Fraunhofer

ILT

FRAUNHOFER INSTITUTE FOR LASER TECHNOLOGY ILT

ANNUAL REPORT 2019

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2019

Fraunhofer-Institut für Lasertechnik ILT

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Dear Readers,

Distinctive know-how and stirring visions are strong cornerstones for shaping progress and changing the world. But they are only two necessary prerequisites to achieving these goals. Principally, one needs not only a committed and innovative team ready to act, but also courage and tenacity to transfer knowledge into concrete, sometimes unusual, solutions to benefit society.

This is precisely where Fraunhofer ILT comes in. Our employees are inspired by the daily confrontation with new challenges from science and industry. Whether it is a matter of developing new laser beam sources for space applications like climate research, using high-power ultrashort pulse lasers for precision drilling of aircraft wings to save fuel, or increasing the productivity of 3D printing systems, the experts at Fraunhofer ILT explore a wide range of possibilities to solve the technical tasks at hand, often breaking completely new ground. This is also the reason why many companies put their trust in us. They know that we at Fraunhofer develop creative ideas and turn them into solutions with rigorously thought-out systems engineering.

In this annual report, you will find many examples of concrete process developments and system solutions that we have implemented in the current year. Since many of our projects must remain confidential, we can only publish a small part of our broad portfolio. If you have challenging tasks of your own, please contact us. We love direct dialog and short channels of communication.

As the new director of Fraunhofer ILT, I see my task as creating a framework that enables our experts to apply their creativity and proven know-how with passion. We diversify our teams in order to open up new perspectives and thus strengthen our innovative ability. Together with our customers and partners, we analyze how the market shifts in laser technology and sound out new horizons for future technologies. In these ways, we can solve challenging tasks from industry and society and help our customers compete both nationally and internationally.

In order to realize new potential for our partners and to shape the future, we are driving forward topics such as digitalization in production and the use of artificial intelligence. In turn, the institute incorporates its findings into the teaching and training of the next generation of students at RWTH Aachen University. As qualified and motivated experts and managers, this generation can then drive the progress forward in our institute and in industry. Let's tackle these issues together. I look forward to stimulating discussions with you.

Cordially,

Constantin Häfner

Prof. Dr. rer. nat. Constantin Häfner

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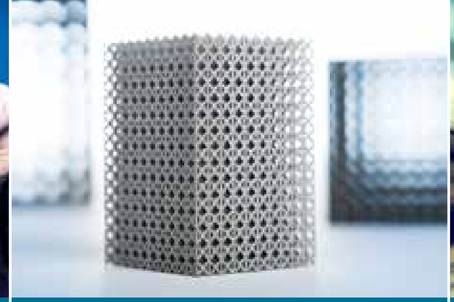

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EVENTS AND PUBLICATIONS

You will find a list of Fraunhofer ILT's scientific publications and lectures as well as bachelor and master theses online in our media center on the Internet at:
www.ilt.fraunhofer.de/en/media-center.html

FACTS AND FIGURES

2019

DECLARATION OF PRINCIPLES

MISSION

We have placed ourselves in a leading position to guide the transfer of laser technology to the industry, world-wide. We constantly expand our expertise and know-how, initiate trends of the future and, thus, decisively contribute to the continuing development of science and technology.

CUSTOMERS

We focus on what our customers need. We place great emphasis on discretion, fairness and partnership in our customer relations. According to the requirements and expectations of our customers, we develop solutions and implement them. We want our customers both to be pleased and pleased to return to us.

OPPORTUNITIES

By concentrating on our core competencies, we expand our knowledge in our networks strategically. We strengthen our network consisting of industrial and institutional partners with complementary services and establish strategic partnerships. We increasingly operate on international markets.

FASCINATION LASER

We are fascinated by the unique properties of laser light and the diversity of applications resulting from them. We are excited by the possibility of setting international standards through leading technological achievements and first-time industrial implementation.

STAFF

Our success is based on the interaction of the individual and the team. Each one of us works independently, creatively and oriented toward a specific goal. All the while, we proceed reliably, with attention to detail and are aware of the need to conserve resources. We place our individual strengths in the team and treat our colleagues with respect and fairness. We work together, across disciplines.

STRENGTHS

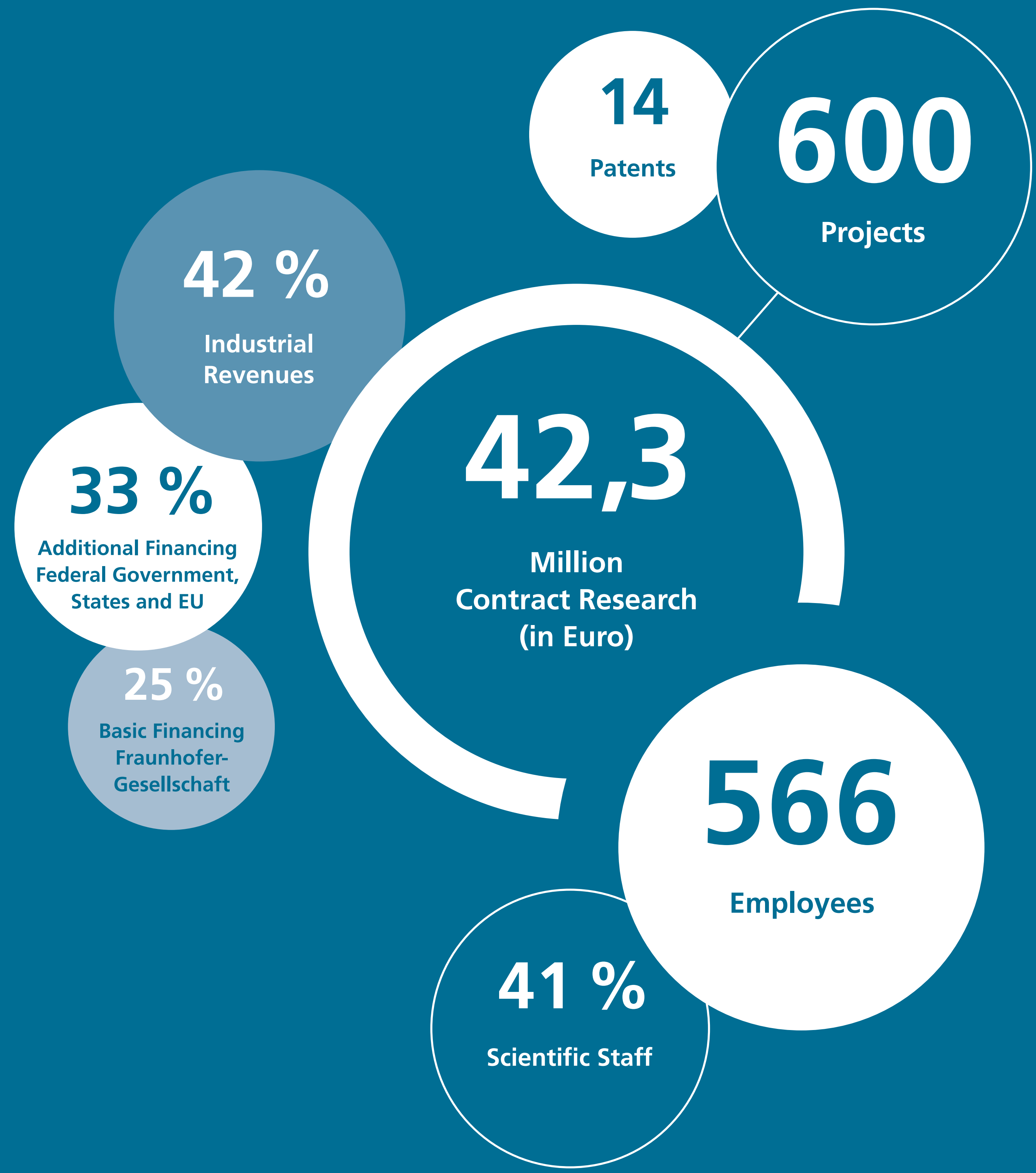
Our broad spectrum of resources enables us to offer one-stop solutions. We deliver innovative and cost-effective solutions and offer you R&D, consulting and integration. We solve our customers' tasks in multi-disciplinary teams using diverse and innovative facilities.

MANAGEMENT STYLE

Cooperative, demanding and supportive. Our management style is based on knowing the value of our employees as individuals, of their know-how and commitment. We have our employees formulate targets and make decisions. We place great value in effective communication, goal-oriented and efficient work as well as in making clear decisions.

POSITION

Our expertise extends from developing beam sources, processing and measuring technologies, via applying them all the way to integrating a plant within the customer's production line. We work in a dynamic equilibrium between applied basic research and development. We actively formulate and design research policy goals.



PROFILE OF THE INSTITUTE

SHORT PROFILE

ILT – this abbreviation stands for combined know-how in the sector of laser technology for more than 30 years. Innovative solutions for manufacturing and production, development of new technical components, competent consultation and education, highly specialized personnel, state-of-the-art technology as well as international references: these are guarantees for long-term partnerships. The numerous customers of the Fraunhofer Institute for Laser Technology ILT come from branches such as automobile and machine construction, the chemical industry and electrical engineering, the aircraft industry, precision engineering, medical technology and optics. With about 570 employees and more than 19,500 m^2 of net floor area, 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 Fraunhofer ILT cover a wide spectrum of topics within laser technology. In the technology area »Lasers and Optics« we develop tailor-made beam sources as well as optical components and systems. The spectrum reaches from freeform optics over diode and solid state lasers all the way to fiber and ultrashort pulse lasers. In addition to the development, manufacture and integration of components and systems, we also address optics design, modeling and packaging. In the technology area »Laser Material Processing« we solve tasks involving cutting, ablating, drilling, cleaning, welding, soldering, labeling as well as surface treatment and micro manufacturing. Process development and systems engineering stand in the foreground, which includes machine and control engineering, process and beam monitoring as well as modeling and simulation. Along with partners from life sciences, ILT's experts in the technology field »Medical Technology and Biophotonics« open up new laser applications in bioanalytics, laser microscopy, clinical diagnostics, laser therapy, bio-functionalization and biofabrication. The development and manufacture of implants, microsurgical and microfluidics systems and components also count among the core activities here. In the technology area »Laser Measurement Technology and EUV Technology« we develop processes and systems for our customers which conduct inline measurement of physical and chemical parameters in a process line. In addition to production measurement technology and material analysis, environment and safety as well as recycling and raw materials lie in the focus of our contract research. With EUV technology, we are entering the submicron world of semiconductors and biology.

Under one roof, the Fraunhofer ILT offers research and development, system design and quality assurance, consultation and education. To process the research and development contracts, we have numerous industrial laser systems from various manufacturers as well as an extensive infrastructure. In the nearby Research Campus »Digital Photonic Production DPP«, companies cooperating with Fraunhofer ILT work in their own separate laboratories and offices. This special form of technology transfer is based in a long-term cooperation contract with the institute in the sector of research and development. As an additional benefit, the companies can use the technical infrastructure and exchange information with experts of the Fraunhofer ILT. Around 20 companies already use these advantages. Alongside established laser manufacturers and innovative laser users, new founders from the sectors of custom plant construction, laser manufacturing engineering and laser metrology find appropriate surroundings to implement their ideas industrially.

DQS certified by
DIN EN ISO 9001
Reg.-No.: DE-69572-01

RANGE OF SERVICES

Services of Fraunhofer ILT

- Development of laser beam sources
- Components and systems for beam guiding and forming
- Packaging of optical high power components
- Modeling and simulation of optical components as well as laser processes
- Process development for laser materials processing, laser measurement technology, medical technology and biophotonics
- Process monitoring and control
- Model and test series
- Development, set-up and testing of pilot plants
- Integration of laser technology into already existing production plants or measuring systems
- Development of X-ray, EUV and plasma systems

COOPERATIONS

Cooperations of Fraunhofer ILT with R&D-partners

- Realization of bilateral, company specific R&D-projects with and without public support (contract for work and services)
- Participation of companies in public-funded cooperative projects (cofinancing contract)
- Production of test, pilot and prototype series by Fraunhofer ILT to determine the reliability of the process and minimize the starting risk (contract for work and services)
- Companies with subsidiaries at the RWTH Aachen Campus and cooperations by the Research Campus Digital Photonic Production DPP

NEW INSTITUTE DIRECTOR

Since November 2019, Prof. Dr. Constantin Häfner has been the director of Fraunhofer ILT. In parallel, he has also taken over the management of the associated Chair for Laser Technology LLT at RWTH Aachen University. As a university lecturer, Prof. Häfner is involved in the diverse activities of RWTH Aachen University, including the interdisciplinary research work of 16 different RWTH institutes within the Research Center for Digital Photonic Production RCDPP as well as the strategic cooperation with industry as part of the Research Campus Digital Photonic Production DPP.

Prof. Constantin Häfner studied physics in Konstanz, Germany and was subsequently awarded a doctorate in physics at the University of Heidelberg. In 2004 he moved to the USA, first working at the Nevada Terawatt Facility at the University of Nevada, Reno, and from 2006 at the Lawrence Livermore National Laboratory in Livermore, California. There, as Director of the »Advanced Photon Technologies« program, he led the development of the world's most powerful laser systems and the research and development of pioneering laser technologies.

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HIGHLIGHTS

Coating a brake disc with the EHLA process

Printed and laser functionalized strain gauge sensors on polymer foils.

Branched microtubes as well as complete microfluidic systems for biomedical analysis technology.

R&D-HIGHLIGHTS 2019

Laser processes for multi-functional composites

Since composites combine the advantages of dissimilar materials, they can be used to exploit great potential in lightweight construction. For the efficient production and processing of composite materials, there is a broad range of laser-based technologies such as joining and cutting processes as well as surface structuring.

Making plastic-metal hybrid compounds requires, however, that metal surfaces first have to be prepared. This can be accomplished, for example, by means of microstructuring with cw laser or micro- or nanostructuring with ultra-short pulsed (USP) lasers and different machine concepts. For such processes, a single-mode fiber laser (at a wavelength of 1064 nm) produces precise undercuts in the magnesium surface at area rates of up to 1000 mm² per second; these undercuts can be filled with plastic in the subsequent hybrid injection molding process. For short glass fiber-reinforced plastic, hybrid connections with high tensile shear strengths up to 22.4 MPa were developed – the components are not only extremely light but also, at the same time, extremely durable.

Laser technology supports the path to printed electronic diversity

Component-integrated electronics can be realized with printed electronics. Wet coating processes such as inkjet, pad or dispensing printing are used to deposit the necessary materials onto the components to integrate electrical functions into them. However, all layers have a common denominator: They require heat post-treatment, which is carried out conventionally in a furnace, for example. In its place, a laser beam can be used, which works much more precisely and quickly: Laser processing takes place in two steps: First, the laser beam dries the layer. As a result, only the functional particles, for example silver, gold etc., remain. The laser then partially or completely melts these micro- or nanoparticles and connects them so that they can conduct electricity, for example.

In the Fraunhofer lighthouse project »Go Beyond 4.0«, the application of electronic functional layers on components from the automotive among others is demonstrated. In vehicles a great deal of electronics in cars and trucks is installed – ranging from the windscreen wiper control over the camera module in the bumper all the way to modern sensors. With the new technology, individual signal and power lines for different equipment options can be applied directly and automatically to mass components such as doors.

Functional thin-film structures for integrated radar sensors

Within the joint project RadarGlass, a coating process chain that enables radar sensors to be integrated in car headlights was developed – milestone for autonomous driving. In the case of radar sensors, it makes sense to install them in the front headlamps. In order to guide and shape the radar beam, small patches of the coating have to be structured. These patches act as small antennas for the radar waves. For that, a laser process was developed at Fraunhofer ILT to shape the antenna elements. The laser-manufactured structures – with a resolution of up to 10 µm – are much more precise than any conventional printing process. Moreover, conventional lithography processes require more steps in the process chain and are limited to flat (or slightly curved) surfaces, two hindrances overcome by the new laser-based process.

New steel materials for 3D printing

One drawback currently prevents 3D printing of case-hardening and heat-treatable steel: suitably qualified and certified materials that would enable components to be additively manufactured in the LPBF process without forming cracks or defects are either unavailable or not yet available in sufficient quantities for industrial manufacturing. North Rhine-Westphalia has launched the lead market project AddSteel, which is aimed at digitalizing the steel industry and developing new function-adapted steel materials for additive manufacturing. One of the project’s key areas of focus is the qualification of the developed materials for laser powder bed fusion (LPBF).

The project partners have chosen to develop alloys in an iterative process, combined with systematic adjustments to the LPBF process and equipment. This will be followed by the construction of technology demonstrators for fabricating new components and spare parts that will be used to test and validate performance and cost-efficiency.

Producing polymer structures faster – two processes in one machine

Either fast or precise – both cannot be achieved in the production of the finest polymer structures with the laser. Or maybe they can? Combining stereolithography and multiphoton polymerization should make it possible: Scientists at the Fraunhofer ILT are developing a machine for high-precision, cost-effective 3D construction technologies using both methods. Therefore, the EFRE project HoPro-3D was launched. So far, various separate processes have been available for the producing of macroscopic polymer structures with a resolution down into the submicrometer range purpose: UV polymerization based on lasers, such as, for example, stereolithography (SLA) or micromirror arrays (DLP), and multiphoton polymerization (MPP) on a microscopic scale. The project partners are now combining the DLP-based process with the MPP process and developing a machine with two selectable exposure systems for either high build rates or high precision. They use high-performance LEDs emitting at 365 nm wavelength and a DLP chip with HD resolution for lithography. The MPP module uses a femtosecond laser with a fast scanner and microscope optics.

The fields of application are manifold, but this machine should prove most interesting for the production of components used in biomedical analysis technology. Support scaffolds for 3D tissue models or complete microfluidic systems are typical application examples for this.

EHLA provides effective protection for brake discs

More than many other auto parts, brake discs are subject to repeated mechanical loads. The “Extreme High-speed Laser Material Deposition”, known by its German acronym EHLA, is ideal for use in the automotive industry, especially for coating brake discs. Conventionally, it’s very difficult to coat brake discs, because they have to withstand high loads, and there are also economic and environmental considerations. With the EHLA process, the powder particles of the coating material are melted directly in the laser beam, rather than in a melt pool on the surface of the component. As a result, the coating process is much faster, rising from the 0.5–2 meters per minute with conventional laser material deposition to as much as 500 meters per minute. This also substantially reduces the exposure to heat of the material being coated. Unlike conventional laser material deposition, where the heat affected zone can have a depth of one or more millimeters, thermal exposure with the EHLA process remains in the micrometer range. The low heat input prevents the carbon to dissolve from the brake disc into the melt, otherwise resulting in brittle phases, pores, joining defects and cracks in the coating and bonding zone. In other words, it is now possible for the first time ever to provide brake discs made of gray cast iron with an effective coating that is firmly bonded with the base material.

STRUCTURE OF THE INSTITUTE

BOARD OF DIRECTORS

Prof. Constantin Häfner
Director (since 1.10.2019)

Prof. Reinhart Poprawe
Director (until 30.9.2019)

Prof. Peter Loosen
Vice Director

Dr. Vasvija Alagic-Keller MBA
Head of Administration

ADMINISTRATION AND CENTRAL FUNCTIONS

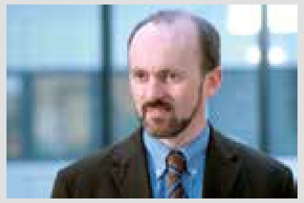
Dr. Vasvija Alagic-Keller MBA
Administration and Infrastructure

Dipl.-Phys. Axel Bauer
Marketing and Communications

Dr. Alexander Drenker
QM Management

Dr. Bruno Weikl
IT Management

COMPETENCE AREAS



Dipl.-Ing. Hans-Dieter Hoffmann
Lasers and Laser Optics

Dr. Arnold Gillner
Ablation and Joining

Prof. Johannes Henrich Schleifenbaum
Additive Manufacturing and Functional Layers

Prof. Reinhard Noll
Measurement Technology and EUV Sources

Board of Trustees 2019 at Fraunhofer ILT.

BOARD AND COMMITTEES

BOARD

The Board of Trustees advises the Fraunhofer-Gesellschaft as well as the Institute's management and supports the links between interest groups and the research activities at the institute. The Board of Trustees during the year under review consisted of:

CHAIRMAN

Carl F. Baasel, ROFIN-BAASEL Lasertech GmbH & Co. KG

MEMBERS

- Dr. Reinhold E. Achatz, thyssenkrupp AG
- Dr. Norbert Arndt, Rolls-Royce plc.
- Dipl.-Ing. Frank C. Herzog, HZG Management GmbH & Co. KG
- Dipl.-Ing. Volker Krause, Laserline GmbH
- Dipl.-Ing. Michael Lebrecht, Daimler AG
- Prof. Gerd Marowsky, Photonik Inkubator GmbH
- Manfred Nettekoven, Kanzler der RWTH Aachen University
- Dr. Joseph Pankert, TRUMPF Photonics Components GmbH
- Dr. Silke Pflueger
- Dr. Torsten Scheller, JENOPTIK Automatisierungstechnik GmbH
- Susanne Schneider-Salomon, Ministerium für Kultur und Wissenschaft des Landes NRW
- Dr. Ulrich Steegmüller, OSRAM Opto Semiconductors GmbH
- Dr. Klaus Wallmeroth, TRUMPF Laser GmbH + Co. KG

The 34th Board of Trustees meeting was held on September 18, 2019 at Fraunhofer ILT in Aachen.

DIRECTORS' COMMITTEE ILA

The Directors' Committee advises the Institute's managers and is involved in deciding on research and business policy. The members of this committee are: Prof. R. Poprawe (until 30.9.2019), Prof. C. Häfner (since 1.10.2019), Prof. P. Loosen, Dr. V. Alagic-Keller, Peter Abels (since 1.11.2019), A. Bauer, T. Biermann, D. Esser, Dr. A. Gillner, H.-D. Hoffmann, V. Nazery Goneghany (until 31.10.2019), Prof. R. Noll, Dr. D. Petring, Prof. J. H. Schleifenbaum, Prof. W. Schulz, Dr. B. Weikl, Dr. J. Stollenwerk.

HEALTH AND SAFETY COMMITTEE ASA

The Health and Safety committee is responsable for all aspects of safety and laser safety at Fraunhofer ILT. Members of this committee are: Prof. R. Poprawe (until 30.9.2019), Prof. C. Häfner (since 1.10.2019), Prof. P. Loosen, Dr. V. Alagic-Keller, A. Bauer, M. Brankers, R. Day, W. Fiedler, R. Frömbgen, A. Hajdarovic, S. Jung, D. Maischner, V. Nazery Goneghany, B. Quilitzsch, M. F. Steiner, F. Voigt, T. Yildirim, Dr. R. Keul (works doctor B.A.D), J. Pohl, S. Schoenen, (B.A.D Gesundheits-vorsorge und Sicherheitstechnik GmbH).

SCIENCE AND TECHNOLOGY COUNCIL WTR

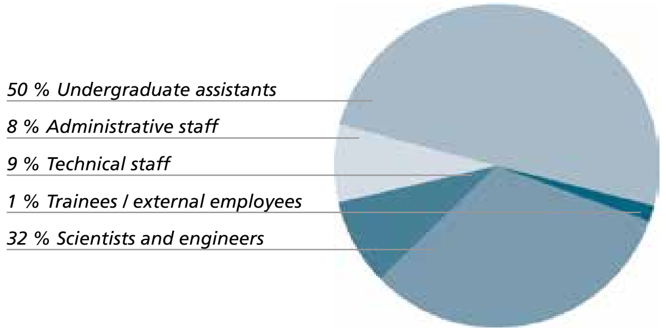
The Fraunhofer-Gesellschaft's Science & Technology Council supports and advises the various bodies of the Fraunhofer-Gesellschaft on scientific and technical issues. The members are the institutes'directors and one representative elected from the science/technology staff per institute. Members of the Council from Fraunhofer ILT are: Prof. R. Poprawe (until 30.9.2019), Prof. C. Häfner (since 1.10.2019), D. Esser.

WORKERS' COUNCIL

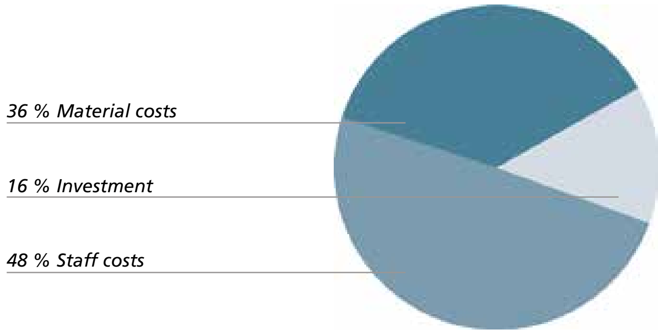
Since March 2003 there is a workers' council at Fraunhofer ILT.

THE INSTITUTE IN FIGURES

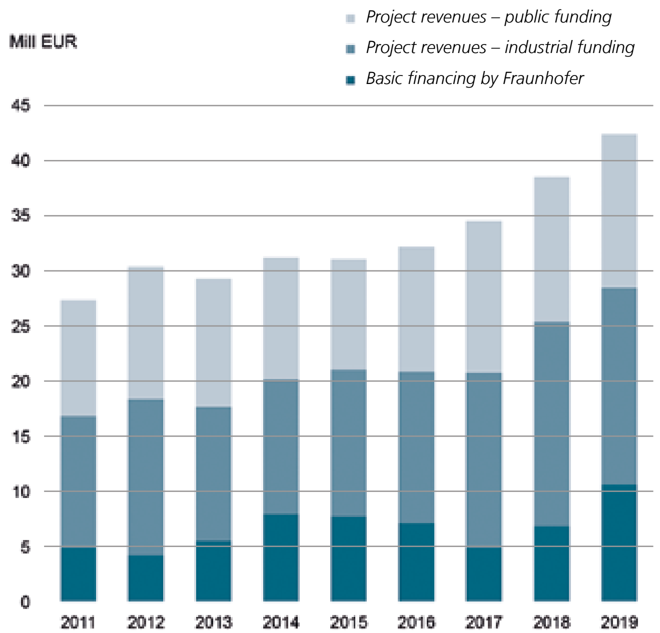
EMPLOYEES 2019	number
Personnel	**275**
- Scientists and engineers	182
- Technical staff	49
- Administrative staff	44
Other employees	**291**
- Undergraduate assistants	282
- External employees	5
- Trainees	4
Total number of employees at Fraunhofer ILT	**566**



EXPENSES 2019	Mill €
- Staff costs	24,2
- Material costs	18,1
Expenses operating budget	**42,3**
Investments	**8,4**



REVENUES 2019	Mill €
- Industrial revenues	17,8
- Additional financing from Federal Government, States and the EU	13,9
- Basic financing from the Fraunhofer-Gesellschaft	10,6
Revenues operating budget	**42,3**
Investment revenues from industry	**0,5**
Fraunhofer industry ρ_{Ind}	**43,2 %**



FACILITIES

The net floor area at the Fraunhofer Institute for Laser Technology ILT amounts to 19,500 m².

TECHNICAL INFRASTRUCTURE

The technical infrastructure of the institute includes a mechanical and electronic workshop, a metallurgic laboratory, a photographic laboratory, a laboratory for optical metrology as well as a department for design and construction.

SCIENTIFIC INFRASTRUCTURE

The scientific infrastructure includes a library with international literature, patent and literature data bases as well as programs for calculation of scientific problems and data bases for process documentation.

EQUIPMENT

The equipment of the Fraunhofer Institute for Laser Technology ILT is permanently being adapted to the state-of-the-art. At present, essential components are:

BEAM SOURCES

- CO_2 lasers up to 12 kW
- disc lasers up to 12 kW
- disc lasers with green wavelength
- mutimode fiber lasers up to 6 kW
- singlemode fiber lasers up to 5 kW
- diode laser systems up to 12 kW
- ultra short pulse lasers up to 1 kW with pulse widths in the range of nano-, pico- and femtoseconds
- frequency-multiplied laser in visible spectral range
- excimer lasers
- broadband tunable lasers
- MIR lasers (ps, ns) with average power > 10 W

PLANTS AND PROCESSING SYSTEMS

- three-axis processing stations
- five-axis gantry systems
- robot systems including six-axis articutated robot with tilt and turn table
- commercial engineering and laboratory systems for laser powder bed fusion (LPBF)
- direct-writing and laser-PVD stations
- beam guiding systems
- various powder and wire feed systems for additive manufacturing
- printer for sol-gel-hybrid polymers and nano- to microscale dispersions

SPECIAL LABORATORIES

- clean rooms for assembly of diode and solid state lasers as well as laser optics
- life science laboratory with S1 classification
- laboratory for battery technology
- application laboratory for high power USP laser users

MEASUREMENT AND SENSOR TECHNOLOGY

- devices for process diagnostics and high speed video analysis
- laser spectroscopic systems for the chemical analysis of solid, liquid and gaseous materials
- confocal laser scanning microscopy
- scanning electron microscope
- Shack Hartmann sensor to characterize laser beams and optics
- measurement interferometer and autocollimator to analyze laser optics
- measurement equipment to characterize ultrashort pulse lasers
- equipment for vibration tests
- single photon detector (APD) for NIR lasers
- systems to characterize powder material
- measuremet system for single quantum detection

HONORS AND PRIZES

Femtec excursion on September 18, 2019 at Fraunhofer ILT.

CAMX AWARD 2019

CAMX Award for team of the NRW project CarboLase

The team of the NRW project CarboLase, which includes Fraunhofer ILT, was presented with the CAMX Award at the »CAMX – the Composites and Advanced Materials Expo« in Anaheim, California, USA on September 25, 2019. Together with scientists from AMPHOS GmbH, Lunovu GmbH, the Institute for Textile Technology at RWTH Aachen University and Kohlhage Fasteners GmbH & Co. KG, the Fraunhofer ILT scientists developed a process for customer-optimized just-in-time CFRP component production using a robot-guided ultra-short pulse laser.

Springorum medal and Borchers badge

The Springorum medals and Borchers badges were awarded on September 14, 2019 during the RWTH graduation ceremony.

The Springorum medal is awarded by proRWTH – the RWTH Aachen University's sponsoring association – to students who have passed their diploma, master's or master's examination with distinction. From the associated chairs of Fraunhofer ILT, Manuel Jung was among those honored in 2019. The medal goes back to the Kommerzienrat Dr.-Ing. E. h. Friedrich Springorum, who founded the Society of Friends of Aachen University in 1918 and was its chairman until 1925.

The Borchers badge recognizes outstanding dissertations. For their doctoral examinations passed with distinction, Torsten Hermanns and Stefan Janssen, both employees of Fraunhofer ILT, received this badge: Torsten Hermanns for his dissertation on the topic of »Interactive Process Simulation for the Industrial Environment using the example of Drilling with Laser Radiation« and Stefan Janssen for his dissertation on »Laser Drilling of CFRP Preforms« at the Faculty of Mechanical Engineering. The man who gave his name to the badge is the Privy Councillor Professor Wilhelm Borchers, who was a full professor of metallurgy at the university from 1897 to 1925.

Spin-off of Fraunhofer ILT wins Start-up Challenge at formnext

The spin-off of Fraunhofer ILT, Laser Melting Innovations GmbH & Co. KG from Aachen, is one of the winners of the »formnext Start-up Challenge« 2019. The Aachen scientists were honored by the jury at formnext in Frankfurt am Main on November 19, 2019 for the development of their low-cost LPBF machine Alpha 140. This system for laser powder bed fusion (LPBF) with metal powder provides, in particular, SMEs with an industrially suitable low-cost system for metallic 3D printing.

TRAINING THE NEXT GENERATION

Girls'Day – Girls' Future Day 2019

On March 28, 2019, the three Fraunhofer Institutes in Aachen opened their doors to interested girls from the 5th to the 7th grade and gave them a glimpse into the institutes' daily work. After the girls were given a brief introduction of the institutes and took guided tours of the laboratories and halls, they were able to carry out experiments themselves on the following topics:

- Vaccine from tobacco: How plants produce drugs
- Experiment: Filtering DNA from a tobacco plant
- Operation »Flying Egg« – Construction of a flying machine
- Experiment: Building your own hologram

Visit of the Young German Physics Association (jDPG) on April 26, 2019

As part of a week of excursions organized by the Young German Physics Association (jDPG), Fraunhofer ILT enabled 25 physics students to take an exclusive tour of the institute on April 26, 2019 at the research location Aachen. The participants were given an application-oriented glimpse into several of the Fraunhofer ILT's main research areas: beam source development, EUV technology, laser measurement technology and additive manufacturing with LPBF.

Student University of Mechanical Engineering from July 15–19, 2019

In 2019, the Student University of Mechanical Engineering again took place, which included the participation of the Cluster of Excellence "Internet of Production" IoP. Twenty-one students from all over Germany, but also from China and Turkey, spent a week at RWTH Aachen University to get a first impression of the Mechanical Engineering course of studies and to see the great variety of opportunities it offers. By visiting various institutes, the participants gained insight into the fields of production engineering, process engineering, plastics, textile and automotive engineering as well as optics and laser technology. In addition to lectures and guided tours of the institutes, the students were also able to run experiments on their own. On July 19, 2019, they then discovered the world of photonics and gained many insights into how laser radiation is generated and what it is used for. Aids were used to make laser beams visible and to explain optical phenomena in everyday life, such as the »Catacaustic in the Coffee Cup«. All in all, the week gave the pupils their first exciting insight into the broad field of mechanical engineering and, beyond that, into the reality of studying and working at RWTH Aachen University.

Femtec excursion – Summer School 2019

On September 18, 2019, 34 enthusiastic STEM scholarship holders from nine universities visited the Fraunhofer Institutes ILT and IPT in Aachen as part of the Summer School 2019. In addition to information on entry and career opportunities and a tour of the laboratories, the scholarship holders were given the opportunity to exchange ideas and network with scientists.

TRAINING THE NEXT GENERATION

Well attended: »Fraunhofer Evening« at the September Special in Aachen.

The original vehicle from Back to the Future at the Aachen September Special.

Fraunhofer Evening on September 20, 2019 at the Aachen September Special

Under the motto »70 Years of Fraunhofer - 70 Years of Future #WHATSNEXT«, the Fraunhofer-Gesellschaft also celebrated its 70th anniversary in Aachen – one of the largest Fraunhofer locations in Germany – as part of a major cultural event, the Aachen September Special.

At this cultural event, the city of Aachen presented a diverse cultural program with many live acts on a total of five open-air stages to the citizens of the municipal region of Aachen and the neighboring countries Netherlands and Belgium.

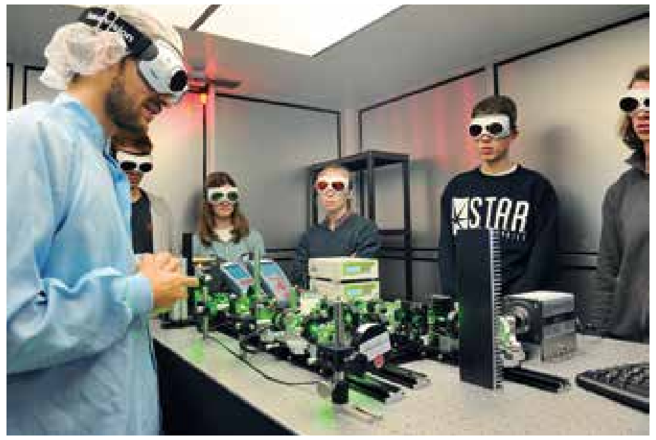
As part of this public event, Fraunhofer ILT, in close cooperation with RWTH Aachen University, organized the »Fraunhofer Evening« on the RWTH stage in front of the main university building on September 20, 2019. In addition to organizing an internationally renowned DJ set (SAMA and GERD JANSON), the Fraunhofer ILT and IPT institutes gave 1000 STEM students the opportunity to exchange ideas and information in a relaxed atmosphere directly at the Fraunhofer joint stand and to find out about entry and career opportunities at Fraunhofer. As a special highlight, Fraunhofer ILT presented the original vehicle from the film Back to the Future to an enthusiastic audience. The evening was moderated by blogger Lisa Ruhfus, alias »Smart Alec«.

Australian doctoral students visit Fraunhofer ILT

Twenty doctoral students from Melbourne visited Fraunhofer ILT and the Chair for Digital Additive Production DAP at RWTH Aachen University on September 27, 2019. The doctoral students were on a study trip under the direction of Prof. Gary Bryant, Associate Dean for Higher Degree by Research, from the School of Science at RMIT University, Melbourne.

32nd bonding company contact fair on November 7, 2019

For the fourth time in a row, Fraunhofer ILT presented itself in Aachen at the largest student-organized company contact fair – the bonding. In addition to 380 other exhibitors, Fraunhofer ILT informed, in particular, students and graduates from the fields of engineering, economics and natural sciences about entry and career opportunities at the institute in personal discussions.



Fraunhofer ILT laboratory tour as part of the jDPG excursion.

»5 to 12« – The RWTH Science Night on November 8, 2019

Every year the RWTH Science Night »5 to 12« presents science in an unusual format at an unusual time. At this event, science is made understandable and tangible for all generations in an entertaining way and with a wide range of exciting lectures, film screenings and cabaret and musical contributions. The Chairs for Laser Technology LLT, for Technology of Optical Systems TOS and for Digital Additive Production DAP of RWTH Aachen University demonstrated the versatility of light as a tool for a wide range of applications at the C.A.R.L. auditorium center in Aachen on November 8, 2019. The chairs LLT, TOS and DAP presented exhibits on the topic »Fascinated by Lasers – Manufacturing with Light«. Two exciting experiments were available: On the one hand, the students could create individual laser-cut giveaways by using a laser cutter interactively. On the other, they were able to use a 3D printer, which will soon be used to build lens holders for smartphones, thereby gaining insights through their own smartphone camera.

In addition, under the motto »Touching Laser Light – Making Music with Light«, the TOS chair presented a laser harp created within a project, and Christian Hinke from the LLT chair gave a lecture on the topic »The Laser – a Fascinating Tool«.

Fraunhofer Digital Escape Game

On December 11 and 12, 2019, Fraunhofer ILT and IPT jointly organized the second »Fraunhofer Digital Escape Game« at Fraunhofer ILT in Aachen.

Around 40 students took up the challenge on two evenings and worked together on the puzzles in the Fraunhofer Escape Room. While the time fuse ticked in the background, potentially triggering an imminent data explosion, the participants demonstrated their creativity, team spirit and technical skills. During a guided tour through the halls and laboratories, the students were able to experience the Fraunhofer working world at the Aachen site live and ask questions.

Participants of the Fraunhofer »Digital Escape Game«.

