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SLT

SPECIAL SECTION
Stuttgart Laser Technology
Forum (SLT)

BEAM ANALYSIS

Fact-checking five common misunderstandings

ULTRASHORT-PULSE LASERS

How to multiply beam paths to create compact laser amplifiers

BEAM SHAPING

Unlocking opportunities for the EV industry

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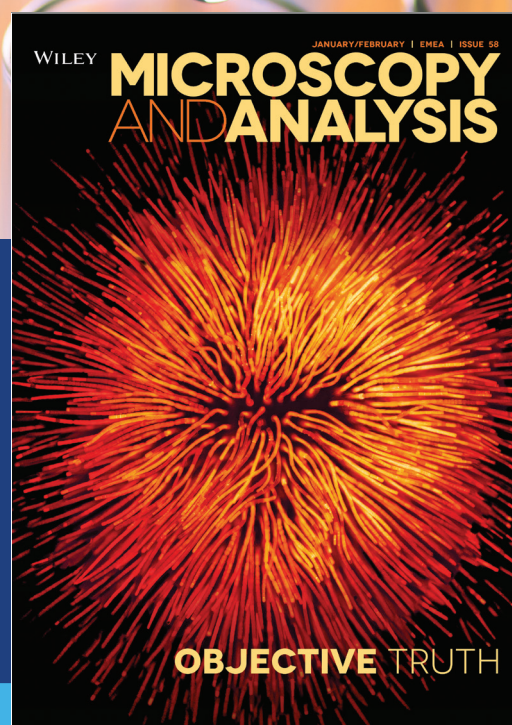
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Dynamic progress of laser technology

New fields of applications and fresh inspiration

On the occasion of the Stuttgart Laser Technology Forum (SLT) 2022, we already highlighted the huge potential that has arisen from the fast progress in the development of flexible lasers, which will soon offer the ability to switch between cw and (ultrashort) pulsed operation at kilowatt average power levels. The prospect of performing virtually all laser-based manufacturing processes with the same laser on one and the same machine bodes well for digital manufacturing and promises fresh inspiration in the corresponding research.

The vision of a universal laser machine is being strongly promoted by the Institut für Strahlwerkzeuge (IFSW) at the University of Stuttgart and is successfully pursued thanks to the new professorship on laser technology in manufacturing that has been created. Our established research competencies, which are currently dedicated to making high-power laser systems more versatile as well as improving our understanding of the processing fundamentals, are rapidly being expanded to include the use of artificial intelligence and the application of laser-based processes for the manufacture of quantum technology components.

With this in mind, the plenary keynotes of the SLT 2024 are devoted to the role of photonics in quantum technology and its industrialization, novel lasers with exciting capabilities, and the exploitation of artificial intelligence, for example in manufacturing. So together with many other exciting contributions, the SLT 2024 will once again provide an outlook into the dynamically developing future of laser technology and will highlight the current trends and achievements. The latest laser system developments will be discussed along with the latest advances in beam shaping and beam delivery. With regard to materials processing, the applications to be presented range from high-precision ablation to additive manufacturing, and include sessions on process monitoring and the potential of laser processing for quantum technology.

We wish you inspiring reading of this issue of PhotonicsViews!

T. Graf *A. Michalowski*



SLT

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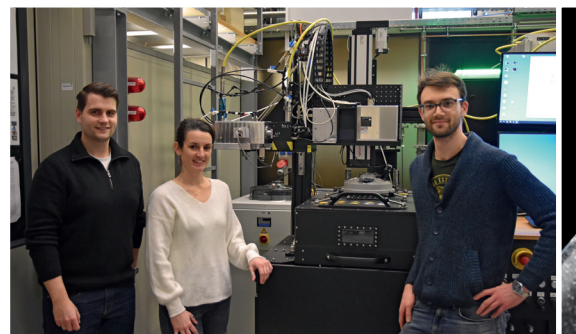
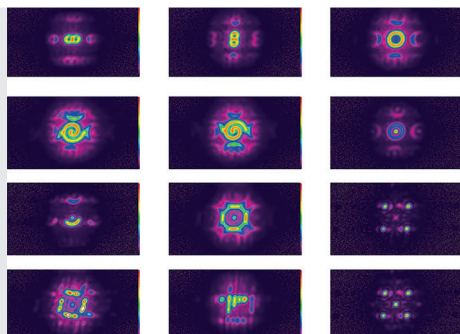
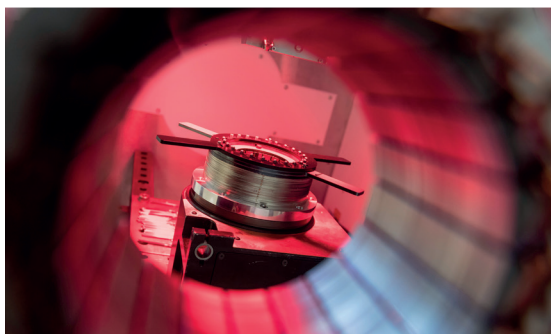


contributing partners



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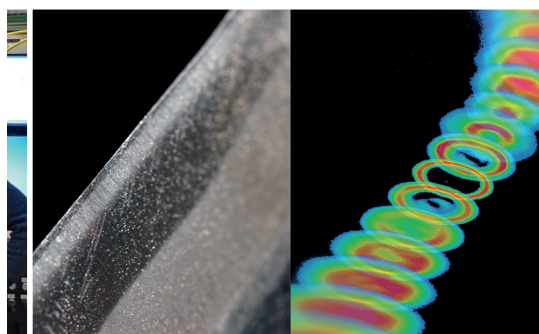
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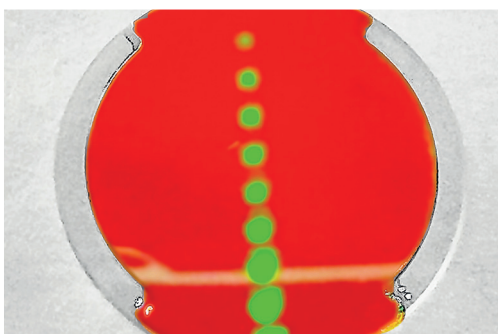
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Jochen Speiser, Raoul-Amadeus Lorbeer, Pirmin Schweizer & Benjamin Ewers

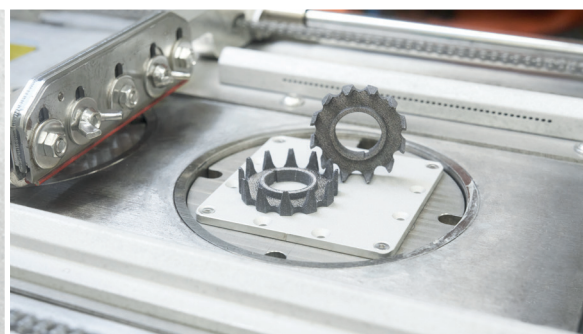
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50 Bridging additive and subtractive manufacturing

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Lasers are showcased in Munich as key enablers in EV manufacturing

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Cover:

Hübner Photonics is in the art of making high performance lasers, from cw single frequency lasers by Cobolt to femtosecond lasers by Valo – always concretely speaking!

www.hubner-photonics.com

X-ray light generated by a laser to inspect e-car batteries

In future, manufacturers of electric car batteries could further improve the durability and performance of electric car batteries with compact X-ray sources.

Institutes in Aachen and Jena has now started to develop these laser-driven X-ray sources under the leadership of Trumpf. The first demo systems are to be

precision. The findings will be incorporated into the development of new batteries. With the conclusions drawn from the analyses, manufacturers will be able to improve, for example, the charging speed.

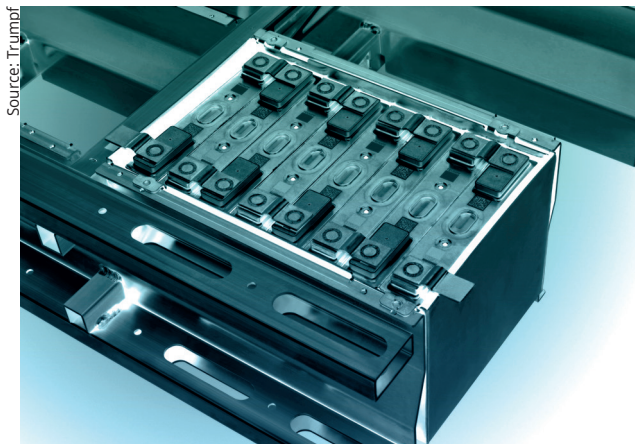
Until now, companies have only been able to carry out such investigations on large particle accelerators more than a hundred meters long. Research stations at these large-scale research facilities are rare. The laser-driven X-ray sources are only about the size of a mobile home and as such are cheaper to manufacture. They are therefore ideal for use in industry.

The high-tech company Trumpf is contributing its expertise in the manufacture of lasers for industrial use to the partnership. The laser serves as a so-called upstream beam source in

the generation of X-rays. The laser pulse hits the target, a metal such as gallium, indium or tin. A plasma is created that emits some of the energy as extremely short-wave light such as X-rays.

BASF and Cellforce are providing battery materials and components for the tests. Ushio Germany and Excillum are contributing their expertise in the field of beam sources. Bruker and Viscom are responsible for the construction of the systems. On the academic side, the University of Hanover and the Fraunhofer Institutes in Aachen and Jena are the driving forces. The research budget amounts to around 15 million euros and the Federal Ministry of Education and Research (BMBF) is funding the project.

www.trumpf.com



The XProLas development partnership that includes Amphos, Active Fiber Systems, BASF, Bruker, Cellforce, Excillum, Ushio, Viscom, the University of Hanover and Fraunhofer

built by 2026. Then, manufacturers will be able to use these systems to monitor the charging and discharging of batteries in real time or determine impurities in the battery with particular

Noctiluca diversifies its business portfolio

The Torun-based company creates proprietary chemical compounds for OLED displays and lighting in a new laboratory with an expanded team to encompass chemical contract research organization (cCRO) services, sublimation, and a broader range of chemical materials. The company already has customers in these areas.

tronics, including displays for monitors, TVs, smartphones, wearables, virtual reality devices, and lighting applications.

Noctiluca's materials are compatible with all production methods used in the display industry – primarily vacuum deposition and solution processing, e.g. ink jet printing. Being a one-stop shop for the display industry, the company can provide both excellent novel materials as well as entire material packages that are ready for implementation by industrial customers. They require little or no materials competency in order to gain a competitive edge by the use of the latest developments in organic chemistry.

The new laboratory was inaugurated in 2023 and has enabled the company to scale its operations.

<https://noctiluca.eu>



The new Noctiluca laboratory, opened in 2023

3rd, 4th and 5th generation emitters and other high performance materials are integral components in the creation of high-quality elec-

Innolume expands quantum dot laser diode production



Quantum dot technology for silicon photonics datacom applications

The Dortmund-based innovator and manufacturer of GaAs quantum dot lasers has substantially expanded its production capacity to address the surging demand for O-band cw lasers and SOAs in several markets, including AI-driven connectivity. For example, according to LightCounting Market Research, shipments of 800+ Gbps optical transceivers are expected to nearly double annually over the next five years, driven by the rapid expansion of hyperscale data centers.

To meet this escalating demand and solidify its leadership position, Innolume has ordered a Riber CPS 442 laser facet passivation machine and a Riber 49 MBE system to expand its existing MBE fleet as part of the overall ongoing investment program to ramp up manufacturing capacity.

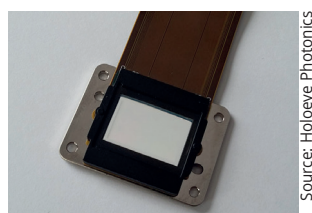
With over twenty years of experience, the company serves various market segments, including datacom, lidar and sensing, industrial, and scientific applications.

www.innolume.com

LCOS technology from JDC purchased by Holoeye

Jasper Display Corp (JDC) was a fabless semiconductor company in Taiwan and the US and provided liquid-crystal-on-silicon (LCOS) spatial light modulators (SLM), LCOS microdisplays and digital modulation controller ICs. The JDC backplane technologies and hardware inventory acquired enables Holoeye to expand product lines on its LETO and GAEA SLM platforms.

Sven Krueger, CEO of Holoeye states: "The fast digital backplane technology from JDC has great potential for phase modulation spatial light modulators with unique features like 4K resolution and an extremely small pixel pitch. We already addressed this in the past with products like LETO and GAEA SLMs. The acquired technology enables us to



JDC LCOS microdisplay

extend and diversify these product lines with versions for highly specialized applications."

Holoeye also offers support for former JDC SLM customers to continue their academic and industrial research and development programs in the future.

Founded in 1999 with headquarters in Berlin, Germany, Holoeye provides products and services in the fields of spatial light modulators, LCOS microdisplay components and diffractive optical elements (DOE).

www.holoeye.com

Civan Lasers opens its first office in Europe

The laser maker from Israel known for its dynamic beam laser technology (cf. p. 26), expands into the continent to meet the growing demand for its innovative solutions in Germany and across Europe, improving the Jerusalem company's capability to deliver enhanced service and support.

The new office will function as a central hub for sales, service, and R&D, with a focus on welding process innovation. It includes a demo room equipped with the latest in laser technology, notably a 14-kW laser with a galvo scanner and a fast axis x-y table in the application lab, designed to support a variety of applications from client demonstrations to in-depth R&D projects.

Situated near the Laser Zentrum Hannover LZH, this location fosters collaboration with a leading



Office entry area

research institute in laser welding and metal additive manufacturing, facilitating the cooperation of talented graduates and underscoring the dedication to innovation.

At the helm of the Hannover office are Joel Meentzen, general manager, and Dr Ing Robert Bernhard, application lab and branch manager. Meentzen expressed his enthusiasm for the new facility, stating, "Our new office will significantly improve our service capabilities and response times for our customers."

www.civanlasers.com

Hamamatsu teams up with Vrije Universiteit Brussel to drive photonics innovation

A new collaboration between Hamamatsu Photonics and Vrije Universiteit Brussel (VUB) aims to establish an enduring relationship focused on advancing photonics innovation. By leveraging VUB's distinguished research group, B-Phot, Prof Hugo Thienpont, and Hamamatsu's industry experience, both entities are committed to exploring new avenues in supporting companies at various stages of photonics development.

Key areas of collaboration include providing support to companies in photonics feasibility studies, proof-of-concept demonstrations, prototyping, and quality control. Additionally, the partnership will explore the development of photonic modules and subsystems to enhance Hamamatsu Photonics' product portfolio.

Furthermore, the alliance will extend its reach to European companies through PhotonHub Europe, facilitating collaborative efforts with partner research institutes across Europe. An exciting outcome of this partnership is the introduction of 'Pilot Lines', a new service aimed at bridging the gap between conceptualization and market-ready photonics products. Pilot Lines facilitate the seamless transition of photonics-based technologies from early-stage development to commercialization.

Pilot Lines was launched during the first of the Hamamatsu Technology Days events from April 25th to June 13th, which take place across eight European cities.

www.hamamatsu.com

www.b-phot.org

www.photonhub.eu

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FOCUS

FOCUS – 10th PRIMES Workshop
on Industrial Laser Beam Diagnostics
Sept. 25 – 26, 2024 in Pfungstadt

ALSO OF INTEREST

Zeiss and Argolight enhance microscopy imaging quality control

Partnership enables users to accurately measure and assess the performance of their microscopy systems

Stemmer Imaging takes over Phase 1

With the acquisition of the competitor, the machine vision systems house steps into the US market

Teledyne e2v works with Airy3D

The collaboration intends to provide affordable 3D vision solutions

Isra Vision has moved

The company has opened new headquarters in Darmstadt

"Multicolor vision" for drone flight, vertical farming, and autonomous driving

European research project HyperImage launched with twelve partners from industry and academia

New lasers for digital holography

Fraunhofer IPM collaborates with Hübner, Zeiss, CyberTechnologies and the University of Freiburg on highly integrated, cost-effective lasers

Framos works with Ridgerun

Strategic partnership aims to provide high-end vision solutions

IC House celebrates its 40th anniversary

Manufacturer of ICs and microsystems looks back to 1984

Siemens to acquire industrial drive technology business of EBM-Papst

Purchased IDT business, which employs around 650 people, includes innovative motion control systems

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**Quantum Effects Award 2024: apply by 30 June**

Presented on the first day of the Quantum Effects 2024 trade fair, the award honors outstanding innovations that open up new prospects in different industries. The award was presented for the first time in 2023. In 2024 it will also be presented for partial solutions from the quantum mechanics areas of sensors, communication, computing, and security. These solutions are characterized by a technology readiness level 5 or higher, possess a high level of innovation and future potential, or are already being used.

Start-ups, established companies and research institutes can submit ideas and solutions. The 2024 award will be presented in four categories: quantum computing hardware, quantum computing software and algorithms, quantum sensors, and quantum communication and networks.

Partial solutions, which come from the quantum mechanics area of sensors, communication, computing and security, are eligible to take part in the competition. Entries must also be characterized by a TRL of 5 or



Quantum Effects Award 2023 trophy

higher and have a high level of innovation and clear future potential or are already being used in initial solutions. Publication or the market launch should not date back more than three years.

Participation in the competition is free of charge.

www.quantum-effects.com/award

AMD's Lisa Su honored with the 2024 Imec Innovation Award

The prize recognizes the contributions of Dr Su recognized for promoting innovation in high-performance and adaptive computing. Since its launch in 2016, the Imec Innovation Award has become a hallmark for recognizing pioneers in the semiconductor industry. Previous recipients include Dr Gordon Moore and Bill Gates.

Before joining AMD, Lisa Su held various engineering and management positions at companies such as Texas Instruments,

IBM, and Freescale Semiconductor. Notably, during her tenure as vice president of IBM's semiconductor research and development center, Su made significant contributions to silicon-on-insulator semiconductor manufacturing technology and creating more efficient microchips. In October 2014, she assumed the role of president and CEO of AMD after joining the company in 2012, becoming the first female CEO of a major semiconductor company.



Lisa Su, AMD chairwoman and CEO

The awards ceremony took place at ITF World (while this issue was printing, 21 – 22 May) in the presence of over 2,000 leaders who gathered at the Royal Elizabeth Hall in Antwerp, Belgium.

www.imec-int.com

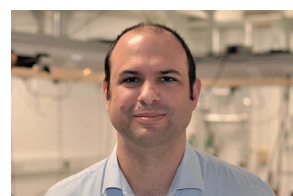
£ 2.5 M to develop new ultrafast laser technologies

John Travers, professor of physics at Heriot-Watt University in Edinburgh and director of the Laboratory of Ultrafast Physics and Optics, has been awarded a Royal Academy of Engineering Chair in Emerging Technologies. The award aims to support 'global research visionaries' and provides ten years of funding for emerging technologies with high potential to deliver economic and social benefits to the UK.

Professor Travers' system creates high-performing, bright ultraviolet light that

has multiple transformational applications in sectors such as manufacturing, electronics, AI, and drug discovery. A key feature of the UV system Prof Travers has invented is its tabletop size. This is tiny compared to the building-sized, multibillion dollar machines currently used to generate UV and X-ray light sources. His system is already being used in 14 different labs around the world, including healthcare and semiconductor settings.

The funding that Prof Travers has been awarded



Ultrafast laser scientist Prof John C Travers

focuses on developing ultrafast, bright ultraviolet X-ray and electron beams, to recruit new staff and also build a center of excellence in this area. Prof Travers is one of four academics in this latest funding round.

www.hw.ac.uk

Recognition of innovations in laser technology for the industry

The winner of the 10,000-euro Innovation Award Laser Technology 2024 is Edwin Büchter, co-founder, mentor, and managing director of Cleansort in Rösrath, Germany. The award was presented on April 17, 2024 in the Coronation Hall of

strength of German photonics research and industry.

These 2024 finalists were awarded:

1st place **Cleansort GmbH**, Edwin Büchter, for laser-based sorting systems for resource-saving recycling of recyclable materials,



Winners, hosts, and presenters of the 2024 Laser Innovation Award

Aachen's Town Hall. Mr Büchter and his team took the first place in the open competition. The international ten-member jury selected three outstanding finalists from the numerous applications received. Around 350 guests attended the award ceremony in a historic setting.

The Innovation Award Laser Technology is presented every two years to laser manufacturers and users as well as researchers and developers who have successfully brought a laser technology innovation from application-oriented research to industrial implementation. The award is presented by the Arbeitskreis Lasertechnik AKL, a network of around 200 laser experts, and the European Laser Institute ELI, a platform that pools expertise and knowledge about optical technology.

In his keynote speech, Dr Peter Leibinger, chairman of the supervisory board of Leibinger SE, focused on the fascination and limitless potential of laser technology and the innovative

2nd place **Audi AG**, Dr-Ing Jan-Philipp Weberpals, for their holistic approach to laser beam welding of high-quality contacts in battery modules, and

3rd place **Cailabs**, Gwenn Pallier, for their Canunda concept to upscale laser processing with beam-shaping (cf. p. 30).

The 2024 jury consisted of Dr Lutz Aschke (Photonics Systems Group, Kraling, D), Dr Pavel Bakule (ELI Beamlines Facility, Dolní Břežany, CZE), Dr Guido Bonati (Fisba, St Gallen, CH), Dr Stefan Hengesbach (Quix Quantum, Enschede, NL), Dr Willem Hoving (Photonics Consultancy, Geldrop, NL), Dr Alexander Knitsch (Trumpf, Ditzingen, D), Eric Mottay (H-Nu, Begles, F), Prof Juan Pou Saracho (U de Vigo, E), Dr José Antonio Ramos de Campos (Lasea, Seraing, B) and Pablo Romero (Aimen, O Porriño, E). Dr Markus Kogel-Hollacher (AKL) and Prof Dr Stefan Kaieler (ELI) were responsible for the organization.

www.akl-ev.de



Helios Plus

BeamWatch Integrated



Integrated Laser Beam Measurement in Automated Manufacturing

Ophir laser measurement systems for industrial applications offer a robust housing and ProfiNET, Ethernet-IP and RS-232 interfaces.

Helios Plus – Compact Power Measurement

- Measures up to 12 kW
- Simple integration
- No water cooling
- Spectral range 450-550 nm & 900-1100 nm

BeamWatch Integrated – Entire Beam Diagnostics

- Non-contact focus shift and spot size
- Focus parameters in real time
- Full measurement in less than 1 second

www.ophiropt.com

Alain Schebath appointed CEO of OptoSigma Europe's new German subsidiary



Source: OptoSigma

Dr Alain Schebath

The global provider of photonics and optical components has formally incorporated its German branch OptoSigma Germany GmbH, based in Munich, and has

appointed Dr Alain Schebath as its new CEO.

Dr Schebath has served as the general manager of OptoSigma Europe since 2021. Regarding this development he remarked, "The establishment of OptoSigma Germany GmbH reinforces our dedication to delivering exceptional support and services to our esteemed customers in Central Europe. This strategic initiative aligns with our commitment to facilitating closer relation-

ships with our customers and ensuring timely access to our extensive portfolio of photonics and optical components."

This milestone represents a significant advancement in OptoSigma's mission to provide exceptional support and services to customers across Central Europe. OptoSigma Germany will operate as a crucial hub to meet the needs of customers in Germany, Austria, Switzerland, Czech Republic, Poland,

Hungary, and Slovakia. With a local presence in Munich, OptoSigma aims to streamline operations, enhance accessibility, and provide tailored solutions to its expanding customer base in these regions.

Guy Ear, CEO of OptoSigma Europe and chairman of OptoSigma USA, welcomed the appointment of the new CEO and the establishment of OptoSigma Germany.

www.optosigma.com

New managing director at Instrument Systems



Source: Instrument Systems

Dr Markus Ehbrecht (l), Dr Yuta Yamanoi

Yuta Yamanoi has assumed the position at the light measurement technology manufacturer in Munich as Yasumasa Kuboyama moved back to Japan to take over a new department in the Konica Minolta Sensing business unit. Since April 2, 2024,

Dr Yamanoi forms the new Instrument Systems management team together with CEO Dr Markus Ehbrecht.

Dr Yamanoi is a scientist with a PhD in earth and space sciences. After eight years in the development department at Konica Minolta Sensing in Japan, in 2016 he transferred to Konica Minolta Sensing Americas Inc. Most recently, he was senior manager for strategic planning in light and display, and the color and appearance division of Konica Minolta sensing business unit in Japan.

www.instrumentsystems.com

HGH appoints EVP, general manager for the US

Johanne Lecomte joins the provider of advanced infrared solutions for defense, security, and industrial applications with over two decades of experience as a sales and business development executive. The former employee of Airbus and Thales Alenia Space has a track record in the space and defense industries, and expertise in technical sales to prestigious government agencies. Coupled with her familiarity in transatlantic work, that makes her a valuable addition to the HGH team. Effective February 2024 she took over as the new executive vice presi-



Source: HGH

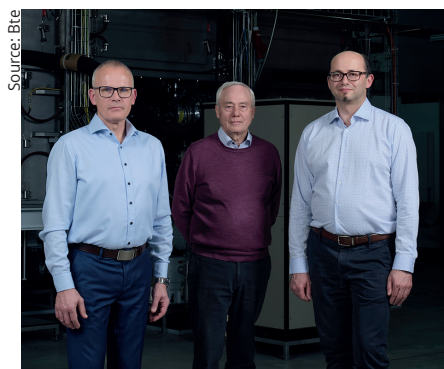
Johanne Lecomte

dent and general manager for HGH USA.

Holding a bachelor's and master's degree in electrical engineering, along with an MBA, she brings a blend of technical knowledge and strategic awareness.

<https://hgh-infrared.com>

Management change at Bte



Source: Bte

Reinhard Born (center) with Damian Janczyk (right) and Ansgar Link

Bte Bedampfungstechnik and Born Coating, Bte for short, is a medium-sized company

based in Elsoff/Westerwald and a renowned optical coating company. More than thirty years after its founding, the former managing director and owner Reinhard Born retired from the management on 1 April 2024. Bte was founded in 1992 at a time when vacuum coating technology was much less established than it is today. However, the demand for optically coated components was steadily increasing, so the company grew rapidly. Born Coating was founded in 2003 with a focus on coat-

ings specifically for the automotive industry.

The number of coating systems has constantly increased to 28 today, with Reinhard Born always focusing on new technologies. The vacuum coating systems range from thermal evaporation and ion-assisted electron beam evaporation to magnetron sputtering. The layer design for customer products has also been and continues to be developed in-house.

Today, almost a hundred employees coat optical com-

ponents for customers in high-tech industries such as automotive, sensor and medical technology.

From 1 April 2024, two long-standing employees will share the management of Bte Bedampfungstechnik and Born Coating: former production manager Ansgar Link and Damian Janczyk, head of electrical engineering. Ansgar Link has been with the company for 28 years, while Damian Janczyk can look back on 20 years at Bte.

www.bte-born.com

Newport Replicated Freeform Mirrors unveiled at Optatec

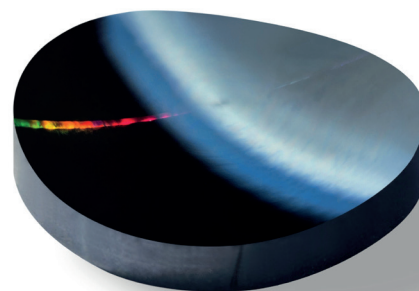
Non-rotationally symmetric reflectors for use in advanced optical systems as a premiere in Europe

MKS Instruments presented the new components at the optics fair in Frankfurt, Germany, in May. The new mirrors remove the optical design constraint of rotational symmetry, enabling optical designers to further increase the efficiency and precision of many types of optical systems, offering improved aberration correction, higher image quality, increased optical throughput, and the promise of a reduced footprint. The new Newport Replicated Freeform Mirrors can be used in many different applications, such as analytical instruments, imaging systems, laser tracking and communications. MKS is recognized for its unique manufacturing and replication processes for custom high precision replicated mirrors.

They utilize optical replication technology, which centers around the use of a precision master to create nearly identical copies. High quality optical replication is an ideal manufacturing process for freeform mirrors as all the engineering and metrology are focused on the master. Once a high-quality

master has been designed, fabricated, and qualified, the optical replication manufacturing process creates nearly exact copies of the highly engineered freeform master. Newport Replicated Freeform Mirrors have a spectral range of 200 nm to 15 μm and the reflective surfaces can be bare aluminum, bare gold, or protected aluminum, enabling a wide application space. The mirrors are enhanced by advanced proprietary metrology tools and techniques to validate the freeform mirror surface figure and ensure part to part accuracy.

“Replicated freeform mirrors give optical designers another important degree of freedom for advanced optical system design, delivering optics without boundaries,” said Marc Tricard, vice president of optical systems business, MKS Instruments. “Newport Freeform Mirrors have been used internally to enable several successful systems designs. MKS’ business model for freeform mirrors is built around decades of providing custom optical components to meet the needs of our



Newport Replicated Freeform Mirrors: precision non-rotationally symmetric reflective optical surfaces for optical systems (Source: MKS Instruments)

customers. They are an excellent addition to our world-class optics initiative.”

MKS works with its customers at the application and system level to custom design a freeform mirror that meets or exceeds the system requirements. The company can supply a replicated freeform mirror at the component level or utilize the freeform mirror technology to deliver as part of an integrated optical sub-assembly.

www.newport.com

Leica Microsystems has revealed a new STED microscopy approach

Extended live cell imaging at nanoscale resolution and with light dose balance

By combining spatial and lifetime information, the new TauSTED Xtend resolves details of live or intact specimens at nanoscale resolution. At the same time, the access to that extra level of information allows working at extremely low light dose. This gives scientists more time to perform studies of biological processes with cutting-edge resolution capabilities.

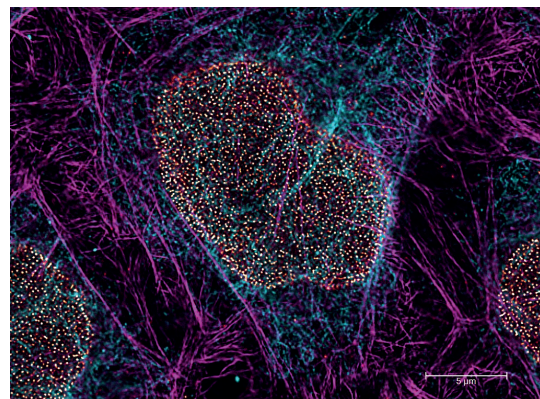
“TauSTED Xtend ensures that live cell experiments can be carried out over a longer time span thanks to the balance of light exposure and resolution, which leads to gentler imaging at stunning nanoscale depths,” said James O’Brien, vice president of life sciences and applied solutions at Leica Microsystems.

The new technique works on-the-fly, allowing researchers to directly monitor fast biological processes at nanoscale

resolution. They can therefore make the most of their experimental window by seeing what happens as it happens.

“TauSTED Xtend offers new opportunities for single and multicolor experiments with green fluorescent proteins and fluorophores that are a workhorse in life science research and currently underused in nanoscopy studies,” said Ulf Schwarz, application manager confocal microscopy at Leica Microsystems. “Scientists can now effectively scale their experiment down to the nanoscale using familiar protocols and a wide range of fluorescent labels and markers commonly used in biological research.”

