr. Joachim Döhner, KUKA Systems GmbH, Augsburg (D)

11:35 Next Generation of Data Driven Lasermachines – Much more than Cutting
Dr. Jens Ottnad, TRUMPF Werkzeugmaschinen GmbH + Co. KG, Ditzingen (D)

11:55 Additive Manufacturing – Digital and Smart
Dr. Tobias Kamps, Siemens AG, München (D)

12:15 Panel Discussion with the Speakers
12:30 Lunch – Visit of the Sponsors' Exhibition

Session 1: Laser Material Processing – Macro, Room Europa

Laser Powder Bed Fusion LPBF

Chairwoman: *Jasmin Saewe,* Fraunhofer ILT, Aachen (D)

14:00 Digital Production with Innovative Steel Materials
Dr. Simon Höges, GKN Additive, Radevormwald (D)

14:30 Modelling Laser Powder Bed Fusion Processes – Goals, Achievements and Gaps
Dr. Mustafa Megahed, ESI Software Germany GmbH, Essen (D)

15:00 Process and Systems Engineering to increase Productivity in Laser Powder Bed Fusion
Tim Lantzsch, Fraunhofer ILT, Aachen (D)

15:30 Coffee Break – Visit of the Sponsors' Exhibition
16:00 Shuttle Transfer to Fraunhofer ILT

Laser Technology Live

16:30 Laser Technology Live at Fraunhofer ILT
19:30 Shuttle Transfer to Eurogress Conference Center

Evening Event

20:00 – 23:00
Networking with Snacks at Eurogress Conference Center

Session 2: Laser Material Processing – Micro, Room Brüssel

Micro Structuring

Chairman: *Martin Reininghaus*, Fraunhofer ILT, Aachen (D)

14:00 High-tech Mastering for Endless Structuring for Micro- and Nanofunctionalized Films
Dr. Tom Felbeck, temicon GmbH, Dortmund (D)

14:30 Machine Technology for Industrial Laser Micromachining
Dr. Jens Holtkamp, Pulsar Photonics GmbH, Herzogenrath (D)

15:00 New Perspectives in Micro Processing with GHz Ultrashort Pulse Lasers
Dr. Clemens Hönninger, Amplitude Laser Group, Pessac (F)

15:30 Coffee Break – Visit of the Sponsors' Exhibition
16:00 Shuttle Transfer to Fraunhofer ILT

Laser Technology Live

16:30 Laser Technology Live at Fraunhofer ILT
19:30 Shuttle Transfer to Eurogress Conference Center

Evening Event

20:00 – 23:00
Networking with Snacks at Eurogress Conference Center

Session 3: Laser Beam Sources, K1-K2

Solid State and Fiber Lasers

Chairman: *Hans-Dieter Hoffmann*, Fraunhofer ILT, Aachen (D)

14:00 High Efficiency Converter Laser
Dr. Matthias Ackermann, Laserline GmbH, Mühlheim-Kärlich (D)

14:30 High Average Power Ultrafast Lasers with High Flexibility for Materials Processing
Dr. Dirk Sutter, TRUMPF Laser GmbH, Schramberg (D)

15:00 Scalable Short Pulse Fiber Lasers
Michael Lee, IPG Laser GmbH, Burbach (D)

15:30 Coffee Break – Visit of the Sponsors' Exhibition
16:00 Shuttle Transfer to Eurogress Conference Center

Laser Technology Live

16:30 Laser Technology Live at Fraunhofer ILT
19:30 Shuttle Transfer to Eurogress Conference Center

Evening Event

20:00 – 23:00
Networking with Snacks at Eurogress Conference Center

Friday, May 6, 2022

Session 1: Laser Material Processing – Macro, Room Europa

Cutting

Chairman: *Dr. Dirk Petring*, Fraunhofer ILT, Aachen (D)

8:30 Enhancing Cutting Performance with an Oscillating Laser Beam article → page 84
Takaaki Yamanashi, AMADA Co. Ltd., Kanagawa (JP)

9:00 Higher Power – Higher Performance?
Prof. John Powell, Lulea University of Technology, Lulea (SE) / Laser Expertise Ltd., Nottingham (UK)

9:30 Use of Acoustic Resonances in Laser Beam Cutting – The Cutting Whistle
Marcelo de Oliveira Lopes, RWTH Aachen University - LLT, Aachen (D)

10:00 Coffee Break – Visit of the Sponsors' Exhibition

Laser Welding

Chairman: *Dr. Dirk Petring*, Fraunhofer ILT, Aachen (D)

11:00 Laser Beam Welding in Vacuum – Industrial Implementations by LaVa-X
Dr. Christian Otten, LaVa-X GmbH, Herzogenrath (D)

11:30 Welding of Thick Metal Plates – Where are the Limits?
Prof. Michael Rethmeier, Bundesanstalt für Materialforschung und -prüfung BAM, Berlin (D)

12:00 MultiPROmobil – Digital Twin meets Multifunctional Laser Robot
Martin Dahmen, Fraunhofer ILT, Aachen (D)

12:30 Lunch – Visit of the Sponsors' Exhibition

Laser Material Deposition

Chairman: *Dr. Thomas Schopphoven,* Fraunhofer ILT, Aachen (D)

14:30 Requirements of Brake Disc Coatings from an OEM Perspective
Dr. Sebastian Gramstat, Audi AG, Ingolstadt (D)

15:00 Coaxial Laser Arc Hybrid LMD with Wire for Additive Manufacturing
Max Fabian Steiner, Fraunhofer ILT, Aachen (D)

15:30 Automation of Hybrid-Additive Process Chains with Adaptive Processes
Jan Bremer, BCT Steuerungs- und DV-Systeme GmbH, Dortmund (D)

16:00 Final lecture (Room Europa)
see more information in session 3

16:30 End of the Lectures

Session 2: Laser Material Processing – Micro, Room Brüssel

Micro Joining

Chairman: *Dr. Alexander Olowinsky*, Fraunhofer ILT, Aachen (D)

8:30 Micro Welding with Temporal and Spatial Beam Modulation article → page 87
Dr. André Häusler, Fraunhofer ILT, Aachen (D)

9:00 Laser Micro Welding of Novel Type of Hermetic Lids for Energy Storage Devices
Georg Haselhorst, SCHOTT AG, Mainz (D)

9:30 Flexible Use of Laser Beam Technology for E-Mobility
Dr. Jan-Philipp Weberpals, Audi AG, Neckarsulm (D)

10:00 Coffee Break – Visit of the Sponsors' Exhibition

Ultrafast Lasers – Applications

Chairman: *Prof. Arnold Gillner*, Fraunhofer ILT, Aachen (D)

11:00 Digitalization for Highly Accurate 3D Laser Processing of Customer-Specific Tools
Dr. Claus Alexander Dold, EWAG AG, Etziken (CH)

11:30 Ultrashort Pulsed Laser Processing for Sustainable Applications
Dr. Karsten Lange, Fraunhofer ILT, Aachen (D)

12:00 Next Level Laser Processes for Gasturbine Manufacturing
Marcel Vollgold, Siemens Energy Global GmbH & Co. KG, Berlin (D)

12:30 Lunch – Visit of the Sponsors' Exhibition

Polishing and Thin Film Processing

Chairman: *Dr. Edgar Willenborg*, Fraunhofer ILT, Aachen (D)

14:30 Fully Digitalized Production Chain with Laser Ablation and Laser Polishing for the Manufacturing of Interocular Lenses
Prof. Reinhart Poprawe, ETERNATECH GmbH, Aachen (D)

15:00 Laser Sintering of Solid-State Battery Layers
Dr. Ralph Delmdahl, Coherent LaserSystems GmbH & Co. KG, Göttingen (D)

15:30 Smart Products through Functional Layers
Dr. Christian Vedder, Fraunhofer ILT, Aachen (D)

16:00 Final lecture (Room Europa)
see more information in session 3

16:30 End of the Lectures

Session 3: Laser Beam Sources, K1-K2

Ultrafast Lasers – Beam Sources

Chairman: *Dr. Peter Rußbüldt*, Fraunhofer ILT, Aachen (D)

8:30 Advanced Photon Sources – Extending the Parameter Range of Ultrafast Lasers
Hans-Dieter Hoffmann, Fraunhofer CAPS, Aachen/Jena (D)

9:00 High Energy Ultrashort Pulsed Laser Sources at 2 µm and Beyond – Results from the NUCLEUS Project
Dr. Maik Frede, neoLASE GmbH, Hannover (D)

9:30 Ultrafast Thin-Disk Amplifiers
Dr. Thomas Metzger, TRUMPF Scientific Lasers GmbH + Co. KG, München (D)

10:00 Coffee Break – Visit of the Sponsors' Exhibition

Lasers with Tailored Wavelengths

Chairman: *Dr. Bernd Jungbluth*, Fraunhofer ILT, Aachen (D)

11:00 Green High-Power Disk Lasers and Industrial Applications
Dr. Evangelos Papastathopoulos, TRUMPF Laser GmbH, Schramberg (D)

11:30 Mid-Infrared Short and Ultrashort Pulse Lasers for Materials Processing
Dr. Sebastian Nyga, Fraunhofer ILT, Aachen (D)

12:00 2 µm Fiber Lasers for Industrial Use
Dr. Peter Fuhrberg, Futonics Laser GmbH, Göttingen (D)

12:30 Lunch – Visit of the Sponsor's Exhibition

Diode Lasers

Chairman: *Dr. Martin Traub*, Fraunhofer ILT, Aachen (D)

14:30 Blue and Infrared High Power Laser Diodes for Material Processing
Dr. Harald König, ams-OSRAM International GmbH, Regensburg (D)

15:00 Efficient High Brightness and High Power Laser Diode Bars operated on Passively Cooled Heat-Sinks
Dr. Ralf Hülsewede, JENOPTIK Optical Systems GmbH, Berlin (D)

15:30 VCSEL for 3D Sensing and LIDAR Applications
Dr. Holger Mönch, TRUMPF Photonic Components, Aachen (D)

16:00 Final lecture (Room Europa):
New Business Areas with Laser Technology - Gas Leak Detection with Helicopter based LIDAR Systems
Matthias Ulbricht, ADLARES GmbH, Teltow (D)

Closing remarks by *Prof. Constantin Häfner*, Fraunhofer ILT, Aachen (D)

16:30 End of the Lectures

Chinese laser market under the new globalization

How to navigate your business in China in these turbulent times

Bo Gu

The Chinese industrial laser market continued to grow in 2021 despite Covid-19, tariff barriers, and disrupted global supply chains. It is becoming more challenging than ever for laser and photonics companies to navigate in this world's largest growing market while serious tension between the US and China still remains, and potentially worsens. We present here the annual performance of the Chinese laser market in 2021, underline some of the developments and trends, and provide some strategies to navigate the Chinese laser market under the new world order. We forecast that the Chinese laser market will have another double-digit growth in 2022.

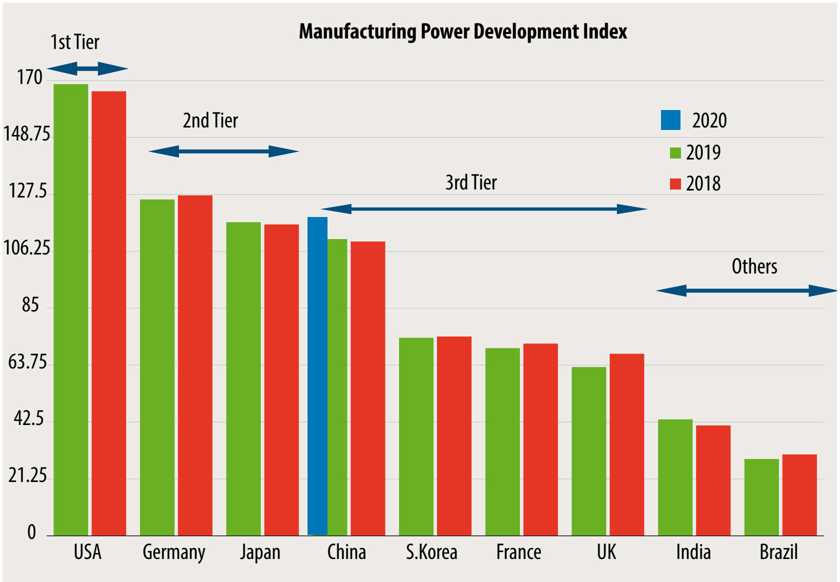

Fig. 1 Developed by the Chinese Academy of Engineering, the 'manufacturing power development index' has been released annually since 2015 and is a tool used by the Chinese government to evaluate the overall level of China's manufacturing industry.

The status of the Chinese economy

The Chinese gross domestic product grew at 8.1 % in 2021 [1]. This resulted in an average annual growth rate over the last two years of 5.1 %. The Chinese economy is larger than that of EU plus UK, and about 77 % of the United States' economy on the nominal basis [2]. The general consensus is that, the Chinese GDP annual growth rate will be in the range of 5 % for the next five years while the US growth will be in the 3 % range annually. In fact, the Chinese government just set its GDP goal at 5.5 % for 2022 at the recent 'two sessions' of the People's Congress.

In order to assess where China stands in the world ranking of manufacturing power before China launched its 'Made in China 2025' plan, the Chinese Academy of Engineering (CAE) developed the so-called manufacturing power development index to evaluate the manufacturing capability and ranking of every country in the world. It has been released every year since 2015 and has become an authoritative index for objectively evaluating the overall level of China's manufacturing industry for the Chinese government. According to the most recent release, the US is leading the way, followed by Germany and Japan in tiers 1 and 2 respectively. China is in tier 3. In 2021, China increased its index by 5.18 points to a total of 116.02, which is very close to Japan's 117.16. This puts China on a trajectory of moving up to the tier 2 group together with Germany and Japan before 2025 (Fig. 1).

China reached the so-called 'Lewis turning point' around 2011 and has used up its population dividend for the last thirty years [3]. Now China is in the era of engineer dividend, as the country produces six million college graduates with STEM degrees out of a total of ten million every year, which is six times what the US produces. Moreover, China has a total of one hundred million engineers and technicians. Its huge engineering talent pool gives the Chinese companies a significant competitive advantage in R&D costs over their overseas counterparts (Fig. 2).

The Chinese laser market

China is the single largest market for industrial lasers in the world [4]. Looking back at 2020, China's laser industry achieved a positive growth of ten percentage points throughout the year, far exceeding expectations, And in 2021 China's laser industry continued its growth trend. The overall size of the country's laser equipment market increased by 18.3 % year-to-year in 2021, reaching a record of 12.9 billion US dollars (Fig. 3). The application of laser technology has become the key for many manufacturing industries to improve their products' quality and to reduce costs, and ultimately improve their competitiveness amid China's transition from the old low tech to the new high-tech industries.

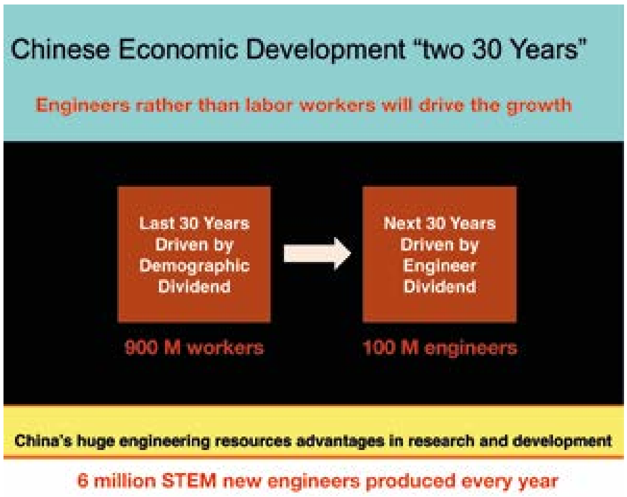

Fig. 2 Two 30-year periods of Chinese economic development. The first period (1981 – 2011) was driven by demographic dividend of 900 million low cost labor. The next period (2011 – 2041) is driven by engineer dividend of 100 million technicians and engineers as China continues to produce 6 million engineers every year.

The industrial laser market alone is about 8 billion US dollars with laser cutting taking the lion's share of 40 %, followed by laser welding (14 %), laser marking (13 %), semi/display (12 %), precision machining (9 %), non-metal processing (7 %) and the rest (6 %).

Fiber laser market

China is the largest market for fiber lasers in the world. Its fiber laser market grew by 15.3 % in 2021 to 1.71 billion US dollars, which accounts for 63 % of the global market. Shipment of 6 kW power levels has increased significantly, and even more explosive are the sales of 10 kW lasers. 12 kW and 20 kW became the main laser sources in sheet metal cutting in China.

As more components of fiber lasers are manufactured by domestic makers, including pump chips of both 915 nm and 976 nm with >20 W, active fibers such as large mode field, double-clad, Ytterbium-doped fibers, passive components like fiber gratings, collimators and couplers, combiners and isolators, the prices of fiber lasers has fallen dramatically. The opportunity to replace the old and often polluting cutting technologies, like plasma cutting, has become possible as the price of fiber lasers has dramatically fallen. More than 150,000 units of plasma cutting machines are sold in China each year.

Indigenization of fiber laser manufacturing in China is accelerating. In addition to the international players, there are at least eleven Chinese laser manufacturers now offering fiber lasers with power levels of 10 kW or above. Max Photonics offers up to 40 kW while Raycus launched its first 100 kW fiber laser in December last year.

The portion of domestic made fiber lasers reached 60.4 % of the total Chinese market in 2021 while it was only 33.6 % in 2017. Fiber lasers with a power of 1 kW or below are all made by Chinese companies and 90 % are made by Raycus and Max Photonics. The localization of 1 to 3 kW and 3 to 6 kW has reached 92 % and 86 % respectively, while it is almost a split at above 6 kW: the current localization levels are 51 % and 49 % for 6 to 10 kW and 10 to 40 kW respectively (Fig. 4).

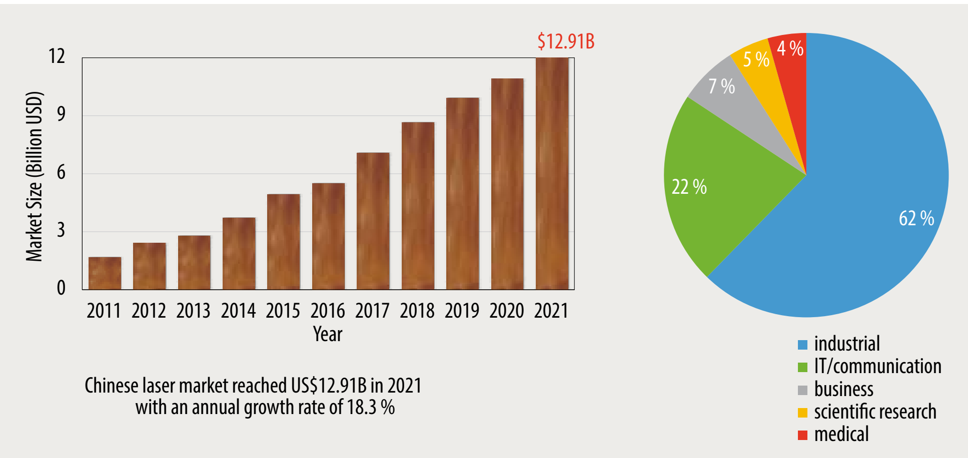

Fig. 3 Chinese laser market size from 2011 to 2021

Ultrafast laser market

Driven by demand in semiconductors, display manufacturing and glass processing, the ultrafast laser market is growing fast in China. A total of 2,400 lasers were sold in China in 2021 by more than 45 manufacturers. 95 % of the ultrafast lasers sold are picosecond lasers. Femto lasers took only a very small portion of the market. Domestic made lasers took 55 % of the total units sold but counted for only 30 % of the overall revenue, which indicates that the Chinese made ultrafast lasers are of a low power level, mostly in the 10 to 50 watts range, while the imported ones are for higher power applications.

The overall revenue of ultrafast laser based systems reached 883 million US dollars in 2021. Sapphire/glass cutting took 48 % followed by flexible printed circuit cutting with 32 %, and QR coding inside glass 8 %, OLED 3 %, semiconductor 3 %, R&D 3 %, and marking 2 %. This mix will certainly change as new applications emerge (Fig. 5).

Like fiber lasers, ultrafast lasers have seen price erosion as well, especially for power levels less than fifty watts, both in IR and UV wavelengths, with a price drop of more than 30 % in 2021.

Driven by the high demands of microprocessing in 5G, AR/VR, artificial intelligence, higher-precision chips, higher-resolution screens, and various flexible materials, the ultrafast laser market in China will continue to grow at a very fast pace in the next few years.

MicroLED laser processing equipment market

MicroLEDs are a relatively new technology that can be used to create high-resolution displays with excellent performance that can be economically scaled

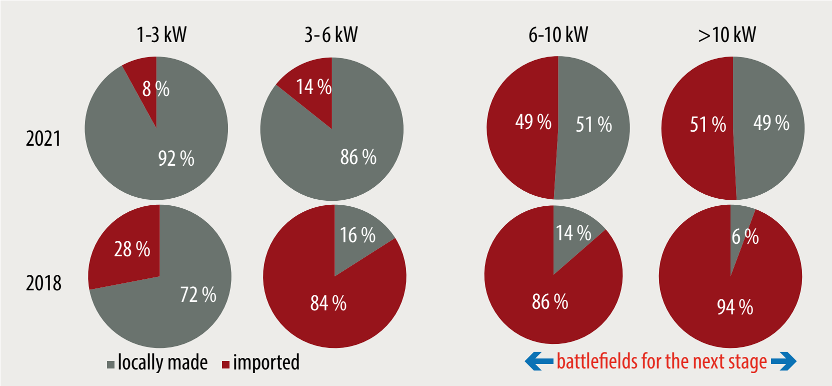

Fig. 4 High power fiber laser indigenization trend in China, 2018 vs. 2021

to very large sizes – easily over 20 feet (6 meters). MicroLED displays will grow into a market worth more than 10 billion US dollars, and lasers will play a key role in the manufacturing of microLEDs by laser lift-off (LLO) and laser induced forward transfer (LIFT) technology. Since 2013, Han's Laser has been developing these systems using its own excimer lasers. Their LIFT and LLO equipment was installed and tested in local display manufacturers during 2021. The positioning accuracy of LIFT machines is ±1 µm with a transfer speed of up to 100 m/h, and the minimum size that an LLO system can handle is 10 µm with 10 µm spacing and a peeling yield of 99.9 %.

Laser cutting market

Laser cutting equipment has always been the largest segment of the laser processing equipment market in China. In 2021, revenue and shipments increased significantly. Even though the spread of the Covid-19 pandemic has intensified, the number of orders for construction machinery and special vehicles closely related to infrastructure, transportation, communications, power plants, agriculture and other industries has not been affected. In fact, domestic orders increased in the first half of the 2021. The total revenue reached 4.34 billion US dollars.

In addition to conventional laser flatbed cutting machines and laser tubing cutting machines, large-format beveling cutting machines as well as three-dimensional, five-axis laser cutting machines for hot forming sheets have also become popular in recent years.

In the second half of 2021, the tight market conditions caused the laser cutting equipment market to decline to a certain extent. Overall it still has a 7.4 % annual growth.

Laser welding market

Driven by the transformation and upgrading of traditional industries, the domestic market has a strong demand for high power laser welding equipment. The demand continued to increase last year, including the increasing demand for the laser welding of batteries. The demand for the laser welding of non-metallic materials has also grown significantly. The laser welding market was 2.52 billion US dollars in 2021, an annual growth rate of 26 %.

Hand-held laser welding equipment has experienced a boom in China since 2019. The overall shipments of hand-held welding equipment were 80,000 and 100,000 units in 2020 and 2021, respectively.

This boom was caused by a few factors, including the low cost of fiber and diode lasers, the low entry threshold of the equipment itself, the easy switching in between pulsed welding, quasi-cw welding and cw welding, and being able to handle various complex welds of workpieces.

Laser cleaning and laser additive manufacturing market

Other laser equipment applications, including laser cleaning and laser additive manufacturing, are gaining momentum. With the increased demands for energy efficiency and environmental protection, the traditional industrial cleaning methods are being gradually eliminated and replaced by laser cleaning. This market is relatively new in China. Since 2018, the domestic laser cleaning equipment market has begun to rise with various new machine models every year. The laser cleaning machines have a broad market potential and can be widely used in the cleaning of molds, bridges, railway rails, weapons and machinery equipment, electronic devices, precision instruments, cultural relics, and also for aircraft and ship paint removal. The market size of the Chinese laser cleaning equipment reached 73 million US dollars in 2021 and it is expected to reach 100 million in 2023.