ALUMNI NETWORK

Prof. Poprawe welcomes about 280 guests at the symposium »Digital Photonic Production and Industry 4.0« in Munich.

Around 60 of more than 200 scientists that earned their doctorates under Prof. Poprawe at the symposium in his honor on the occasion of his farewell in Munich.

LIVING ALUMNI NETWORK AT FRAUNHOFER ILT

Fraunhofer ILT and the associated chairs and subject areas of RWTH Aachen University significantly contribute to the qualified training and advanced training of young scientists in the field of laser technology. In 2019 alone, 109 students completed their bachelor's or master's theses at Fraunhofer ILT and 16 employees their doctorate degrees. Thanks to their practical experience and in-depth insight into innovative developments, these employees are equipped with the best prerequisites to take up work in science and industry. They are, therefore, junior staff in demand.

To promote contact between alumni and ILT employees as well as with each other, Fraunhofer ILT has been operating the alumni network »Aix-Laser-People«, which now counts more than 450 former alumni, since 2000. Over 80 percent of alumni work in the manufacturing industry, many of them in laser-related industries. 20 percent of alumni continue to work in science and alumni have founded more than 40 companies. By transferring »innovative minds« into industry and science, the institute makes a direct benefit to society. In addition to the alumni network »Aix-Laser-People«, the association »Arbeitskreis Lasertechnik AKL e.V.« bundles the thematic interests of those who continue to work in the field of laser technology. About 150 alumni, i.e. a good third, are members of the AKL e.V.

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New alumnus: The international laser community bids farewell to Prof. Poprawe

Under the title »Digital Photonic Production and Industry 4.0 – what it means for education and research?«, Fraunhofer ILT organized a symposium in honor of Prof. Dr. Reinhart Poprawe on June 23, 2019 in the run-up to the world's leading trade show LASER World of PHOTONICS. Some 280 companions from industry and science accepted his invitation to come to Munich, including executives from Fraunhofer ILT and associated RWTH chairs as well as directors of German laser centers and university institutes. On the occasion of his retirement, they paid tribute to his scientific work as a professor of laser technology and his bridge-building from Fraunhofer-specific contract development to basic research and university education.

After Prof. Reinhart Poprawe's welcoming address, Dr. Reinhard Pfeiffer, Deputy Chairman of the Board of Management of Messe München, and Prof. Ulrich Rüdiger, current Rector of RWTH Aachen University, addressed Prof. Poprawe and his guests. This was followed by food for thought on digitalization given by Dr. e. h. Peter Leibinger, Deputy Chairman of the Management Board of the TRUMPF Group, Prof. Alfred Gossner, former Fraunhofer CFO, and Prof. Burkhard Rauhut, former Rector of the RWTH Aachen University. They spoke of topics such as digitalized learning or interdisciplinary education and clearly emphasized that Prof. Poprawe was a role model in teaching his subject matter. For example, he introduced new teaching formats, such as the »Flipped Classrooms«. It is not without reason that the students awarded him the teaching prize of the Faculty of Mechanical Engineering of RWTH Aachen University four times.

During his time as chair holder he was also first reviewer for over 200 dissertations. Furthermore, the speakers agreed that Prof. Poprawe has set standards with his consistent and visionary work in photonics. As Vice Rector for Research, Structure and Young Scientists at RWTH Aachen University, Prof. Poprawe was one of the initiators of the RWTH Aachen Campus, which is now growing into one of the most important international technology landscapes and brings together innovative minds from industry and science to collaborate in one place.

Under his leadership, the Photonics Cluster has been working on new ways of generating, shaping and using light since 2010, especially as a tool for industrial production. Around 30 companies and their laser experts have already become established in this environment and use the short distances to better generate new ideas and creative solutions to upcoming technological issues. Private investors created the structural conditions for this on the campus. Funded by the Federal Ministry of Education and Research (BMBF), the Digital Photonic Production DPP Research Campus has helped establish new forms of long-term and systematic cooperation between RWTH, the Fraunhofer-Gesellschaft and industry – a result of the personal commitment of Prof. Poprawe and his Aachen team.

Prof. Reimund Neugebauer, President of the Fraunhofer-Gesellschaft, explained via video message: »Prof. Poprawe embodies the Fraunhofer spirit through and through: Our patron saint was active in the field of optical technologies and, like him, Prof. Poprawe has always viewed innovations with a view to concrete applications. Since the founding of Fraunhofer ILT in Aachen, Prof. Poprawe has played a major role in shaping the leading global position of the German laser industry. When the positive effects of technology clusters were not yet recognized, he had already laid the foundation for Aachen's focus on combining optical technologies, mechanical engineering and process technology«.

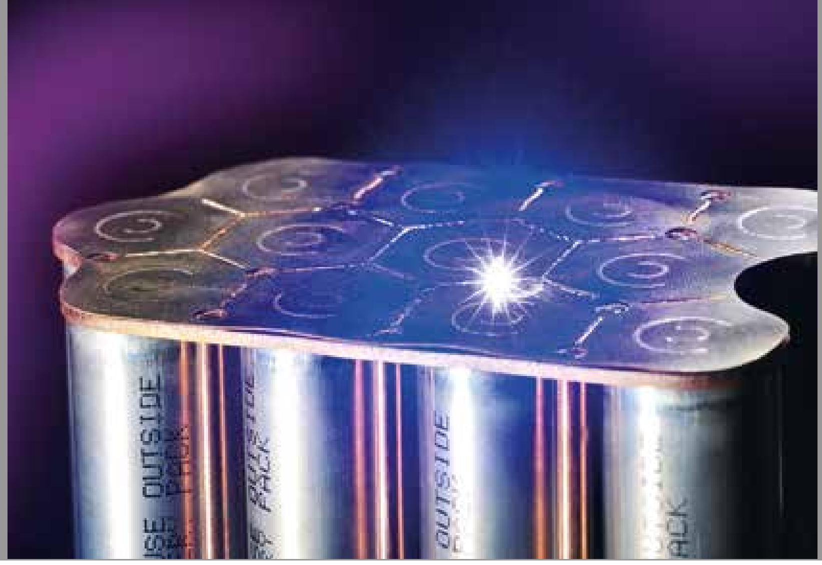
The symposium concluded with a panel discussion on »Digital Photonic Production and Industry 4.0 – what it means for education and research?« with Dr. E.h. Leibinger, Prof. Gossner, Prof. Rauhut and Prof. Poprawe, moderated by TV presenter Tobias Ranzinger. The conclusion of the discussion: Especially in the manufacturing industry, the advent of digitalization opens up new perspectives, both in terms of innovative products and services and in terms of new sales markets and more efficient processes. Laser-supported manufacturing also contributes to the systematic development of Industry 4.0 concepts through networking with the virtual world of the Internet.

The honorary symposium was held as part of the »Lasers in Manufacturing LiM« conference, which was organized by the WLT Wissenschaftliche Gesellschaft Lasertechnik e.V.

Sources and further information on the Internet at:
www.fraunhofer.de/en/quick-limks/alumni.html

MOBILITY

LASER TECHNOLOGY SOLUTIONS FOR INDUSTRY AND SOCIETY



RESEARCH FOR THE MOBILITY OF TOMORROW

Two trends dominate mobility today: the growing automation in production and the transition to electric drives. Both developments are pushing forward interest in laser technology. Fraunhofer ILT is therefore conducting intensive research into efficient systems technology for industrial applications of today and tomorrow. In addition to applications in lightweight construction, battery technology or the manufacture of fuel cells, Fraunhofer ILT is also working on new technologies for recycling.

Using a single laser tool to cut, weld and manufacture additively

For mobility today, both hybrid lightweight construction and electromobility are indispensable. Which, in turn, means that companies much perform a balancing act between flexibility and productivity. Rapidly changing products, fluctuating batch sizes and new types of manufacturing concepts dominate the scene, especially for small- and medium-sized companies.

For this environment, Fraunhofer ILT and three partners have launched the joint project »MultiPROmobil – Multifunctional robot technology with a universal laser tool for separating, joining and additive manufacturing processes in semi-bionic e-mobile lightweight construction«. With its partners, the institute aims to develop a laser processing head and robot technology to flexibly and economically produce sheet metal assemblies. The system should not only be able to cut and weld, but also to generate additive structures and do this in a »flying change« – without having to change optics or nozzles.

In addition to the technology, the processes will also be optimized. Using the highly flexible process chain, the partners of MultiPROmobil are designing vehicle components digitally and testing the new methods. As a first application example, the wishbone of an electric vehicle is being constructively optimized, then cut, welded and reinforced with additive structures in the multifunctional laser robot cell without having to retool.

Agile, laser-supported production allows engineers to design flexible and scalable process chains for sheet metal processing, which is especially important to help industry gradually introduce electromobility.

Basic research for mobile energy storage

While lithium-ion batteries with liquid electrolytes still dominate the scene, solid state batteries are expected to play a major role in electromobility in the next ten years. In addition to new materials, research also needs to develop crucial process and system technology for the industrial production of solid-state batteries.

In the infrastructure project »NextGenBat – Research Infrastructure for Future Battery Generations«, Fraunhofer ILT, together with five institutes of RWTH Aachen University and Forschungszentrum Jülich, is building a research and development infrastructure for the next battery generation. Fraunhofer ILT is setting up its own Battery Lab as part of this project. In NextGenBat, the partners are developing individual process steps as modular components. They are also testing materials and measurement technology as well as researching how the various solid-state battery systems can be produced and processed. A further essential working point is the recycling of batteries.

The institutes involved intend to expand the existing infrastructure in such a way that companies in NRW in particular will find optimal conditions and support for developing next-generation battery materials and systems.

Laser processes for the battery of the future

We expect major technological challenges as electromobility progresses. For example, electrified commercial vehicles will require larger batteries and higher charging currents, which will increase the demands on joining processes such as laser microwelding.

Laser technology offers great potential for more cost-efficient and energy-saving processes along the entire process chain. This applies to cutting, structuring and joining processes as well as to drying or sintering processes. Innovative laser drying processes, for example, enable a more efficient energy input than conventional continuous furnaces, while at the same time being significantly more compact.

Hydrogen – Energy carrier of the future

The use of renewable energies to replace fossil fuels places high demands on storage systems of the future. Hydrogen holds great potential as the energy carrier of the future. In terms of conversion into electricity, fuel cells play an important role – for electromobility and as a supplier of electricity and heat, e.g. for building services engineering.

The challenges in mobility are great, for example in the production of bipolar plates. Depending on the design, a fuel cell stack consists of several hundred of these plates. They must be joined together so that they are hydrogen-tight all the way round. This results in seam lengths of more than 200 meters per fuel cell. Here, laser welding needs to be not only fast, but must also produce seams with high quality.

With its R&D activities, Fraunhofer ILT is setting the course for the flexible and efficient production of components for fuel cell technology, thus helping to make mobility climate-neutral.

Selected research results
Mobility: pages 37, 82, 86, 87, 88, 89, 90 and 93.

Further information on the Internet at:
www.ilt.fraunhofer.de/en.html

PRODUCTION
LASER TECHNOLOGY SOLUTIONS FOR INDUSTRY AND SOCIETY

EFFICIENT SYSTEM TECHNOLOGY MAKES SERIES PRODUCTION PROFITABLE

As one of their core tasks, the Fraunhofer institutes transfer research results into industrial applications, focusing their attention on engineering, i.e. the development of process and systems technology. This is crucial for current trends such as 3D printing or the use of ultrashort pulsed lasers: Only with reliable and highly efficient system technology can the new processes be transferred to series production.

Multi-beam systems for higher throughput in USP lasers

Ultra-short pulsed (USP) lasers with pulse durations in the pico and femtosecond range promise amazing things: They can process nearly any material with the highest precision. The heat input into the workpiece during processing is negligible, making it possible to produce precise contours in plastic and other thermally sensitive materials without damaging them. Until now, the reduced productivity of the processes has limited them from penetrating the market to a greater extent. This is currently changing, as beam sources with an average power up to the kW range are becoming available, a development that enables processes to be scaled upwards. However, the increased average power also requires new system engineering approaches so that the available power can be implemented in the corresponding processes. Only with the right process technology and control can the high quality of the processing be guaranteed and the throughput of the processes increased at the same time.

Fraunhofer ILT has developed solutions for this purpose along the entire process chain. One of its approaches is to distribute the pulse energy of the laser beams homogeneously into a matrix with many identical sub-beams. This matrix can very quickly process larger areas with periodic structures. Metallic microfilters with 20,000 holes per second have already been drilled with such a system. A further field of application is the drilling of large wing components of airplanes so as to prevent turbulent flows and significantly reduce air resistance.

In a current research project, the institute is developing the systems engineering in which the individual partial beams of a beam matrix switch on and off independently of each other, similar to a matrix printer. Another approach under development uses a liquid crystal modulator, which enables the dynamic generation of different beam patterns or profiles even during processing.

The successful use of such multi-beam optics or even new ultra-fast scanners requires that the process control on the workpiece be optimized. To this end, Fraunhofer ILT has developed special simulation software that can be used to simulate thermal effects during USP laser processing.

Precision machining on the rise

The growing interest in USP laser technology also results from the industry's desire for ever higher precision in laser material processing. To this end, our experts are also investigating conventional solid-state lasers with shorter wavelengths. A long-term goal is the creation of structures in the micrometer and sub-micrometer range. In this way, laser materials processing could replace wet chemical processes that are currently still used to create such micro- and nanostructures. In addition to new beam sources, special optics are also being investigated.

Cutting the cost of additive production in half

The primary goal of additive production is to reduce effort and costs. Higher efficiency can be achieved either with more power or with less effort. Complex metal components such as turbine blades, gearboxes or engine parts can be manufactured additively with laser powder bed beam fusion. At present, however, the individual process steps are usually still carried out in isolation and require experts to often manually intervene in the process.

As part of the project »IDEA - Industrialization of Digital Engineering and Additive Manufacturing«, 14 partners from industry and science want to make the laser powder bed fusion process suitable for series production by reducing product costs as well as development and throughput times by about 50 percent. Above all, there is great potential in more efficiently coupling hardware and software. Time and costs can be reduced by using uniform data formats, process simulations, modern production control systems and the consistent recording of production data.

Two pilot lines will be set up as part of the project: one at Siemens Gasturbinenwerk Berlin and one as a model for small and medium-sized companies at MBFZ toolcraft GmbH in Georgensgmünd.

3D printing for series production in the automotive industry

Process chains also need to be digitalized in the automotive industry for additive technologies to break into this sector. Together with partners from research, large companies and SMEs, Fraunhofer ILT has, therefore, launched the project »IDAM - Industrialization and Digitalization of Additive Manufacturing (AM) for Automotive Series Processes«.

In the IDAM project, 3D printing is being transferred to an industrialized and highly automated series production process in the automotive industry for the first time. Upstream and downstream processes will be integrated as far as possible and a continuous data chain is to be newly established.

For this purpose, two modular and almost completely automated AM production lines are being set up at the BMW Group's Additive Manufacturing Center in Munich and at the Bonn plant of the automotive supplier GKN Powder Metallurgy. The targeted quantities will send a signal to the joint project: 50,000 components per year are planned in the production of identical parts and over 10,000 individual and spare parts.

Selected research results
Production: pages Seite 39, 46, 51, 54, 56, 57, 58, 62, 63, 66, 79 and 84.

Further information on the Internet at:
www.ilt.fraunhofer.de/en.html

DIGITALIZATION
LASER TECHNOLOGY SOLUTIONS FOR INDUSTRY AND SOCIETY

EFFICIENTLY IMPLEMENTING DIGITALIZATION IN PRODUCTION

Digitalization is compelling the industry to undergo a complex transformation process. With it, a company can introduce digital technologies and processes to ultimately achieve a digital return on an investment: an increase in efficiency and profit. Yet there are many questions behind this: How can the new technology be introduced without interrupting production? What costs are involved? And how do we take people with us? Fraunhofer ILT has been working on digital technologies for many years. Thanks to this experience, we can advise and comprehensively support companies at every step of the transformation process.

Digitalization begins with an assessment

When one looks into a workshop today, one still sees an environment dominated by classic machine tools in many places. Especially for medium-sized companies, the transition to new, digitally networked technologies often progresses slowly. It usually begins invisibly with the digitalization of individual steps in existing work processes. Fundamental changes in the interaction of operational processes, personnel and technology begin with an assessment of digitalization's benefits: Where can upcoming investments be sensibly combined with digitalization? Where are gains in efficiency possible? Fraunhofer ILT has developed a starter package to address these questions. Our experts analyze the requirements and present approaches from their respective service offerings. In this way they create the basis for a systematic analysis of potential and added value with regard to the company's processes and objectives.

Together, they identify concrete applications in which digitalization in the production environment can contribute to the company's success. The final recommendation on how to implement the new technology summarizes both analysis and potential and describes concrete solutions that will enable the company to make a successful start into the next generation of production.

Test phase in the »Digital Light Factory«

Once the potential has been clearly analyzed and the responsible parties have decided which new investments should be made, the technology is implemented into the production process. In order to integrate the new technologies, the production process should only be interrupted as briefly as possible. However, a test phase, employee training and, if necessary, process optimization are essential.

Fraunhofer ILT has created a special infrastructure for this purpose, the »Digital Light Factory«. Here, users can install, test and qualify machines and processes for production in a real-life environment. The individual and isolated development and production environment comprises the production technologies with all the desired control and automation interfaces. Depending on the objectives in the Industry 4.0 Maturity Index, this environment is integrated into a virtual or real MES or ERP system via an individual network connection.

Customer-specific manufacturing systems are prepared in the Digital Light Factory for the digitally integrated production start-up. Furthermore, additional sensors can be installed and tested and processes can be optimized. Our experts are also available for training. In preparation for commissioning at the production site, they train engineers and operators as part of system validation.

A step closer to the future: the AI laboratory

Artificial intelligence (AI) is increasingly being used as a tool for digitalization, up to now mostly in quality assurance, e.g. for pattern recognition. Especially in larger data sets, from deviations or trends a suitably trained system can identify process deviations or the final component quality, for example. Such AI-based systems can already provide information on the contamination of protective glass or the wear of drive systems.

Thus, predictions (predictive maintenance) can be made to maintain a system, an innovation that, on the one hand, can reduce downtime and, on the other, detect errors outside the tolerance range. In this way, modern production systems are getting closer and closer to »zero defect production«. For example, in laser welding in automotive engineering or microjoining in battery technology, welding seams can already be analyzed in real time with image-based monitoring systems and the seam quality reliably classified with adapted algorithms.

Developing and adapting AI processes are accordingly complex. For this purpose, Fraunhofer ILT has set up an AI laboratory. There, users can experiment with their own data on the basis of prepared modules and, thus, test new architectures based on deep neural networks (deep learning) in addition to established methods from the field of machine learning (ML). Specially developed system environments provide a high-performance infrastructure for the various application tests. The results are prepared in a way that is understandable for users so that they can make qualified decisions. The AI laboratory also provides an environment for the safe operation of technical systems in which AI solutions are used at the control level.

The digital toolbox

Digitalization is still new territory for many companies. Although it simplifies processes in many places and leads back to common standards, each company has to consider how it can integrate this technology. Therefore, Fraunhofer ILT offers an approach that integrates man, machine and processes together. We develop solutions together with our customers and implement them according to our customers' needs. For this reason, we have a wide range of technologies and components such as simulation and networking technologies as well as a variety of sensor systems, optics and laser systems at our disposal. Ultimately, the technology is defined by the application.

Selected research results
Digitalization: pages 50, 55, 59, 66, 67, 83, 90 and 95.

Further information on the Internet at:
www.ilt.fraunhofer.de/en.html

HEALTH

LASER TECHNOLOGY SOLUTIONS FOR INDUSTRY AND SOCIETY

LASER-BASED 3D PRINTING FOR THE DEVELOPMENT OF NEW IMPLANTS

Lasers have established themselves in everyday clinical practice for both therapeutic applications and diagnosis in many medical sectors. However, lasers also bring about major changes, for example in the laboratory or in medical technology. The strengths of laser technology are particularly evident in personalized medicine. Technologies such as laser-based 3D printing show how know-how from industrial production can advance medical technology. The range of applications is wide: from individualized hearing aids to ingrowing bone implants and heart valves made from the body's own cells.

Automated and individual production

Already today, every hearing aid or tooth model is unique. The question is how time and costs can be saved in the production of individualized parts. For small plastic parts in particular, the experts at Fraunhofer ILT can offer a highly efficient method for industrial production: »TwoCure« is a process that can create three-dimensional structures more quickly, more easily and, above all, fully automatically. With the help of this photolithographically based method, plastic parts can be manufactured without any supporting structures at all. This saves preparatory and finishing work and allows better use of the entire installation space. With a TwoCure system, for example, several hundred individual earmolds for hearing aids can be produced in one day.

Additively manufacturing load-adapted implants

Implants that replace hard tissue are subject to the highest demands: They must be biocompatible, durable and also extremely resilient. The researchers at Fraunhofer ILT have invested a great deal of time in optimizing materials and processes for laser-based 3D printing of metal structures in order to manufacture implants.

The method of choice is laser powder bed fusion (LPBF). This method enables the manufacture of implants and prostheses with a precise and individual fit. Complex internal structures can also be used to achieve a high degree of stiffness adapted to the bone. In addition, the integration of precisely defined pores in the metal surface improves bone ingrowth. Our experts work together with physicians to develop additively manufactured vertebral body implants that are individually designed in terms of geometry, stiffness and structure and are locally load-adapted. In this way, the sinking of the implanted cages (inserts for the intervertebral space) into the adjacent vertebral bodies can be significantly reduced.

Resorbable materials for natural healing processes

Using an implant to stimulate bone growth and allowing the supporting structure to be resorbed by the body over time goes one step further. For this purpose, a net-like support structure (scaffold) is built and consists of an absorbable polymer and collagen. While the laser-sintered polymer structure primarily performs a supporting function, the collagen induces a natural bone healing process. This is intended to stimulate the endogenous regeneration of bone and bone-cartilage.

Growing a heart valve

Research into the interactions between laser-structured surfaces and living cells also continues at Fraunhofer ILT. For example, lasers can be used to modify artificial surfaces in various steps so that they exert mechanical, topographic and molecular stimuli on cells and specifically influence their growth. Micro- and nanostructures change, for example, the roughness and wettability of surfaces, which influences cell adhesion and proliferation.

Surfaces can also take over photochemical functionalities. In this case, certain chemical groups on the surface are activated with light. These anchor groups can then lead to the targeted immobilization of peptides, proteins or growth factors. In connection with techniques from the 3D printing of polymers, there are even more possibilities. Our scientists are investigating how support structures that stimulate vascular growth can be printed in the future. In other words, how to get the body's own cells to generate tissue supplied with blood on a support structure. One goal here, for example, is the cultivation of an artificial heart valve using the patient's own tissue. If the support structure is made of bioresorbable material, it can even be degraded by the body itself. Fraunhofer ILT uses photolithographic methods to construct polymer support structures and to test their mechanical properties. In addition, the new materials are tested for their biocompatibility.

To avoid the need to introduce artificial materials into the body in the future, Fraunhofer ILT's scientists are also researching laser-based bioprinting (or »laser assisted bioprinting« LAB for short) to print living cells. This is where the LIFT method comes into play. In the future, the researchers hope to create artificial organ structures supplied with blood, such as heart tissue.

Selected research results
Medical technology: pages 40, 75, 98, 99 and 100.

Further information on the Internet at:
www.ilt.fraunhofer.de/en.html

ENVIRONMENT

LASER TECHNOLOGY SOLUTIONS FOR INDUSTRY AND SOCIETY

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PHOTONICS FOR CLIMATE AND ENVIRONMENTAL PROTECTION

Photonics offers unique and sustainable solutions for environmental protection and climate research. It makes a significant contribution to understanding the causes of climate change and to lowering greenhouse gas emissions, for example by reducing power consumption, as in the case of LEDs, CO_2 emissions or material savings through new recycling processes. Photonic technologies make it possible to combine economic efficiency and environmental protection. Efficient laser processes can also be used to reduce the environmental impact of microplastics – thanks to filters with laser-drilled tiny holes that can remove harmful particles from water.

Environmentally friendly energy management thanks to photonics

In the case of renewable energies such as photovoltaics or wind energy, photonic processes enable higher efficiency and a longer service life. Laser-based thin-film technologies can be used better than any other process for the economical and environmentally friendly production and modification of extremely thin, functional layers, for example for photovoltaics or electronics.

»Urban mining« with lasers - Next generation recycling

In the field of environmental services, complex challenges have to be overcome, for example, those resulting from the increasing diversity of materials and miniaturization of electronic components, such as the disused circuit boards of computers, servers and mobile phones. Here, a comprehensive recycling of materials is necessary, whereby extremely fast and precise laser processes can be used for detection and sorting. Mixed metal scrap can be sorted using laser technology, for example, to recover valuable alloys with high tungsten, cobalt or tantalum content.

In the ADIR project, a European consortium aims to pave the way for the next generation of recycling of electronic waste. For this reason, it is developing laser-based processes and machines to automatically disassemble and separate electronic components and recover valuable materials. Components such as batteries, tantalum capacitors, magnets or vibration alarms can be selectively extracted and then special materials such as technology metals or rare earths can be recovered.

Laser-manufactured filters against the flood of microplastics

Laser processes also play an important role in reducing the environmental impact of microplastics. These tiny plastic parts are created in various ways, for example as abrasion from vehicle tires or when modern functional textiles are washed. They are also used in cosmetics, as fillers or binders. Such particles end up in our wastewater and pose considerable problems for sewage treatment plants. Especially tiny particles of less than a few 10 micrometers cannot be filtered out cost-effectively with conventional technologies, thus ending up in the environment.

Fraunhofer ILT is developing a technology for the efficient drilling of metal foils and other materials with diameters in the range of one micrometer. Laser systems with ultra-short pulses in the pico and femtosecond range are particularly suitable for this purpose. In the BMBF-funded project SimConDrill, partners from industry and science are developing a durable filter module for the extraction of microplastics, even from large amounts of water. The filter module with laser drilled holes efficiently filters particles as small as 10 micrometers out of the water and works blockage-free. The filter module was developed and tested for sewage treatment plants, but mobile applications in sewer rinsing vehicles or in private households are also conceivable. This innovation also shows great potential for the purification of ballast water.

Particularly efficient: Easy scalability through multi-jet concepts

To make holes, for example in filter foils, a multi-beam concept is used in which a laser beam is split into many partial beams. With diffractive optical elements (DOE), more than 200 partial beams can be used specifically for processing with a precision down to the sub-micrometer range. This process can make 12,000 drill holes per second with a diameter of less than 1 µm in metal foils.

Climate research with customized lasers

Photonics also makes an indispensable contribution to understanding the causes of climate change. Satellite-based, robustly designed laser measurement systems, for example, meet the extreme requirements for long-term use in space and enable researchers to precisely analyze the sources of and sinks for climate-damaging gases in the atmosphere.

Within the framework of the Franco-German climate research mission »MERLIN«, a light radar (LIDAR, Light Detection and Ranging) will be deployed in space; it uses laser pulses to measure the concentration of methane in the atmosphere and, unlike in the past, is independent of sunlight.

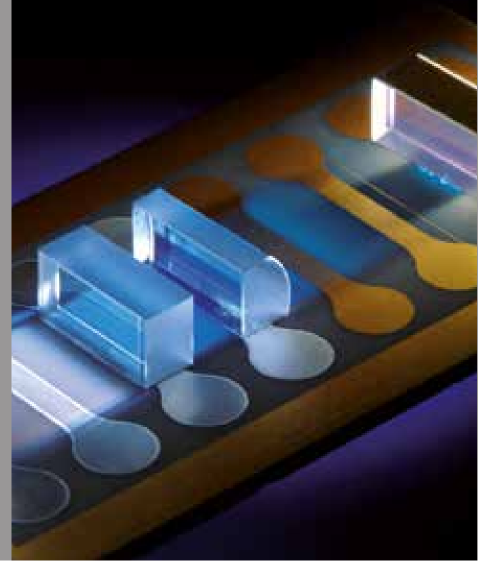
Higher atmospheric layers, becoming increasingly important in climate research, can also be specifically analyzed from earth. Until now, it has been very difficult to obtain measurement data there – a compact LIDAR system offers new possibilities. Together with the Leibniz Institute for Atmospheric Physics (IAP), Fraunhofer ILT has developed a system with a diode-pumped alexandrite laser. This allows the size and energy requirements of previous systems to be reduced by a factor of 100 and allows precise measurements to be made at the targeted altitudes of up to 120 km. Several of the new LIDAR systems are soon to be used for the first time in a network to measure wind and temperature fields in the middle atmosphere both three dimensionally and time-resolved. In the medium term, the compact LIDAR systems could also be used on aircraft and satellites.

Text excerpts from the SPECTARIS study 2019 in cooperation with Fraunhofer ILT »Licht als Schlüssel zur globalen ökologischen Nachhaltigkeit«

Selected research results
Environment: pages 43, 47, 77, 81, 105, 106 und 112.

Further information on the Internet at:
www.ilt.fraunhofer.de/en.html

TECHNOLOGY FOCUS



LASERS AND OPTICS

The technology field Lasers and Optics focuses on developing innovative laser beam sources and high quality optical components and systems. Fraunhofer's team of experienced laser engineers builds beam sources which have tailor-made spatial, temporal and spectral characteristics and output powers ranging from µW to GW. These sources span a wide range of types: from diode lasers to solid-state lasers, from high power cw lasers to ultrashort pulse lasers and from single frequency systems to broadband tunable lasers.

In the field of solid-state lasers, oscillators as well as amplification systems with excellent power data hold the center of our attention. Whether our customers are laser manufacturers or users, they do not only receive tailor-made prototypes for their individual needs, but also expert consultation to optimize existing systems. In the realm of short pulsed lasers and broad band amplifiers in particular, numerous patents and record-setting values can be provided as references.

Furthermore, this technology field has a great deal of expertise in beam shaping and guiding, packaging of optical high power components and designing optical components. This field also specializes in dimensioning highly efficient free form optics. In general, the lasers and optics developed here can be applied in areas ranging from laser material processing and measurement engineering to illumination applications and medical technology all the way to use in aerospace applications, quantum technlology and pure research.

LASER MATERIAL PROCESSING

Among the many manufacturing processes in the technology field Laser Material Processing, cutting and joining in micro and macro technology as well as surface processes count among its most important. Whether it be laser cutting or laser welding, drilling or soldering, laser metal deposition or cleaning, structuring or polishing, generating or layering, the range of services spans process development and feasibility studies, simulation and modeling, as well as the integration of processes in production lines.

The strength of the technology field lies in its extensive know-how, which is tailored to customer requirements. In such a way hybrid and combination processes also result. Moreover, complete system solutions are offered in cooperation with a specialized network of partners. Special plants, plant modifications and additional components are the constituent part of numerous R&D projects. For example, special processing heads for laser material processing are being developed and produced, based on a customer's specific needs. In addition, process optimization by changing the design of components as well as systems to monitor quality online count among the specializations of this technology field.

Customers receive laser-specific solutions that incorporate the working material, product design, construction, means of production and quality control. This technology field appeals to laser users from various branches: from machining and tool construction to photovoltaics and precision engineering all the way to aircraft and automobile construction.

MEDICAL TECHNOLOGY AND BIOPHOTONICS

Together with partners from the Life Sciences, the technology field Medical Technology and Biophotonics opens up new areas of applications for lasers in therapy and diagnostics as well as in microscopy and analytics. The process Selective Laser Melting, developed at the ILT, allows implants to be generated, tailored to the individual patent on the basis of data from computer tomography. The material variety ranges from titanium through polyactide all the way to resorbable man-made bone based on calcium phosphate.

In close cooperation with clinical partners, this field develops medical lasers with adapted wavelengths, microsurgical systems and new laser therapy processes for surgery, wound treatment and tissue therapy. Thus, for example, the coagulation of tissue or precise removal of soft and hard tissue is being investigated.

Nanoanalytics as well as point-of-care diagnostics demand inexpensive single-use microfluidic components. These can now be manufactured with high precision up into the nanometer range using laser-based processes such as joining, structuring and functionalizing. Clinical diagnostics, bioanalytics and laser microscopy rely on the institute's profound know-how in measurement technology. In the area of biofabrication, processes for in-vitro testing systems or tissue engineering are being advanced. Thanks to its competence in nanostructuring and photochemical surface modification, the technology field is making a contribution to generating biofunctional surfaces.

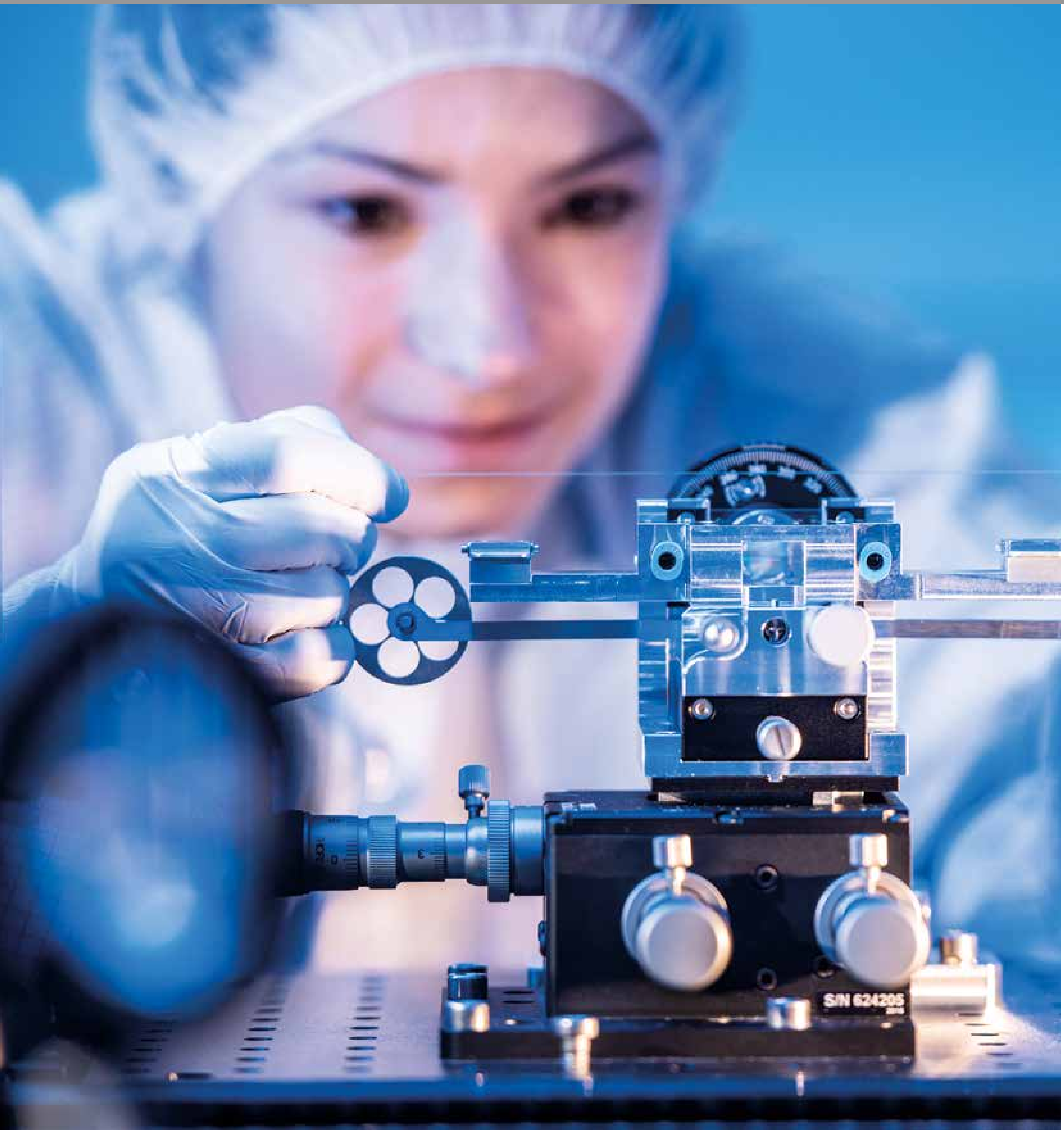
LASER MEASUREMENT AND EUV TECHNOLOGY

The focus of the technology field Laser Measurement Technology and EUV Technology lies in manufacturing measurement technology, materials analysis, identification and analysis technology in the areas of recycling and raw materials, measurement and test engineering for environment and security, as well as the use of EUV technology. In the area of manufacturing measurement technology, processes and systems are being developed for inline measurement of physical and chemical parameters in a process line. Quickly and precisely, distances, thicknesses, profiles or chemical composition of raw materials, semi-finished goods or products can be measured.

In the field of material analytics, the institute has acquired profound know-how in spectroscopic measurement processes. Applications are automatic quality control and positive material identification, monitoring of process parameters or online analysis of exhaust gases, dust and wastewater. The more precise the chemical characterization of recycling products, the higher their recycling value. Laser emission spectroscopy has proven itself as an especially reliable measurement tool. In addition to the development of processes, complete prototype plants and mobile systems for industrial use are produced.

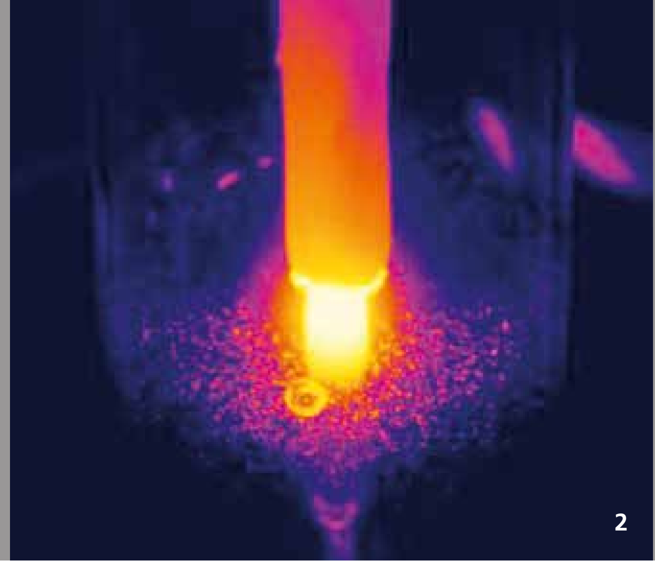
In EUV technology, Fraunhofer's experts develop beam sources for lithography, microscopy, nanostructuring or x-ray microscopy. Optical systems for applications in EUV engineering are calculated, constructed and manufactured as well.