The approach is the next step in the evolution of stimulated emission depletion (STED) imaging, offering extended live-cell-imaging times at the cutting edge of nanoscale resolution. In



STED for Cell Biology: Multicolor fixed-sample, image acquired using TauSTED Xtend 775

combination with the Leica Stellaris 8 Falcon FLIM microscope, it is now possible to perform multifluorophore STED imaging with lifetime-based species separation.

www.leica-microsystems.com

Source: Brigitte Bergner et al., U Munich

Current control with ultrafast light pulses

New approach uses optoelectronic metasurfaces to induce local directional charge flows

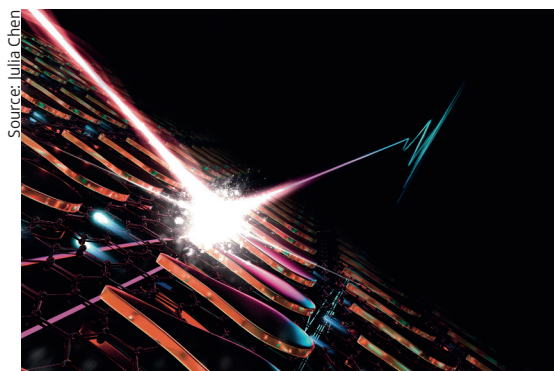


Illustration of vectorial optoelectronic metasurfaces in which ultrafast pulses induce local directional charge flows around symmetry-broken plasmonic nanostructures

The company Menlo Systems has a collaboration with Los Alamos National Laboratories (LANL) for their ongoing research into the control of ultrafast dynamics in solid-state systems.

The group of Hou-Tong Chen, located at LANL in New Mexico, has developed a new way to control and shape charge currents on the nanoscale. The team developed sub-wavelength scale gold resonator nanoantennas that were excited by pulsed near-infrared light to enable control of the direction, amplitude, and location of nanoscale charge currents in a monoatomic layer of graphene.

The process harnesses symmetry breaking of the structures, as well as the photothermoelectric dynamics of graphene to provide easier control over vectorial currents, with response times of less than a picosecond. Menlo Systems' development team contributed by developing a terahertz imaging method to extract hyperspectral imaging data from the vector fields,

using our industry-proven TeraSmart terahertz spectrometer together with the new ELMO 780 XHP femtosecond fiber laser and state-of-the-art TERA15-RX-FC terahertz antennas.

This technique is not limited by material properties or dynamics, as is the case for conventional electronic circuits, bringing enormous potential in emerging science and technology. These new capabilities could radically improve applications such as nanomagnetism, ultrahigh-speed wireless communications, materials characterization, as well as for the generation of terahertz radiation.

Reference: J. Pettine et al.: Light-driven nanoscale vectorial currents, *Nature* 626, 984 (2024); DOI: 10.1038/s41586-024-07037-4

www.menlosystems.com

Gas detector to prevent millions of air pollution deaths

New air quality monitoring project uses cutting-edge laser technology

A new gas-sensing network that analyzes multiple gasses in real time in towns and cities is being developed to prevent deaths caused by ambient air pollution. This new air quality monitoring system uses cutting-edge laser technology to detect even the smallest amount of toxic gasses in large, densely populated regions.

With multiple sensors connected to form a gas analysing network, the units can spot trace amounts of numerous gasses – including nitrogen dioxide, sulphur dioxide, carbon monoxide, ozone, and particulate matter – in real time in dynamic environments like schools, towns, and cities.

Currently, methods for assessing air quality in urban environments rely on huge units the size of refrigerators, which can cost up to € 100 K. Low-cost sensors rely on chemical reactions, which are inaccurate and can give false readings.

However, the 6.9 million euro EU-funded project called Passepartout aims to provide a compact detector with a complete understanding of the types and concentrations of toxic gases at a much more reasonable price. Project coordinator Dr William Whelan-Curtin said: "The miniature Passepartout hyperspec-

tral optical-based sensors will provide a comprehensive approach to understanding urban air quality. To have a widespread network and to take meaningful steps towards a smart city, current, expensive methods are not feasible."

The system works by using the photo-thermal and photo-acoustic

“We would like to make the technology as common as video surveillance by installing a detector on every lamppost.”

Dr William Whelan-Curtin

effects. The laser creates pulses or small blasts of laser light. When the laser light hits a toxic gas, the molecule absorbs light energy, giving off a heat 'signature' that is then reported back to the system. The system then unmistakably identifies what the harmful gas is, as well as how much of it is present. The Passepartout system goes a step further by using quartz tuning fork technology or quartz-enhanced photo-acoustic spectroscopy, QEPAS.

QEPAS is particularly useful for the detection and quantification of trace gases in challenging environments. A quartz tuning fork with a sharp mechanical resonance is used to detect the signals generated by the gas sample while suppressing the background noise. This tuning fork detects

the acoustic waves generated by the gas as it heats and cools. The signal is then analyzed to determine the concentration of the target gas. The exact wavelengths of the laser, or lasers, can be tuned to match



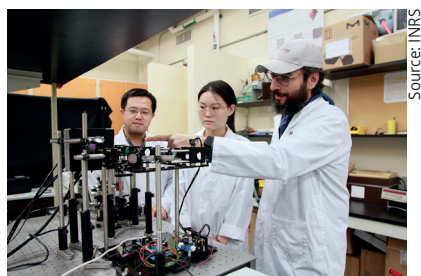
Source: MTU

the characteristic absorption spectrum of the target gas, meaning the system categorically detects specific gases, like carbon monoxide or sulphur dioxide.

"We are working to provide a system with high precision and excellent spatial resolution to detect NO_x, SO₂, NH₃, CH₄, CO, CO₂, and black carbon," Whelan-Curtin said. The Passepartout project includes twenty partners and is coordinated by Munster Technological University. (Source: Photonics21)

A faster, more efficient imaging system for nanoparticles

New technique pushes back some of the limits of the infrared imaging of rare-earth doped nanoparticles



Jinyang Liang, Miao Liu, and Fiorenzo Vetrone from INRS in front of the SWIR-PLIMASC device

Teams led by Jinyang Liang and Fiorenzo Vetrone from the Énergie Matériaux Télécommunications Research Centre at the Institut National de la Recherche Scientifique (INRS) have developed a new system for imaging nanoparticles. It consists of a high-precision, short-wave infrared imaging technique capable of capturing the photoluminescence lifetimes of rare-earth doped nanoparticles in the micro to millisecond range. This discovery paves the way for promising applications, particularly in the biomedical and information security fields.

Liang and Vetrone's teams have combined streak optics with a high-sensitivity camera. The result is called SWIR-PLIMASC – short-wave infrared photoluminescence lifetime imaging microscopy using an all-optical streak camera. It vastly improves mapping of the optical properties of SWIR photoluminescence lifetimes. It is the first high-sensitivity, high-speed SWIR imaging system in the optics field. It responds to a wide spectral range, from 900 to 1,700 nm, allowing photoluminescence to be detected at different wavelengths and/or spectral bands.

In fundamental science, these unprecedented results will allow scientists to synthesize rare-earth nanoparticles with even more interesting optical properties.

Reference: M. Liu et al.: Short-wave Infrared Photoluminescence Lifetime Mapping of Rare-Earth Doped Nanoparticles Using All-Optical Streak Imaging, *Adv. Science* 11(11), March 2024; DOI: 10.1002/advs.202305284

<https://inrs.ca>

Organic electronics lead to new ways to sense light

A new soft, flexible, and wireless optical sensor based on carbon nanotubes and organic transistors

Researchers from Sanken – the Institute of Scientific and Industrial Research at Osaka University – have developed an optical sensor on an ultrathin, flexible sheet that can be bent without breaking. It is so flexible that it even works after it has been crumpled into a ball.

Instead of traditional light sensors, the researchers use an array of tiny carbon nanotube photodetectors printed on an ultrathin polymer substrate (less than 5 µm). When exposed to light, the carbon nanotubes heat up, creating a thermal gradient that then generates a voltage signal. Doping the nanotubes with chemical carriers during printing further increases their sensitivity. Using these nanotubes, visible light as well as

infrared light such as that related to heat or molecules can be measured.

Along with the carbon nanotube sensors, organic transistors are also printed on the polymer substrate to organize the voltage signals into an image signal, transferred via Bluetooth.

The optical sensor is highly sensitive over a wide range of wavelengths, withstands frequent bending, and even worked after it had been crumpled.

Reference: R. Kawabata et al.: Ultraflexible Wireless Imager Integrated with Organic Circuits for Broadband Infrared Thermal Analysis, *Adv. Mater.* 36(15), April 2024; DOI: 10.1002/adma.202309864

www.osaka-u.ac.jp

ALSO OF INTEREST

A new approach to design efficient light-emitting materials

University of St Andrews researchers found a way to develop bright, efficient, and colorful OLEDs.

Tunable colored films for displays and sensors

New method allows the simultaneous fabrication of multiple structural colors responsive to mechanical stimuli.

New high-speed microscale 3D printing technique

The new scalable high-resolution process is based on roll-to-roll continuous liquid interface production.

Reimagining the optical diode effect

New material shows a large nonreciprocal absorption of light depending on the direction of light propagation.

Integrated light as a key to future computers

Brunswick and Jena cooperate on optoelectronic components in the federally-funded OptoGaN project.

Printing stronger materials five times faster

A new process using light at two wavelengths creates stronger nonmetallic materials five times faster than traditional additive manufacturing.

Protecting light beams from gain and loss

Demonstration of robust light propagation in open systems for the first time.

Full-sized tandem PV module with 25 percent efficiency

A research team from the Fraunhofer ISE has produced a PV module using perovskite silicon tandem solar cells from Oxford PV.

Improving image correction in light microscopy

New web tool provides a corrective factor to determine the depth of an image.

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Innovations and networking at SPIE Photonics West 2024

Visitor and exhibitor numbers exceeded the previous year



Photronics Germany booth at the German Pavilion



German Evening at the Leica Store

The SPIE Photonics West trade fair in San Francisco from January 30 to February 1 brought together more than 1,500 exhibitors and over 24,000 trade visitors from 70 countries. In addition to impressive innovations and insights into research and new technology, the international photonics community benefited from numerous networking opportunities.

The Quantum West trade fair celebrated its premiere this year with developers of hardware and quantum-based technology for a wide range of applications. "SPIE Photonics West is one of the highlights for the international photonics industry. The German Pavilion and the trade fair were fully booked and the accompanying program with over 5,000 technical presentations was inspiring. We were particularly pleased about the great atmosphere and the added value for our members and exhibitors," emphasizes Dr Andreas Ehrhardt, board member of OptecNet Deutschland.

Photronics Germany, the alliance of Spectaris and OptecNet Deutschland, once again represented more than 700 member companies and research institutions with its own information booth at the German Pavilion. This is funded by the Federal Ministry for Economic Affairs and Climate Protection (BMWK) and supported by AUMA – the Association of the German Trade Fair Industry. The inclusion in the national trade fair program was initiated by Spectaris and supported by OptecNet Deutschland.

Seventy-one companies and research institutions were part of the German Pavilion and presented their innovative optical components and system solutions. Initiated by Spectaris in collaboration with the BMWK, the German Pavilion was expanded for the first time with an information module to address and attract international professionals. The International Placement Service (ZAV) of the Federal Employment

Agency provided information about Germany as a place to work and live.

The networking highlight was once again the German Evening at the Leica Store, organized by Photonics Germany on January 31 with more than 140 participants. After a welcome by Dr Andreas Ehrhardt and Dr Wenko Süptitz, Consul General Oliver Schramm emphasized the innovative power of the photonics industry. Dr Dorothea Schütz (BMWK) provided information about Germany as an attractive place to work and live. For many years, the German Evening has been one of the most popular networking events for actors in the photonics industry.

The next SPIE Photonics West will take place from 28 – 30 January 2025. Photonics Germany is committed to ensuring that there will be a German Pavilion and a German Evening again next year.

www.photonics-germany.de ■
www.spectaris.de ■ www.optecnet.de

The optics and photonics community meets in Naples in September at EOSAM

EOSAM, the EOS Annual Meeting, takes place for the 12th time in 2024. This year the major international scientific conference and exhibition is organized in Naples from 9 – 13 September, in close collaboration with the Italian Society for Optics and Photonics, SIOF, the Italian branch of EOS. It covers all

aspects of optics and photonics within several topical meetings and sessions (cf. p. 59). It is attended annually by over 500 top researchers, key leaders, students, and industry experts from over 30 different countries all over the world. EOSAM is a great platform for presenting the most recent research

EOSAM 9-13 September 2024
European Optical Society Annual Meeting
Naples, Italy

results, connecting and catching up, as well as bridging the gap between research, education, and industry.

Join the event with early bird fees before 30 June 2024.

www.europeanoptics.org



A playground for new cluster services

Photonics4Industry project: networking, employee skills and recruitment, and digital services

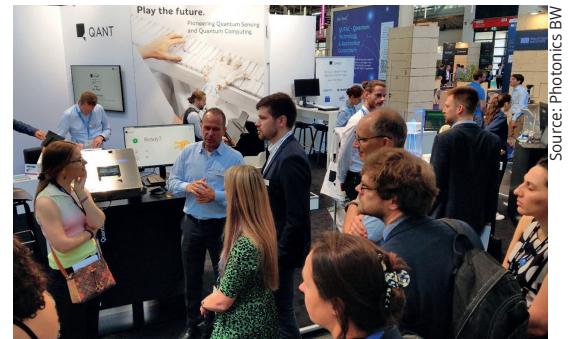
The clusters Photonics Austria, Photonics Bretagne, Photonics BW, Photonics Finland, and Toolas (Lithuania), designed and implemented a range of new services to their members within the Photonics4Industry project.

Most prominent and aided by travel grants through the ClusterXChange scheme were the joint delegation trips. In 2023, three different types of events were organized: participants from all the consortia clusters were invited to Photonics Austria's event held in conjunction with the International Day of Light, Photonics Finland's Optics and Photonics Days, and Photonics BW's

program in connection with the Laser World of Photonics trade show.

To address the SMEs need for a skilled workforce, an international job board was set up at the project's digital platform: photonics4industry.eu/jobs. Photonics Bretagne created the PhD Days, and Photonics BW organized the Advanced Optical Design Seminar.

Regarding digital services, Photonics BW established a dedicated search engine that is also the access point to an automated matchmaking tool, allowing members to specifically search for potential partners in Austria, Baden-Württemberg, Brittany, Finland



Source: Photonics BW

Joint delegation trips connect European companies and researchers and enable networking between different clusters

and Lithuania – access the service under photonics4industry.eu/p4i-matchmaking-tool

Comprehensive roadmap to drive the integrated photonics industry forward



PhotonDelta and MIT Microphotonics Center's initiative involves contributions from more than 400 organizations including Airbus, Meta, NASA, Dupont, General Motors, ESA, and Vodafone Ziggo

More than 400 technology, academic and industrial organizations from around the world have contributed to a new integrated photonics roadmap, Integrated Photonics System Roadmap – International (IPSR-I), led by foundation PhotonDelta and the Microphotonics Center at the Massachusetts Institute of Technology (MIT).

IPSR-I provides a technology roadmap and a clear way forward for building a global, aligned integrated pho-

tonics industry with the ability to help solve major societal challenges. This is underpinned by a call to establish and sustain a trust-based global network of industrial and R&D partners, who work together to create photonic-integrated circuits (PICs) technology and systems requirements. By aligning the entire supply chain from research to end users, the integrated photonics industry will be able to drive volume manufacturing of PICs.

The integration of photonics with electronics is the key enabler for the creation of smaller, faster and more energy-efficient devices. It has the potential to create a large number of new applications and advancements in many areas, including autonomous vehicles, data telecom and healthcare.

IPSR-I was officially launched during the Executive Forum at OFC in San Diego on March 25th, 2024.

www.photondelta.com/ipsr-2024

'MasterPlus' program to see the light in September

Launched by Optics Netherlands and PhotonDelta in partnership with TUs Delft, Eindhoven, and Twente

The new MasterPlus program in optics and photonics (MPOP) will be a talent pipeline for the optics and photonics industry, which makes a significant contribution to the Dutch economy, and has a strong annual growth rate. By integrating academic expertise with industry needs, the program promises to produce highly skilled professionals poised to drive innovation and growth in the field.

The three technical universities in the Netherlands are set to offer a new

specialization in optics and photonics within existing master's programs in applied physics and electrical engineering. MPOP goes live in September 2024.

Each university will deliver its own specialist courses in optics and photonics, as well as facilitating inter-university activities and training, giving students the flexibility to attend courses across different university campuses or unique internships with leading companies and innovative startups.

www.mpop-programme.com



Source: TU Delft

Lecture for applied physics students at Delft University of Technology with Aurèle Adam, program director of the master applied physics

EPIC welcomes new member to its board of directors

Björn Dymke succeeds his colleague, Trumpf CTO Berthold Schmidt



The 2024 board (l-r) Samuel Bucourt, Björn Dymke, Nicoletta Casanova, Shahida Imani, Christian Bosshard, and Basil Garabet, with EPIC's leadership team, Ulrike Helfferich and Carlos Lee

During the Annual General Meeting 2024, the European Photonics Industry Consortium announced that Björn Dymke, managing director of Trumpf Laser, has joined its board of directors. With extensive experience in photonics technology and a deep understanding of

the industry, Dymke will bring valuable insight and perspective to EPIC's mission of promoting and advancing the photonics industry in Europe.

Björn Dymke studied business administration with a focus on finance, and received his doctorate degree at the University of Tübingen, Germany. He joined Trumpf in 2008 and has held numerous executive positions. From 2016 on, he served as CFO for Trumpf in the US, before taking over responsibility for the central finance functions at the headquarters in Ditzingen in 2020. Since 2023, he held responsibility for Trumpf's solid-state laser business and became managing director of Trumpf Laser in Schramberg.

"I am honored to join the board of directors of EPIC and to have the opportunity to work with such a dis-

tinguished group of leaders in the photonics industry," said Björn. "I look forward to contributing my knowledge and experience to help EPIC promote the growth and success of the European photonics industry."

EPIC is owned by its members and managed by the board of directors. Beside the new member Björn Dymke, it further consists of: Basil Garabet, president and CEO, NKT Photonics (Denmark) – president of EPIC, Adam Piotrowski, CEO, Vigo Photonics (Poland), Samuel Bucourt, CEO, Imagine Optic (France), Christian Bosshard, managing director, Swissphotonics (Switzerland), Nicoletta Casanova, CEO and president, Femtoprint (Switzerland), and Shahida Imani, CEO, Singular Photonics (UK).

<https://epic-photonics.com>

EPIC awards for Viacheslav Artyushenko and Axel Kupisiewicz

Consortium honors leadership in the manufacturing of industrial laser machines, special optical fibers



EPIC 2024 CEO Award for Axel Kupisiewicz, Lasea



EPIC president Basil Garabet (r) delivers the EPIC Lifetime Achievement Award to Viacheslav "Slava" Artyushenko, CEO of Art Photonics

founder and CEO of Lasea, during its annual general meeting. The award recognizes his outstanding leadership and contributions to the photonics industry.

Kupisiewicz holds a master's degree in applied sciences from Université Liège, Belgium, and a master's degree in economics and management from HEC, Belgium. After a brief stint in the space sector, he founded Lasea in 1999 at the age of only 25. Pioneering femtosecond lasers since 2003, Lasea specializes in manufacturing micromachining systems that enable precision cutting, marking, engraving, and drilling. Its main sectors include medical, watchmaking and electronics, with prestigious clients worldwide, including two GAMAMs.

Within two decades, Lasea expanded globally, establishing subsidiaries in France, the US, and Switzerland, securing its position as a leader in ultra-short-pulse laser micromachining. With an annual growth rate of thirty percent for twelve years, it boasts over 120 patents, employs 190 people, has 3,000 machines installed across five continents, and enjoys a consolidated income exceeding 41 million euros.

Viacheslav "Slava" Artyushenko is the recipient of the 2024 EPIC Lifetime Achievement Award for his outstanding contributions and leadership in the optical fibers industry. The CEO of Art Photonics has led the company to become a major player in the global market for special optical fiber products and spectroscopy fiber probes.

Born in 1954, Artyushenko graduated from Moscow Physical-Technical Institute and got his PhD in solid-state physics in 1981. In 1998 he founded Art Photonics in Berlin, Germany, to use his polycrystalline infrared fiber technology to develop fiber probes for spectroscopy, medical diagnosis, and control of industrial processes as well as high-power laser cables for medical, industrial and scientific lasers. The company has become one of the worldwide leading manufacturers of fiber cables, bundles, and spectroscopy probes for industrial, medical, and scientific applications, offering a very broad spectral range from 0.3 to 16 μm . In December 2023, Art Photonics was acquired by the Nynomic group.

www.epic-photonics.com

The European Photonics Industry Consortium (EPIC) has presented its CEO Award 2024 to Axel Kupisiewicz,

Photonics on the beach

EPIC brings together international stakeholders on the French Riviera



Group picture of the participants in the EPIC AGM Run

The EPIC Annual General Meeting & Summit gathered more than 350 attendees in Juan Les Pins, France. The agenda of the three-day conference was oriented toward CEOs, covering strategic topics such as entrepreneurship, innovation management, and new markets. Other sessions were tailored for CTOs to discuss the challenges and opportunities in photonics technology. The small village on the Côte d'Azur provided an exceptionally good setting for networking activities such as the EPIC Run or an early morning swim.

During the event, we welcomed Björn Dymke, managing director of Trumpf Laser, to the board of directors. Dymke will bring a valuable

financial perspective that is particularly crucial for the growth of the photonics sector.

The recipient of the EPIC CEO Award 2024 was Axel Kupisiewicz, founder and CEO of Lasea. "This award is a recognition of the hard work and dedication of the entire team at Lasea. It also confirms that choosing femtosecond laser technology for micromachining was a wise decision," said Kupisiewicz.

The EPIC Lifetime Achievement Award 2024 recognized the trajectory of Viacheslav (Slava) Artyushenko, CEO of Art Photonics, whose company was acquired by the Nynomic group in December 2023.

<https://epic-photonics.com>



Source both images: EPIC

Basil Garabet, president of EPIC, presents the EPIC CEO Award 2024 to Axel Kupisiewicz, founder and CEO of Lasea



Scan to see the photo album with all the pictures

Save the date for EPIC upcoming events:

- 3 June 2024
EPIC Online Technology Meeting on Photonics for Vision and Eye Research
Online Event
- 4 – 5 June 2024
EPIC Technology Meeting on Photonic Integration and Packaging at Fraunhofer IZM, Berlin, Germany
- 7 June 2024
EPIC HR Workgroup Meeting
Online Event
- 12 June 2024
EPIC Marketing Meeting on Social Media II – Special focus on B2B companies
Online Event
- 12 – 13 June 2024
EPIC Technology Meeting on Specialty Optical Fibers: New Designs and Novel Applications at Photonics Bretagne, Lannion, France
- 14 June 2024
EPIC Sustainability Workgroup Meeting
Online Event
- 1 July 2024
EPIC Online Technology Meeting on Photonics for Sea Exploration and Oceanography
Online Event
- 2 – 6 September 2024
EPIC Members Delegation to Taiwan, Taipei, Taiwan
- 16 September 2024
EPIC Online Technology Meeting on Photonics Hybrid Photonics Integrated Circuits
Online Event
- 17 September 2024
EPIC Technology Meeting on Photonics for NewSpace – Optical Communication during ESA Industry Days
Noordwijk, The Netherlands
- 18 – 19 September 2024
EPIC Technology Meeting on Photonics for Miniaturized Optics: From Components to Use-Cases at Sony DADC, Salzburg, Austria
- 25 – 26 September 2024
EPIC Technology Meeting on Laser Micromachining: New Developments and Applications at Light Conversion
Vilnius, Lithuania

For the list of all events, visit:



<https://epic-photonics.com/epic-events>

"In tune with lasers"

Milan Mashanovitch, president of Freedom Photonics, talks to Ivan Nikitski, technology manager at EPIC

Freedom Photonics is a subsidiary of Luminar Semiconductor, a US manufacturer of semiconductor lasers, photodetectors and high-functionality PIC-based products. EPIC's technology manager for quantum technology and PICs Ivan Nikitski interviewed the company's president, Dr Milan Mashanovitch.



Source all images: Freedom Photonics

▲ Milan L. Mashanovitch, PhD

What is the background to you co-founding and becoming president of Freedom Photonics?

In 1998, I began a PhD in electrical engineering at UC Santa Barbara. My research was on the design, modeling, fabrication, and characterization of photonic integrated circuits with a focus on a monolithic tunable wavelength converter for all optical networks and label swapping. UC Santa Barbara was, and still is, a very entrepreneurial university and many startups were created in the late 1990s as part of the Internet bubble. But by the time I was ready to graduate in 2003, the dot-com market had crashed, there were very few opportunities in photonics, and many people were changing fields.

Wanting to stay in Santa Barbara and continue working in photonics, the only realistic option for me was to use the infrastructure and ecosystem that exists in the United States for small companies, and to set up my own company. Encouraged by my professor, I got together with a couple of partners, and we founded Freedom Photonics in 2005 with me as director of business development.

How has the company developed?

The work I had done in my PhD formed the core of our early product portfolio:

from then on, we continued to commercialize advanced semiconductor photonic component technology, and we were the first company in the US to acquire a photonic wire bonding capability.

In 2010, I became general manager, and in 2017, CEO – until 2022 when the company was acquired by Luminar, and we became part of Luminar Semiconductor. That is when I became the president of Freedom Photonics, a wholly owned subsidiary.

In the last 17 years, our workforce has grown to more than sixty people, and we now have a range of products based mainly around indium phosphide and gallium arsenide compound semiconductor platforms, including single frequency lasers, tunable lasers, semiconductor optical amplifiers and high-speed modulators.

What have been your main challenges?

On a personal level, coming from a research background, I was not prepared for the challenges of management. I had to learn about program management, how to work with people, how to take care of people, and how to motivate people – basic psychology. As regards the company, the main challenge in the beginning was acquiring finance for equipment and personnel,

which we managed to obtain in the form of government non-recurring engineering funding. Our business and revenue continued to grow and, in hindsight, it all worked out fine, but it needed to work out right. Fortunately, we have never shrunk throughout the history of the company, mainly due to the strength of the team and the people we have.

Another challenge has been recruitment due to the relatively limited job market pool here in Santa Barbara and the problems of convincing people to join a smaller company with a different set of incentives compared to a larger company. This is where our great culture helped – good people bringing more good people. There is also the challenge of convincing people to move to here because although Santa Barbara is a really nice place to live, it is very expensive and more provincial than, say, the Bay Area.

Having said that, with the power of Luminar now behind us, things have improved as we now have access to their recruitment resources, and additional sites in Orlando, Boston, Princeton, and Colorado Springs.

What are your best selling products?

Besides our lasers for automotive lidar, it is our tunable lasers, ranging from



1,530 nm up to 1,750 nm. We have a product called InstaTune, a fast, random-access tunable laser for test and measurement, fiber sensing and gas sensing applications.

What are the technologies?

We have high-power, high-efficiency single mode semiconductor lasers, as well as fast tunable semiconductor lasers at a variety of wavelengths from C band and all the way to 1,800 nm. We also have our aura-tapered amplifiers, which have high efficiency, high output power, and very high output beam quality for applications needing high power in a form factor smaller than erbium-doped fiber amplifiers.

On the photodetector side, we have high-power photo detectors for RF over fiber type applications where you can get and detect high photocurrents with a linear response up to very high frequencies ranging from 22 to 100 GHz.

What are your main markets?

Optical sensing and lidar have always been good markets for us. Being a small, resource-limited photonics company, it has been hard, if not impossible, to compete head-to-head with the big players in well-established markets. So from the onset we started looking for various developing niche markets and a lot of our work came from private label development and products for sensing, aerospace and optical communications, where we operate to this day. We are also still very active in the R&D space, with the US government being a key customer, both with contract R&D and delivering hardware to NASA and the Department of Defense. Acquisition by Luminar has enabled us to become a

supplier into the automotive lidar market, and to use that scale and investment to better address other markets and products.

How do you see the future?

We will continue integrating our business into Luminar Semiconductor, which has some very aggressive business plans for scaling up and targets for growth. Right now, we have about 160 people across all our sites and we are looking at all sorts of different ways of growing. Lidar and other types of optical sensing will remain key areas in terms of where the overall market is going. We are also aware that AI is eating up all the hardware resources and the bandwidth and creating a lot of energy. It is very inefficient, but there are a lot of opportunities, or rather necessities, to resolve the whole optical interconnect situation and make AI practical, efficient, and scalable.

Do you think AI will continue to grow or is it just a bubble?

It is definitely a bubble right now – but the technology is real, and here to stay. The main problem for AI is that on the software side, there is no real production code running on it because it is too slow and too expensive. At the moment, the estimate is that every query on Chat GPT costs around 0.35 cents just from processor utilization, and obviously that is not a scalable business. Current generations of processing chips of today are not yet fully optimized to be able to handle the computational needs of AI. So to make AI feasible, I think two things are necessary: first, we need to build the correct, power efficient computational hardware infrastructure; sec-

The fast, random-access tunable laser InstaTune is a compact, self-contained module capable of emitting any wavelength within the specified range in the 1,550 nm and 1,650 nm wavelength bands

ond, using photonics, we need to help solve the challenge of moving massive amounts of data chip-to-chip, and eventually within the chip, using the whole new area of co-packaged optics. This is a large new photonics market that is being formed.

If you started again, what would you do differently?

I would try not to worry so much and have more faith that things will work out – as they nearly always do. There are a million potential outcomes for every decision you make that never materialize. In fact, what usually happens is that the outcome is the one that you never even considered.

What is your advice for the next generation of entrepreneurs?

It is a fun journey and you will learn a lot, but it is important to find mentors, as I have been fortunate to do throughout my career. Be open to improving yourself and realize that you are not perfect and that you need to continue learning and growing. The outcome is never perfect, and you need to comfortably exist in this space of ambiguity.

Also, embrace the fact that you have created something real that is useful to your customers, and take satisfaction from knowing that what you have made is serving a useful purpose and helping the world in various ways.

Dr Ivan Nikitski, Technology Manager

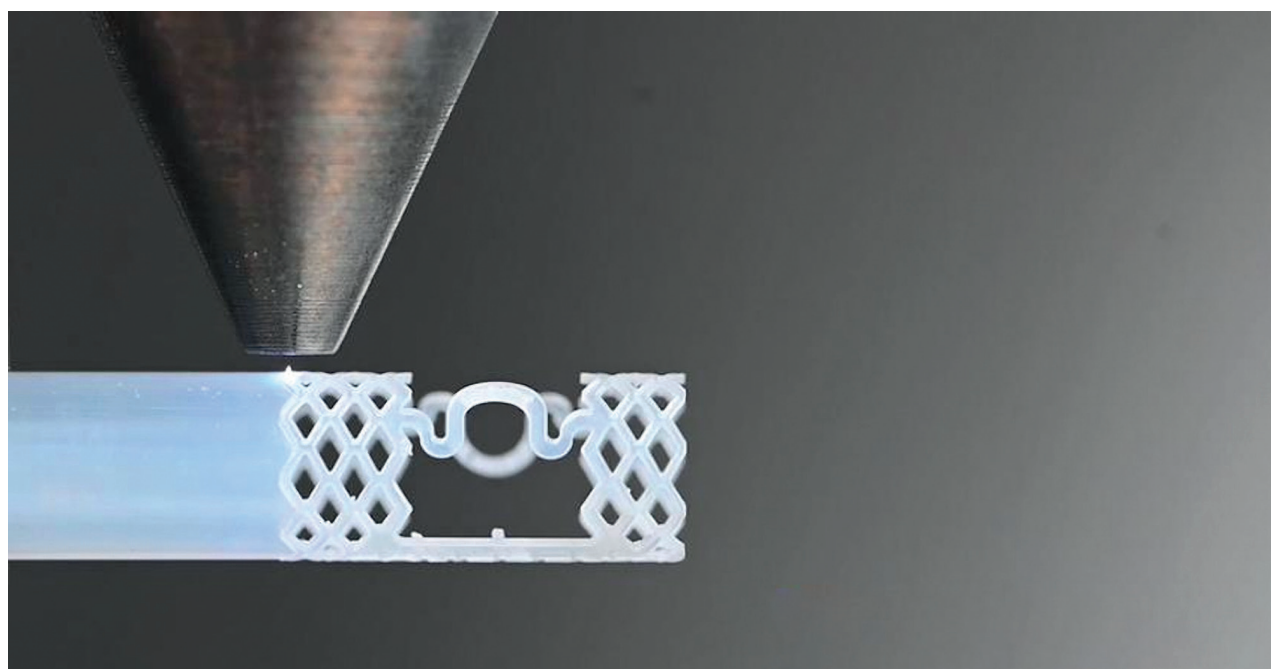
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Photonic technologies for implantable medical devices

New photonic technologies and novel applications in the manufacturing and post-processing treatment of medical implants

Antonio Castelo-Porta



Source: Coherent

Medical implants have benefited in the last years from established photonics manufacturing processes such as laser cutting and marking, but also from emerging ones such as additive manufacturing and surface structuring. The orthopedic sector has been using them for many years to improve the efficiency of the manufacturing processes and as a way to provide traceability and quality control for each part. Their use has been extended to a large number of new implants. We will review in this article some novel photonics technologies applied to the manufacturing and post-processing of medical implants.