The laser additive manufacturing market continues to mature and grow at a rapid pace. It reached over 2 billion dollars for the first time in 2021. The low cost of fiber lasers, as well as various laser control techniques and beam

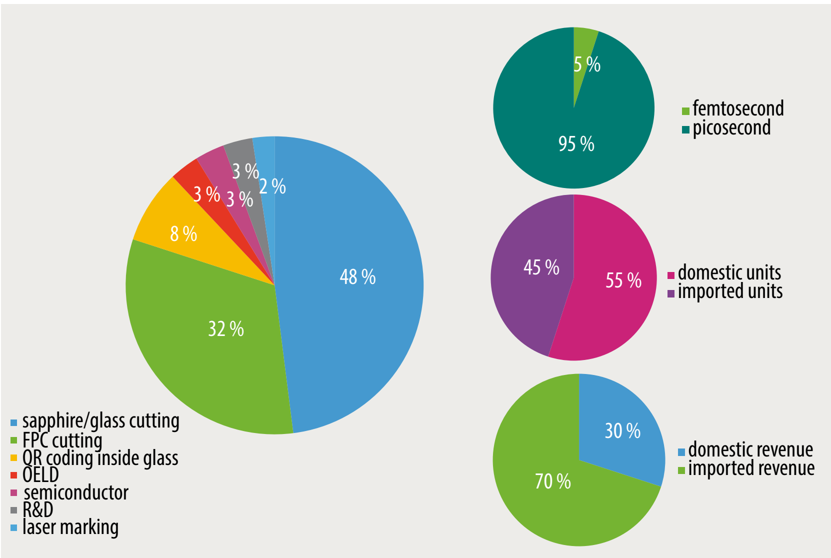

Fig. 5 Chinese ultrafast laser market landscape

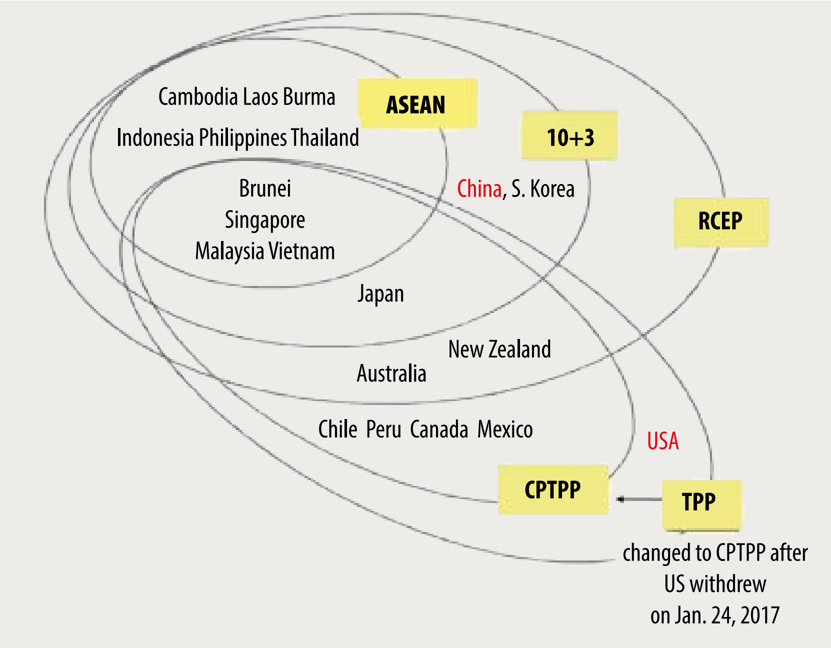

Fig. 6 Regional economic integration in Asia – RCEP (Regional Comprehensive Economic Partnership, 11 countries) and CPTPP (Comprehensive and Progressive Agreement for Trans-Pacific Partnership, 15 countries).

manipulations dedicated to the laser 3D printing process have accelerated its growth.

STAR Market – new Chinese stock exchange platform for high tech companies

The Chinese laser industry became the darling of the capital market in 2021. The Science and Technology Innovation Board STAR Market in Shanghai Stock Exchange was launched on June 13, 2019 [5]. This is a registration-based system aiming at high-tech companies with potentially high growth and strong research and development, but below par on revenue and net profit. This stock exchange platform no longer puts net profit first and therefore increases the capital market's tolerance towards an innovative economy. STAR Market has accelerated the deep integration of hard technology industries such as the lasers and photonics industry with the capital market, and has triggered a large number of high-quality lasers and photonics companies to flock to the capital market. A total of twenty photonics companies submitted for IPO in 2021, covering the entire laser industry chain. Three went IPO successfully – Inno Laser, Focuslight Technology, and Beijing FJR – and four passed the Shanghai Stock Exchange, awaiting the registration decision by the China Security Regulatory Commission (CSRC): Han's CNC Technology, Ever-Bright, Delphi Laser, and FOCtek. The remaining thirteen are in the queue. It is anticipated that more laser and photonics companies will be in the queue for IPO in 2022. The high P/E values of China's stock market for high-tech companies gives a financing advantage to the Chinese laser companies and enables them to rapidly grow and expand.

Asian regional integration

Another noticeable development was that the Regional Comprehensive Economic Partnership (RCEP) went into effect on January 1, 2022 and Comprehensive and the Progressive Agreement for Trans-Pacific Partnership (CPTPP) became effective on December 28, 2018 [6]. These two trade agreements provide a foundation for Asian regional economic integration and will have an important impact on the laser industry (Fig. 4). China fully supports these trade deals while implementing its own dual-circulation strategy, i.e., domestic and international circulations because they interlock with each other. International companies should pay more attention to this development and should consider China and the rest of Asia together in their corporate strategies, including the supply chain and product localization.

Winning strategy in China

The world is going through some major changes and photonics companies are facing issues caused by decoupling and supply chain interruptions. Here I present you with some concrete steps on how to navigate your business in China in these turbulent times of US-China decoupling [7]:

1. **Supply chain** – adopting the 'China plus one' supply chain model to increase agility and resilience. Diversify your business in the neighboring countries.
2. **Products/market** – Use an 'In China, for China' strategy designed specifically for the domestic market. Formulate a multiyear strategy for product localization based on your company's competitive advantages over local alternative products. Take advantage of ongoing Asian regional integration.
3. **Local talent/organization** – Recruit more local talent. Set up factories in China to ensure access to the local market to serve the Chinese markets as well as the neighboring countries.
4. **Winning the trust and support of the local government** – Have a dedicated person or team to deal with constant regulation changes and to fully understand what areas are supported by the government and factor them into your plan.
5. **Acquiring local assets** where China has the strength to complement your business.
6. European Companies could find new opportunities in China, but in the long run the process of decoupling will affect every company. So begin now to lay the groundwork for the localization by adjusting your supply chains, products, customer base, and organizations.

Adapting now will mitigate risks and ensure the most advantageous position to gain a competitive edge, no matter how the US-China relationship plays out. Abandonment or withdrawal will never be a winning strategy.

Outlook for the Chinese laser market

Vicious price wars in fiber lasers, laser cutting machines, ultrafast lasers, and upstream optical devices will gradually evolve into competition with customized solutions. The speedy response to customers' needs and services will be more important factors than prices. Having a high quality engineering team, and a reliable and timely service network will bring a huge competitive advantage to the enterprise.

As the global economy is still weak and uncertain, and the world, including China, is moving towards 'peak carbon dioxide emission / carbon neutrality', i.e., 'carbon zero', strong alliances and win-win cooperation between enterprises are gradually replacing vertical integration and becoming the new business model for the Chinese laser industry in the post-pandemic era.

Capital investment in the Chinese laser industry is increasing and so is the support by the government, especially local government, through their industrial policies and 'laser industrial parks or clusters'. These laser parks aim to achieve industrial scales and clusters and to provide support for the local industrial chain. These measures will give significant advantages to the Chinese laser industry. One would expect the establishment of many such laser parks in China in the next five years, i.e., during the Chinese '14th Five-Year Plan' period.

The annual growth rate of the Chinese industrial laser market for 2022 is expected to be around 10 %.

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[1] China National Bureau of Statistics. https://data.stats.gov.cn
[2] According to IMF and World Bank.
[3] A Lewis Turning Point occurs when a country's surplus labor evaporates, pushing up wages, consumption and inflation rates.
[4] *B. Gu*: Industrial Laser Solutions **34** (2019) 6, 6–8.
[5] http://star.sse.com.cn/en/ SSE STAR Market – The Science and Technology Innovation Board in Shanghai Stock Exchange was launched on June 13, 2019. This is a registration-based system aiming at high-tech companies with potential high growth and strong research and development, but below par on revenue and net profit.
[6] CPTPP-Comprehensive and Progressive Agreement for Trans-Pacific Partnership became effective on December 28, 2018 with 11 countries. China has applied for its entry on September 16, 2021. RCEP-Regional Comprehensive Economic Partnership went into effect on January 1, 2022 with 15 countries. These two trade agreements provide a foundation for Asian regional economic integration.
[7] *B. Gu:* Laser Focus World **57**(2021) 1, 19–25.

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Bo Gu founded BOS Photonics in Boston, Massachusetts, USA, after thirty years of corporate life. He is continuing to develop the next generation of photonics technologies and to provide independent consulting services to the laser and photonics industry. Many years working in China and Asia as a corporate executive have given him a great insight and a unique perspective about the region, especially its business environment and the market dynamics. His technical contributions to the lasers and photonics fields made him elected Fellow of many professional societies including SPIE, Optica (formerly OSA), Laser Institute of America (LIA), and the Chinese Optical Society (COS).

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An overview of global and European photonics markets and industry

Photonics contributes to make Europe's economy more competitive and is essential to global market growth

Thierry Robin, Benoît d'Humières, and Jacques Cochard

Adapted from [1]

The global photonics market has grown very rapidly in recent years and reached 733 billion US dollars in 2019. The European photonics industry also had a sharp increase (from € 76 B in 2015 to € 103 B in 2019), outperforming EU GDP by three times. Moreover, the global and European photonics industry has proven to be quite resilient to the effects of the Covid-19 crisis. In fact, already present in various high-end and next-generation products, photonics technology has proven to be a long-term driver of growth through its indispensable role in many current and future markets.

In this article we present the results of a study realized by Tematys in cooperation with Photonics21. This study began in 2020 and the final report was published in May 2021 [1]. The base year chosen was 2019 because company revenues were available for this year at the beginning of the study. Also the world economy was affected in 2020 by an unforeseen and brutal recession caused by the Covid-19 pandemic. At the end of the article we provide some data on the impact of the pandemic in 2020 and the recovery in 2021. Our study shows that both the photonics global market and European industry had a sharp increase in recent years, exceeding global GDP growth. We also present an analysis of the European and global photonics industry by application segment.

The global photonics market grew by 7 % p.a., 2015 – 2019

The global market for photonics components and systems accounted for $733B (€ 654 B) in 2019. The market grew at a CAGR (compound annual growth rate) of 7 % during the four years from 2015 to 2019, more than double the rate of global GDP. For comparison, OECD industry as a whole grew at an average of 1.3 % per year over the same period and Chinese industry at about 6 % per year. The growth of photonics worldwide over a long period is depicted in Fig. 1.

This outcome on growth is in line with other studies (e.g. the last SPIE market study used a different perimeter and focused on components but mentioned a growth of 7.6 % in the last six years) [2]. The photonics industry has also grown in terms of the number of manufacturers and employees. OIDA estimated in 2019 that more than 3.5 million people are employed in photonics companies around the world [3].

Addressing major challenges and concerns for the future

Besides components and materials, the major application segments are photonics for consumer IT, medicine and biology, environment, lighting & energy and

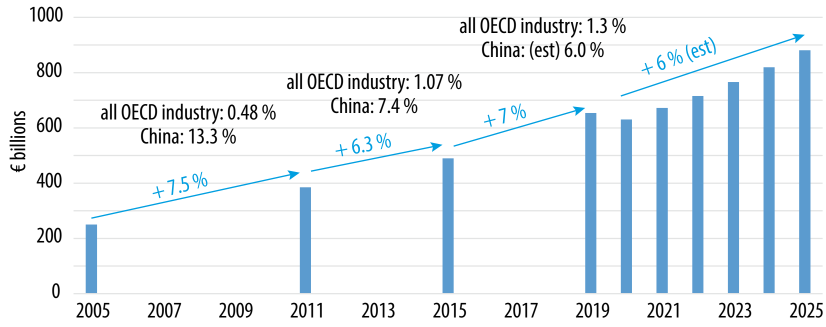

Fig. 1 Photonics worldwide market in billion euros from 2005 to 2025 (Source: Photonics21 / Tematys)

Industry 4.0, showing that photonics is contributing directly in the challenges of the future such as the digitalization of production and society, health and wellbeing, sustainable development and environment. Other main segments such as mobility, defense and security, food and agriculture, address major concerns shared by citizens in Europe and elsewhere.

The global market for photonics breaks down into application segments as detailed in Fig. 2.

A particular segment covers photonic components and materials (lenses, lasers, LEDs, detectors, fibers …) and was worth $ 95.2 B in 2019. All other segments consist of photonic systems and subsystems and together accounted for $ 638 B or 87 % of the total.

Photonics production is mainly located in Asia. In 2019, more than 65 % was accounted for by China, Japan, Korea, Taiwan, and a few other Asian countries including Vietnam, Malaysia, Singapore, Thailand and India. Europe and North America accounted for 16 % and 15 %, respectively. Other photonics producing countries include Israel, Turkey, Australia, New Zealand, and Brazil. China is the leading producer with a share of almost 30 %, ahead of Europe (16 %), North America (15 %), Japan (12 %), Korea (11 %), and Taiwan (9 %). Note that here 'Europe' means the EU 27 plus the UK and Switzerland. These production shares are calculated taking into account the country of manufacturing of the products as opposed to using the nationality of the companies (location of the headquarters). Asia is particularly strong in displays, PV and LED production whereas Europe leads in optical components as well as photonics for industry and healthcare. When displays and photovoltaic products are excluded, Europe was leading with approximately 24 % share in 2019.

Europe maintains market share, defends #2 global position

The European photonics industry accounted for € 103 B in 2019 (with a CAGR of 7 % from 2015 to 2019), comprised more than 5,000 companies and contributed about 3 % of the total manufacturing within Europe. It provides about 1.5 % of the total manufacturing employment, with a revenue per employee of around € 250 k. The size of the photonics industry in Europe exceeds the size of the microelectronics industry, which was worth € 75 B in 2019 (when including micro/nano-electronic semiconductors, components, materials and tools) [4].

Within Europe, Germany accounts for the largest photonics production volume with a share of 40 %. France and the United Kingdom hold a similar share of 15 %. The Netherlands (6 %) and Italy (5 %) follow while Switzerland holds a 4 % share. The other European countries hold a combined share of 15 %. Note that aside from the overall market share, there is a 'specialization' in some segments for the countries and they often have a greater share in their specialty.

What is noticeable is that the recent growth of the European photonics industry for the period 2015 – 2019 is roughly in line with the global rate. Europe was then able to maintain its market share over recent years and defend its number 2 global position. The European photonics industry is therefore a sector with a remarkable dynamism.

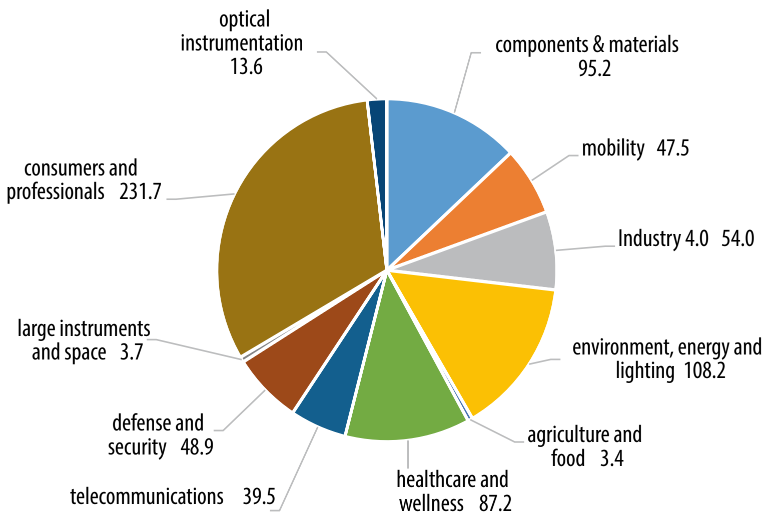

Fig. 2 Breakdown of the global market (billion US$ – 2019) by application segment (Source: Photonics21 / Tematys)

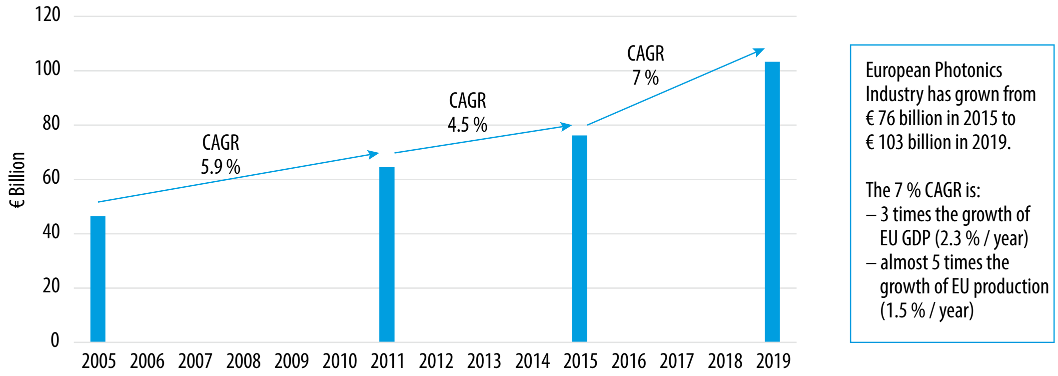

Fig. 3 Long-term evolution of the European photonics industry (Source: Photonics21 / Tematys)

European photonics exceeding overall industry growth

Beyond size (which is the reference indicator for a traditional industry), a key enabling technology (KET) is assessable by its dynamics. The European photonics industry grew from € 76 B in 2015 to € 103 B in 2019 with a growth rate of 7 % per year and a share of 16 % of the global market. It is growing faster than many other high-tech industries (for example, IT industry: 4.5 % [5], medtech: about 5 % [6]) and also much faster than the EU GDP (see Fig. 3).

EU photonics employment growth is twice that of industry

The European photonics industry created over 30,000 jobs in the period 2015 – 2019 to reach 390,000 employees, representing an annual growth rate of 2.1 %. This growth is much higher than the growth of employment in European manufacturing as a whole (about 1 % CAGR for EU28). The difference between the growth of European photonics in terms of revenue and employment is due to significant productivity gains. European photonics is currently seeing the transformation of its manufacturing processes with a significant impact on jobs and skills. The growth of European photonics employment is, however, not without recruitment problems, particularly among SMEs.

Four important segments are dominating

The European photonics industry breaks down into application segments as detailed in Figs. 4 & 5. The largest segment in Europe, photonics systems for industry, was worth € 19.2 B and accounted for the largest share in the global markets: more than 40 %. Europe is very well positioned this segment which includes industrial laser systems, semiconductor manufacturing and machine vision.

Three further segments account for a significant production volume and, at the same time, a substantial global market share well above average. The segment covering photonic components and materials was worth € 16.6 B in 2019 and a market share of about 20 %. Staying strong in this segment is important as it consists of the building blocks used for all photonics systems. Photonic devices and systems for healthcare and wellness, accounted for a European production volume of € 15.9 B. Europe is well placed in medical instruments and systems with a global market share of 26 % in 2019. In photonics systems for environment, lighting and energy, European production accounted for € 16.7 B in 2019. Europe has a significant market share in the field of lighting (25 %) and in environmental monitoring (30 %). Finally, Europe is also very well positioned (market share >30 %) in optical instrumentation and in photonics for space.

Although lagging behind in the two biggest photonic markets (displays and PV), the European share has been maintained in 2019, stressing the huge dynamism of other photonics segments in Europe, especially those described above.

Photonics quite resilient to the effects of the Covid-19 crisis

In 2020, the world economy was affected by a recession caused by the Covid-19 pandemic. The pandemic and its direct and indirect effects caused a sharp decline in many sectors in both demand and production. This decline was followed by a gradual recovery. The impact has been very different across the economic sectors. Our assessment shows that the photonics industry was

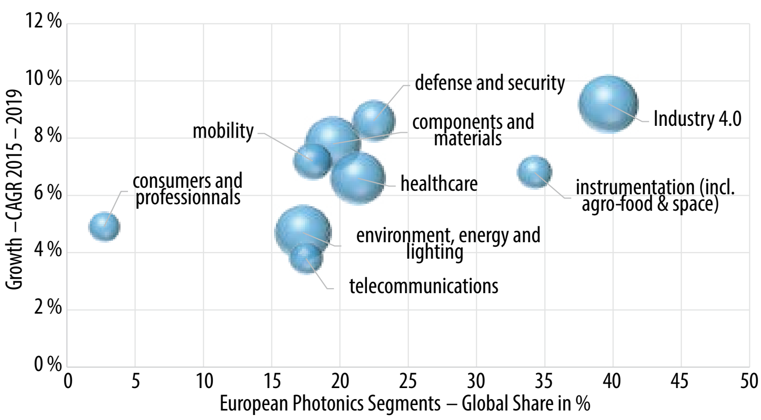

Fig. 4 European photonics segment growth and market share – 'bubble sizes' are proportional to the size of the segment (Source: Photonics21 / Tematys)

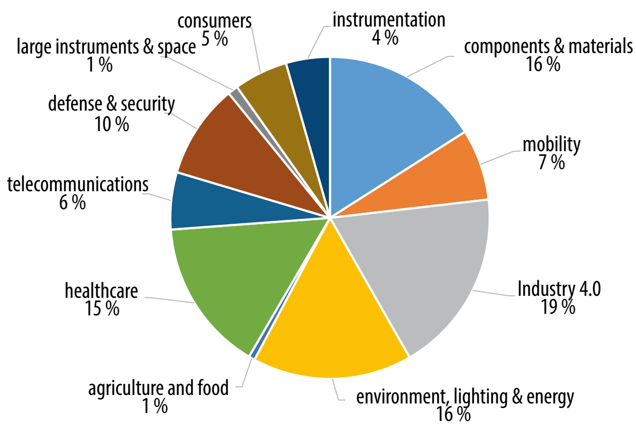

Fig. 5 European photonics industry – breakdown by application segment (Source: Photonics21 / Tematys)

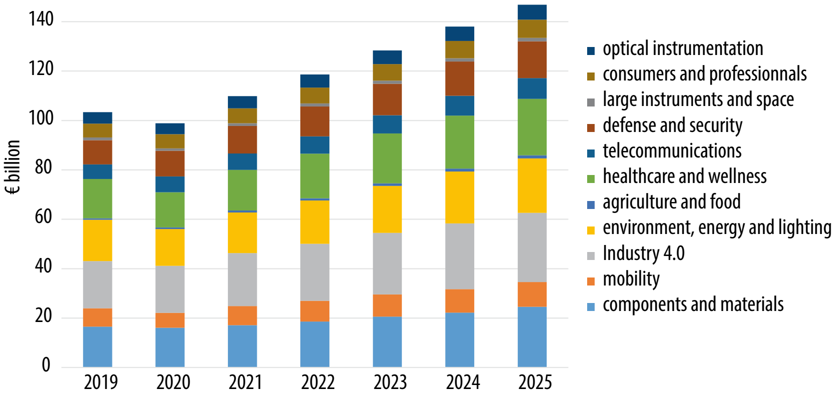

Fig. 6 Forecast for the European photonics industry by segment

quite resilient to the effects of the Covid-19 crisis but the affected segments are recovering at different levels and speeds. We see a decline of an order of magnitude of 3 % in 2020 and a return to growth in 2021 with an offsetting effect of about 10 % (see Fig. 6: the forecast for the European photonics industry by segment). Of course, we still have to wait to fully assess the impact of the crisis in the medium and long term.

One main reason for the resilience of photonics is its widespread use in many sectors. In fact, photonics is an important key enabler for many applications and serving those application markets requires constant innovation at the leading edge of the technology.

Innovation and investment keys to maintain competitiveness

In European photonics companies, R&D spending is high (10 % of turnover on average), which is crucial to maintain or even expand their share in this fast-growing and highly competitive industry. The ratio of total investment is also well above the EU average.

This high capital intensity is combined with a longer return of investment than e.g. with software. This higher risk means that many European investors are less inclined to get involved in photonics companies which is not the case of foreign investors. It must be part of the ambition for more sovereignty to ensure sufficient risk and venture capital for European photonics companies.

The level of investment, particularly in research and innovation, should be maintained and even increased because it is key to the successful development of European photonics: this can further strengthen the strong core segments and launch a win-back strategy for the others when appropriate – also in the light of more strategic sovereignty.

*

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[1] *Photonics21 – European Technology Platform, VDI Technologiezentrum & Tematys:* Market Data and Industry Report 2020
[2] https://spie.org/news/2020-optics-and-photonics-industry-report
[3] Lighting The Path to a Brighter Future, How optics and photonics impacts the global economy, OSA, 2018.
[4] Study on the Electronics Ecosystem, Publications Office of the European Union, 2020.
[5] From 2015 to 2019 – Source: IT Industry Outlook, CompTIA, 2020.
[6] From 2014 to 2018 – Source: https://www.medtecheurope.org/datahub/market

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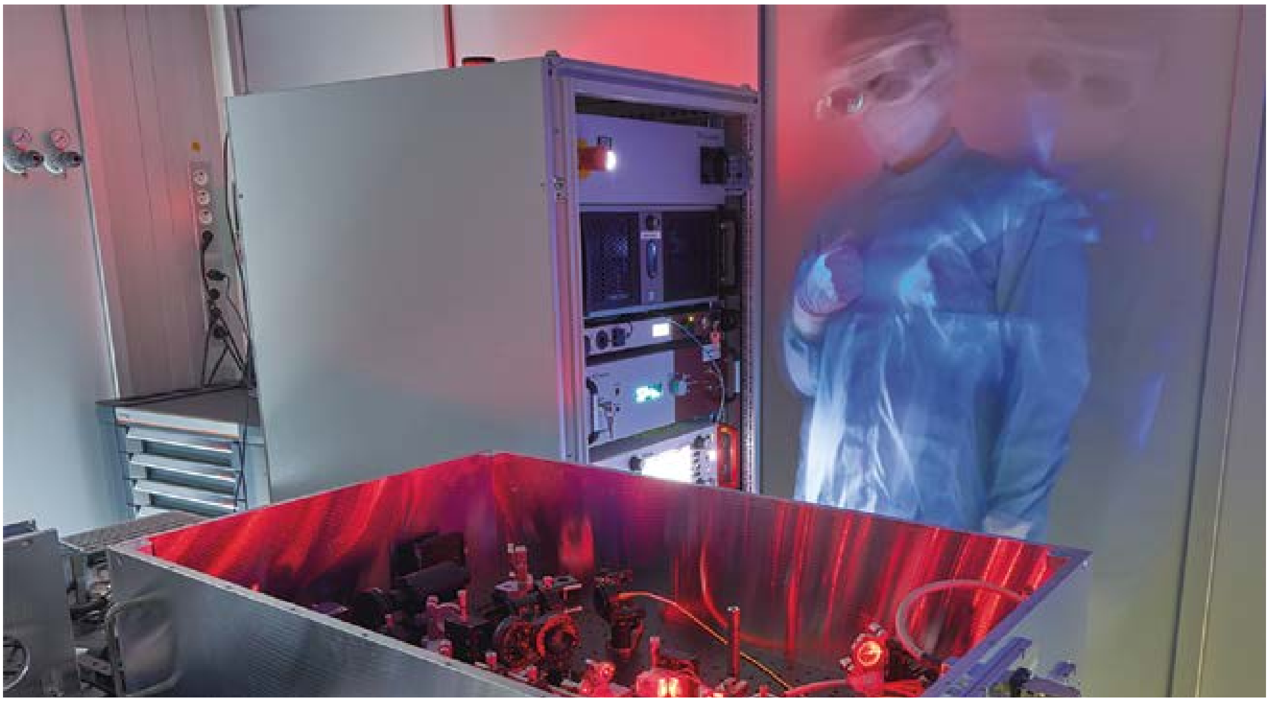
Laser: a proven tool with a lot more potential

No matter whether it is for welding or for the structuring of surfaces, the laser is now an integral part of many industrial processes. And it still has a lot of potential for future applications.