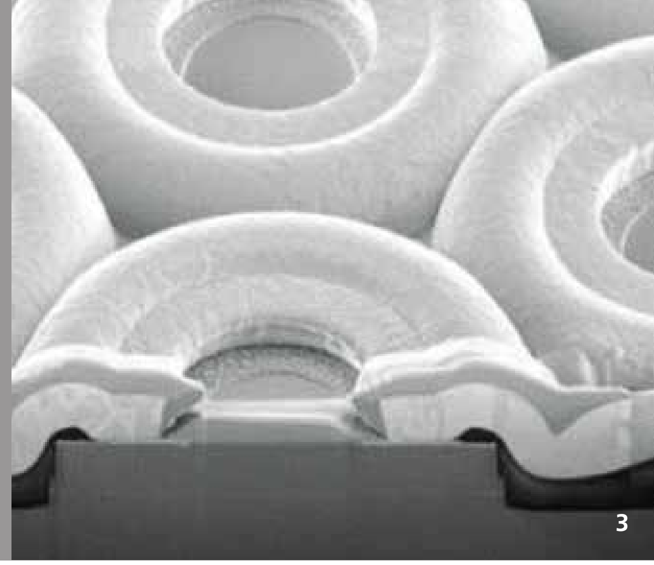
LASERS AND OPTICS

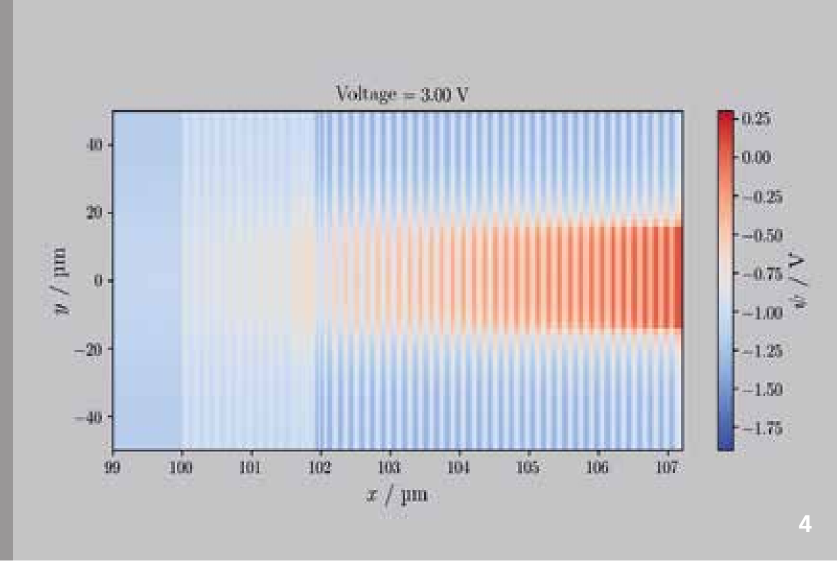


Writing of Bragg gratings in optical fibers.

CONTENTS







DEVELOPMENT OF AN OPTICAL SYSTEM FOR GROWING β-GA_2O_3 SINGLE CRYSTALS

Task

β-Ga_2O_3 is a wide bandgap semiconductor characterized by a particularly large bandgap of about 4.8 eV. Compared to SiC or GaN, β-Ga_2O_3 single crystals can be grown comparatively efficiently and economically due to their low melting point of about 1800 °C. Currently, mainly crucible-based processes such as the Czochralski method are used for this purpose. However, the purity of the crystals achievable is limited by melt contamination owing to diffusion of crucible material. By applying the crucible-free, laser-diode-heated floating zone (LDFZ) method, the Japanese National Institute of Advanced Industrial Science and Technology (AIST) has been able to efficiently grow high purity Ga_2O_3 crystals. In a joint project with AIST, Fraunhofer ILT is continuing to develop the LDFZ method and to grow crystals with a diameter of up to 51 mm.

Method

In the LDFZ method, the generally polycrystalline starting material is irradiated radially with laser diodes and melted in a defined area. For this purpose, Fraunhofer ILT is developing and setting up an optical system, with a fiber-coupled diode laser used as the beam source. So that a process-adapted intensity distribution can be generated, the radiation emerging from the fiber is homogenized and split into five beams of equal power, which are finally guided radially to the processing point via deflecting mirrors.

Results

The diameter of the crystals grown at AIST using the LDFZ method was increased during the project from 8 mm to currently 12.7 mm. In addition, Fraunhofer ILT has developed an optical system which can be used to grow crystals with a diameter of 38 mm and 51 mm. The optical system will be set up at Fraunhofer ILT in 2020 and operated in combination with a diode laser having a maximum optical output power of 20 kW.

Applications

Currently, the industry is investigating Ga_2O_3 crystals and other metal oxides grown using the LDFZ method and their suitability for applications in high-performance electronics.

This project is funded by the Fraunhofer-Gesellschaft within the ICON program.

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1 Optical setup for the crystal growing system.

2 Temperature profile on the Ga_2O_3 crystal during the growth process.

MODELING AND SIMULATION OF VERTICAL-CAVITY SURFACE-EMITTING LASERS

Task

Vertical-cavity surface-emitting lasers (VCSELs) constitute an increasingly important alternative to edge-emitting laser diodes. Despite their low manufacturing costs, diffraction-limited, narrow-band emission and excellent modulation capability, VCSELs were only used for optical data transmission and sensor technology for a long time since the good beam quality could only be generated at single mW per individual emitter. For several years now, Fraunhofer ILT has been working in close collaboration with TRUMPF Photonic Components GmbH to improve VCSEL for high-power applications. In addition to increasing the brightness of high-power VCSEL by means of external resonators, Fraunhofer ILT's activities are currently focusing on developing chip designs for selectively addressable VCSEL arrays of high pulse energy for use in driver assistance LIDAR systems.

Method

Fraunhofer ILT is developing the SEMSIS software to simulate, either isolated or coupled, various physical phenomena relevant to semiconductor lasers. These include electrical as well as heat transport and light propagation in semiconductor nanostructures or the optical properties of light-amplifying quantum well structures. In close connection with experimental work, Fraunhofer ILT is using computer simulations to investigate real or potential semiconductor laser structures in terms of the achievable laser parameters.

Results

The software enables users to develop a fundamental understanding of the specific laser parameters and their limiting effects as well as the design of novel semiconductor structures, all of which are optimized with respect to beam quality, output power or pulse parameters. Thus, they can significantly reduce cost- and time-consuming parameter studies on real manufactured semiconductor lasers.

Applications

In addition to the classic fields of application – optical data transmission and sensor technology – these vertical cavity emitters are increasingly being used in high-power applications, e.g. in the heat treatment of materials. Since selectively addressable VCSEL arrays can be used to dynamically generate flexible intensity profiles, they have become interesting beam sources for digital production in addition to their use in the driver assistance LIDAR systems investigated here.

Parts of the work presented in this report were carried out on behalf of the Federal Ministry of Education and Research under the grant number 13N14895.

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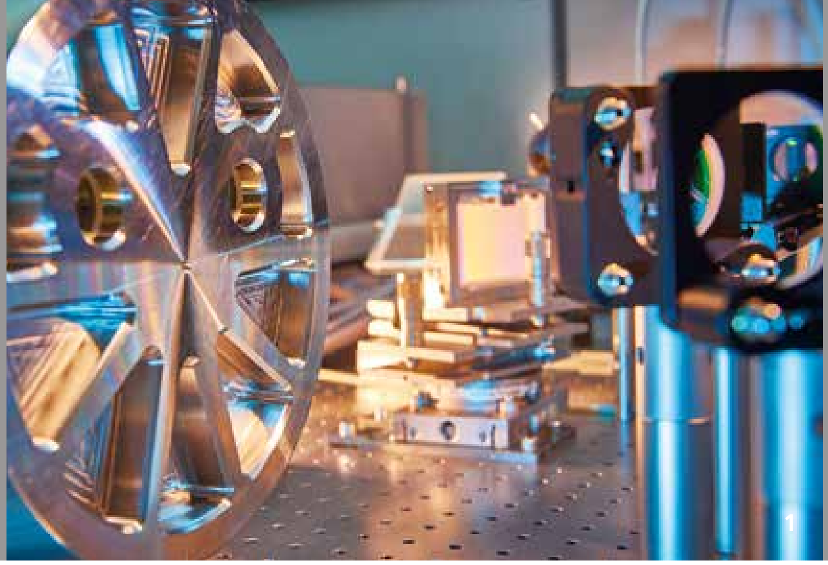
3 SEM image of a VCSEL array.

4 Simulation of the spatial distribution of the electrostatic potential in a VCSEL semiconductor heterostructure.



SCALABLE ULTRASHORT PULSE LASER WITH < 30 FS PULSE DURATION AND > 500 W OUTPUT POWER

Task

Based on ytterbium-doped laser media, ultrashort pulse lasers with pulse durations < 1 ps have become well established in many scientific and industrial applications. Since their power can be scaled up to the kW range at repetition rates of several 100 kHz, they offer high throughput and short measurement times in industry and science at reduced costs per watt. Within the Fraunhofer Cluster of Excellence Advanced Photon Sources CAPS, this potential shall be tapped for applications requiring significantly shorter pulse durations below 100 fs.

Method

Although pulse durations < 100 fs can be directly addressed by other laser materials such as Ti:sapphire, their power is limited to values below 100 W. Therefore, nonlinear pulse compression of powerful ytterbium-based ultrashort pulse lasers offers a clear advantage, which can be implemented by spectral broadening in a gas-filled multi-pass cell with subsequent compression by dispersive mirrors. Compared to other compression schemes, this method is particularly well suited for high powers due to its high efficiency > 90 percent and the absence of limiting apertures.

Results

To demonstrate the scalability of the approach, Fraunhofer ILT developed and built a laser system based on a commercial ultrashort pulse laser, a 2-stage Yb:INNOSLAB amplifier and nonlinear pulse compression. This system consists of a gas-filled (4 bar argon) multi-pass cell (800 mm long, 22 roundtrips) and a compressor with 9 dispersive mirrors. The pulses of the laser system – at 590 fs pulse duration and 1.1 mJ pulse energy – are hereby compressed to 30 fs at 1.06 mJ pulse energy (26 GW pulse peak power). At a repetition rate of 500 kHz, the output power is 530 W with an almost unchanged beam quality $M^2 < 1.2$.

Applications

The laser system presented here can be used profitably if particularly short or broadband pulses with high average power are required. This is especially true for nonlinear processes such as frequency conversion to MIR, EUV or the generation of THz radiation. A further scaling of the average power to ~ 2 kW at similar repetition rates is planned.

The R&D project underlying this report was funded by the German Federal Ministry of Education and Research under the grant number 13N13782 and by the Fraunhofer Cluster of Excellence Advanced Photon Sources CAPS.

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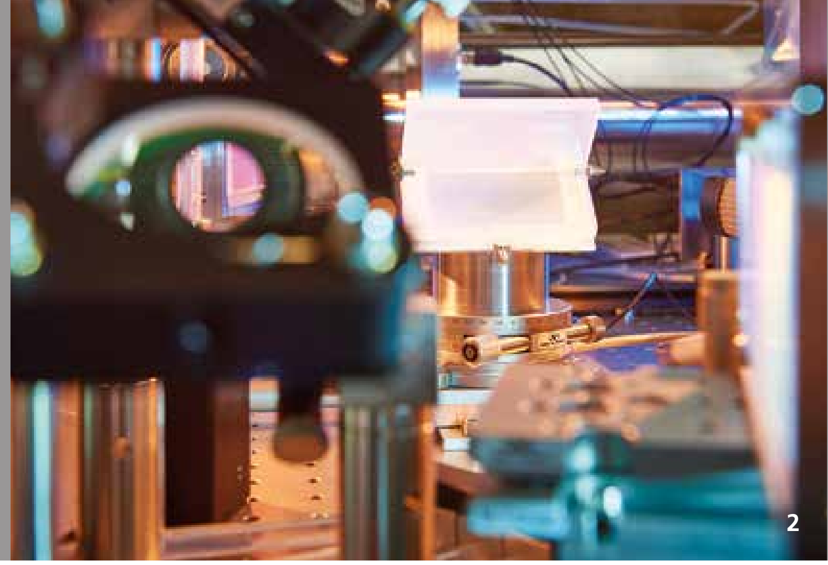
1 Pulse compression unit.



FRAUNHOFER CAPS – USER FACILITY FOR ULTRASHORT PULSE LASERS WITH HIGHEST AVERAGE POWERS

Task

Ultrashort pulse lasers enable research not only to develop new applications through precise structuring in micro material processing along with a minimal heat-affected zone, but also to generate coherent radiation in the XUV range. When the power of ultrashort pulse lasers is scaled, their precision can be transferred to large-area applications with high throughput as well as highly demanding processes such as the machining of ultra-hard ceramics and fiber-reinforced plastics. The User Facility of the Fraunhofer Cluster of Excellence Advanced Photon Sources CAPS will provide laser users from research and industry with a new generation of ultrashort pulse lasers for application studies.

Method

Fraunhofer CAPS is developing ultrashort pulse lasers whose average power is one order of magnitude higher than that of the ultrashort pulse laser sources available today. The CAPS User Facility at Fraunhofer ILT was officially opened on September 18, 2019, and aims to make these novel laser beam sources available to industry and research at an early stage. Together with other Fraunhofer partner institutes, the facility will also advance the development and investigation of future-oriented applications.

In the next few years, the researchers plan to reach up to 10 kW average output power at pulse durations of less than 50 fs. This laser radiation is variably guided into three fully equipped user cabins. These can be flexibly adapted for the respective application investigations.

Results

The CAPS User Facility offers a unique opportunity for industry and research to investigate optical processes using a laser beam source with unprecedented average power for their purposes. As the application laboratory continues to be developed, interested persons are invited to approach the contact persons listed below.

Applications

The foreseen applications cover a broad spectrum in the fields of production, imaging, materials and basic research, such as high-precision machining of materials with high productivity, generating coherent EUV radiation and soft X-rays for imaging and lithography processes, and modifying materials for use in quantum technology.

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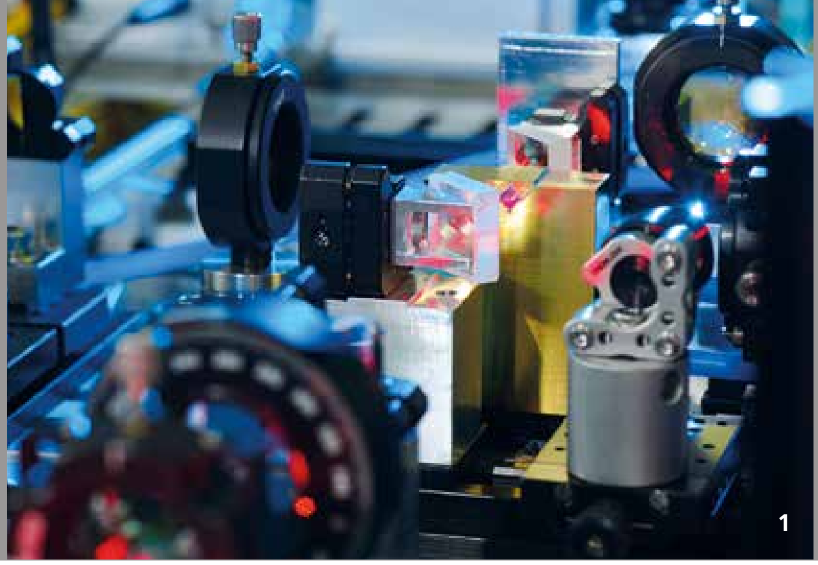
2 Amplification of the average power of ultrashort pulse lasers up to 10 kW.



AMPLIFIER FOR PULSED LASER RADIATION WITH 2.9 µM EMISSION WAVELENGTH

Task

Within the cooperative Fraunhofer-Max-Planck project DIVESPOT, Fraunhofer ILT is investigating the direct amplification of laser pulses in the MIR range with output wavelengths around 3 µm, pulse durations below 1 ns and repetition rates in the kHz range. Novel amplification materials are used to address the wavelength range without nonlinear processes. The project aims to develop a new tool for surgery, e.g. for the removal of soft tissue. Laser pulses with a pulse duration of less than 1 ns and a wavelength around 3 µm generate a particularly small heat-affected zone due to high absorption and short duration. The targeted biological tissue can thus be ablated without damaging the surrounding tissue.

Method

The chromium-doped II-VI compound semiconductor material zinc selenide is used as the amplifying medium. Since the luminescence lifetime of Cr:ZnSe in the upper state at room temperature is only about 5 µs, the pump power must be provided in high-energy, short pulses for efficient pumping. Therefore, Q-switched thulium solid-state lasers with a wavelength of 1.9 µm and pulse lengths of a few 100 ns are used as pump sources. The laser beam source was built as a master oscillator power amplifier (MOPA), whereby a seed laser beam source with few µJ pulse energy was amplified in a double pass through two rod-shaped amplifier stages.

1 Amplifier stage with Cr:ZnSe amplification medium.

Results

A two-stage laser amplification system based on the amplification medium Cr:ZnSe was built. With this system, Fraunhofer ILT was able to demonstrate a maximum gain of about 10 and a pulse energy of more than 300 µJ at a repetition rate of 1 kHz. The pulse duration of the laser radiation with an emission wavelength of 2.91 µm was about 1 ns.

Applications

Laser beam sources in the MIR are suitable for use in the medical field, e.g. as laser scalpel for soft tissue applications, but also for other materials that have a high absorption in the MIR such as plastics. Furthermore, these laser beam sources can be used for molecular spectroscopy.

The project DIVESPOT has been funded within the Fraunhofer-Max-Planck cooperation program.

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ULTRASHORT PULSE LASER BEAM SOURCE AT 3.4 µM FOR PROCESSING POLYMERS

Task

The wavelength of a laser can be decisive for the efficiency and quality of laser machining processes. For example, while different polymers show a pronounced absorption at a wavelength of 3.4 µm, this wavelength range is not addressed by commercially established lasers, such as solid-state and fiber lasers. In contrast, the transmission of polymers in the common wavelength range at 0.5 µm or 1 µm is very high, which makes it difficult to introduce energy into material.

Within the joint research project IMPULS, funded by the Federal Ministry of Education and Research, Fraunhofer ILT is investigating high-power INNOSLAB-based modular ps-lasers to make ultrashort pulse laser processing cost- and power-efficient with absorption-adapted wavelengths. For the efficient processing of polymers, the output wavelength of these lasers is specifically adapted to the absorption maximum of the polymers by means of nonlinear frequency conversion.

Method

In the IMPULS project, Fraunhofer ILT is investigating different conceptual approaches for the parametric frequency conversion from 1 µm to 3.4 µm. These consist of an optical parametric generator and, optionally, of one or more downstream optical parametric amplifiers in which PPLN crystals with large apertures are used as nonlinear media.

Results

Based on a three-stage parametric frequency converter, Fraunhofer ILT built a beam source with an average output power of 15 W at an emission wavelength of 3.4 µm, a pulse duration of 10 ps and pulse frequencies of 300 kHz to 1 MHz.

Applications

The beam source developed here can be used for structuring and cutting polymer films, e.g. PE, PEN and PP. The analysis of parameter-equivalent cutting experiments at 1 µm and 3.4 µm wavelengths shows that cuts are possible with 20 to 50 times less power due to the optimized wavelength. In addition, cut edges at a process wavelength of 1 µm show a pronounced tendency to color changes owing to the higher heat input. This does not occur at a wavelength of 3.4 µm or only to a significantly limited extent.

The R&D project underlying this report was carried out on behalf of the Federal Ministry of Education and Research under the grant number 13N13966.

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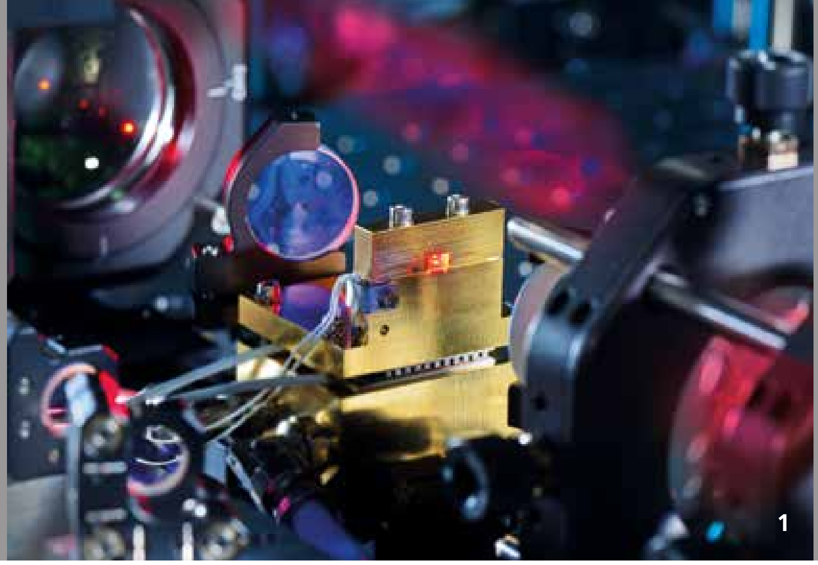
Cut kerf in PEN film:
2 ... after a laser cut with 3.4 µm wavelength.
3 ... after a laser cut with 1 µm wavelength.



CONTINUOUSLY DIODE-PUMPED ALEXANDRITE LASER WITH 6.5 W OUTPUT POWER

Task

Scaling the output power and efficiency of continuously emitting diode-pumped alexandrite lasers is an ongoing subject of research. Thanks to their tuning range between 700 - 800 nm, they provide access to atomic and ionic resonance lines. When alexandrite is pumped with laser diodes in the red spectral range, these lasers have higher efficiency, a smaller installation space and lower thermal load compared to pumping them with flash lamps. To extend the application potential, Fraunhofer ILT has increased the output power in the transverse fundamental mode compared to the current state of the art.

Method

The laboratory setup of a longitudinally diode-pumped alexandrite laser is used to demonstrate the potential of scaling the laser to higher powers. The alexandrite crystal is pumped longitudinally with laser radiation at the wavelength of 638 nm. For this purpose, the output beams of two commercial diode modules are polarization-coupled and the transverse properties symmetrized with a step mirror. A total pump power of up to 58 W is achieved with a beam quality of M_x^2 = 100 and M_y^2 = 110.

Results

Fraunhofer ILT has demonstrated a continuous-wave power of 6.5 W at 25 W absorbed pump power from its alexandrite laser in fundamental-mode operation (M^2 = 1.1), a power that sets the current record for diode-pumped alexandrite lasers. The free-running wavelength at maximum power is 752 nm.

The result underscores the potential of diode-pumped alexandrite lasers for the emission of laser radiation tunable in a wide spectral range with average output powers in the watt range. Current investigations are helping us better understand thermal effects in the crystal in order to operate the laser efficiently at even higher pump powers.

Applications

The arrangement can be extended to investigate the generation of ultrashort pulses by mode locking since alexandrite has a large gain bandwidth. Furthermore, frequency doubling within the resonator makes it possible to generate tunable laser radiation in the UV in a single conversion step.

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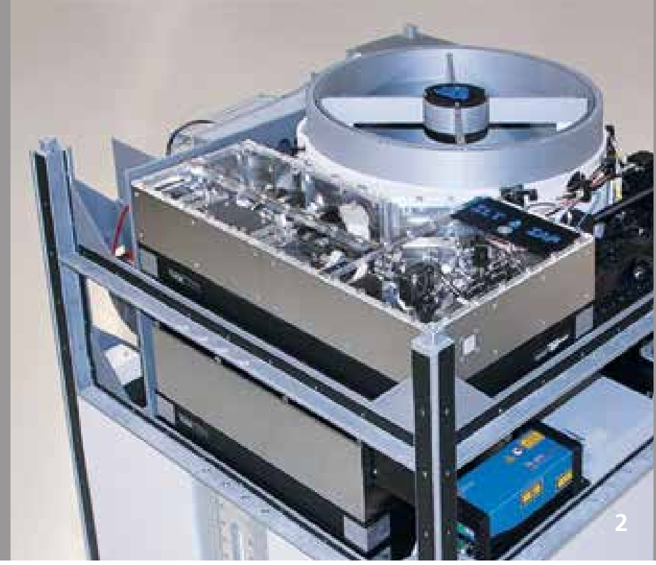
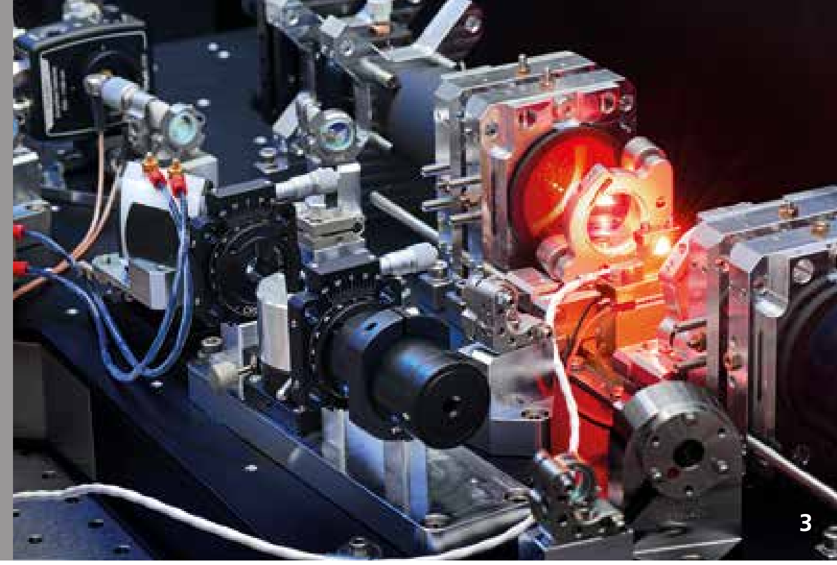
1 Continuously diode-pumped alexandrite laser.





DIODE-PUMPED ALEXANDRITE LASER FOR A COMPACT LIDAR SYSTEM

Task

At the Leibniz Institute for Atmospheric Physics (IAP), mobile resonance LIDAR systems are being used to measure temperature profiles of the atmosphere at altitudes between 80 and 110 km. To accomplish this, the Doppler width of a metal resonance line is spectroscopically determined as a measure of temperature. The institute used flash lamp-pumped alexandrite ring lasers as laser emitters for a long time. The successful development of the first diode-pumped alexandrite laser significantly increased the efficiency and reduced the space requirements. On this basis, IAP and Fraunhofer ILT jointly developed a new type of compact LIDAR system (~ 1m³) using innovative LIDAR technology, which can be used to measure the entire atmosphere from the troposphere to the lower thermosphere. For this purpose, Fraunhofer ILT developed an improved prototype of the laser and integrated it into a new LIDAR system.

Method

The prototype operates as a Q-switched alexandrite ring laser. The pump source is fiber-coupled, which increases flexibility and maintainability, and is based on two commercial diode laser modules, each emitting up to 40 W average power at 638 nm in continuous operation. Stable single-frequency operation is achieved by seeding with a narrow-band diode laser and by electronic control of the resonator length. The output wavelength of the alexandrite laser can also be continuously tuned in the potassium resonance range with the wavelength of the seeder. After completion in the laboratory, the laser was integrated into the system of IAP, which contains the laser's peripheral equipment as well as the entire LIDAR technology.

Results

In transverse fundamental mode operation (M^2 < 1.1), the laser emits pulses at a wavelength of 770 nm, an energy of 1.7 mJ and a repetition rate of 500 Hz. The pulse duration is 800 ns with a spectral bandwidth of less than 5 MHz. Thus, the total space requirements including the cooling technology as well as the energy consumption could be reduced by a factor of 100 compared to the previous LIDAR system, which used a flash lamp-pumped laser.

Applications

In the next step, several such systems will be built and combined to form a LIDAR array with spatial coverage over several 100 kilometers. In the ALISE research project (grant number 50RP1605) funded by the German Federal Ministry of Economics and Energy, Fraunhofer ILT and Leibniz IAP also investigated how the technology can be implemented for satellite-based atmospheric research.

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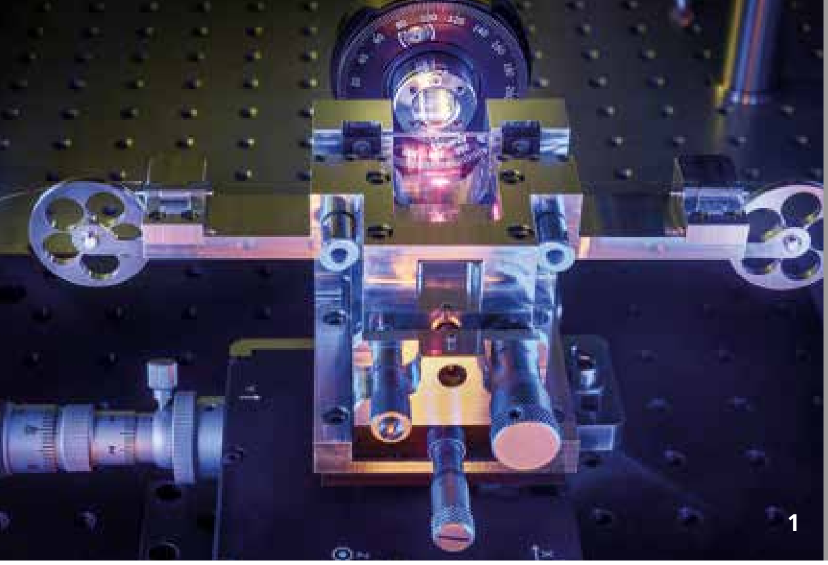
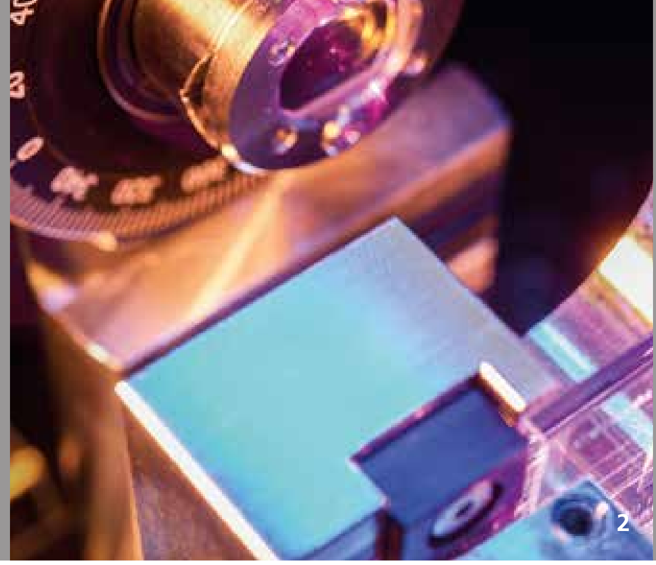
2 Alexandrite laser integrated in a LIDAR system, © Leibniz IAP, Kühlungsborn.
3 Diode-pumped alexandrite laser.





MULTIMODE FIBER BRAGG GRATING AS OUTPUT COUPLER MIRROR FOR XLMA-BASED FIBER LASERS

Task

Multimode fiber lasers are among the most cost-effective and efficient beam sources for cw laser applications and are, therefore, used for many industrial applications such as welding and cutting. For these sources, the resonator is usually formed by the active laser fiber and dichroic mirrors. Fiber Bragg gratings (FBGs) are periodic modulations of the refractive index written in fibers and act as fiber-integrated wavelength-selective mirrors. FBGs have only been used in transverse single-mode fiber laser oscillators so far. Within the BMBF project EKOLAS Fiber Bragg gratings for transverse multimodal fiber lasers have been developed as output coupler mirrors. This allows the construction of a fiber-integrated resonator, which can reduce the number of optical elements and thus increase the mechanical robustness of the system.

Method

The periodic modulation of the refractive index is written into the fiber core using an USP laser in the infrared emission range and two-beam interference. The basis of the writing process is the non-linear absorption in the glass, which eliminates the need to pre-treat the fiber. Therefore, the process can be used for a large number of commercially available undoped and doped fibers.

Results

Thanks to the setup developed in the project, FBGs could be written into active »extra large mode area (XLMA)« fibers as fiber-integrated output coupler mirrors with reflection coefficients of < 10 percent and tested in laser resonators with output powers up to 800 W. Due to their property as wavelength-selective mirrors, FBGs also act as frequency stabilizing elements and can thus be used to improve the spectral brilliance of the laser system.

Applications

For fiber-coupled multimode high-power fiber lasers, this technology makes it possible to generate the output coupler mirror and to stabilize the frequency with fiber-integration at the same time, thus dispensing with additional optical elements.

The R&D underlying this report was conducted on behalf of the Federal Ministry of Education and Research under the grant number 13N13914.

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1 FBG workstation.

2 Long-term exposure of the FBG writing process using USP laser radiation.

DEVELOPMENT OF A HERMETICALLY SEALED, SOLDERED FIBER GUIDE

Task

Optical glass fibers for guiding laser radiation require interfaces that are usually implemented in the form of fiber plugs and guides. In special applications, e.g. in high-power electronics, special measuring systems and space technology, the optical system is located in a vacuum or in an inert gas environment so that each external interface must be sealed in a vacuum-tight manner. The fiber guides used for this purpose should sufficiently hermetically seal the optical system to prevent contamination. The assembly procedure must not affect the optical properties of the fiber. For this reason, a vacuum-tight fiber guide should be developed using soldering technology.

Method

The fiber is mounted in a fiber guide specially designed for soldering and hermetic sealing. With suitable solders, fibers can be mounted on metallic and non-metallic substrates under ambient conditions. First, a process is used to wet the fiber and the fiber guide with the solder. The wetting process does not require an intermediate layer as a metallization. The use of soft solders is advantageous for reducing thermally induced stresses.

Results

Optical measurements show that the soldering technology for polarization-maintaining fibers has a marginal influence on the beam properties after the fiber. Since the fiber is mounted without fiber connectors, there is also no loss of power at this point. The tightness of the fiber guide was determined with a pressure rise test, and a leakage rate of $Q \leq 1.15\ 10^{-6}$ $mbar*l*s^{-1}$ was proven. Due to the high thermal conductivity of the interface, higher optical power can be transmitted, which is in contrast to conventional assembly methods. The mechanical strength of the soldered joints was verified by tensile tests.

Applications

The assembly technology presented here, using soldering methods, can make the process of fiber assembly more economical and efficient. Moreover, in addition to robust, hermetically sealed and outgassing-free fiber assembly, this technology makes it possible to construct long-term stable and vacuum-tight fiber guides for use in industry and research.

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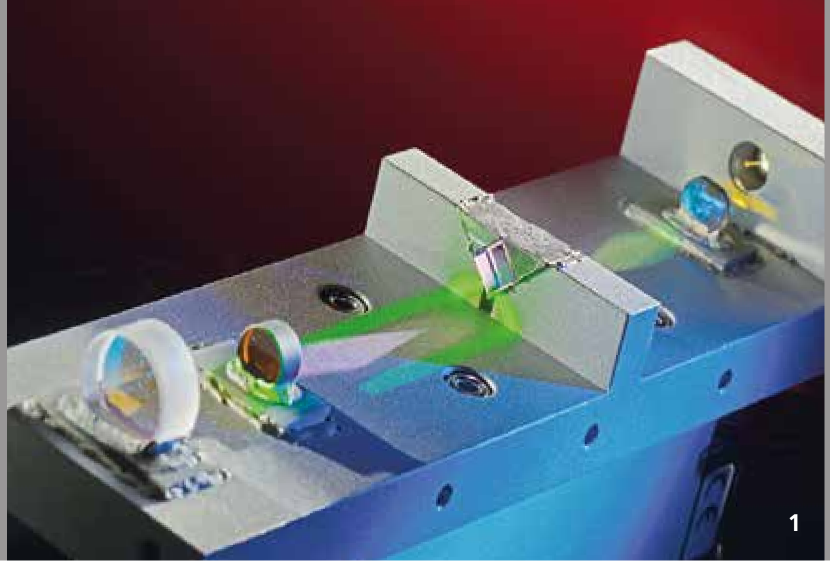
3 Metal-fiber soldered joint.



ASSEMBLY TECHNOLOGY FOR COMPACT OPTO-MECHANICAL COMPONENT GROUPS

Task

New soldering technologies can be used to build robust optical components and systems that are outgassing-free and stable for the long-term. The project described here aims to join materials – without using flux – that are difficult to wet without a mediator layer so that work steps such as the metallization of components are no longer necessary. This technology can also be used in ambient air, and thanks to this, both equipment and work steps are no longer needed for creating an inert gas atmosphere, as is the case with classic soldering technology. To be developed is an assembly technology that can be used for the construction of compact laser beam sources.

Method

The assembly technology was used to build a solid-state laser developed at Fraunhofer ILT. All of the optical components were assembled using the above-mentioned soldering technology. Especially developed for the alignment of opto-mechanical components in the aerospace industry, the pick & align technology was used to align components actively. Thanks to the inductive heat supply and different soldering systems, optical components can be individually mounted and adjusted in limited space. The use of soft solders is advantageous for reducing thermally induced stresses.

Results

A fully functional laser beam source has been constructed using the soldering technology developed at Fraunhofer ILT. The same performance is achieved as with classical optics holders. Since the interfaces have high thermal conductivity, the heat can be optimally dissipated from the system, in contrast to conventional mounting methods, so that a rapid thermalization of the laser was achieved. The dimensions of the mounted laser beam source are 153 x 40 x 20 mm^3. The mechanical strength of the soldered joints has been proven by tensile tests. The assembly will soon be subjected to temperature cycle, vibration and shock tests.

Applications

The innovative concept makes the assembly process more economical and efficient. The developed assembly technology enables the construction of compact, robust and long-term stable laser beam sources. These can be used, for example, to mark and label, in metrology and medical technology as well as for miniaturized, complex systems in quantum technologies. The assembly concept opens up a wide range of applications in industry and research.

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1 General view of the laser system.

BAKEOUT FACILITY FOR THE CLEANING OF OPTO-MECHANICAL COMPONENTS

Task

In close cooperation with Airbus Defence and Space (ADS) GmbH in Ottobrunn, Fraunhofer ILT is building a so-called »bakeout facility« to clean the components of the laser for MERLIN, a satellite-based methane LIDAR climate mission. While some components can be cleaned manually, others cannot. For them, the bakeout process uses a controlled outgassing process – which is generated under vacuum and by heating the components – to remove molecular contamination from them. This process is attractive when highly integrated and complex components have to be cleaned and when doing so manual alone does not guarantee that the components are uncontaminated.