Medical implants and other implantable devices must function properly in the human body and not cause any harm to the patient. Manual processes were initially used to ensure the quality of the products and to comply with the extremely high requirements of manufacturing a medical component, but photonics processes soon established themselves as a great alternative to meet the demands of mass production of some of these components. Both passive (such as stents, heart valve frames, bone nails ...) and active implants (such as pacemakers, defibrillators or neural

sensors) have benefited from the advantages offered by laser technology. Apart from the well-known characteristics of speed, efficiency and accuracy, there are some other specific advantages in the case of medical implants. The first one is the ability to perform precise and automated 3D tasks. This is very interesting, for example, for the development of complex structures like stents, but also for welding some of the electronic components in the active implants. In the last case, tight tolerances must be maintained and lasers can offer significant advantages in the production of

▲ Polymeric scaffold cutting with an ultrashort-pulsed laser

lossless electrical connections and stable weld seams, which will ensure the proper operation of the active implant. Another interesting property is the biocompatibility offered by laser processes, as they are an ideal tool to process biocompatible materials and to ensure the proper integration of the implant with the living tissues or organs.

Different photonics technologies have been applied to ensure the sterility



Source: Lumos Laser

Laser cutting of an IOL lens: (a) before; (b) during; and (c) after the laser process

of these components. On the one hand, it is possible to process the surface of the implant with lasers to create structures on which germs do not adhere; on the other hand, different coating techniques and materials have been explored to improve the integration of external components and to reduce or eliminate the presence of bacteria on the surface. These technologies have achieved great results in implant disease prevention.

Laser cutting of medical implants

Laser cutting is the preferred process for manufacturing some passive medical implants. Stents, valve scaffolds or the flex delivery tubes required for a range of surgical interventions (neurovascular, cardiac, renal, spinal, orthopedics ...) require precision dicing or ablation to produce these complex parts. There is a high demand for geometrical repeatability, rapid throughput and minimum post-processing. Given the different types of materials used (both metallic and plastics), different approaches have been proposed by the manufacturers to cover the demand of the market: continuous-wave (cw), modulated cw, ultrashort pulses etc. On the one hand, cw or modulated cw is a great option for fast processing of some of the metals widely used in medical implants, and they are much simpler lasers. On the other hand, one of the main advantages of laser cutting with ultrashort pulses is that there is virtually no heat input, which avoids the heat-affected zone (HAZ) area in metals and the melting of heat-sensitive polymers. As the interaction time is much shorter than the thermal diffusion time, these lasers offer cold ablation cutting instead of thermal cutting.

Coherent has been working on the two options mentioned above. Firstly, the company has developed a fiber laser fusion cutting system with modulated cw lasers. This is a standard solution for components made of metals such as stainless steel and cobalt-chrome as it typically provides higher processing speeds. Secondly, they have developed an ultrashort-pulsed laser cutting system using fs lasers, the best solution in the case of bioresorbable polymers and magnesium. It is also the preferred option in the case of implants made of nitinol because, as we already mentioned, the heat-affected zones are reduced, it offers smaller strut widths, and it reduces post-processing efforts. In order to take advantage of both technologies, Coherent has developed their StarCutTube hybrid tube cutting system. This machine includes a 1,035 nm, 60 W, 350 fs laser and a 1,070 nm, 100 or 200 W modulated cw fiber laser, with options for both wet and dry cutting as well as auto tube loading for unattended overnight operations.

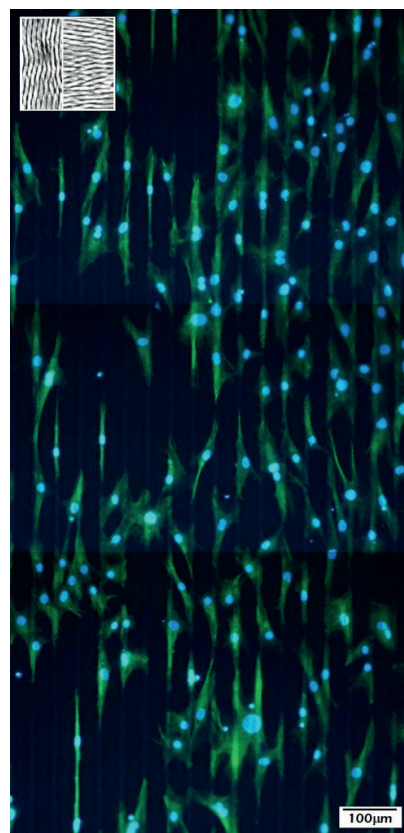
Fluence Technology has focused on ultrafast lasers with their model Jasper X0, a 1,030 nm femtosecond laser with a great combination of short pulses, high energy peak and customizable repetition rate (from 270 fs to 8 ps). Fluence Technology has proven the performance of the laser in the fabrication of different medical implants, including one of the most challenging, the fabrication of stents made of thermally sensitive biodegradable PLA.

The special case of intraocular lenses

An intraocular lens (IOL) is a lens implanted in the eye, usually as part of treatment for cataracts, or to correct other vision problems such as short and long sightedness. These eye problems are

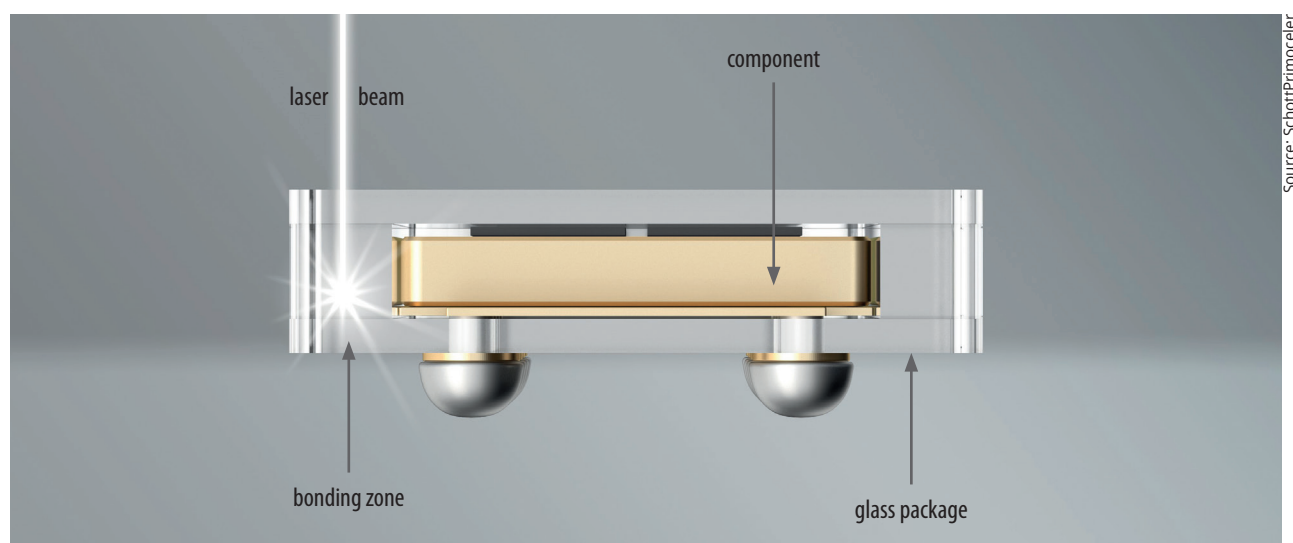
becoming increasingly common, so new manufacturing methods of IOLs have been explored in recent years to cover the high demand for these lenses. As most IOLs are made of silicone, acrylic or other delicate transparent polymers, their manufacture requires delicate processes to ensure the utmost precision and quality in mass production.

Laser cutting is nowadays a common tool in the manufacturing of IOLs. One challenge though is keeping the thermal stress induced on the materials low, especially when high pulse energies are used. It can lead to the creation of micro-defects and melting, which could significantly compromise the quality of the lens. Lumos Laser has developed an innovative GHz burst, pulsed femtosecond laser to address these challenges. The ultrashort pulse durations coupled with the optimized GHz burst parameters allow the controlled energy



Source: CEIT

► Distribution of hMSCs cultured on nanostructured micrometric patterns. Inset: top view of the LIPSS-nanostructured micrometric patterns fabricated on stainless steel, consisting in 10 and 30-μm wide stripes in which the nanopatterns are rotated 90°.



Source: SchottPrimoceler

Glass wafer microbonding process

delivery to the material, significantly limiting thermal stress. This control is crucial to prevent the defects mentioned above, and ensuring the integrity and precision of the intraocular lenses. By delivering lower energy pulses at a high repetition rate, GHz burst lasers not only reduce the risk of material damage but also enhance the material processing efficiency. This characteristic is critical to meeting the industrial needs of high-speed production with high repeatability.

Another laser process for implants: surface texturing

Ideally, medical implants should rapidly achieve and maintain long-term mechanical stability, which is determined primarily by their integration into the supporting living bone. This osseointegration capacity can be improved by modifying some surface properties, such as roughness, wettability or surface chemistry. Laser surface texturing has emerged as a promising method for this kind of treatment, offering increased control and reproducibility while reducing the processing time and costs. A wide range of micro and nano-scale topographical features and patterns can be generated and, in the case of femtosecond lasers, significantly less nanoparticles from plasma plume condensation are generated.

The CEIT Research and Technology Center has developed some processes for the surface treatment of implants to enhance osseointegration. They found that human mesenchymal stem cells (hMSCs) tend to attach and preferentially align in a longitudinal direction to nanopatterns created on

the surface of metallic implants. CEIT researchers used an 800 nm, 130 fs laser to pattern stainless steel surfaces with laser induced periodic surface structures (LIPSS), with and without changing the chemical composition of the material. These nano patterns were created by a single pass of the laser beam over the implant surface, and they noticed that the movement of different cells on the surface could be controlled according to the type of structure generated on the surface.

CEIT participated in the EU Laser4Surf project in order to evaluate the potential of LIPSS for the mass production of implants with functional surfaces. The goal of the project was to perform laser surface texturing in implants to improve their osseointegration and ensure their biocompatibility, but also to ensure that the process was clean, environmentally friendly, fast, and cost effective. Another goal of the project was to meet the regulatory standards with the proposed technique, including no modification of the metal, no changes in geometrical features, no release of adverse components, and good mechanical properties of the implants. The tests performed during the project showed that the proposed techniques met all these requirements. Although there was some leaching of Al, Fe and V, all values were well below the acceptable limit and the mechanical tests demonstrated good mechanical properties with no significant difference in maximum insertion/removal torque or axial pullout strength. The Laser4Surf project showed that implants could be successfully textured using femtosecond laser processes at an industrial scale.

Photonics in the manufacturing of active and smart implants

Active medical implants, such as pacemakers, defibrillators or neural sensors, consist of tiny components and sensitive electrical parts. Some of them (e.g. batteries, wires, circuits ...) must be first manufactured individually and then assembled. The presence of these sensitive components in the implant makes their hermetic seal necessary to protect both the patient and the part of the implant.

Trumpf has developed appropriate laser welding processes to ensure that active implants are welded at low heat to prevent damage to the delicate materials inside. Because of their special design, sensors or plastic components often lie very close to the welding area of the implants, especially if they are smaller and more complex. Trumpf proposes weld seams as the best alternative, due to their interesting advantages: they are very fine and smooth and have hygienic, non-porous surfaces. They are also hermetically sealed, protecting both the patient and the internal device components after implantation.

Laser welding can also be used to ensure lossless electrical connections within a specified contact area. Trumpf has been working on the control of pulse frequencies and strengths, enabling welding at low heat and joining of almost all metallic materials. This is particularly relevant for flexible printed circuit boards in defibrillators and pacemakers or for connecting sensitive sensor systems, due to the high mechanical loads that these weld seams must withstand.

Another interesting example is glass microbonding (GMB). It is an innova-

tive process for the wafer-scale sealing of implants containing electronics with an all-glass hermetic electronic package. The hermetic seal is formed using an extremely precise laser to fuse glass-to-glass by melting only the cross section where the glass meets, an area of just a few microns, while leaving all other surfaces untouched. It is also additive-free and components sealed with GMB can be as small as a few mm³. The technique can be performed at chip-scale all the way up to wafers as large as 12" (30.5 cm), making it simple and cost-effective to scale up for high-volume manufacturing.

Schott Primoceler is a pioneer in the use of GMB in smart implants. Their technology has enabled the next generation of these medical components, which must be miniature, contain more sensors and be placed close to the treated area, have a wireless connection for data transfer, and be made from materials compatible with magnetic resonance imaging (MRI). All of these requirements can be met by Schott Primoceler's GMB technology. Firstly, room temperature sealing does not damage coatings, other active layers, or the biosensors. Secondly, implants are highly reliable as there are no adhesives, no outgassing, and they are fully hermetic. Thirdly, miniaturization is possible thanks to the

fact that the heat-affected zone is just a few micrometers, which means less bulk and thinner materials. Fourthly, transparency enables RF transmission. Finally, a wafer-level process means it is relatively easy to scale up with many devices per wafer and therefore provide high yields.

Conclusion

Laser technologies have shown a lot of advantages in the manufacturing and post-processing of medical implants and other implantable devices. They can meet the requirements of mass production while maintaining the strict requirements of medical and healthcare components: speed, effi-

ciency, accuracy, biocompatibility, and sterility. Laser cutting, marking and welding have already been widely used in the fabrication of both passive and active implants, and surface texturing or glass microbonding has already demonstrated interesting capabilities of improving integration into the human body and sealing electronic components in active implants. Although different laser sources are still used to perform different tasks in this market, ultrafast lasers seem to be the most suitable solution due to their ability to reduce the thermal stress in the material and their capability of manufacturing very small parts.

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Source: EPIC

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Previews

SLT

Flexible laser plastic welding as an addition to AM

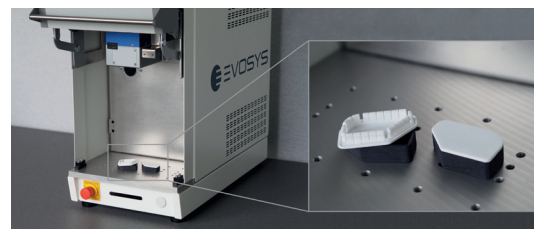
Highly efficient welding of additively manufactured thermoplastic components

Individualization, shorter product cycles and prototyping are leading to increased use of additive manufacturing (AM) in industry. A reliable and versatile process like laser plastic welding is needed to join parts with other additively manufactured or injection molded parts. AM is even more economical than injection molding (IM) for small quantities due to the short time from model to functional part, and additional tooling being unnecessary.

However, 3D printed parts have challenging optical properties, such as decreased transmission and high scattering of the laser within the part. A method was developed to pretreat the AM parts with a second laser to address

this challenge. Additionally a design which enables the integration of clips into the additively manufactured parts in order to provide an easier clamping method was developed. For testing purposes, PA12 demonstrator parts were manufactured both additively and by injection molding, enabling different material combinations to be welded and investigated that are interesting for different application cases.

DOI: 10.1002/phvs.202400015



Welding of a snap clamping demonstrator part on the EvoWeld Mini table top machine (Source: Evosys Laser)

Evosys Laser GmbH

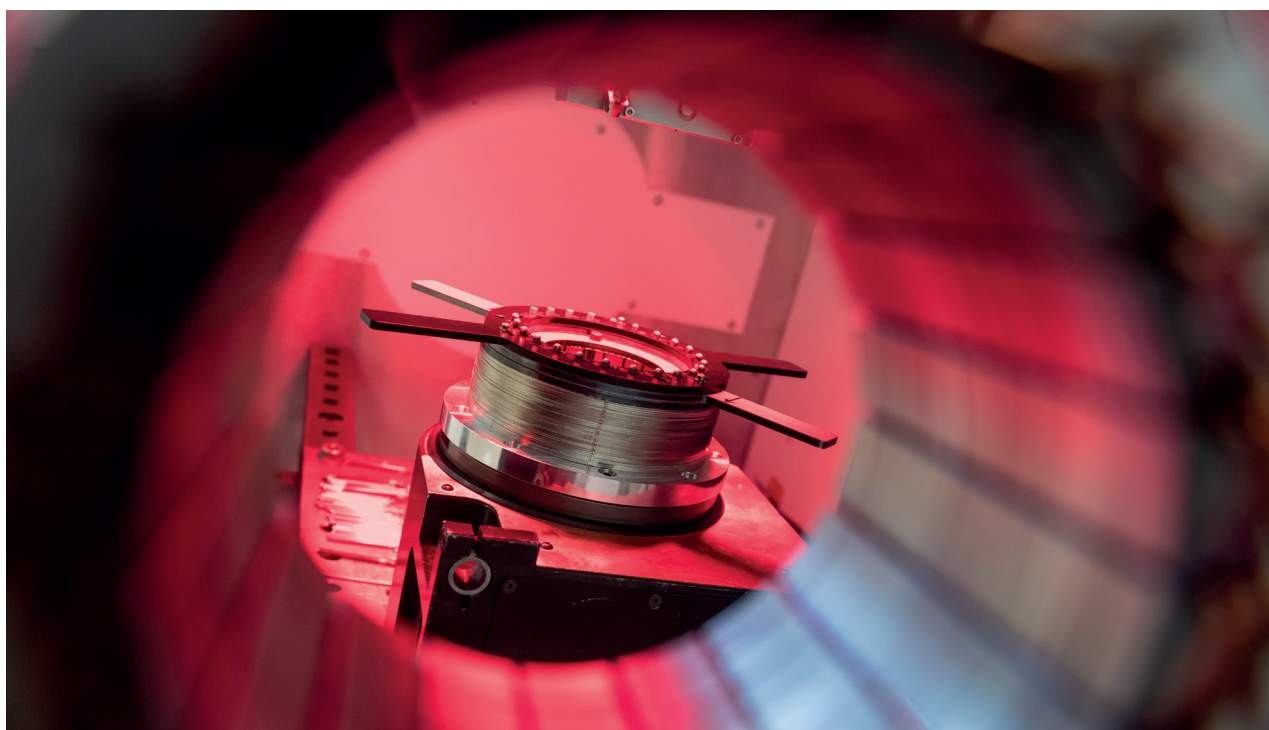
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Meet us at the SLT Exhibition

Unlocking opportunities for the EV industry with beam shaping of high-power lasers

How dynamic beam shaping lifts productivity of hairpin stators

Oliver Bocksrocker, Kai Fiechtner, Matthias Beranek, Nicolai Speker, and Tim Hesse



Source all images: Trumpf

The electric vehicle (EV) industry is witnessing unprecedented growth, driven by the global shift towards sustainable transportation. Laser welding has emerged as an important technology in this sector, offering a welcome way of reducing production costs and expanding the options in manufacturing new batteries and e-drive technology. While laser sources have rapidly evolved, introducing power levels of 24 kW and beyond, the efficient application of such high laser power in welding processes remains a challenge.

Company

TRUMPF

The high-tech company, founded in 1923 as a mechanical workshop, offers production solutions in the machine tool and laser sectors. It is driving digital connectivity in manufacturing industry through consulting, platform, and software products. TRUMPF is one of the world technological and market leaders for machine tools used in flexible sheet metal processing, and also for industrial lasers.

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This contribution addresses the disparity between the laser power available and its transformation into increased productivity during the hairpin welding process. The limitations, particularly in melt bath dynamics, hinder the full potential of high laser power. In response to this challenge, our contribution explores innovative beam shaping approaches to overcome these limitations and to harness the benefits of higher laser power in the welding process. Through detailed demonstrations, we show how the application of new beam shaping techniques can

render higher laser power practical in welding, thereby raising productivity to unprecedented levels. This research not only contributes to the optimization of laser welding for electric vehicle components but also opens doors for broader applications in advanced manufacturing technology.

The EV industry has grown rapidly from small to large-scale manufacturing plants over the last few years. Advances in production technology such as scanner-based laser welding have facilitated this transformation by enabling much faster production than any other. The

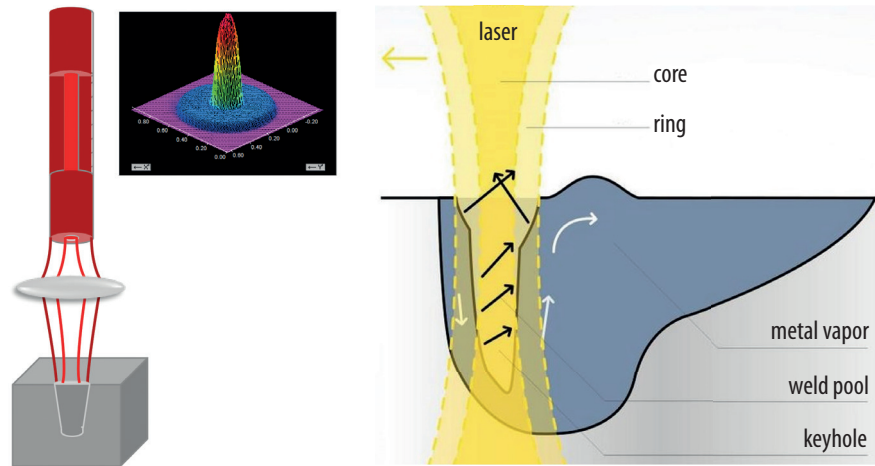


Fig. 1 Effect of BrightLine Weld on the welding process [5]. The laser beam is coupled into an inner fiber core and also into a coaxial ring.

tough requirements of battery and e-drive production have also accelerated the development of laser sources with higher power and brilliance, which in return increased the necessity to develop new applications to use these advanced tools. Beam shaping is one key method that opens the door to higher productivity by enabling more laser power to be used, pushing the process limits to higher levels.

In the following article, the advancements in hairpin welding are shown, and how the welding time could be reduced by a factor of 2.5 by adapting the spot size and the beam profile of the laser.

Superimposed laser beams

Welding the electrical contacts of diverse batteries or e-drives, which are primarily made of aluminum, copper, and steel, requires a low-spatter process with low heat input and no pores inside the weld seam. Additionally, the penetration depth and volume of the molten material should be kept to a minimum. To meet these requirements, the process must be stabilized by controlling the shape and dynamics of the keyhole and the surrounding melt pool.

An elucidated methodology [1–4] is used to address these features and govern welding processes by stabilizing the keyhole. This is achieved by superimposing two laser beams, a core beam, and a ring fiber beam, known as BrightLine Weld. This generates a stabilizing influence on the keyhole and the surrounding melt pool. This innovation is widely used in various applications involving copper, aluminum, and steel components, such as in the EV industry.

Fig. 1 shows the beam profile of the superimposed laser beams from a TruDisk BrightLine Weld laser source in the focal plane. The sketch demon-

strates that both beams, from the ring and core fiber, are superimposed and introduced into the keyhole. As a result, the keyhole opening is more conical than it would be without the ring beam, which is the main effect of stabilization during the process. This phenomenon not only creates a stable keyhole but also leads to a significant increase in molten material near the surface. Both effects are crucial in reducing spatter and pore formation [6].

Experimental setup

Table 1 provides a detailed description of the experimental configuration. All welding trials were conducted using PFO33-3 scanning optics in combination with the TruDisk 8000 multi-mode laser source.

With more and more laser power available at affordable prices, the question today is how to translate this high laser power on the workpiece into higher productivity. This is where beam shaping comes in. There are several ways to adjust the beam profile, such as beam combining, beam splitting or shifting the intensity within a beam. In addition, the beam profile can be shaped statically or dynamically, i.e. the beam profile can change its shape over time during the welding process. This is demonstrated in this paper for hairpin welding.

The laser system works by splitting the main beam into a core and a ring

fiber, each of which is directed along its own path (see Fig. 2). This splitting ensures efficient utilization of the laser power for welding applications. A notable feature of this setup is the consistent availability of full power regardless of power distribution, providing optimal performance throughout the welding process.

The ratio of power distributed to the core and ring fibers is precisely controlled by rotating the beam-splitting wedge. This fine-tuning capability allows the precise adjustment of the power distribution to meet specific welding requirements with the utmost accuracy. In addition, the system offers full power control from 0 to 100 %, providing the flexibility to adjust the intensity of the laser beams according to the intricacies of the welding task at hand. An outstanding and new feature of the system is its Dynamic BrightLine Weld capability, which dynamically switches the power ratio between the core and ring fibers during the welding process. This dynamic adjustment optimizes welding conditions in real time, adapting to changing parameters and ensuring consistent quality throughout the weld.

Welding results

The process of laser-based hairpin welding poses significant challenges, as it requires precise and rapid join-

Laser	TruDisk 8000
2-in-1 configuration	BrightLine Weld
Optics	PFO33-3
Focal length	450 mm
Collimation length	140 mm
Laser power	8 kW (switchable between core-ring)

Table 1 Experimental setup

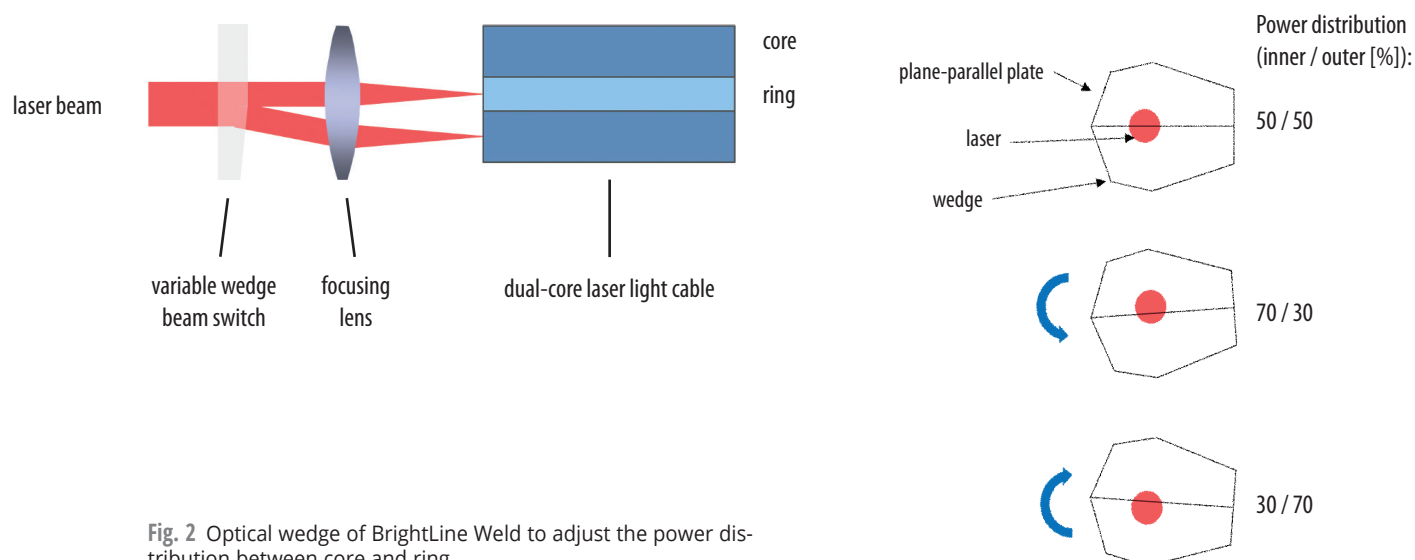


Fig. 2 Optical wedge of BrightLine Weld to adjust the power distribution between core and ring

ing while minimizing pore formation, heat input, and spatter. A deep understanding of the process is necessary to prevent instabilities and to achieve accurate connections in hairpin stator designs. This is accompanied by the need to maintain high process efficiency, minimize material loss, and optimize cycle times while preserving structural integrity. Multimode lasers with 2-in-1 fiber guidance are predominantly used to weld copper hairpins with high laser power and stringent quality requirements. Trumpf's BrightLine Weld technology – available for disk and fiber lasers – is preferred over alternative high-power beam shaping technologies due to its ability to utilize the full laser power, regardless of the

split ratio. Additionally, the split ratio can be adjusted within a versatile range from 0 to 100 %. The optical setup for fiber coupling is designed to support interchangeable fibers and integrate with multiple beam outputs while preserving beam quality integrity.

To address the challenges of short process times and minimized spatters and pores, BrightLine Weld technology is applied to ensure robust, conductive connections, significantly reducing pores and spatters compared to processes using the core fiber alone (refer to Fig. 3). Dynamic adjustments to the split ratio of laser power between the core and ring fibers during the welding process offer a synergistic approach, combining rapid processing times with

reduced pore generation. The laser power is alternated between the core and ring fibers throughout the welding process to optimize results. Although spatters are diminished, they are still observable at small amounts with this process strategy.

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- [1] O. Bocksrocker, N. Speker, M. Beranek, and T. Hesse, T. (2019): Reduction of spatters and pores in laser welding of copper hairpins using two superimposed laser beams, *Laser in Manufacturing Conference*, Munich.
- [2] N. Speker, P. Haug, S. Feuchtenbeiner, T. Hesse, and D. Havrilla, (2018): BrightLine Weld – spatter reduced high speed welding with disk lasers, *Proc. SPIE 10525*, <https://doi.org/10.1117/12.2287205>

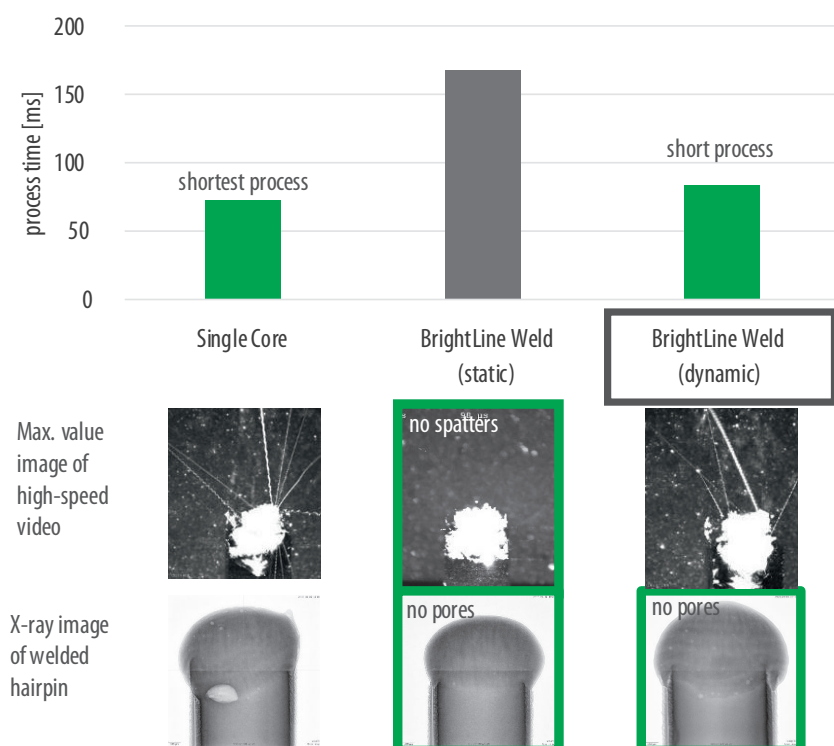


Fig. 3 Comparison between the welding performance of the TruDisk 8000 multimode laser using the single-core, static and dynamic BrightLine Weld processes. The corresponding spatter and pore images show an improvement in speed and quality for the dynamic BrightLine Mode process.