Source: Fraunhofer ILT, Volker Lannert

Lasers reliably cut and weld body panels and gearbox components in the automobile industry. They repair turbine blades in the aircraft industry with laser deposition welding and generate customized and lightened components for the space industry using the laser powder bed fusion process. Short pulse lasers are contributing greatly in the electronics industry to the miniaturization of new devices through their drilling, cutting or structuring capabilities. In summary: the laser is an all-round tool that has established itself in the most varied of industries.

▲ **Fig. 1** Laboratory prototype for a low-noise quantum frequency converter developed in the Fraunhofer Cluster of Excellence CAPS.

Tailored laser light can be precisely adapted to the relevant process by forming and guiding the beam. The wavelength is chosen specifically for the material being processed. But is that the end of the story? Have the laser sources and applications been largely exhausted? Not by a long way: the laser tool still offers much undiscovered potential that industry and science is currently finding. Innovative laser beam sources can enable new or improved production processes. And in reverse, unsolved production process difficulties need new laser beam sources or adaptations to existing systems. What is currently being made possible by this mutual dependence is shown by experts from the Fraunhofer Institute for Laser Technology (ILT) in Aachen, Germany, and their cooperating companies in this article.

High-power, ultrashort-pulse lasers are the shining stars

The ultrashort-pulse (USP) laser is a very special beast: the length of its pulse is measured in picoseconds or femtoseconds. The heat generated in the material is very low due to the extremely short interaction time of light and material. A stumbling block, however, is the power: while lasers for opticians suffice with just a few watts, industrial production lasers need many hundreds or even thousands of watts. This type of USP laser was not available to industry until recently: the gap has been filled by institutes such as the Fraunhofer ILT. “In the last few years we have been able to push into

Fig. 2 Precise deep drilling in a turbine blade with a USP laser

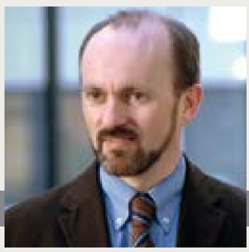
the realms of femtosecond lasers with one kilowatt of power", says Hans-Dieter Hoffmann, competence area manager Lasers and Laser Optics at Fraunhofer ILT. And with success: USP lasers with an average power of 100 to 300 watts have meanwhile become commonplace in industry. ILT spin-offs such as Amphos or Edgewave already offer USP lasers up to 1.5 kilowatts.

The researchers in Aachen are currently working together with the Fraunhofer Institute for Applied Optics and Precision Engineering IOF in Jena in the Fraunhofer Cluster of Excellence Advanced Photon Sources CAPS to further scale up the power of pico or femtosecond lasers: they want to reach the level of three, five or even ten kilowatts average laser power and develop devices suitable for industry. The researchers have also built a user facility in the CAPS cluster in which laboratories are equipped to test the very latest lasers for interested users from industry and science. "At the high intensities that we generate with the femtosecond lasers, we can even process transparent materials such as glass, sapphire, certain semiconductors or silica carbide," says Prof. Arnold Gillner, competence area manager Ablation and Joining at Fraunhofer ILT. The accuracy is of the order of nanometers while the processing is virtually athermal. Ultrashort-pulse lasers can drill a hole with a diameter of less than 0.5 micrometers. This is of interest, for example, for the medication of lung patients using a metered dose inhaler.

USP lasers are also sustainable: among other things, they can replace corrosive etching processes. "This is a very promising initiative for the credible implementation of a circular economy that we are following here at Fraunhofer ILT in numerous projects," says the institute head Prof. Constantin Häfner. The production of micro and nanostructured surfaces is also being followed by the Temicon company. "We are increasingly looking for solutions that enable us to work on the tools directly – without the lithography and galvanizing processes in between," explains Mike Bülters, Temicon's head of product development. "We view USP technology as a possible alternative to transferring tightly-focused scatter functions or even refractive or diffractive optical functions over a large area onto embossing cylinders."

One thing that continues to drive the researchers of Fraunhofer ILT in USP technology is the transition from micro to macro. How can the functional characteristics that can be created with a USP laser on various different materials at a microlevel be scaled up to large-scale components? One example would be microscopic holes in a room aerosol filter, or for microfilters as they are used in foodstuffs technology. But one question always remains open: how do we get the power down onto the road? Digitalization is playing an important role here by providing precise control and shaping of the laser beam, for example by using so-called multiscanner systems.

The enormously high intensity that can be achieved with USP lasers promises very interesting applications in the long term. "USP lasers can even produce x-rays that far exceed the brilliance of conventional sources by focusing light in space and time to such a high energy density," says Häfner. "This will open up new areas of application." Another



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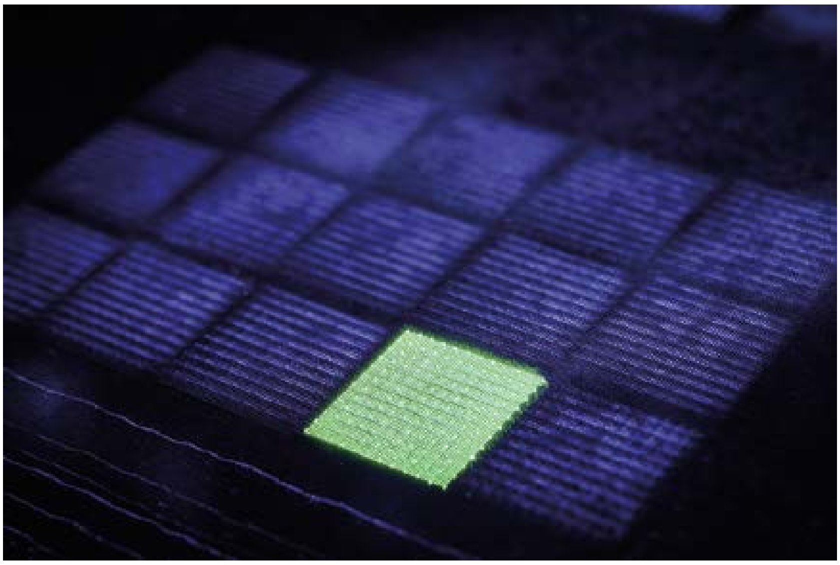


Source: Fraunhofer ILT, Volker Lannert

Fig. 3 Multibeam technology: today 144 partial beams can be used for production: Fraunhofer ILT scientists are working on parallel USP laser processes with up to 1000 partial beams for further productivity increase.

future possibility may be to bring particles up to almost light speed within just a few centimeters by using high-intensity lasers instead of building gigantic particle accelerators. A kilometer-long synchrotron could be envisaged in the future as a tabletop device – at least for one or the other industrial application. The Fraunhofer ILT is also researching these 'secondary sources'.

Laser technology processes for efficient batteries and fuel cells

One area with a lot of development potential for lasers is in the developing market for batteries and fuel cells. "The electric vehicles industry and markets are very dynamic – companies must be able to react quickly to the appearance of new materials and product designs," says Joachim Döhner of Kuka Systems. Lasers are already being used in the manufacture of batteries today, for example for the structural welding of battery cases or connecting the cells.

Kuka and the Fraunhofer ILT are working together on joining technologies. "The biggest challenge that companies see with using lasers is in the quality and reproducibility," explains Gillner. "Specialist know-how in materials and processes is required here." Laser-related solutions with optimum quality and reproducibility are available by using different wavelengths or adaptive beam forming. With regard to the speed of production, the limiting factor is not the laser but the machine. That is why the Fraunhofer ILT experts are in conversation with industrial companies to find new processes and system designs.

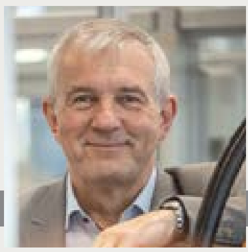
It makes sense to use the laser at the start of the sequence of processes, maybe during the coating and drying of the active material of battery cells, the structuring of the material to expand the surface and for the cutting of the electrodes. Process monitoring and documentation of the quality continue throughout the entire sequence of manufacturing processes. "The challenge here is to evaluate the signals from the process monitoring for the following steps and to transfer them into performance indicators," says Alexander Olowinsky, head of the micro joining group at Fraunhofer ILT. "The documentation obligation of the battery manufacturers helps us here because we can generate a high volume of production data and of a high quality." The researchers want to process the massive amounts of data and improve their understanding of the processes by using machine learning.

Not only is the production of batteries interesting for lasers, but also the manufacture of fuel cells, in particular proton exchange membrane (PEM) cells. A current challenge here is the production volume. For compound bipolar plates, like those already widely used in stationary applications, the surfaces can be easily freed of polymer substances using a laser. The opinion of Kuka, however, is that their large-scale use – and thereby the perspective for innovations in fuel cell technology – still lies some way ahead in the future.

Digital production of tomorrow: additive manufacturing

Although cutting, joining and ablation are the best-known applications of lasers, they can also do a lot more. For example, they can do additive manufacture of components, layer for layer. This type of digital production is not only interesting for toolmaking but also in the oil and gas industry, the automobile industry as well as in aerospace technology. The Fraunhofer ILT is leading investigation into two particular methods of additive manufacturing: laser material deposition and laser powder bed fusion.

The laser material deposition proces consists of melting a substance in



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powder or wire form with the laser and metallically melting it together with the base material. This is the method used to repair turbine blades with laser material deposition, protecting offshore pipes against wear and corrosion or improving the service life of brake discs. "The high quality of the deposited layers together with its economy and versatility for various applications is making the procedure increasingly attractive for a volume market," explains Thomas Schopphoven, ILT's competence area manager Laser Material Deposition. "But the process is very complex: many interrelated parameters have to be taken into account. Managing this complexity is the key to ensuring satisfactory quality and robustness, and a core subject of study for the institute. We are working on adaptive process management in which the machine adapts and controls the process itself with the help of artificial intelligence," says Schopphoven.

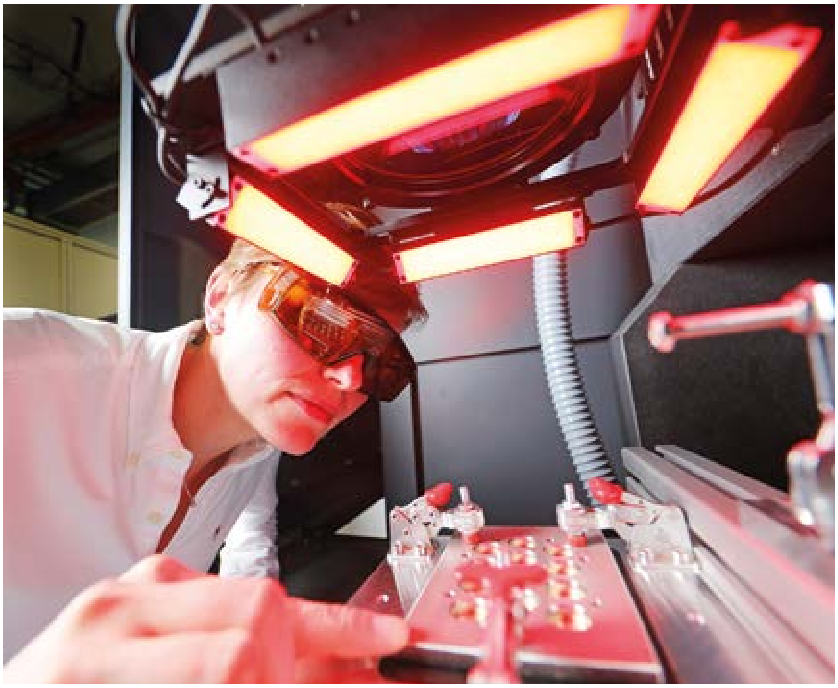

Fig. 4 Laser welding machine for the production of battery modules

Apart from laser deposition welding, the laser powder bed fusion (LPBF) process is making the biggest waves in 3D printing. "Increasing productivity and the robustness of the process are top of the agenda – we are directing our research into these two aspects," explains Jasmin Saewe, competence area manager LPBF at Fraunhofer ILT. Saewe and her colleagues are investigating the individual adjustment of process parameters to the requirements of the components. Naturally the whole process chain is considered here, digitally of course. AI and machine learning are therefore integrated elements of current research projects in order to reach the target of 'first time right' processes.

A further aspect is the integration of prior and subsequent process steps into one machine. A question that arises with all of these initiatives is how to integrate these production systems into the modern computing infrastructure – and preferably as user-friendly and application-specific as possible. "Various different business models are possible," explains Moritz Kröger, a scientist at the Chair of Laser Technology (LLT) of RWTH Aachen University, and at Fraunhofer ILT, responsible for cloud integration of the systems. "With a more long-term vision the analysis software could be rent from other providers, which would significantly lower the entry cost for such systems."

"As a research institute, we view ourselves as an interface between users and new research subjects: we have the perspective of the users, but we are deeply anchored in the system technology – and together with the system technology manufacturers we develop the next generation of machines", says Saewe. One company that has been working together with Fraunhofer ILT for many years in this way is Toolcraft, a medium-sized company with almost four hundred employees. "It is amazingly helpful and motivating for us to be able to work on the industrialization of various methods, such as laser material deposition or laser powder bed fusion," says Christoph Hauck, member of the executive board of Toolcraft AG. "We have a brilliant sparring partner in Fraunhofer ILT." Hauck still sees a lot of potential in additive manufacturing: "AM is currently at the level of machining in the 70s." New approaches such as the combination of additive and subtractive methods in conjunction with a 6-axis robot are future ideas that promise Hauck high added value. But he also sees four clear priority challenges: first of all, the enlargement of the powder beds to be able to produce larger compo-

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Christoph Hauck
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Dr. Jochen Stollenwerk
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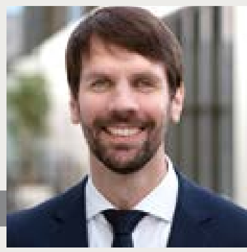


Dr. Christian Vedder
Fraunhofer ILT

Source: Fraunhofer ILT, Volker Lannert

Fig. 5 LPBF-manufactured component with integrated sensors

nents. Secondly, an improvement of the quality and reproducibility. Thirdly, the digitalization of the entire process chain, and finally, the combination of various methods within one machine.

Functional surfaces and smart components

A further area of application of the jack-of-all-trades laser is the functionalization of surfaces. "For example, cheap but brittle cast components can be enhanced and protected from wear by using a laser to deposit a thin surface layer of ten to twenty micrometers on the surface," says Jochen Stollenwerk, acting competence area manager Functional Layers and Surfaces at the Fraunhofer ILT. A surface treatment makes sense when a corrosion protection layer or layers to reduce wear are required. Hard wear-resistant layers for ball or roller bearings can also be achieved with a sol-gel coating, which can be easily applied and converted into a hard ceramic layer through laser treatment. "The laser allows us to make the functionality of a surface independent of the base material," Stollenwerk concludes.

The researchers are facing a central issue with so-called 'smart parts': how can measurement characteristics be incorporated into the surface layers by using a laser? One possible answer: printable electrically conductive inks made of nanoparticles that sinter during the laser treatment and take on their electrically conductive characteristics. This sort of process does not just enable single functional layers to be created, in fact multiple layers can be created to produce complete sensors. The target is clear: sensor production should be fully automatically coupled to the production of the components. In the long term, for example, this would allow stick-on expansion measurement strips to be replaced. "We are creating the sensor application on the surface of conventionally manufactured components, but we are also working on ideas today for the integration of printed sensors into additive manufactured components. This gets the most out of the digital, additive processes," says Christian Vedder, head of the group Thin Film Processing at Fraunhofer ILT. In future this will allow smart components to be created entirely on a 3D printer. These parts will be able to communicate their current loading during use, and thereby prevent critical loading scenarios. "Laser treatment is particularly suitable for coating large 3D items and temperature-sensitive substrate materials, among them hardened steel," says Vedder.

There will also be medical applications: sensors built into artificial hips could register when a patient has adopted an unnatural way of walking or the artificial joint is being excessively stressed. Structure-borne noise or pressure could also be measured via printed sensors using piezoelectric inks that crystallize under the laser beam. There are potential uses for such sensors everywhere that the structural condition of valuable investment goods such as wind generators, turbines and aircraft must be monitored.

In summary, even though it is already an established technology, the laser still has a lot more potential.

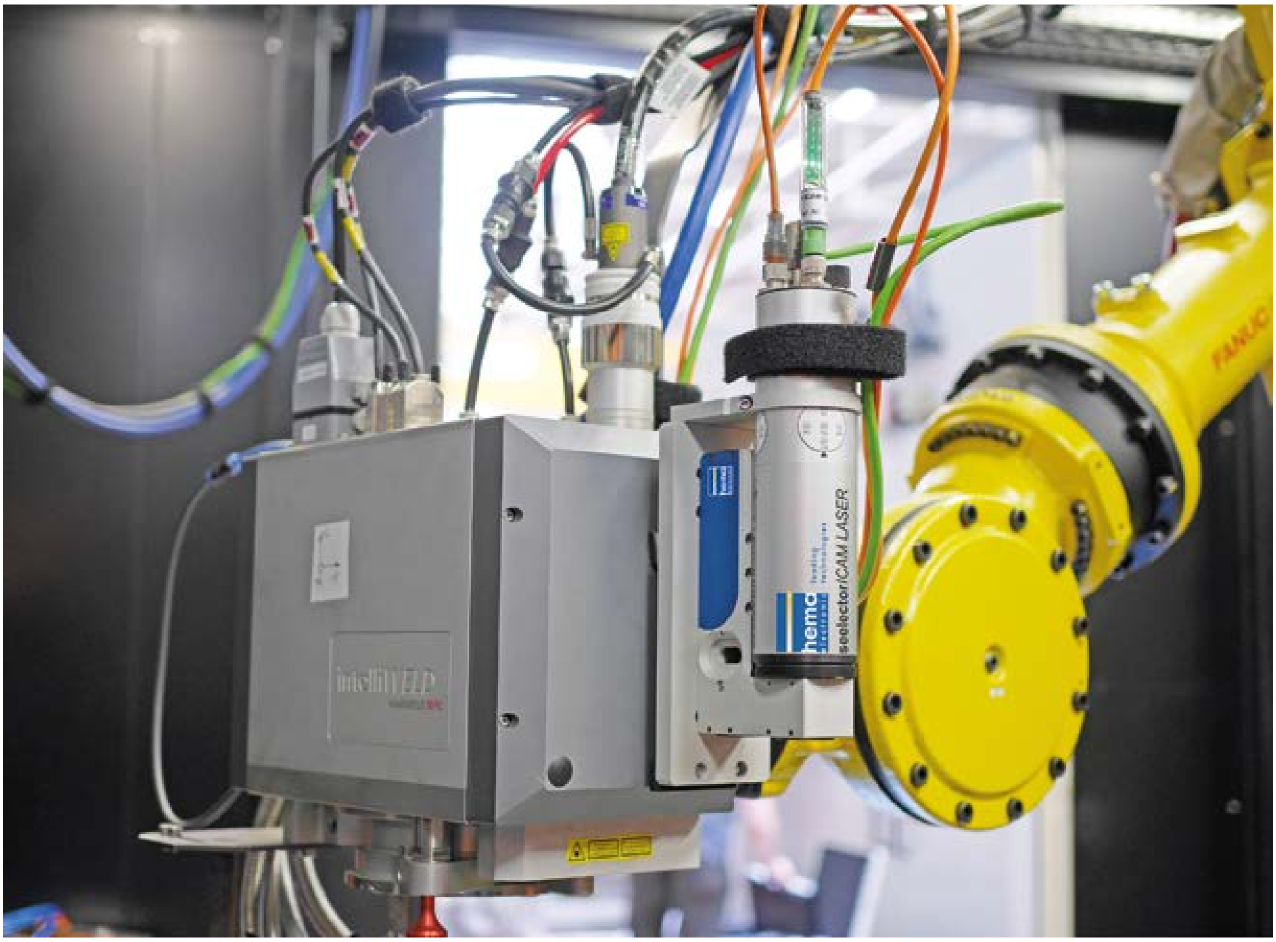
*

Text: Dr. Janine van Ackeren, freelance science journalist, Duisburg, Germany

Laser weld quality: it’s in the process!

The inspection of laser welding processes is anything but trivial – new technologies are needed to provide high-level quality control

Charlotte Helzle



▲ **Fig. 1** Hema Electronic’s seelector-ICAM Laser quality assurance system can be deployed in conjunction with 3D scanning units for remote laser welding applications, such as intelliWELD from Blackbird. (Source: FFT Produktionssysteme)

Laser-welded seams are state-of-the-art in car body construction, where the strength of a weld seam is the most important criterion – but hardly detectable from the outside. The latest technology for inline process monitoring enables reliable and effective quality monitoring. It combines robot-assisted welding and inline quality control.

Most conventional welding inspection methods work indirectly by observing the process emissions. From their behavior, conclusions can be drawn about characteristics of the weld that will become evident later. Using this method, however, the later effects are only predicted, not verified – with corresponding uncertainty.

The reasons for this are thermo-mechanical influences, localized and temperature-dependent expansion and shrinkage in the component, and local cooling conditions that determine the behavior of the material in the weld zone.

These influences cause unpredictable effects that are independent of the process emission. As a result, the best outcomes are obtained by test methods that take place when the molten material has come to rest again.

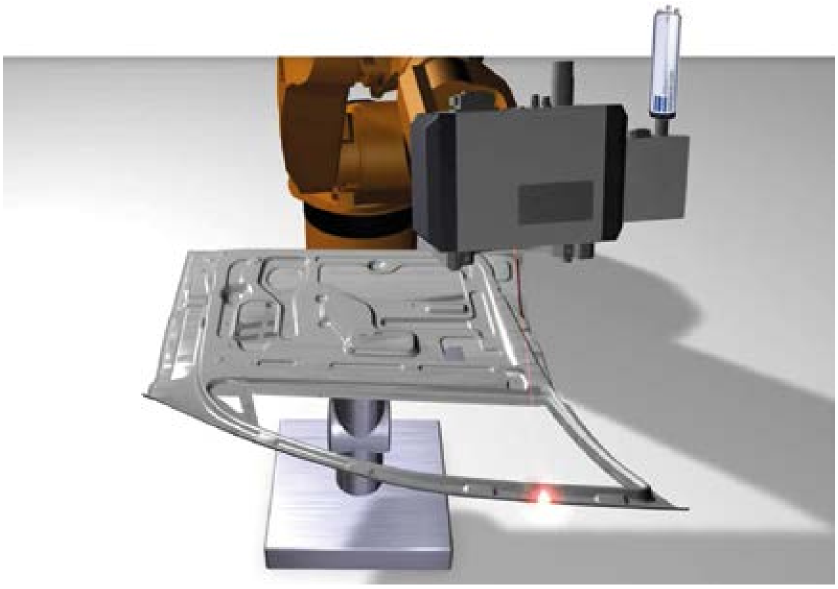


Fig. 2 Laser scan welding in car body construction (Source: Hema Electronic)

The strength of a weld does not necessarily show on the surface

Measuring the surface of a weld bead and assessing its uniformity says nothing about the weld penetration depth or internal pores. It is therefore not possible to make a statement about the strength of the weld. This could be solved by methods using ultrasound or x-rays that shine through the weld. However, they are only possible after the welding process is finished and once the material has largely cooled down. In addition, they require a separate measuring station and take a long time, which qualifies them only for random sampling.

Why high-speed cameras may not solve the problem

Another approach to the testing of welding processes and a favorite of researchers are high-speed cameras. With 500 images per second and more, the course of a welding process can be documented very well using this technology. The observation of the weld pool and the plasma light are indeed a great help in understanding the process. However, this does not help in the search for welding defects such as holes, cracks and pores and therefore their use is not practical for quality control in the production process. This is because holes and cracks do not exist in the molten bath. They only form during the solidification phase in the cooling material. At the same time, the recording of the cooling behavior during the solidification phase is limited to defects on the surface. The weld penetration depth or the bond between the upper material layer and the lower material layer cannot be detected by pure surface testing.

In addition, the enormous amount of data generated by so many images cannot be evaluated quickly enough during a production process to enable real-time production control. This means that high-speed cameras are very well suited for scientific research, but a different solution must be chosen for production monitoring.

Measuring annealing: a different approach

A method is needed for fast-paced serial production that can keep up with the process cycle and also immediately provide the quality information for further handling at the end of the processing of a component. The system must generate the most reliable information possible with as little data as possible, and also provide the eminently important evidence concerning the quality of the connection between galvanized steel sheets.