Method

The vacuum chamber of the bakeout facility has a volume of 750 x 750 x 750 mm^3, in which a pump system can generate a vacuum of ≤ 1E-6 mbar. Heating resistors are used to heat the components to be cleaned so that temperatures of up to 120 °C can be reached. A so-called »Thermoelectric Quartz Crystal Microbalances (TQCM)« sensor is used to measure the remaining contamination. Fraunhofer ILT designed and set up a cold trap to prevent the TQCM sensor from falsifying measurement results when there is high build-up of contamination. This cold trap consists of multistage Peltier elements and the facility's mechanical system.

Results

Currently, the bakeout facility can generate pressures of down to 4E-7 mbar and heating temperatures of up to 100 °C. With the Peltier element-based cold trap, temperatures as low as -40 °C could be demonstrated. In the future, heating temperatures of 120 °C and cold trap temperatures of -45 °C shall be tested. To validate the bakeout process and the cleanliness of the plant, ADS Ottobrunn and Fraunhofer ILT will carry out evaluation and acceptance tests in the next months.

Applications

Bakeout facilities are important plants that ensure flight hardware for space travel is free of contamination. Since they reach high cleanliness standards, these facilities can also play an important role in the construction of solid-state lasers, frequency converters, UV optics or high-power ultra-short pulse lasers.

Special thanks go to ADS Ottobrunn for the conceptual design of the facility and the continuous support in the validation process.

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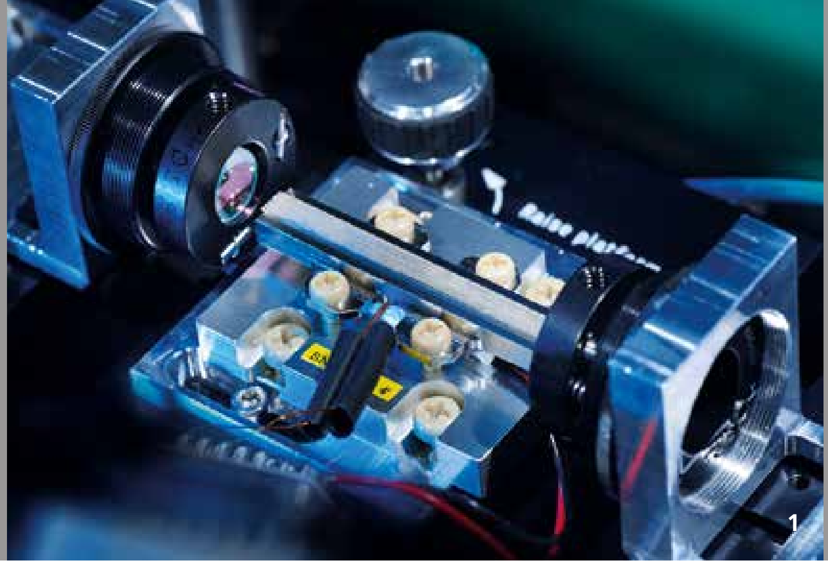
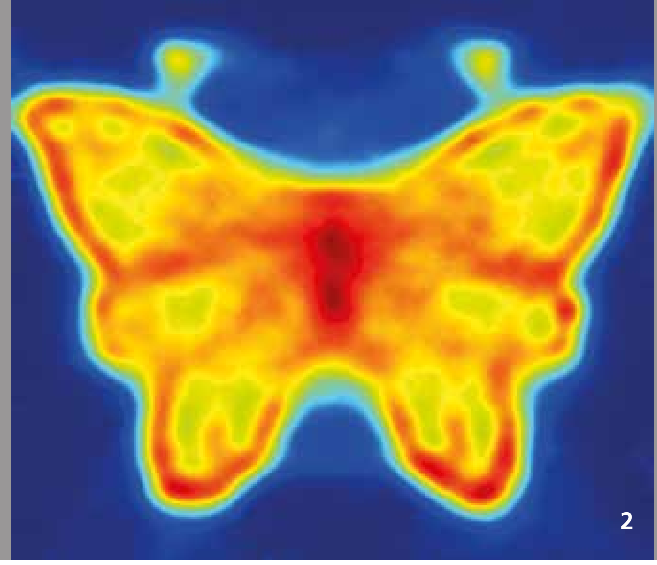
2 Bakeout Facility.





EFFICIENT FREQUENCY CONVERSION FOR QUANTUM COMMUNICATION IN FIBER OPTIC NETWORKS

Task

Powerful quantum computers and quantum networks will enable completely new types of applications that cannot be accomplished with classical computers. For fiber-optic quantum networks, photonic quantum bits (qubits) in the low-loss telecomunication C band around 1.55 µm have to be used to cover long operating distances. Solid-state based spin qubits are a promising platform to develop scalable quantum computers. These can emit photons in the wavelength range of 800 to 900 nm for the optical coupling of several qubits (so-called »flying qubits«). Optical interfaces in the form of quantum frequency converters (QFC) are required to convert the wavelengths into the telecommunication bands.

Method

In quantum frequency conversion (QFC), the wavelength of single photons, which serve as »flying« qubits, is specifically changed without changing other properties of the photons. A first step toward developing efficient quantum frequency converters is, thus, demonstrating a highly efficient frequency conversion of single photons or classical input fields with sufficiently low power. For conversion – analogous to classical parametric frequency conversion – a powerful laser is used in addition to the input and output fields to drive the conversion process in nonlinear crystals.

1 Setup for frequency conversion of single photons in waveguides.

Results

Based on a periodically poled lithium niobate (PPLN) waveguide pumped by a commercial fiber laser at 1950 nm, the frequency conversion from 856 nm to 1526 nm was demonstrated to be 87 percent efficient. The input power at 856 nm was 1.8 mW. In a next step, Fraunhofer ILT is investigating the conversion of single photons at 856 nm, whereby they expect to reach a similar efficiency.

Applications

The conversion demonstrated here is a first step towards implementing efficient quantum frequency converters, a key component for future quantum networks. Quantum frequency converters are still a crucial component for accomplishing quantum repeaters.

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DESIGNING FREE-FORM OPTICS FOR PARTIALLY COHERENT LASER RADIATION

Task

Free-form optics make it possible to shape beams flexibly so that adapted intensity distributions can be generated. For laser beam sources, however, the methods for designing free-form optics have been limited to either completely coherent or completely incoherent sources. Since laser beam sources often behave partially coherent, the methods need to be adapted.

Method

In order to consider the partial coherence of radiation, the Chair for Technology of Optical Systems (TOS) at RWTH Aachen University has implemented an alternative definition for radiance, a definition that transfers the wave character and the coherence properties of light into a ray tracing model. By implementing this, TOS can modify the designing algorithms for incoherent radiation already existing at the institute to consider sources with arbitrary coherence properties.

Results

Since the algorithm has been continuously developed, it is now possible to design and build free-form optics for various applications. In particular, the target intensity distribution and the laser beam source can be freely specified. The efficient implementation via ray tracing also minimizes the computation needed. Furthermore, the coherence properties changed during transmission by optical elements can be calculated.

Applications

The method implemented here can be used to dimension free-form optics for application-adapted beam shaping in laser material processing. Further potential can be found by analyzing the transformation behavior of the coherence properties of arbitrary sources after they pass through optical elements.

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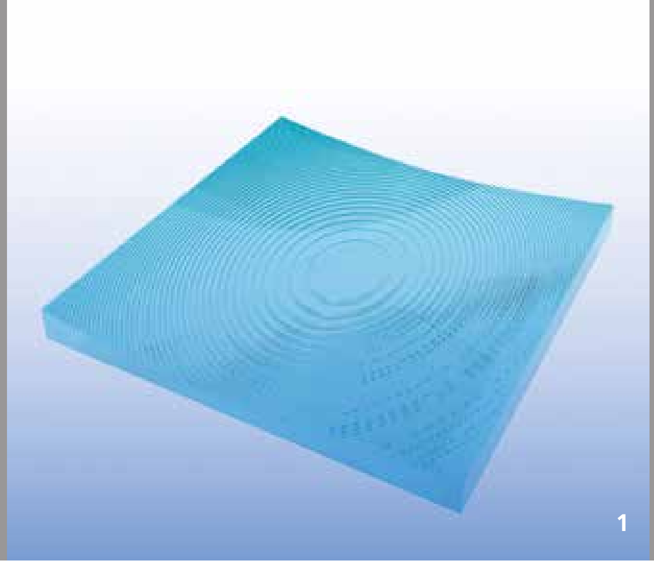
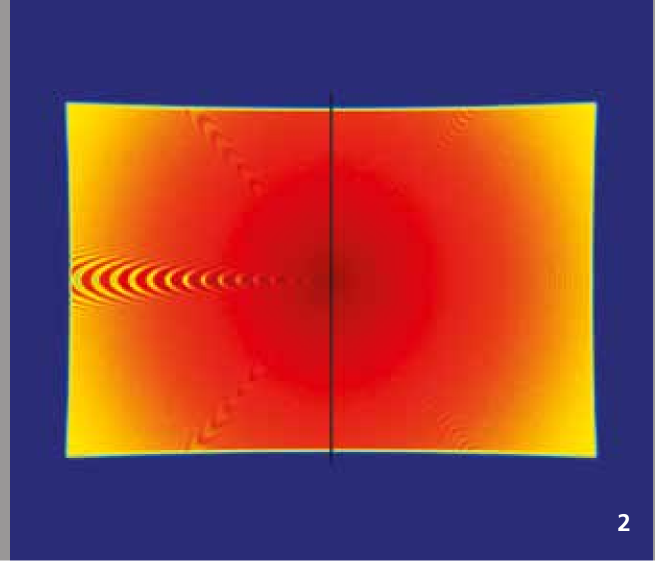
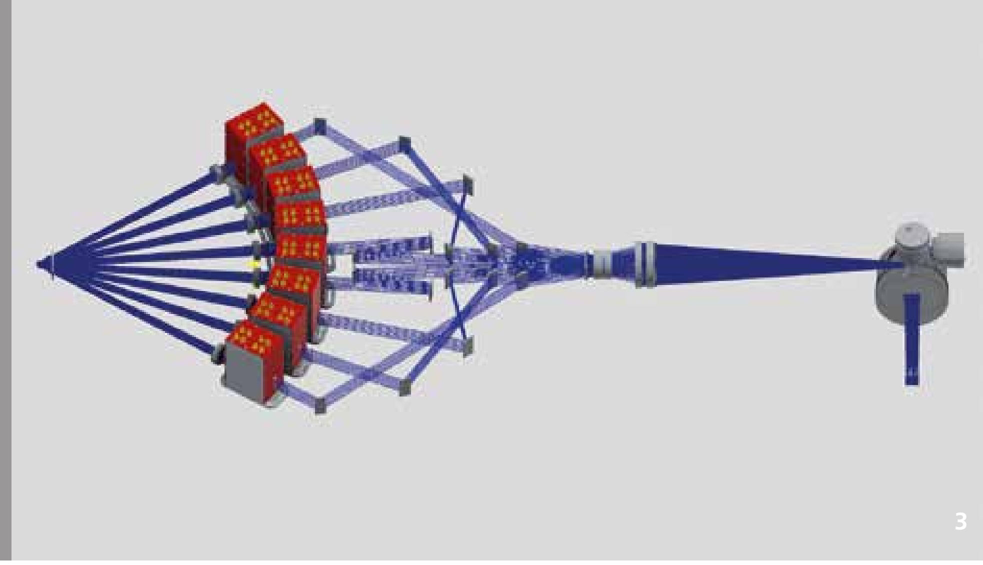
2 Irradiance distribution simulated with free-form optics for a partially coherent laser beam source.

3 Calculated surface for generating illuminance distribution.







FAST RAY TRACING OF SEGMENTED FREE-FORM LENSES

Task

Non-rotationally symmetric free-form optics are increasingly being used in consumer products. In order to reduce weight and material consumption as well as production time and, thus, costs, the industry is using fresnelization to minimize the component size of the optics. Since some of the light is refracted at the segment boundaries, the quality of the image decreases; however, the effect can be reduced by adapting the segment boundaries to the optics and the light source. This is particularly true for free-form optics since the high number of degrees of freedom means that the contour lines do not usually have rotational symmetry. The design of an individual fresnelization is based on repeatedly imaging the segmented free-form lens by means of ray tracing, which requires high computing power because there are many degrees of freedom of the free-form optics as well as the additional fresnelization.

Method

To design fresnelized free-form optics, the Chair for Technology of Optical Systems at RWTH Aachen University implemented a problem-adapted algorithm that allows efficient ray tracing. The segmentation is automatically calculated from the freeform surface and can, thus, be used as the basis for a multi-target function optimization procedure. Not only is the image quality of the segmentation taken into account, but also manufacturing constraints and the thickness of the lens. The developed program can be run on a conventional PC.

Results

For different applications, different fresnelization strategies can be considered, such as segmentation of the curved or flat side of the lens and segmentation along geometric curves or contour lines.

Applications

The method implemented here can be used for various consumer products, e.g. cameras of mobile phones or headlights in cars. Current work on the fresnelization of free-form optics focuses on the reduction of the moiré effect in heads-up displays.

The R&D project underlying this report has been carried out on behalf of the Federal Ministry of Education and Research under the funding code 13N14707.

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1 Design of a segmented free-form optic.
2 Simulated intensity distribution of a segmented free-form optic before (l.) and after (r.) the reduction of the moiré effect.

VARIABLE MULTI-BEAM OPTICS FOR PROCESSING WITH HIGH-POWER USP LASERS

Task

Ultrashort pulse (USP) laser processing is currently uneconomical for many industrial applications since the extremely high pulse energy can lead to plasma formation or thermal accumulation on the workpiece. Thanks to a powerful »dot-matrix printer«, the laser power can be divided into 64 partial beams, which can be switched on or off individually.

Method

A two-dimensional diffractive optical element (DOE) is used to split the raw beam of a 1 kW USP laser beam source into 64 partial beams. The individual beams are switched on and off by means of acousto-optical modulators (AOM), which deflects the unneeded beams into a beam dump. All other beams are coupled into a galvanometer scanner and focused on the workpiece. The diameter of the laser beams has to be varied several times due to the components involved; two telescopes are designed for this purpose. In addition, the spot distances on the workpiece and the distances of the individual AOM are specified. Prisms and mirrors are used to adjust the position of the individual beams. Since the optics will be integrated into an industrial demonstrator, its dimensions impose further restrictions.

Results

The optical design is divided into two areas. Since the AOM modules can each switch eight beams simultaneously, the entire optics is divided into eight parallel, independent optical systems. For this purpose, Fraunhofer ILT has developed an optics design which fulfills the boundary conditions for the beam path and the spot properties for each sub-optical system.

Applications

The most important fields of application can be found in the surface structuring of functional structures as well as in the manufacture of forming, embossing and printing tools.

The EU project MultiFlex underlying this report is being carried out as part of the »European Union's Horizon 2020 Research and Innovation Program« under the funding code 825201.

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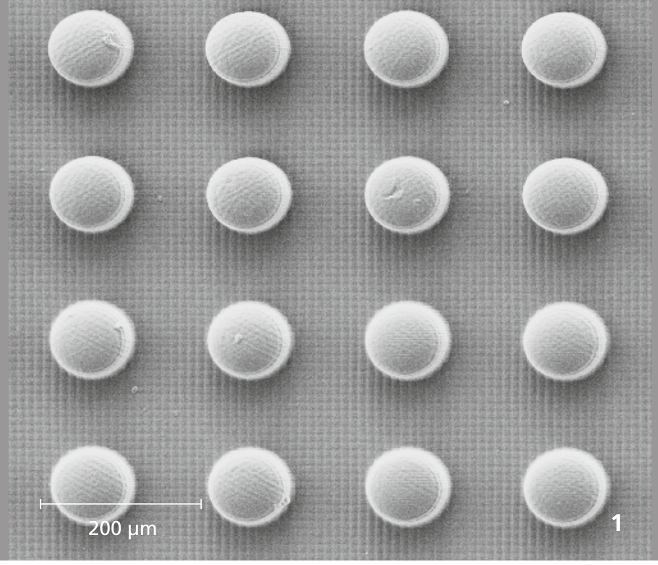
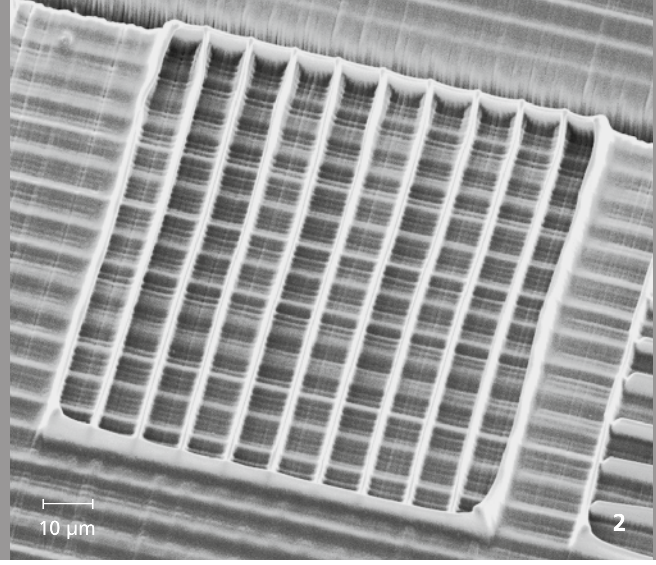
3 Design of the beam path.

LASER MATERIAL PROCESSING

CONTENTS

Ultrashort pulse laser for surface structuring: high-power tools for precision manufacturing.





COMBINATION OF UV AND MULTIPHOTON POLYMERIZATION FOR 3D PRINTING

Task

UV photo crosslinking in 3D printing can be used to make plastic components out of photo resins to precise specifications. A resolution above about 20 µm can be achieved for lateral structures, and the depth resolution is similar. Much more precise geometrical shapes can be made when multiphoton polymerization (MPP) with long-wave radiation is used, but the build-up rate is two to three orders of magnitude lower. Thus, extremely precise components can be produced, but not economically.

Method

High build-up rates and simultaneously high precision can, however, become possible when these two processes are combined: the majority of the component built with UV polymerization and only the finest structures with an MPP process. The planned process requires the two exposure modules for UV and MPP processes be combined in one system along with the option for using one or the other.

Results

In the first phase of the project, the processes were combined to test the individual modules and a plant concept was drawn up. Both modules could be used one after the other to produce a component in the same resin bath without having to remove the component.

Applications

The combination process can be used to great advantage for manufacturing components that are only produced in small or medium quantities and for which the manufacture of injection molding tools would be uneconomical. The largest volume fraction can be cross-linked with the relatively fast UV polymerization, whereby only geometric elements with a resolution < 10 µm can be written with the slower and more precise MPP process. Typical applications include microfluidic analysis chips that need to be connected to the macroscopic ports of analysis equipment, but require functional elements with dimensions in the micrometer range for mixing and filtering components.

This project is being carried out within the framework of the HoPro-3D project financially supported by the federal state of North Rhine-Westphalia and by the European Regional Development Fund (ERDF) under the funding code EFRE-0801252.

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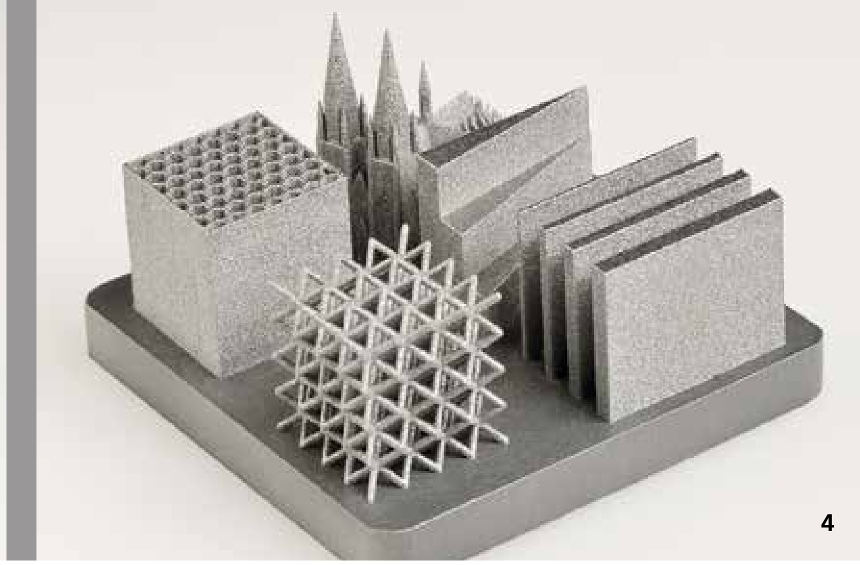
1 MPP printing of columns on a UV-polymerized base.
2 Writing of lines with 10 µm spacing and 2 µm width on a UV-cured base.



GEOMETRY-ADAPTED PROCESS CONTROL FOR LPBF

Task

Laser powder bed fusion (LPBF) can be used to manufacture highly complex components by melting powdered starting material layer by layer. After a powder layer has been applied, the laser is moved over the areas of the powder layer and melts it using a pre-defined processing strategy consisting of scan sequences and process parameters. Currently, when selecting a processing strategy, the industry takes the component's geometric characteristics into account only to a limited extent. In most cases, it defines one strategy for the entire component, which means that very different areas – filigree and solid – are processed in exactly the same way. The results, however, are form deviations, component distortion and restrictions in surface quality and productivity.

Method

Within the Fraunhofer lighthouse project futureAM, Fraunhofer ILT is investigating how the LPBF processing strategy can be better adapted to the component's geometry. To enable the LPBF process parameters to be adjusted down to the level of individual scan vectors, the institute is modifying the system and control technology correspondingly. In addition, it is developing software for component analysis in order to assign the process parameters specific to a geometrical form. The novel processing strategies are developed by the production and evaluation of test specimens, which are representative for critical component areas. These include, for example, overhangs or filigree structures. The process is monitored in relevant component areas with the help of a thermographic camera to investigate the temperature distribution and cooling behavior of the test specimens.

Results

Thanks to the novel processing strategies, the dimensional deviations within a component layer can be reduced by more than 30 percent for Ti6Al4V. In addition, components can be manufactured with an overhang angle of up to 80°, which is not only an increase of 35° compared to the state of the art, but also significantly reduces the amount of support structures required. The software tools developed enable users to automatically parameterize the components to be manufactured and selectively control the LPBF system during the exposure process.

Applications

The results of the project can be applied across all sectors for the production of any components using LPBF and transferred to other materials. When the process limits are extended further, new applications for the LPBF method will also be opened up.

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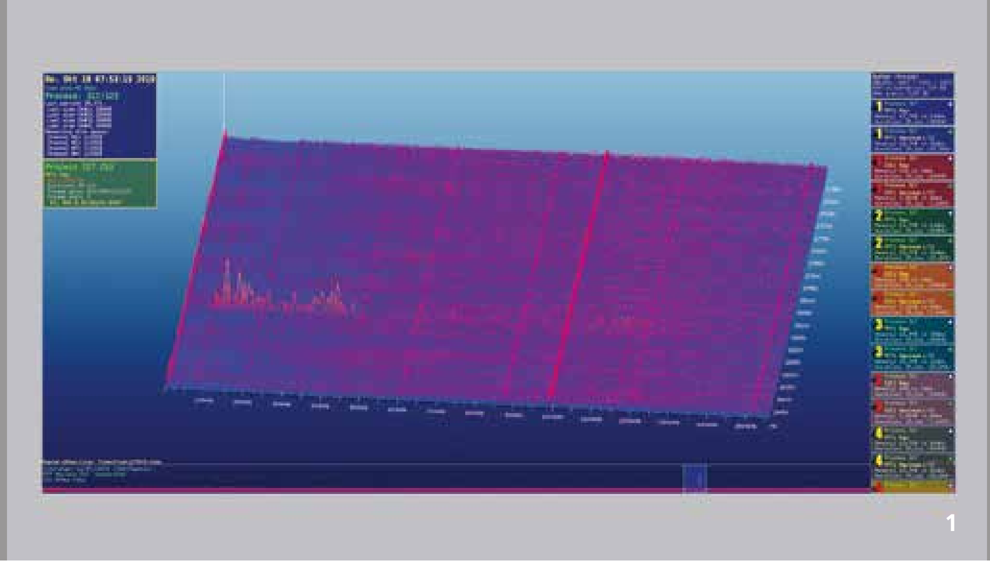
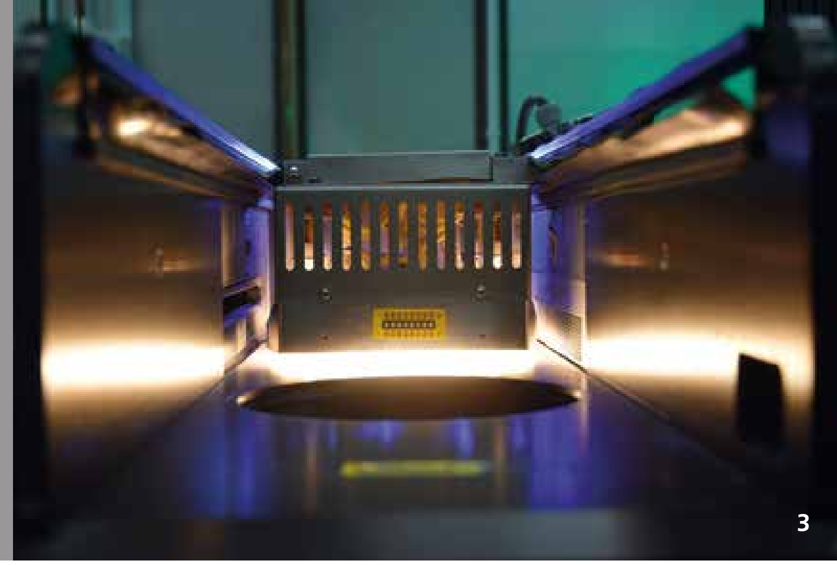
3 Overhang structures made of Ti6Al4V manufactured with LPBF.
4 Components made of Ti6Al4V using controlled energy input.





LPBF PROCESS MONITORING USING ULTRASOUND

Task

As part of the Fraunhofer lighthouse project futureAM, acoustic sensors are being used to monitor the laser powder bed fusion (LPBF) process. The project aims to detect typical defects in LPBF early and reliably, such as cracks and delaminations. Three piezo sensors and a laser microphone are used for detection. Airborne and structure-borne sound is detected up to the MHz range. During the first experiments, it became apparent that the clear assignment of the ultrasonic signals to process events posed a challenge.

Method

An LPBF machine was converted so that the three piezo sensors could be attached to the underside of the substrate plate. The laser microphone for airborne sound measurement was installed in the process chamber. The sound waves emitted by the process are detected by the four sensors and subjected to a Fourier transformation. The time and frequency signals thus obtained are analyzed with respect to relevant statistical features. So that the ultrasonic signals can be assigned to process defects and events, the signals are induced in a targeted manner and recorded by additional sensors such as a laser power meter, pyrometer and thermographic camera.

Results

The experiments and data analyses have shown that the process events and defects examined have unique signal characteristics that can be assigned to a specific event or defect. Cracks, delaminations, and overhang exposures can now be clearly detected in the LPBF process thanks to the piezo sensors and the laser microphone.

Applications

In this research project, the sensor design has already been successfully applied to LPBF to detect component defects at an early stage. In addition, this setup can also be used for other laser material processing methods such as laser beam welding or laser material deposition (LMD). The advantage is that the sensors can be easily integrated into industrial laser processing machines and also easily retrofitted into existing systems.

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1 Detection of a process deviation.

DIRECT POWDER BED PREHEATING USING NIR MODULES FOR LPBF

Task

In the laser powder bed fusion (LPBF) process, preheating systems can be used to reduce thermally induced residual stresses; thanks to preheating, LPBF can manufacture components with less distortion or can process materials susceptible to cracking. Conventional preheating systems, however, only heat the building platform itself. Since LPBF manufactures in layers and since the distance increases between the building platform and the processing plane, the temperature in the processing plane decreases during the process. To solve these drawbacks, current research is focusing on systems that directly preheat the processing plane. As part of a bilateral industrial project with the company AdPhos Innovative Technologies GmbH, Fraunhofer ILT has developed a preheating system based on adphosNIR® technology to address this issue.

Method

The core of the preheating system developed here consists of emitters that emit a wavelength spectrum in the near infrared (NIR) range with a maximum at 800 nm. The adphosNIR® module used can hold six such emitters with a total power of up to 12 kW. By mounting the module on the powder application unit of an LPBF system, Fraunhofer has been able to preheat the plane directly above the powder bed. Compared to other approaches for direct preheating of the processing plane, scattered radiation can be minimized and preheating concentrated on the powder bed. However, the powder bed is only preheated cyclically during the powder application process.

Results

With cyclical preheating, an almost constant temperature of 500 °C can be set when processing Inconel® 718 before remelting and independent of the overall height. The process-induced residual stresses have been reduced, as confirmed by distortion measurements on cantilevers. Trials with the high speed steel HS6-5-3-8 show that this preheating system makes it possible to build test specimens with an overall height of 50 mm without cracks. This is not possible when using a conventional, commercial system that only preheats the building platform. Furthermore, NIR preheating can be applied to achieve a much more homogeneous microstructure.

Applications

Thanks to the preheating developed here, almost constant temperatures can be maintained during the LPBF process on the machining plane, independent of component height. There are various applications that can profit from this, especially when processing materials difficult to weld, such as high speed steels or hard materials. In the »AM of WC-Co« project, Fraunhofer ILT is investigating how NIR preheating can be used in LPBF to process WC-Co, together with the Institute for Material Applications in Mechanical Engineering IWM and the Machine Tool Laboratory WZL at RWTH Aachen University.

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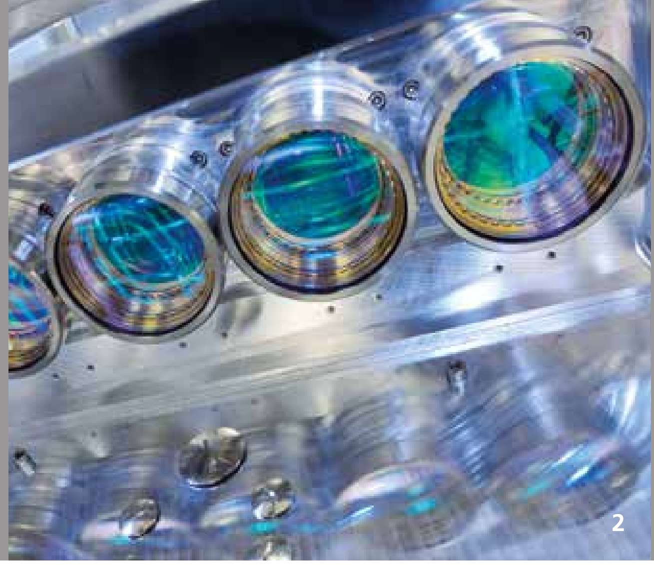
2 Significant reduction of distortion when using NIR preheating.

3 Preheating of the machining plane by an adphos®-NIR module.



MULTI-SCANNER PROCESSING HEAD FOR LASER POWDER BED FUSION (LPBF)

Task

To produce large metal components using LPBF, Fraunhofer ILT has developed a scalable machine design with a movable processing head (optical system and local shielding gas guide). The previous prototype only has a single laser scanner unit, which limits the build rate and results in long production times, particularly for large components. As part of the Fraunhofer lighthouse project futureAM, a processing head with five laser scanner units has been developed and tested.

Method

The design of the optical system – in particular the arrangement of the 2D galvanometer units and the shielding gas system – are a central component of the research work. To increase productivity, the institute has searched for a high overlap between the adjacent scan fields. At the same time, the most homogeneously possible shielding gas flow in the processing head must be ensured. As far as the achievable component accuracies are concerned, the optical system must be calibrated so that defects do not occur in the transitions between the scan areas. In addition, suitable processing strategies are required so that the simultaneous remelting processes do not impair each other.

Results

The prototype of the machining head has five compact galvanometer units arranged in a row and a footprint of 200 x 500 mm². Five fiber lasers with a maximum output of 400 W serve as beam sources. By using a simulation to adapt the flow components, Fraunhofer was able to achieve a homogeneous shielding gas flow across the entire width of the processing head. To improve accuracy, the institute also developed a new method for calibrating and aligning the scan fields; to increase productivity, it developed a CAM system that optimizes the scanner utilization in the process and minimizes the manufacturing time. On the basis of manufacturing trials, suitable machining strategies were identified that enable high productivity with high process robustness and component quality.

Applications

Thanks to machine and process technology presented here, LPBF components with a size of up to 1000 x 800 x 400 mm³ can be manufactured reliably and productively. The knowledge gained can be transferred to the development of new, commercial systems.

This project has been supported financially by the Fraunhofer-Gesellschaft.

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1 LPBF process with five simultaneous melting processes.
2 Optical system of the processing head.

INTEGRATION OF PRINTED ELECTRONICS IN LPBF COMPONENTS

Task

Intelligent components that provide data on their production status and condition are a central component of current developments in »Industry 4.0«. By combining thin film processing (TFP) with additive manufacturing, research can pave the way to the production of so-called »smart parts«. The sensors that make these parts »smart« can not only be freely positioned in the component, but can also be manufactured additively, just like the component itself.

Method

Fraunhofer ILT develops process chains for integrating additively manufactured sensors (strain gauges) into additively manufactured components. Additive manufacturing of the component using laser powder bed fusion (LPBF) is interrupted for the integration of the sensor, which is additively manufactured with TFP technology. Here, the different materials and structures are printed directly onto the component layer by layer and then functionalized (sintered, melted, hardened, etc.) using laser radiation. For the production of strain gages, the insulation layer, the measuring grid and the encapsulation are applied one after the other. The LPBF building process is then continued, closing the cavity and thus fully integrating the sensor into the component.

Results

By means of this innovative process chain, printed multi-material layer systems can be integrated directly into complex, additively manufactured components. The time-consuming preparation of discrete sensors is, therefore, no longer necessary.

Applications

The integration of strain gages is of interest for a large number of high-quality, heavy-duty components, e.g. in toolmaking, in turbomachinery or in combustion engines. The potential of the process chain is not limited to producing strain gages, however. Overall, the combination demonstrated here – of »printed electronics« and additive component manufacturing – constitutes a key technology in the production of intelligent components.

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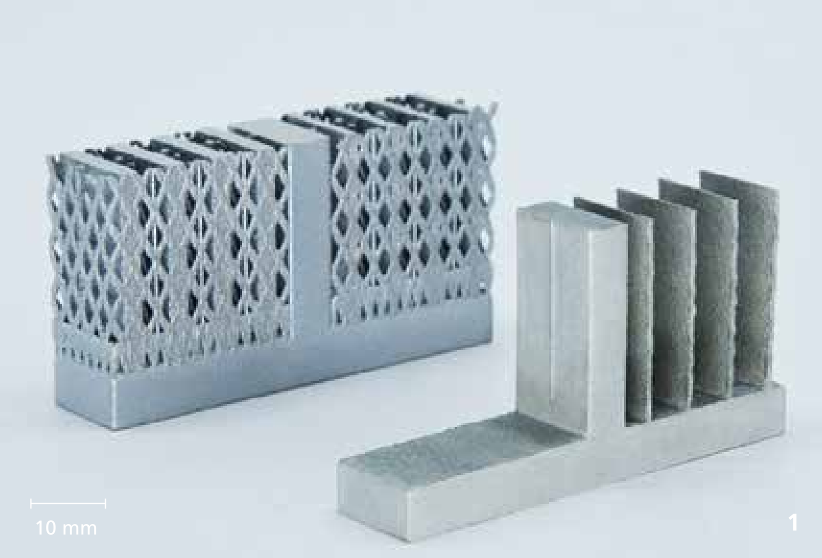
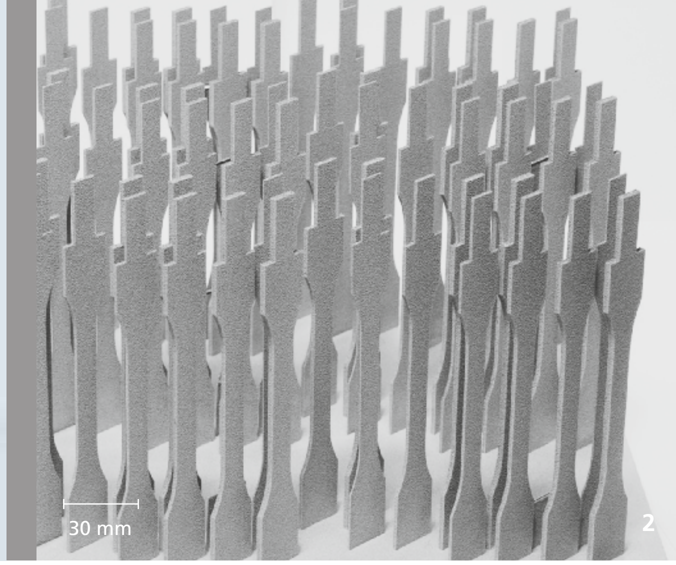
3 Additively manufactured component with printed strain gauge.





SUPPORT DESIGN FOR WET CHEMICAL SUPPORT REMOVAL OF LPBF COMPONENTS

Task

A considerable manual effort is required to remove the supports needed in the laser powder bed fusion (LPBF) process, thus posing a major obstacle to the process' widespread use in series production. One approach to automate this is wet-chemical removal: The support structures are dissolved by means of a chemical etchant. For the supports to be removed completely, however, their design has to be adapted. According to the current state of the art, the support structures are essentially adapted to the LPBF process and not to potential post-processing steps. While vector supports (single scans) can be completely and quickly chemically dissolved, volume supports, which are essential for faultless production, can only be dissolved with a delay. To resolve this issue, Fraunhofer ILT has been testing porous volume supports, which are just as resilient as conventional solid volume supports, but can be dissolved as quickly as vector supports.

1 Twincantilever with supports that have been wet-chemically removed (left: vector and porous supports, right: vector and conventional solid supports).

2 Prepared flat porous tensile specimens.

Method

Within the framework of an ongoing research project, Fraunhofer ILT has been investigating how various LPBF process parameters influence the porosity and strength of the supports. Moreover, it is examining the chemical material removal using the material AlSi10Mg. The results were then transferred to a supported component (twincantilever).

Results

From the results, Fraunhofer ILT has identified LPBF process parameters allowing the production of porous supports that can be dissolved much faster and that have almost the same strength as conventional solid supports. By applying the results to a supported twincantilever, it demonstrated that the process parameters could be transferred to supported components.

Applications

Due to the simple plant technology, the wet chemical process can be used both on a small scale and for industrial series production. Since the support design is easily adapted, the wet chemical support removal can be transferred to many applications and can, therefore, be made available to a wide range of industrial applications.

The R&D project underlying this report has been carried out on behalf of the Federal Ministry of Education and Research under the funding code 13N15080.