- [3] E. Papastathopoulos, O. Bocksrocker, K. Fiechtner, S. Pricking, R. Flaig, O. Effinger, and T. Ryba, T. (2022, March): Advances in beam shaping of high-power CW lasers with BrightLine weld technology. *High-Power Laser Materials Processing: Applications, Diagnostics, and Systems XI* (Vol. 11994, p. 1199402). SPIE. <https://doi.org/10.1117/12.2607138>
- [4] E. Papastathopoulos, E., F. Baumann, F., O. Bocksrocker, T. Gottwald, A. Killi, B. Metzger, S. Schad, N. Speker, T. Ryba, and S. Zaske, S.: High-power high-brightness disk lasers for advanced applications, *Proc. SPIE*. 11664, (2021).
- [5] O. Bocksrocker, A. Riccio, K. Fiechtner, C. Siebert, M. Richmond, N. Speker, and T. Hesse (2024, March). Dynamic beam control of fiber lasers drives innovation in laser material processing for the EV industry. *Fiber Lasers XXI: Technology and Systems* (Vol. 12865, pp. 50-55). SPIE.
- [6] M. Omlor, E. Reinheimer, T. Butzmann, K. Dilger (2023). Investigations on the formation of pores during laser beam welding of hairpin windings using a high-speed x-ray imaging system. *Journal of Laser Applications*, 35(3).

Authors

Oliver

Bocksrocker is an expert for laser applications, facilitating the path to new product ideas for electrical vehicle (EV) industries. He is a mechanical engineer with experience in R&D of laser welding, cutting and sensors, and brings together scientific and operational parts of the company.



Kai Fiechtner is a development engineer for laser processes that are used in the EV industry. He studied photonic engineering at the University of Stuttgart, and has been involved in the further improvement of welding applications, especially in motor and drive technology.



Nicolai Speker studied physical engineering in optical measurement and control technology at the Heilbronn University of Applied Sciences.

After initially working as a developer of CO₂ high-power lasers, he has been responsible for process and application development of laser cutting, laser welding and laser metal deposition welding for many years, and heads this research group.



Tim Hesse is head of R&D, laser applications, at Trumpf Laser- und Systemtechnik AG.



Matthias Beranek

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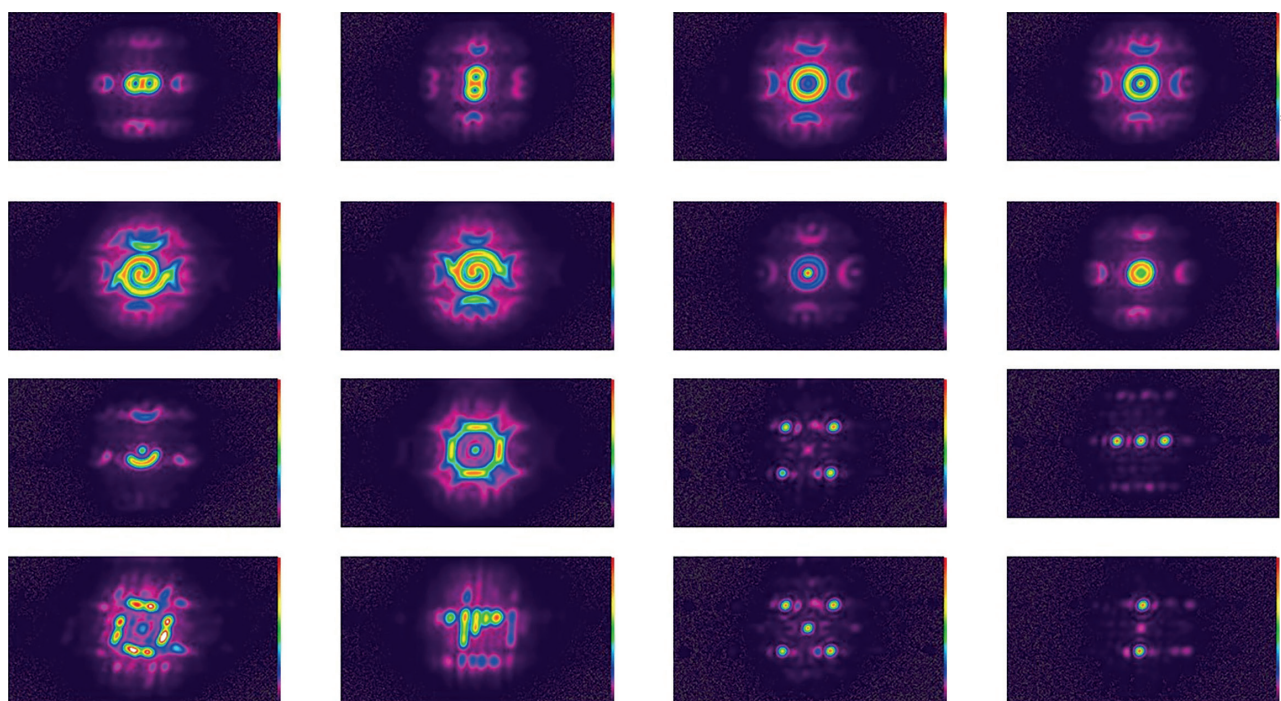
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Dynamic beam shaping with coherent beam combining

A description of the physics underlying coherent beam combining, capabilities and applications

Eyal Shekel



Coherent beam combining (CBC) is a method of enhancing laser power. It has recently transitioned to industrial applications, unveiling new possibilities in laser technology. CBC merges multiple laser channels from a single source, controlling their phase to create constructive or destructive interference. The optical phased array (OPA) and filled aperture methods exemplify CBC's advancements, enabling dynamic and precise beam manipulation. This technological evolution opens avenues for versatile applications in various industries, significantly advancing our capability to harness laser technology for complex tasks.

Coherent beam combining is well-known method of scaling laser power, but its industrial applications have seen little traction due to its challenging engineering, making it available only in several laboratory setups for those who were able to overcome the many obstacles. Since the first industrial lasers were introduced only several years ago, its capabilities and applications are just beginning to be understood and explored, creating a new frontier for laser technology. At the heart of CBC lies the fundamental principle of merging multiple laser channels originating from a single source while ensuring their coherence. Through the

manipulation of the relative phase of each channel, it becomes possible to change the laser's output by inducing either constructive or destructive interference.

CBC methods

One of the techniques within CBC is the optical phased array (OPA), which facilitates the combination of laser channels in the far field. This method enables the manipulation of the laser beam in the x, y, and z axes at remarkably high frequencies in the GHz range. Referred to commercially as the dynamic beam laser (DBL) by Civan Lasers, OPA represents a sig-

nificant advancement in CBC technology, since it is at the forefront of CBC development and offers capabilities that were never possible before by other means.

Another approach to CBC is the filled aperture method, which shares certain similarities with its OPA. This process commences with a common laser source, which is subsequently amplified and divided into multiple channels. However, instead of manipulating the channels in the far field, filled aperture uses a grating to combine the separate beams. By precisely adjusting these phases, the method

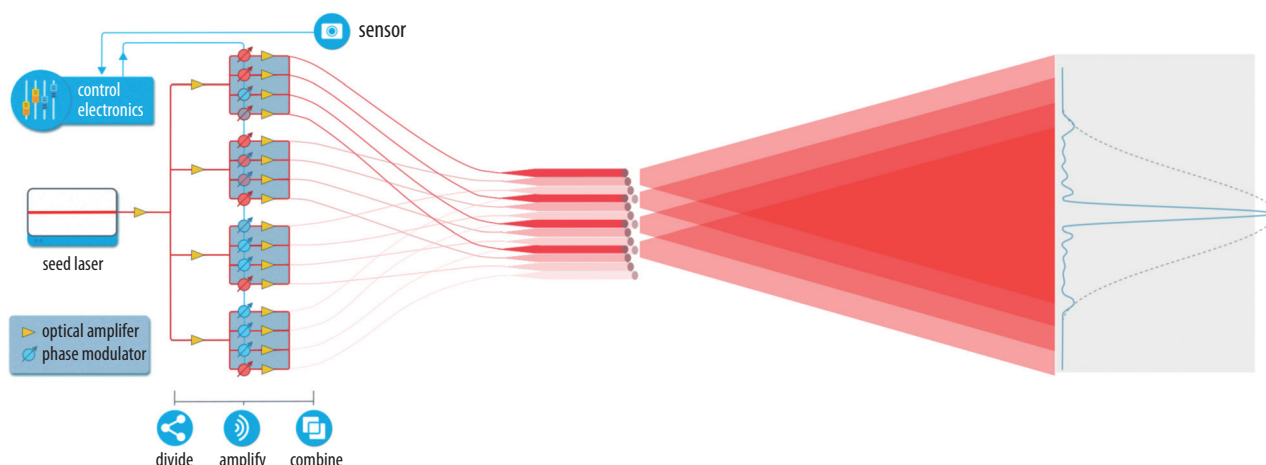


Illustration of the coherent beam combining of an optical phased array laser

achieves constructive interference in specific locations, ultimately resulting in the combination of the separate beams into a high-quality, single-mode beam. The filled aperture method lacks the dynamic beam-shaping capabilities inherent in the optical phased array approach. Unlike OPA, which allows for real-time manipulation of the laser beam, filled aperture generates a static beam. Filled aperture lasers have advantages in temporal modulation over other lasers, since they are able to modulate just by change of phase, which can be done at GHz frequencies.

Dynamic beam laser features

The dynamic beam laser (DBL) introduces several features that open new capabilities for laser systems. At the forefront of these are dynamic beam shaping, shape frequency control, shape sequence programming, and focus steering. These attributes collectively empower users with unprecedented control and versatility, enabling a wide range of applications across diverse industries.

Dynamic beam shaping stands as a cornerstone feature of the DBL, allowing users to manipulate the laser

beam's spatial profile in real time. Unlike traditional fixed-beam lasers, which emit a static beam with a pre-determined shape, the DBL offers the flexibility to dynamically adjust the beam's shape on the fly. This capability is particularly valuable in applications where precise control over beam geometry is essential, such as laser materials processing.

The dynamic beam shaping feature allows users to design any arbitrary beam shape while controlling its geometry, density, and order of generation. DBLs generate beam shapes by jumping between points. It is possible to control the spatial and temporal characteristics of the beam in various ways. The laser comes with software that can be used separately from the laser itself to allow users to design new beam shapes in advance. The software includes a grid where the user clicks and draws a beam shape. By clicking on the box several times, the user will add more density to the beam shape at that point, since the laser beam will stand at that point for a longer time. Additionally, the user can control the order in which the beam jumps between points. For example, when creating a beam in the shape of

a ring, the beam can jump from one point to another either clockwise or vice versa, counterclockwise. It is also capable of jumping randomly from one point to another.

Shape frequency is another feature of the DBL, allowing users to adjust the frequency at which beam shapes are spatially modulated. Frequency is defined as the number of times the shape is completed in a second. As a result, there are several parameters affecting how fast the beam jumps between points. The first parameter that influences the frequency is the number of points that make the beam shape; for example, a ring beam can be constructed with twenty or eighty points. The beam will jump between points at a different time in both cases, since

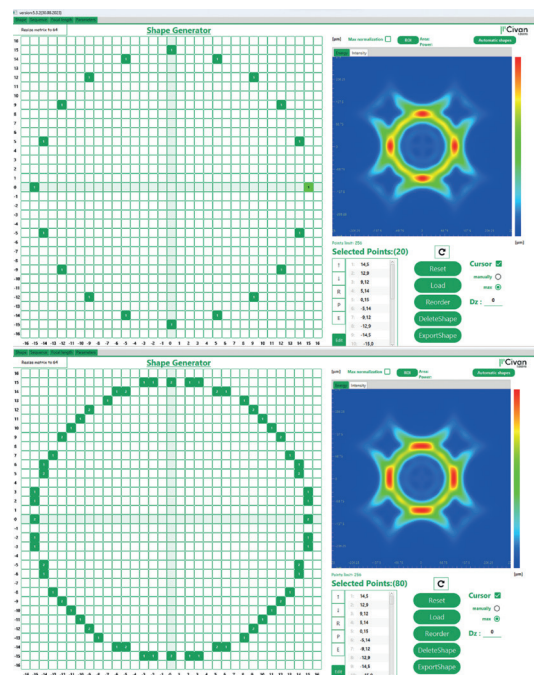
Company

Civan Lasers

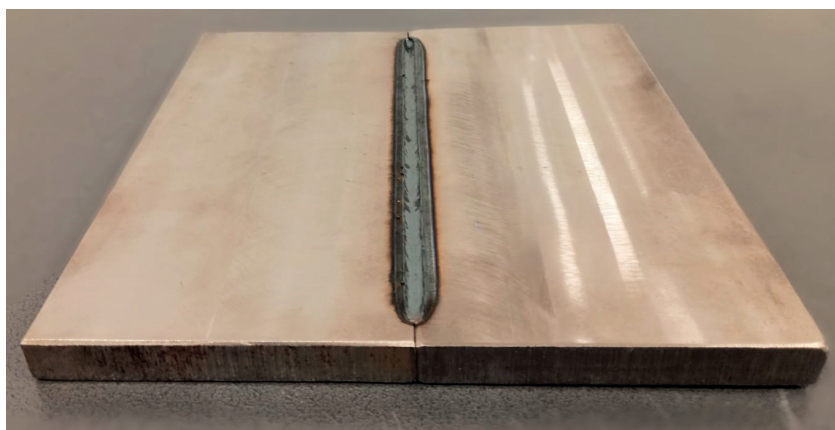
The Jerusalem-based hi-tech company with offices in the US and Germany manufactures fiber lasers with coherent beam combining and optical phased array technology. The lasers are uniquely suitable for material processing, FSO, power transmission, and a wide variety of other uses. Civan's high power lasers are integrated into industrial material processing systems, serving a multipurpose role, whether be it cutting, welding, additive metal manufacturing, live beam adjustment and correction and many other research applications.

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Shape generation software capture. Top image: ring beam shape constructed from 20 points. Bottom image: ring beam shape constructed from 80 points



The high power with the large depth of focus and focus steering achieve high quality welds in thick sections.

the time spent in a ring constructed of eighty points if you wanted to maintain the same frequency would be a quarter of the time spent in a ring formed of twenty points.

Shape sequences allow users to transition between various beam shapes within specified timeframes. The functionality is part of the shape generation software used to design beam shapes. Within the software, users have the flexibility to select the desired beam shapes for transition and define the duration for each shape in the sequence. If the duration of each beam shape is shorter than the time the laser is on, the sequence will repeat itself.

Focus steering enables dynamic movement of the laser focal point. Traditional laser systems typically have a fixed focal point, limiting their flexibility and adaptability in complex machining and processing tasks. In contrast, the DBL's focus steering capability allows users to dynamically adjust the beam's focal position along the z axis in real time. This gives the user higher tolerances in focal position as well as the ability to extend the depth of focus by adding electro-optical movement of the focal position.

Characteristics of dynamic beam lasers

The individual beams used in coherent beam combining are of high beam quality, with each being a single-mode

beam. Even when merged, these beams retain their individual characteristics, contributing to the overall quality of the combined beam. However, due to the generation of high orders within the combined beam, its quality cannot be accurately assessed using the standard beam measurement of M^2 . The single-mode attributes, such as a large depth of focus and low divergence, remain evident in the combined beam. The beam diameter is determined by the focal length employed, and the relationship between focal length, beam diameter, depth of focus, and focus steering is detailed in Table 1.

Utilization of DBL in material processing

Dynamic beam shaping provides a straightforward method of manipulating weld geometry. It is intuitive to grasp that a narrow beam shape like a single point, would result in a narrow and deep weld, while a wider beam shape, such as a ring, would produce wider and shallower penetration, assuming equal power usage. However, in certain scenarios such as welding aluminum to copper, employing a wider beam shape with shallower penetration can actually enhance mechanical strength by minimizing intermetallic mixing.

The shape frequency is a powerful tool for controlling molten material

flow and optimizing the weld process to minimize or eliminate defects such as porosity and spatter. By adjusting this frequency, manufacturers can exert precise control over the dynamics of the molten material, influencing its flow behavior and distribution within the weld pool.

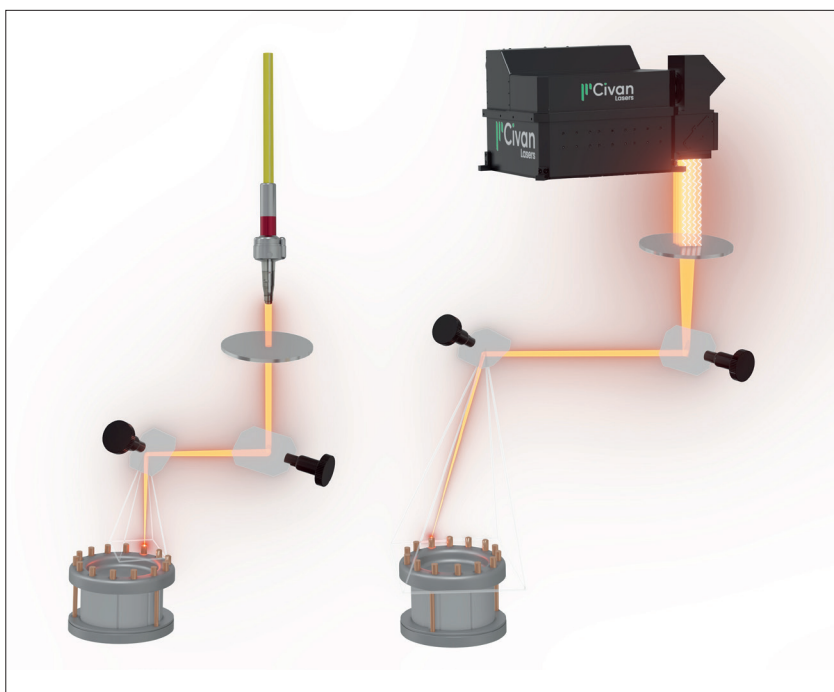
In the welding of hairpins, the effectiveness of shape sequencing was showcased as a solution to address issues arising from passing over the gap between the hairpins, known to induce porosity and spatter. A strategic approach using shape sequencing was employed to overcome these challenges. Initially, a sequence consisting of four individual points followed by a larger point was designed. This sequence began with the application of the four individual points, allowing for the melting of the material and bridging the gap between the hairpins. Subsequently, a seamless transition to a larger beam shape covering both hairpins was executed within a timeframe of five microseconds.

Focus steering by galvo scanners has been integrated to eliminate the need for costly optics like F-theta lenses or mechanical adjustments of the focal plane based on location. With DBL technology, the position of the focal plane can be altered electro-optically.

The aforementioned examples illustrate just a few ways that researchers and practitioners have leveraged the capabilities of the DBL. As adoption of the system increases, more innovative solutions are being devised that capitalize on its potential. Several new features are currently under investigation for future implementation. One such feature involves using multiple sensors to detect backreflection in order to predict the quality of welds.

Focal length [mm]	Depth of focus [± mm]	Focus steering [± mm]	Central lobe diameter [μm] FWHM	Beam steering area x-y axes [μm]
750	2.9	7	43	260
1500	11.5	29	86	520
3000	45	115	171	1020
6000	183	460	342	2040

Table 1



Comparison of using a galvo scanner with a standard laser and a DBL. The DBL can have a long focal length and corrects the focal position electro-optically. This avoids the need for sophisticated optics and mechanical movements of a focusing lens

Additional applications for DBL

The same technology and, in some instances, even identical laser systems are suitable for a variety of additional uses. The DBL can actively correct wavefront distortions, providing an efficient means of free-space propagation, even under atmospheric conditions, by compensating for turbulence aberrations. Furthermore, the electro-optical beam steering feature aids in maintaining a line of sight, allowing more energy to reach the receiver or desired area.

These distinctive capabilities open up several potential applications. For instance, using the DBL at a $1.5\ \mu\text{m}$ wavelength for free space optical communications is one such application. Civan Lasers has demonstrated the capability of a DBL system to transmit data at 130 Gb/s over a distance of 10 km. In this context, another benefit

of the DBL is its ability to scale power, which can be particularly advantageous at the $1.5\ \mu\text{m}$ wavelength.

Dynamic beam lasers offer innovative solutions to address challenges in space, such as debris removal and power transmission. For space debris, DBL systems can be tuned to deliver precise, high-intensity laser beams to target and alter the trajectory of debris, effectively mitigating potential collisions with satellites and spacecraft. This precise beam control also makes DBL ideal for wireless power transmission in space. The ability to direct and modulate laser beams allows for the efficient transfer of energy over vast distances, providing a viable method to power satellites or even lunar bases from afar. The electro-optical steering capabilities of DBL ensure that the laser maintains accurate alignment with the receiving device, maximizing energy

transfer efficiency and opening up new possibilities for sustainable power solutions in space environments.

Summary

Dynamic beam lasers, which utilize coherent beam combining, have been commercially available for only a few years and are increasingly being adopted across various industries. More of their capabilities are being explored and documented as these lasers are integrated into material processing applications – such as welding in the automotive and shipbuilding sectors, metal additive manufacturing via directed energy deposition (DED), and laser powder bed fusion (LPBF). A deeper understanding of their features enables users to discover innovative ways to leverage this laser technology.

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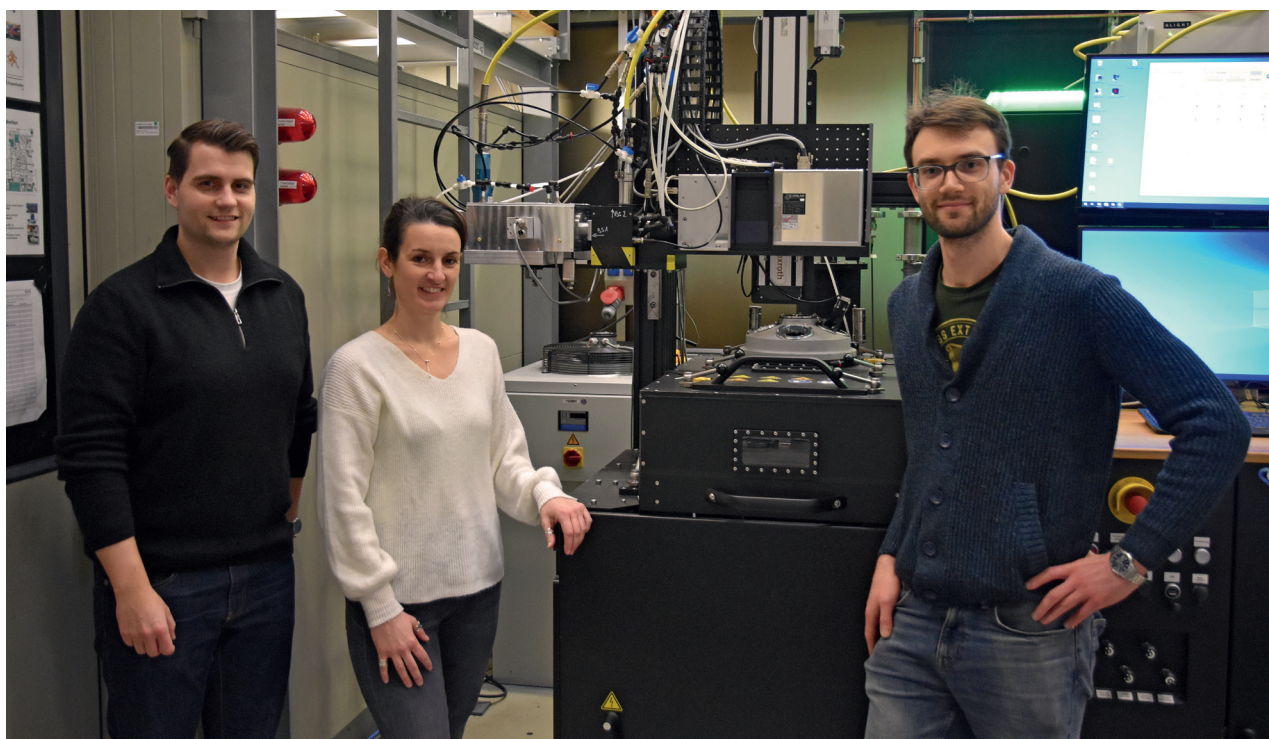


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Beam shaping to tackle laser powder bed fusion challenges

Multi-plane light conversion to increase the printing speed and reduce hot-cracking

Gwenn Paillier & Niklas Prätzsch



Source all images: Callabs

Additive manufacturing (AM), a term synonymous with the future of fabrication, has revolutionized industries by offering unparalleled flexibility in design and production. At the heart of this transformative technology is laser-based powder bed fusion of metals (PBF-LB/M), the process with the highest geometrical resolution having the largest market share (86 %, Wohlers) amongst all AM processes. By selectively melting and fusing powder material layer by layer with a laser, PBF-LB/M enables the creation of complex and high-strength components, previously unthinkable with traditional subtractive manufacturing methods.

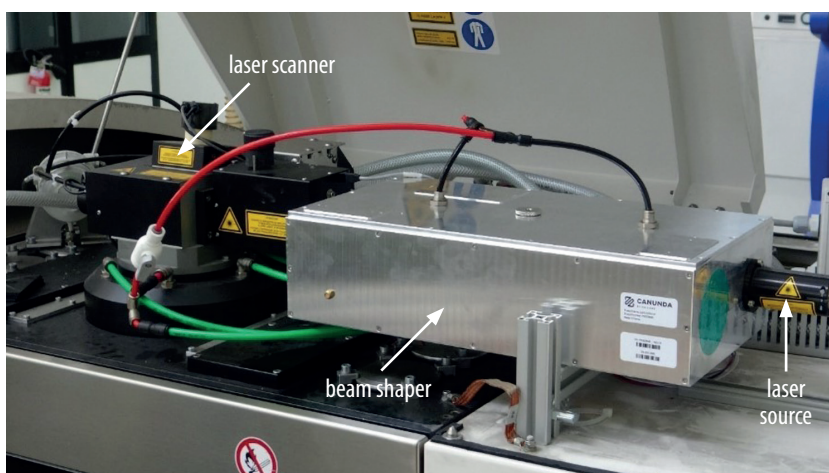
The inception of PBF-LB/M dates back to the late 20th century, emerging from the broader development of additive manufacturing techniques that sought to reduce waste and increase manufacturing efficiency. Over the years, PBF-LB/M has matured into a key driver of innovation in sectors such as aerospace, automotive, and healthcare, among others.

The market for PBF-LB/M has seen substantial growth, driven by its adoption across these diverse sectors.

As the technology advances, it opens up new possibilities for customization and the production of components that meet specific industry needs, further expanding its market reach. However, the journey of PBF-LB/M is not without its challenges. For further widespread industrial use in demanding applications, it is crucial to increase the productivity of the process by maintaining the high mechanical properties of PBF-LB/M manufactured parts.

▲ Project participants (l-r): Niklas Prätzsch, Gwenn Paillier, and Marvin Kippels

Firstly, enhancing print quality is paramount – specifically by reducing phenomena such as hot cracking, can compromise the structural integrity of printed components, limiting the range of materials that can be effectively processed and thus hindering the technology's applicability across broader mate-



► PBF-LB/M beam shaping module

rial spectra. Addressing this challenge is crucial to expand PBF-LB/M's material versatility, including the ability to print new powder types with higher performance or specialized properties.

Secondly, increasing the productivity of PBF-LB/M systems is essential to improve the return on investment (ROI) of these machines. Today, the relatively slow speed of PBF-LB/M compared to traditional subtractive manufacturing and casting poses a significant barrier to its widespread adoption for volume production. Enhancing the speed of PBF-LB/M is not just about boosting productivity; it is a strategic imperative to make additive manufacturing a viable alternative for industries like automotive, where cost-efficiency and scalability are key. Achieving this could unlock new markets, transitioning PBF-LB/M from individualized applications to mainstream manufacturing.

As we delve deeper into the capabilities and potentials of PBF-LB/M, it becomes evident that overcoming these challenges is not just beneficial but necessary for the continued evolution and adoption of additive man-

ufacturing. The pursuit of solutions such as advanced beam-shaping techniques promises to address these issues head-on, heralding a new era of efficiency and quality in additive manufacturing. This implies the transition from manufacturing the whole part with a given set of parameters (including beam shape) to manufacturing each section / region / area / ... of a part with geometry-adapted parameters – high productive parameters with beam shaping in bulk sections vs. typical Gauss intensity distribution for contours.

State of the art

The advancement of PBF-LB/M technology has been significantly influenced by the evolution of beam-shaping techniques, which have demonstrated the potential to address some of the most pressing challenges in additive manufacturing. The state of the art in beam shaping reveals a fascinating interplay between innovative geometric configurations of laser beams and their impact on the printing process, ultimately leading to improvements in quality and efficiency.

One notable development has been the application of elliptical beam shapes. Research has shown that using an elliptical beam can significantly reduce thermal gradients during the printing process. This, in turn, refines the microstructure of the printed material, leading to enhanced mechanical properties of the final components. The controlled heat distribution afforded by the elliptical beam plays a critical role in this improvement, underscoring the importance of beam geometry in optimizing PBF-LB/M processes.

Furthermore, the utilization of annular beam shapes has been demonstrated to mitigate the balling effect, a common issue in PBF-LB/M that can lead to defects and irregularities in printed parts. The annular beam shape contributes to a larger process window, yielding a more robust and faster printing process. This beam shape facilitates more uniform energy distribution across the material, enhancing melting and solidification dynamics to achieve smoother surfaces and more consistent quality.

The adoption of top-hat (uniform intensity) beam shapes has also shown

Company

Cailabs

The company was founded in 2013 and is a French deep-tech enterprise that designs, manufactures and sells innovative photonics products for telecommunications and industrial lasers. A world leader in complex light shaping, its technology is currently covered by nineteen patents. Its innovative components are used in various fields, from aeronautical wiring to factory local area networks, including laser manufacturing. They have contributed to several world records – in particular, the fiber optic throughput record held by the Japanese operator KDDI.