A different approach is taken by Hema Electronic's seelectorICAM Laser quality assurance system in conjunction with 3D scanning units for remote laser welding applications such as intelliWELD from Blackbird (Fig. 1) or the Trumpf PFO 3D (Fig. 4) – both of which have proven their worth in numerous industrial installations together with the Hema system. It detects the so-called 'false friends' – defects that cannot be recognized on the surface – by measuring the glow that is clearly visible in steel for several milliseconds after the laser has stopped applying energy to the weld. The intensity and spread of the glow of the weld form the basis for its evaluation. This provides access to the primary characteristics of the weld, which actually enables reliable conclusions about its strength and quality to be drawn (Fig. 2).

Extensive test series of the method implemented by Hema Electronic in cooperation with Daimler showed

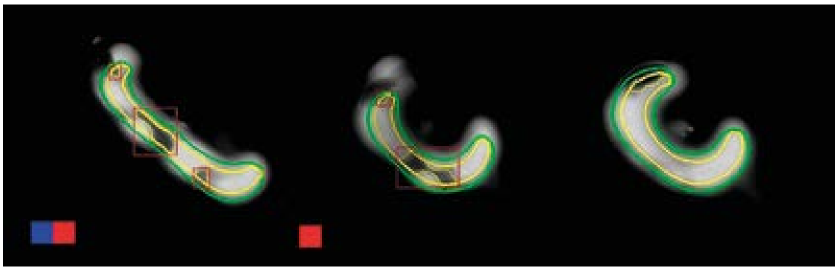


Fig. 3 A single image per weld seam is sufficient for reliable and fast quality assessment using the seelectorICAM Laser system. (Source: Hema Electronic)

that, in addition to detecting the 'false friends', superficial seam defects can also be reliably assessed using a single image per weld seam (Fig. 3).

But how does the inspection process work in detail?

The laser welds its seam to join the sheets. After welding, the weld itself still glows slightly. This visible glow can be further improved by briefly reheating the seam, which is done by passing over it again with a defocused and reduced laser power in the opposite direction. The uniformity of the after-annealing achieved in this way increases the reliability of the evaluation. The laser power is then lowered further and the deflection mirror is directed onto the seam. The image is acquired after a short waiting time of about 10 ms, during which the solidification process of the melt has progressed sufficiently. The camera of the system is directed centrally through the laser optics onto the welded seam and captures an image. The laser then moves to the next weld. The evaluation of the acquired images begins immediately and takes place in parallel with the subsequent welds and image captures. The entire evaluation is available as soon as the last seam has been welded. The component can be sorted as passed or failed as a result of the evaluation. This data is available for further use in the production line and for rework; the system transfers the data to the process computer and releases the line for the next component.

Welding aluminum: special challenges for quality control

In addition to steel and galvanized steel, aluminum is becoming increasingly important in vehicle construction due to its weight-saving features. A particular difficulty with aluminum welding in quality control is the high light reflection of the surface. Bare and rough areas reflect very differently. This results in undesirable effects both in the coupling of the laser beam and in image acquisition. Image acquisition with thermal cameras suffers from the reflections, as do images in the visible wavelength range. Also, the direct transfer of the previously described solution for process and quality control is not possible since aluminum does not show annealing. The heat conduction in this material is so fast that experiments with thermal cameras and with spectrometry were not successful. To enable reliable quality assessment, Hema has therefore further developed the 'seelectorICAM LASER' system for use in aluminum car body construction. It uses a two-step analysis: in the first step, an image is taken on the top side of the sheet immediately after welding and smoothing the seam, in which the edge distance of each seam to the component edge (if any) is determined and checked. In the second step, an image is taken on the reverse side of the component, before smoothing the underside of the seam, in order to detect a material leakage from the seam that guarantees a sufficient weld penetration depth. After testing, the underside can be smoothed with a defocused laser if desired. The advantage of this smoothing is the restoration of a smooth surface and the original material thickness. The result is reliable quality and strength assurance, but also a smooth surface with restoration of the original material thickness.

The image evaluation

During image evaluation, the system calculates measured values such as brightness, geometric data of the image features and evaluation results for the assessment of the weld and stores them in Excel spreadsheets where they are available for process monitoring. The rework station displays the rejected welds – both their position on the component and the defects found – so that rapid and targeted rework is possible. In addition, the system detects any welding system malfunctions or unsuitable settings from the images.

During setup, the user works interactively with the images and measurement results. The operator can parameterize the system and has control over the evaluation process at all times. Data and images can be called up on the system PC. The user can optionally store them in data records assigned to the serial numbers of the manufactured components along with other production information.

Fast and easy inline integration

A laser welding system with a scanner head is a prerequisite to be able to integrate the quality assurance system into an existing production line. Suitable lasers include scanners such as intelliWELD from Blackbird (Fig. 1) or the Trumpf PFO 3D (Fig. 4). The quality assurance system itself consists of the

Fig. 4 A Trumpf PFO 3D with a Hema ICAM LASER camera on a KUKA robot (Source: Mercedes-Benz AG)

camera and its software, a PC for the parametrization, display and storage of details, a database interface for inspection results (RDS), a PLC connection to control the inspection and material flow, and a connection on the laser to trigger the 'seam images'.

The seelectorICAM LASER is an intelligent embedded vision system with on-board data processing capabilities. This allows the raw data to be evaluated in the smart camera in real time. The camera is located in the beam path of the laser and has a brightness dynamic of 170 dB for strong image contrast. Its software consists of the image acquisition and evaluation software on board the camera and the operator software on the PC. The camera is operated via a user interface on the system PC. When changing components, the operator simply selects the new, associated program. Teach-in or adaptation to a component for which a program already exists is basically not necessary. As a result, the Hema system can be integrated quickly and easily into any laser welding production line. It immediately provides quality control data and enhances the quality and productivity of the production process.

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Ultrafast lasers today

The continuous increase in average laser power opens new horizons for femtosecond laser processing

Eric Mottay

Source: Alphanov

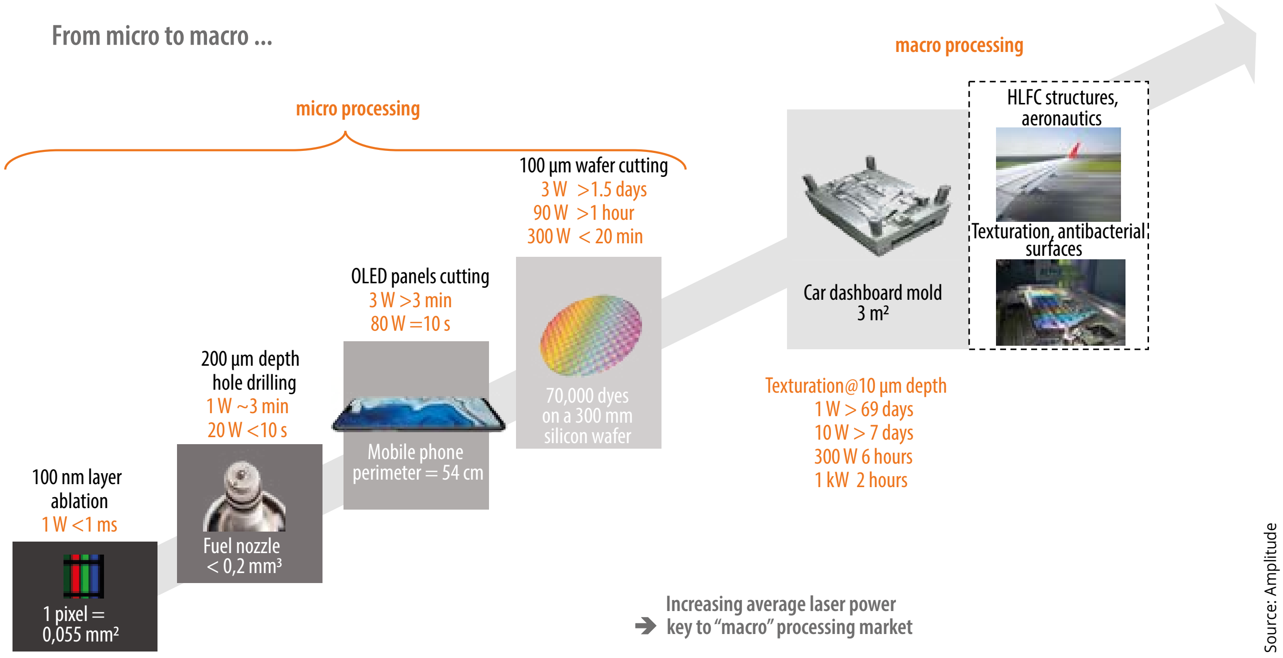
Ultrafast lasers have seen a tremendous increase in average power over the past ten years, with industrial lasers now reaching the kW level. We are at a turning point in femtosecond technology, which will enable new fields of use and new methods of production. High laser power and the associated beam engineering enable significant improvements in industrial productivity and open access to large new markets, such as aeronautics, energy, and mobility.

▲ High area surface femtosecond laser texturing

Ultrafast lasers, i.e. pulsed lasers operating in the picosecond or sub-picosecond domain, have transformed high precision laser manufacturing over the last three decades. Since the mid-nineties, two of their characteristic features have been shown to be of great interest for material processing. Their short pulse duration and associated high peak power provide a particular type of ablation applicable to all materials where electrons are ionized in a plasma before any heat transfer to the lattice. In practical terms, this means that the laser-matter interaction is over before any heat can build up in the material, offering a virtually athermal process. Coupled with the tight focus typical of laser processing, and the high optical power allowing interaction on almost any material, the potential benefit is obvious: micromachining of any material with high accuracy, a small feature size and no thermal effects such as crack formation or surface melting.

The laser sources that were initially available were complex and expensive systems, and as such were mostly confined to the realm of the laboratory. Industrial applications had to wait until the early 2000s where a period of intense laser development led to a new generation of diode-pumped, compact and reliable lasers suitable for industrial deployment. During this time, the three main industrial laser technologies still in use today were developed, namely thin disk, fiber and slab. Using Ytterbium as the active material, they form the basis of today's industrial applications.

As laser technology matured, a billion dollar market gradually emerged, built around an ecosystem of laser manufacturers, system integrators, technology centers and research institutions, with Europe at its core and affecting all segments of human activity. In the medical domain, vision correction applications such as lasik rapidly expanded and new procedures, for instance in cataract surgery, quickly followed. Ultrafast lasers repaired tiny defects in sophisticated OLED display screens and later on were used to cut the same screens. They are now essential components in the man-



ufacture of all modern smartphones. New and innovative marking applications were developed, such as deep black aesthetic marking of consumer electronics devices, or the inscription of invisible codes inside glass that met the traceability and anti-counterfeiting needs of the pharmaceutical industry. Further laser and application development now enable drilling and high precision cutting as well as sophisticated surface texturing, for instance in the luxury watchmaking industry. Other advances, such as the microwelding of glass or dissimilar materials or the manufacturing of intricate 3D structures in glass by laser and chemical etching, have expanded the range of applications.

The road to high power

As varied as these applications are, they nevertheless share common features. They require micron-size resolution and typically cover very small areas, often of just a few square millimeters. A single femtosecond pulse will remove a tiny amount of material with very high precision, leading to fairly limited ablation efficiency, of the order of a few cubic millimeters per minute in most cases. Increasing the ablation efficiency would therefore allow for a greater processed volume in the same amount of time and, as we will see, has the potential to unlock new markets.

Even if some alternative options, such as gigahertz processing, are now being actively explored, the main route to increase the ablation efficiency remains an increase in the average laser power. This can be done either by increasing the energy contained in one pulse, or by increasing the number of pulses per second, i.e. the repetition rate of the laser.

Increasing the average power of the laser has been a key driver for the development of industrial applications for the past several decades. Current high-volume manufacturing processes, such as OLED display panel cutting, use lasers with a power range of ten to one hundred watts, moderate pulse energy (typically a few hundred microjoules) and a high repetition rate (typically from 10 kHz to several MHz). Increasing the ablation rate to open new markets for femtosecond laser processing would require an increase of the laser power by an order of magnitude.

The active material in current industrial lasers, the ytterbium ion, presents specific challenges for high power operation. Due to its low emission cross-section, it requires a very high pumping intensity to achieve sufficient gain for efficient laser operation. This can be done by tightly focusing the pump diode beam into the laser material, but since the pump to laser conversion efficiency is not perfect, this means that a large amount of heat has to be extracted from a small volume.

Any high-power laser technology therefore needs to provide for efficient heat extraction from the laser amplifier, while maintaining sufficient gain for laser operation. Three technology alternatives have been developed over the years, and have proven their capabilities for high power operation.

The first approach, the thin disk laser, relies on the material geometry of the laser amplifier to ensure efficient heat extraction. The laser material is a slim Yb-doped crystal mounted on a very efficient heatsink for optimal extraction. In addition, the laser spot is kept fairly large so that the thermal gradient in the laser crystal is mostly unidirectional, and therefore a high spatial beam quality can be maintained. An additional benefit of this approach is that the beam size can in principle be made arbitrarily

Company

Amplitude

Amplitude is a manufacturer of ultrafast lasers for industrial, medical, and scientific applications. The group consists of three manufacturing locations in Bordeaux and Paris, France, and San Jose, USA., and an extensive network of support offices in Europe, Asia, and North America. Amplitude offers a unique and distinct product portfolio: diode-pumped ultrafast lasers, ultrahigh energy ultrafast lasers and a full line of high-energy, solid-state laser products. From ultrafast industrial fiber lasers to petawatt-class high intensity lasers, Amplitude is focused on helping its customers to bring new solutions to the market.

www.amplitude-laser.com

Source: IFSW, U. Stuttgart

The Tresclean project (tresclean.eu) aims at developing high-throughput laser-based texturing for fluid-repellent and antibacterial metal surfaces

large, and that high pulse energy can be achieved. Recent work has demonstrated output energies at the joule level with this technique, to be compared with the hundreds of microjoules typically used for material processing applications. The main limitation is the low single-pass amplification in the crystal, as well as the limited pump absorption due to the low crystal thickness. Sophisticated pump configurations using multipass designs with parabolic mirrors as well as a more complex laser design can partially circumvent this drawback. In a collaboration between Amplitude and the Institut für Strahlwerkzeuge (IFSW) of Stuttgart University, a kilowatt laser using a 125 µm thick Yb:YAG disk in a 24-pass pump cavity and an 80-pass laser amplification delivered a pulse of 1 mJ at a repetition rate of 1 MHz with a pulse duration of 560 fs [1].

A second elegant approach is the use of Yb-doped optical fibers as the active laser medium. The immediate benefit is that the heat to be extracted is distributed all along the fiber length over a large area and can therefore be fairly easily removed. Achieving high average power is therefore comparatively easier than with other approaches. In addition to the efficient heat extraction, high laser gain is possible thanks to the long propagation length in the fiber. The main challenge is that single transverse mode operation is required in the fiber core in order to maintain excellent beam quality. This places stringent requirements on the optical design, which cannot be met with traditional fiber manufacturing techniques. Only the advent of microstructured fibers with a large doped core and efficient coupling of the pump light have allowed this limitation to be circumvented. The finite size of the fiber core and cumulative non-linearities in the fiber still limit the available energy per pulse.

As early as 2010, researchers at the University of Jena demonstrated an 830 W average power fiber laser, delivering 10.6 µJ, 640 fs pulses at a repetition rate of 78 MHz. In a recent feat of engineering, the same team demonstrated 10.4 kW average power operation by coherent combining of twelve individual amplifiers [2].

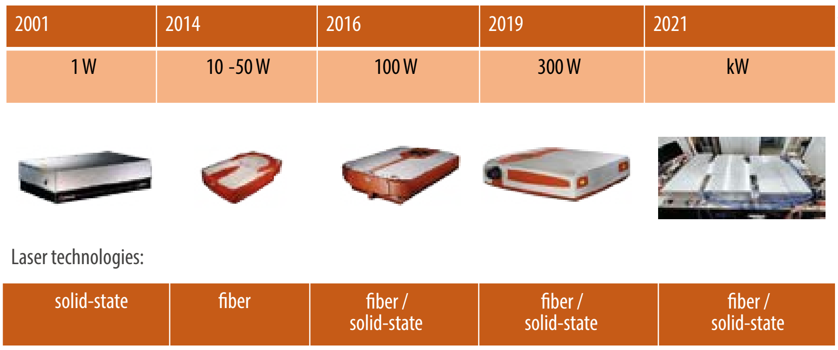
The third approach was pioneered by the Fraunhofer Institute for Laser Technology ILT in Aachen [3]. The active material is an Yb-doped parallelepiped crystal with a rectangular cross-section. The heat generated by the pump diodes is extracted from the top and bottom surfaces while the laser beam is amplified in a multipass arrangement. The pulse energy increases during each pass, along with the beam diameter, allowing a constant fluence on the crystal surface to be maintained. Using this technique, high efficiency as well as high energy can be reliably achieved. The unilateral heat dissipation may induce some astigmatism into the beam that has to be carefully taken into account in the laser design. The slab technology [4] has been transferred to several industrial companies over the years, such as Amplitude, Amphos, and Edgewave. Delivering pulse energy in the tens of millijoules range, femtosecond operation and high repetition rates, it is now becoming the de facto standard for high average power operation in an industrial environment.

Beam engineering for high power operation

The availability of high average power lasers alone is not sufficient to guarantee high ablation efficiency and large-scale microprocessing. Irradiating a material with a high repetition rate, high average power laser means that even if the single pulse, ultrafast interaction has very low residual heat deposition, a gradual build-up of heat between the pulses leads to unwanted thermal effects, severely degrading the processing quality and negating the benefits of ultrafast laser processing. Two strategies are possible to mitigate the heat accumulation.

If the available pulse energy is high enough, the beam can be divided into several beamlets with manageable average power. This allows the processing speed to be increased by multiplying the number of beams while maintaining the optimal processing quality in each individual beam. A collaboration between Amplitude and the Fraunhofer ILT within the framework of the European Multiflex project aims at coupling a kilowatt average power, femtosecond laser system to a dynamic beam splitting system. Coupling diffractive optical elements with active control via acousto-optic modulators allows precise control of each individual beamlet in a 64 × 64 grid [5].

A high scanning speed is a requirement to efficiently use low energy, high repetition rate systems so that a beam does not stay too long on a single point and so that the average power density



Source: Amplitude

Femtosecond lasers – developments over the years. 1000× increase in average power in 20 years.

on the material remains low. A new generation of polygon scanners, enabling scan speeds of tens or even hundreds of meters per second, removed an important bottleneck. Because polygon scanners only deflect the laser beam in a single direction at constant speed, the synchronization between the laser and scan head become critical. Advanced synchronization features in the laser allow true 'pulse on demand' operation and open the way to new processing approaches.

A second ultrafast revolution

The growing availability of kilowatt-class femtosecond lasers, as well as progress in beam engineering and application development, means that we are at the edge of a new step in the development of ultrafast laser processing. By bringing high precision microprocessing to large scale environments, new markets and applications will open in the next few years.

As an example, the Tresclean project is exploring the potential of ultrafast lasers to create antibacterial surfaces on home appliances such as dishwashers. The project has demonstrated the high speed texturing of a large metal mold, imparting the surface with new functionality, which can then be transferred to the final manufactured part.

In another example, the Multipoint project is developing a high-power, ultrafast laser processing system for high throughput microdrilling of large titanium panels used in the fabrication of hybrid laminar flow control (HLFC) structures in the aerospace industry.

In the display industry, the availability of high-power, green or UV femtosecond lasers offers new perspectives for the efficient cutting and processing of AMOLED screens of increasing size and complexity.

In the longer term, high average power femtosecond lasers are ideal sources to generate extreme UV radiation for semiconductor metrology. High-energy, high-power lasers create x-rays that can be used for advanced medical imaging applications.

With the cooperative community of industrial laser manufacturers, technology and research centers and component manufacturers, a bright future still lies ahead for ultrafast laser processing.

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[1] *D. Holder, R. Weber, C. Röcker, G. Kunz, D. Bruneel, M. Delaigue, T. Graf,* and *M. Ahmed*: High-quality high-throughput silicon laser milling using a 1 kW sub-picosecond laser, Opt. Lett. **46** (2021) 384-387

[2] *T. Eidam, S. Hanf, E. Seise, T.V. Andersen, T. Gabler, C. Wirth, T. Schreiber, J. Limpert* and *A. Tünnermann*: Femtosecond fiber CPA system emitting 830 W average output power, Opt. Lett. **35** (2010) 2, 94-96

[3] *P. Russbueldt, T. Mans, G. Rotarius, J. Weitenberg, H.D. Hoffmann,* and *R. Poprawe*: 400 W Yb:YAG Innoslab fs-amplifier, Opt. Express **17** (2009) 12230-12245

[4] *P. Russbueldt, T. Mans, J. Weitenberg, H.D. Hoffmann,* and *R. Poprawe:* Compact diode-pumped 1.1 kW Yb:YAG Innoslab femtosecond amplifier, Opt. Lett. **35** (2010) 4169-4171

[5] *O. Hofmann, J. Stollenwerk,* and *P. Loosen*: Design of multi-beam optics for high throughput parallel processing, Journal of Laser Applications **32** (2020) 012005

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Eric Mottay is the CEO of Amplitude, a company he founded in 2001 and which is now a leading manufacturer of ultrafast lasers for industry and science. He is passionate about laser technology and applications development and believes that sound engineering and collaborations are the key to success in photonics.

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Meet us at AKL '22

Enhancing cutting performance with an oscillating laser beam

A newly developed high-brightness 4 kW oscillator in combination with LBC technology, which is a dynamic beam shape control, leads to significant improvements

Takaaki Yamanashi

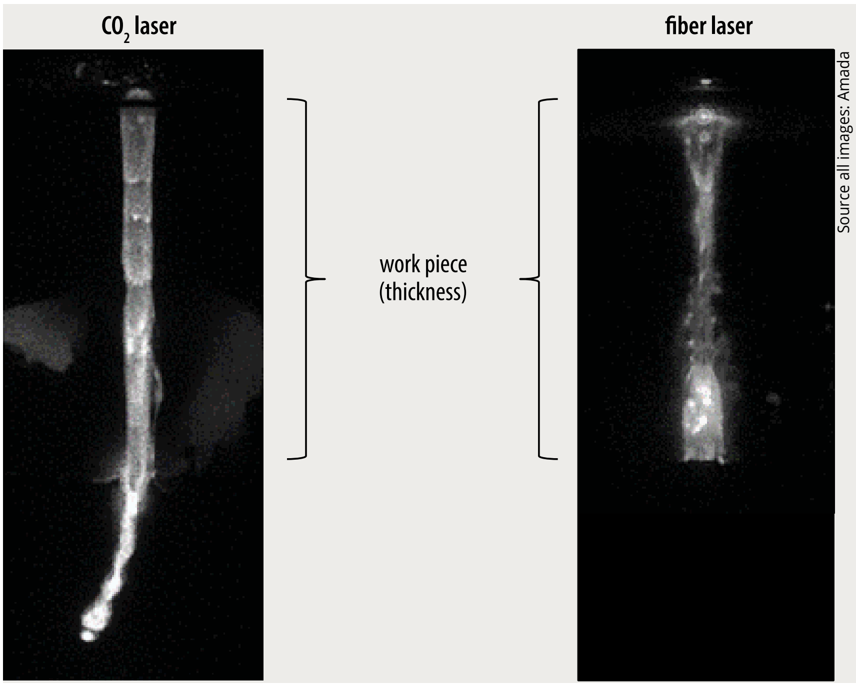

Fig. 1 Comparison of typical cutting performance between a CO_2 laser and a fiber laser

Fiber lasers feature higher energy conversion efficiency than CO_2 lasers, which enables a simple structure and energy-saving design. Consequently, in the laser cutting processes for metal sheets, operators have been shifting usage from CO_2 lasers to fiber lasers at an accelerated pace because of their reduced maintenance, improved metal absorption rate due to their wavelength and other advantages. In actual practice, fiber lasers are superior to CO_2 lasers in high-speed cutting processes for thin metal sheets. However, as the thickness of the metal sheet increases, problems arise where fiber lasers have inferior performance to CO_2 lasers in terms of dross adhesion, cutting surface quality, and other factors.

Drawing on our extensive R&D experience in fiber lasers at Amada, we decided to focus on the effect of light on metal materials by analyzing and comparing the cutting performance of a CO_2 laser and fiber laser. We were able to conduct a wide range of trials on the light from fiber lasers by taking advantage of Amada's own product line of fiber lasers. Fig. 1 shows a comparison of the cutting performance between a CO_2 laser and fiber laser. It can be seen that the molten metal flows smoothly when the CO_2 laser is used, but not with the fiber laser. The flowing state of the molten metal and the melting temperature were repeatedly compared and analyzed for their physical properties. This analysis enabled Amada to develop two beam profile control technologies.

To improve the metal cutting performance of the fiber laser, a wide range of beam profile control technologies has been developed by several companies, but these are static control methods (Fig. 2) throughout.

Amada also uses the ENSIS technology, which is a method for static control of the beam profile. Improved cutting performance using this technology has even given effective performance in high power fiber lasers of 6 kW and more. However, generally as the oscillator output increases, the power consumption also increases, and the laser machine becomes more expensive.

For this reason, from the perspective of SDGs, Amada has concentrated on improving the cutting performance for fiber oscillators in the medium output range where there is low power consumption. At Amada, we conducted R&D on the effects of cutting performance improvements and the optimum oscillation method using dynamic beam profile control technology where laser beams are oscillated at high speeds. We could dramatically improve the interaction efficiency between the laser beam and metal by oscillating the low-order focus point of the fiber laser at high speed to any selected shape while maintaining high brightness.