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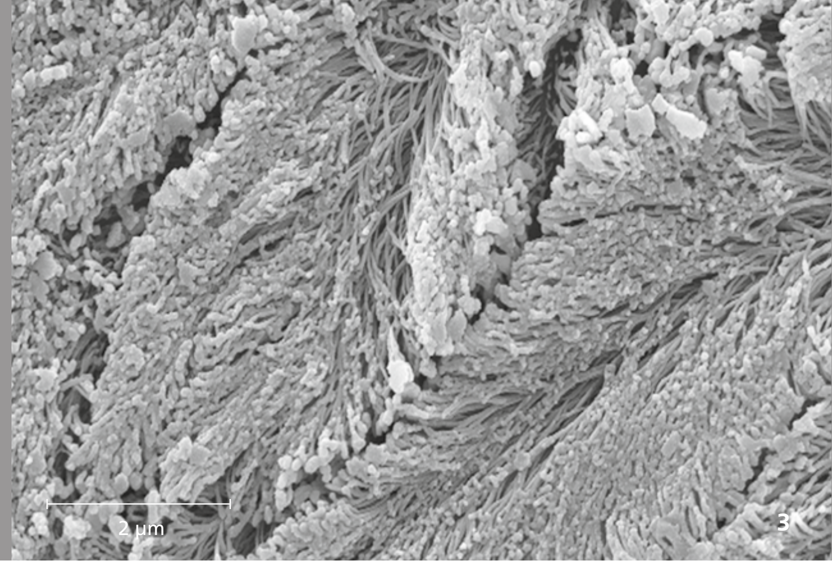

DEVELOPMENT OF A HIGH STRENGTH/HEAT RESISTANT AL-ALLOY FOR ADDITIVE MANUFACTURING

Task

The market for Al-based alloys for additive manufacturing is today defined by commercially available AlSi alloys and Scalmalloy®. Especially at elevated temperatures (~ 250-300 °C), however, AlSi alloys exhibit insufficient mechanical properties. Scalmalloy® has significantly better mechanical properties, but since scandium – a rare earth metal – is used, it is expensive and, therefore, only attractive for special applications. Conventional wrought Al alloys are not an alternative since they cannot be processed with additive manufacturing processes as they are prone to hot cracking. The work presented here aims, therefore, to develop a less expensive alloy with properties comparable to those of Scalmalloy®.

Method

In laser-based additive manufacturing, eutectic AlNi alloys have been identified as promising candidates for investigation. Starting from the binary composition, alloying additions are added in order to enhance the mechanical properties by precipitation hardening. The selection is based on simulated phase diagrams. Rapid experimental validation is performed by means of laser material deposition (LMD). A graded setup allows chemical composition to be varied over the setup height so that an interval of chemical compositions can be analyzed within a single sample.

Results

The binary Al-Ni base alloy (7.5 wt.% Ni) has successfully been processed with AM (LMD and laser powder bed fusion (LPBF)), which is confirmed by the lack of cracks and high component density > 99.9 percent. The hardness values determined (~ 160 HV) in the processed state are greater than comparable values for the alloy AlSi10Mg (~ 125 HV). Current research is identifying further mechanical properties and investigating how the addition of different strengthening agents influences the mechanical properties of the promising binary AlNi alloy.

Applications

The research presented here could be of interest to the automotive and aviation sectors as these new alloys can potentially replace Fe-Ti-based alloys. In particular, by broadly using such alloys with improved mechanical properties, these sectors will not only be able to save weight, but also reduce emissions. Increasing demands, e.g. due to downsizing of components, also require higher strength/heat-resistant materials.

The HAlUr project has been funded within the framework of the internal programs of the Fraunhofer-Gesellschaft MAVO and carried out in collaboration with the Fraunhofer Institutes IWM and IGCV.

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3 SEM image of eutectic Al-Ni fibers.

COAX HIGH POWDER FEED NOZZLE »COAX-HighNo«

Task

The coaxial powder feed nozzles previously used for laser material deposition (LMD) have a drawback: They have to be completely replaced or extensively reworked if they are mechanically damaged or worn out by the powder. These nozzles have an outer and an inner cone in their lower area, which are aligned to each other and, thus, create a gap for the coaxial powder supply.

Method

In order to reduce the required maintenance, Fraunhofer ILT has developed a new type of powder nozzle, whose tip, when damaged, is significantly easier to replace. This tip consists of an inner and an outer cone and can be exchanged as a monolithic unit. The gap size of the tip can be varied, based on the powder mass flow required and the particle size distribution of the powder conveyed. This way, the nozzle does not need additional adjustment.

Results

The use of replaceable, monolithic powder nozzle tips (inner and outer cone) minimizes the need for repairs as the nozzle tip can be replaced quickly and without readjustment. This significantly reduces production downtimes. Users can replace the nozzle tips on their own.

Specially coated nozzle tips increase the wear resistance so that the range of application is significantly extended both for large powder mass flows, as characteristic for extreme high-speed laser material deposition (EHLA), and for abrasive powders, such as carbides.

Applications

The newly developed powder feed nozzle with exchangeable nozzle tips as a monolithic unit can be used in all fields of application of both conventional and extreme high-speed laser material deposition.

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1 Coaxial powder feed nozzle COAX-HighNo.

2 Exchangeable tip for the coaxial COAX-HighNo powder nozzle.

LASER MATERIAL DEPOSITION WITH COAXIAL WIRE FEED

Task

Fraunhofer ILT has developed a 5 kg compact processing head for laser material deposition (LMD), which makes direction-independent 3D processing possible thanks to a coaxial wire feed. This processing head has been qualified in various projects for the application of iron, aluminum, nickel and titanium based alloys. The nickel-based alloy IN 718, which is relevant for turbomachinery, has been developed for this process as part of the work in the »International Center for Turbomachinery Manufacturing (ICTM Aachen)« community. The overriding objective here is to determine the geometric, mechanical and microstructure/macrostructure properties of 3D structures produced by wire LMD. In a first step, material test samples made of IN 718 were produced and analyzed.

Method

First, the institute identified suitable process parameters, developed build-up strategies and then produced 3D structures from which tensile specimens were manufactured. These samples were subjected to heat treatment and subsequently analyzed. In particular, the mechanical properties of the generated structures were examined. The process parameters were then transferred to a 3D geometry.

Results

Suitable process parameters and build-up strategies could be determined for IN 718 in order to produce 3D solid bodies with a dimensional accuracy of < 0.2 mm (Fig. 3). The maximum laser power used was 1 kW. Thanks to coaxial protective gas guidance, virtually oxide-free 3D structures could be produced. The metallographic analysis shows an extremely low porosity, ≤ 0.1 percent, and good metallurgical bonding of the layers. In the tensile tests, the structures achieved the required values according to DIN EN 10302. The process parameters were transferred to a 3D geometrical form, as demonstrated by the production of a component (Fig. 4).

Applications

This processing head can be used for LMD with wire-shaped filler materials for coating, repairing and additive production. The system weight and the size allow its use in systems with low load capacity and/or high dynamics.

The demonstrator shown was developed within the framework of the ProLMD project »Innovations for the Production, Service and Work of Tomorrow« funded by the Federal Ministry of Education and Research.

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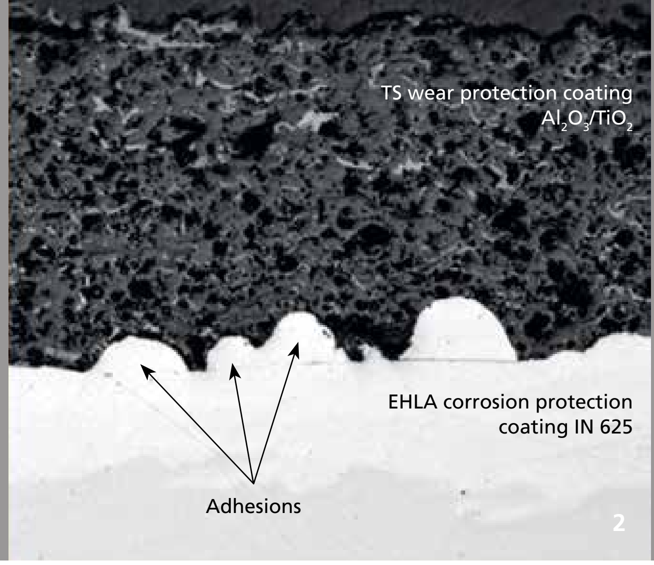
3 3D structure (144 x 14 x 60 mm^3, horizontal and vertical) out of IN 718 manufactured with Wire LMD.

4 Boroscope flange out of IN 718 manufactured with Wire LMD.



EHLA/TS DUAL-LAYER SYSTEM FOR CORROSION AND WEAR PROTECTION

Task

Instead of manufacturing components completely from a high-performance material, a company can reduce costs by making them with less expensive materials and coating them at critical zones with the stronger material. Extreme high-speed laser material deposition (EHLA) – developed by Fraunhofer ILT – can be used to produce corrosion protection layers in the thickness range of 50–250 µm with metallurgical bonding. Thermal spraying (TS) is suitable, among other things, for processing hard spray materials such as ceramics to improve wear protection. The two-layer system, consisting of an EHLA and a TS layer, combines the advantages of both processes and, thus, offers effective corrosion- and wear protection. Within the framework of KERAMIK, a project of the German Welding Society (DVS), suitable process strategies have been developed to achieve the greatest possible adhesion of the TS wear protection layer to the EHLA corrosion protection layer. The work is being carried out in cooperation with the Surface Engineering Institute (IOT) of RWTH Aachen University.

Method

Fraunhofer ILT is investigating different process strategies for the production of the thinnest possible, corrosion-resistant EHLA layers with a rough surface. To test this, it applies an EHLA layer to a test part, then, without further processing, IOT applies a TS layer on top of it. For the EHLA layer, the powder materials 316 L and IN 625 have been investigated and for the TS layer, the materials Al_2O_3/TiO_2 and Cr_3C_2/NiCr. The EHLA/TS-layer composite was tested for corrosion resistance in a salt spray test (DIN EN ISO 9227). The adhesive tensile strength of the TS layer on the EHLA layer was tested by means of the adhesive tensile test PAT (DIN EN 582).

Results

By developing suitable process strategies, the partners could produce EHLA coatings of 316 L and IN 625 with 50–250 µm layer thickness on S355 substrates; these coatings passed the corrosion test. The roughness could be adjusted in the range of Rz = 40–80 µm by metallurgically bonded adhesions of powder particles or powder particle agglomerates on the EHLA layer surface. Furthermore, the adhesive tensile strength of the TS layer Al_2O_3/TiO_2 could be increased by 70–80 percent. TS coatings made of Cr_3C_2/NiCr have such a high adhesive tensile strength that the measuring equipment failed.

Applications

The two-layer system EHLA/TS is particularly suitable for applying corrosion and wear protection on rotationally symmetrical, heavy-duty components such as hydraulic cylinders for the offshore sector.

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1 EHLA process.
2 Cross-section of the EHLA/TS layer system, © IOT, RWTH Aachen University.

ADDITIVE PRODUCTION OF A DEMONSTRATOR FOR A ROCKET COMBUSTION CHAMBER WITH LMD

Task

As the number of innovative space companies grows, competition between them increases, which in turn requires them to reduce costs when manufacturing special components. Additive processes such as laser material deposition (LMD) are, therefore, being investigated as alternatives to conventional manufacturing, e.g. forging, machining. The reason for this is, among other things, the considerable costs of forging blanks and electron beam welding for components made of nickel-based superalloys. Here, additive manufacturing offers significant advantages: Forging blanks are no longer needed and, at the same time, the amount of raw material needed is reduced. In addition, AM's flexible, integral approach can be used to combine individual parts and, thus, reduce the number of welding seams. The project presented here aims to manufacture a rotationally symmetrical shell structure with a connecting flange as a monolithic component made of Inconel 625 by LMD for a rocket combustion chamber of the Ariane Group (Fig. 3).

Method

The component to be manufactured is the upper shell (US) including its connecting flange of the distributor ring for a demonstrator rocket combustion chamber. Based on the development of suitable process parameters and build-up strategies, the upper shell is manufactured using a CAD model as a continuous toroidal shell without a flange. In the following step, the connecting flange is built directly on the shell, which is conducted by a jointed-arm robot with turn-tilt module, a 4 kW disk laser and a coaxial Fraunhofer ILT powder feed nozzle. The component is scanned and digitized with an optical system so that the assembly result, the distortion and the allowance for mechanical post-processing can be checked.

Results

The upper-shell demonstrator (D_a 400 mm) with integrated connecting flange was completely and successfully built from Inconel 625 (Figure 4). The weight of the LMD volume is 12.5 kg with a process time of approx. 24 h. Thanks to digitalization of the part's geometry, a sufficient allowance for post-processing could be proven.

Applications

The findings of the LMD space demonstrator can also be transferred to other industries. These findings have great promise, in particular, for components that require costly blanks and/or have a high machining volume, such as integral and engine components for the aviation sector or turbines made of high-performance materials for energy generation. Moreover, the tool and mold making industry, e.g. for component modification, can make effective and flexible use of these findings.

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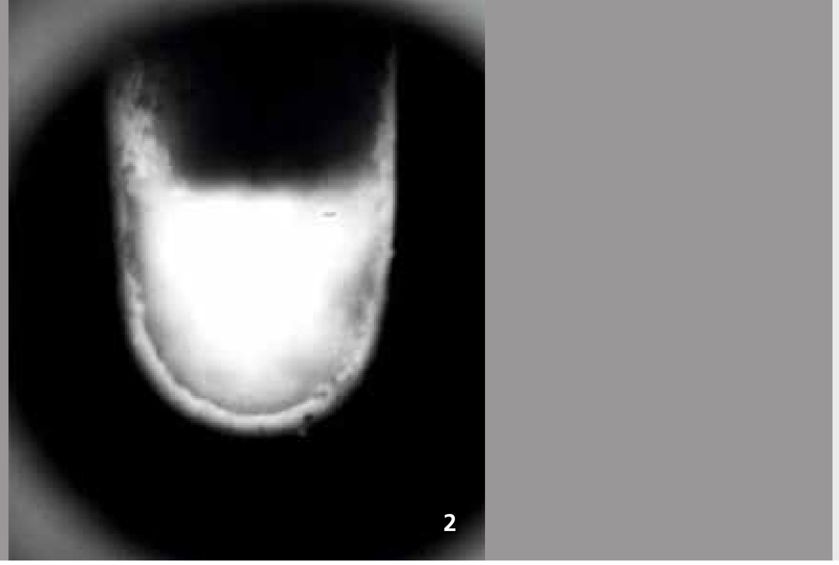
3 CAD model of the upper shell including flange.
4 Demonstrator component according to LMD design.



INTELLIGENT PROCESS MONITORING FOR LASER MATERIAL DEPOSITION

Task

Laser material deposition has established itself as a method for functionalizing surfaces, repairing and modifying components and manufacturing new parts. To produce high-quality components or parts with long processing times, however, the industry requires complete documentation of the processes used. Owing to wide variety of applications and the large number of process parameters, there is a great need for application-specific monitoring strategies to ensure product quality.

Method

Fraunhofer ILT uses machine learning methods to adapt process monitoring systems to specific applications. In a training phase, process videos of the thermal emissions of the machining process are correlated with quality features of the process result. On the basis of this data, a large number of image features can be analyzed regarding their relevance to the respective process. The classification is carried out with different algorithms from the field of machine learning and allows the component quality to be evaluated reliably. As this selection is implemented in production, not only can the quality be documented, but the defect class can also be assigned, in order to specifically prevent defects from occurring. The system can be further trained during production in order to optimize the quality or to adapt to changing boundary conditions.

Results

With this approach, Fraunhofer ILT has effectively adapted camera-based process monitoring to different applications and implemented its functionality in a plant-integrated system. This system also supports the process setup and enables a user to calibrate the »powder gas jet«. Moreover, it provides extensive functions for quality assurance in laser material deposition.

Applications

Applications include all areas of laser material deposition where monitoring of the process control is required. The most important areas of application include machine and tool construction as well as engine and power train construction.

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1 Sensor module of the process monitoring system.
2 Thermal emissions of the melt pool.

DIGITAL PROCESS SHADOW FOR LASER MATERIAL DEPOSITION

Task

In the Fraunhofer high-performance center »Networked, Adaptive Production«, Fraunhofer ILT is developing a digital process shadow for the laser material deposition (LMD) process. The process shadow is intended to provide a basis, using measurement data, for evaluating how to monitor and improve the LMD process. For this purpose, the institute has considered a systematic approach for the acquisition, processing and utilization of measurement data from process monitoring sensors and machine control.

Method

In a first step, suitable measurement data sources are selected. For the LMD process these are, on the one hand, measurement data from the machine control, material supply, laser beam source and peripherals and, on the other, sensor data from the laser beam/melt pool interaction zone (e.g. emitted heat radiation). These data are merged in a second step. Specifically, the emitted thermal radiation is measured with a pyrometer as a function of the LMD process control. The data of the machine control are collected using the standard machine communication protocol OPC UA.

Results

By merging tool-center-point (TCP) coordinates and pyrometer measurement data recorded online, Fraunhofer ILT is able to display measurement data geographically as well as chronologically. This means that the measurement data are no longer interpreted in a time-resolved manner, but also tracked in the component in a spatially resolved manner by assigning the actual TCP coordinates. This way, process irregularities or defects can be detected with spatial resolution. Other signals from the control system and systems connected via bus interfaces (laser beam source, powder conveyor, etc.) can also be used in this way. With this concept, a practice-oriented digital image of a process is created, providing reliable information for monitoring and improving the LMD process.

Applications

In the pilot line »Gas Turbine Blade Repair« of the high-performance center, Fraunhofer ILT has applied the concept presented here for the repair of turbine blade tips (tip repair) using LMD. In a next step, it will conduct research to determine which process and component defects can be tracked using the measurement data obtained. With the open communication standard OPC UA, the concept can be applied independently of machines, controls and applications.

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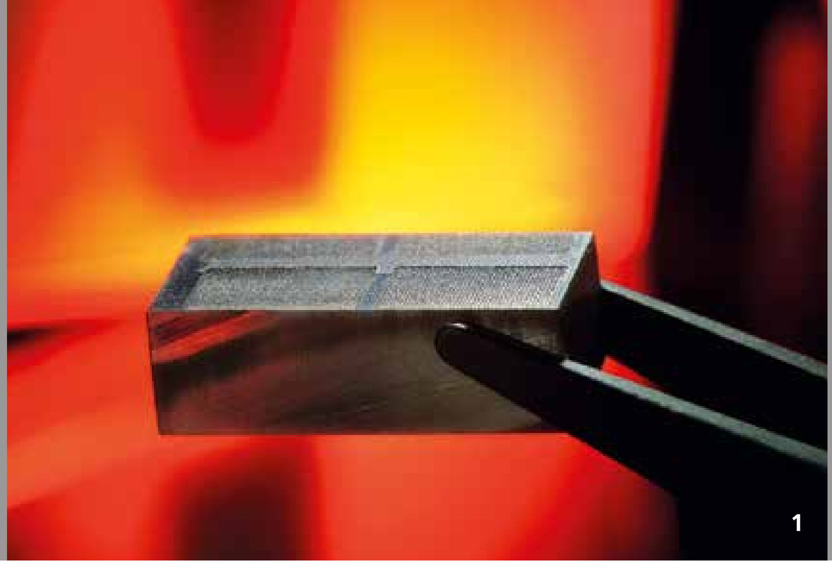
3+4 Digital process shadow for a tip repair process.



METALLIZATION OF CERAMICS THROUGH PROCESS-ADAPTED MATERIAL DESIGN

Task

Materials innovations often succeed by combining dissimilar materials intelligently. Their very different thermophysical properties, however, present special challenges when, for example, metallic and ceramic materials are combined, such as in electronic and optical applications. The soldering technology currently in use is limited by the temperature range – when soldering partner is melted, the ceramic material can be damaged – and by the complexity of the necessary vacuum technology. In the LaMeta project, Fraunhofer ILT and its partner Euromat GmbH are developing new soldering materials especially designed for metallization with laser radiation. They can be used to reduce the temperature needed in the process by up to 200 °C and to replace vacuum furnace treatment by selective remelting with laser radiation.

Method

The project partners have considered the composition of the solder, the application technique and the laser process to produce firmly adhering metallic layers with a thickness of several 10 µm on Si- or W-based ceramics. Ag-based active solders are added with various micro- and nanoadditives to trigger chemical reactions with the ceramic. For the application, they are printed or sprayed in the form of pastes or inks. Material design and laser process parameters are adapted to each other in an iterative process. The functionality of the metallization is tested by soldering LEDs and joining honing tools to the produced coating.

Results

Initial silver layers with nanoadditives could be applied to tungsten carbide with thicknesses of 11±2 µm without cracks by remelting the silver layer spread on it. Current challenges are improving the homogeneity of the coating application and achieving required values with regard to conductivity, adhesion and thermal stability.

Applications

In addition to the applications mentioned above, the process could also be used in the areas of sensor technology, electronics and optics.

The project is being implemented with funding from the European Regional Development Fund (ERDF) under the funding code EFRE-0801115.

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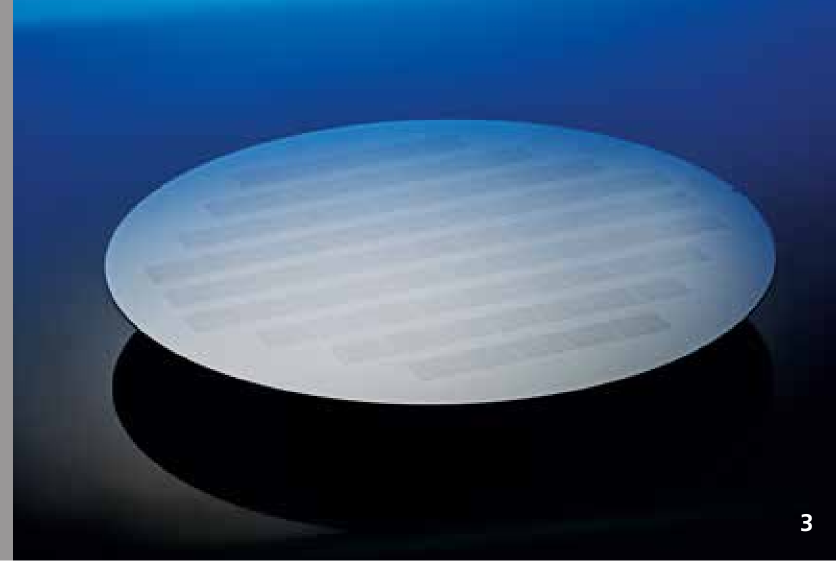
1 Silver layer on tungsten carbide.



SELECTIVE LASER CRYSTALLIZATION OF THICK AMORPHOUS SILICON FILMS ON TEMPERATURE SENSITIVE SUBSTRATES

Task

MEMS sensors (micro-electro-mechanical systems) form the core of today's inertial sensors, which the industry uses in large quantities, e.g. as accelerometers in mobile devices in automobiles. To meet the ongoing trend towards increased performance with simultaneous miniaturization, Fraunhofer ILT is developing a laser-based process to produce sensor structures monolithically on the evaluation electronics, a process that can replace conventional wire- and solder-based processes. For this new process, process temperatures < 420 °C need to be maintained in the area of the integrated electrical circuits.

Method

To produce the sensor structure, Fraunhofer ILT uses CVD or PVD processes to deposit amorphous silicon layers with thicknesses in the range of 10 µm on the circuit-carrying wafers at temperatures of up to 400 °C. Laser processing is then employed to crystallize the layers and, thus, increase the electrical conductivity. The thermal impact on the circuits is reduced as compared to the alternative processes thanks to the local selectivity and high heating and cooling rates achievable by laser processes. Mechanical stresses in the wafer are reduced by means of adapted thermal management. Subsequently, sensor units are released from the functionalized layers using classical microelectronic manufacturing processes.

Results

Thanks to the newly developed laser process, the layer resistances can be lowered by more than four orders of magnitude down to < 0.05 Ω*cm (50 Ω/sq at 10 µm layer thickness). Thereby, the thermally induced stresses in the wafer can be successfully reduced, which prevents cracks from forming in the layer material and reduces the deformation of the exposed structures. Area rates of 6 mm²/s are currently being achieved.

Applications

The developed process can be used in the semiconductor industry to increase the performance and miniaturization of mechanical and optical sensor units.

The MUSIC project has been funded within the framework of the internal programs of the Fraunhofer-Gesellschaft MAVO.

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2 Close-up of the laser-crystallized fields.
3 8" silicon wafer with selectively laser-crystallized fields.

1

LASER CRYSTALLIZATION OF PRINTED PIEZOELECTRIC ACTUATOR LAYERS

Task

Microelectromechanical systems (MEMS) are becoming more and more important as electrical circuits are becoming miniaturized and increasingly integrated in a wide range of electronic devices. For microactuators, such as those used in microspeakers or micropumps, piezoelectric thin films are used as they deform mechanically when an electric field is applied. According to the current state of the art, lead zirconate titanate (PZT) is the most powerful piezoelectric functional ceramic. With conventional, mostly vacuum and mask-based processes, producing such piezoelectric thin films would be extremely time consuming and costly. By combining inkjet printing and laser-based functionalization processes, Fraunhofer ILT has been able to produce highly functional thin-film MEMS on an industrial scale with relatively little time and low costs.

Method

Specially adapted PZT inks are applied to 8" wafers with ink-jet printing processes and then crystallized by laser radiation at local temperatures of about 700 °C. By applying several PZT layers, each 10 to 20 nm thick, the project partners are able to produce actuators with total layer thicknesses of 2–3 µm.

Results

The inkjet printing process could be used to deposit the inks with minimum achievable structure widths of approx. 100 µm. The piezoelectric properties of PZT layers produced by laser radiation are almost identical to those of conventional processes (e.g. furnace crystallization). However, the thermal load on the laser-processed wafer is lower. Typical deflections of an approx. 1 µm thick crystallized PZT layer are approx. 100 pm per volt of applied voltage. The required processing time can be reduced from several minutes per layer in conventional processes to a few seconds. The laser crystallization is temperature-controlled by the laser power as the regulating variable, so that temperature fluctuations are limited to a maximum of +/- 10 °C.

Applications

Piezoelectric layers can be applied in sensor technology, e.g. for measuring structure-borne noise, or in actuators in micro-pumps and relays, inkjet printers and communication technology.

The R&D project underlying this report has been carried out jointly with IWE2 of RWTH Aachen University and Fraunhofer ISIT on behalf of the Federal Ministry of Education and Research under the funding code 03VPP02223.

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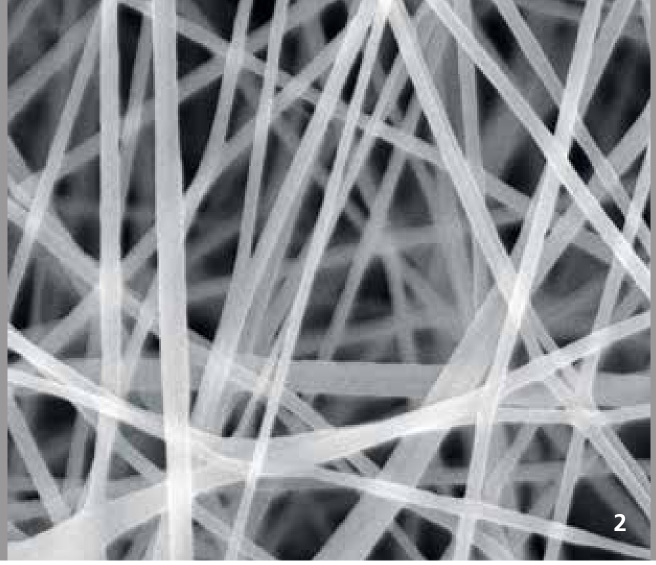
1 Si-wafer with inkjet-printed, laser-crystallized PZT layers.



2

LASER-INDUCED STABILIZATION AND CARBONIZATION OF PAN FIBROUS WEB

Task

Nowadays, carbon nano-fibrous web is almost exclusively produced by further processing electro- or rotation-spun PAN solutions. To manufacture carbon fibrous web, the industry conventionally stabilizes PAN fibrous web in time- and energy-consuming oven processes, first at 200–400 °C for approx. two hours in air, and then carbonizes them under inert gas for approx. 30 minutes at temperatures around 1300 °C. Melt-spun fibrous web, which should be preferred to avoid the use of solvents, cannot currently be stabilized and carbonized by means of furnace processes.

Method

In cooperation with the project partners Leibniz Institute for Interactive Materials DWI and Fraunhofer Institute for Applied Polymer Research IAP, Fraunhofer ILT is developing a laser-based process that can be used to stabilize and carbonize rotationally spun fibrous web. In addition, the partners are chemically modifying the PAN solutions so that they can be processed in a melt spinning process and stabilized and carbonized by means of laser-based processes. Furthermore, the laser-based carbonization process is expected to produce fibrous webs with graded porosity and specific surfaces in the range of several 100 m^2/g.

Results

The fibrous web can currently be stabilized and carbonized, in subprocesses, both with continuously emitting and pulsed laser beam sources, depending on the chemical modifications of the fibrous webs. The fibers are not melted, thus preserving the fiber structure. The irradiation time for the stabilization of 2.5 cm^2 fibrous web is currently approx. 20 s and the irradiation time for carbonization approx. 40 ms. Future research will work on reducing the times for stabilization further and on adjusting of the fiber porosity.

Applications

The carbonized, highly porous fibrous webs are used as electrode material in high-performance electronic components (supercapacitors, batteries, fuel cells), in filter media (hot gas filtration, regenerable HEPA filters) and in adsorbents (body odor neutralization).

The R&D project underlying this report has been carried out on behalf of the Federal Ministry for Economic Affairs and Energy within the framework of joint industrial research under the funding code 19616 BG.

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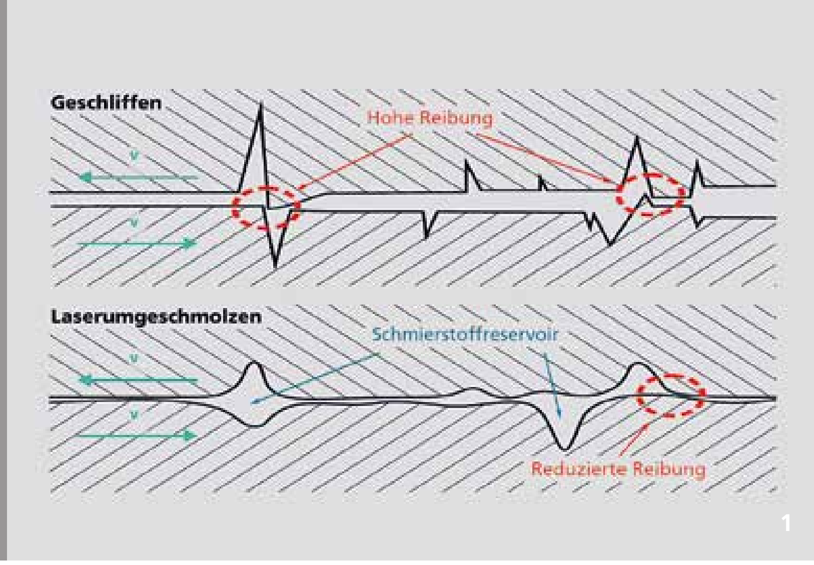
2 SEM image of a laser-stabilized PAN fibrous web, © DWI.



LASER MELTING FOR REDUCING FRICTION IN TRIBOLOGICALLY STRESSED COMPONENTS BY ADJUSTING THE SURFACE TOPOGRAPHY

Task

In drive technology, especially in transport, more than one third of primary energy consumption is caused by the conversion of mechanical energy into movement. To a large extent, the efficiency in drive technology is influenced by friction losses in components subject to tribological loads, such as rolling bearings, gear teeth or valve drives. Using low-viscosity oils combined with a specifically adjusted roughness or surface topography is a suitable measure to reduce friction. To set defined surface topographies for components with complex geometries, however, the industry requires additional, time-consuming and cost-intensive manufacturing processes.

Method

Laser melting (λ = 1064 nm) is an alternative manufacturing process to face such challenges. In contrast to laser structuring, laser melting does not remove material, but redistributes it in the molten phase using the material's own surface tension. In this process, only the roughness peaks are rounded off by local melting so that the grinding grooves, which serve as lubricant reservoirs, are preserved. This is intended to achieve an improved lubricant film build-up and, at the same time, reduce friction since the roughness peaks are rounded off. For this purpose, ground discs (material: 100Cr6) are remelted with pulsed laser radiation (pulse duration t = 400 ns) and then measured on a ball/disc tribometer. During this process, the ball is up to half in the oil bath so that lubricant is transported by rotation into the tribological contact between ball and disc. The coefficients of friction are compared with those of ground surfaces, which depict the state of the art for gears.

Results

Laser melting can be used to reduce the coefficient of friction by 40 percent in the mixed friction area, as compared to ground surfaces. The coefficient of friction is, thus, in the range of conventionally polished surfaces.

Applications

The targeted use of laser melting as a manufacturing process for tribologically loaded components is conceivable especially in automotive engineering, but also in the field of wind energy, for example. The tribometer tests were carried out at the Institute for Machine Elements and Systems Engineering MSE at RWTH Aachen University.

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1 Schematic representation of the surface contact of two surfaces moving relative to each other.

LASER-BASED HEALING OF SUBSURFACE DAMAGE IN GLASS

Task

In the conventional production of optical components made of glass, microcracks – so-called »subsurface damage (SSD«) – are commonly induced under the processed edge layer during grinding and polishing steps. These SSD must be removed with a time-consuming chain of increasingly finer grinding and polishing steps. In each of these process steps, material is removed down to the deepest damage of the previous step, whereby new, smaller defects are caused again. This iterative process means that producing high quality optics is associated with high throughput times and costs. Alternative processes such as hot pressing, on the other hand, are limited to high quantities, can only treat compressible geometries and have lower accuracy.

Method

An alternative approach is the use of CO_2 laser radiation (λ = 10.6 µm). This radiation is absorbed near the surface, with typical optical penetration depths of a few tens of micrometers, thereby making laser polishing of fine-ground glass possible: A thin edge layer is melted and, due to the surface tension, smoothens. However, the locally limited melting of the surface can potentially also be used to heal subsurface damage. To test this hypothesis, Fraunhofer ILT surface treated rough-ground flat samples of fused silica and N-BK7 with a laser polishing process and examined them for remaining SSD.

Results

Using the flat samples with a diameter of 30 mm made of fused silica and N-BK7, Fraunhofer ILT could show that the originally existing SSD of up to 80 µm depth was completely eliminated after laser processing. Healing can already be performed at speeds up to a factor of four faster than the conventional laser polishing process. The pure process time of the laser-based SSD healing is, therefore, less than 2 seconds for an N-BK7 lens with a diameter of 30 mm, for example.

Applications

Laser polishing to heal subsurface damage in glass components can be used to reduce the complexity of process chains in optics manufacturing, thus lower throughput times and unit costs. This applies in particular to the production of aspheres and free-form surfaces.

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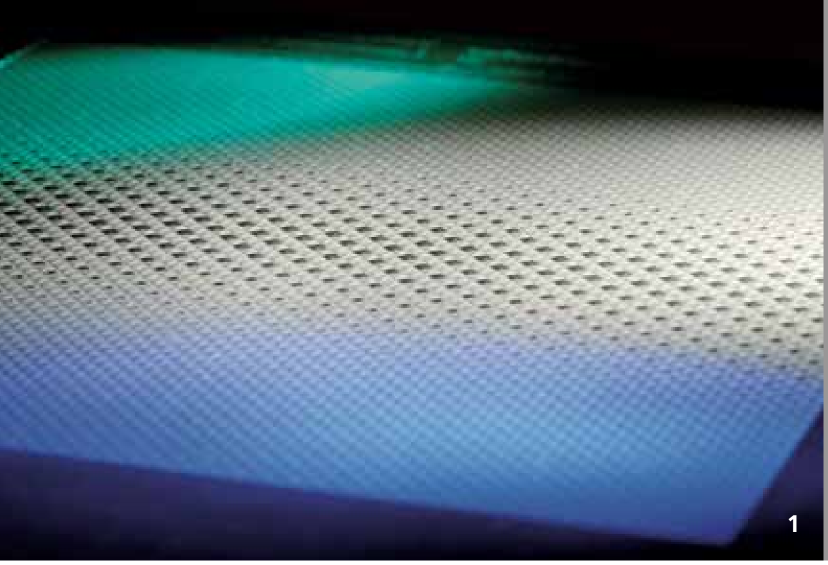
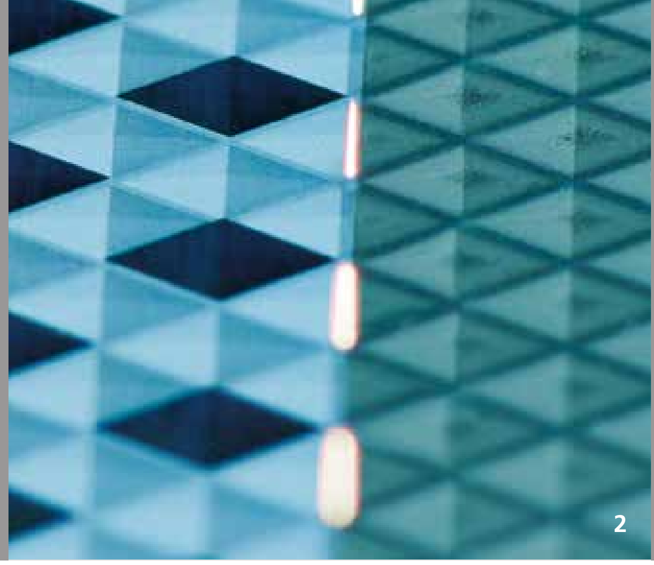
2 Ground fused silica surface with spherical grinding (Ø ~ 3 mm). Depths: spherical grinding approx. 150 µm, subsurface damage approx. 70 µm.

3 Laser-polished fused silica surface with spherical grinding (Ø ~ 3 mm).





POLISHING WITH ULTRASHORT PULSE LASER RADIATION

Task

Ultra-short pulsed (USP) laser beam sources are opening up more and more areas of application since they allow flexibility in the design of components and miniaturization up to structure sizes < 10 µm. After USP laser ablation, 3D structures have a surface roughness of 0.4 µm to 2 µm depending on the process parameters used. If this does not meet the requirements, as is the case when transparent plastics are molded, the structures have to be polished downstream, thus placing the highest demands on the surface quality of the molding tool. Since the structure sizes are in the range of a few micrometers, manual polishing cannot be used for the subsequent process step. Machine-assisted polishing processes are also not suitable for the sometimes very complex and small structure sizes.