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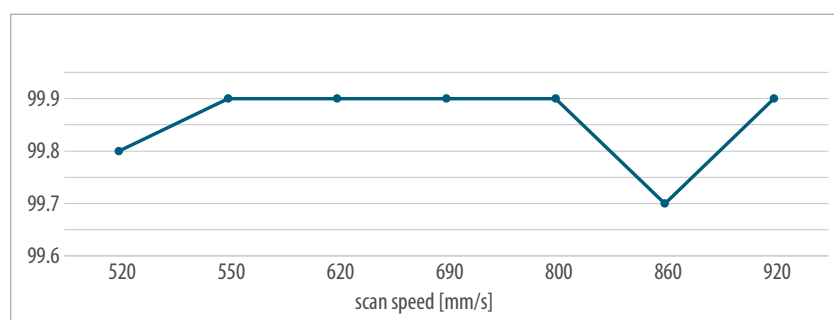
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With around 570 employees and more than 19,500 m² net floor space, the Fraunhofer Institute for Laser Technology ILT is among the most significant contracting research and development institutes in its sector worldwide. The four technology areas of the ILT cover a wide spectrum of topics within laser technology. In the Laser Material Processing technology area we solve tasks involving cutting, ablating, drilling, cleaning, welding, soldering and marking as well as surface treatment and additive manufacturing. Process development and systems engineering stand in the foreground, covering machine and control engineering, process and beam monitoring as well as modelling and simulation.

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Relative density in percent
vs scan speed in mm/s

promise in reducing spatter – tiny particles that can detract from print quality and lead to material wastage. In certain conditions, a top-hat beam configuration has been associated with reduced spatter, thereby paving the way for faster printing speeds by minimizing disruptions and defects during the printing process.

In terms of beam-shaping methodologies, two primary approaches have been identified: modifications within the laser system (e.g., dual-core lasers) and external shaping mechanisms. External shaping techniques include diffractive optical elements (DOEs) based on diffraction principles, multi-plane light conversion (MPLC) based on mode propagation, and aspheric optics that utilize ray propagation. Each method, while capable of producing similar beam shapes, influences the PBF-LB/M process differently due to the unique way in which the beam is structured and interacts with the material.

Among these, the MPLC technology stands out for its capacity to address two critical challenges in PBF-LB/M: the reduction of hot cracking and the acceleration of printing speed. MPLC achieves this by offering unparalleled control over the beam profile, ensuring optimal energy distribution and interaction with the powder bed. This technology has been instrumental in advancing PBF-LB/M, providing a pathway to enhance material properties and increase the efficiency of the printing process.

In summary, the state of the art in beam shaping for PBF-LB/M is a vibrant

landscape of technological innovations that have the potential to revolutionize additive manufacturing. By addressing key challenges such as hot cracking and printing speed, these advancements not only improve the viability of PBF-LB/M for a wider range of applications but also push the boundaries of what is possible in additive manufacturing.

Success in printing nickel alloy using beam shaping

A breakthrough in the PBF-LB/M printing of challenging materials like nickel alloy was achieved through strategic beam shaping. The technique implemented has proven pivotal in overcoming the notorious issue of hot cracking. This achievement was exemplified in a case study involving an older-generation EOS M280 machine, equipped with a 200 W laser, which previously faced limitations in printing Inconel 939 due to the prevalence of hot cracking.

The implementation of a top-hat beam shape, characterized by its uniform intensity distribution, was key to this success. Specifically, a top-hat beam with a 90 μm diameter in the processing plane was employed. Remarkably, across all tested speeds, ranging from 550 mm/s to 925 mm/s, the production of samples without any hot cracking was achieved, while also meeting the stringent quality criteria for powder density. Notably, this was accomplished with a microstructure size of 250 μm , using parameters such as a 100 μm hatch spacing, 195 W power, and a 40 μm layer thickness. This technique facilitated printing across the entire field of the F-theta lens, demonstrat-

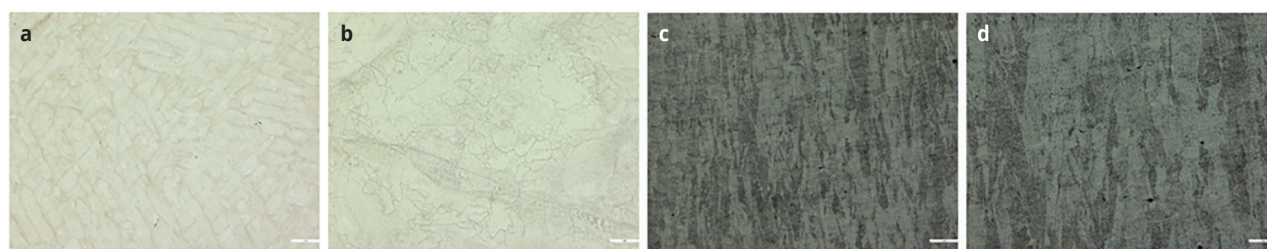
ing the versatility and robustness of the approach.

The mechanical properties of the printed Inconel 939 components, including yield strength, elongation at break, and Young's modulus, were found to be on a par with those produced using a Gaussian beam at higher power settings. This equivalence in mechanical performance, achieved at lower power and without the risk of hot cracking, signifies a substantial leap forward in the PBF-LB/M field.

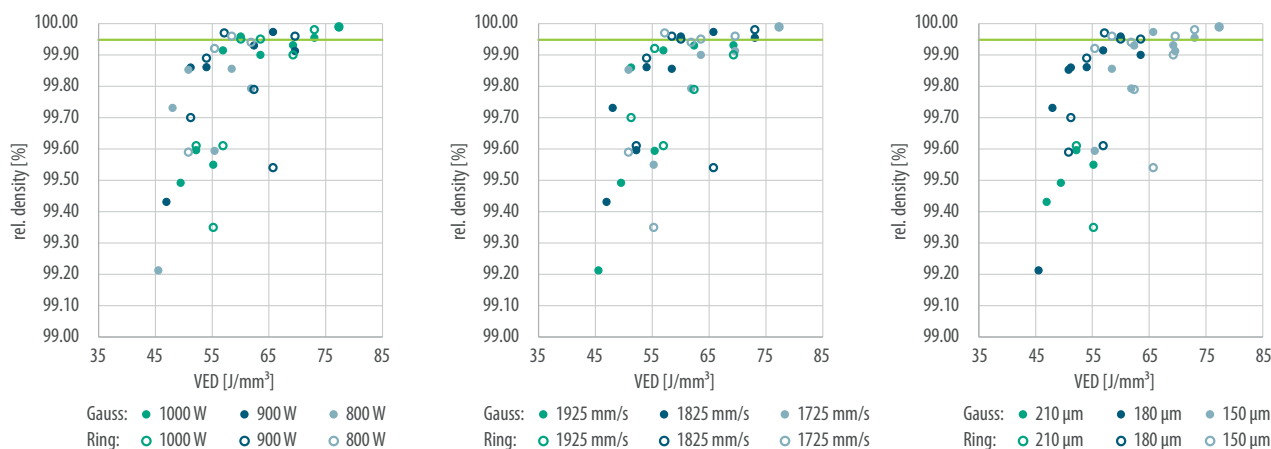
Moreover, the quality of the printed parts suggests a potential pathway towards eliminating the need for time-consuming and costly post-processing steps, such as hot isostatic pressing (HIP). The ability to print high-quality nickel alloy components directly, without the necessity for extensive post-processing, represents not only a significant cost and time saving but also a remarkable advancement in the additive manufacturing of high-performance materials. This achievement underscores the transformative impact of beam shaping in PBF-LB/M, opening up new possibilities for the industry and setting a new benchmark for the printing of challenging alloys.

Accelerating PBF-LB/M printing speeds

The collaboration with Fraunhofer ILT, the inventors of PBF-LB/M that has significantly contributed to the development of the process itself, focused on a paramount challenge within the additive manufacturing industry: increasing printing speeds. This study aimed to elucidate the differences in printing



Micrographs of sample in x-y direction (a, b) and in z direction (c, d). Magnification: 50 $\times$ for (a) and (c), 500 $\times$ for (b) and (d)



Relative density vs VED

performance between Gaussian and annular beam shapes, particularly in the context of improving productivity.

For a baseline, the R&D machine used in this study typically achieved a building speed of 5 mm³/s at a power setting of 300 W. The experiments conducted during this collaboration sought to explore the potential of operating at significantly higher power levels, specifically around 1 kW, to print a nickel alloy (Ni625). The investigation covered process windows for power settings ranging from 800 – 1,000 W, speeds from 1,420 – 1,680 mm/s, and beam diameters of 180, 210, and 240 μm.

The findings revealed that it was possible to identify parameter combinations for both Gaussian and annular beams that yielded components conforming to density requirements. In both cases, the building rate was enhanced by a factor of 3.3 compared to the baseline. However, a significant difference emerged during the trials: the process utilizing a defocused Gaussian beam generated excessive spattering. This led to the inability to print all reference cubes across the entire printing area in a single go, as the protective

window of the machine suffered considerable damage during the process. The necessity to remove and replace the window, especially in an industrial setting, would disqualify the manufactured part, rendering the defocused Gaussian beam impractical for industrial use.

To quantify this issue, high-speed videos were used to analyze the spatters, allowing for an assessment of their direction and velocity. This analysis made it possible to count the spatters and categorize them, revealing two primary phenomena: the annular beam resulted in spatters with generally slightly higher rejection angles, but with a significantly larger scattering cone, which did not direct towards the protective window, and the spatters were slower, with two times fewer particles exceeding speeds of 10 m/s. Consequently, the spatters traveled shorter distances and caused less damage to the window.

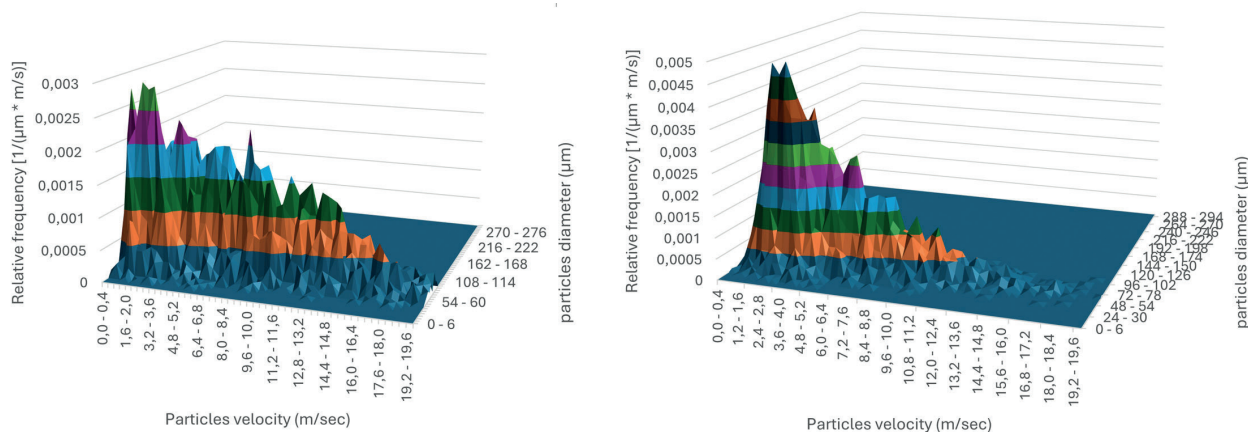
In summary, the use of an annular beam shape enabled robust and industrial-level printing at speeds 3.3 times faster than the baseline, without the detrimental effects observed with the defocused Gaussian beam.

This advancement marks a significant milestone in the quest for more efficient PBF-LB/M processes, showing the potential of beam shaping to meet the industry's needs for faster, more reliable additive manufacturing solutions.

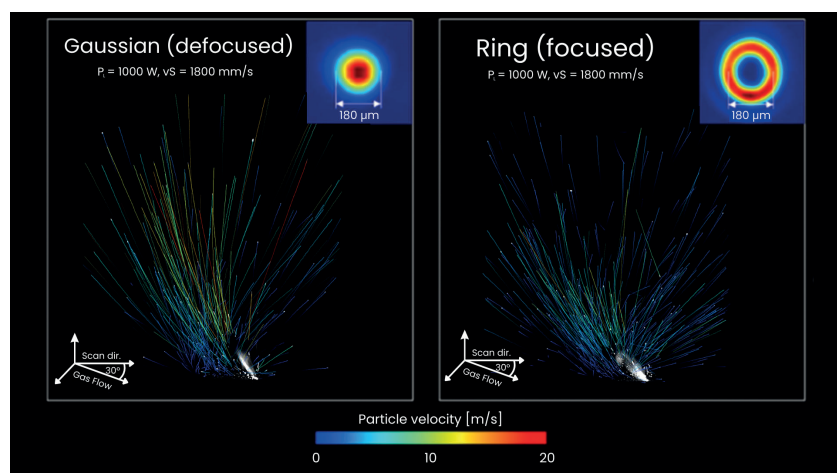
Advantages of the MPLC solution

The multi-plane light conversion (MPLC) technology represents a groundbreaking solution in the domain of PBF-LB/M by addressing some of the most critical challenges in the field, particularly concerning beam shaping at high power levels. The MPLC technology's inherent advantages stem from its fully reflective design, which ensures stable and robust performance even at high power settings. This was convincingly demonstrated during tests at 1 kW, indicating that these conditions are well within the capabilities of MPLC solutions, and not their upper limit.

A key feature of MPLC technology for PBF-LB/M applications is its ability to provide versatile beam shaping options, such as annular or M-shaped beams, while also offering a bypass feature to revert to the original Gaussian



Spatters density vs speed vs size – defocused gaussian (left), ring beam (right). Note the different scale in y and z, respectively



Projection comparison during an PBF-LB/M process with a Gaussian beam (defocused) and with a Ring shape (focused)

beam when necessary. This flexibility is crucial to optimize printing processes; for example, using a wide annular beam can increase printing speeds when filling in the bulk of a part, while switching to a fine Gaussian beam enables the precise printing of detailed features or contours. Such adaptability ensures that speed and quality are not mutually exclusive but can be achieved simultaneously within a single laser system.

MPLC technology affords unprecedented control over the beam shape. Unlike dual-core lasers, MPLC allows for the independent adjustment of the annular beam's thickness, its diameter, and the diameter of the Gaussian core. This capability facilitates real optimization of the printing process, enabling faster speeds without compromising the quality of the final product.

Another significant advantage of MPLC over other beam shaping solutions is its inherent large depth of field. This attribute of the technology enhances process performance by reducing the need for stringent precision during setup and execution, simplifying the operational requirements to achieve the best results. The larger depth of field ensures that the beam

maintains its desired shape and effectiveness over a greater range of distances, making the PBF-LB/M process more forgiving and robust, particularly when dealing with complex geometries or when slight variances in layer height may occur.

MPLC technology represents a significant advancement in additive manufacturing, offering a suite of benefits that include high-power compatibility, flexible beam shaping capabilities, and an increased depth of field. These features collectively enhance the efficiency, quality, and versatility of PBF-LB/M processes, marking a substantial step forward in the pursuit of faster, more reliable additive manufacturing solutions.

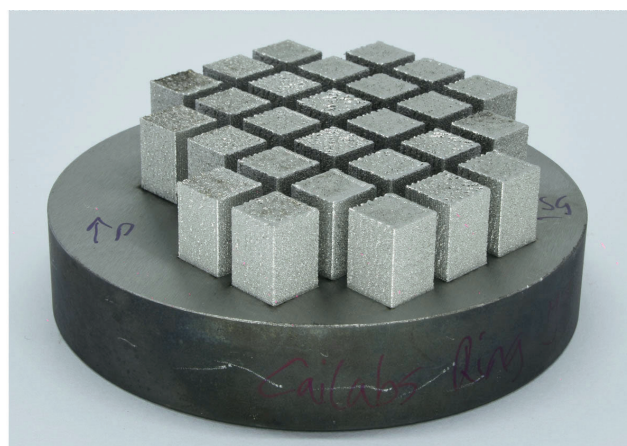
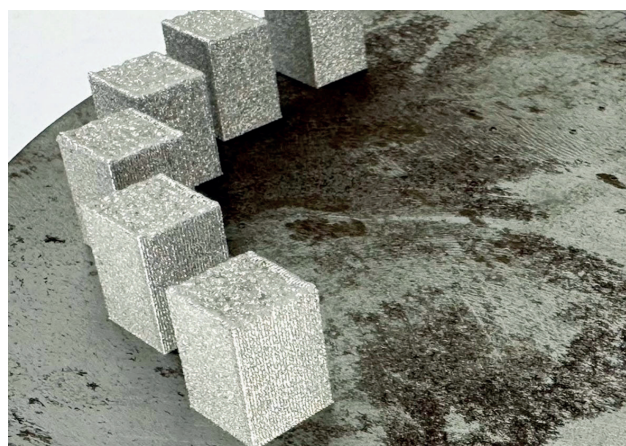
Conclusion

In conclusion, the exploration and adoption of advanced beam shaping techniques, particularly through the innovative use of multi-plane light conversion (MPLC) technology, herald a new era in PBF-LB/M capabilities. By enabling precise control over beam shape and offering the flexibility to adapt to both high-speed bulk printing and fine detail work, MPLC

technology significantly enhances the efficiency and quality of the PBF-LB/M process. Collaborations with pioneering institutions like Fraunhofer ILT underscore the industry's commitment to overcoming longstanding challenges, such as hot cracking and the need for faster printing speeds, to unlock the full potential of additive manufacturing. The successes achieved in printing materials like Inconel 939 and the advances in processing speeds represent more than just technical milestones; they signal a shift towards more versatile, robust, and economically viable manufacturing solutions. As we move forward, the continued development and integration of beam-shaping technology promise to further revolutionize the additive manufacturing landscape, making it an even more compelling choice for a wide range of industrial applications.

Perspectives

Looking ahead, the ambition to further accelerate the PBF-LB/M process remains a central goal, with an audacious target of increasing printing speeds by up to tenfold. Achieving this unprecedented level of efficiency will



Comparison of L-PBF printed samples without beam shaping (left) and with beam shaping (right)

necessitate pushing the boundaries of current technology, specifically by operating at power levels as high as 2 kW and by developing even more optimized beam shapes. Collaborative efforts are already underway, with key partners engaging in advanced simulations to identify and refine the optimal beam geometry for these high-speed, high-power conditions.

However, the pursuit of speed is only one facet of the broader challenge. Ensuring that such increases in productivity do not come at the expense of process quality is paramount. As such, alongside efforts to boost printing speeds, there will be a continued focus on enhancing the overall quality of the PBF-LB/M process. This will likely involve further innovations in beam shaping, as well as advancements in process monitoring and control technology, to ensure that the final printed components meet the stringent requirements of industries reliant on additive manufacturing. In sum,

the future of PBF-LB/M looks to not only redefine what is possible in terms of printing speed but also to elevate the

standards of quality and reliability in additive manufacturing.

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Niklas Prätzsch is responsible for all R&D activities related to the develop-

ment and improvement of laser powder bed fusion (PBF-LB/M) processes and systems as group manager for process and systems engineering at Fraunhofer ILT. His group with eight researchers is part of the laser powder bed fusion department. Niklas is leading several research projects for a range of industrial sectors including turbomachinery, automotive, and aerospace. He holds a master's degree in mechanical engineering from RWTH Aachen University and has been working at ILT since 2019.

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Preview

Full article in PhotonicsViews issue 4/2024

Increased productivity by combined laser processes

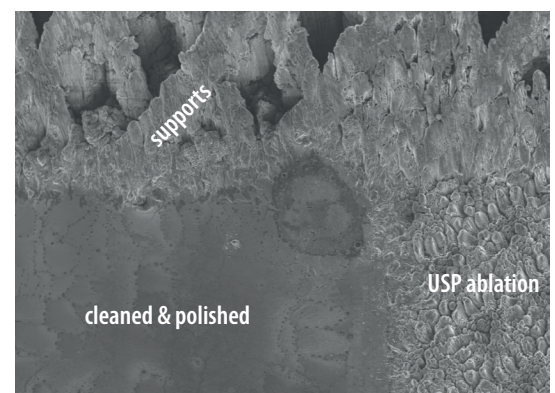
Laser-based post processing of additive manufactured metal parts

3D-printed metal components, made by powder bed fusion processes, exhibit a low surface quality in the as built state, which is also strongly dependent on the surface orientation in the printing process and is therefore insufficient for direct industrial applications. In addition, the powder bed fusion process requires support structures to connect thermally overhanging component structures and minimize distortion, which are today usually removed by machining or manually work, which is very time-consuming and costly. This poses a particular challenge for delicate and filigree component structures.

Laser-based post processing represents a possibility to enable contactless and therefore a force and wear-free, fully automated surface post-processing. Material removal using ultra-short-pulsed (USP) laser radiation enables high-precision machining. However, there is a conflict of objectives between a high material removal rate/productivity through the use of

high average laser power and a simultaneously high surface quality of the removed surface.

In this new approach, an OCT-controlled USP ablation process is cyclically combined with intermediate laser cleaning and laser polishing within the post-processing process. This enables precise removal of the support structures with simultaneous correction of the component shape, enabling a surface quality, which is suitable for industrial use. A significant increase in overall productivity at laser-based finishing of metal 3D printed components could be demonstrated.



Combined laser post processing steps of PBF – LB parts for an increased productivity: Initial supports, removed supports by controlled USP laser ablation, final laser cleaned and laser polished surface (Source: HS Aalen)

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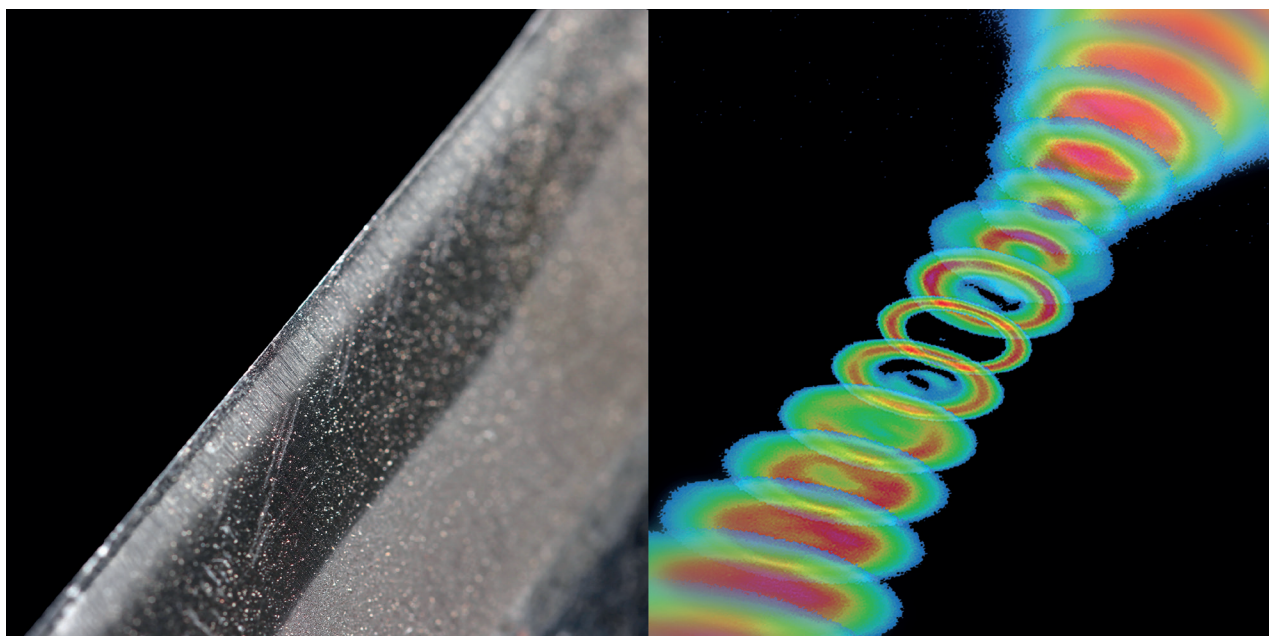
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Laser myth busting

A fact-based check of five common misunderstandings about laser beams in industrial use

Andreas Rudolf and Christof Blumenstein



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High-power laser systems are routinely employed as production tools, but the laser beam itself is sensitive to various disturbances, especially in the light of current trends toward extreme power and high beam quality. Suitable tools are available to characterize the process-relevant beam parameters – from power through focus dimensions to scanner-imposed properties. Yet either the challenges or the measurement tools tend to be underestimated – justifying a closer look at some of the common myths.

Laser material processing is the art of using light as a production tool. The analysis of the laser beam as such is an important upstream activity, performed with specialized measurement tools. This article sheds light on typical misunderstandings about the latest challenges and capabilities in measuring high-power laser beams.

Myth 1: Camera-based beam profilers are not capable of analyzing multikilowatt lasers

The typical task of a beam profiler is to measure and visualize the intensity distribution of a laser beam in a specific plane perpendicular to the optical axis, as illustrated in Fig. 1. The measurement tool should reproduce the real beam profile as accurately as possible,

with negligible distortion caused by its own optics and beam guidance. Camera-based profilers are a popular choice due to their ease of use, compactness and flexibility. High laser powers pose a challenge though, as bare camera chips already saturate at low beam intensities in the order of a few $\mu\text{W}/\text{cm}^2$ – which is an intrinsic limit set by their delicate opto-electronic microstructure. The chip can be directly exposed to a beam only up to this limit without giving falsified values or the chip being damaged.

Above this limit, the incoming beam must be magnified and/or attenuated. The magnification cannot be increased indefinitely due to the maximum size of suitable camera chips, while the attenuation is generally more scalable. Partially transmissive optics such as

▲ On a knife's edge: A blade and a laser beam share many analogous properties – and are both easily dented, compromising the processing results.

neutral density (ND) filters are commonly inserted into the beam path for incoming beam intensities of the order of a few W/cm^2 .

Going up to even higher intensities, any transmissive attenuator will fail due to thermal stress, as it will either aberrate the beam too strongly or the optic will suffer cracks or burn-ins. Nevertheless, camera-based analysis of beams with 1 kW and well above is possible, and has been industrialized into readily available products. Even extremely brilliant beams with foci as small as 15 μm and peak intensities of

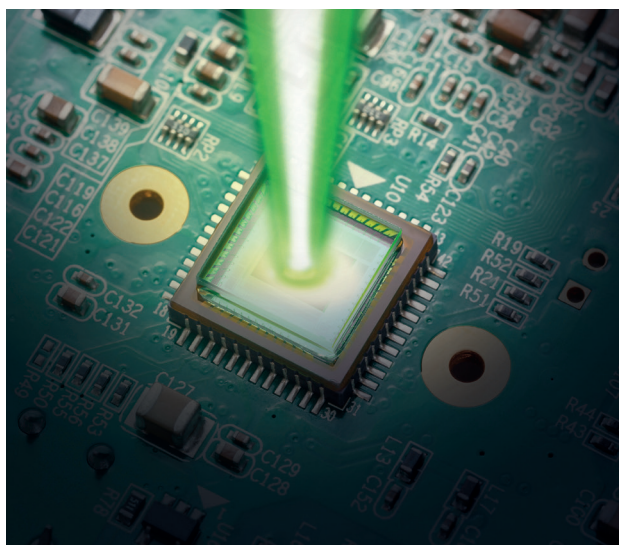


Image sensors – like CCD or CMOS – are well suited to sample the two-dimensional intensity distribution of a laser beam, both with high spatial and temporal resolution. To overcome the intrinsic intensity limit, the incoming beam is magnified and/or attenuated, which allows to analyze even multikilowatt beams.



Beam-scanning elements, e.g., galvanometric mirrors, impose their dynamics on the laser beam. New measurement techniques are available to analyze such fast-moving beam. This allows regular validation of the beam properties which is an essential part of quality assurance, e.g., to create flawless parts is laser powder bed fusion.

the order of GW/cm^2 can be handled [1]. How is this possible? The key is a highly integrated optical system that combines and intertwines aberration-free magnification and reflective multistage attenuation. If they are carefully designed, all optical distortions – including focal shift – are about one order of magnitude smaller than distortions imprinted on the incoming beam by typical laser systems and processing heads. Such a camera-based measurement tool can also be described as a high-power microscope, allowing a direct look into the eye of a focused laser at its maximum power. The possible uses are manifold and include

research, product development, quality management and service.

Myth 2: Scanner-based beam guidance systems can be fully characterized with traditional measuring devices

Fast beam steering as illustrated in Fig. 2 has enabled numerous applications such as powder bed fusion, EV battery manufacturing or functional surface generation. The laser beams themselves in such applications are not 'new', and are employed in fixed optics equally well; for example, a $50\text{ }\mu\text{m}$ Gaussian focal spot generated from a 1 kW single-mode laser. That is why, in a scanner setup, it is straightforward to analyze a beam with traditional power meters and beam profilers. This is usually performed under perpendicular incidence, for which most measuring devices are designed.

The beam deflection is driven by high-speed elements such as galvanometric mirrors or a polygon scanner – which superimpose their own dynamics onto the laser beam, including their inaccuracies and drifts. For many applications, additional optics relay the focal spots onto a flat plane either passively (e.g., an f theta lens) or actively (e.g., a motorized z-shifter). Also, not every movement is inherently synchronized with the laser emission (switched on/off, laser power) which usually remains the job of the laser electronics, driving the pump diodes accordingly.

Given all these scan-specific aspects, one quickly realizes that a large set of additional laser parameters come into play through beam steering – all of which can potentially jeopardize the application if misadjusted. They include:

- positional accuracy in x-y-z, across the entire scan field
- overlap accuracy of multiple beams sharing a scan field
- laser power under any accessible beam angle
- speed and direction of the beam
- delay time between beam movement and laser emission
- possible beam clipping within the optical system at certain deflection angles.

So far, destructive marking of anodized plates and their subsequent coordinate measurement has been the standard method of shedding light on these parameters – which is slow, costly, and has technical limitations in laser power and multilaser overlap. Also, it can hardly reveal any time-dependent effects such as focus shift. Suitable fully-optical tools have therefore been developed in recent years [2]. The probing element is a flat glass plate with an engraved microstructure. Scanning the beam across the structure creates a distinct scattering signal, recorded by photodiodes, which is then analyzed for the above-mentioned parameters. Measurements can be performed under the same conditions as the actual application, i.e., at maximum speed and laser power. Direct feedback to

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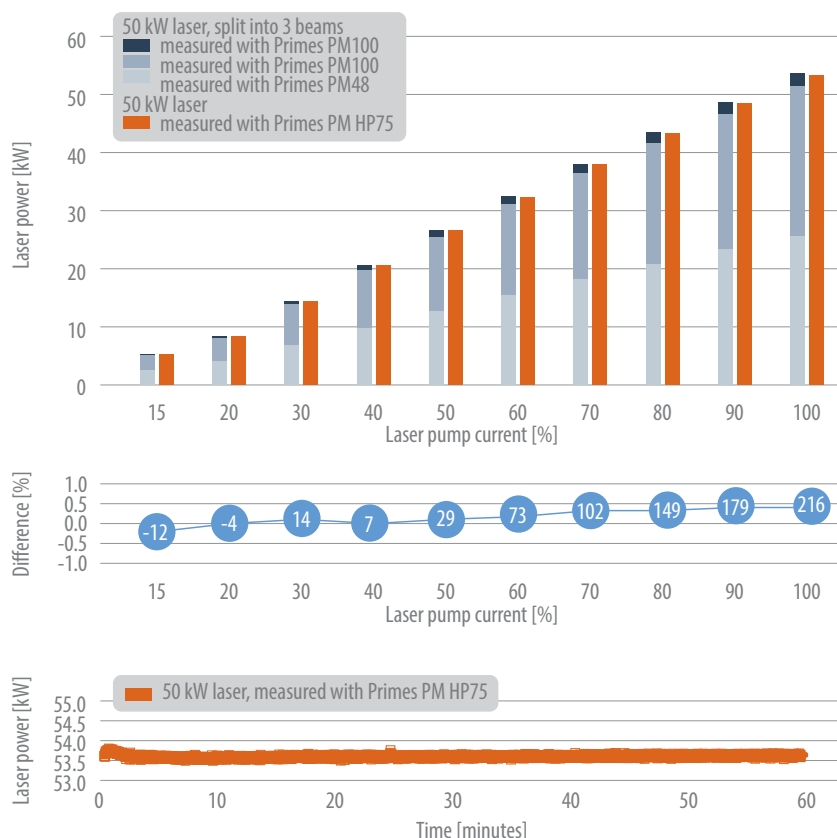
Primes is a globally-renowned pioneer in laser beam diagnostics, fueled by the vision that high-power lasers can reliably drive mass production. Since 1992, a series of key technologies has been industrialized and more than 30,000 measuring systems have been installed worldwide. These include power meters, beam profiling devices, scan-field profilers and production-integrated solutions. PRIMES products are widely recognized for their high precision, long durability and powerful software.