Fig. 4 shows a conventional laser cutting method without beam control and the image of a laser beam using locus beam control (LBC) technology. For a conventional laser cutting method without beam control, shown on the left, the beam of the fiber laser, which is sharp when thin sheets are cut, is focused in a small area on the surface of the metal material and instantly melts the material at a high energy density for high-speed cutting. For medium and thick plate cutting, the focal position is shifted by changing the distance between the lens and the metal material to obtain the appropriate cutting width for cutting, and the focusing diameter on the surface of the metal material is increased for cutting. The energy density of a laser decreases as the focusing diameter increases for the same laser power. The lower the energy density, the longer it takes for the metal material to melt and the slower the cutting speed as a result. One way to compensate for this decrease in energy density is to increase the power output of the laser that irradiates the metal material. This is one of the reasons why the competition to increase the power output of fiber laser oscillators has become increasingly fierce in recent years. LBC technology, on the other hand, is a cutting method that controls the path of the beam to match the material and thickness by oscillating the light at high speed while maintaining a sharp light with high energy density. Consequently, by controlling the sharp light with high energy density, the laser energy can act on the metal material more efficiently than before.

The absorption rate of the laser beam into metallic materials varies with the angle of incidence of the beam. As shown in Fig. 5, the angle of incidence at which the absorption rate increases is different for a fiber laser and a CO_2 laser. If the fiber laser is fired at the same angle of incidence as the CO_2 laser, the fiber laser will have a lower absorption rate than the CO_2 laser. To use the energy of the fiber laser efficiently, the angle of incidence must be reduced. LBC technology makes it possible to significantly increase cutting speed and reduce dross adhesion on the back of the material compared to conventional laser cutting methods.

The effect of this LBC technology was also found to work well with sharp light having a high energy density. Amada therefore developed a single-module 4 kW oscillator with sharp light having high energy density. Conventional

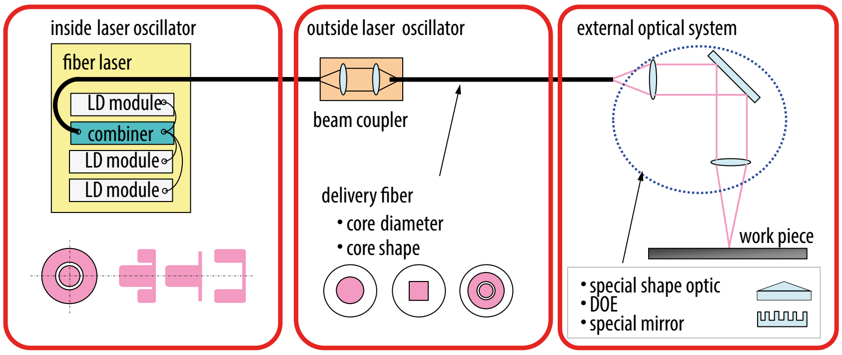

Fig. 2 Typical beam profile control methods

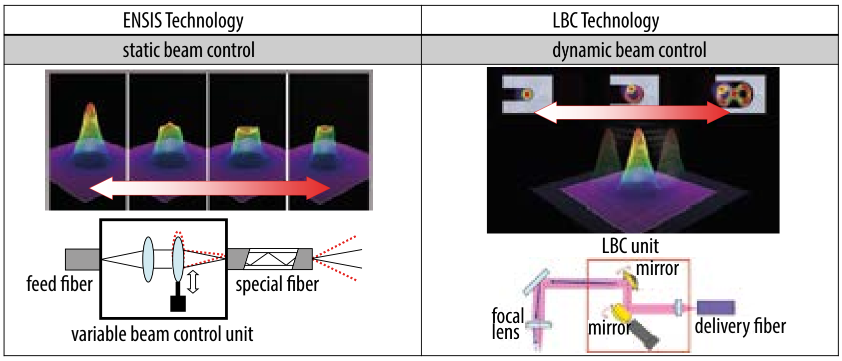

Fig. 3 Amada's two beam profile control methods

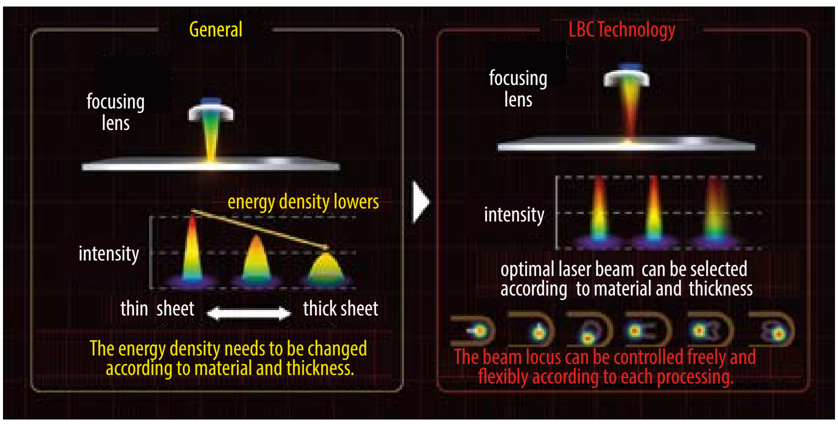

Fig. 4 Comparison between locus beam control (LBC) technology and conventional cutting methods

Company

AMADA

The AMADA Group provides a full range of solutions not only for five major businesses, which are sheet metal machinery, cutting machines, grinding machines, stamping press, and micro-welding, but also software, peripheral equipment, tooling, maintenance and service. As a comprehensive global manufacturer of metalworking machinery, AMADA contributes to the development of manufacturing considering what is most necessary from the customer's point of view.

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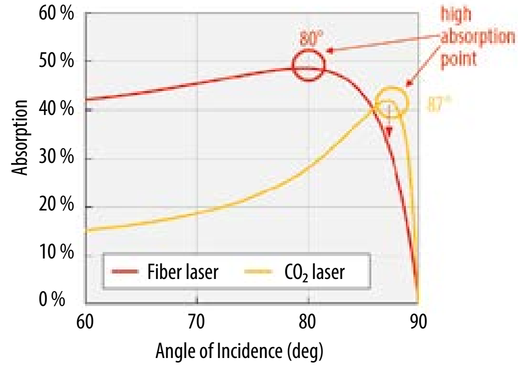

Fig. 5 Laser absorption in iron vs the angle of incidence

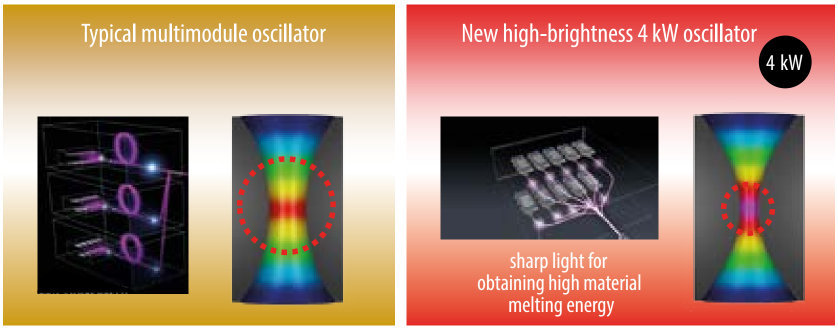

Fig. 6 Newly-developed high-brightness 4 kW oscillator

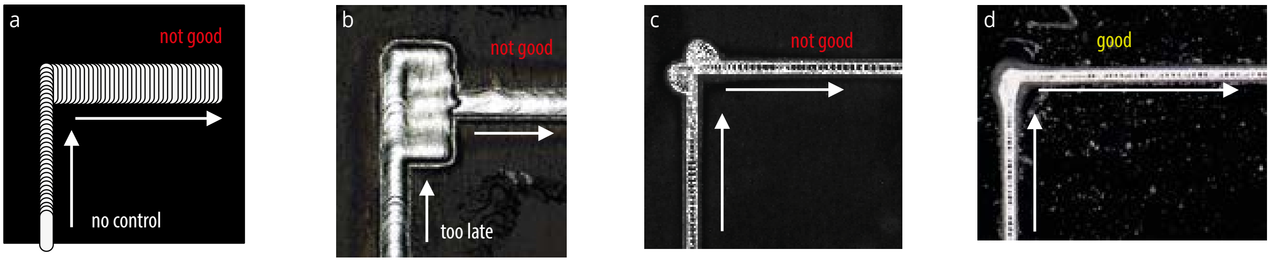

Fig. 7 LBC technology has a directional beam profile, producing problems at corners (a – c). Vector control can overcome these (d).

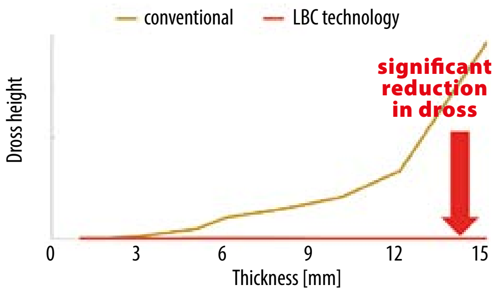

Fig. 8 Comparison of dross height of stainless steel

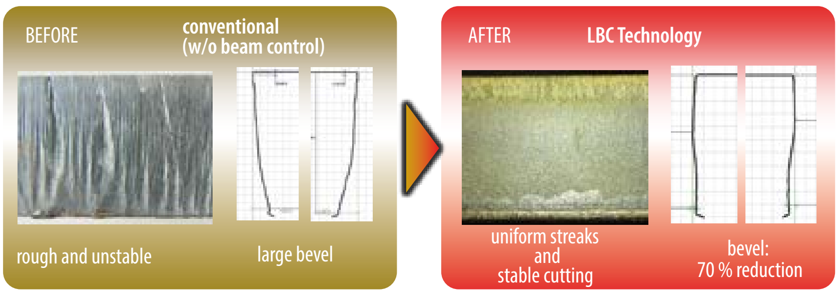

Fig. 9 Comparison of mild steel with 22 mm thickness

multimodules combine and output the beams generated by multiple laser modules, making it difficult to obtain sharp, high-brightness light. The newly-developed high-brightness 4 kW oscillator is used in combination with LBC technology to enable a significant improvement in cutting performance compared to the conventional method.

Author

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In addition, due to its dynamic beam shape, LBC technology has a directional beam profile that depends on the oscillation pattern of the beam. This means that the oscillation pattern of the beam needs to be rotated to match the cutting advancing direction. If the pattern is not rotated, we obtain the result shown in Fig. 7a, and if the timing of the rotation is different from that of the laser head, we obtain the result shown in Fig. 7b. Even if the rotation is well timed, the beam oscillation pattern may generate a bite at the corner as shown in Fig. 7c. In these cases, cutting will not produce the desired shape and so Amada has also developed control technology to prevent these problems. We call it vector control technology. Vector control allows the user to obtain an appropriate cutting shape from any cutting direction (Fig. 7d).

One result of implementing LBC technology is improving the cutting speed for aluminum. When the cutting speed by the conventional cutting method is taken as 100 %, LBC technology improves the cutting speed by about two-fold. This cutting speed is equivalent to the performance of an oscillator with 1.5 to 2 times the laser power. A comparison of the costs for cutting stainless steel shows a significant cost reduction of about 50 % compared to the conventional method. The dross was also noticeably reduced by using the different oscillation patterns for LBC technology (Fig. 8). The high-intensity sharp light and appropriate oscillation of the LBC can also enable stable oxygen cutting with a good cutting surface for mild steel, which is difficult to cut using conventional methods (Fig. 9).

Looking forward, at the Amada Group we will continue to work on developing laser cutting technology and products to support manufacturing from the customer's perspective based on our company motto, "Growing together with our customers."

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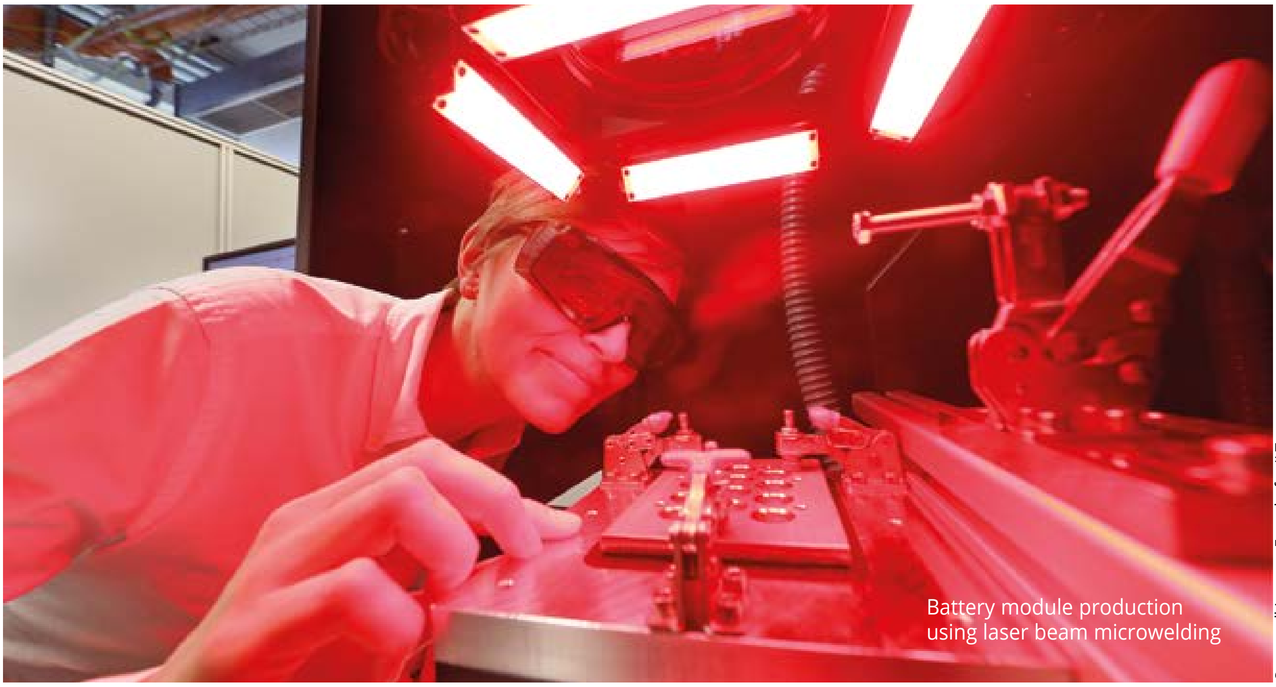
Extending the degrees of freedom in laser beam microwelding

How can seam geometry and process quality be controlled by applying temporal and spatial power modulation?

André Häusler & Marc Hummel


Battery module production using laser beam microwelding

Source all images: Fraunhofer ILT

Using spatial and temporal power modulation, new degrees of freedom can be gained in process efficiency, quality and seam geometry, which are of particular interest for the increasing requirements of electromobility in the production of battery cells and power electronics. Through the targeted synchronization of these two compensation methods, synergies can be used and any limitations that may arise can be overcome.

Laser beam welding has long since arrived in industry as an established joining technology and most recently serves important fields of application like the contacting of battery cells or the welding of bipolar plates for fuel cell technology. Different requirements and design ideas for the joints require a flexible joining technology that can reliably address the boundary conditions. With the help of spatial and temporal power modulation, the degree of freedom of the process can be extended and the seam shape as well as the process stability can also be influenced.

For years, laser beam microwelding has been of steadily increasing interest to the research and industrial landscape all over the world. The development of highly brilliant laser beam sources in the near infrared range and the continuing falling price development of fiber lasers have contributed to this trend. With the help of these beam sources, which have very good focus ability, beam diameters of just a few 10 µm can be achieved, which lead to ever greater intensities due to the continuously increasing maximum available laser power. Intensities of over 400 MW/cm^2 can already be achieved today using space-saving 19-inch rack variants. These high intensities are particularly helpful when welding copper and aluminum. The high intensity produces a deep welding effect, even with the low absorption coefficients in the near infrared wavelength range due to the material properties. These high intensities combined with the small focal diameters lead to small weld seam cross-sections, which are generally a disadvantage for electrically conductive connections.

On the one hand, this situation is a disadvantage for contacts in battery technology and power electronics – large seam widths and connection areas are required here due to the high currents to be transmitted. The charging times for battery-powered vehicles are directly related to the maximum current that can flow through the battery pack without causing thermal over-

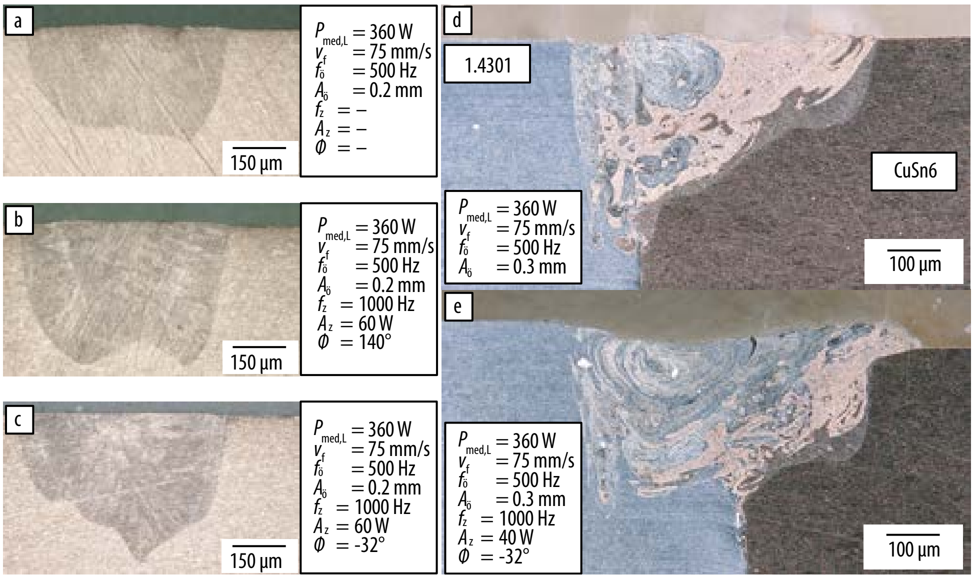


Fig. 1 Precise adjustment of the weld seam geometry by superimposing spatial and temporal power modulation: weld seam with spatial power modulation (a); weld seam with spatial and temporal power modulation (b), weld seam with spatial and temporal power modulation (c), compensation of the seam tilt in unequal material combinations (d, e)

heating and corresponding damage to the cells.

On the other hand, looking at the applications for welding bipolar plates for fuel cell technology, it is precisely these small focal diameters and resultant small weld seam widths that are required to trim the flow field design to greater efficiency, even though the weld seam is part of an electrical connection. This is because a small weld seam width results in scaled-down structural gaps in the flow field, which leads to a larger reaction area and thus to increased efficiency of the final fuel cell.

Spatial power modulation for larger connection areas

So how can we increase the connecting area of the weld seam during welding without losing the intensity needed for deep welding processes? The solution is spatial power modulation. This is a circular oscillation superimposed on the linear feed direction, which creates a spiral path movement of the laser beam. This form of movement leads directly to several positive effects: firstly, due to the path movement, material that was already molten is reprocessed with the laser beam again. In this way, energy that has already been absorbed into the material is partly used again. This leads to larger melt pool volumes than with conventional welding using only a linear path geometry. Secondly, due to the high oscillation frequencies (f = 1000 Hz), high path velocities are realized (v > 700 mm/s) that influence the tilting of the keyhole and thereby further increase the energy input during the deep welding effect through multiple interactions between light and matter. Thirdly, the two additional parameters of amplitude and frequency, used to describe the spiral trajectory of the laser beam oscillation, provide design freedom in the geometric shape of the weld seam. The conventional welding V-shape therefore becomes a U-shape. This means that there is only a slight influence on the connection width if there are local fluctuations in the welding process.

In summary, these positive aspects of spatial power modulation allow the process efficiency – given by the quotient of applied laser energy and the resultant melted volume – to be significantly increased. An increase in the melting volume can then be achieved for the same welding time and with the same laser power. This aspect is particularly important when looking at CO_2-reduced production. So increasing process efficiency while minimizing the electrical energy required will become a prime consideration for research worldwide in future.

The disadvantage of the asymmetric spiral trajectory of the laser beam, however, is the differing line energy during one oscillation. The higher path movement of the laser beam in the feed direction leads to lower local energy input and vice versa. This results in a fluctuation in the welding depth transverse to the feed direction.

Temporal power modulation and how it can influence the process

Another method of influencing the laser beam welding process is temporal power modulation. Basically, a distinction is made between pulse shaping with pulsed laser beam sources and the temporal change of the laser power in laser beam processes with continuous laser beam sources [1].

While temporal pulse shaping is mainly used for pulsed beam sources to influence the thermal and metallurgical properties during the solidification process, it is used for continuous seam welding over the entire weld length. One of the most widespread implementations of continuous temporal power modulation is the superimposition of a sinusoidal modulation on the laser power. Investigations have shown that an improvement of the seam quality as well as a reduction of the fluctuation of the welding depth occurs particularly at frequencies <1 kHz [2].

In addition to this compensation of quality and precision characteristics, temporal power modulation can also be used to specifically influence the welding depth and, as with the power ramps already mentioned, to adapt it to the application.

Synchronized spatial and temporal power modulation for targeted control of the welding depth

In summary, we can now state that we can use two different compensation strategies in laser beam microwelding, which individually can significantly increase the stability of precision and quality. However, spatial power modu-

Institute

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lation has a considerable disadvantage due to the asymmetric path geometry. This effect can be reduced by synchronized application with temporal power modulation. In this way, not only can the corresponding seam cross-section be produced symmetrically, but also the material-specific characteristics of the seam can be corrected when joining dissimilar materials. The resulting seam geometry is largely determined by the material-specific properties of absorption, heat conduction, melting point, and specific heat capacity. If the task is to weld two completely different materials, such as aluminum and copper, it is not possible to achieve a symmetrical connection between the two joining partners without suitable compensation.

Synchronization of the two power modulations is technically challenging. Since spatial power modulation can realize frequencies of up to 4 kHz, temporal power modulation must operate in the same frequency range. For this reason, the two control signals must be calibrated with an accuracy of a single microsecond, which requires precise knowledge of the position of the scanner mirrors and the level of the emitted laser power.

Fig. 1 shows the results of symmetrical design by applying spatial and temporal synchronized power modulation to the same (1a – 1c) and different (1d – 1e) species. Figures 1a and 1d both show the cross-sectional area of the welds with spatial power modulation only.

By selectively superimposing spatial and temporal power modulation, it was then possible to generate other weld geometries in the cross-section (W or V-shape) in addition to increasing the connection cross-section. The initial geometry, shown in Fig. 1a), shows a tilt to the right side of the cross-section. By extending the superposition of the local power modulation with a temporal power modulation, W and V-shaped profiles (1b and 1c) could be generated in the cross-section of the weld. This can be used, for example, to join sensitive components in an I-joint arrangement with even more targeted energy input. These measures could also reduce the weld penetration depth differences in dissimilar material systems from 58 % to 17.7 % (1d and 1e) [3]. However, with certain combinations of process parameters and material combinations, the local power modulation caused defects in the form of pores. This requires detailed adjustment of the laser parameters with respect to the material and the joining combination.

New design possibilities in laser microwelding

The two compensation methods of temporal and spatial power modulation already provide strategies to increase process efficiency and quality. The combination of these two methods and precise synchronization of the two methods of variation provides completely new freedom in seam design. The energy input in the respective joining partner can be controlled in a targeted manner, even with strongly differing material properties, so that uniform mixing and a constant bond can be achieved. In addition, the advantages of the individual power modulation come into play, such as increased process efficiency and stability.

We will see more variations to the classic circular focus geometry in laser beam welding in future. Current developments include changes to the beam shape towards dynamically adapted or combined foci of circles and rings. We will see how new developments will open another chapter in the dynamic adaptation of the process and allow further design freedom in weld seam geometry – always with the potential for further combination with synchronized power modulation..

*

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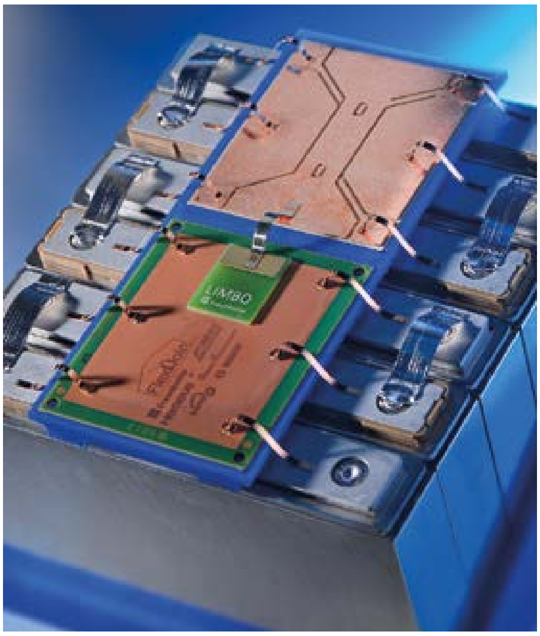

Fig. 2 Laser-assembled battery module for application in electromobility

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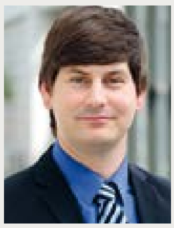
[1] *F. Schmitt*: Laserstrahl-Mikroschweißen mit Strahlquellen hoher Brillanz und örtlicher Leistungsmodulation. Dissertation. Aachen: Shaker (Berichte aus der Lasertechnik) (2012)

[2] *A. Heider, A. Hess, R. Weber, T. Graf*: Stabilized Copper Welding by Using Power Modulated Green and IR Laser Beams. In: Institut für Strahlwerkzeuge, Stuttgart (2011).