Method

Fraunhofer ILT has developed a process using USP laser radiation to polish three-dimensional microstructures in the same machine after USP laser ablation. Actually, the advantage of USP processing consists of an ablation process dominated by evaporation and without melt formation. However, a molten phase is required to smooth roughness peaks and polish workpieces. A locally limited melt film can also be produced with USP laser radiation thanks to the extremely high pulse repetition rate of several 10 MHz and a pulse picker, which separates individual pulse groups in the kHz range at a controlled frequency.

Results

Thanks to its spatial and temporal energy deposition, Fraunhofer's process can achieve remelting depths in the range of a view 100 nm up to 10 µm depending on the application. Above all, USP polishing can significantly lower the micro-roughness, which means surface roughness is reduced by up to a factor of four, and the process has a surface rate of 12.2 cm²/min. In combination with the USP-based production of three-dimensional microstructures, gloss effects can be selectively generated and quality improved.

Applications

In addition to applications involving molding tools, polishing with USP laser radiation is also attractive to the automotive, consumer goods and electronics industries.

The R&D project underlying this report was carried out on behalf of the Federal Ministry of Education and Research within the framework of the eVerest project under the funding code 02P14A145.

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1 Metal tool with three-dimensional structures made and polished with USP lasers.

2 Process for selective USP polishing after USP structure generation and laser cleaning.

LASER POLISHING OF PLASTIC MICRO-OPTICS

Task

Plastic optics are often produced by injection molding or, less frequently, by mechanical turning or milling, but these processes are not suitable for producing single pieces or individual optics. Thus, a flexible process is necessary for the individualized manufacture of micro-optics made of plastic. This is particularly interesting in medical technology, e.g. for intraocular lenses or contact lenses, in order to manufacture patient-specific products. In this context, laser-based shaping processes, e.g. ablation by ultrashort pulse radiation (USP radiation), can be convincing thanks to their largely geometry-independent processing and high precision. However, in order to use this manufacturing process for micro-optics production, the surface topography must be polished afterwards.

Method

Thermoplastics can be polished with the laser polishing process by remelting the material near the surface. Since surfaces processed with USP usually have very good shape accuracy, but a high micro-roughness, polishing without changing the geometry is necessary. The surface is heated up to just above the softening point over the entire surface using CO_2 laser radiation. High-frequency roughness is smoothed by the surface tension. Due to short interaction times, the thermal influence on the overall optics is kept as low as possible to avoid distortions to the geometry. The interaction time is usually less than one second. This is repeated several times, whereby the micro-roughness is reduced in each iteration step, until the roughness corresponds to optical quality.

Results

The geometry of a plastic optic with a diameter of a few millimeters can be produced by ablation with USP radiation having a vertical resolution of 1 µm. The surface roughness in a 1 x 1 mm² measuring field is then approximately Sa ≈ 0.4 µm, which corresponds to an opaque surface. This roughness can be reduced to Sa < 10 nm by laser polishing.

Applications

The demand for products customized to an individual patient is growing, particularly in medical technology. The process presented here can be used, for example, to manufacture intraocular lenses or contact lenses.

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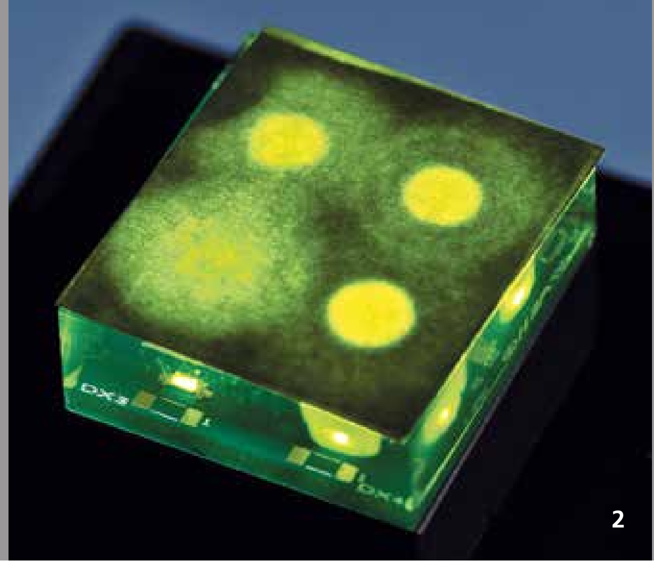
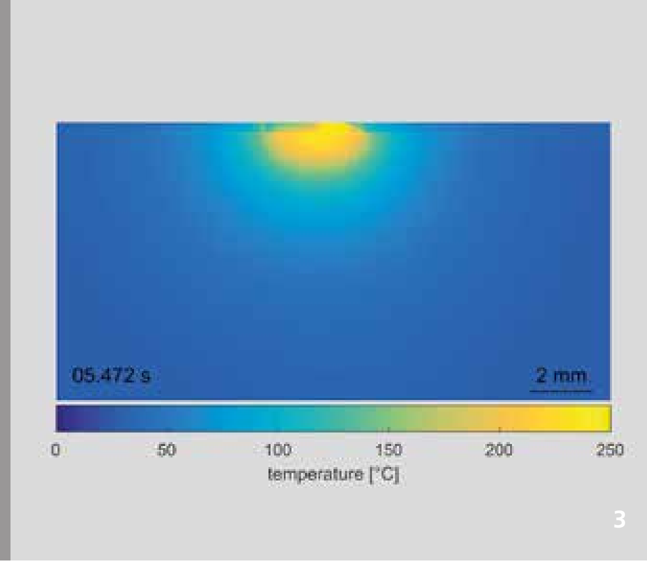
3 Microstructured (left) and laser polished (right) intraocular lens.





LIGHT ABSORBING STRUCTURES IN PRINTED OPTICS BY MEANS OF LASER MODIFICATION

Task

To date, optical systems have been composed of various optical elements such as lenses, mirrors, apertures etc. in order to achieve a defined function. Such systems are, however, difficult and generally expensive. The complexity of optical systems can be reduced significantly by using free-form surfaces. 3D printing of polymer free-form optics is possible with inkjet or stereolithography (SLA) technology. So that functions can be integrated to an even higher degree, light-absorbing structures, so-called baffles, can be created in the 3D printed optics by means of focused laser radiation.

Method

The polymer-based materials are modified with ultrashort laser beam pulses, thereby locally and selectively changing the optical absorption and scattering properties. The process is designed in such a way that the modification can be introduced during printing, but also subsequently in the volume, i.e. in the finished printed optics. For this purpose, areas are selectively processed on the basis of a three-dimensional digital model until the desired structure, such as apertures or diffusers, is created in the optics. A significant advantage is the great freedom of design of the digital model and the possibility to create almost any complex structure with a resolution of a few micrometers.

Results

Using the innovative laser process, Fraunhofer ILT could create light-absorbing structures several millimeters below the surface of 3D-printed refractive optics. The processing both laterally and in depth allows a great design freedom in the design of baffles. By adjusting process parameters and stacking structures, the institute was also able to adjust the degree of residual transmission of the structures. Moreover, it has produced a demonstrator with cylindrical baffles of different stacking density (1, 4 and 8) for adjusting the radiation pattern of LEDs. The shading function is shown in Figure 2.

Applications

In both the automotive and aerospace sectors, the technology promises new possibilities for the development of lighting concepts with extended design options and a great potential for lightweight construction. The high degree of integration also opens up new opportunities in medical technology and for metrological solutions.

The work has been funded as part of the internal programs of the Fraunhofer-Gesellschaft, the lighthouse project »Go Beyond 4.0«.

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1 Optical baffles with different degrees of absorption.

2 Light shaping compared to the non-shaded LED.

THERMOGRAPHY TO OPTIMIZE THE HEAT INPUT DURING ULTRASHORT PULSE PROCESSING

Task

For the productivity of ultra-short pulse (USP) processes to increase, the power needs to be scaled. When this is done, however, process quality suffers owing to thermal effects – such as molten material, changes in material structure or distortion – despite the short pulse durations. The heat input limits the applicable power, especially when processing thermally sensitive materials such as plastics or thin metal foils.

Method

By using thermography during the machining processes and comparing it with mathematical models, the Chair for Laser Technology at RWTH Aachen University has been able to gain a detailed understanding of heat input for the processes under investigation. The heat distribution on the surface of the machined materials is recorded over the process time for different process parameters. The temperature development over time is then evaluated and compared with a simulation based on a physical residual heat model.

Results

As residual heat accumulates during USP processes, very complex interrelationships between the process parameters prevail, interrelationships that cannot be fully understood with reduced physical models. For example, temperatures can differ by a factor of three when the repetition rate is varied at constant average power. Furthermore, during the process, surface effects can cause changes that are not covered by the static models for heat input. When these effects are understood, the processes can be optimized with respect to minimized heat input at maximum productivity.

Applications

The understanding acquired here can help to implement high average power for structuring metallic workpieces as well as processing thermally sensitive materials, e.g. from the packaging industry (plastics) and filter technology (metal foils).

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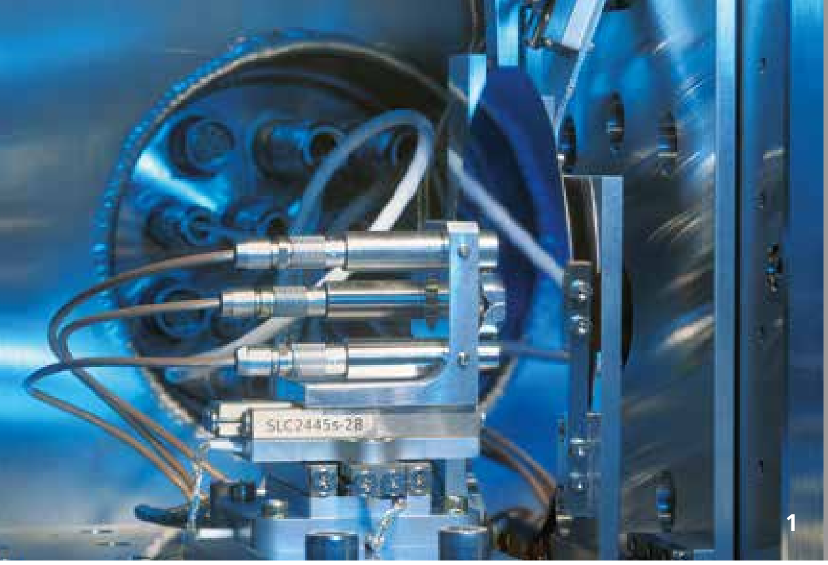
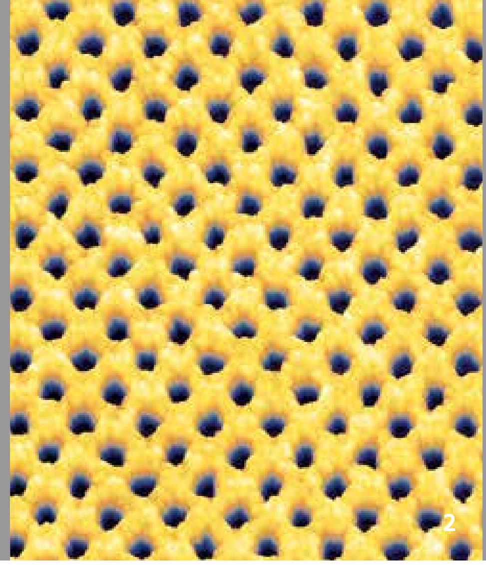
3 False color image of the temperature distribution during USP processing of stainless steel.

4 Copper structure produced by an USP process at 300 W average power.





NANOSTRUCTURING IN THE SUB 50 NM RANGE

Task

To further develop nanotechnology, research needs methods of structuring with a resolution below 100 nm that can be scaled to large surface areas. Optical lithography processes with drastically reduced wavelengths are particularly suitable for generating the desired small structure sizes. Lithography with extreme ultraviolet radiation (EUV; 13.5 nm) is, therefore, currently being introduced as a structuring technology for the next chip generations in industrial mass production. Such large-scale industrial EUV systems are, however, costly and not suitable for manufacturing in small and medium quantities. For applications that require periodic structures, interference effects can be used to reduce the complexity of the optical system, significantly reducing the cost of such systems.

Method

Fraunhofer ILT has developed an EUV nanostructuring facility on the basis of an EUV gas discharge source and customized interference transmission masks. A precise dosage monitor and a sophisticated mask/wafer spacing system ensure that exposure conditions are reproducible. Since the wafer is positioned at a sub 100 µm distance from the mask, various interference effects, including the achromatic Talbot effect, can be used to form a desired intensity distribution. In a working distance range of 20 µm, a stationary intensity distribution is formed, which is then used for nanoscale structuring. Highly efficient phase masks are used to enhance the contrast of the intensity modulation and, thus, to reach the theoretical resolution limit.

Results

With the developed structuring equipment, Fraunhofer ILT has generated periodic nanostructures down to a size of 35 nm. Thus, the range of structure sizes that can be produced in house is extended to a sub-100 nm range. The new technology will now be made available to a wider user community.

Applications

Periodic nanostructures on square-centimeter surfaces can be used in the optical industry as broadband anti-reflection coatings or polarizers, in medicine and biotechnology as nanoscale particle filters or in electronics and metrology as novel sensory elements.

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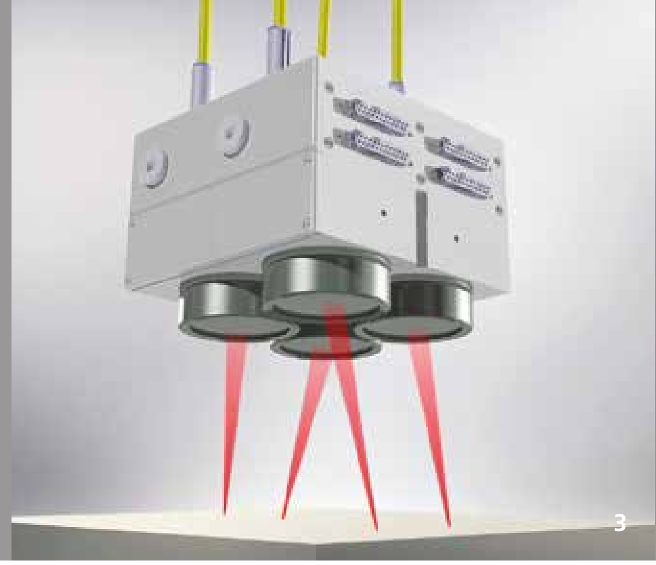
1 Mask-wafer positioning system.

2 Nanostructures with 35 nm hole diameter (AFM image).



»SCANPLEX« – A SCANNER ARRAY FOR PARALLEL LASER MATERIAL PROCESSING

Task

Research is currently investigating various approaches to increase productivity in laser material processing. For example, Fraunhofer ILT is pursuing a multi-laser approach for applications where productivity cannot be increased because higher laser power imposes process limitations. An increase in the number of laser beam sources used makes it possible to raise the process speed almost proportionally to this number. For this a scanner system is required, which is capable of precisely and quickly guiding the individual beams – independently of each other – over the processing field. For a multi-laser approach, conventional galvanometer scanners are severely limited in terms of the laser beams that can be used per area since they need such a large installation space.

Method

In order to significantly increase the power of independent multi-beam processing, Fraunhofer ILT has developed the »Scanplex« scanner array, which combines four 2D deflection units for parallel laser material processing in a housing of the size of a conventional 2D processing head. The scan head is based on the mini-scanner technology developed at Fraunhofer ILT, which combines a small construction volume with a large aperture. The use of compact F-theta lenses makes it possible to process an area of 120 x 120 mm² in parallel with four separate laser beams.

Results

A demonstrator of the scanner array with 2 x 2 2D deflection units was set up in the laboratory and is currently in the characterization phase. Microstructuring with a green laser was used to demonstrate the potential of this scanner technology. Specifications of the scanner array are as follows:

Construction volume, l x w x h	140 x 140 x 90 mm³
Focal length f	160 mm
Scan field size A	120 x 120 mm²
Scanning speed v_s	≤ 8 m/s
Aperture D	7 mm
Irradiance E	≤ 500 W/cm²
Interface	XY2-100

Applications

- Laser marking and engraving
- Additive manufacturing
- Micromachining
- Laser cleaning

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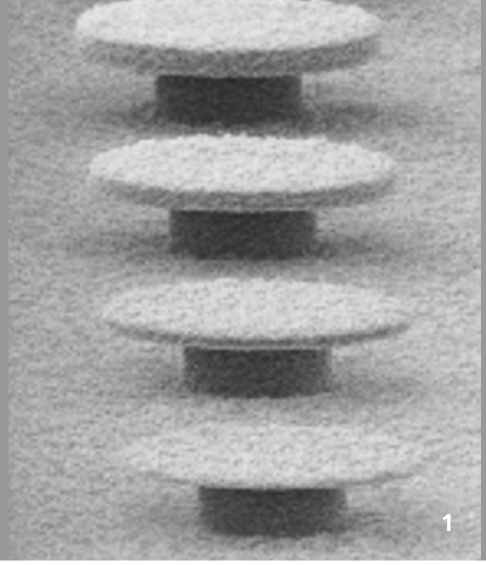
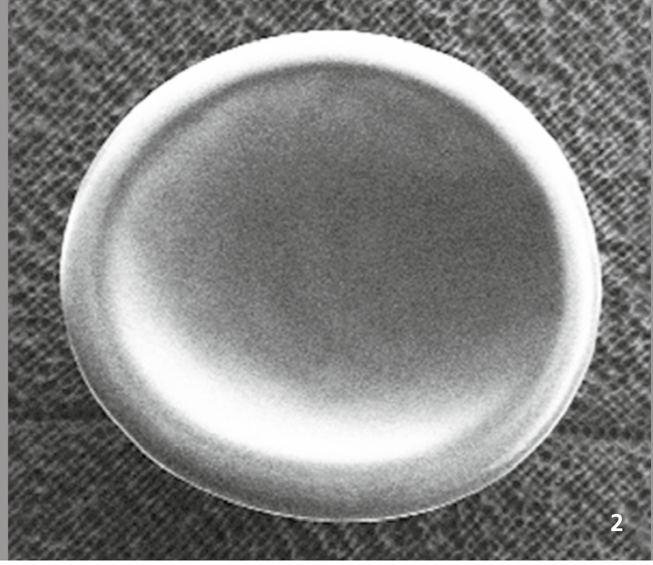
3 »Scanplex« 2x2 scanner array.

4 2D mini scanner.





SELECTIVE LASER ETCHING FOR THE MANUFACTURE OF FUSED SILICA MICRO RESONATORS

Task

As networking in the industrial and private sectors grows worldwide, high-performance optical network technologies are increasingly in demand. These are commonly based on the wavelength division multiplexing (WDM) process. Here, light of different wavelengths is mixed in order to transmit several pieces of information simultaneously. Currently, the light of each wavelength is generated with a separate laser beam source, but the energy consumed in this process is increasingly becoming an environmental factor and cost driver. Therefore, research is focusing on the development of novel, energy-efficient and compact light sources in different materials. Optical microresonators are a promising possibility to make these light sources a reality.

Method

Fraunhofer ILT is using selective laser-induced etching (SLE) as an innovative process for manufacturing micro-resonators out of fused silica; this process can be used to generate almost any geometrical shape. For this purpose, the resonator geometries to be manufactured are created in a CAD/CAM process chain, structured into the substrate by means of ultrashort pulsed laser radiation and then exposed by wet chemical etching.

Result

The manufactured disc-shaped microresonators have a diameter of 50–200 µm and a disc height of 2–10 µm. The roughness on the upper side of the disc is reduced to Ra ~ 50 nm by laser polishing. The bottom side of the disc has a roughness in the range of Ra ~ 0.5–1.0 µm, depending on structuring and etching before polishing. The geometry of the disc can be adapted individually by adjusting structuring and etching.

Applications

Microresonators can be used as frequency combs in optical network technologies, thus representing an alternative to the light sources currently used. Microresonators in optically nonlinear materials enable an adjustable frequency conversion through appropriate phase matching, which is required in the field of optical quantum sensor technology to generate entangled photons.

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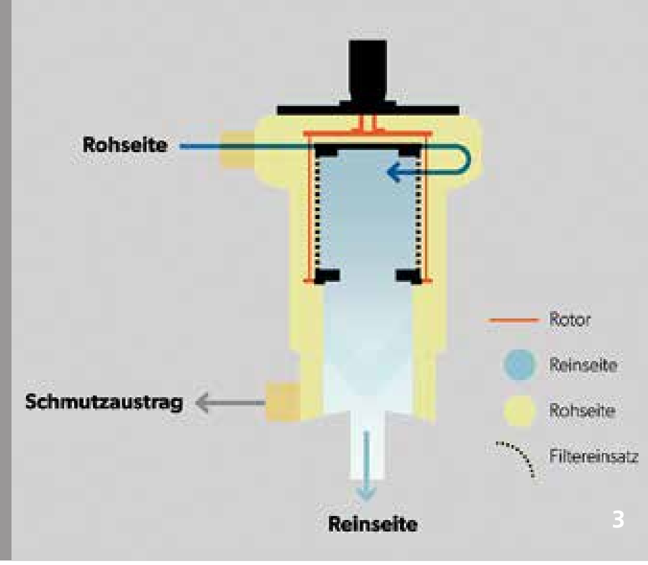
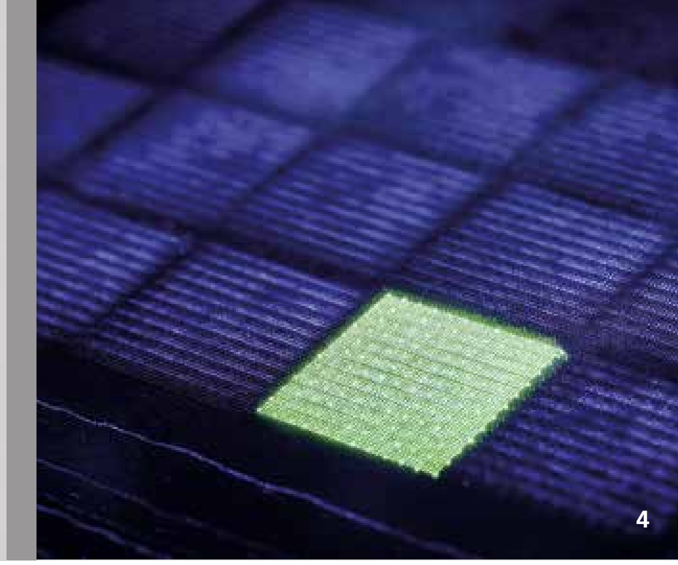
1 Disc resonators with 100 µm diameter (REM).

2 Micro resonator after laser polishing (REM, top view).





INNOVATIVE FILTER MODULE FOR THE SEPARATION OF MICROPLASTICS FROM WASTEWATER

Task

Microplastics are extremely small plastic particles with a diameter of < 5 mm. They are deliberately added to cosmetic products such as peelings or soaps or result from natural abrasion and erosion, such as from tires. Such microplastic particles make their way into wastewater and cannot be completely separated out by regular sewage treatment plants. For this reason, new innovative water filters urgently need to be developed to prevent microplastics from entering the environment, thus protecting it from their growing threat.

Method

Within the SimConDrill project, a cyclone filter has been modified in such a way that microplastics of up to 10 µm diameter can be separated from wastewater. To produce this filter, Fraunhofer ILT has developed a laser process with an ultrashort pulse (USP) laser that can drill 10 µm diameter drill holes into the stainless steel filter elements. In advance, the drilling process was simulated to accelerate its development. Currently, the institute is developing and testing a process monitoring strategy to ensure that the filters are manufactured without defects. Above all, this strategy guarantees that all holes in the filter element are completely drilled through, which is essential for the filter to function efficiently and economically.

Results

Using the successfully adapted USP laser drilling process, the institute can produce suitable drill holes even in materials of up to 500 µm thickness.

Applications

In wastewater technology, metal filters are not only suitable for filtering small particles, but also for taking samples for analysis. With the technology presented here, the plastic filters currently used can be replaced by laser-drilled metal filters. In addition, the micro-drilling of metal foils is also important for many other applications. Metal sieves and metal filters are used, for example, in biotechnology, medical technology or pharmaceuticals. If the process allows smaller and smaller hole sizes as development progresses, sterilization filters can also be produced.

The R&D project – SimConDrill – underlying this report is being carried out on behalf of the Federal Ministry of Education and Research under the funding code 02WQ1479E.

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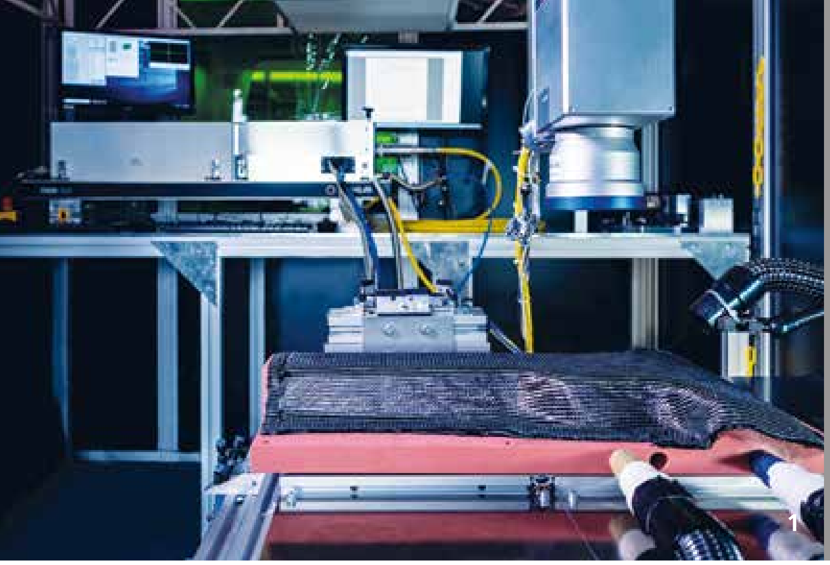
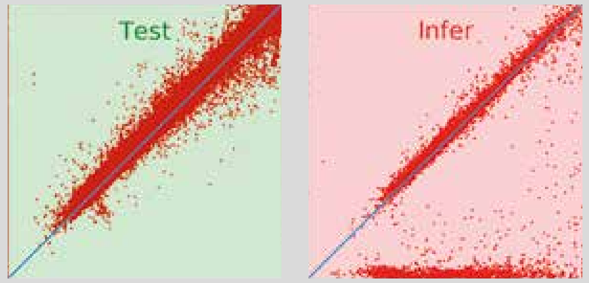
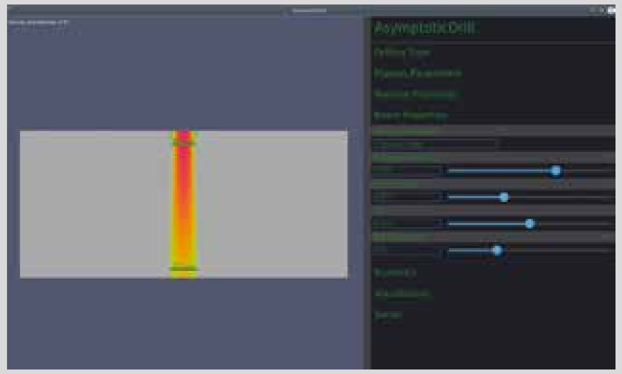
3 Schematic diagram of the cyclone filter, © KLASS-Filter GmbH.

4 Processing of a metal foil by means of USP laser drilling.







ROBOT-GUIDED LASER DRILLING OF CFRP PREFORMS

Task

When metallic force transmission elements are integrated into CFRP components as detachable connections, the components are commonly drilled, placing special demands upon the production technology. Defects such as thermal damage and delamination must be prevented at all costs since both the carbon fibers and the complex process chain for the production of CFRP components are costly. Ultrashort pulse (USP) laser drilling is already suitable for producing high-quality and precise holes on the dry preform. This process-safe material processing, however, has so far failed as it lacks a suitable ablation process for 3D-formed CFRP semi-finished products.

Method

Within the publicly funded CarboLase project, Fraunhofer ILT together with AMPHOS has developed a technology to guide the USP laser radiation from the beam source via a hollow core fiber to a galvo scanner. The scanner is mounted as a processing head on an articulated arm robot. Thanks to the integrated beam stabilization, the mirrorless beam guidance can be used to dynamically move the scanner over a CFRP preform. In and above the forming tool, on which the CFRP preform is fixed, suction devices are installed to remove particles and vapors. By means of scanner processing, any 2.5D contours adapted to the later load case can be introduced into the preform. After the drilling process, the scan head is removed and an effector is attached with which load input elements are inserted into the drilled preform. In the subsequent process step, the functionalized preform can be infused with the matrix material and then cured.

Results

Accurately fitting holes can be produced since the laser ablation is precise and does not generate any defects. The subsequent matrix infusion creates a multi-material connection without needing additional adhesives. The inserts bonded directly to the matrix material achieve up to 50 percent higher maximum pull-out force compared to conventionally manufactured components with glued-in inserts.

Applications

The dynamic USP laser drilling process is particularly useful when processing lightweight components in the aerospace industry as well as for automotive engineering. Since the fasteners are significantly stronger, the highly automatable process can also help save both material and costs in the production of CFRP components.

This project was carried out with funding from the European Regional Development Fund (ERDF) under the funding code EFRE-0800793.

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1 Flexible and automated UKP laser ablation for CFRP preforms, © ITA - RWTH Aachen University.
2 Adhesive-free mounted inserts in a CFRP B-pillar demonstrator, © ITA - RWTH Aachen University.

RESIDUAL NEURAL NETWORKS FOR RAPID PREDICTION OF DRILLHOLE TAPER

Task

Artificial neural networks and especially deep artificial neural networks have been used successfully in image processing for quite some time. Since they are able to map strong nonlinearities, these networks are attractive for making predictions in production engineering. One hurdle that has to be overcome, however, is that data is often scarcely available. This issue could be solved by enriching experimental data with simulated data, but before the industry can apply artificial neural networks as tools, their prediction quality must be assured and computation time reduced.

Method

The existing drilling model AsymptoticDrill can generate sufficient data in sufficient quality. Based on these simulation data, a neural network can be trained and evaluated to then approximate the drilling model. Subsequently, numerical errors are determined and run-time experiments are performed.

Results

The trained network approximates the drilling model in sufficient quality. The calculation time is shorter than the model by a factor of 140. The relationship between training data and approximation quality can be analyzed to provide criteria for the selection of training data.

Applications

The methodology can be transferred to other manufacturing processes for which sufficient data of sufficient quality are available. The approximation of the data is a regression task that can be solved by training the artificial neural network.

The work was carried out at RWTH Aachen University as part of the federal and state excellence strategy »EXC 2023 Internet of Production« and funded by the German Research Foundation (DFG) e.V.

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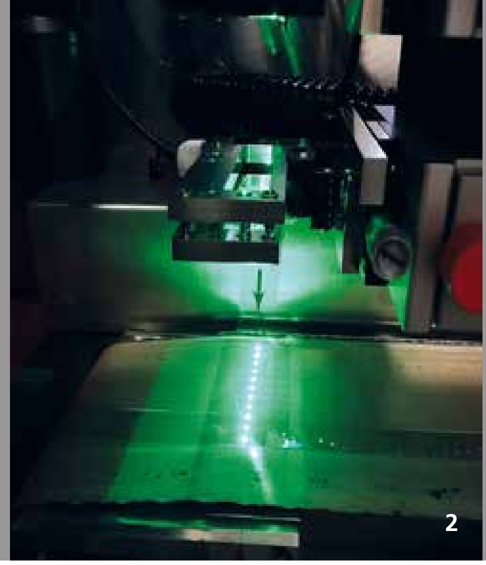
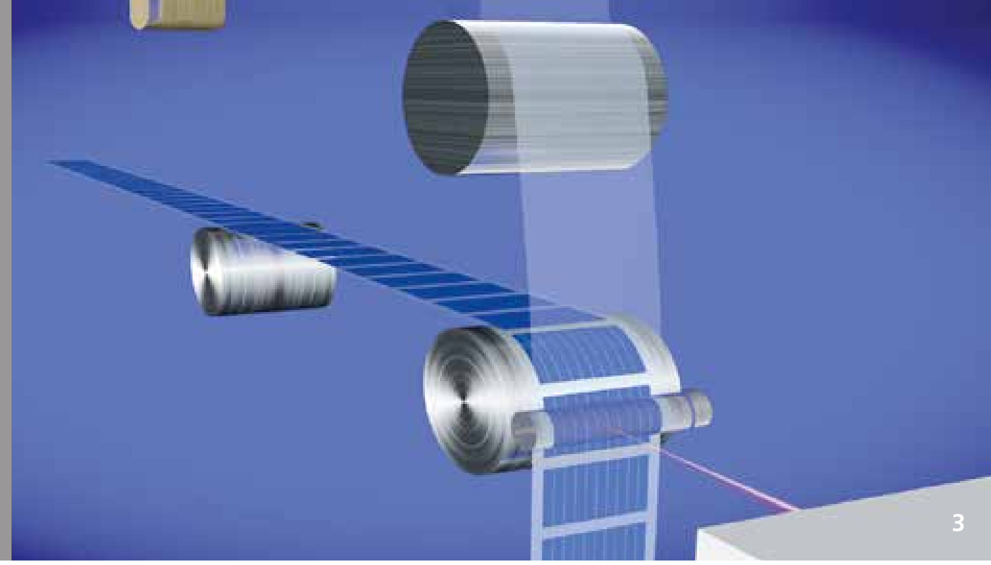
3 Conicity and prediction of the neural network.
4 Simulation tool AsymptoticDrill.





COST-EFFECTIVE PRODUCTION OF ORGANIC PHOTOVOLTAICS IN A ROLL-TO-ROLL PROCESS

Task

Photovoltaics is one of the supporting columns of renewable energies. In comparison to classic silicon-based photovoltaics, organic photovoltaics shows great promise since, among others, producing them uses resources more economically. Indeed, only a few grams of organic material are needed to produce photovoltaic surfaces that measure a few square meters and are flexible and transparent. In the future, a large number of surfaces will be able to contribute to energy generation through decoratively designed organic solar cells; hence, research and development have focused on producing organic photovoltaics on an industrial scale. Production in a roll-to-roll process without complex vacuum technologies represents a cost-effective key technology to achieve this.

Method

Current findings from the laboratory on the layer structure of an organic solar cell have been transferred to the roll-to-roll process and combined with innovative process technologies. All sub-processes – from coating and cell separation using ultrashort pulsed laser radiation to the encapsulation of the finished solar cell – have been optimized to ensure the most efficient manufacturing process. Inline process analysis and integrated process control complete the implemented system technology.

Results

With belt speeds of up to 5 m/min, thin films with thicknesses between 10 nm and 250 nm have been applied to conductively coated PET substrates. High-precision and innovative laser processes from the short pulse and ultra-short pulse range are used in the sub-steps drying, scribing/separation, decoating and encapsulation. The individual processes are monitored and the overall process is controlled by the built-in sensor technology.

Applications

Organic solar cells can be used in various areas due to their flexibility and transparency. Among the broad spectrum of uses, they can be incorporated into clothing, applied to curved surfaces and installed in interior spaces.

This project was carried out with funds from the European Regional Development Fund (ERDF) under the funding code EFRE-0801547.

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1 Roll-to-roll plant for the production of organic solar cells.

2 Scribing/separation by means of ultrashort pulsed laser radiation.

LASER TRANSMISSION WELDING OF MULTILAYER POLYMER FILMS IN A ROLL-TO-ROLL PROCESS

Task

Roll-to-roll manufacturing processes are becoming increasingly important in many fields of application, thus constituting a key component for efficient industrial production. This is particularly true for multi-stage production chains in which, for example, coating processes are integrated. One example is the photonic production of organic solar cells. Here, functional solar cells are produced in several combined coating and laser-ablation processes on a flexible polymer-based substrate. Due to the organic substances they contain, these solar cells are highly sensitive to water and oxygen after production. For this reason, encapsulation is absolutely necessary to ensure protection against degradation and, thus, an adequate service life in their later application. This is done with so-called transparent ultra-high barrier films (UBF) to maintain the highest possible efficiency. The thermoplastic polymer base film of these multilayer polymer films enables direct welding with a corresponding wavelength-adapted laser beam source.

Method

The particular challenge that laser transmission welding poses in the roll-to-roll process is to apply the necessary joining pressure locally despite the moving polymer film ribbons. For this purpose, either a globo-optic is used, which can be moved by an axis system and allows local pressure to be applied by a glass ball, or alternatively a galvanometric scanner system can be used in combination with a glass roller.

Results

In both cases, strong and reproducible weld seams can be produced. While the configuration with the globo-optic is more suitable for weld seams in the feed direction and at lower web speeds, the more complex, scanner-based approach can also be used to generate transverse seams at higher ribbon speeds. Thus, the appropriate process can be used, depending on the requirements.

Applications

Sectors that can profit from this technology include the production of organic electronics, packaging technology, medical technology and the automotive industry.

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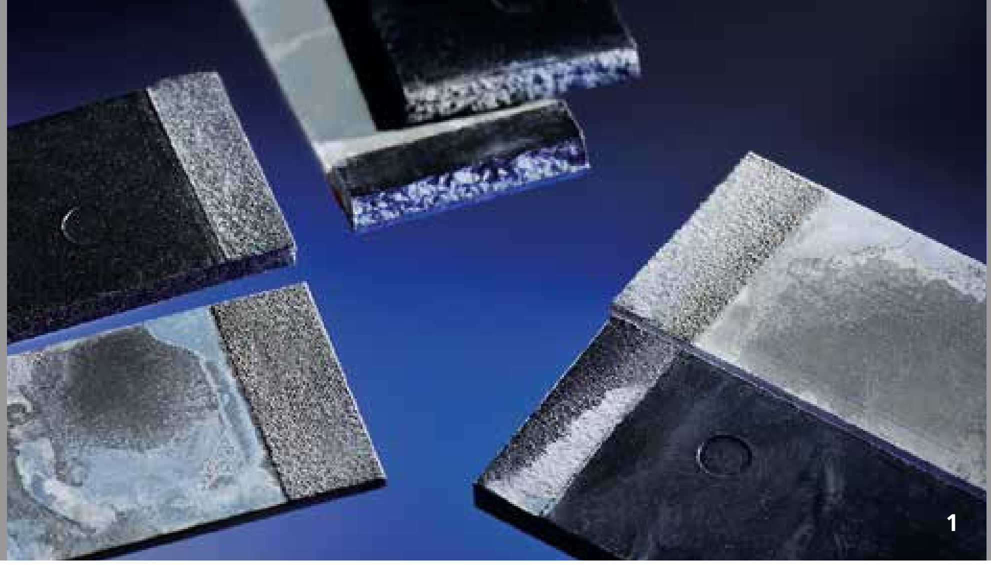
3 Combination of scanner system and glass roller.