Event Information

Save the date for FOCUS: The 10th PRIMES workshop on laser beam diagnostics, 25 - 26 September:

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Results of a benchmark study, in which four different calorimetric laser power meters measured a 50 kW fiber laser. Comparison of the power readings at different laser output powers, with an agreement well below $\pm 1\%$ (top / middle, values in blue circles in watts). Single calorimeter measurement over a 1-hour period at 53.5 kW, with a standard deviation of 0.1 % (bottom)

the control system is possible in order to swiftly calibrate the scan system.

Myth 3: Calorimetric measurement of laser power is a guess-o-meter at best

Calorimetry is the measurement of heat that is transferred via a physical, chemical or biological process. One of these processes can be the absorption of laser light by a material – this is the basic underlying principle of every calorimetric laser power meter. The basic calorimetric equation is simple and carries variables that are easy and accurate to measure: $P = m c_p \Delta T$, where m is the mass of the material, c_p its heat capacity and ΔT its temperature increase through absorption [3].

Please note: calorimetry is not to be confused with thermoelectricity. Thermoelectric sensors (sometimes also called thermocouples or thermal sensors) rely on the electric voltage generated by a heat temperature gradient along a conductor.

It is a challenge to implement a precise calorimetric measurement for laser powers of the order of milliwatts and lower. This is because the resulting temperature increase is tiny and easily disturbed by ambient influences. Starting with laser power in the range of single Watts, calorimetric power sensors are state-of-the-art and have

been crucial in developing high power lasers and applications. The technology has been scaled up successfully to the order of 100 kW without compromising on accuracy.

Accuracy was demonstrated in a recent benchmark study: four calorimeters were tested with a high-power fiber laser from IPG capable of emitting up to 53.5 kW. In a first sequence, the laser was measured with a single calorimeter (Primes PM HP75). For the second sequence, the output beam was split into three beams that were measured individually with three calorimeters (two Primes PM100, one Primes PM48) and then summed up. Both sequences were performed at ten different power levels, ranging from 5 to 53.5 kW. Fig. 3a shows the results of the two sequences, and Fig. 3b plots their mismatch. Excellent agreement is found, with a maximum difference of only 0.4 %, which is a remarkable result given that a total of four calorimeters were involved. To demonstrate the temporal stability, Fig. 3c shows a measurement over a 1-hour period at 53.5 kW with the single calorimeter. The impression of a flat line is supported by the min-max spread of 0.9 % and the standard deviation of 0.1 %. Calorimeters have already been extended to self-calibrating devices

by employing an electric heater and precision power circuitry. This has even been recognized by the national metrology institute of Germany (Physikalisch-Technische Bundesanstalt, PTB) which has implemented a Primes EC-PM calorimetric power meter (where EC denotes electrically calibrated) as a national standard for laser power [4].

Myth 4: Laser beam diagnostics have barely improved over the last few decades

The analysis of laser beams used to be an expert domain performed with laboratory tools – fragile, difficult to operate, and even harder to make sense of the acquired data. One could say a physicist had to be bundled with every tool. Today, much of the expert knowledge has been incorporated into the devices as well as into the software for control and evaluation. On the hardware side, improvements have been made in ruggedness, measurement speed and connectivity. This has enabled inline beam diagnostics, running directly within mass production lines, for example in automotive plants [5]. Any process-relevant deviation of the laser beam can be captured within seconds to prevent the production of high-cost scrap. Also, portable beam diagnostics tools have

Using modern software for laser beam diagnostics requires no programming skills or mathematic formulas. Graphical user interfaces, visualized results and a “traffic light” rating facilitate first-time operation.



been developed for worldwide troubleshooting by service personnel.

On the software side, both the data acquisition and data analysis are performed via graphical user interfaces, eliminating the need for formularies and programming. Even complex algorithms have been implemented – such as those for the statistical analysis of a series of beam caustics – and the results are presented in a concise way for direct interpretation; see illustration in Fig. 4. This has enlarged the user community, allowing even occasional and inexperienced users to deliver reliable results.

As explained above, the measurement capabilities have generally been enhanced as well, in accuracy, power scaling and dynamic beam parameters. Looking further ahead, the next milestone will be the integration of beam diagnostics into the processing head itself. With direct access to the inter-

nal optical beam path, the relevant laser beam parameters can not only be monitored in real time, but also closed-loop controlled. This will safely remove the usual compromise between high productivity and process stability.

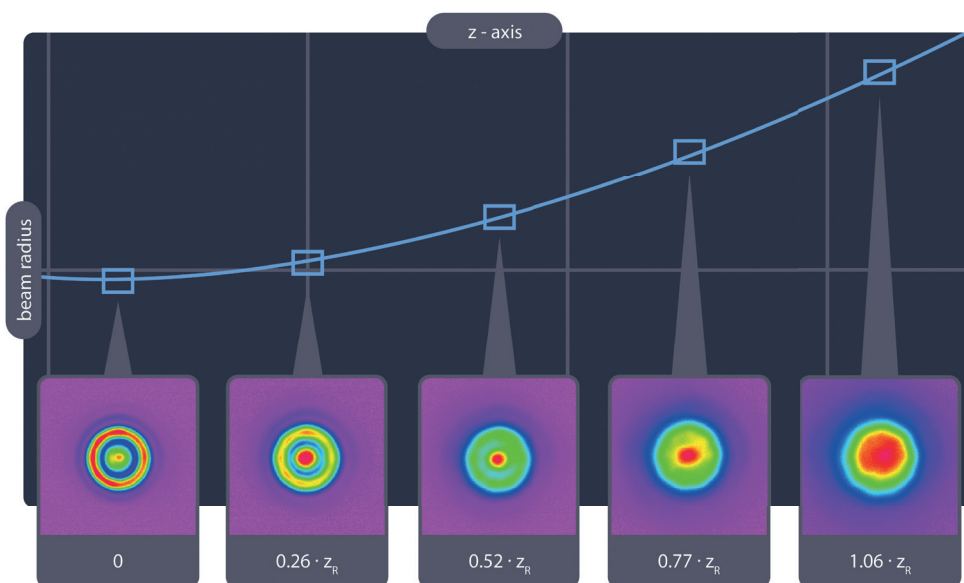
Myth 5: Ring-shaped laser beams can be properly evaluated based on the well-established ISO11146 standard

The propagation of laser beams is commonly characterized by parameters that are defined in the ISO 11146 standard. This includes well-known quantities such as 2nd-order moment beam width ($D4\sigma$), Rayleigh length (z_R) and the beam propagation factor (M^2). This framework gives appropriate results for typical beams that range from Gaussian to top-hat shape in their focal plane.

In recent years, a multitude of beam shaping technologies to generate ring-shaped beams with different complex-

ity has emerged and found its way into applications – and the above-mentioned quantities struggle to compare those beams meaningfully. The analysis is even more challenging for ‘mixed’ beams in which a central beam is surrounded by a ring. As an example, Fig. 5 shows a caustic measurement of an nLight AFX laser in its beam shaping index 5. In the focal plane, the central Gaussian spot and the surrounding ring carry 10 % and 90 % of the total power respectively.

By definition, the Rayleigh length is the axial distance from focus where the beam diameter has increased by a factor of $\sqrt{2}$ – usually accompanied by a minor change of the intensity distribution. Checking the AFX beam profile at this distance from the focal plane shows no ring structure at all anymore, just a near-Gaussian distribution. The ring structure ‘survives’ only for about one third of the Rayleigh length, and



Characterizing ring-shaped beams with traditional metrics like Rayleigh length can be misleading. In this example, the focal ring structure has vanished at about half of the Rayleigh length. New metrics are required to describe ring-shaped beams adequately.

turns into a low-intensity flat-top at about half the length. So for applications that rely on a ring-shaped intensity distribution at the focal plane, the Rayleigh length may be overly large, which can lead to false assumptions about the process window and process stability. Apparently, new metrics are necessary to describe arbitrary ring-shaped beams in an adequate, robust and more application-driven way. Primes is currently evaluating promising methods for a generalized analysis of ring-beams. Looking further ahead, such metrics may act as a blueprint for a new or updated ISO norm on ring-beam analysis.

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- [1] S. Kraft et. al.: *Phys Status Solidi A* (2024), 2300725, 1-5, <https://doi.org/10.1002/pssa.202300725>
- [2] A. Koglbauer: *Laser Tech J* **15** (2018), No 3, 40-44, <https://doi.org/10.1002/latj.201800016>
- [3] R. Klein et. al.: *Laser Tech J* **13** (2016), No 4, 45-47, <https://doi.org/10.1002/latj.201600025>
- [4] F. Brandt et. al.: *DGaO Proceedings* (2013), P6, https://www.dgao-proceedings.de/abstract/abstract_only.php?id=1582
- [5] B. Stumpp: *PhotonicViews* **16** (2019), No 4, 62-64, <https://doi.org/10.1002/phvs.201900035>

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Christof Blumenstein

is head of sales and marketing at Primes. Together with his 27-strong team, he serves and consults customers worldwide, drawing from his wealth of experience in laser beam diagnostics. With his deep understanding of both the measurement technology and modern laser applications, he takes on every challenge in characterizing laser beams.

Prior to joining Primes in 2011, he earned his degree in optical technology and digital image processing at Darmstadt University of Applied Sciences.

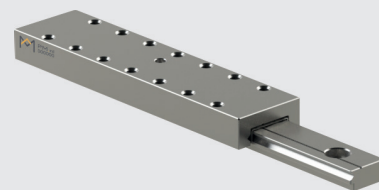


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Scaling up laser polishing using a polygon scanner

Combining a high power boost laser with ultrafast beam deflection using a polygon scanner to significantly increase the area rate of laser polishing

Linda Pabst, Robby Ebert, and André Streek

Surface roughness has a significant influence on the performance and appearance of components. By combining a boost laser with ultrafast beam deflection using a polygon scanner, very high processing speeds can be achieved. A 65 % improvement in surface roughness has been achieved on stainless steel, with $S_a < 0.1 \mu\text{m}$, while the gloss has increased from 130 to 366 GU. As a result, the previously matt surface became reflective, improving the appearance of the material. A real area rate of $156 \text{ cm}^2/\text{s}$ was achieved, comparable with industrial process times.

The visual appearance and functional properties of a product are significantly influenced by its surface roughness, including wear resistance, sliding properties, and biocompatibility. Surface treatment is therefore a common final step in industrial production. Despite technological advances, smoothing and polishing is still typically performed manually, a time-consuming process.

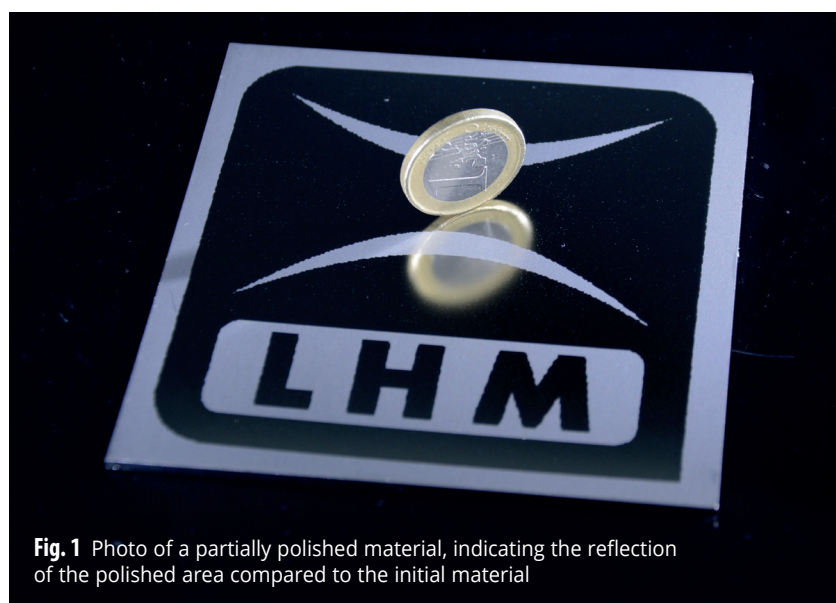


Fig. 1 Photo of a partially polished material, indicating the reflection of the polished area compared to the initial material

Source all images: H.S. Mittweida

In recent years, laser smoothing or laser polishing has emerged as an alternative process, but usually with low area rates.

The maximum throughput of laser processes is normally limited by the available average laser power or the speed at which the laser energy can be distributed over the workpiece surface. Laser sources with high average power have been developed in recent years, making the processing speed the limiting factor. The development of industrial polygon mirror scanners that allow high deflection speeds and therefore good energy distribution in a short processing time addresses this problem. Polygon scanners can deflect a laser beam fifty times faster than galvo scanners and are therefore especially advantageous for full-surface processing. Another advantage is the elimination of acceleration distances compared to galvo scanners. A disadvantage is the limited laser utilization of the scanner due to the necessary switch-off at the polygon mirror edge, especially with a large aperture or a large beam diameter. The MOEWE scanner

has a maximum utilization factor of 50 % due to its aperture of 30 mm.

At the initiative of Moewe, the IPG Laser company has developed a special laser that provides twice the average power in a short time of up to 5 ms, is used on the polygon line, and then switches off to recharge during the necessary switch-off at the polygon mirror edge. This means that almost 100 % of the average power of the laser can be used. The special lasers are available as ns boost lasers.

How laser polishing works

Laser polishing is based on localized melting of the surface by the laser beam and surface tension, resulting in a smoothing of the surface. No material is removed in the process but instead it is redistributed in the melt, unlike traditional polishing which is an abrasive process.

The laser beam melts a thin surface layer and the surface tension causes the melt to flow from the peaks to the valleys. The material then solidifies in a smoothed form. The laser beam is

Institute

Laserinstitut Hochschule Mittweida

The Laserinstitut Hochschule Mittweida (LHM) has been one of the leading research institutes in the field of laser technology in Germany, with internationally recognized research results on several innovative processes, for over 50 years. The focus of application-orientated research and development at the LHM is on laser nanotechnology, laser microtechnology and high-rate processing. The development of extremely fast processes using polygon scanners has been at the forefront for 15 years.

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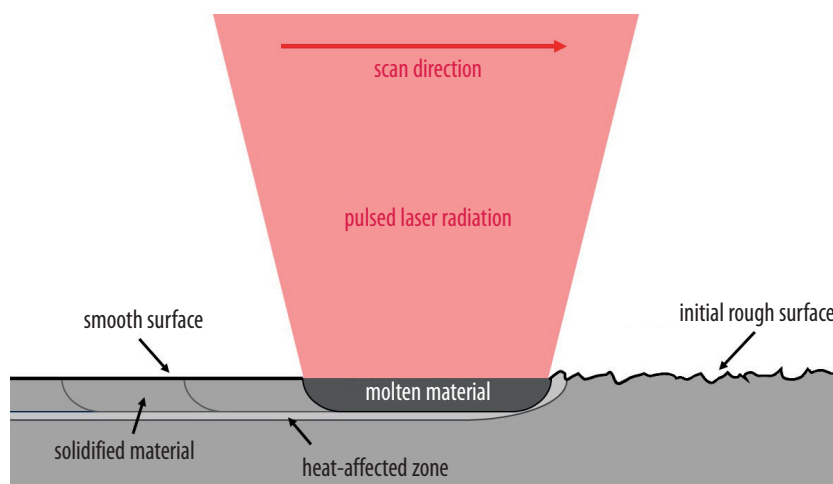


Fig. 2 Process principle of laser polishing using a pulsed laser

moved across the sample surface in a controlled manner to process a large area. When using pulsed laser beams, there is no continuous melt pool, the material solidifies between two laser pulses whereby the solid surface is re-melted with each laser pulse, see Fig. 2. Due to the high processing speed and short pulse duration, the thermal exposure time is short and only a very thin surface layer of a few micrometers is melted. The heat input into the material is therefore low, resulting in a small heat-affected zone and avoiding distortion of the components. Furthermore, the surface can be solidified without pores, hidden defects or cracks, and the gloss of the material can be increased by selecting appropriate laser parameters. Fine roughness, small surface defects or larger irregularities can be compensated for by applying the correct laser parameters and the resulting melt pool dynamics.

Experimental methodology

A ns-boost YLPN-150-25x100x100-600-BST-S laser from IPG Photonics with an average power of 3 kW and a power of 6 kW in boost mode was used in this study. The maximum boost time was 5 ms, after which the laser needed the same time to recharge, resulting in an operating duty cycle of 0.5. The multimode laser beam source had a square fiber with dimensions of $400 \times 400 \mu\text{m}^2$. The fiber end was imaged onto the sample surface using a collimator with a focal length of 85 mm and an F-theta optic with a focal length of 163 mm and a scan length of 105 mm, resulting in a square top-hat intensity distribution with a spot size of $0.77 \times 0.77 \text{ mm}^2$ in the imaging plane. The pulse duration could be varied between 30 and 100 ns.

A PM 100 polygon scanner from Moewe Optical Solutions was used for the ultrafast beam deflection. This was developed to deflect the extremely high laser power with low losses. Thanks to the synchronized and precise control of the laser by the scanner, the large spot areas can be placed very precisely or even as a pattern. The processing was performed in a normal atmosphere. Stainless steel 1.4301 was used as the sample material. The initial surface roughness of the material was $S_a = 0.275 \pm 0.009 \mu\text{m}$.

The sample was analyzed before and after processing to evaluate the effect of laser processing on the material surface. This allowed the influence of different process parameters on the surface properties to be determined. Firstly, the sample surface was optically analyzed using a light microscope and secondly, the surface roughness S_a was measured using a laser scanning microscope (Olympus Lext 3D OLS4100) according to DIN EN ISO 4288. Finally, the gloss was measured using a Rho-point IQ 20/60/80 Gloss Haze DOI meter. The gloss value was measured

according to the international standard ISO2813 in gloss unit GU.

Results of ultrafast polishing of metal surfaces

The pulse repetition rate, and thus the pulse energy, was varied in order to utilize the full laser power of 6 kW. An optimum pulse energy of 30 mJ and a fluence of 5.06 J/cm^2 were determined for the polishing of stainless steel, and a pulse repetition rate of 200 kHz was used. It turned out that only the longest pulse duration of 100 ns was suitable. Shorter pulse durations lead to an insufficient polishing effect due to the low melting depth and a considerable oxidation of the material caused by the higher melt pool temperature that occurs when processing with a higher intensity at the same optimum pulse energy in a normal atmosphere. Despite the relatively long pulse duration of 100 ns, an intensity of 50.6 MW/cm^2 was achieved on the sample surface. The full laser power of 6 kW could therefore be applied to the polygon line and the full average power of the laser could be used in the polishing process.

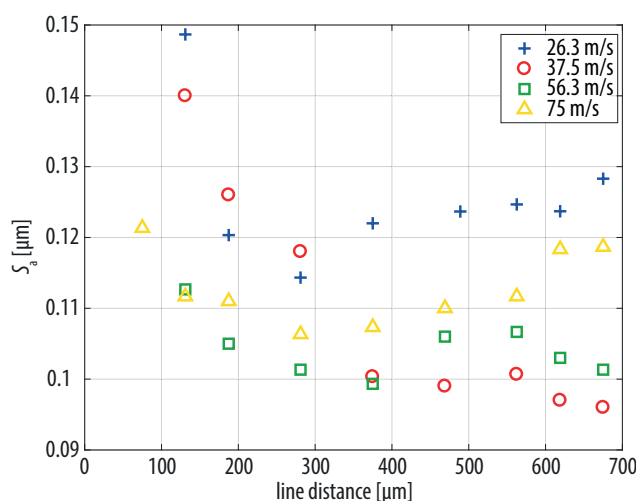


Fig. 3 Surface roughness S_a as a function of the line distance at various scan speeds

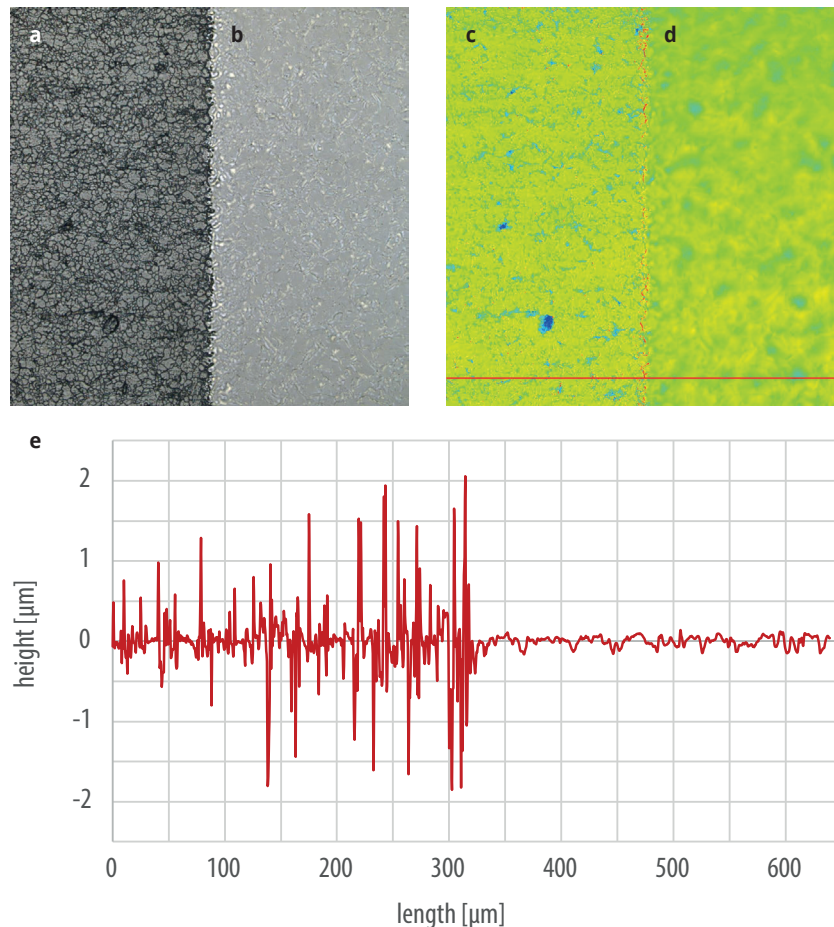


Fig. 4 3D measurement of the initial (a, c) and the polished surface (b, d), microscope image (a, b), 2D height image (c, d) and height profile (e) along the red line in c, d.

The arithmetic average surface roughness of the initial material was $S_a = 0.275 \pm 0.009 \mu\text{m}$. Fig. 3 shows the surface roughness S_a measured as a function of the line distance at different scan speeds. A significant reduction in the initial roughness was achieved in a large parameter range, with a surface roughness of $S_a < 0.11 \mu\text{m}$. As the line distance increased, the surface roughness decreased to a local minimum. When the line distance was further increased, increased roughness was observed in some cases. The position of the minimum was dependent on the scan speed: the lower the scan speed, the greater the line distance at which the local minimum occurred, see Fig. 3. At a scan speed of 75 m/s, corresponding to a pulse overlap of 50 %, the minimum was located at a line distance of 288 μm , corresponding to a line overlap of 62.5 %. At a scan speed of 37.5 m/s, corresponding to a pulse overlap of 75 %, the minimum was observed at the highest analyzed line distance of 675 μm , corresponding to a line overlap of only 10 %. The achievable area rate depended mainly on the line distance whereas the area rate increased as the line distance increased.

The minimum roughness of $S_a = 0.096 \pm 0.003 \mu\text{m}$ was achieved at a scan speed of $v = 37.5 \text{ m/s}$ and a line distance of 675 μm , corresponding to a roughness reduction of 65 % compared to the initial material. This results in a pulse and line overlap of 75 % and 10 %, respectively. With these processing parameters, the real area rate was $104 \text{ cm}^2/\text{s}$ and the processing time was only $1.6 \text{ min}/\text{m}^2$. A processing time of only $1.07 \text{ min}/\text{m}^2$ could be achieved with an only slightly higher roughness of $S_a = 0.101 \pm 0.005 \mu\text{m}$, at a higher area rate of $156 \text{ cm}^2/\text{s}$. This corresponded to a 50 % increase in area rate with a 63 % reduction in roughness, compared to the initial material. The scan speed was $v = 56.3 \text{ m/s}$ and the line distance was 675 μm , resulting in a pulse and line overlap of 63 % and 10 %, respectively.

By using a top hat intensity profile, the line overlap could be very small, resulting in very high process speeds, achieving industry-relevant process times for laser beam polishing. Fig. 4 shows a microscope image (left) and false color topography image (right) for the initial (a, c) and polished (b, d)

surfaces. For the polished surface, the optimum process parameters with the highest area rate were used. The initial surface showed a rough surface with grain structure and irregularities, see Fig. 4a, 4c. Despite the use of pulsed laser radiation, no overlapping of the individual pulses is recognizable in the processed area, the surface was completely and homogeneously re-melted, see Fig. 4b, 4d. The roughness profile of the cross section along the horizontal red line indicated in Fig. 4c, 4d is shown in Fig. 4e. In the left half, the initial surface, a high roughness can be seen with maximum peaks and valleys of $\pm 2 \mu\text{m}$, corresponding to a maximum height of the roughness profile $R_z = 4 \mu\text{m}$. In contrast, the polished surface, right half, has a significantly lower maximum height of the roughness profile of only $R_z = 0.3 \mu\text{m}$. The surface is much smoother and the average surface roughness as well as the maximum roughness height have been significantly improved. However, the waviness of the surface could not be completely removed, resulting in a surface that is still not ideally smooth.

The gloss value of the initial material was $130 \pm 1.5 \text{ GU}$ and the surface had a matt appearance. The gloss value as a function of line distance at different scan speeds is shown in Fig. 5. An increase in gloss was achieved for almost all the parameters analyzed compared to the initial material ("Ref"). A local maximum was observed as a function of line distance. The best gloss values were measured for the same parameters for which the lowest roughness was determined, compare Figs. 3 and 5. The highest gloss value obtained was $366 \pm 2.5 \text{ GU}$, corresponding to a 182 % improvement. This allowed the previously matte surface to become reflective, as shown in Fig. 1, thereby enhancing the material's appearance significantly.

Conclusion

The combination of the laser's boost mode with the polygon scanner allowed the full average laser power to be used for the polishing process. Furthermore, the square top hat intensity distribution enables higher area rates by significantly reducing the line overlap compared to Gaussian intensity distribution. As a result, a real area rate of up to $156 \text{ cm}^2/\text{s}$ could be achieved. The processing time was only $1.1 \text{ min}/\text{m}^2$, achieving industrially-relevant process times for laser beam polishing. This

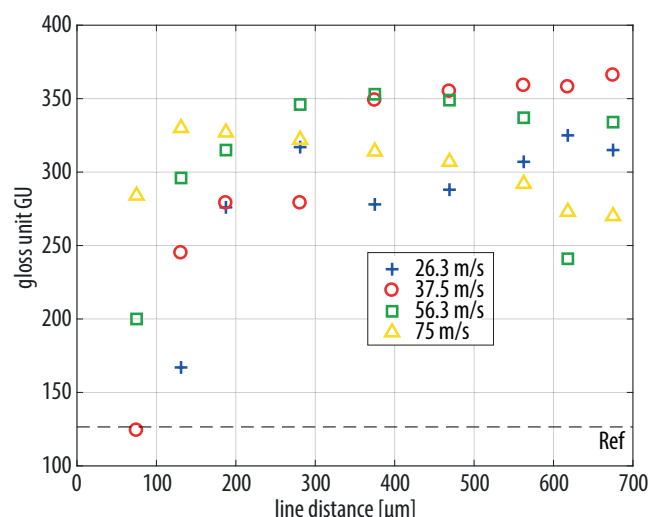


Fig. 5 Gloss of the material surface as a function of the line distance at various scan speeds

opens up completely new applications for the laser polishing process.

A significant reduction in surface roughness down to $S_a < 0.1 \mu\text{m}$ by simultaneously increasing the gloss

value of the treated area could be achieved. As a result, the previously matt surface became reflective, improving the appearance of the material. The innovative boost principle of the laser

works very well in combination with the polygon scanner and could be used for other processes.

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Robby Ebert

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André Streek

was educated and graduated in 2004 in physical engineering. He has been working as a research and development engineer in various fields of laser research. His profession is in additive manufacturing, high rate laser processing and in the development of high speed polygon scanning systems. He holds various patents in laser processing, rapid prototyping, and polygon scanning.



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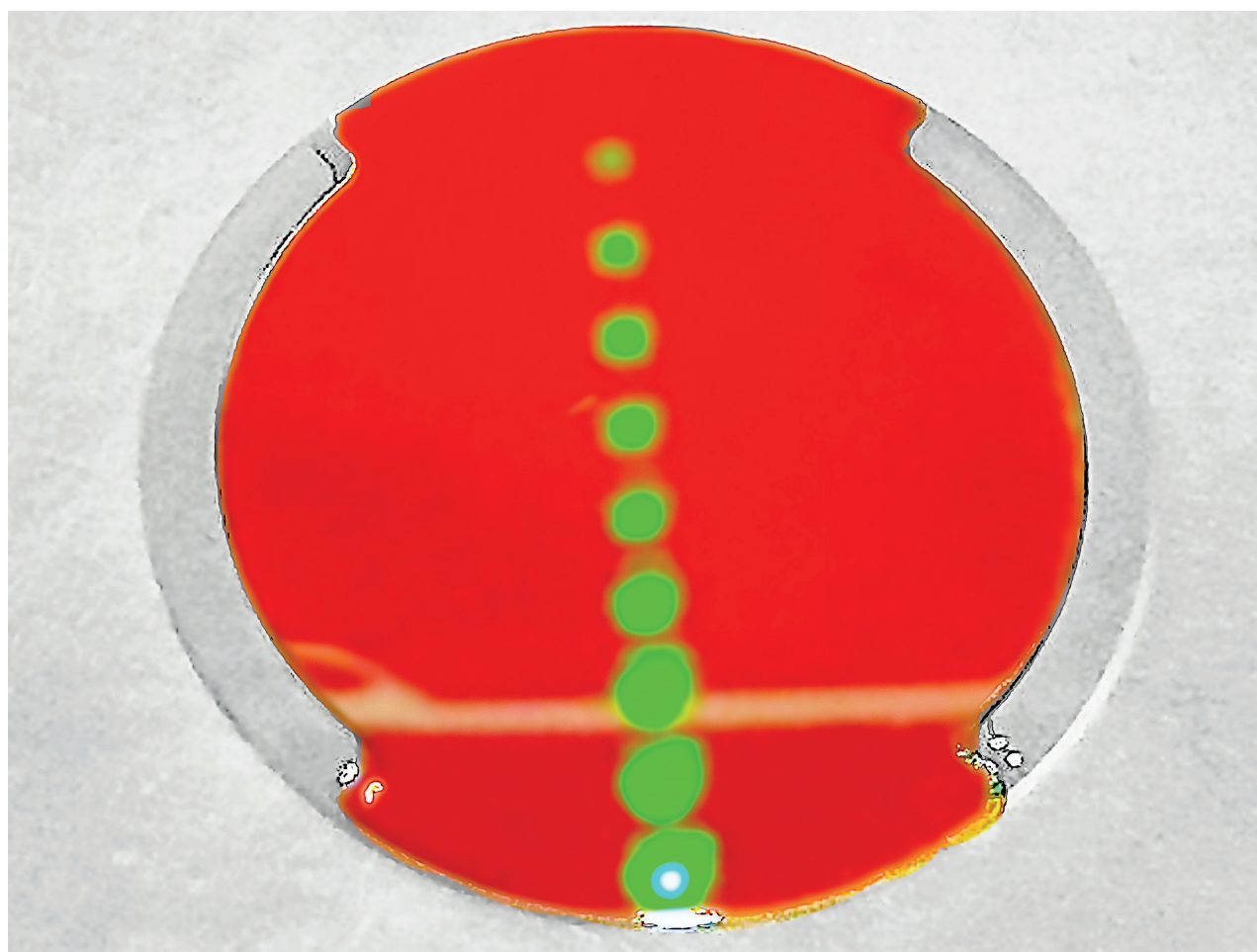
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Thin disks with a wedge

How to multiply beam paths within a thin monolithic crystal to create compact laser amplifiers

Jochen Speiser, Raoul-Amadeus Lorbeer, Pirmin Schweizer, and Benjamin Ewers



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Over the last decade, multipass thin-disk amplifiers have allowed astonishing laser properties to be achieved, but one drawback of these systems lies in their size and complexity. We show here an alternative approach with a wedged thin-disk crystal significantly shrinking and simplifying multipass thin-disk amplification.