[3] *M. Hummel, A. Häusler, A. Gillner:* High-Precision Adjustment of Welding Depth during Laser Micro Welding of Copper Using Superpositioned Spatial and Temporal Power Modulation. In: J. Manuf. Mater. Process. **5** (2021) 4, 127; https://doi.org/10.3390/jmmp5040127

Authors



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Augmented / virtual / mixed reality systems optical terminology

Definitions, explanation, considerations for requirements formation – part II: spectrum and polarization, ghost and stray light, uniformity, and conclusion

Olga Resnik, Yosi Arazi, Yoni Kaganovitz, and Assaf Levy-Beeri

Source all images unless noted otherwise: Joya Team

▲Fig. 7 Yosi trying on and evaluating an AR system performances at the AWE Nite TLV Meet-up (Augmented Reality TLV)

In this part of our tutorial, we attempt to explain and cover several most important non-imaging parameters that form the complementary part of the base requirements list for an XR system specification. The non-imaging part of the system specification is often treated with less attention, and in many cases is the reason for dissatisfactory system performances. In our extensive experience, we found that this part is critical when designing an XR system, since the non-imaging parameters have very high impact on the visual image perception and ultimately the user experience. Taking them into consideration from early design stages on can make the difference between the mediocre performances product and the product that produces the 'wow effect'.

Read part I: https://doi.org/10.1002/phvs.202200007

The image source requirements strongly depend on the system's intended use, and the projected image type and characteristics have a significant impact on the specific requirements. Here are several different cases when system image source spectrum and polarization should be tailored to the use case scenarios in order to create an optimal design.

Spectrum and polarization

The image source spectrum plays a major role in the output XR system image color. The various microdisplay technologies have a significantly different output color space, so proper attention should be paid to the microdisplay technology trade-off and integration in the optical design. In addition, non-imaging and illumination design shall be done as part of the system design in order to simulate the final image colors. These are translated directly to the user experience and their expectations of image to match the real-world object's colors. More about the different microdisplay technologies can be found in [2].

Spectrum and polarization specifications shall include the following details: The image source spectral curve shall be specified as a normalized weight curve versus wavelength in [μm] or [nm]. For a Gaussian spectral curve, it is sufficient to provide only the peak wavelength and the spectral width (FWHM). If the image source is built of sub-spectra, as in LCD sub-pixels, the spectral curve for each sub-spectrum shall be provided.

Image source polarization shall be specified (if the system is sensitive to polarization), when both polarization type and orientation vector shall be detailed, preferably with an illustration.

The resulting system image color requirements, as seen by the user, shall be generally defined as the *u'*, *v'* (or *x*, *y*) prime color coordinates (RGB) on the CIE color chart. This provides the information about the resulting system color space.

We can illustrate the typical resulting color space triangles of different microdisplay technologies on the CIE color chart (Fig. 8). Basically, the display image can contain only the colors within the triangle, with prime RGB colors at the triangle vertices. For those familiar with the CIE chromaticity diagram, this provides a good qualitative comparison between the different microdisplay technologies. In the case of an augmented reality (AR) system when the projected image is combined with a bright direct scene view, the scene illumination causes the projected image colors to appear washed out and the color space is significantly reduced. Each projected image prime color brightness must be high enough to maintain discernable color. On the other hand, there is a trade-off between image brightness and image color saturation. The various microdisplay technologies not only differ in color space performance, creating a less saturated color image as shown in (Fig. 9), but also in brightness performance. Generally, the more saturated prime colors are (giving larger color space), the less brightness can be achieved, resulting in a lower image see-through contrast. In AR systems in particular, this is one of the hardest compromises. Some of the systems use local or global outside scene dimming to enhance both the image contrast and color.

Another aspect of AR systems is image polarization, which shall be defined as well as the polarizing effects

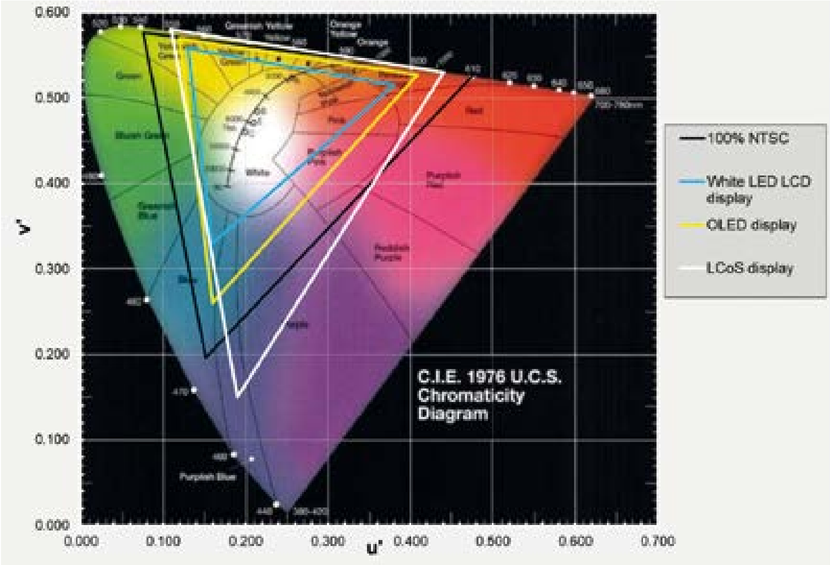

Fig. 8 Typical color space corresponding to different microdisplay technology type colors. This illustrates the span of color shades that can be produced by each of the microdisplay types. Display manufacturers sometimes provide color space data referring to the NTSC standard: this chart shows an example of LCD with a white LED backlight results in 37 % NTSC; an OLED display gives 60 % NTSC; an LCoS display gives 93 % NTSC. Today there are display technologies that can achieve higher than 100 % NTSC color space in large displays while microdisplays still suffer from smaller color space performances.

on a see-through scene view. The system shall not interfere with the user's ability to see other displays or information sources properly. Some of the use cases involve users wearing sunglasses or other alternative polarizing elements.

In the case of a mixed reality (MR) system when the projected image is combined with a direct viewing camera, the projected image color space shall match the direct viewing image colors so that there is no significant difference between the two channels in terms of familiar real-world objects color perception that can impact the user experience.

In the case of a virtual reality (VR) system when a full video image is projected, the impact of image color and polarization is much lower, when there is no comparison to the real-world objects. The human vision is highly comparative and sensitive to contrast, so the color space image characteristics can be compromised either without any or with only a low impact on the user experience.

Ghost and stray light

The optical system is designed in a way to produce the required image quality, but in reality it also produces unwanted artifacts that degrade the image quality. These can be caused by reflections from mechanical parts, coatings, diffusive surfaces, diffractive surfaces, scattering, unwanted TIR effects, even bonding material scattering and just rays going where we did not want them to go!

There are several terms that are used for these artifacts and we mainly use two of them to classify two prime types of artifacts:

Fig. 9 Illustration of a color image using different types of microdisplay technology: the left image shows an LCoS microdisplay image; the center image shows an OLED microdisplay image; the right image shows an LCD microdisplay with a white LED backlight image. New OLED technology improvements can result in a color image closer to the LCoS microdisplay performance. When imposing the projected image on the bright background of an AR see-through channel using these different microdisplay technologies, the brightness of each color becomes a more important factor in color saturation, rather than the initial microdisplay color saturation, because of the bright background impact on projected color image perception.

Fig. 10 Looking through augmented reality glasses with multiple artifacts. Even low intensity ghosts from sunlight or bright sources are highly visible, especially when color separation is present.

Ghost: this term is used for artifacts that hold some connection or resemblance to the projected information, but appear to the user at a different field angle / position / size / orientation / intensity / color / apparent image distance (any of these or, more typically, a combination of several) than the actual image. It is sometimes also referred to as a 'double image' when the unwanted image is close to the actual image. A ghost is a type of artifact that can create misleading information: the user may see a target at the wrong position and this can lead him to make a wrong decision.

Stray light: this term is used for artifacts that do not have any connection to the projected information, and appear to the user as blurred spots or shapes that reduce image contrast, quality or just create distraction. Stray light is a type of artifact that cannot create misleading information, because it does not give the user any information, it just interferes with the projected image, reduces its quality, makes it less visible or obscured.

Ghost and stray light are defined in percent [%], relative to the main image intensity (or brightness). The standard requirement originated from the military specifications for ghost and stray light is <2 %. Are these requirements sufficient to ensure that the artifacts will not be seen by the user? Based on extensive experience with AR systems, we know they are not … one such example is shown in Fig. 10.

Traditional optical design software tools (such as Zemax, CodeV, OSLO etc.) are focused on imaging parameters of optical system design such as MTF / CTF, distortion, AID, field curvature etc. These tools have very limited simulations of all the peripheral parts of the system such as coatings, filters, scattering or diffusive elements, elements' edges and rims, mechanical parts, or bonding layers that can be the source of ghost and stray light artifacts. So best practice techniques are used to control ghost and stray light in the design stage (low curvature surfaces, anti-reflection coatings, rim blackening, baffles on mechanical parts etc.). This results in a painful discovery of all the artifacts only when the prototypes are ready. Even then, there are no analytical tools to find the sources of the artifacts and eliminate them other than rigorous testing and lab experiments. This considerably increases the time and effort required to manufacture mature and ready-for-production systems without artifacts. Many products just go onto the market with the artifacts and the engineers work to reduce them on the next product version release.

Recently available optical design software tools for non-imaging and illumination design, such as LightTools (from Synopsys), provide the ability to model, analyze, and solve the ghost and stray light artifacts in any system at an early design stage. These tools are also used to evaluate other non-imaging parameters such as brightness, uniformity, color, polarization etc. Even if some of the artifacts are not revealed until the prototypes are evaluated, the system model enables the sources of ghost and stray light in the system to be found, to see the exact path of the unwanted rays and to eliminate all the artifacts.

Ghost and stray light specifications shall include the following details:

Since ghost and stray light have different effects on the user experience, their requirements shall be given separately. Ghost intensity requirements shall typically be lower than the stray light. Ghost and stray light requirements shall be set as a ratio between the artifact to back-

Fig. 11 An illustration of color and brightness non-uniformity: color changes from warmer yellowish colors on the left side of the left image to the cooler bluish colors on its right side; the right image illustrates the brightness non-uniformity from the center of the image to the diagonal corners. In a real system, the image is a combination of several different non-uniformity phenomena.

Image courtesy of Synopsys

Fig. 12 Illustration of virtual prototyping using Synopsis LightTools software of a head-up display (HUD). The simulation shows different image non-imaging effects and allows the resulting image quality to be evaluated. The various parameters that can be seen (marked by yellow) are the see-through contrast and color on the highly lit background; the color uniformity (on the bar area); the see-through transmission (darker HUD beam splitter); the ghost images (white lines without corresponding lines on the scene); the prismatic deviation (white separation line appears 'broken')

ground in addition to the ratio between the artifact and the main image. They should not only be limited to the system FOV, since the artifacts outside the FOV can also be seen and bother the user.

The ghost and stray light requirements depend on the system's projected image content, specifically on the image background or see-through background. Here are several different cases where system ghost and stray light requirements should be tailored in order to create an optimal design.

Generally in all XR systems, the projected image content has a significant influence on the visibility of the artifacts, especially on the type of image: symbols on a dark background vs a full video image. So the ghost and stray light requirements shall be tailored to the image content.

In the case of an AR system when the projected image contains symbols or text that is combined with a direct scene view, the outside scene background brightness is high, especially in outdoor applications. In this case, the ghost and stray light requirements can be very relaxed.

In the case of an MR system when the projected image is combined with a direct viewing camera / night vision system, the direct viewing channel background brightness will also dictate the ghost and stray light requirements.

In the case of a VR system when a full video image is projected, the image background is very low and even low artifacts are highly visible on a dark background. In this case, the ghost and stray light requirements shall be very strict.

Uniformity

The image quality can be expressed in different parameters: uniformity is one of the main parameters that we classify as a non-imaging quality parameter. When talking about uniformity, it usually refers to uniformity through the FOV, so when the user is looking at the projected image we refer to the uniformity in different areas of the image. We can also talk about uniformity through the system pupil, but this is a different case. While uniformity is a very generic term, we can talk about different types of uniformity: large / small area uniformity; brightness uniformity; contrast uniformity; color uniformity; polarization uniformity and more. An example of the effect of brightness and color non-uniformity of image quality is shown in **Fig. 11.**

Different types of uniformity are the main non-imaging parameters representing significant aspects of image quality and the user experience. It is very important to define these requirements based on a user's needs and to perform a non-imaging system design and simulations. The non-imaging and illumination design software tools, such as LightTools (from Synopsys) provide the ability to model, analyze and optimize the image uniformity parameters in any system at the early design stage. We call this process virtual prototyping, since it allows the overall system resulting image to be visualized as it will be seen by the user before any of the actual system components are manufactured and their performance and various effects can be evaluated, as shown in **Fig. 12**.

If a non-imaging design part is omitted, then the first time the uniformity can be evaluated is when the prototypes are assembled and tested. If the results are then not satisfactory and the requirements are not met, little can be done to improve the design. Many products just go to market with the non-imaging performance on a 'best effort' basis, just updating the requirements to fit the measured results, and compromising the user experience.

Brightness uniformity is specified in [%], color uniformity is unitless. There are many different formulae for uniformity or non-uniformity, so it is useful to specify the parameter calculation formula together with the requirement values. The uniformity requirements are often defined based on the experience of assuring the requested image quality. Another good source for these requirements can be found in the VESA (Video Electronics Standards Association) IDMS – Information Display Measurements Standard.

Uniformity specifications shall include the following details:

Uniformity shall be defined for a given measurement pupil size, which correlates to the user's eye pupil size and depends on outside lighting conditions.

It is very important to define the large area and small area uniformity requirements separately. Uniformity testing point locations shall be defined in order to cover the whole FOV.

The brightness and color uniformity shall be defined for each system prime color, as well as for the 'white' color.

Uniformity requirements, similarly to the other parameters, depend on the system's use and the image content. Here are several different cases that impact the system uniformity requirements in order to create an optimal design and user experience.

In all extended reality (XR) system types, it is very important to consider the human vision characteristics to produce the requirements that will ultimately create a good user experience. Since the human eye is more sensitive to contrast, and hence to the small area non-uniformity, small area non-uniformity requirements shall be tighter than the large area non-uniformity.

In the case of an AR system when the projected image is combined with a bright direct scene view, the scene illumination causes the projected image colors to appear washed out and the color space is significantly reduced. Each projected image prime color brightness must be high enough to maintain discernable color, which also drives the brightness uniformity requirements. For the same reason, the prime colors' coordinates must be uniform through the FOV so the colors do not lose their purity across the image. Some systems use local or global outside scene dimming to enhance both the image contrast and color.

In the case of an MR system when the projected synthetic image is combined with a direct viewing camera, the reference point of the two images' brightness and color uniformity can be artificially controlled by adjusting the two images' settings.

The image quality perception of a symbolic or a text image is different to that of a full video image. So in case of a VR system when a full video image is projected, the large area image uniformity is important, so the requirements must be tighter.

Conclusion

The process of XR system design starts with understanding and covering the various system aspects or parameters. These parameters are derived from specific use-cases and have to support the intended functionality. Formation of the requirements specification is essentially a trade-off between the different system parameters, strongly related to the specific use case and prioritizing the requirements with a higher impact on the user experience. This should be an iterative process where the goal is to find the correct balance and eventually to create the optimal working point for a tailor-made system design. We ultimately want to create a system – and eventually a product – that will stand out and conquer the market, and this can only be done with a deep understanding of the use-case and customization of the various parameters for it.

The XR systems field is a very rich and interesting subject, as many would agree. In this article we have barely touched the tip of the iceberg – there are many more things to cover, even in the confined topic of optical terminology for this type of system. Only a few terms were covered in this paper. More details and many other terms can be found in our constantly growing and updated optical terms library blog [1]. There are still many other aspects of XR systems to learn, discuss and share. One of the goals we wanted to achieve was to make our contribution to the wonderful XR community and share our experience and insights into this vast field.

Most of the information we share in this paper is based on more than twenty years of experience working and developing XR systems for a variety of applications and use cases. During these years, we have learned from many colleagues that have worked with us on various system designs and development and have made their contribution to our knowledge and expertise in the XR systems field. We are grateful for that. Special acknowledgement goes to Sasson Abraham, our professional mentor and a dear friend, who supported and believed in us through many years of mutual work.

DOI: 10.1002/phvs.202200008

[1] Optical Terms Library, joyateam.com/blog/categories/optical-terms-library
[2] Microdisplay Technologies, AR, and HUDs, oled-info.com/microdisplay-technologies-ar-and-huds

Authors

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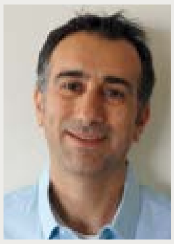
Yosi Arazi, BSc in optical engineering, is an optical designer, a co-founder and CEO of Joya Team. Yosi is an expert in the optical design of HMDs, AR / VR and night vision systems with over twenty years' experience in the field. Yosi also has experience in HUD systems, projection polarization systems, thermal systems, hologram design and more. Yosi owns many innovative ideas, some of which have led to patents and unique IP. His vision produces our unique design methodology starting from requirements, multi-functional interfaces to holistic system design.

Yoni Kaganovitz, BSc in optical engineering, is a co-founder of Joya Team. Yoni has over twenty years' experience in system design of optical testing equipment for HMDs, AR / VR systems, night vision systems, camera systems, optical tracker systems and more. Yoni has led the development and design of optical testing equipment from the definitions and characterization stage, system engineering, design, verification and integration in the production line.



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Photonics: a pillar for extended reality technologies

An overview of how photonics will be highly invested in the future of XR and the market applications landscape

Jérémy Picot-Clémente

Extended reality (XR) is an all-encompassing term for virtual reality (VR) and augmented reality (AR), which are technologies that have the potential to revolutionize the way we work, interact with each other and the environment, and the way we experience and feel things.

These technologies have become very popular over the last few years due to the numerous recent evolutions of the technologies that make up the architecture of XR systems, of which photonics is one of the pillars, but also due to society truly accepting them, which is a relatively new phenomenon. Each of these notions of mixed, augmented or virtual reality has its own peculiarity: AR refers to an interactive experience of a real environment with information generated by optical systems, and is similar to classic glasses; virtual reality immerses the user in a totally virtual world generated by optical systems and screens, often integrated into a head-mounted system; mixed reality is a mix of these two technologies.

The term used to group all of these notions is 'extended reality' or XR. This article will present why photonics are pillars of these technologies and how they will play an important part in our future, as we are at the dawn of a true revolution.

Extended reality (XR) is a term that encompasses all technology related to virtual, augmented or mixed reality (see Fig. 1). This concept of a reality-virtual continuum was first introduced by Paul Miligram in 1994 although these three are in fact not new: the first relative work dates from the end of the 20th century. However, due to the technological limitations of time, there was only little evolution up until the early 2010s, from when new technological advances

▲ Leveraging various partners, Dispelix continue to raise the bar with LBS technology and their displays – they deliver one of the lightest, brightest and thinnest waveguides on the market, which display clear full color vivid images all on a single layer. (Source: Dispelix)

have allowed the AR/VR machine to be revived. Since then, we have seen a growing interest in these technologies, from investors to the creation of start-ups, as well as more general interest on the part of the consumer through

1) The 'metaverse' can be defined as an immersive 3D space that consolidates multiple AR and VR experiences to create a converged environment where users can interact with each other and with the 3D world around them.

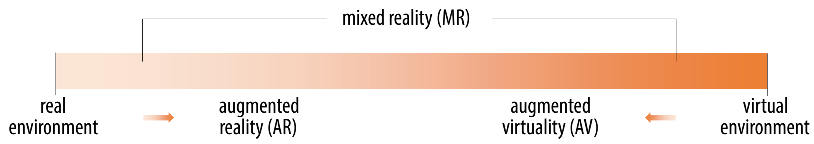


Fig. 1 Miligram's reality-virtuality continuum (Source: EPIC)

the gaming universe and, even more recently, with the 'metaverse'[1] which is attracting the biggest tech companies in the world (Meta, Google, Microsoft, Apple …).

The possibilities offered by XR technologies in terms of applications are enormous. This is reflected in the growth predictions for technologies related to XR over the next few years, particularly for photonics (micro-optics, display technology and light engines). XR related technology has been, and will be, revolutionizing the way people interact with the virtual world, whether it is through extreme immersion for VR in the gaming world, training simulators (defense, health, education), through partial immersion accessible to a wider audience, or through AR glasses in areas such as sports, health, etc.

VR/AR has a long technical history, but it is still an emerging industry and its development has not been finalized yet. Every XR system is developed around five main pillars that can be defined as near-eye display, rendering processing, perception and interaction, network transmission, and content creation (Fig. 2).

The photonic pillar of AR/VR

To create complete AR/VR experiences from a photonics perspective, it is necessary to use a head-mounted display or glasses with advanced, integrated, transparent displays and depth mapping sensors that will facilitate the mapping of the real-world environment: this is the near-eye display pillar of XR technology.

Furthermore, one of the biggest challenges in the emergence and standardization of XR is miniaturization and the ultimate compactness of the extended reality systems. There have been many decisive technological developments in recent years in both augmented reality and virtual reality that have confirmed the potential of this technology. Although photonic technology cannot yet respond to the limited number of concrete use cases, it can already be a predominant player in the reduction of the price and size of the products that make up the XR market. Several photonic technologies such as holographic optical elements (HOEs), lithography (SRG, metasurfaces) and micro-LEDs have considerably modified and improved XR display systems, where system compactness, comfort and optical efficiency are considered to be key purchase factors in this industry. However, AR and VR are facing several common challenges to satisfy the demanding requirements of human vision, including field of view (FoV), eyebox, angular resolution, dynamic range, and correct depth cue.

The two major types of diffractive optics are the HOEs that are based on wavefront recording and the manually written devices like surface relief gratings (SRGs), which are created by lithography. While SRGs allow a large amount of freedom in the design of local grating geometry, some recent publications indicate that the combination of HOE and freeform optics can also offer great potential for arbitrary wavefront generation. Furthermore, the advances in lithography have also developed optical metasurfaces beyond diffractive and refractive optics and miniature display panels such as micro-LEDs (light-emitting diodes). These devices hold the potential to boost the performance of current AR/VR displays while still keeping a lightweight and compact form.

The goal of AR and VR display development is to offer reality-like images that can simulate, merge into, or rebuild the surrounding environment. This is still challenging at the present stage, especially for AR systems since most components not only require further performance enhancement, but also a reduction of both power consumption and size.

Holographic optical elements (HOEs)

An HOE is an optical element that is produced by using a holographic imaging process. It refers to a recorded hologram that reproduces the original wavefront. HOE is one of the latest areas of holography application. Many optical elements in devices have been replaced by HOEs such as lenses, filters or diffraction gratings. Holographic optical elements are particularly popular in the industry nowadays because of their ease of production. They have low manufacturing cost and are capable of performing several functions within a single element. HOEs started to be used some time ago for head-up display (HUD) systems and head-mounted displays (HMD) in the automotive field. In AR this technology is usually coupled with a MEMS-based collimated light scanner (typically a laser-based scanner) that scans the holographic optical element that is embedded in the lens of the device and then redirected onto the human retina surface.

New developments of HOE-based technology are being worked on, such as PPHOEs (photopolymer HOEs) and LCHOEs (liquid crystal HOEs), which are ultrathin optical elements that provide alternative solutions to traditional optics. Their unique features of multiplexing capability and polarization dependency further expand their capability of new wavefront modulations.

PPHOEs have a relatively small refractive index modulation and therefore exhibit strong selectivity on the wavelength and incident angle. Another advantage of PPHOEs is that several holographic elements can be recorded in the same photopolymer film by consecutive exposures. On the other hand, LCHOEs are interesting because of their

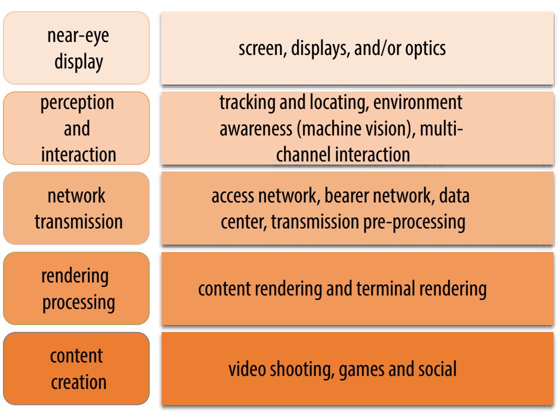


Fig. 2 XR technology architecture pillars (Source: EPIC)

important sensitivity to the polarization state of the input light. This technology offers new opportunities for dynamic wavefront modulation in display systems.

Nanoimprint lithography (NIL)

Imprint lithography has a long history, and implementation of the technology is now being developed at the nanoscale. Unlike many other lithographic techniques, imprint lithography can be applied cost effectively to address the patterning needs of a diverse number of applications at nanometer scale. It creates patterns by the mechanical deformation of imprint resist and subsequent processes (the imprint resist is usually a polymer that is cured by UV light or heat during the process). It has increasingly become a key enabling technology to support new devices and applications across a wide range of markets. Leading manufacturers of AR devices, optical sensors and biomedical chips are already using NIL and realizing the benefits of this technology, including the ability to mass manufacture micro and nanoscale structures in several industrial processes such as roll-to-roll (R2R), roll-to-plate (R2P) or plate-to-plate (P2P).

Micro-LEDs

Today, mainstream near-eye displays are mostly liquid-crystal displays (LCDs) and organic light-emitting diodes (OLEDs). Despite the numerous advantages of these display technologies, both LCDs and OLEDs have technical limitations and cannot meet the display needs of AR/VR because of the slow response speed or poor conversion of LCDs, the rapid aging or low color purity of OLEDs. Micro-LEDs, which inherited the characteristics of inorganic LEDs and have micron-level dimensions, combine blue, green, and red subpixels to reproduce a color. They offer the potential to significantly improve the brightness as well as to enhance the robustness, the lifetime, and the global resolution of the display system. In addition to this, micro-LEDs are more power efficient, which is very relevant for battery-powered products such as AR/VR systems. Over the last decade, the broad prospects for micro-LED applications have attracted a large number of manufacturers, and the XR market is obviously not spared.