AGEING BEHAVIOR OF THERMALLY JOINED PLASTIC-METAL HYBRID COMPOUNDS

Task

Multi-material design opens up new ways of optimizing weight since it employs different materials adapted to local loads. However, joining technology, especially for plastics and metals, faces a particular challenge as the materials are physically and chemically dissimilar. In addition, hybrid joints are subjected to high stress during use because the materials have different properties, such as thermal expansion and corrosive infiltration. The ageing behavior of such compounds is, therefore, of crucial importance for the long-term stability of a component that consists of them.

Method

Fraunhofer ILT has developed a process chain in which laser radiation is used to create microstructures in the metallic joining partner. In the subsequent thermal joining process, the plastic is melted and bonds with the microstructures. So that long-term stability can be better understood, hybrid joints of different metals (aluminum alloys, steel) with polypropylene are subjected to climatic change and corrosion tests. Lap shear tests are then used to determine the strength before and after aging.

Results

The results of the lap shear test before and after the climatic change tests, with up to 30 cycles between -40 °C and 80 °C, show no significant decrease in the bond strength of the hybrid joints. Likewise, the corrosion climate change tests do not impair the lap shear strength in any detectable manner. This testing thus confirms that the process can compete with other joining methods for plastic-metal hybrid connections in a variety of applications.

Applications

Thanks to the good long-term stability of the hybrid connections under a wide range of environmental conditions, the laser-based joining process is particularly suitable for applications in automotive engineering or the aerospace industry.

The IGF project AGeD underlying this report was carried out on behalf of the Federal Ministry of Economics and Energy under the grant number 20.326N

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1 Fractured surfaces of the hybrid connection after corrosion tests.

LASER BEAM MICRO-WELDING WITH BEAM SOURCES IN THE VISIBLE WAVELENGTH RANGE

Task

As vehicles and everyday objects are increasingly becoming electrified, materials with high electrical and thermal conductivity, such as copper and aluminum, need to be contacted efficiently. The laser beam sources currently used by the industry typically operate at a wavelength of $\lambda \approx 1$ µm, which has low absorption, especially in copper-based alloys, thus leading to an unsteady energy input into the welding process.

Method

Beam sources at a wavelength in the visible spectrum can be used to achieve higher absorption, e.g. in copper alloys, to achieve a more constant energy input during welding processes and to reduce irregularities due to fluctuations in the coupling degree in the weld seam.

The radiation sources used for this purpose usually work with electromagnetic waves at a wavelength of 515/532 nm (green) or 450 nm (blue); they are either based on frequency doubling of conventional solid state lasers in the near infrared wavelength range or use direct diode lasers.

Results

In particular, Fraunhofer ILT has investigated how such high feed rates can be reached, while taking the changed focusing conditions into consideration since the beam is generated differently for blue and green beam sources. Furthermore, the institute has looked at the achievable welding depth in relation to the laser power and placed it in connection with the achievable coupling degrees. Furthermore, Fraunhofer ILT has investigated how spatter, pores, etc. – quantified by the seam surface roughness – influence the seam quality when different process regimes are used.

Applications

These new laser beam sources in the visible wavelength range can be applied especially where the metals joined have bonds showing irregularities in the seam shape due to their absorption-related properties. These include, in particular, the fields of power electronics, electromobility and microelectronics.

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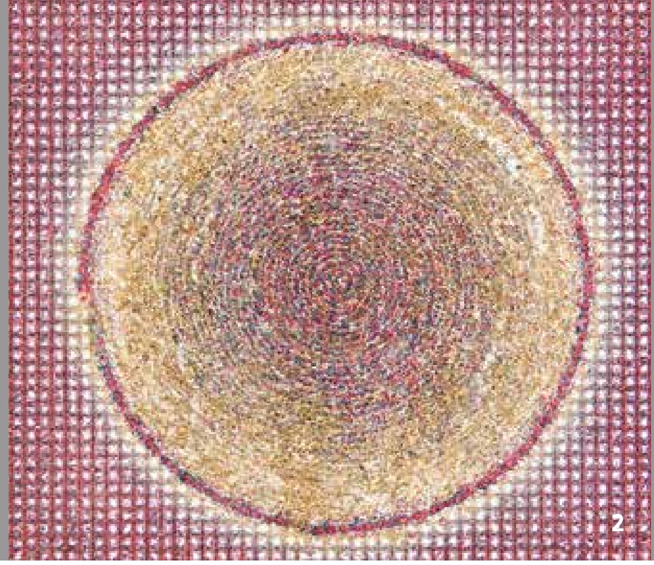
2 Thin-film contacts by means of green laser beam sources.

3 Laser beam welding of battery modules with blue laser radiation.



MICROWELDING WITH SHORT PULSE LASER BEAM SOURCES

Task

Joining high-current connectors made of copper or aluminum with large cross-sections pose a special challenge in joining technology. They are increasingly used in power electronics and contacted to thermally and mechanically sensitive substrates (e.g. battery cells and printed circuit boards). It is essential to precisely control the welding depth and energy input with minimum component stress. The use of nanosecond beam sources provides a novel solution to better control the energy input and to contact dissimilar materials.

Method

A nanosecond pulsed fiber laser is mainly used where material needs to be ablated, such as for laser drilling, engraving, cutting and laser structuring. Fiber lasers operated in continuous wave (CW) mode are generally used for contacting copper and aluminum connectors. In order to investigate the suitability of a pulsed laser beam source for welding, Fraunhofer ILT is defining the process limits and investigated samples made out of dissimilar materials in terms of various properties, such as contact resistance and mechanical load capacity. For benchmarking purposes, a fiber laser operated in continuous mode is used to produce samples for comparison.

Results

The laser beam source described here was integrated into a typical setup for laser welding and used for welding copper connectors that were up to 300 µm thick. Welding depths and seams with comparable quality to conventional laser beam welding could be demonstrated.

Applications

Welding with a nanosecond pulsed fiber laser can be applied in various areas of power electronics and battery technology. The nanosecond laser is particularly important where several processes (including structuring and welding) have to run in parallel. In addition, this laser beam source allows for greater flexibility when welding high-gloss metals.

The work was carried out as part of the MikroPuls project funded by the German Federation of Industrial Research Associations »Otto von Guericke e. V.« under the funding code IGF No. 20.895 N.

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1 Positive pole contact with a copper connector without burn-through.
2 Spiral blind weld.

LASER WELDING PLANT FOR THE PRODUCTION OF LARGE LITHIUM-ION BATTERY CELLS

Task

To produce large round lithium battery cells, the industry has to join cell poles to cell windings and create a conductive connection. This requires a laser welding cell that can be used to produce in small series. The aim of the work presented here was to develop a particularly flexible system technology that allows variable weld seam geometries and is suitable for different metallic materials.

Method

Initially, Fraunhofer ILT carried out feasibility and process development studies of the welding tasks. From the results of these studies, it derived the requirements for the system technology. The necessary components were then assembled at Fraunhofer ILT and the complete system for semi-automatic process control was tested; afterwards the system was delivered.

Results

The laser welding system developed for the production of large round cells has already been delivered to a customer, installed on site and commissioned together with the operators. Since then, several small series have already been successfully produced on the system.

With the support of Fraunhofer ILT, an additional laser welding process was developed to produce a safety component, which is additively welded to the battery cell within the overall system. Thus, the portfolio of laser welding tasks could be extended thanks to the high system flexibility. The institute is already planning to develop and implement further welding tasks.

Applications

The laser welding system is suitable for joining metallic materials. This also includes non-ferrous metals and precious metals.

The large round cells currently produced with the laser welding plant are mainly used in the automotive and aerospace sectors. However, this area shall be significantly expanded, for example to include maritime applications.

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3 Large round cell, © EAS Batteries GmbH.
4 Process plant for welding large round cells.

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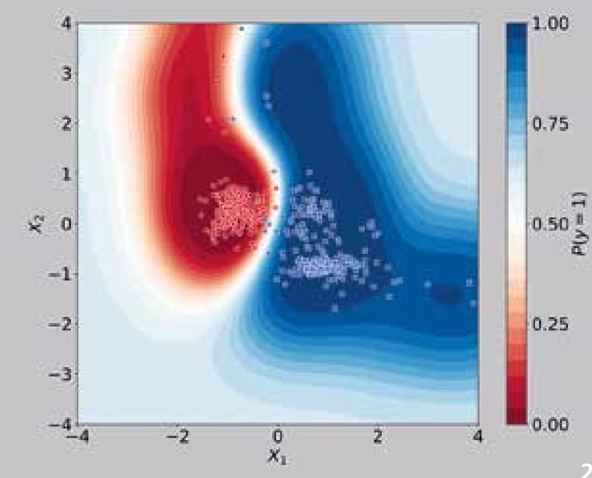

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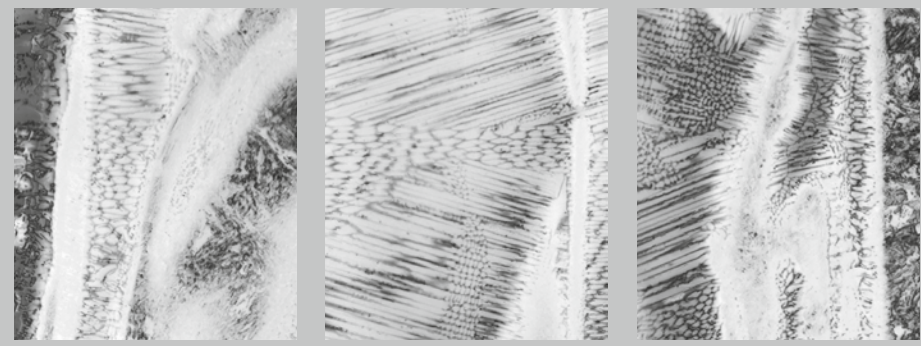

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AI-BASED QUALITY ASSURANCE FOR BATTERY WELDING

Task

On behalf of 4D Ingenieurgesellschaft für Technische Dienstleistungen mbH, Fraunhofer ILT evaluated the application of AI-based methods for monitoring contact welds on batteries. In the system under investigation, a photo diode captures the process radiation emitted by the interaction zone during welding. Although they aim to develop a precise quality assurance system, classical approaches to interpreting sensor signals do not result in an evaluation that is pseudo-error-free and at the same time without error slip. To predict the actual quality state of a weld based on the sensor signals more reliably, the institute applied the methods of artificial intelligence, specifically machine learning, to reveal hidden patterns within the measured data.

Method

Fraunhofer ILT was able to use more than 32,000 measurement signals from individual welds, including their quality evaluation (OK or not OK). From these measurements, the institute extracted characteristic features and specific fingerprints of the signals. In addition to simple signal features such as mean value and standard deviation, it also extracted time- and frequency-dependent features such as Fourier, wavelet and autocorrelation coefficients from the signals. Subsequently, an algorithm from the field of supervised learning was used to teach a classification model with which welds and the associated quality categories (OK or not OK) can be evaluated.

Results

The AI-based evaluation allows the weld seam quality to be divided into not OK and OK. The classification result reaches an accuracy of more than 80 percent for this data set, although a visual evaluation of the signals, performed by a human expert, hardly recognizes the quality categories needed to be differentiated. During the development, 700 features were determined based on the raw signal. It has been shown that the error detection rate reaches a maximum with the most significant 31 features. This reduces the effort for the application by more than 95 percent.

Applications

The AI process can be applied to detect irregularities and defects in laser beam welding of battery components. In addition, the procedure can also be used within the framework of »Industry 4.0« for documentation and, in particular, for improving the quality of further laser material processing.

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1 Welded battery composite consisting of several individual cells.

2 Decision limits of a classification algorithm in 2D feature space.

WELDING DISSIMILAR JOINTS OF ULTRA-HIGH STRENGTH AND SUPRADUCTILE STEELS

Task

When laser radiation is used for the fusion welding of differently alloyed steels, mixing of either alloy causes alterations of the alloy of the fused zone. Local changes of composition impair the microstructure, and hence, the mechanical properties of the welded joint. Since it is difficult to predict these properties, the mixture and the resulting distributions of the alloying elements should first be determined in order to understand the flow during processing and its effects on weld quality.

Method

Samples of combinations of press-hardened chromium steel or dual-phase steel with high-manganese steel were produced under variable parameters during welding tests on lap joints. Element analysis with EDX as well as low load hardness testing was used to evaluate the results metallographically. The mechanical properties were tested in KS2 and shear tensile tests.

Results

Combining the three analysis methods makes it possible to precisely determine the resulting phases. A wide range of microstructures between austenitic and martensitic appear with different varieties in all connections. It was not possible to determine if the local alloys influenced the strength since failure occurred in the heat-affected zone of the dual-phase steel or the martensitic steel. In combination with the mid carbon martensitic chromium steel, heat treatment leads to a considerable improvement in strength. The mapping of the local alloys in the COHMS diagram shows that the assumptions made there are valid, also for laser-beam welded joints.

Applications

The fundamental work presented here shows the strengths and weaknesses of the respective analysis and testing methods. Especially for the strength tests, adjustments to the test part geometry are still necessary in order to examine the weld seam itself. These adaptions will provide a procedure to assess dissimilar fusion welds for almost all applications in the sheet metal processing of steel.

The IGF project VP 1175 (IGF 19556 N) of FOSTA has been funded by the AiF within the framework of the program for the promotion of joint industrial research of the Federal Ministry of Economics and Energy.

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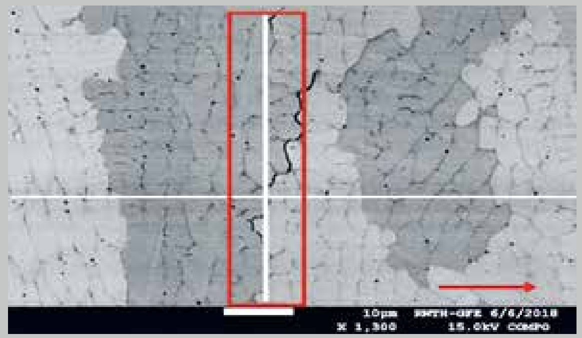
3 Local microstructure formation by varying mixing in the weld.



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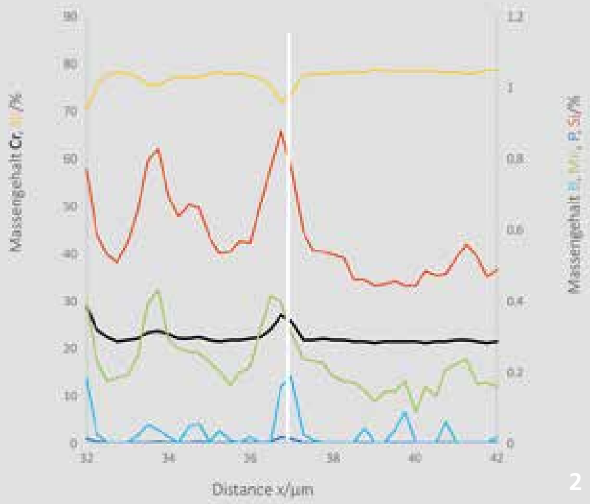

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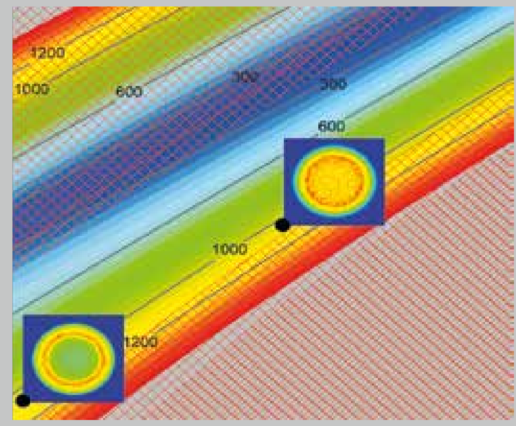

3

CRACK FORMATION ANALYSIS IN WELDS OF NIMONIC 75 AND STELLITE 31

Task

In the course of developing a process, Fraunhofer ILT determined that Nimonic 75 and Stellite 31 could be suitably joined by welding. After the welding process was qualified, a modification of Nimonic was used, which resulted in hot crack formation. The cause of both the crack formation and the effective path had to be determined in an error analysis. Furthermore, a regulation had to be developed in order to prevent the error from occurring in the future.

Method

Welding tests have shown that the presence of boron, which is added to Nimonic 2.4951 to improve creep resistance, results in cracks during welding. With this alloy, the cracks were distributed over the entire weld seam, whereas with the 2.4630 modification they were limited to the slopes. To test the damage hypothesis, an electron microscopic study was carried out.

1 Microstructure in flat cut.

2 Element distribution (in the marked area).

Results

After the metallographic analysis did not reveal any differences between the material variants, the high-resolution electron beam microanalysis indicated that the welding defects were caused by boron. In the dendritically solidifying microstructure of the weld seam, this element results in precipitates forming at the grain boundaries through co-segregation with accompanying and alloying elements, in particular silicon; these precipitate remain as hot cracks in the microstructure due to their low ductility. From the results, the limits of the alloy constitution were derived with respect to crack-forming elements and an adjustment of the joining strategy. These findings are being incorporated into a repair process for turbine parts. In addition, the results show that generatively produced components can be welded safely since the alloys can be more easily adjusted than is the case with wrought alloys.

Applications

The alloys examined here are used in gas turbine construction due to their good properties at high temperatures. With the improved weldability and safety resulting from the research results presented here, welded joints of the two materials can also be used in apparatus engineering.

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MULTIFUNCTIONAL LASER TOOLS FOR LIGHTWEIGHT CONSTRUCTION AND ELECTROMOBILITY

Task

Highly varied products, changing batch sizes and new production methods require extremely flexible manufacturing concepts. In this context, laser technology – combined with digitalization – is predestined for solving various issues of economical production. In the MultiPROmobil project, Fraunhofer ILT is developing a multifunctional laser processing head and robot technology for the flexible and economical production of components in the field of electromobility.

Method

Based on analyzing the requirements for production and component properties, Fraunhofer ILT first integrated the cutting, welding and additive production processes into one processing head. A combi-head was used, with which the various processes can be carried out without needing to retool the system. Serving as an application example is the triangular control arm of an electric vehicle, which is to be processed in a multifunctional laser robot cell. A flexible clamping technique is used to securely hold the components during production. Digital twins are used to map the machine, processes and component, thus enabling virtual commissioning.

3 Set of characteristic curves of beam distributions for additive manufacturing steps.

Results

A multifunctional processing head was designed as a tool to solve the manufacturing task. The construction of a laboratory sample has been completed; special features are an optical system for flexibly adapting the beam properties to the requirements of the three different processes as well as for the functions of supplying the gas and additives. The robot, clamping fixture and laser technology are networked in the production cell and implemented as digital twins to optimize the production tasks.

Applications

The further development of the combi-head in the MultiPROmobil project shows potential, in particular, for small and medium-sized enterprises that want to make an important contribution to the future market of electric mobility. In the future, several multifunctional robots will also be used in highly flexible production cells. This will allow process chains to be designed in a very flexible and scalable way with a view to the gradual introduction of electromobility.

This project is being carried out with funding from the European Regional Development Fund (ERDF) and the State of North-Rhine Westphalia under the funding code EFRE-0801253.

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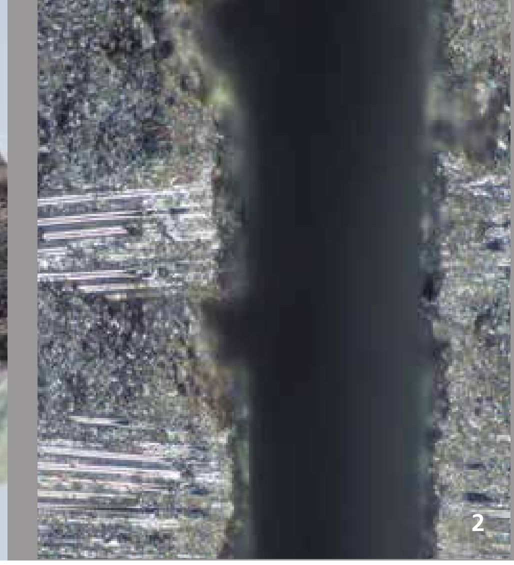

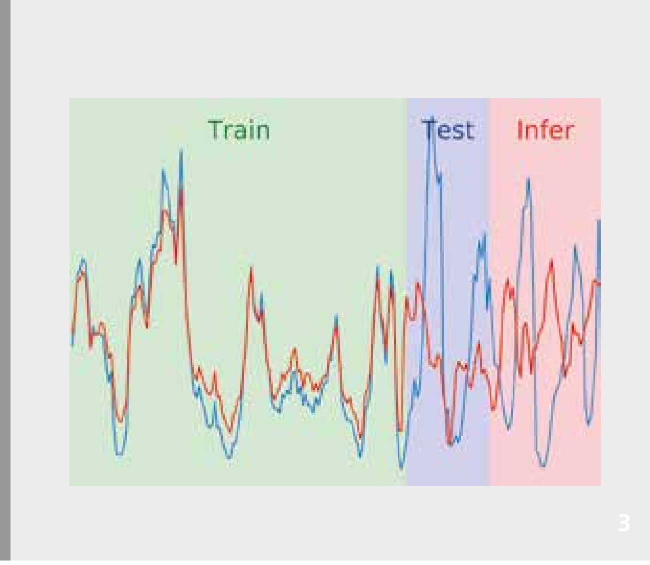

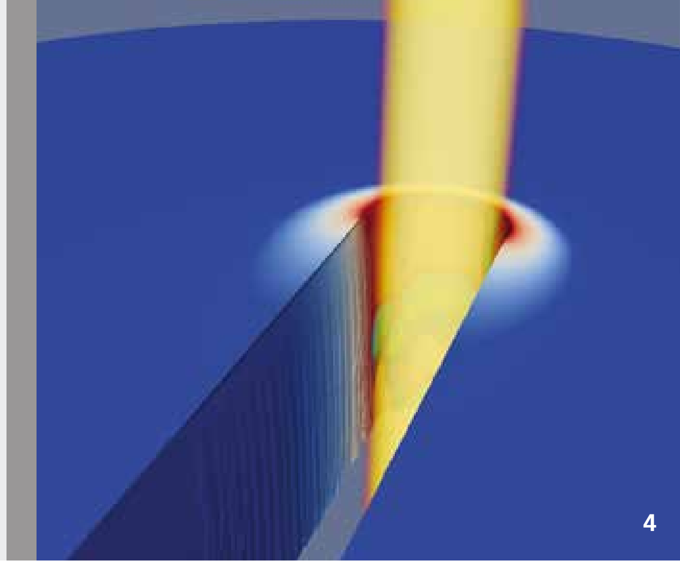

CUTTING CERAMIC MATRIX COMPOSITES (CMC)

Task

Ceramic matrix composites (CMC) form a young group of materials in which ceramic fibers are embedded in a ceramic matrix, thereby increasing the ductility and crack resistance compared to conventional technical ceramics. The high-temperature and abrasion-resistant CMC materials are used in aerospace and turbine construction, among others. Since the mechanical properties of CMCs make machining them extremely difficult, laser cutting provides manufacturing advantages over conventional processes such as milling or drilling thanks to its wear- and force-free operation.

Method

For the CMC materials Al_2O_3/Al_2O_3 and SiC/SiC, Fraunhofer ILT has investigated cutting methods with cw fiber lasers. It has examined both remote cutting with a scanner in multi-pass ablation as well as gas-assisted cutting with conventional focusing optics and direct formation of a continuous kerf on a 3–4 mm thick sample material. Using laser powers of up to 5 kW, the institute developed a parameter field that leads to economical processing times.

Results

With both cutting methods, the materials can be separated without cracks and at cutting speeds in the range of several meters per minute. Clean cut edges are achieved primarily with cutting gas support, which minimizes the re-deposition of ablated products on the cut surface. Only a thin, non-continuous recast zone is formed with SiC/SiC.

Applications

Due to its high material costs, CMC is mostly used for high-tech applications in aerospace and plant construction. As cost-effective and reliable laser-based processes become available, however, this technologically promising group of materials can be used by a wider range of industrial sectors.

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1 Bore hole with Ø 10 mm in Al_2O_3/Al_2O_3.
2 Cross section of the kerf (detail).

CONVOLUTIONAL NEURAL NETWORKS FOR THE PREDICTION OF CUT SURFACE PROFILES

Task

The mean profile height is one essential quality feature in sheet metal cutting with lasers. Moreover, by predicting surface profiles from in-situ process signals, research can better understand the cutting process and develop approaches for fast closed-loop control of the laser radiation. For this purpose, a relationship must be established between a very fast front signal, which is caused by fast moving waves on the melt front, and the one to two orders of magnitude slower generation of the cut surface profile.

Method

A profile signal is extracted from a dynamic process simulation and from in-situ high-speed videographies of trim cuts on a horizontal line in the upper third of the cut surface. Each discrete profile value is assigned to a preceding section of the front signal as input for a neural network. Because of their short training time and their ability to extract patterns, convolutional neural networks (CNN) are used to analyze the interconnection between the two signals.

Results

Spatially averaging the signal from the melt front improves the quality of the prediction of the surface profile, compared to local signals (train). Amplitude and frequency are already described by the neural model within the correct range (test and infer). By analyzing the relationship between the input variables and the quality of the network as well as the extracted features, Fraunhofer ILT and the Chair for Nonlinear Dynamics of Laser Processing NLD at RWTH Aachen University were able to verify and extend the process understanding.

Applications

Machine learning can make a significant contribution to the data-driven investigation of the interrelationships between dynamic process variables. Using the example of laser fusion cutting, the institutes analyzed whether a model-based control of the laser parameters with neural networks reduces the mean profile height. This methodology can be transferred to processes in which suitable in-situ signals are available for closed-loop control.

The work presented here was carried out in the context of the Collaborative Research Centre SFB1120 »Precision Melt Engineering« at RWTH Aachen University and was funded by the German Research Foundation e.V. (DFG). We wish to express our sincere gratitude for the sponsorship and support.

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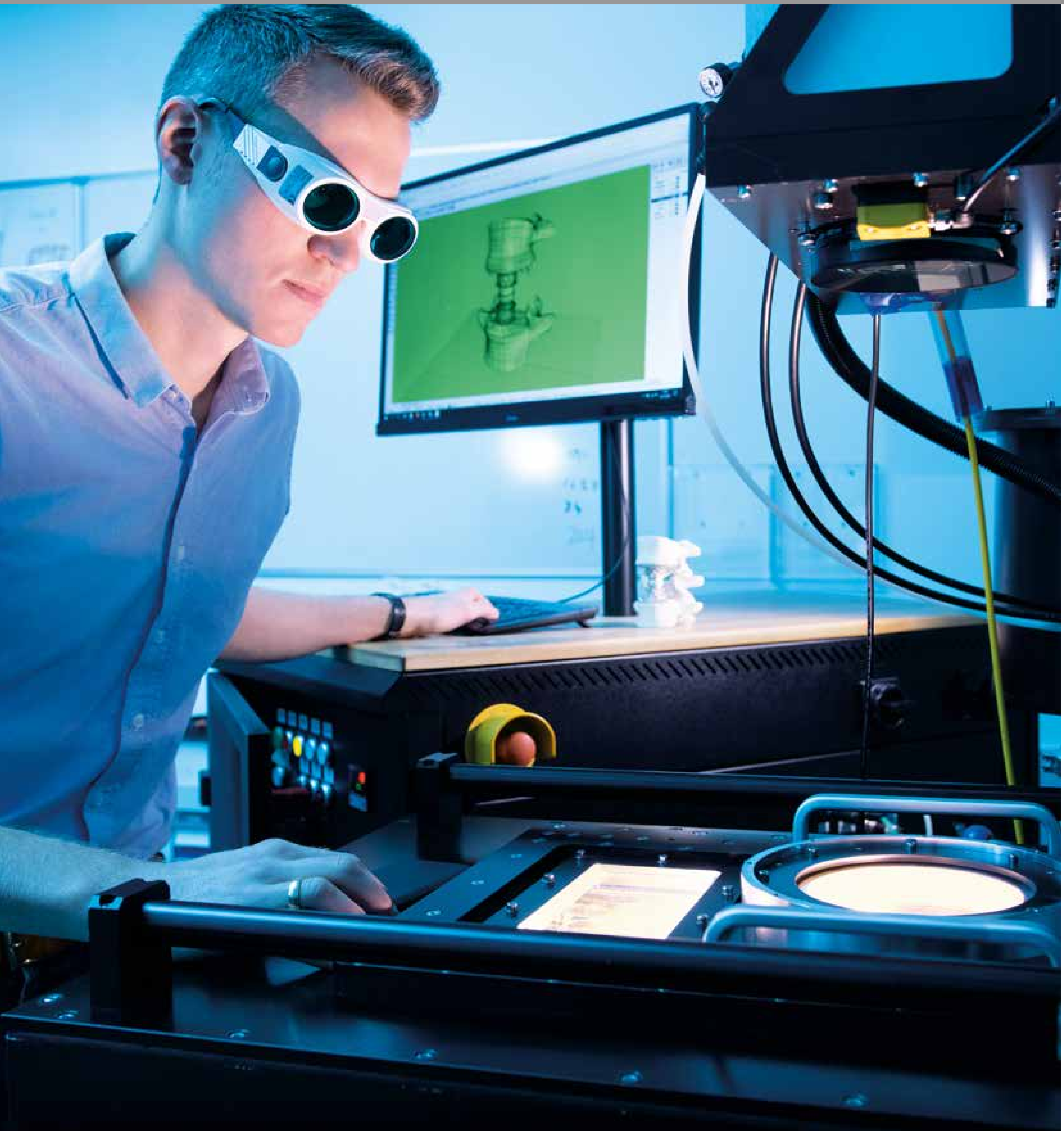
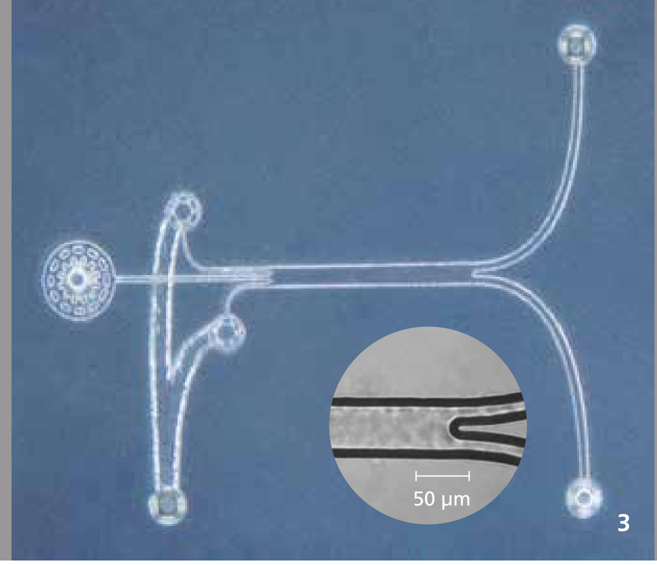
3 Input signal and neural network prediction.
4 Simulation of melt waves.

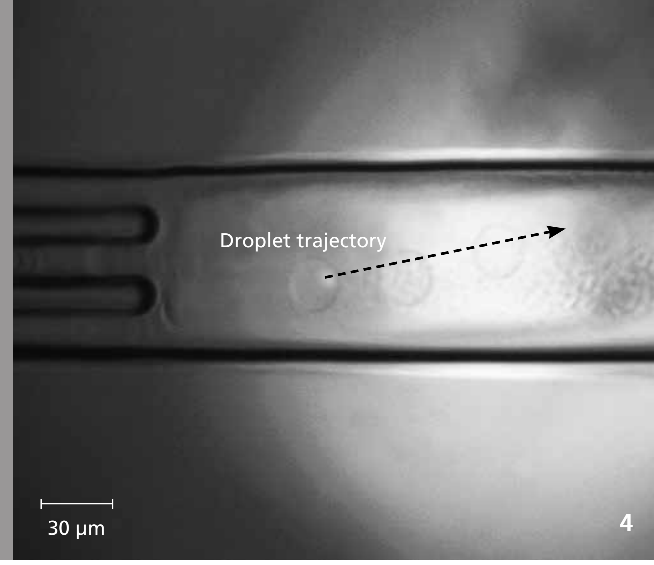
MEDICAL TECHNOLOGY AND BIOPHOTONICS



CONTENTS

Laser beam melting of a vertebral-body implant.





MICROFLUIDIC DIAGNOSTIC SYSTEMS FOR CLINICAL MULTIPLEX ANALYSIS

Task

Cells and biomolecules circulating in the blood are carriers of diagnostic information, the analysis of which is a key to highly effective, individualized therapeutic concepts. By acquiring various molecular diagnostic and microbiological parameters simultaneously, physicians can generate an accurate clinical picture and, thus, develop an individually adapted therapy for the patient. In order to establish such multiplex diagnostics in everyday clinical practice, they need diagnostic assays and automated readout systems that measure as many parameters as possible at low cost with a small sample volume.

Method

Scientists at Fraunhofer ILT have developed a screening system that can analyze a large number of different diagnostic particles in one sample. Each particle type presents its own species of capture molecules on its surface, which specifically bind an analyte to be detected. The particle is identified through its characteristic fluorescence and scattering properties; the bound analyte molecules are detected and quantified through a fluorescent secondary marker. By acquiring and differentiating the different particle species and the analyte molecules bound to them, this system can detect many different diagnostic parameters simultaneously in a single measuring step. The screening systems use laser beam sources specifically adapted to the measurement task, are compact and provide real-time data processing.

Results

Based on a microfluidic system, a functional model for an in-vitro diagnostic device has been developed, which automatically measures particle samples and their bound analytes with an integrated fluorescence and scattered light sensor system. This in-vitro diagnostic device currently allows up to 24 different disease markers to be detected. A real-time-capable electronic platform developed for this purpose controls the measuring system and evaluates the measured data, enabling integration into automation solutions such as fully automated diagnostics laboratories.

Applications

Fields of application are infection and autoimmune diagnostics, microbiological rapid tests and preventive medicine.

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1 In-vitro diagnostic device or clinical multiplex analysis.

2 Micro flow cell of highly integrated measuring optics.

OPTOFLUIDIC SORTER FOR HIGH-THROUGHPUT SCREENING OF ENZYMES

Task

The advantages of biotechnology lie in its ecological and economical production compared to large-scale chemical production. In addition, it can be used to produce completely new types of products. The key to advancing biotechnological production processes is using the appropriate technical enzymes that catalyze these processes. To find such process-optimized technical enzymes, research needs to be able to screen millions of candidates obtained from gene libraries. This requires high-throughput processes that screen the activity of the enzymes and separate out the candidates with good catalytic properties.

Method

For each individual gene in the library, the corresponding enzyme is expressed in a micro-droplet in a cell-free manner. The enzyme activity in each micro-droplet can be measured via its fluorescence through enzymatic conversion of a substrate into a fluorescent product. In a microfluidic system, these droplets are examined for their fluorescence intensity at high-throughput with kilohertz frequencies. Droplets of high fluorescence intensity are separated from the droplet stream in a sorting chamber with dynamic optical tweezers. The force for deflecting the droplets is generated by the momentum transfer when the laser beam is refracted at the drop.

In collaboration with Fraunhofer IME, Fraunhofer ILT has developed this method as part of the DARWIN preliminary research project funded by the Fraunhofer-Gesellschaft. The institutes intend to screen a gene library with one million candidates within a few hours.

Results

In a fused silica microfluidic system, the droplets were hydrodynamically focused and classified according to their fluorescence signal. To date, screening rates of up to 5 kHz have been achieved. With optical tweezers, micro-droplets with a fluorescence signal above threshold can be deflected from the hydrodynamic focus within 8 ms. In this process, forces of several nanonewtons are achieved.

Applications

The optofluidic sorter can be applied primarily to screen enzymes expressed in a cell-free manner. It can also be used, however, to develop pharmaceutical products, screen chemical syntheses and sort heterogeneous cell ensembles.

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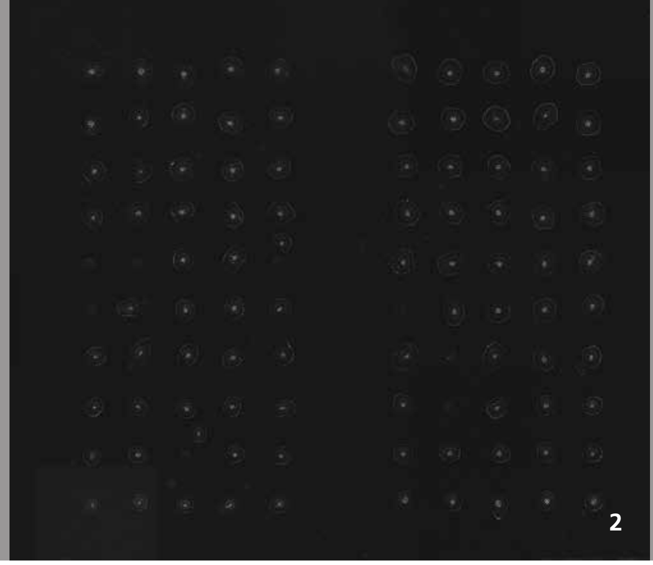
3 Microfluidic sorting chamber of the optofluidic sorter.

4 Trajectory of a microdroplet sorted out in the tweezer focus.



NEW HYDROGELS FOR LASER-BASED PRINTING OF FABRIC MODELS

Task

Laser-assisted bioprinting (LAB) is based on the process of laser-induced forward transfer (LIFT). To print with single cells or clusters of cells, a hydrogel is needed, which absorbs the laser radiation, forms a uniform, stable layer of constant thickness and is biocompatible. Up to now, 5 percent gelatin has been used for single cell printing, but this has proved unsuitable for printing cell clusters at temperatures around 37 °C and increased humidity. Therefore, a new hydrogel needed to be established.

Method

LAB is currently being tested with a MIR beam source at a wavelength of 2.94 µm and a hydrogel that consists of more than 95 percent water. Water serves as absorption medium for the LIFT process. Typically used for cell cultures, the hydrogel Matrigel® was diluted with cell culture medium according to the manufacturer's instructions, a step that makes it possible to apply gel layers with a thickness < 100 µm. The gel crosslinks at approximately 37 °C. Fraunhofer ILT investigated how uniformly the hydrogel as well as living cells could be transferred in the semi-automated LIFTSYS® system under climate-controlled conditions.