The availability of larger and more powerful pulsed laser systems has enabled ever more high-throughput material processing methods [1, 2, 3]. Industrial high-power laser systems allow these new methods to be introduced into the manufacturing of new parts [4]. Pico-second (ps) laser sources in particular are currently lacking in availability and affordability. This is not exclusively but in part due to the complexity of high power ps-amplifier systems. Starting

from a very promising technology – multipass thin-disk amplifiers – the reduction of the necessary optical components promises an affordable, efficient, and scalable method of creating the next generation of high-power ps-laser sources.

Thin-disk systems rely on optical arrangements that redirect the laser radiation multiple times onto the thin-disk. These are necessary to overcome the relatively low absorption and amplification

▲ **Fig. 1** Multiple reflections from a wedged thin disk at a wedge angle of 1° . Visible are the coated areas in red as well as the reflections of one white LED appearing as a line of green spots.

of the thin crystal geometry. This drawback is offset by the beneficial cooling efficiency, resulting in systems capable of reaching kilowatt power levels. The goal of the wedged thin-disk (WTD) is to capture the laser radiation for mul-

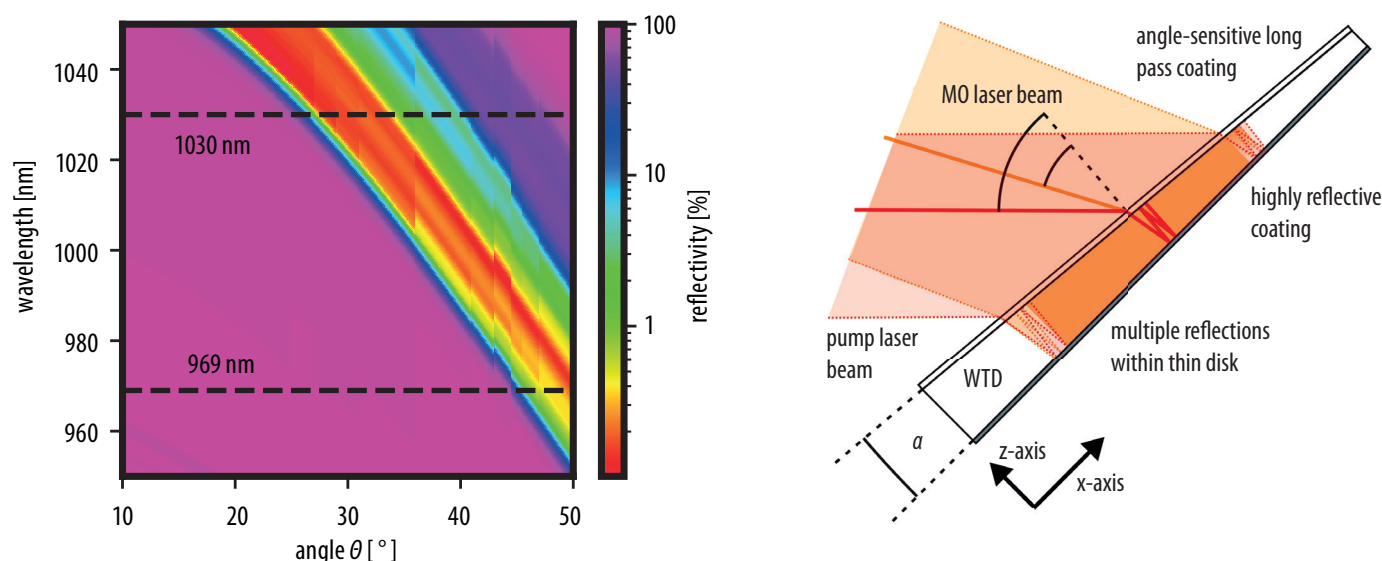


Fig. 2 Measured and extrapolated wavelength and angle dependent reflectivity of the custom band-pass filter applied to the WTD (left). Section view of the wedged-thin disk. Shown here are the incident master-oscillator (MO) laser beam, pump laser beam, front and back-coating, the wedge angle α as well as the axes x and z relevant to the wedge's symmetry (right).

multiple round trips within the thin-disk itself, making most of the external optics unnecessary, while keeping the essential benefits of a thin-disk amplifier.

Monolithic wedged thin-disk beam folding

Laser beams can be captured between two optical surfaces if they have the right properties. One possibility is the combination of a mirror surface with an angle dependent reflector. A long-pass filter typically has the appropriate angular transmission and reflectivity [4].

At higher power levels, band-pass filters are more suitable while still supporting the basic concept. The reflectivity of such a band-pass coating is shown in Fig. 2 on the left. It can be seen that the coating acts as a band-pass at a given angle of incidence (AOI) with respect to the wavelength. Likewise, the coating acts as a band-pass at a given wavelength with respect to the AOI as indicated by the dashed lines.

This property allows the transmission of radiation into the crystal at a given AOI while reflecting the same radiation at a smaller angle of incidence. In the case of an Yb:LuAG crystal, the master oscillator (MO) laser beam at 1,030 nm will enter at an AOI of 28°. As shown in Fig. 2 on the right, the crystal itself is wedged in shape and provides a highly reflective coating at the opposing surface. After one reflection, the succeeding AOI reduces to 24° in air due to the refractive index of the crystal and the wedge angle α of 1°. The reduced AOI is small enough to be reflected at the front coating. This

results in additional reflections, gradually reducing the AOI. Eventually, the beam reverses direction and the AOI increases until the beam reaches the transmission angle and exits the wedged thin disk.

The same effect can be applied to the pump laser beam. Also shown in Fig. 2, the pump radiation at 969 nm can enter the system at 47° and is captured as well after one reflection. Approximately 95 % of the pump radiation is deposited within the crystal, including all losses due to the absorption within the crystal.

Power scaling of wedged-thin-disk laser resonators

First experiments showed the potential of the concept to reach high average powers. A simple multimode I-resonator employing a concave output coupler with a radius of 1 m and transmission of 36 % was used to test the potential power levels of the WTD. Fig. 3 shows on the left that an output-power of up to 890 W cw laser radiation was achieved at 2000 W of pump radiation [6]. This corresponds to a slope efficiency of almost 60 %, an optical-to-optical efficiency above 50 % and a crystal temperature around 130 °C.

The first experiments also allowed the amplification of a single pass through the WTD to be evaluated. This corresponds to fifteen reflections from the back side of the wedge. A small signal gain factor of 10 was demonstrated for cw radiation, and showed the potential of the WTD to be utilized in a multipass WTD amplifier arrangement.

Pulsed amplification

Our current objective is to achieve an average power of at least 100 W for ps-pulsed laser radiation. A picosecond laser source with an average power of 25 W (Edgewave, FXz50-1-GF-e) was chosen to achieve this power level. The pulse duration was determined to be 2 ps with a spectral width of 0.8 nm full width half maximum. The repetition rate ranged from 5 kHz to 5 MHz. To cover different levels of MO power, the repetition rate was varied while the pulse energy was kept constant, reaching 5 μ J at the input of the WTD. The beam entered the WTD and was

Institute

Deutsches Zentrum für Luft- und Raumfahrt

The Institute of Technical Physics at the German Aerospace Center (DLR) develops laser systems for applications in aerospace as well as for security and defense purposes. At the Institute's locations in Stuttgart and Lampoldshausen, scientists, engineers and technicians work on interdisciplinary topics covering the detection and orbit manipulation of space debris, the laser-based remote detection of harmful and hazardous substances, long-range laser effectors, and laser-based flight instruments (air data).

The Institute of Technical Physics is a center of excellence for civil security and defense research, with many years of experience in the development and evaluation of high-power laser systems and active optical system technology, research into long-range beam propagation and laser-matter interaction.

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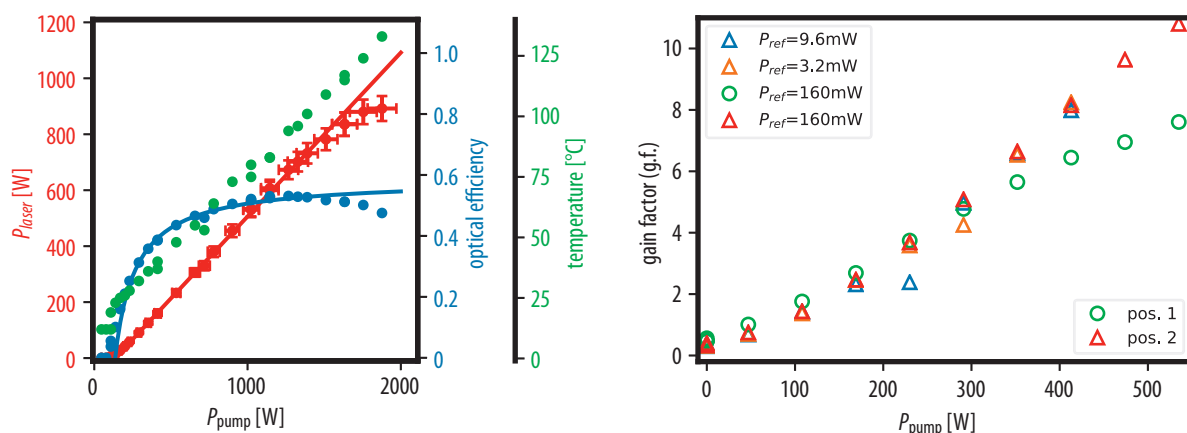


Fig. 3 Left: Optical-to-optical power of a WTD I-resonator. The optical efficiency and temperature captured with an IR-camera are also shown. Right: Small signal gain for a single pass of cw radiation through the WTD. (Images originate from [6] under CC-BY4 license (<https://creativecommons.org/licenses/by/4.0/>))

reflected fifteen times from the back surface before exiting the wedge again.

By tilting the WTD surface around its x-axis (see Fig. 2 right) the laser beam is no longer reflected back into itself – the beam will be deflected by twice the rotation angle around the x-axis. This enables the exiting beam to be separated from the incoming laser beam. By adding a quarter wave plate and a concave mirror, the beam is reimaged onto the WTD while the polarization is rotated by 90°. After re-entering the WTD and being amplified by fifteen more reflections from the back of the WTD, the beam finally exits the thin-disk and is fed into the beam diagnostics by a thin film polarizer (TFP). The setup is able to measure pulse energy, average power, pulse duration, M^2 , as well as the phase front with a Shack-Hartmann sensor. The WTD was pumped with a fiber-coupled 969 nm laser diode capable of reaching up to 2 kW of pump power. The fiber facet was reimaged onto the WTD for optimal coupling.

Various conditions of the double pass WTD amplification were tested by varying the pump power as well as the MO repetition rate.

The results are summarized in Fig. 5, the most interesting of which may be observed at the tested repetition rates of 10 kHz and 5 kHz as well as the highest repetition rate of 5 MHz. The highest pulse gain was observed at 5 kHz and 10 kHz repetition rates, corresponding to a low average MO power in the small signal gain range. This allowed pulse energies of up to 175 μJ at an average power of up to 1.75 W to be reached, demonstrating the potential for higher pulse energy amplification if suitable MO parameters can be met at high repetition rates. An average power of 95 W was demonstrated while the pulse energy at a 5 MHz repetition rate reached 19 μJ . This corresponds to a differential extraction slope of 28 % and an optical-to-optical efficiency of up to 22 %. These parameters are already suitable for ultrafast materials processing.

Conclusion and outlook

It turns out that the wedged thin-disk amplifier can be used for ps laser amplification and is capable of reaching high average output powers of around 100 W. This is achieved with a drastically reduced complexity compared to state-of-the-art thin-disk multipass amplifiers.

The major drawback of the altered shape of the thin disk lies in its break of rotational symmetry. This leads to thermal gradients that are no longer rotationally symmetric as well as corresponding phase errors of the amplified radiation. Despite potential approaches to further improve the amplification of the system, we are currently focusing on the correction of aberrations introduced by the thermal change of the refractive index in the WTD. The asymmetry introduces more aberrations than the typical defocus and spherical aberration experienced by the beam in planar thin-disk systems. Therefore, a spatial light modulator (SLM) will be used in proceeding work to evaluate the pos-

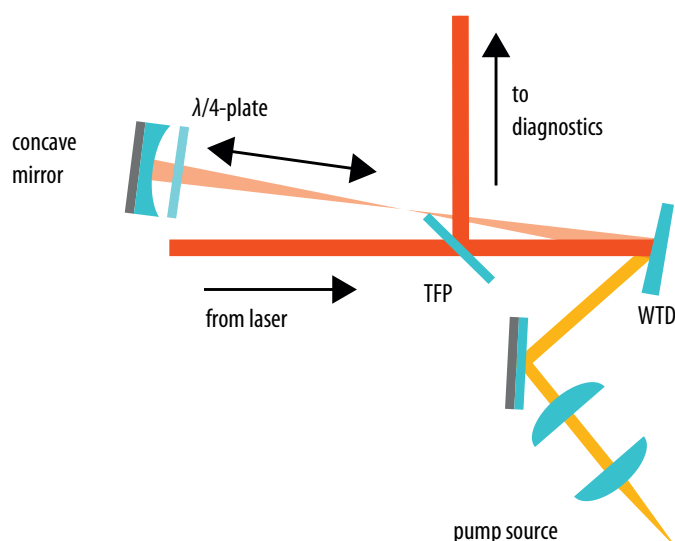


Fig. 4 Schematic amplifier setup. The MO beam path is indicated in red. The pump beam path is indicated in orange. Major components are the wedged thin-disk (WTD), quarter-wave plate ($\lambda/4$ plate), concave mirror, thin-film polarizer (TFP) and pump source.

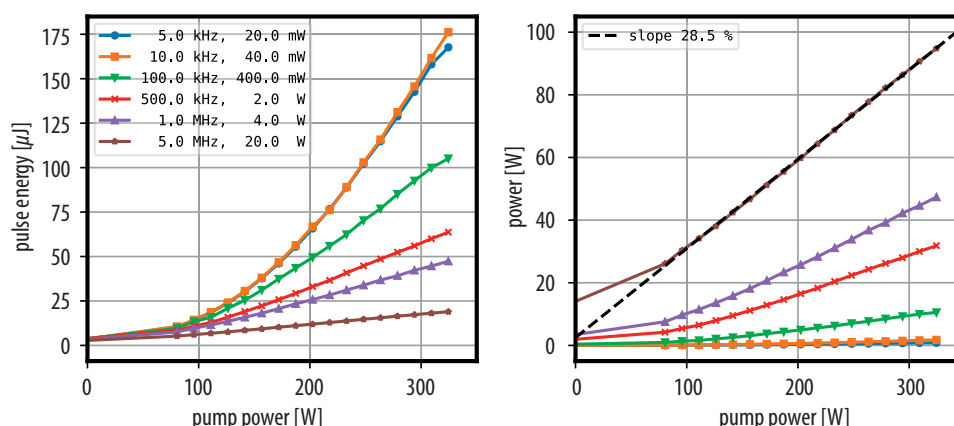


Fig. 5 Amplification of ps laser pulses at multiple MO repetition rates as well as a variety of pump powers. Left: Pulse energy vs. pump power. Up to 175 μJ of pulse energy were reached. Right: Output power vs. pump power. At high repetition rates, the power extraction became saturated and an effective output power of >90 W was reached. The differential extraction slope reached 28 %.

sibilities of beam pre-shaping to compensate for the additional aberrations. Recent results indicate a big improvement of the beam quality, although the desired high beam quality has still not been reached [7].

Simultaneously, the practicality of the WTD for the amplification of higher pulse energies at reduced repetition rates as well as the evaluation of the approach at different wavelengths and with different materials will be part of further investigations.

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- [1] M. Abdou Ahmed, C. Roecker, A. Loescher, F. Bienert, D. Holder, R. Weber, V. Onuseit, and T. Graf, "High-power ultrafast thin-disk multipass amplifiers for efficient laser-based manufacturing" *Advanced Optical Technologies*, Bd. 10, No. 4-5, 285-295, 2021.
- [2] D. Brinkmeier, D. Holder, A. Loescher, C. Röcker, D. J. Förster, V. Onuseit, R. Weber, M. Abdou Ahmed, and T. Graf, "Process limits for percussion drilling of stainless steel with ultrashort laser pulses at high average powers" *Applied Physics A*, 128, No. 35, 2022.
- [3] D. Brinkmeier, V. Onuseit and T. Graf, "Feasibility assessment of parallelized helical drilling" *Optical Engineering*, No. 62, 035106, 2023.
- [4] E. Mottay, "Ultrafast lasers today: The continuous increase in average laser power opens new horizons for femtosecond laser processing" *PhotonicsViews*, Vol. 19, No. 2, 80-83, 2022.
- [5] B. Ewers and R.-A. Lorbeer, "Interference filter based beam confinement for increased mechanical phase modulation" *OSA Continuum*, No. 2, 1502-1509, 2019.
- [6] R.-A. Lorbeer, B. Ewers, C. Santek, D. Beisecker, J. Speiser and T. Dekorsy, "Monolithic thin-disk laser and amplifier concept" *Optica*, Bd. 7, 1409-1414, 2020.
- [7] R.-A. Lorbeer, P. Schweizer, B. Ewers, A. Fischer, J. Speiser, and T. Dekorsy, "Compact chirp-free ps-pulse Wedged Thin-Disk Amplifier" *SPIE High-Power Laser Ablation VIII*, 12939-34, 2024 – proceedings not yet published.

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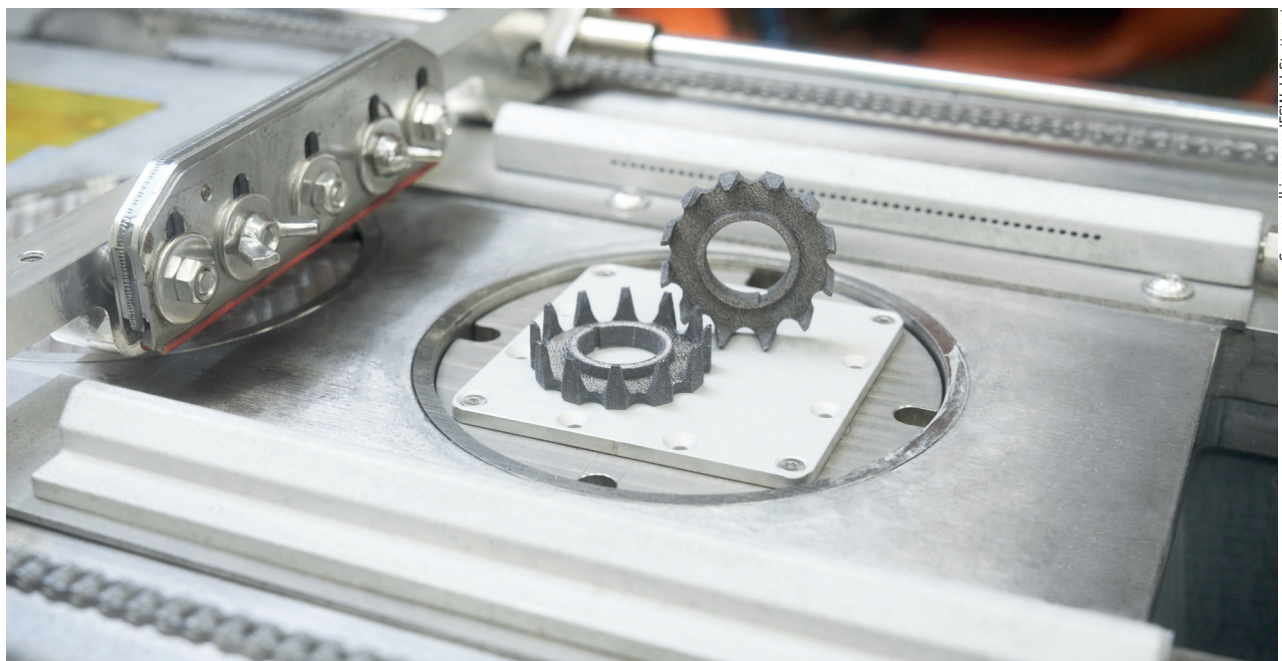
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Bridging additive and subtractive manufacturing

Exceeding the limits of conventional manufacturing with combined continuous-wave and ultrafast lasers

Daniel Holder, Manuel Henn, Matthias Buser, Christian Hagenlocher, Volkher Onuseit, and Thomas Graf



Source all images: IFSW, U Stuttgart

Additive manufacturing with laser powder-bed fusion (PBF-LB/M) can generate complex metal parts with a high degree of design freedom, which are already being used in various industries. However, the PBF-LB/M process faces some limitations in achievable surface quality and feature size. To address these challenges, we have developed a novel hybrid manufacturing approach that combines additive manufacturing via PBF-LB/M with subtractive manufacturing via ultrafast laser machining. By alternating between additive and subtractive processes, it is possible to not only mitigate the limitations of each process but also to introduce new functionality. This synergistic combination enables the creation of parts with superior surface finishes and deep and narrow internal features that are not possible with a single method alone.

Additive manufacturing (AM) has emerged as a transformative approach for the fabrication of complex metal parts. Among AM techniques, laser powder-bed fusion (PBF-LB/M) stands out for its flexibility and versatility. The inherent design freedom, coupled with the potential for mass customization and reduced material waste, positions PBF-LB/M as a sustainable and innovative manufacturing pathway.

The limitations of the process are in particular the dimensional accuracy and surface quality that can be achieved, as well as the minimum fea-

ture size that can be achieved. These limits can be overcome by subtractive post-processing with ultrashort laser pulses. For example, depth-controlled micromachining with ultrafast lasers enables a reduction of shape deviations and surface roughness of around sixty to eighty percent to just a few micrometers [1, 2]. In addition, postprocessing with ultrashort laser pulses opens up the potential for further functionalization of surfaces by creating surface structures in the micrometer and nanometer range [3]. These surface structures can be used, for example,

to improve water repellency and heat transfer in heat exchangers [4].

In order to push the boundaries of laser-based manufacturing even further, a new method of combined additive and subtractive processing has been developed at the IFSW. In this AddSub process, alternating processing with continuous wave (cw) and ultrafast lasers enables the creation of particularly smooth walls and narrow internal structures with previously unattainable aspect ratios [5, 6]. The method and the potentials of this novel manufacturing technique are presented in the following.

Method for combined additive and subtractive manufacturing

Fig. 1 shows the experimental setup and the processing steps of combined additive and subtractive manufacturing. A cw laser and an ultrafast laser partially share the same beam path and scanner system in one station and a flip mirror is used to switch between the two lasers. The cw laser used is a Yb:YAG disk laser (Trumpf, TruDisk 8001) with a wavelength of 1,030 nm. The ultrafast laser is a Yb:YAG laser (Trumpf, TruMicro 5050) with a wavelength of 1,030 nm and a pulse duration of 8 ps. A galvanometer scanner (Scanlab, IntelliSCAN 30) was used to scan the beam over the powder bed and the surface of the generated sample. An f-theta lens (Sill Optics) focused the beam of the cw laser and ultrafast laser to a diameter of 190 and 28 μm , respectively.

Parts were generated using the PBF-LB/M method by melting layers of iron powder particles with a particle size between 20 and 50 μm on a build plate with a temperature of 200 °C in a nitrogen atmosphere. The beam of the cw laser with an average power of 400 W was scanned over the powder bed with a scanning speed of 1.5 m/s and a line hatching distance of 100 μm to generate layer thicknesses of about 50 μm . After each generated layer, the beam of the ultrafast laser with an average power of 30 W – at a pulse repetition rate of 300 kHz – was scanned over the previously generated layer one thousand times at a scanning speed of 3.2 m/s to create a narrow slit (or groove) with a width of approximately 40 μm .

The first six consecutive processing steps of this additive and subtractive principle (AddSub method) are illustrated in Figs. 1a to 1f. The initial layer is created by melting the powder on the substrate, as illustrated in Fig. 1a. Following to this, the AddSub method involves the flip mirror switching to the ultrafast laser to locally ablate material of the previously added layer, as illustrated in Fig. 1b. Subsequently, a new powder layer is added and locally molten in the PBF-LB/M process, as depicted in Fig. 1c. The ultrafast laser is then employed to ablate material of the second layer at the same position as in Fig. 1b. This results in an ablated structure with a depth equal to the height of two layers, as shown in Fig. 1d. An animation of the combined process can be found online at [8].

The AddSub method allows for two novel use cases, which were impossible to demonstrate in the past. These two use cases are shown below.

Smoothering the walls of LPBF-generated metal parts

Fig. 2 shows an oblique view of an iron part produced by PBF-LB/M with magnifications of two walls of the part. The left side shows the wall without further processing, i.e. how these walls usually look after generation with PBF-LB/M. The right side shows the wall produced by the AddSub method, which means the wall was ablated using the ultrafast laser after adding each layer. This results in cuts over the total height of the parts.

The wall of the left side shows a poor surface quality, a rough surface topography due to the adhering powder particles. These powder particles cause high roughness values, usually $S_a > 10 \mu\text{m}$ depending on the build angle [3]. Smoothing the walls with the AddSub method significantly reduces the roughness to $S_a \approx 1 \mu\text{m}$ and thus allows to parts with a high surface quality to be produced. In contrast to the post-processing method shown in [1], the AddSub method creates a smoothed surface with perfectly vertical walls over a range of several millimeters.

Fabrication of deep structures with unprecedented aspect ratios

The AddSub method can be used to create not only smooth walls, but also narrow structures within the part with extremely high aspect ratios (depth to width). Fabrication of small structures by machining with ultrafast lasers is strictly limited to aspect ratios in the lower two-digit range due to physical limitations of the fluence in the tip of the groove [9] or hole [10]. In the case of combined additive and subtractive processing, however, only the thickness of the previously melted layer needs to be drilled or cut. The maximum possible depth of the structures is therefore only limited by the build height of the PBF-LB/M system. This is shown in Fig. 3 for three narrow slits that were produced within an iron cube of $5 \times 5 \times 5 \text{ mm}^3$. Fig. 3a shows the generated parts (left) and a cross-section of the generated slits (right).

The slits produced have a width of only around 40 μm over the entire part height of 5 mm. This is equivalent to an aspect ratio (depth to width) of 125:1,

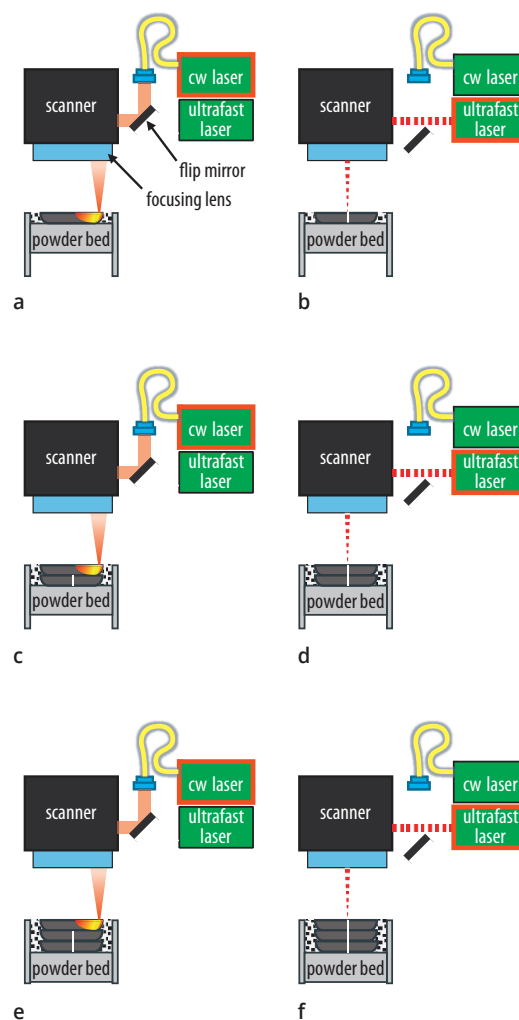


Fig. 1 Setup and consecutive processing steps of combined additive and subtractive processing using continuous wave and ultrafast lasers [7].

Institute

Institut für Strahlwerkzeuge (IFSW)

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

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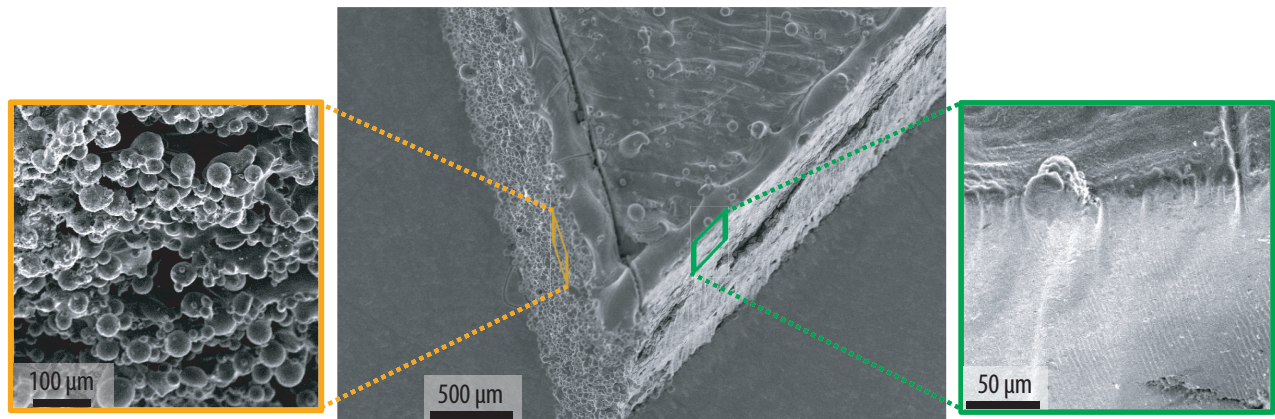


Fig. 2: Wall surfaces before and after subtractive processing with ultrashort laser pulses [7].

which was previously impossible to achieve with conventional micromachining methods. The results measured from the cross section shown in Fig. 3a were also confirmed by the computer tomography (CT) scans shown in Fig. 3. The CT scans also confirm the continuity of the slits and that no powder particles are enclosed in the structures. Recently published results show too that the slits can be created not only vertically in the part, but also at angles of up to 30° by adapting the scanning strategy [11].