Metasurfaces and SRGs

Metasurfaces are two-dimensional metamaterials with unprecedented capabilities to manipulate light through their ultrathin and flat architectures. They consist of an array of subwavelength spaced structures with individually engineered wavelength dependent polarization/phase/amplitude response. Mastery of the manufacture of metalenses gives infinite possibilities to wavefront modulation, a property that is not available in natural materials. Metasurfaces have aroused strong research interest in the development of new solutions for AR/VR because of their capability to shape the wavefront and their material fineness. With improved performance, they offer the prospect of tiny optical elements integrated into small, high-performance, lightweight headsets and smart glasses.

Solutions providers of the XR industrial landscape

Dispelix

Founded in 2016, Dispelix is a designer and fabless manufacturer of mass-manufacturable diffractive waveguide displays and display modules for augmented reality (AR) and mixed reality (MR) eyewear and headset usage. Its patented DPX waveguide unlocks new freedoms in AR product design with unmatched image quality, performance and efficiency. The company also designs customized waveguide displays and licenses intellectual property to customers that develop game-changing products for fast-evolving AR eyewear markets. Led by sought-after experts in optics and photonics manufacturing, Dispelix powers AR experiences that push boundaries. The company has about 60 employees but aims to reach 100 employees by the end of 2022, and is headquartered in Finland with offices in the US, China and Taiwan.

https://dispelix.com

WaveOptics

Founded in 2014, WaveOptics is a designer and manufacturer of revolutionary augmented reality (AR) glass lenses and light engines – two key optical components of any AR headset and aimed to unlock the potential of augmented reality for the mass market. WaveOptics AR lenses (also known as waveguides) and projectors are integrated into smart glasses, enabling users to see digital images overlaid on top of the real world. WaveOptics technology is designed to be used for immersive AR experiences in industrial, enterprise and consumer markets. The company aims for its waveguides to be the core optical component used in all AR wearable devices, driven by its unique technology and expertise, which enable unparalleled manufacturing scalability and visual performance as well as versatility for numerous applications.

WaveOptics is headquartered in Oxfordshire, UK, has offices in Taipei and Beijing, and was acquired by Snap in 2021.

https://enhancedworld.com

Inoptec

Inoptec, based in Germany, stands for innovation, optics, and technology. Its technology is a unique and outstanding vision enhancement system that enables instant light adaptation and protection. The system developed by Inoptec combines light adjustment in real time, contrast enhancement and dynamic light protection. The company also offers industry partners its consulting and R&D services around their patented core technologies and know-how.

https://inoptec.com

Phabulous, the European pilot line for freeform micro-optics

In recognition of the strategic importance of micro-optics for the European economy and the urgent need to ramp up FLMA production in Europe, in 2018, an EU-funded consortium of nineteen companies and research organizations was formed to create the infrastructure for a self-sustainable pilot line for the manufacture of FMLAs. This initiative, known as Phabulous, is led by the Swiss research and technology organization CSEM, providing highly advanced and robust manufacturing technology for optical free-form microstructures and has two basic aims.

The first aim of Phabulous is to strengthen Europe's leading position as a technology and machine provider for the production of micro-optics based on a value selling model that retains the high-cost and high-value technology portfolio in Europe. The second aim is to develop easily accessible, world class manufacturing facilities to enable European companies to implement micro-optical components in their products and compete advantageously with their global competitors. The pilot line has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 871710.

https://phabulous.eu

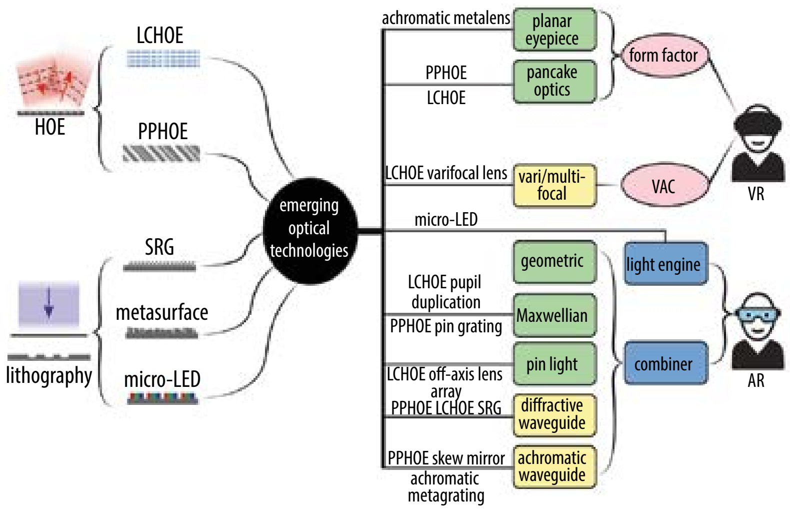


Fig. 3 Schematic of emerging photonics technologies applied to XR. On the left, technologies are presented, on the right, how these technologies can be applied. (Source: adapted from [1])

On the other hand, surface relief gratings (SRGs) are diffractive gratings that have been primarily used as input/output couplers of waveguides. Their surface is composed of corrugated microstructures and different shapes, including binary, blazed, slanted, and even analogue. The parameters of the microstructures are determined by the target diffraction order, the operation spectral bandwidth, and the angular bandwidth.

Compared to metasurfaces, SRGs have a much larger feature size and can therefore be fabricated using UV photolithography and subsequent etching. They are usually replicated by nanoimprint lithography with appropriate heating and surface treatment.

XR markets are blooming

The XR market is a real business opportunity for photonics technologies. The augmented and virtual reality market share by application has been dominated by the consumer segment for a long time and is expected to maintain its dominance in the coming years. However, there is an emergence of many other applications in defense, medical (for simulation or support applications), education and culture, media and social networks, and – not to forget one of the players that will be predominant and decisive in the years to come – the automotive industry with massive investment in XR technologies and in particular in AR (Fig. 4). The XR industry is therefore benefiting from the incredible growth in the XR needs of the various applications mentioned above and the associated investments. This is partly why XR technology will be one of the most important players in the digital technology landscape in the next years.

According to Allied Market Research the XR market size was valued at $ 14.84 B in 2020, and is projected to reach $ 454.7 B by 2030, registering a compound annual growth rate (CAGR) of 40.7 %. Growth of the mobile gaming industry and the increase in internet connectivity act as key drivers of the global AR and VR markets. In addition, increase in the use of consumer electronic devices is expected to fuel global augmented and virtual reality market growth.

Fig. 4 Non-exhaustive panel of current XR applications.

VR in gaming

The video game industry has been one of the most important drivers in the adoption and emancipation of VR technology by the consumer. From a growing market in the early 2000s, it is now one of the most important aspects of this technology. The demand in this market is largely driven by the rising adoption of this technology among gamers.

Following the prevision of Fortune Business Insight, the global virtual reality in gaming market is projected to grow from $ 7.92 B in 2021 to $ 53.44 B in 2028 at a CAGR of 31.4 % in the 2021 – 2028 period.

AR/VR in sport and entertainment

Media and entertainment have always been about ensuring the best viewer experience, and sports have played a significant role in the process. From the time when sports could be viewed at home on TV from a fixed camera angle, we have come to a time where consumers are offered various camera angles all through the sports telecast. The use of VR technology for telecasts of various live sports events seems like the next big leap that is going to be instrumental in driving VR in the sports and entertainment market globally.

According to a global VR in Sports and Entertainment market report, published by Sheer Analytics and Insights, the total market was valued at $ 2.3 B in 2020 and is expected to reach $ 56.7 B at the CAGR of 32.5 % in 2020 – 2031 period.

AR/VR in healthcare

The global augmented and virtual reality in healthcare market finds that increasing awareness among consumers is skyrocketing market growth, that is primarily driven by increasing penetration of connected devices in the healthcare sector. The growing implementation of IoT applications in healthcare using different sensors, and the recent advances in VR surgery also make this healthcare field one of the main AR/VR markets in the next few years.

According to Vantage Market Research, the total global augmented and virtual reality in healthcare market is estimated to reach $ 18.7 B by 2028, up from $ 1.5 B in 2021, at a CAGR of 30.2 %.

AR in automotive

The market for augmented reality automotive applications is primarily driven by the increase in adoption of advanced driving assistance systems by OEMs across different vehicle types and by consumer demand for in-vehicle safety features that could potentially reduce collisions and injuries caused by human driving errors. The market is also influenced by the increasing level of driving automation and progress toward fully autonomous vehicles.

Research and Markets forecasts that the automotive AR and VR market is expected to reach $ 5.76 B by the year 2026, at a CAGR of 79.5 % during the forecast period 2020 – 2026.

AR/VR in defense and aerospace

XR in defense and aerospace has created lucrative market opportunities. VR has provided a fully immersive and digitized environment. This technology is bringing real benefits and value to simulate, reproduce, and design products in a safe environment. The introduction of AR/VR solutions has positively impacted the aerospace and defense industry in the last few years.

The analysis by Fortune and Business Insights sees the global virtual reality in the aerospace and defense market size at $ 391.6 M in 2018 and is projected to reach $ 5,841 M by 2026, a CAGR of 37.9 % during the forecast period.

Conclusion

Throughout this article, the different elements have highlighted the fact that XR technologies will become widespread in the future. Whether they will be used in our daily lives, through our hobbies, through various forms of entertainment or through work, people will be led to use VR and AR technology. This article has also shown that, due to the role of photonic technology in the emergence of extended reality – as it is one of its main pillars – photonics should benefit from the boom in XR application markets, both from the point of view of research and development and from industrial production. All lights are green for the future of the XR industry, and photonics will be one of the major players.

DOI: 10.1002/phvs.202200013

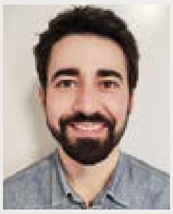
[1] *J. Xiong, E.-L. Hsiang, Z. He, T. Zhan* and *S.-T. Wu:* Augmented reality and virtual reality displays: emerging technologies and future perspectives, Light: Science & Applications **10** (2021) 216

[2] *Y. Wu, J. Ma, P. Su, L. Zhang* and *B. Xia:* Full-Color Realization of Micro-LED Displays, Nanomaterials **10** (2020) 12, 2482

[3] *T. Zhan, K. Yin, J. Xiong, Z. He, S.-T. Wu:* Augmented Reality and Virtual Reality Displays: Perspectives and Challenges, iScience **23** (2020) 8, 101397

[4] *B.C. Kress:* Optical Architectures for Augmented-, Virtual-, and Mixed-Reality Headsets, SPIE.digital library, 2020

Author



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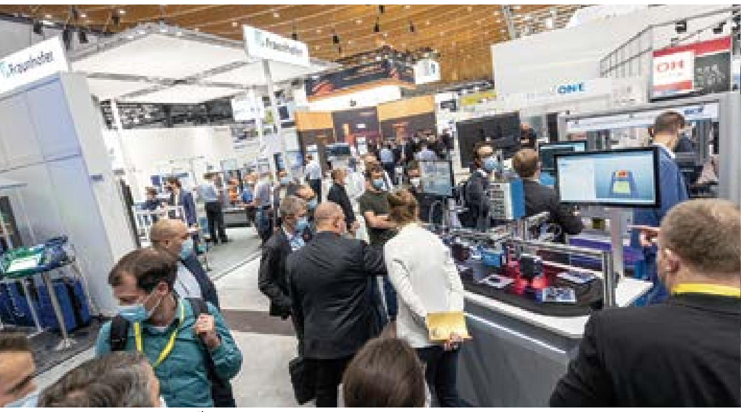

Source: Wiley

Source: P.E. Schall

April 26 – 29, 2022
Laser World of Photonics
Munich, Germany
https://world-of-photonics.com

May 03 – 06, 2022
Control / MedtecLive with T4M 2022
Stuttgart, Germany
www.control-messe.de / www.medteclive.com

May 04 – 06, 2022
AKL'22
Aachen, Germany
www.lasercongress.org

May 10 – 12, 2022
Sensor + Test
Nuremberg, Germany
www.sensor-test.de

May 12 – 14, 2022
EMVA Business Conference 2022
Brussels, Belgium
www.emva.org

May 15 – 20, 2022
CLEO
San Jose, CA, USA
www.cleoconference.org

May 17 – 19, 2022
Rapid.Tech 3D
Erfurt, Germany
www.rapidtech-3d.com

May 30 – June 02, 2022 **NEW DATE**
Hannover Messe
Hanover, Germany
www.hannovermesse.de

June 07 – 11, 2022
123nd Annual Meeting of the DGaO
Pforzheim, Germany
https://dgao.de/jahrestagung

June 08–11, 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

Read event previews and reviews on www.wileyindustrynews.com/en/events

Photonics West's in-person return to San Francisco

SPIE safely welcomed the international photonics community back to Moscone Center

Impression from the Moscone Center foyer (Source: SPIE)

The largest annual photonics conference and exhibition, including its Bios, Lase, and Opto symposia and the AR|VR|MR conference, garnered more than 10,000 registered attendees, hosted more than 950 exhibitors, and included 2,100 technical presentations from 22 to 27 January.

After a two-year hiatus, SPIE had looked forward to once again host its flagship event Photonics West, requiring proof of vaccination and wearing of masks for all attendees following the local regulations and national guidelines for hosting an event of such a size.

"We very much appreciate all the support from exhibitors, attendees, volunteers, and presenters who truly made the event a success," said SPIE's CEO Kent Rochford. "Everyone embraced San Francisco's health and safety protocols, resulting in a safe meeting. There's nothing like coming home to Photonics West, and the enthusiasm we witnessed throughout the week proves that there is nothing like in-person events."

Across Lase, Opto, and Bios, plenary speakers included Irina Larina of Baylor College of Medicine, Aydogan Ozcan of the University of California, Los Angeles, Shy Shoham of New York University, Lihong Wang of Caltech; Andrea Blanco-Redondo of Nokia Bell Labs, Michael Kues of Leibniz University Hannover, and Tammy Ma of Lawrence Livermore National Laboratory.

With the Prism Awards 2022 honoring the top new optics and photonics products on the market and the dynamic Startup Challenge pitch competition, SPIE Photonics West showcased and recognized the best optics and photonics technologies, trends, and entrepreneurial opportunities. The brand-new SPIE Career Hub offered four days of professional development panels, tips, and networking opportunities. In addition, Quantum West – organized in partnership with the Quantum Economic Development Consortium (QED-C) – featured experts and invited speakers discussing market prospects and the path toward a quantum-focused commercial ecosystem, complementing the strong technical program. And, during a special event, SPIE and the University of Rochester announced the establishment of the one million dollar SPIE Graduate Fellowship in Optical Sciences and Engineering.

Following the in-person week, on-demand access to the conference presentations was available for all paid attendees between 21 and 27 February as part of an extended SPIE Photonics West on-demand program. The nearly 3,000 online presentations included those recorded live during Photonics West, as well as pre-recorded presentations from authors who were unable to travel or attend in person. In addition to the conference recordings, posters and poster preview videos and all recorded plenary and keynote presentations were available for viewing.

SPIE Photonics West 2023 will take place 28 January to 2 February at the Moscone Center in San Francisco. The call for papers for the 2023 event will open in spring of 2022.

https://spie.org

Irina Larina from Baylor College speaking at Bios (left) and Tammy Ma from LLNL at Lase Plenary and Hot Topics (right; Source: SPIE)

Stuttgarter Lasertage – SLT 2022

Preview: 21 – 22 June 2022, Stuttgart, Germany

For the 11th time, highlights and innovations in the field of industrial, laser-based manufacturing will draw experts and users to the Stuttgart Laser Technology Forum (SLT).

The conference enables a unique transfer of knowledge through visionary plenary events and top-class expert lectures. The LASYS 2022 International Trade Fair for Laser Material Processing and the SLT 2022 conference mutually benefit each other.

In research, the focus is primarily on material influences in welding, but also in additive processes. In ablative processes, developments are being spurred on in particular by the current rapid increase in the average power of ultra-short-pulsed lasers, which also pose major challenges in terms of system technology. These are all topics that will also shape the SLT 2022.

The mission of the SLT is to address laser technologies for materials processing in a fundamentally scientific and yet comprehensible manner with a strong contribution by international and German research institutions and to exemplify the scientific conclusions by presentations on corresponding industrial implementations.

Invited plenary speakers on June 21 will be Dr Christian Schmitz, Trumpf Lasertechnik GmbH and the professor newly appointed to the chair of Laser Technology in Manufacturing at the IFSW. On June 22, Prof Dr Ludger Overmeyer from the Leibniz Universität Hannover, Dr Thomas Stammler of Carl Zeiss SMT GmbH and Prof Dr Thomas Graf, IFSW, University of Stuttgart, will give plenary talks.

The talks will be given in English or German, with simultaneous translation of all presentations.

Selected presentations will be featured in a special section of PhotonicsViews issue 3/2022, June / July.

www.slt.uni-stuttgart.de
www.xing-events.com/slt

LASYS international trade fair for laser material processing

Preview: 21 – 23 June 2022, Stuttgart, Germany

"The Place to Beam" – The next Lasys will be held at the Stuttgart Trade Fair Center from 21 to 23 June 2022. It is the only international trade fair that consistently focuses on system solutions for laser material processing. Since the start of the trade fair in 2008, it has become successfully established as a user platform for laser system solutions and applications. Lasys covers all industries and materials, and is primarily aimed at decision-makers from international industry.

Lasys has become an indispensable event for the industry. With its consistent focus on system solutions in laser material processing, it has clearly positioned itself as a user trade fair. Lasys is the ideal platform for special applications, new fields of application, as well as industry trends and innovations.

Important key players and a large number of medium-sized enterprises are domiciled within a radius of 300 kilometers around the leading high-tech Stuttgart region. Mechanical engineering, automotive industry, electrical engineering, information, technology, medical technology, and biotechnology all have the best transport infrastructure of any trade fair center in Europe.

The location of the Stuttgart Trade Fair Center right next door to Stuttgart Airport and the A8 motorway, as well as the fast connection to Stuttgart central railway station are unique in Europe. Exhibitors and visitors could not travel to Stuttgart any faster! The short duration of the trade fair saves resources, the clear thematic focus ensures low wastage and a trade fair site with short distances.

The industry will also benefit this year again from the valuable knowledge transfer of the Stuttgart Laser Technology Forum (SLT), which brings together researchers, developers and users in a congress on the first two days of the trade fair. The SLT is organised by the Institut für Strahlwerkzeuge (IFSW) at the University of Stuttgart. The IFSW adopts a holistic research approach from the laser beam source to the application in manufacturing processes. The SLT Forum has been held in close cooperation with Lasys since 2008.

www.lasys-messe.de

APE Angewandte Physik & Elektronik GmbH

APE is a worldwide operating manufacturer of equipment in the field of ultrashort laser pulses. Its portfolio includes autocorrelators, spectrometers and other pulse diagnostic systems. The company is one of the international market leaders in the field of wavelength conversion using optical parametric amplifiers (OPA), synchronously pumped optical parametric oscillators (OPO) or wavelength multiplication (SHG, THG, FHG, DFG). From single components to complete turnkey solutions, APE offers everything from a single source including matching accessories to adjust various parameters (repetition rate, spectral bandwidth and more). APE instruments are used in scientific institutions and research centers worldwide,

often in basic research in physics, chemistry, biology and medicine. Devices from Berlin can be found in almost all well-known institutes and universities worldwide. Laser manufacturers also appreciate our precisely manufactured devices and use them to control the quality of their own products in order to optimize their production.

APE employs about seventy people. All products are developed and produced in Berlin according to high quality standards. The devices are distributed directly as well as through partners in over forty countries. Since 2010, APE Applied Physics & Electronics, Inc., a subsidiary in California, USA, has been serving the North American market.

The first-class quality of APE precision instruments as well as competent and expert customer service are standards with which the company meets the high demands of a market that is constantly moving.

A very close contact to the customers is maintained in order to permanently improve and further develop the products.

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LASER World of PHOTONICS, Hall B5, Booth 317

Edmund Optics – from design to prototype to volume production

- 80 years successful company history
- EO offers over 34.000 products and holds a large inventory for fast delivery
- US based company with global locations for manufacturing, sales and distribution
- Global manufacturing capabilities: prototyping, customized production, modifications with quick turnaround, serial production
- 20.000 stock products available for quick modifications
- Trustful partner for various industries, institutions, institutes, and universities
- EO ranked preferred supplier of optical components for the past 13 years
- Dynamic successful company and employer of choice with interesting job openings
- One-Stop-Shop offering the must trustful brands of the industry
- Technical Support in various languages
- More than 1.200 employees globally

We Design I We Manufacture I We Deliver

Edmund Optics® (EO) is a leading global manufacturer and distributor of precision optics, optical assemblies and imaging components with headquarters in the US and manufacturing facilities in the US, Asia and Europe and sales representatives around the globe. With a portfolio of more than 34.000

products, EO has a large inventory of optical components for immediate delivery and offers products, standard or customized, in small quantities but also in volume for various industries. With a global team of experts in optical design and manufacturing, EO is ready to support trendsetting projects – from prototyping all the way to serial production. Want to learn more or get the product you need – contact us!

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LASER World of PHOTONICS, Hall B6, Booth 518

Gigahertz-Optik

With its innovative and high-quality products as well as application solutions, Gigahertz-Optik enjoys a high regard from its international customers within the field of optical radiation measurement technology. As a manufacturer, Gigahertz-Optik offers standard and custom-made solutions. Regular investments in new technologies ensure that Gigahertz-Optik is able to offer modern measuring solutions to its customers in industry and science.

Regarding laser power measurements, Gigahertz-Optik offers a variety of different solutions, ranging from compact average power sensor through multipurpose integrating sphere setups to detectors for full pulse characterization of nanosecond-pulsed sources.

Integral light measurement devices	Spectral light meter	Complementary products
UV Radiometer	Handheld devices	Integrating spheres
Photometer	High-end devices	Integrating sphere light sources
Hazard	UV Spectroradiometer	Calibration standards
Laser Power Detectors	Weather-proof devices	Electronics, optomechanics
High-Speed integrating spheres	Light transmission	Optically diffuse materials

Company

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LASER World of PHOTONICS, Hall A6, Booth 500

Hamamatsu Photonics

Hamamatsu Photonics is the Japanese manufacturer of optoelectronic detectors, light sources and systems. The company was founded in 1953 in the city of Hamamatsu City, where it is still located for research and production today. Hamamatsu Photonics is one of the world's leading innovators in photonics; develops and produces components across the entire range of light-based technologies and is a leading high-tech supplier for a wide range of industries such as: chemical analysis, medical, automotive, security, x-ray and sensor technology.

The systems division produces a wide range of image processing systems used in life sciences, digital pathology, semiconductor manufacturing, process control and basic research.

Hamamatsu Photonics Deutschland GmbH, which has been based in Herrsching am Ammersee in Bavaria since 1986, has more than 100 employees and serves not only Germany but also the following countries: Austria, Bulgaria, Croatia, Czech Republic, Denmark, Greece, Hungary, Israel, Montenegro, the Netherlands, Poland, Romania, Slovakia and Turkey.

Managing director is Dr. Reinhold Guth.

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LASER World of PHOTONICS, Hall A6, Booth 305

Hübner Photonics

Hübner Photonics is committed to supplying high performance and innovative lasers that meet or exceed the market's expectations concerning quality, reliability and robustness. Hübner Photonics offers the full range of:

- Single and multi-line lasers by Cobolt
- CW tunable lasers
- Laser combiners
- Femtosecond lasers
- Terahertz imagers and spectrometers

Through continuous technology development, customer orientation and an ISO certified quality management system, Hübner Photonics has become a preferred supplier of lasers to major instrument manufacturers and leading research labs for cutting-edge applications in the areas of fluorescence microscopy, flow cytometry, Raman spectroscopy, metrology, holography, nanophotonics and quantum research. Hübner Photonics has manufacturing sites in Kassel, Germany and Stockholm, Sweden with direct sales and service offices in USA.

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LASER World of PHOTONICS, Hall B5, Booth 421

Innovative optical and optoelectronic components

IMM Photonics develops and produces optical and optoelectronic products for a multitude of applications.

Since our founding in 1992, we have been offering new and innovative components and modules to numerous customers from various technology sectors. From metrology and analytics, biophotonics and medical engineering to optical data transmission and security technology – our products are deployed in several areas of industrial production.

Standard products include laser diode modules and collimators, fibre optic components, glass fibre testers and UV light sources for UV curing. Upon request, they can be customised and further developed according to specific customer requirements.

In addition to standard products, we also offer OEM and ODM services. In the development of customised solutions, we adhere at all times to the customer's specifications, budget and time schedule. As a reliable and competent partner, we accompany our customers along the entire process – from prototyping to series production.

Manufacturer, developer and distributor – with thirty years of experience in the photonics industry, a team of qualified engineers and developers, production sites in Germany that meet the highest technical standards and a global partner network, we are in a position to offer our customers innovative and economically effective solutions, even for complex tasks.

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LASER World of PHOTONICS, Hall B5, Booth 100

Your experts for light measurement solutions

Instrument Systems
KONICA MINOLTA Group

Instrument Systems fosters innovative product ideas with high-end light measurement technology. Our solutions are indispensable for producers of VCSEL/laser-based systems, consumer electronics, displays, exterior automotive lighting, and LED/SSL modules. They all benefit from the high-precision CAS series of spectroradiometers: widely used as reference instruments, which measure precise and accurate from UV to IR. In combination with 2D imaging cameras, integrating spheres, and goniometer systems, our flexible light measurement systems cover all testing needs from lab to production.