Enabling novel applications in e-mobility

The AddSub process enables the development of new applications, for example in the field of e-mobility. One promising application is transversal flux machines with narrow slits in soft magnetic components to reduce eddy current losses. Fig. 4a shows one half of a simplified ring core sample that was designed for a first test run. The magnified cross section illustrates the arrangement of slits in the sample.

The AddSub method was used to manufacture multiple ring core samples according to the designed geometry. These are shown in Fig. 4b and are currently being measured for eddy current losses.

Conclusion and outlook

In summary, we have developed a novel hybrid manufacturing approach that combines additive manufacturing using PBF-LB/M and subtractive manufacturing using micromachining with ultrashort laser pulses. By alternating between additive and subtractive processes, we were able to overcome the limitations of each process and demonstrate vertical and smooth walls with a low roughness of approximately 1 μm as well as deep and narrow internal structures with an aspect ratio (depth to width) of 125:1.

Future research will be directed towards the further optimization of the AddSub process, with the objective of reducing the number of pores resulting from PBF-LB/M and increasing the productivity of the micromachining process. Both topics will be addressed by the use of a novel high-power, thin-disk multipass laser system developed at the IFSW. This system is capable of emitting a nearly diffraction-limited output beam composed of continuous wave or ultrashort pulsed radiation or both continuous wave and ultrashort pulsed radiation [13] with the potential for adapted processing strategies for high-power laser micromachining [14].

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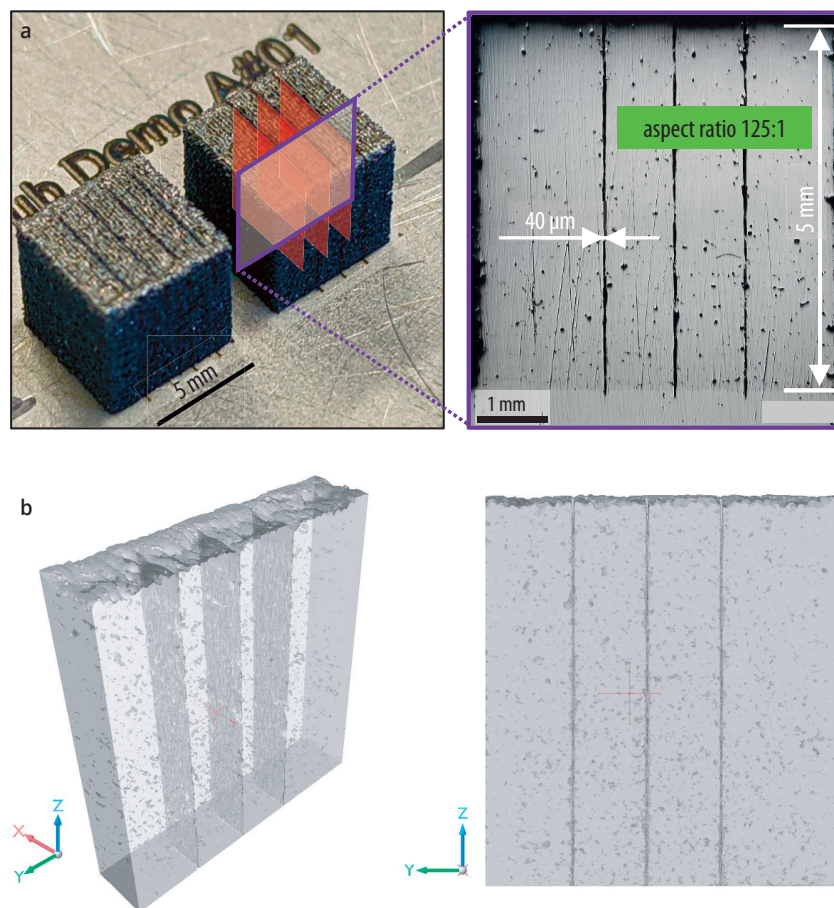


Fig. 3: Deep and narrow slits generated in a PBF-LB/M generated metal part by the AddSub method, which were analyzed using cross sections (a) and CT scans (b) [7].

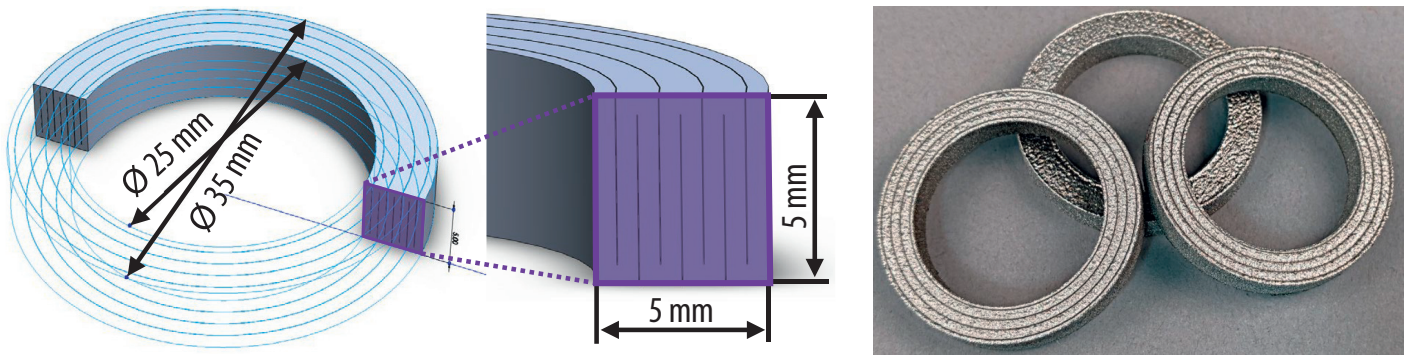


Fig. 4: Design of ring core samples (left) and results achieved by the AddSub method (right) [12].

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DOI: 10.1002/phvs.202400022

- [1] D. Holder, A. Leis, M. Buser, R. Weber, and T. Graf: High-quality net shape geometries from additively manufactured parts using closed-loop controlled ablation with ultrashort laser pulses, *Advanced Optical Technologies* 9, 101–110 (2020).
- [2] D. Holder, M. Buser, A. Leis, R. Weber, and T. Graf: Post-processing of additively manufactured metal parts by ultrashort laser pulses for high-quality net shape geometries and advanced functionality, *IOP Conference Series: Materials Science and Engineering* 1135 (2021).
- [3] D. Holder, F. Hetzel, R. Weber, and T. Graf: Surface treatment of additively manufactured metal parts for any arbitrary wetting state between superhydrophilic and superhydrophobic, *Procedia CIRP* 111, 715–720 (2022).
- [4] D. Holder, A. Peter, M. Kirsch, S. Cáceres, R. Weber, V. Onuseit, R. Kulenovic, J. Starflinger, and T. Graf: Enhancing heat transfer at low temperatures by laser functionalization of the inner surface of metal pipes, *Scientific Reports* 14 (2024).
- [5] M. Henn, M. Buser, V. Onuseit, R. Weber, and T. Graf: Combining LPBF and ultrafast laser processing to produce parts with deep microstructures, *Lasers in Manufacturing Conference (LiM)* (2021).
- [6] M. Henn, M. Buser, V. Onuseit, R. Weber, and T. Graf: Increasing the precision of Laser-Based Powder Bed Fusion by process combination with in situ laser ablation, *Procedia CIRP* 111, 61–64 (2022).
- [7] C. Hagenlocher, M. Henn, M. Buser, K. Cirakoglu, J. Michel, V. Onuseit, and T. Graf: Exceeding the limits of conventional manufacturing by means of combining additive and subtractive material processing with cw- and ultrafast lasers, *Procedia CIRP* (submitted) (2024).
- [8] Institut für Strahlwerkzeuge (IFSW), University of Stuttgart, “Neues Forschungsprojekt ADDSUB – New Research Projekt ADDSUB,” <https://www.youtube.com/watch?v=UISGiaZxXVs>
- [9] D. Holder, R. Weber, and T. Graf: Analytical Model for the Depth Progress during Laser Micromachining of V-Shaped Grooves, *Micromachines* 13 (2022).
- [10] D. J. Förster, R. Weber, D. Holder, and T. Graf: Estimation of the depth limit for percussion drilling with picosecond laser pulses, *Optics Express* 26, 11546–11552 (2018).
- [11] M. Henn, M. Buser, D. Holder, C. Hagenlocher, and T. Graf: Exceeding the limits in laser materials processing by bridging additive and subtractive manufacturing with continuous wave and ultrashort pulsed lasers: manufacturing of parts with undercuts, *Proc. of SPIE* 12876 (2024).
- [12] D. Kolb, M. Hofele, M. Henn, M. Buser, V. Onuseit, T. Graf, and H. Riegel: Enhancement of additive manufactured soft magnetic components by precise air gaps combining laser powder bed fusion and ultrafast laser ablation, *Lasers in Manufacturing Conference (LiM)* (2023).
- [13] C. Schmittner, A. Loescher, C. Reiff, T. Graf, and M. Abdou Ahmed: Fast switchable CW to ultrashort pulsed high-power laser beam from a single thin-disk multipass amplifier, *Proc. of SPIE* 12864 (2024).
- [14] D. Holder, M. Henn, A. Peter, S. Faas, A. Feuer, C. Freitag, R. Weber, V. Onuseit, and T. Graf: Ultrafast laser applications in the kW-class, *PhotonicsViews* 19, 40–46 (2022).

Authors

Daniel Holder

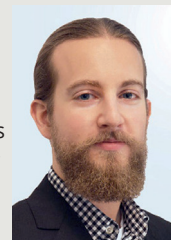
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LaserEMobility Workshop 2024

Lasers are showcased in Munich as key enablers in EV manufacturing

Ali Gökhan Demir

Following the success of the previous two years, LaserEMobility Workshop returns on July 17 – 18, 2024, with this edition to be held in Garching near Munich. The event brings together key players in EV manufacturing and laser technology with participants from industry and academia in a unique format. The two-day event will display recent developments in laser beam technology, new applications, monitoring systems, and many other discussion topics for an international community.



The next decade will be characterized by a significant increase in the use of electric vehicles (EVs). To meet this development, laser-based manufacturing processes will be essential for efficient and high-quality production. As the level of EV production rapidly increases, so will the demand for laser processing systems and the need for new laser processes. Lasers provide digital tools for EV manufacturing that have well-established adaptability to different materials, sizes, and product scenarios. The demand for laser-based manufacturing systems has highlighted the knowledge gap between the specific products in e-mobility applications and laser technology that must be bridged.

The advent of vehicle electrification is revolutionizing material types, usage, and manufacturing processes, alongside

vehicle design. Modern electric drives, or e-drives, are finding applications in various modes of transportation such as automobiles, drones, trains, aircraft, and ships. There is a growing need for lighter weight, extended drive ranges, and faster recharging capability as the number of these vehicles on the road increases. In contrast to traditional combustion engine vehicles, electric vehicles typically have fewer components but require more flexible welding, heat treatment, cutting, trimming, and texturing. Especially in the automotive sector, manufacturing plants must adapt to the reduced number of components and the increased necessity to weld multiple parts together.

Manufacturing processes must become highly digitalized, versatile, and reliable in order to address the need for swift changes in vehicle models and component variety. Laser-based manufacturing emerges as a vital solution, positioning these processes as the standard in e-vehicle production. Lasers are already employed in a range of applications, including hairpin stripping and welding, cutting and texturing Li-ion electrodes, welding battery busbars, and cutting composite materials [1]. The significant decrease in the cost of laser sources, optics, and components over the past decade has

facilitated their widespread adoption in e-vehicle manufacturing. Despite the maturity of laser technology, both system developers and end-users must keep pace with the escalating demands of e-vehicle production.

The LaserEMobility Workshop is an initiative to accelerate the adoption of laser use in manufacturing for the next generation of electric vehicles and to promote collaboration among stakeholders in the e-mobility sector who develop, use, or require laser-based manufacturing tools. Organized under the auspices of the Italian Manufacturing Association – AITeM – by three leading European universities, TU Munich, Politecnico di Milano, and the University of Bologna, the event has become a reference place of discussion. The workshop has previously been held in Bologna and Milan, moving this year to Germany for the first time on July 17 – 18, in Garching near Munich. The presentations will cover application-oriented topics over the whole field of laser material processing for electromobility, including:

- Battery cell and system manufacturing
- Processing of new battery materials and technology
- Electric drivetrain manufacturing
- Fuel cell manufacturing
- Lightweight construction

Event

LaserEMobility

The two-day event on 17 – 18 July 2024, is free of charge for all participants upon online registration. The event venue is the Science Congress Center Munich, Walther-von-Dyck Str. 10, 85748 Garching near Munich, Germany.

The 2023 LaserEMobility Workshop was held at Politecnico di Milano, reaching over 200 participants with more than 35 presentations from industry and academia.



- Process monitoring and control
- Digitalization and data-driven process optimization
- Sustainable electric vehicle manufacturing

The Technical University of Munich will host the in-person, two-day event and is expecting participants from research, laser component manufacturing, system integration, and the application communities. In addition to technical presentations for an international audience, the exhibition zone will showcase cutting-edge technologies. Additionally, a guided laboratory

tour at the TUM Institute for Machine Tools and Industrial Management IWB will offer hands-on insights into academic laser research. Upon registration, the two-day event will be free of charge and provide a unique opportunity for academics and industry leaders to share their latest research and insights.

- [1] A. G. Demir, J. Kriegler, A. Fortunato, L. Caprio, C. Geiger, L. Hille, M. K. Kick, A. Ascari, E. Liverani, and M. F. Zaeh: Challenges and Opportunities for Laser Applications in Electric Vehicle Manufacturing. In: Lecture Notes in Mechanical Engineering, Vol. Part F1351, pp. 219–253.

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Previews

Full article now online and later in PhotonicsViews issue 4/2024

Creating advanced photonics AI assistants

The first optical design copilot based on a novel dynamic agent approach

Optical design, a critical aspect of many scientific and technological applications, presents a wide variety of complex challenges, a mix of mathematical calculations, physical constraints, the search for suitable optical elements, and the execution of simulations – all of which require a high level of expertise and precision. The idea of leveraging artificial intelligence (AI) assistants to aid in these tasks has gained traction over the past couple of years. While its potential has already shown success in a plethora of applications, in the optical design arena it has largely remained untapped due to limitations in existing models.

The makers of 3DOptix, the advanced cloud-based optical simulation software, embarked on a mission to develop Opti-

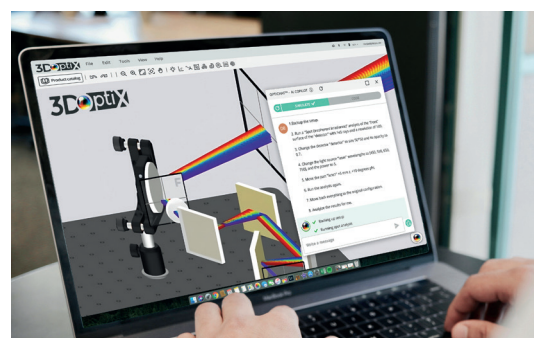
Chat, the first AI assistant designed to overcome the limitations of traditional AI models for optical design. In this article, we dive into the challenges of developing AI assistants in optics, present the dynamic agent framework, and show how OptiChat promises to transform optical design.

DOI: 10.1002/phvs.202400014



3DOptix Ltd

Prof. Haim Suchowski
Rehovot, Israel
e-mail: haims@3doptix.com
Web: www.3doptix.com



Source: 3DOptix

For domain experts such as optical designers, scientists, and photonics engineers, AI assistants often have limitations in their information accuracy and scope. 3DOptix has developed a dynamic approach to overcome these limitations that enables the creation of a proficient optical design copilot.



Source: Optica



Source: P E Schall

June 04 – 06, 2024

SLT 2024

Stuttgart, Germany

www.slt.uni-stuttgart.de



September 11 – 13, 2024

EOSAM 2024

Naples, Italy

www.europeanoptics.org



June 11, 2024

Photonics Germany Future Summit

Photonics & Quantum Technologies

Berlin, Germany

<https://photonics-germany.de>



September 11 – 13, 2024

CIOE

Shenzhen, China

<https://cioe.cn>



June 11 – 13, 2024

Sensor + Test

Nuremberg, Germany

www.sensor-test.de

September 15 – 19, 2024

13th CIRP Conference on Photonic Technologies

[LANE 2024]

Fuerth, Germany

www.lane-conference.org

June 11 – 14, 2024

EPHJ

Geneva, Switzerland

<https://ephj.ch>

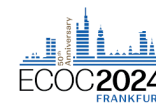


September 23 – 25, 2024

ECOC2024

Frankfurt, Germany

www.ecocexhibition.com



July 17 – 18, 2024

LaserEMobility

Workshop 2024

Garching, Germany

<https://laseremobility.com>



September 24 – 27, 2024

Micronora

Besançon, France

<https://micronora.com>

September 25 – 26, 2024

W3+ FAIR

Jena, Germany

<https://w3-fair.com/jena>

August 18 – 22, 2024

SPIE Optics + Photonics

San Diego, CA, USA

<https://spie.org>

October 08 – 09, 2024

Quantum Effects

Stuttgart, Germany

www.quantum-effects.com



Read event previews and reviews on www.wileyindustrynews.com/en/events

A successful 10th birthday in Wetzlar

Review: W3+ Fair, 13 – 14 March 2024, Wetzlar, Germany

The 10th W3+ Fair in Wetzlar, the networking trade fair and conference for enabling technologies in the fields of optics, photonics, electronics and mechanics, was all about technological innovations in a volatile environment. However, there was little sign of this at the event. With around two hundred exhibitors, partners and speakers, including OptoTech, Oculus, Hensoldt, Trioptics, Harmonic Drive, Werth Messtechnik and Janitza, the exhibition area was packed to the brim. 35 % of the exhibiting companies came from Hesse, 40 % from other German states and 25 % from abroad. 11 countries were represented, among them Switzerland, the Netherlands, the Czech Republic and the USA.

At the start of the accompanying 'en-tech.talks' conference, the region's big players took to the stage: Carl Zeiss, Leica Camera, Bosch Thermotechnik / Buderus Deutschland and Justus Liebig

University Giessen impressively demonstrated why the Wetzlar/Hesse region is ahead in many areas of technology. The main topic of 'Hessen in Space' by prominent speakers was very well attended. Moderated by Heraeus Quarzglas, RWTH Aachen University and the two German pioneers of fusion energy – Focused Energy from Darmstadt and Marvel Fusion from Munich – then presented their visions for a CO₂-free energy source. The Technische Hochschule Mittelhessen took a broad look into the future with its keynote speech "AI as CEO" and ventured a prediction as to whether management tasks could also be taken over by artificial intelligence in the future. The invitation from TeamMit, the new network that aims to support the Central Hessian automotive supplier industry in its transformation process, was also well received.

The many competence partners of W3+Fair were also well represented



Source: Fleet Events

The W3+ Fair – "Made in Wetzlar"

for the 10th anniversary, including the long-standing gold partners Wetzlar Network and EPIC, the world's largest photonics network, as well as OptecNet Deutschland, Spectaris, IVAM, AMA, and many more.

The next W3+ Fair in Wetzlar will take place on March 26 & 27, 2025. In Jena, the W3+ Fair will open its doors on September 25 & 26, 2024.

<https://w3-fair.com>

Spotlighting a thriving and expanding optical communications and networking industry

Review: OFC 2024, 24 – 28 March, San Diego, USA

The 2024 Optical Fiber Communications Conference and Exhibition (OFC) has exceeded the organizer's expectations and solidified its status as the premier global event for optical networking and communications. With 12,500 registrants from 74 countries, a showcase of more than 630 exhibiting companies (23 % more than 2023), and hundreds of sessions with industry-renowned and invited speakers, OFC 2024 was an unparalleled gathering for industry professionals and the global hub for innovation and collaboration in the field.

Topics such as 800ZR, coherent PON, linear pluggable optics (LPO), multicore fiber, artificial intelligence (AI), data center technology, quantum networking, and more captured the interest of industry leaders, experts, academia, media, analysts and students worldwide, facilitating the exploration of the latest advancements in optical technology.

OFC general chairs were Chris Fludger of Infinera, Germany, Roland Ryf of Nokia Bell Labs, USA, and Dimitra Simeonidou of the University of Bristol, UK. Esteemed industry luminaries Anita Döhler, CEO of NGMN Alliance; Inder Monga, executive director of ESnet; and David Richardson, partner researcher at Microsoft, headlined the OFC Plenary. They explored cutting-edge technologies, including quantum networking and next-generation networks, providing invaluable insights into the evolving landscape of optical communications.

The sold-out exhibition, held from 26 – 28 March, was a highlight, featuring more than 630 industry-leading companies representing the entire ecosystem of optical communications and networking. Attendees had the opportunity to explore groundbreaking technologies, innovative optical components, devices, systems, test equipment, software and specialty fiber products.



Source: Optica

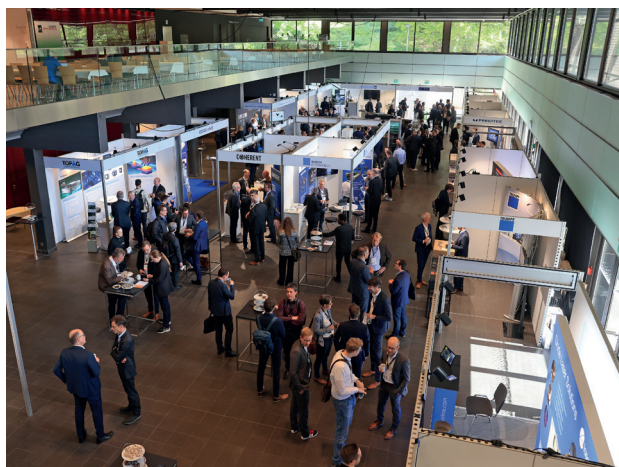
Exploring technology at the OFC 2024 exhibition

To meet the unique needs of a global audience, OFC 2024 was held in a hybrid format with in-person and virtual components. All technical program sessions and show floor programs will be available on-demand for later viewing by technical registrants. OFC 2025 takes place 30 March – 3 April, in San Francisco, California, USA.

www.ofcconference.org

“Huge, completely untapped markets for photonics”

Review: AKL'24, 17 – 19 May 2024, Aachen, Germany



Conference-accompanying exhibition



Panel discussion at the Gerd Herziger session

The AKL'24 – International Laser Technology Congress 2024 fully confirmed its reputation as a leading forum for the European laser industry: there were 525 participants and 81 speakers from 21 countries, a fully booked exhibition accompanying the conference, and 60 “Laser Technology Live” demonstrations in the laboratories of the Fraunhofer Institute for Laser Technology ILT and RWTH Aachen University. The congress focused on innovations for established laser applications as well as potential billion-euro markets of the future – including cyberphotonics, quantum technologies and laser-ignited inertial fusion energy. Once again, the Gerd Herziger Session was a highlight.

“We have not finished researching the laser. On the contrary – 60 years after its invention – things are just getting started!” said Prof Constantin Haefner in his closing speech at AKL'24. Looking ahead, he sees huge, completely untapped markets for photonics with sales potential of many hundreds of billions of euros in quantum technology, sustainability, secondary sources, cyberphotonics, and inertial confinement fusion. Haefner's list also reflected the top topics of the AKL.

One topic was omnipresent in the three-day lecture program: artificial intelligence (AI) is opening up new horizons for research institutes, laser system providers and their users. Indeed, AI is becoming a highly effective tool, especially when combined with dynamically advancing digitalization and ever more closely-meshed sensory process monitoring. This is

because masses of data are generated along industrial process chains, which companies can process into information with added value thanks to AI. During the Gerd Herziger Session at AKL'24, Fraunhofer ILT director Haefner discussed what this means for value creation and business models in laser technology with three top managers from the industry: Dr Hagen Zimer, board member and CEO of laser technology at Trumpf in Ditzingen, Dr Christoph Rüttimann, CTO of Bystronic Group in Niederörsz (CH), and Dr Christopher Dorman, executive vice president of the Coherent lasers business.

The panelists agreed on the already rapidly increasing impact of AI on the photonics industry. And they reported on how their companies are embracing AI without any hesitation – and creating added value for their customers. “Access to data and the ability to derive added value from it with AI is already synonymous with competitive advantages,” Haefner concluded.

Photonics must act to maintain its role

In the medium term, there is much more at stake, namely the question of who will control the photonics markets in the future: Suppliers of photonic hardware or software companies – are the latter only integrating lasers into digital platforms as a commodity and shifting the actual value creation to digital services? In order to maintain its current status, the industry needs to act quickly, all three panelists agreed. Their joint thesis: data science is the enabler

for a deeper understanding of laser sources, laser processes, measurement, and sensor data. AI, machine learning and digital twins are expanding the technological repertoire, which in the medium term will enable self-learning machines and first-time-right production.

It became clear at the congress that the photonics industry is already on this path. AKL's forum on digitalization and AI in photonic production showed the extensive co-operation between Mercedes and Trumpf in this area. Presentations by Dr Markus Kogel-Hollacher, Precitec, Dr Simon Höges, GKN Additive, Dr Wolfgang Rohringer, Xarion Laser Acoustics, Dr Michael Ungers, Scansonic MI, Thibault Bautze-Scherff, Blackbird Robotersysteme, and Christoph Franz, 4D Photonics, also showed how intensively the industry is driving this topic forward.

Other forums and sessions focused on the latest developments in functional surfaces, laser medical technology, additive manufacturing, and beam sources. Just like the further development of optical systems, these will have a major influence on the future markets of photonics – be it quantum technologies, cyberphotonics or laser-ignited inertial confinement fusion, to which Haefner dedicated an impressive closing lecture.

www.lasercongress.org

Preview: EOSAM 2024

9 – 13 September, Naples, Italy

EOSAM, the European Optical Society's Annual Meeting, takes place for the 12th time in 2024. The major international scientific conference and exhibition will take place this year in Naples,, in close collaboration with the Italian Society for Optics and Photonics, SIOF, the Italian branch of EOS.

The event covers all aspects of optics and photonics within several topical meetings and sessions. It is attended annually by over 500 top researchers, key leaders, students, and industry experts from over 30 different countries all over the world. At the event, we anticipate over 100 speakers each day within parallel sessions.

EOSAM includes high-level presentations on the current and most impressive research. There will be several plenary speakers taking the stage: Hatice Altug, Anna C. Peacock, Claudio Conti, Miles Padgett, Fredrik Laurell, and Kishan Dholakia.

The meeting consists of a week full of scientific, industrial, and educational programs. Recent research results

will be presented to a wide international audience, for connecting and catching up, as well as bridging the gap between research, education and industry.

Submission is still open for the following topical meetings (TOMs) and sessions:

- EU Project Session (in collaboration with Photonics21)
- TOM1- Silicon Photonics and integrated optics
- TOM2- Frontiers in Optical Metrology
- TOM3- Optical System Design, Tolerancing and Manufacturing
- TOM4- BioPhotonics and biosensors
- TOM5- Nanophotonics

EOSAM 9 -13 September 2024
European Optical Society Annual Meeting
Naples, Italy



- TOM6- Optical Materials
- TOM7- Ultrafast Phenomena
- TOM8- Nonlinear and Quantum Optics
- TOM9- Opto-electronics, Nanotechnologies & Microsystems
- TOM10- Applications of Optics and Photonics

Also focused sessions on holography and structured light, optical fibers technology, passive radiative cooling, photonics for cultural heritage, and machine learning for optics, and photonic computing for AI.

In addition to these sessions, EOSAM includes sessions on industrial mastering of optical technolo-

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gies and systems (IMOTS), industrial optics podium session (in collaboration with EPIC), as well as an early stage researcher session.

As in previous EOSAM conferences, in addition to the conference program of contributed and invited speakers, the association provides an additional benefit to all registered attendees in the form of tutorials, topical meetings (TOMs) and focused session. The tutorials will be held on Monday, 9 September 2024. Confirmed tutorial speakers include Sebastian Riese, Oliver Föhnle, Jacopo Bertolotti, Ignacio Moreno Soriano, Francesca Intonti, Alberto Puliafito, Katerina Kusova, Giovanni Pellegrini, Luca Sortino, and Stefania Campopiano.

Collocated with the EOSAM conference, the EOS will again host an industrial exhibition to bridge the gap between research and industry. It offers

the industrial forum as a new option for companies to bring forth their HR or product-related news to the whole audience of the EOSAM. The association invites all exhibitors to take part in the scientific program and submit a paper to any of the topical meetings and sessions. Companies are provided with the perfect setting to promote their expertise and products, announce job opportunities, create new leads, and strengthen existing ones. The EOSAM Exhibition takes place 10 – 12 September.

Sponsoring is warmly welcomed to maintain the great level of quality of the networking events and breaks, to benefit the student attendees, and support the best student presentation awards.

To book an exhibition space or sponsor package, or to discuss additional options, please contact the EOS execu-

tive director Elina Koistinen elina@europeanoptics.org.

Reserve your table and sponsoring package now to ensure you receive the best spot and visibility at the conference. Items are sold as first booked-first served (gold and silver sponsors will have priority in selecting the booth location).

Join the event with early-bird fees before 30 June 2024:

www.europeanoptics.org/events/eos/eosam2024.html



Preview: CIOE 2024

11 – 13 September 2024, Shenzhen, China

The 25th China International Optoelectronic Exposition will again present the entire optoelectronics industry chain to the world in September at the Shenzhen World Exhibition and Convention Center. With an exhibition area of 240,000 square meters, CIOE brings together over 3,700 high-quality exhibitors from more than 30 countries and regions worldwide, aiming to attract over 120,000 professionals to gather

under one roof, network with industry peers, explore business opportunities and exchange insights on future trends.

Co-located with seven sub-expos covering sectors such as information and communication, precision optics, laser and intelligent manufacturing, infrared, intelligent sensing, display technologies, etc., CIOE serves as a one-stop efficient procurement platform for industry professionals to source materi-

als, components, equipment, and solutions. Additionally, it is an

ideal trade platform for precise one2one business matching, rapid expansion of industry networks, as well as your best access to China's optoelectronic market.

Get your free pass to CIOE 2024 here:

<https://reg.cioe.cn>



Preview: 50th European Conference on Optical Communications – ECOC 2024

22 – 26 September 2024, Frankfurt, Germany

50 years of ECOC! In 2024, the event takes place in Germany. The organizers are looking forward to celebrating this special anniversary and have planned some outstanding social events. The European Conference on Optical Communication (ECOC) is Europe's leading conference on optical communications, and one of the largest and most prestigious events in the field worldwide. The conference brings together experts

and leaders from academia, research and industry across the globe to share their latest breakthroughs and visions for the future.

ECOC is a place to expand one's knowledge, discuss new ideas, and network with others. It encompasses everything from the materials and devices that make optical communication possible, to the systems and networks that use them.

The ECOC Exhibition has been running for nearly 30 years and has grown to become the largest optical communications exhibition in Europe as well as the key meeting place for decision makers from across the fiber optic communications technology industry. It occupies the central three days, 23 – 25 September.

www.ecocexhibition.com
www.ecoc2024.org



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