Exceptional solutions allow the inspection of temporal, electrical, spectral and spatial properties of laser diodes and VCSELs. The VTC 4000 infrared camera enables ultrafast and polarization-controlled 2D characterization of VCSEL arrays in the near-field, simultaneously for every single emitter. The integrated polarization analysis ensures an unprecedented radiant power measurement accuracy with minimal error budget. With the Pulsed VCSEL Testing System PVT, Instrument Systems offers a solution specifically for nanosecond pulse driving and measurement as used for lidar or time-of-flight applications. To meet the challenges of automotive quality insurance, the LumiTop 4000 combines imaging and spectral measurement technology for a fast end-of-line inspection of the latest OEM display quality standards.

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LASER World of PHOTONICS, Hall A6, Booth 221

LASEROPTIK – home of high power laser optics and coatings

LASEROPTIK
Home of high power optics and coatings

Laseroptik is a manufacturer of high LIDT laser optics and coatings from VUV to IR and employs more than 38 coating machines using 7 different coating methods. They include e-beam evaporation, ion assisted deposition (IAD), ion plating, magnetron sputtering, ion beam sputtering (IBS) and atomic layer deposition (ALD).

Laseroptik offers an express coating service starting with a 24 hour option for rapid prototyping. Coatings and optics can be configured in the online app "LOOP", a database with more than 1200 coatings plus substrates and coated components.

Typical products are high LIDT mirror and AR coatings, thin-film polarizers, gradient filters, dispersive coatings like GTI mirrors, chirped mirrors and mirror pairs, attenuators, customized filters, metal-enhanced coatings, coatings on crystals, fibers, viewports and space optics.

Laseroptik offers special capabilities in their Ion Beam Sputtering section. Two IBS coaters have been built up for coatings on large substrates of up to 2 meters in length or 550 mm in diameter.

Please see also the latest development of high LIDT coatings on large optics for petawatt laser systems (→ page 54).

With a team of about 100 people, Laseroptik produces up to 180,000 coated optics per year for laser applications in industry, medicine and scientific research.

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LASER World of PHOTONICS, Hall B6, Booth 119

Lumibird: the specialist in laser technologies

Lumibird is one of the world's leading specialists in lasers. With over 50 years of experience and expertise in three key technologies – solid-state lasers, laser diodes, fiber lasers – Lumibird manufactures high performance lasers for the industrial, scientific, defense, space and medical markets.

3D scanning, lidar, ADAS, atom cooling, materials research, combustion analysis, end-pumping, photoacoustic imaging, telemetry, satellite communications, nuclear fusion... are just some of the many applications of Lumibird lasers.

Listed on the stock exchange, the group (formerly Quantel-Keopsys) is headquartered in France and is present on several continents through its nine production and R&D sites and its sales and support offices.

Lumibird, employs over 900 people and is growing at a double-digit rate.

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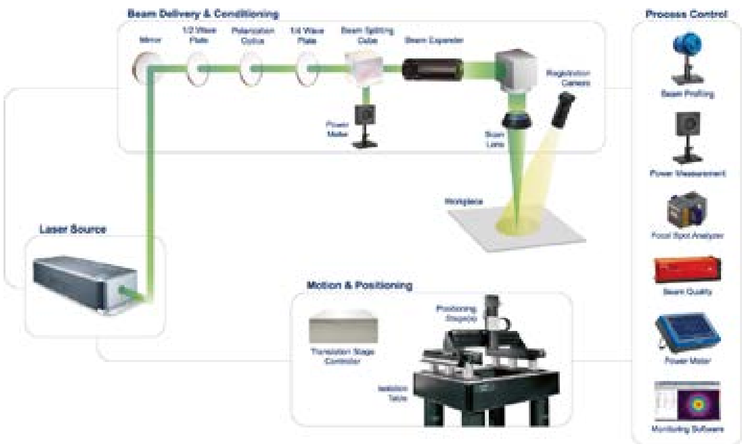
LASER World of PHOTONICS, Hall B5, Booth 151

Enabling the technologies that transform our world

MKS Instruments is a global provider of instruments and solutions to measure, monitor, deliver, analyze, power and control critical parameters in advanced manufacturing and research applications. Spectra-Physics, Ophir and Newport are brands within the MKS Instruments Photonics Solutions Division. ESI is a brand in our Equipment Solutions Division. Spectra-Physics combines groundbreaking laser technologies with deep application expertise to deliver industry leading lasers for precision industrial and scientific research applications. Ophir specializes in laser and LED measurement products, including laser power and energy meters and laser beam profilers. Ophir also provides high-performance IR thermal imaging lenses and optical elements as well as optics for CO_2 and high-power fiber laser material processing. Newport provides a full range of solutions including motion control, optical tables and vibration isolation systems, photonic instruments, optical and opto-mechanical components. MKS Photonics Solutions enhance our customers' capabilities and productivity in the semiconductor, industrial technologies, life and health sciences, research and defense markets. The Equipment Solutions Division provides laser-based manufacturing solutions for the micro-machining industry that enable customers to optimize production. Our market is composed primarily of flexible and rigid PCB processing/fabrication, semiconductor wafer processing and passive component manufacturing & test. Our solutions from both divisions support our Surround the Workpiece^{SM} offerings, in which we deliver leading products and services in the lasers, photonics, and optics markets.



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LASER World of PHOTONICS, Hall A6, Booth 219

Novanta

Novanta is a trusted technology partner to medical and industrial OEMs (original equipment manufacturers), with deep proprietary expertise in photonics, vision and precision motion technologies. We engineer mission-critical core components and subsystems that deliver extreme precision and performance, enabling our customers to improve productivity, to achieve breakthrough performance and to enhance people's lives. Our highly engineered component and sub-system solutions, and deep expertise in advanced photonics, vision and precision motion make us the global technology partner of choice for medical and advanced industrial OEMs.

Learn more about our laser processing solutions by visiting www.novanta-photonics.com

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LASER World of PHOTONICS, Hall A6, Booth 560

Lasers love Owis – for a reason

Optical beam handling systems form the basis for individual assemblies and may be combined perfectly with optical components as well as manual and motorized positioning units, thanks to our modular system. High-precision linear, rotational and swivel movements may be carried out with up to nine axes in combination with our controllers. Multi-axis systems can be positioned. The Owis Vacuum Series is designed for extremely high vacuum with pressure ranges of 10^{-11} mbar, where we have developed a unique competence.

Plus with system – individually designed and manufactured – everything from a single source

With Owis Engineering, you benefit from an improved price-performance ratio and minimum construction size with maximum quality through combination, simplification and optimization. We support you in the fast and flexible setup of alignment and handling systems, in application-specific customizing, or when it comes to further developing your laboratory setup into a production-ready series product, the Owis Optics Box. Thanks to our high production depth we are very flexible and reduce your time to market to a minimum.

As a medium-sized, owner-managed company based in Staufen/Germany, we develop and manufacture solutions for scientific institutions and industrial companies worldwide. For decades, we have been appreciated in measurement and testing technology, research and science, the semiconductor industry, bio and medical technology, image processing and sensor technology as well as analytics and diagnostics. Benefit from our years of experience!

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LASER World of PHOTONICS, Hall B5, Booth 321

Photon Energy

Photon Energy GmbH, an ISO 9001 certified German company, has been established as a reliable partner for industry and science for many years. The globally acting company provides tailored solutions for laser material processing and precision micro-machining as well as qualified and individual customer support.

Photon Energy specializes in development and manufacturing of high quality pulsed and ultra-short-pulsed laser sources and laser marking devices for industrial and medical applications. The compact nano- and picosecond-DPSS-lasers as well as the newly developed fiber-based femtosecond lasers are available as standalone and OEM versions. Besides laser sources Photon Energy also offers complete workstations and turnkey table top systems for marking and surface structuring applications, as well as for high precision micromachining.

Photon Energy works with customers to select the right laser for their individual requirements by creating samples for customized evaluation. For this purpose Photon Energy is equipped with a well-equipped application laboratory with many analysis options. In addition they are cooperating with a scientific community with various projects Europe wide.

Such requirements range from simple markings to high-precision applications in metal and plastic as well as brittle materials such as glass and ceramics. Special processes such as TGV and cutting can also be realized.

Competence, reliability and innovation are the focus of Photon Energy for a successful customer cooperation.

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LASER World of PHOTONICS, Hall A6, Booth 371

Precision linear guides and frictionless slides

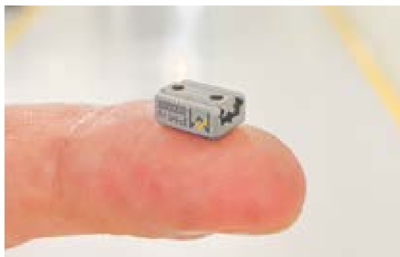
PM is the leading European manufacturer of standard and customized precision linear bearings, linear slides, miniature slides, rotation bearings, sub-assemblies and engineered-to-spec motion systems. We are a family-owned company in the Netherlands and employs more than 200 people. Known as a trusted partner for hundreds of global players operating semiconductor industry, optical and metrology sectors, medical technology to industrial automation, space and defense industries.

PM has over 50 years in-depth manufacturing knowledge and critical products are made in house. With the manufacturing capabilities extremely small sized products up to large machined products (example vacuum chambers, accurate large machine elements and frames) can be supplied.

The product portfolio of linear bearings includes ball, cross roller and needle roller linear bearings. Besides linear bearings, PM is specialized in linear slides and offers various miniature slides. The newest innovation is the extremely compact cross roller linear slides MSR which includes anti-cage creep technology and offers a highly accurate movement at high speeds.

Other products are the compact and flat rotary table bearing for precise rotary motion and the gonio bearings which offer precision and low friction curved motion, originally developed for use in optical lenses applications

Furthermore, the portfolio includes customized xy-stages, positioning systems and advanced motion systems with accuracies at sub-micron level. With a deep expertise solutions can be offered that meet the specific requirements of



a wide variety of industry applications. Assembly of the products is done in conditioned low-dust assembly rooms, for semiconductor and medical customers ultrasonic cleaning, assembly and qualifying in cleanroom classes 6 and 7 is offered.

Company

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Competence in beam diagnostics

Primes develops and produces market leading systems for laser beam characterization in industrial applications. Our spectrum of high-precision, durable products is put to use in numerous branches, such as automotive industry, industrial machinery, additive manufacturing as well as R&D and laser manufacturing. Primes is an important player on the global market, represented by twelve distributors and a subsidiary in Japan. We have a clear customer focus and provide worldwide consulting.

Primes provides robust, industry proven, ready-to-use-systems for industrial environments. They are easy to integrate in production processes due to standardized interfaces. Thanks to the in-house design of hard- and software we can offer optimal solutions for a wide variety of laser measuring tasks as well as for nearly all major laser- and machine builders. Our core competence lies in beam diagnostic devices for use in the processing area of systems with multi-kilowatt laser power.

As an ISO 9001 certified company, precision is our standard. Our calibration laboratory has years' experience in the calibration of power meters at process relevant power levels as well as in the validation of camerabased and opto-mechanical beam profilers. Our extensive spectrum of beam sources – ranging from UV over VIS and NIR to CO_2 lasers – offers the perfect conditions for this.

With a global installation base of more than 25,000 systems, Primes has gained highest reputation and is renowned for offering sophisticated solutions in the cross-sectional technology "laser".

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www.primes.de

LASER World of PHOTONICS, Hall A6, Booth 241

Laser beam deflection and positioning

With over 35,000 systems produced and delivered annually, Scanlab is the leading, independent OEM manufacturer of scan systems and control solutions.

The products and systems are used for laser material processing (e.g. marking, welding, cutting, drilling, micromachining, additive manufacturing) and for medical and biomedical technology (e.g. ophthalmology, dermatology, confocal microscopy). The company offers solutions optimized for each of these highly varied markets and demanding applications.

The product range includes high-performance galvanometer scanners, 2D- and 3D-scan heads, ultra-compact scan heads for high-speed applications (more than 1,200 cps), complex scan solutions for USP and high-power lasers (multi-kW range), customized systems, vision solutions, advanced control electronics (also on-the-fly), laser processing software, laser optics and accessories.

Scanlab secures its international technology leadership through pioneering developments in electronics, mechanics and optics, as well as a trustful partnership with customers and laser technology users. The ISO 9001 certified company is committed to highest product quality, comprehensive expert advice and dependable deliveries.

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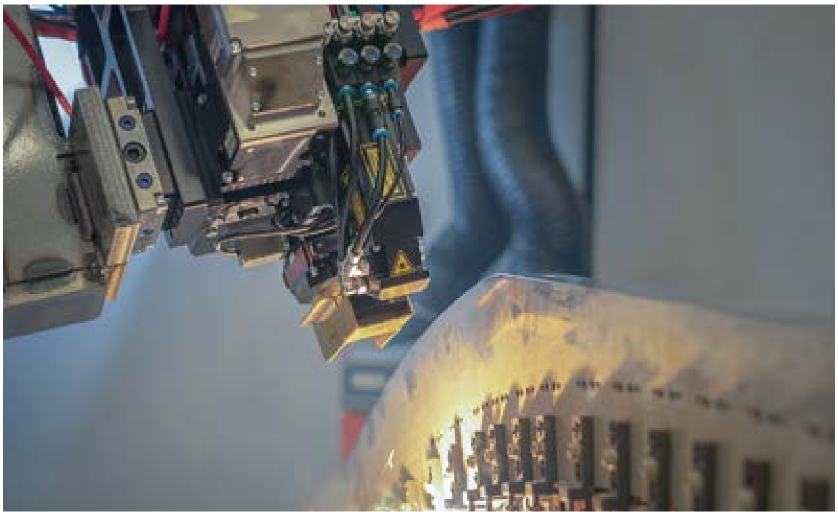
LASER World of PHOTONICS, Hall A6, Booth 239

Scansonic – the top choice for intelligent laser processing

Berlin-based Scansonic MI GmbH is one of the world's leading manufacturers of laser processing optics, optical sensor technology, and process monitoring systems. Since its founding in 2000, Scansonic has been tirelessly developing new industrial applications for laser technology. With its innovative processing heads for laser welding, laser brazing, laser cutting, laser hardening, and laser coating, Scansonic customers achieve the highest quality in their manufacturing processes. Scansonic's laser welding with optical and tactile seam tracking sets global standards in vehicle bodywork and e-mobility applications.



One important area of focus for Scansonic is the creation of customized solutions. Most of the company's approximately 130 employees come from the fields of design, lasers, electronics, or software and process development. They are continuously working on new developments for the entire process chain – from initial concept to serial production. Whether it involves new materials, modified component geometries, or fine-tuning a process, the company works closely at every stage with customers who rely on Scansonic to solve their production challenges. The Scansonic Laser Application Center is one of the largest and most modern centers of its kind in the world, with eleven laboratories as well as a wide variety of laser types and robot models.

Scansonic offers its customers onsite support around the world through its global distribution and service network, as well as branch offices in the USA and China.

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LASER World of PHOTONICS, Hall A5, Booth 311

High-quality optical components

Schäfter+Kirchhoff
OPTICS, METROLOGY, AND PHOTONICS GmbH

The company Schäfter+Kirchhoff GmbH is based in Hamburg, Germany, and was founded over 60 years ago. From here we manufacture high quality optical products that are delivered to customers all around the world.

Our current product lines are polarization-maintaining fiber optics, lasers for machine vision and line scan cameras. A special focus is set on the winning combination of high optical and high mechanical precision, which is the basis for the high quality, stability and durability of our products.

One example of successful opto-mechanics is the 60SMS laser beam coupler, which is used to couple into polarization-maintaining fibers. This demanding task requires very high precision and quality in order to reach long-term stable and high coupling efficiencies. Further fiber optics components are available for the wavelength range 360 – 2100 nm.

Another field of opto-mechanics is machine vision that uses laser line or spot generators as well as line scan cameras. Ruggedized solutions for industrial purposes are only possible by using high-quality optics, mechanics and electronics. This is true for defined and thin laser line geometries or especially small laser spots as well as complete line scan camera based scanner systems. The Corrosion Inspector, e.g., is an automated and objective analy-

sis tool for corrosion phenomena that offers a fast and precise evaluation according to international norms. The line scan cameras used are also supplied as OEM components and offered with different interfaces.

Our extensive know-how and highly qualified, strongly committed employees are the driving force behind the company. To have sales, research and development, as well as manufacturing so closely knit together, ensures a quick and efficient response to customer needs.

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LASER World of PHOTONICS, Hall B5, Booth 320

JPT Opto-Electronics

Registered in 2006, Shenzhen JPT Opto-Electronics focuses on the R&D, production, sales, and technical services of laser technology. Based on laser technologies, JPT integrates leading technologies such as laser and optics, test and measurement, motion control and automation, machine vision. The company highly values intellectual property and has applied for more than 600 patents and software copyrights. In 2019, JPT went public in the STAR Market of Shanghai Stock Exchange.

Leading manufacturer of MOPA pulsed fiber lasers

In the past 16 years, JPT has continuously innovated and is always seeking breakthroughs in technology with the mission of "Leading Optical Technologies for People" while keeping improving of the excellent consultant, management, R&D and sales team, where the key team members consist of several PhDs and masters from global famous universities and research institutes. JPT MOPA pulsed fiber lasers have been the first ones to be mass-produced in China which bridged the long-term technical gap in this field. With the excellent precipitation and accumulation of laser technology, JPT has harvested lots of honors and been widely recognized as:

- Top 1 of MOPA pulsed fiber laser in global
- Top 3 of fiber lasers manufacturers in China

Laser technology promotes industrial application

JPT provides multi category of laser source including ultrafast lasers, CW fiber lasers, DPSS lasers and ultrafast lasers. These products are widely used in many kinds of manufacturing processes, such as black marking on anodized aluminum, color marking on stainless steel, deep engraving, welding of dissimilar metal sheets, paint removal of plastic product, laser cleaning, glass drilling, lithium battery processing, electrode tab and photovoltaic silicon wafer cutting, etc. JPT laser technology is being used in an increased number of industries, including 3C, PV, lithium battery, PCB, semiconductor, communications, detection, machinery, transportation, medical industry and etc.

STOCK CODE: 688025

Company

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Shenzhen, China, 518110
phone: +86 755 29528181
fax: +86 755 29528185
e-mail: sales@jptoe.com
www.jptoe.com

LASER World of PHOTONICS, Hall A5, Booth 419

Innovative solutions for optics and photonics

Sill Optics is the specialist for quality and innovation in the field of photonics technologies. With regard to customized development as well as standard solutions we have established ourselves internationally and are one of the leading companies in this business.

With highly qualified and motivated teams, we have the flexibility to create photonic solutions in a targeted, efficient and economical manner for our customers.

Main activities
The production spectrum covers a wide range from the production of lenses up to complete systems for following applications:

- Laser technology: Industrial material processing, e.g. micromaterial processing, additive manufacturing
- Imaging optics, e.g. industrial metrology, quality assurance
- Medical technology, e.g. microscopy, analytical technology
- Science and research, e.g. trapped ion lenses

Services
Development and production of

- Spherical precision lenses
- Precision apsheres
- Low absorption coatings
- Mechanical components
- Optomechanical components
- Electronics

Technology focus

- Optical and mechanical solutions in high end applications
- Alignment turning device
- High precision assembly
- Optical thin films and absorption measurement devices

Company

Sill Optics GmbH & Co. KG
Johann-Höllfritsch-Straße 13
90530 Wendelstein, Germany
phone: +49 9129 9023-0
e-mail: info@silloptics.de
www.silloptics.de

LASER World of PHOTONICS, Hall A6, Booth 414

SmarAct

With the development and production of market-leading solutions in the field of high-precision positioning technology, metrology and automation technology, SmarAct reliably accompanies their customers in achieving their goals.

The broad product portfolio – from single stages to complex parallel kinematics, miniaturized robots, control systems and measurement technology – is completed by automated microassembly solutions. Even the most challenging customer requirements can be met by maximum adaptability and complete in-house production.

Since its founding in 2005, SmarAct has steadily grown from a small team of engineers to a company with 200 highly skilled members. Today, SmarAct draws on years of experience and, above all, on a very passionate team with unconditional customer focus.

The left picture below shows a 3-axis positioning system, consisting of SmarAct's PLF scanning stages, that optimizes the coupling of light at 633 nm from one single-mode optical fiber into a second by actively adjusting the relative position of the fiber cores. The picture to the right shows one of SmarAct's hexapod-like positioning systems, the SMARPOD 110.45 in a UHV-compatible version.

Company

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26135 Oldenburg, Germany
phone: +49 441–800 87 90
phone: +49 441–559 79 18 0
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www.smaract.com

LASER World of PHOTONICS, Hall B5, Booth 113

Synova

Synova, headquartered in Duillier, Switzerland, develops and manufactures advanced laser machining systems that incorporate its proprietary water jet guided laser technology (Laser MicroJet®) in a true industrial CNC platform. The hybrid Laser MicroJet (LMJ) method of machining combines a laser with a "hair-thin" water jet that precisely guides the laser beam by means of total internal reflection.

Synova's 3 and 5-axis machines allow fast and precise machining of a wide range of materials, from metals to ultrahard and brittle materials such as diamond or ceramic, to complex composites – without thermal damage, debris deposition and taper.

The company has delivered over 400 machines, designed for applications such as drilling cooling holes in turbine blades, faceting rough diamond stones and processing semiconductor equipment consumables.

Synova employs over 100 people worldwide, including 35 engineers, who mainly focus on researching new material cutting solutions, further applications and laser cutting equipment. Aside from research, both the final assembly and testing of up to 100 machines a year are performed in Synova's modern, 3000 square meter facility in Duillier. Synova has established subsidiaries in the USA, Japan, India, Korea, Germany and China for optimized customer support.

Synova is a company with global reach focused on delivering high quality solutions and services to its customers wherever they are. We strongly believe that the motor of our success and growth are our technology, experience and dedication to our customers.

Company

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Route de Genolier 13
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phone: +41 21 55 22 600
e-mail: sales@synova.ch
www.synova.ch

LASER World of PHOTONICS, Hall A6, Booth 361

Toptica Photonics

Toptica has been developing and manufacturing high-end laser systems for scientific and industrial applications for twenty years. Our portfolio includes diode lasers, ultrafast fiber lasers, terahertz systems and frequency combs. The systems are used for demanding applications in biophotonics, industrial metrology and quantum technology. Toptica is renowned for providing the widest wavelength coverage of diode lasers on the market, providing high-power lasers even at exotic wavelengths.

Toptica develops and manufactures high-end laser systems for scientific and industrial applications. OEM customers, scientists, and over a dozen Nobel laureates all acknowledge the world-class exceptional specifications of Toptica's lasers, as well as their reliability and longevity.

Founded in 1998 near Munich (Germany), Toptica became one of the leading laser photonics companies by aiming for, and consistently delivering high-end specifications. Toptica's diode lasers are appreciated for excellent coherence, wide tuning range and ideal beam profiles.

Toptica's 400 employees take pride in developing customized systems. In close collaboration with several universities and institutes, latest scientific discoveries are frequently incorporated into commercial products. With a global distribution network, Toptica provides exceptional service worldwide.

Short profile Toptica Photonics

Founded: 1998
Employees: 400 (2021)
Revenues: 85 Mio. € (100 Mio $)
Legal form: Aktiengesellschaft (AG), private ownership
Presidents: Dr. Wilhelm Kaenders, Dr. Thomas Renner
Chairman: Dr. Dieter Schenk

Company

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82166 Graefelfing / Munich, Germany
phone: +49 89 85837-0
e-mail: sales@toptica.com
www.toptica.com

LASER World of PHOTONICS, Hall B5, Booth 103

Vistec Electron Beam

As a long-standing equipment supplier, Vistec Electron Beam GmbH, Jena (Germany) is providing leading technology solutions for advanced electron-beam lithography (EBL). Based on the Variable Shaped Beam (VSB) principle, the lithography systems are mainly utilized for semiconductor manufacturing and advanced research as electron-beam direct write in semiconductor industry, mask making as well as integrated optics, photonics and several new emerging markets. The company is located in Jena, Germany and maintains service & support centers in Europe, Taiwan & in the US.

Company

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07743 Jena, Germany
phone: +49 3641 7889 0
fax: +49 3641 7889 222
e-mail: electron-beam@vistec-semi.com
www.vistec-semi.com

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Nd:YAG lasers, pulsed

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Laser optics and components

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www.zuendoptics.com

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www.materion.com/balzersoptics

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Mirros, UV

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Optical Components

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Prisms

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Windows, optical

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www.zuendoptics.com

Material processing systems

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Marking systems

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info@polytec.de

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www.essentoptics.com

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12 November 2021 Editorial deadline

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- Beam forming / beam analysis
- Optical components

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22 April 2022 Publishing date
22 March 2022 Advertising deadline
23 February 2022 Editorial deadline

Focus: Laser World of Photonics / AKL '22

- Ultrashort-pulse laser sources
- Laser materials processing
- Optical measurement
- → with company profiles

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22 August 2022 Editorial deadline

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- Laser welding und cutting

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02 December 2022 Publishing date
01 November 2022 Advertising deadline
05 October 2022 Editorial deadline

Focus: Quantum Technology

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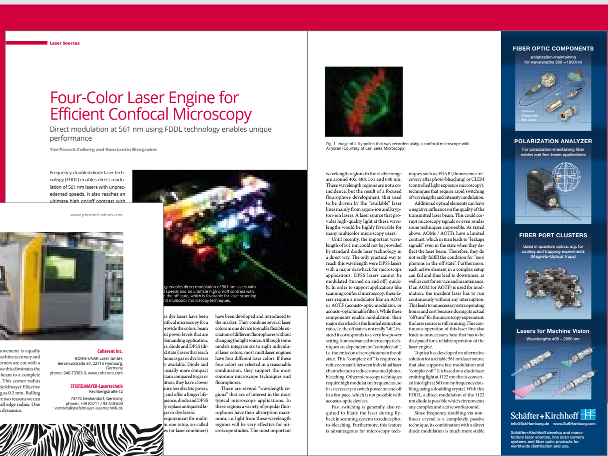
- Laser materials processing



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Company Index

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