Results

Thanks to Matrigel®, the institute could demonstrate that drop patterns could be printed uniformly for the first time and at a success rate of more than 95 percent. The transfer efficiency is thus about 30 percent higher than with gelatin. Fraunhofer ILT also demonstrated that cell clusters can be successfully transferred using Matrigel®.

Applications

The use of Matrigel® as a hydrogel opens up new fields of application for LAB in 4D bioprinting since cell clusters can be printed, thus promoting advances in tissue engineering. The construction of organoid structures and the development of organ-on-a-chip systems, for example, are of great interest for pharmaceutical research. Matrigel® as a transfer layer for LAB is particularly suitable for processing demanding cell types such as stem cells or cardiomyocytes. The overarching, visionary goal is to develop cardiovascular implants and artificial organs.

The work presented here was carried out as part of the innovation competition »Artificial Organs from the Laboratory« of the Federal Ministry of Education and Research.

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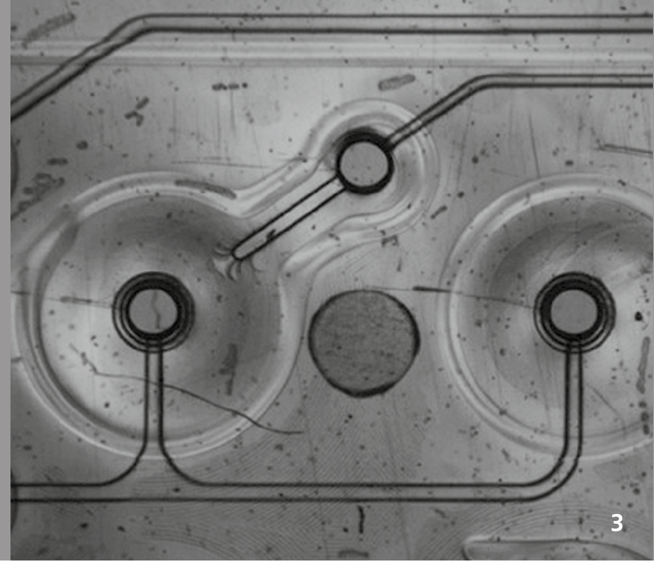
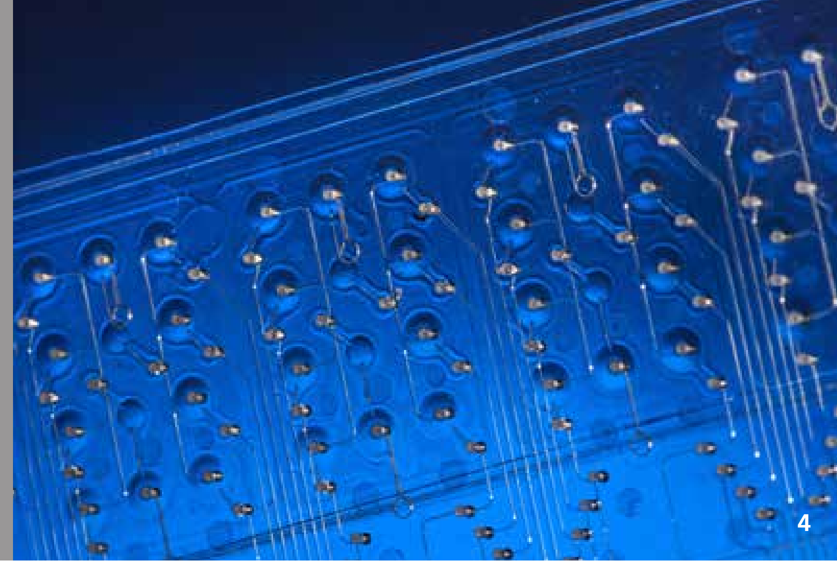
1 Layer thickness measurement of a hydrogel layer.

2 Overview of a printed image of four fields of five times ten drops each.





ENCAPSULATION OF MICROFLUIDIC CHIPS MADE OUT OF CYCLOOLEFIN COPOLYMERS

Task

Commonly used in the life science sector, among others, microfluidic chips make it possible to transport, mix and filter even the smallest amounts of liquid down to the picoliter range. These chips are commonly used as microreactors or blood glucose meters. Encapsulating the microchannels in a media-tight manner, however, poses a great challenge for conventional joining technology since the channels have such small structural dimensions in the micrometer range. Absorber-free laser transmission welding with beam sources in the NIR range opens up new perspectives here due to its high flexibility. By using short focal length focusing optics, Fraunhofer ILT is able to melt the plastic in a defined manner, which avoids excessive melt ejection and, thus, prevents blockage from forming in the channels themselves.

Method

In a joint project with m2p-labs GmbH in Baesweiler, Fraunhofer ILT welded the basic body of a microfluidic bioreactor to a film of cycloolefin copolymers (COC) in media-tight manner using laser transmission welding. A thulium fiber laser with an emission wavelength of 1940 nm is used as the beam source. In this wavelength range, plastics have a natural absorption, which means that absorber material, such as soot, does not need to be used. This way, the transparency of the component is not affected.

Results

The exact guidance of the laser beam along the channel structure ensures media-tight encapsulation. Since the seam width is only 150 µm, the thermal load on the component remains low. In addition, a thermal penetration depth < 1 mm also prevents damage to other channel structures on the back of the component.

Applications

In addition to the encapsulation of microfluidic components, absorber-free laser transmission welding is particularly suitable for applications where high transparency is required and absorbers cannot be used for biocompatibility reasons, e.g. in medical technology.

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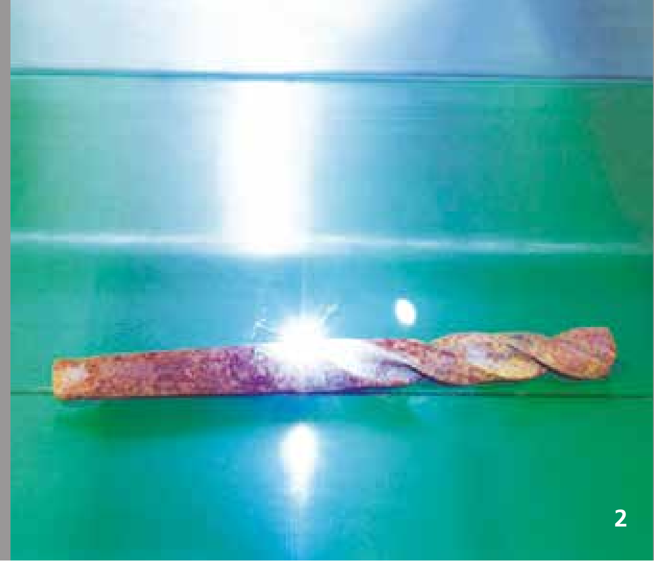
3 Measurement of the seam geometry using a polarization microscope.

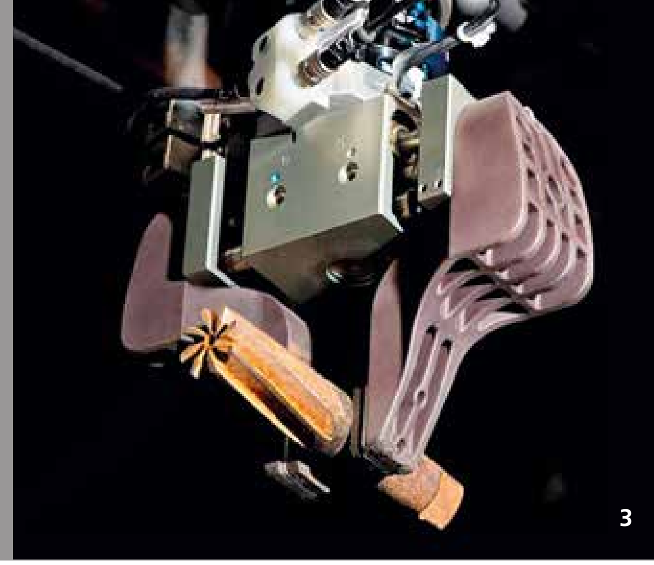
4 Tightly welded COC components.

LASER MEASUREMENT AND EUV-TECHNOLOGY

Optical measurements made on bone models for laser surgery.

CONTENTS





MOBILE SPECTROSCOPY FOR DETERMINING CARBON CONTENT IN STEEL

Task

To analyze the elements in metals with cordless handheld instruments, Fraunhofer ILT is developing a method and conceptual setup to use laser-induced breakdown spectrometry (LIBS) with highly integrated components; furthermore, it is investigating its analytical performance in the laboratory. Fraunhofer ILT has focused on carbon detection since determining its content in steel is not only economically important, but poses technical challenges. Concentrations down to the range of 0.01 percent are to be measured with a compact setup that can be used in a mobile handheld device.

Method

In close cooperation with laser development and metrology, Fraunhofer ILT has developed a passively Q-switched laser, spectral detection and the guidance of laser and measuring radiation for mobile use. The device's size, weight and energy management play a decisive role along with its capability to analyze materials. Key points of the development are the compromise between these boundary conditions and opposing requirements for spectral resolution, inert gas atmosphere in the sample area as well as duration, sensitivity and reproducibility of the measurement. Parameters of the LIBS detection have been tuned in such a way that the carbon spectral line can be detected and low carbon contents quantitatively verified.

1 Compact setup with laser, spectrometer and optical components for the analysis of steel (approx. 23 × 12,5 × 7 cm³).

Results

The decisive criterion for analytical performance is the detection limit for carbon in steel. The institute has achieved the world's best figure – 0.0034 percent, corresponding to 34 µg/g – for compact LIBS (cf. Opt. Express 27, 36855-36863, 2019). This result showed that mobile spectroscopy is advancing into areas that were previously not possible or only possible to a limited extent. One example is the distinction between the technically important and widely used stainless steels 1.4301 and 1.4307 (also known as 304 and 304L), which differ only slightly in their carbon content. The results show that the hand-held device can be used to test for them quickly, even when the components containing these steels have already been mounted.

Applications

Mobile, hand-held spectroscopy systems allow fast elemental analysis of metals in metal production, processing and recycling industries. Applications include the monitoring of production processes, materials identification and incoming inspection of raw materials or semi-finished products.

This project has been financially supported by the Fraunhofer-Gesellschaft.

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PILOT PLANT FOR LASER-ASSISTED SORTING OF SPECIAL ALLOYS

Task

Among all raw materials, metals are among those that can be recycled with practically no loss of quality, provided they are collected separately and at a high degree of purity. Moreover, some metals have a high material value or are considered to be critical for production supply in Europe. Manually sorting scrap metals is only possible to a limited extent, however, since there are a great variety of metal alloys used in technical applications; these individual metals often cannot be distinguished by the naked eye. Here, Fraunhofer ILT and its partners are introducing a fully automatic sorting process for a large number of alloys of special metals into practical use for the first time.

Method

Fraunhofer ILT has developed a method that performs direct laser spectroscopic analysis of scrap parts on a conveyor belt. Here, laser-induced breakdown spectrometry (LIBS) is used to analyze the composition of the alloy components for each scrap piece and to determine the corresponding sorting class. The multi-element analysis with LIBS allows users to detect a large number of alloys. To make use of this potential, the concept foresees using a robot to sort the metals automatically, which, in contrast to classical sorting methods, is not limited to a small, fixed number of sorting fractions.

Results

Together with project partners, Fraunhofer ILT has set up and commissioned a pilot plant in an industrial recycling company to sort special alloys such as high-speed steels or hard metals fully automatically. The LIBS analysis is supported by an integrated laser cleaning system as the surfaces of the metal parts are frequently contaminated. Using laser-based image recognition, the system can identify the individual pieces of scrap and determine suitable measuring positions. In combination with the LIBS results, the detected geometry information is used to control the gripping and ejection of the parts by the robot.

Applications

The process demonstrated here can be transferred to other areas of metal recycling of piece goods. By combining geometry measurement and fast chemical analysis, the research group is also opening up new potential for future automated applications in inline process control.

The R&D project underlying this report was carried out on behalf of the Federal Ministry of Education and Research under the funding code 033R181B.

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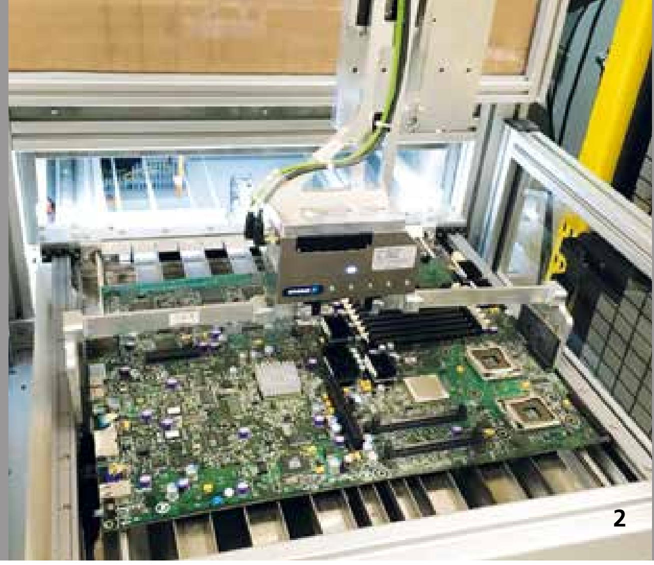
2 Laser analysis of an HSS drill.
3 Robot handling for sorting, © Cronimet, Karlsruhe.



DEMONSTRATOR SYSTEM FOR LASER-BASED RECOGNITION OF ELECTRONIC COMPONENTS

Task

Modern electronic equipment contains a large number of different materials, only some of which can be recovered at the end of their useful life with current recycling methods. Other valuable technology raw materials can be recovered for the recycling sector, however, if they are separated into fractions having high concentrations.

Method

The ADIR consortium has developed an automated demonstration plant for selectively removing electronic components from old electronics. For such a plant to function, specific information is needed: which components are present in the electronic devices, where they are mounted and what they consist of. Image processing, 3D laser measurement and laser spectroscopy are used to collect this information, which is then stored in a database.

Results

An inspection system was set up and integrated into the demonstrator. It accepts electronic boards from pre-processing, takes high-resolution color images and then measures the 3D height structure on the board.

The results are compared with those of known circuit boards already stored in the database. The constituents of unknown components are identified by laser-induced breakdown spectrometry (LIBS) and the components, supported by image processing software, are evaluated to determine target fractions. In this way, a digital image of all processed circuit boards is created and can be used in the subsequent process step, in which laser desoldering removes and sorts the valuable components. The process has already been successfully tested in field trials in a recycling plant. Specialized metallurgical operations have extracted valuable materials such as tantalum as a secondary raw material from the enriched sorting fractions.

Applications

When information is lacking on the structure and material composition of old equipment, the high-quality recycling of raw materials faces an obstacle. Here, digitally networked optical metrology can close the gap and enable society to use resources efficient and economically.

The work was carried out as part of the EU project ADIR under the funding code 680449.

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1 CAD drawing of the demonstration plant.

2 Automatic transfer of a circuit board to the inspection system.

FIRE – AN ELECTRONICS PLATFORM FOR PRECISE, REAL-TIME MEASUREMENT AND CONTROL TECHNOLOGY

Task

Fraunhofer ILT develops devices for production and laboratory measurement technology. The central element of these devices is a powerful electronic unit that can be connected to application specific dedicated sensors and actuators. The electronic unit is designed as an open platform which allows various application-specific functions to be implemented quickly. It also ensures continuous non interrupted data processing in real time and can provide high computing power if required. The institute has also implemented communication interfaces to systems important for laser technology applications; these include the connection to scanner systems and sensors.

Method

Fraunhofer ILT has developed a modular concept, consisting of a central base circuit board with versatile interfaces and a suitable portfolio of peripheral boards. Using this platform, application-specific electronic units can be assembled for new devices. For the interfaces provided, great importance has been placed on using international standards as well as real-time-processing capability.

The base unit features a high-end FPGA and an integrated dual core ARM processor with 1500 MHz clock frequency. Embedded Linux is used as operating system.

Results

The platform is based on an FPGA from Intel with a computing power of up to 500 GFLOPs. The following hardware interfaces were implemented on the base circuit board: Gigabit-LAN, Industrial Ethernet, camera interface, CAN bus, three serial interfaces and 11 additional peripheral interfaces. These are suitable for connecting laser beam sources, scanners, A/D and D/A converters, encoders, photomultipliers, photodiodes, programmable logic controllers (PLC) and precision scales etc.

Applications

The platform can be used in laser measurement and laser medical technology devices, such as distance sensors, opto-fluidic sorters and laboratory devices based on fluorescence measurement technology.

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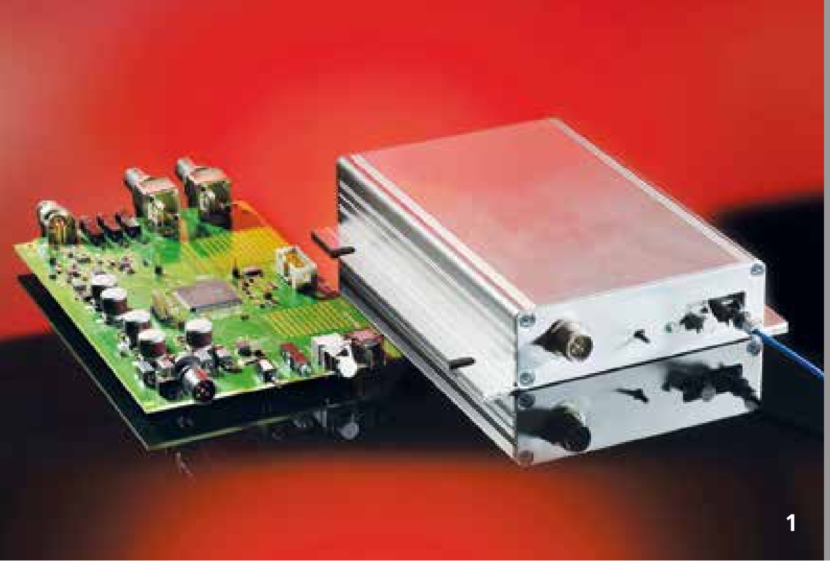
3 Electronics platform FIRE.

4 The basic circuit board for FIRE.



INLINE SENSOR SYSTEM »BD-X« WITH FPGA ELECTRONICS FOR REAL-TIME DATA PROCESSING

Task

Absolute measuring interferometric sensors are used in production measurement technology for the non-contact detection of geometric features. The sensors developed at Fraunhofer ILT have measuring ranges of up to 20 mm, achieve measuring accuracies of 1 µm and operate at measuring frequencies of up to 80 kHz. The continuously generated data volume of 300 MB/s must be processed in the measuring cycle, and the data processing must be carried out without interruption and in real time to control production processes.

Method

Field programmable gate arrays (FPGA) are particularly suitable for continuously processing large amounts of data since they allow parallelization and, thus, acceleration of computationally intensive operations. Fraunhofer ILT has developed an interface board based on an Arria 10 module from Intel with its own programming and put it into operation for the first time as part of the INSPIRE R&D project funded by the Federal Ministry of Education and Research BMBF.

Results

The institute has determined the response delay time between an external signal triggering a measurement and the output of a control signal calculated from the measurement result experimentally: It is 0.1 ms. At the FPGA the control signal could be transmitted as an optical, pulse-coded signal with an effective resolution of 16 bits over a distance of 100 m and then as output via a DA converter. The optical transmission is advantageous because it is insensitive to electromagnetic interference in an industrial environment.

Applications

First applications are the autofocusing of laser machining processes and the control of cold rolling processes in metal processing. Fraunhofer ILT has developed »bd 1« and »bd 4« sensors with one or four independent measuring arms for these and other applications, such as laser welding or laser cladding. Available measuring wavelengths are in the ranges around 835 nm, 1 µm and 1.5 µm.

The R&D work underlying this report was carried out, among others, on behalf of the German Federal Ministry of Education and Research under the funding code 13N14290.

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1 Optoelectronic D/A converter for fiber-optic transmitted control signals with connected optical waveguide (blue).

2 »bd-4« sensor and FIRE data processing electronics with fiber optic measuring arm (yellow).

MINIATURIZED OPTICAL MEASURING PROBE

Task

Optical metrology is already being used in many areas – distance/3D component measurement, optical material determination and optical coherence tomography, among others – with great success. To open up further fields of application, research is developing new methods in order to reduce the size of the measuring equipment. In cooperation with Fraunhofer ILT, the Chair for Optical Systems (TOS) at RWTH Aachen University is miniaturizing an existing measuring system using a measuring probe for measuring drop sizes in steam power turbines. For this purpose, the institute has adapted the optical system to the special requirements of small installation spaces and used a novel manufacturing system to mount the system mechanically.

Method

To measure the local droplet size distribution, optics are required which, on the one hand, introduce light into the measuring volume and, on the other, detect the light scattered by the droplets and transmit it to a photomultiplier. As a measurement, the system detects the intensity of the control light induced by passing drops. To precisely measure the local drop size distribution, a sharply defined and well-defined measuring volume is required (illumination optics: focus diameter 10 µm, back focal length 3 mm). As a result of the miniaturized size (Ø ≤ 8 mm), mechanical lens mounts have been manufactured as fused silica tubes for the holders of the optical components using Selective Laser Etching (SLE). The optical system consists of two assemblies, one for focusing the laser radiation coupled via an optical fiber into the measuring volume and the other for the directional reception of the laser radiation scattered by the drops.

Results

The measuring probe – developed in cooperation with the RWTH Aachen University chairs LLT, DAP and IKDG – has already been successfully used in experimental tests. The new miniaturized measuring probe allows precise measurements of the local drop size distribution. The holders for the optical system manufactured with SLE have proven themselves and will be optimized in further projects.

Applications

In principle, optical measuring methods, in which a small installation space plays an important role, can benefit from the knowledge gained in this project. The use of SLE-manufactured lens mounts allows miniaturization while maintaining mechanical and thermal stability. In addition to the measurement methods, the findings can also be transferred to laser material processing at powers < 100 W, thus opening up new areas of application.

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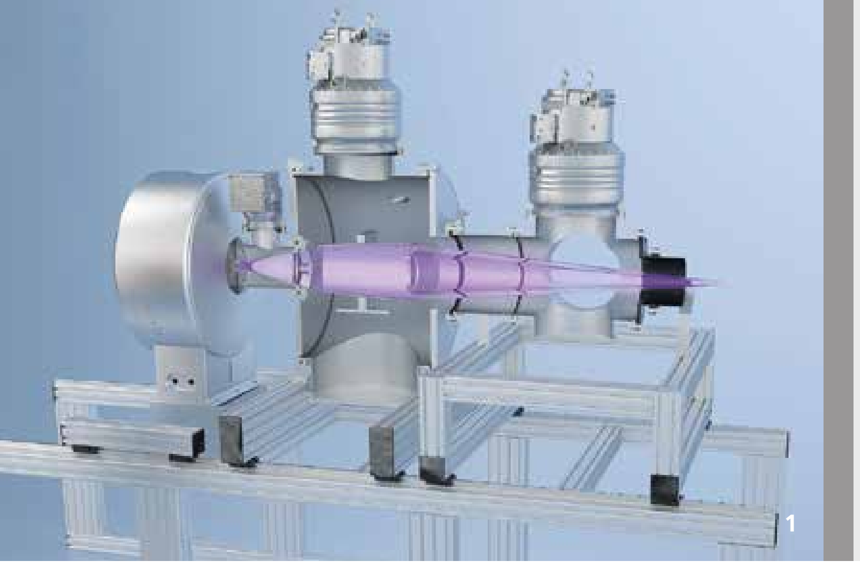
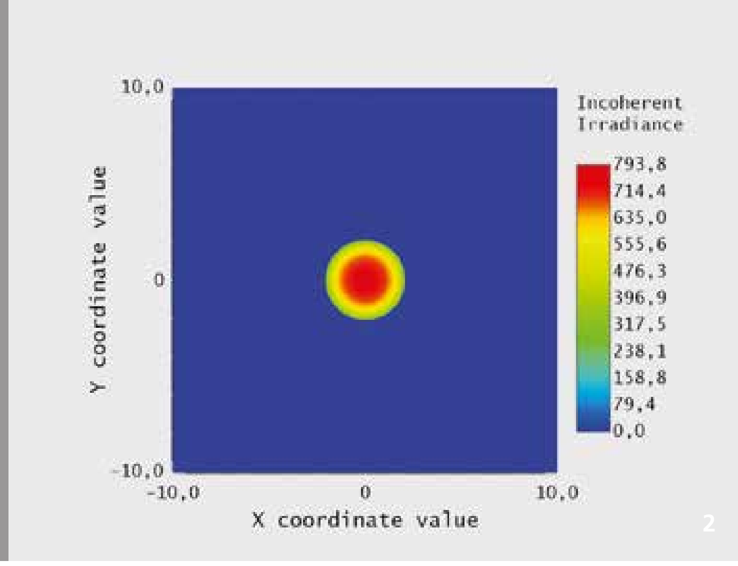
3 Focusing and acquisition module.

4 Mounted measuring probe.





SYSTEM FOR IRRADIATION EXPERIMENTS IN EXTREME ULTRAVIOLET

Task

To develop extreme ultraviolet lithography (EUVL), research is needed to develop and qualify optics and components as to their long-term stability under the influence of high EUV irradiances. Such investigations can provide information on the thermal load capacity or wear due to EUV-induced contamination as a result of such irradiation.

Method

Using a discharge-based radiation source it developed, Fraunhofer ILT dimensioned a source-collector system that allows irradiation experiments at intensities exceeding the state of the art. At an electrical input power of about 8 kW, the radiation source emits an average EUV power of up to 700 W/2πsr in a spectral range of 10–18 nm (broadband); of this, about 40 W/2πsr is in the 13.5 nm range of particular interest for EUV lithography in a spectral bandwidth of 0.27 nm (in-band). The pulse repetition rate of the xenon-based radiation source ranges up to 2500 Hz. The emission volume is approximately cylindrical with a diameter of about 500 µm and a length of 3–5 mm. The isotropically emitted light is accumulated by a collector in grazing incidence and focused on the sample to be treated. When dimensioning the collector, the institute had to take into account the requirements given by the respective task, such as spot size, average power or peak intensity.

Results

With the source-collector system shown in Figure 1, an average irradiation power of about 40 W/cm² (broadband) and about 4 W/cm² (in-band) can be achieved, having a spot diameter of about 1.6 mm. A slightly modified optical system allows an approximately homogeneous irradiation of an area with a diameter of about 4 mm at a correspondingly lower intensity (Fig. 2). In a multiplex system with four source-collector modules, an average power of more than 120 W/cm² (broadband) and more than 12 W/cm² (in-band) can be expected at a repetition rate of up to 10 kHz.

Applications

The described system – for irradiating samples in the extreme ultraviolet at a central wavelength around 13.5 nm – is being used in the EUV lithography sector, in particular.

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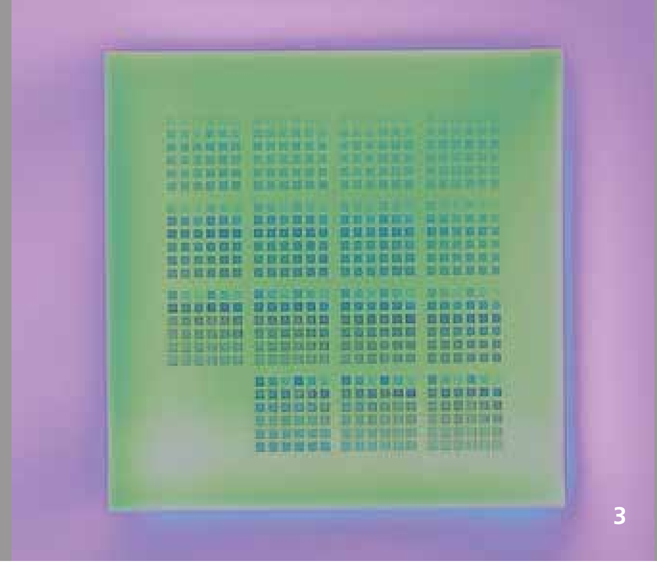
1 Source-collector system for extreme ultraviolet radiation.

2 Calculated intensity distribution with spot size of 4 mm.



CHARACTERIZATION OF HIGH-RESOLUTION EUV PHOTORESISTS FOR INDUSTRIAL APPLICATIONS

Task

High resolution and EUV-sensitive photoresists are required for the continuous reduction of structure sizes in industrial lithography with extreme ultraviolet radiation (EUV; standard wavelength: 13.5 nm). For characterization, however, suitable compact laboratory equipment is still not commonly available. To counter this, Fraunhofer ILT has developed the EUV laboratory exposure tool (EUV-LET), which enables EUV resists to be characterized in terms of sensitivity, contrast and resolution at the industrial standard wavelength of 13.5 nm.

Method

To characterize EUV resists for industrial lithography at 13.5 nm, the scientists at Fraunhofer ILT employ a multilayer mirror to spectrally filter the broadband EUV radiation of the plasma-based gas discharge source. Here, a main wavelength of 13.5 nm is applied with a relative spectral bandwidth of 4 percent. By means of a dose monitor, the pulse energy is continuously measured and used as the basis for the exposure time. The photoresist-coated wafer is located in a positioning unit, which allows a series of exposures to be made on the wafer. In addition, the mask-wafer distance can be adjusted down to an accuracy in the nm range. This way, resolution tests can be conducted in addition to simple contrast curves. For the highest possible resolution, the researchers use the method of achromatic Talbot lithography. Previously achieved resolutions are in the sub-30-nm range for hole arrangements and sub-40-nm for line arrangements.

Results

The EUV-LET is used to characterize different EUV resists with respect to contrast, sensitivity and resolution. Moreover, it enables fast and easy testing of new resist compositions at a wavelength of 13.5 nm.

Applications

This compact lithography system can be used to develop and characterize photoresists with extreme ultraviolet radiation for further use in industrial lithography.

The R&D project underlying this report has been carried out on behalf of the Federal Ministry for Economic Affairs and Energy under the funding code ZF4109602RE8.

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3 Transmission mask for resolution tests.

4 EUV laboratory exposure tool (EUV-LET).

ELECTRO-HYDRAULIC SHREDDING OF MOBILE PHONES

Task

To recover materials from electronic components, the industry must not only shred the material, but also separate out the individual elements into as identical fractions as possible. With today's common shredding – with impact crushers and subsequent metallurgical treatment – some recyclable materials can only be recovered to a small extent or not at all. The work in the ADIR project focuses on the recycling of mobile phones.

Electro-hydraulic fragmentation has already been successfully demonstrated as a well-known method for shredding electronic scrap. In this process, shock waves are generated by short, strong current pulses in water, which shred the material to be treated. In order to make this process more attractive for the throughput of large quantities, Fraunhofer ILT shall minimize the energy required to generate the shock waves.

Method

A demonstrator has been set up at Fraunhofer ILT in which the capacitively stored energy is converted in a current pulse generator of low inductance. Compared to the state of the art, the energy input has been reduced by a factor of four.

1 Components of mobile phones with exposed vibration alarms.

2 Electrohydraulic fragmentation system.

At an electrical pulse energy of only 0.3–1 kJ, current pulses in the range of 40–80 kA could be generated. This allows pressure pulses to be built up in a water spark discharge of 50–100 MPa.

Results

In initial investigations, components containing valuable substances, such as vibration alarms or loudspeakers, could be separated from the plastic housing of mobile phones. Further work is aimed, for example, at the complete disassembly of electronic circuit boards.

Applications

The electrohydraulic fragmentation with optimized energy input was carried out using the example of mobile phones, whereby an extension of the process to other types of electronic scrap is possible. In general, electrohydraulic fragmentation of composite materials, such as laminated glass, concrete or slags, is an attractive method for separating the recyclables bound in them.

The work was carried out as part of the EU project ADIR under the funding code 680449 (Next Generation Urban Mining - Automated Disassembly, Separation and Recovery of Valuable Materials from Electronic Equipment).

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FUNDING BODIES

Some joint projects presented in this annual report have been supported with public funding. We would like to express our gratitude to the public donors for their support at this point.

Bundesministerium für Bildung und Forschung

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EUROPÄISCHE UNION
Investition in unsere Zukunft
Europäischer Fonds für regionale Entwicklung

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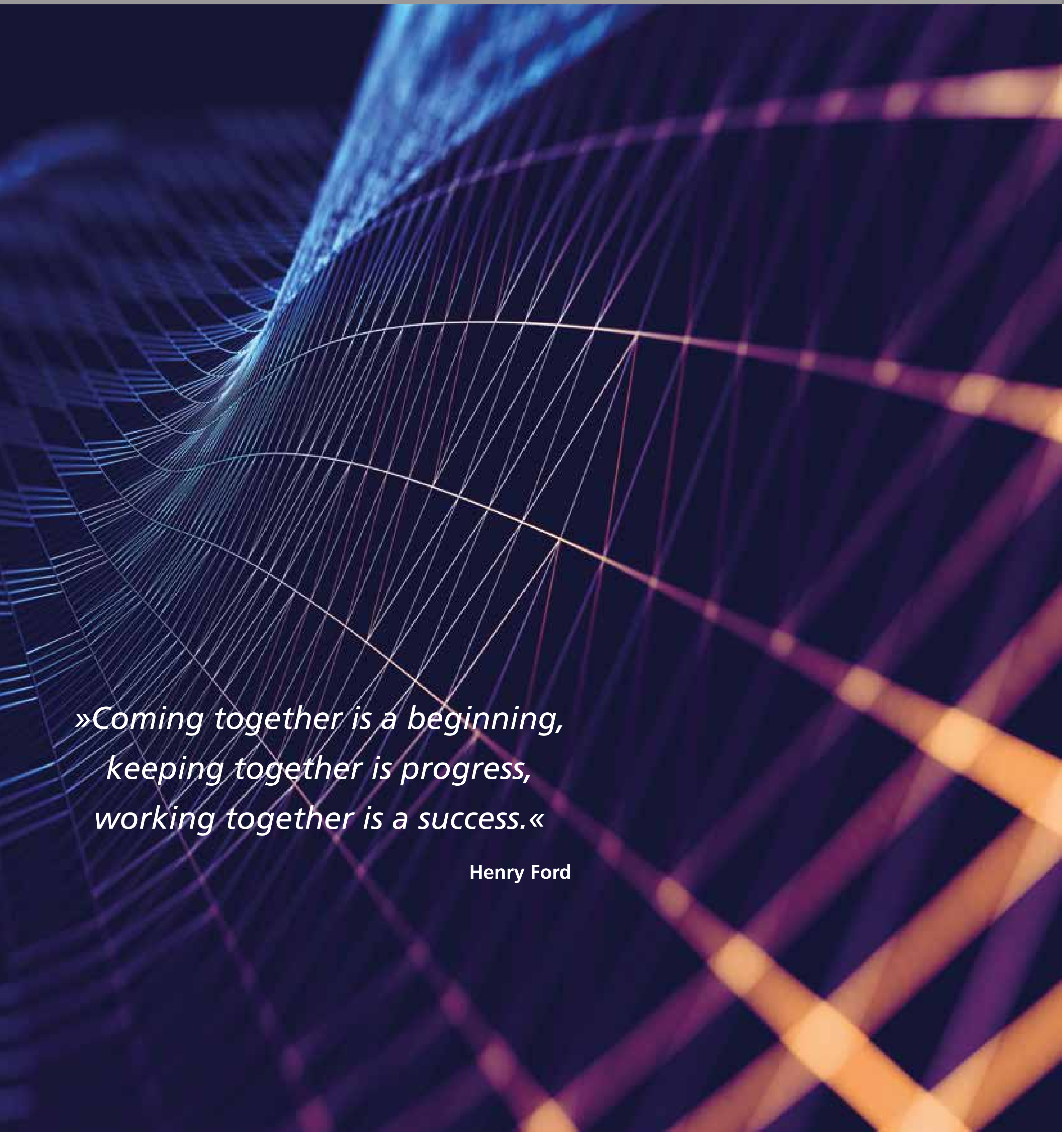
Investitionen in Wachstum und Beschäftigung

Die Landesregierung Nordrhein-Westfalen

DFG Deutsche Forschungsgemeinschaft

NETWORKS AND CLUSTERS



THE FRAUNHOFER-GESELLSCHAFT AT A GLANCE

THE FRAUNHOFER-GESELLSCHAFT

The Fraunhofer-Gesellschaft is the world's leading applied research organization. With its focus on developing key technologies that are vital for the future and enabling the commercial exploitation of this work by business and industry, Fraunhofer plays a central role in the innovation process. Based in Germany, Fraunhofer is an innovator and catalyst for groundbreaking developments and a model of scientific excellence. By generating inspirational ideas and spearheading sustainable scientific and technological solutions, Fraunhofer provides science and industry with a vital base and helps shape society now and in the future.

At the Fraunhofer-Gesellschaft, interdisciplinary research teams work together with partners from industry and government in order to transform novel ideas into innovative technologies, to coordinate and realize key research projects with a systematic relevance, and to strengthen the German and the European economy with a commitment to creating value that is based on human values. International collaboration with outstanding research partners and companies from around the world brings Fraunhofer into direct contact with the key regions that drive scientific progress and economic development.

Founded in 1949, the Fraunhofer-Gesellschaft currently operates 74 institutes and research institutions. The majority of our 28,000 staff are qualified scientists and engineers, who work with an annual research budget of 2.8 billion euros. Of this sum, 2.3 billion euros is generated through contract research. Around 70 percent of Fraunhofer's contract research revenue is derived from contracts with industry and publicly funded research projects. The remaining 30 percent comes from the German federal and state governments in the form of base funding. This enables the institutes to work on solutions to problems that are likely to become crucial for industry and society within the not-too-distant future.

Applied research also has a knock-on effect that is felt way beyond the direct benefits experienced by the customer: our institutes boost industry's performance and efficiency, promote the acceptance of new technologies within society, and help train the future generation of scientists and engineers the economy so urgently requires.

Our highly motivated staff, working at the cutting edge of research, are the key factor in our success as a scientific organization. Fraunhofer offers researchers the opportunity for independent, creative and, at the same time, targeted work. We therefore provide our employees with the chance to develop the professional and personal skills that will enable them to take up positions of responsibility at Fraunhofer, at universities, in industry and within society. Students who work on projects at Fraunhofer Institutes have excellent career prospects in industry by virtue of the practical training they enjoy and the early experience they acquire of dealing with contract partners.

The Fraunhofer-Gesellschaft is a recognized non-profit organization that takes its name from Joseph von Fraunhofer (1787–1826), the illustrious Munich researcher, inventor and entrepreneur.

FIELDS OF RESEARCH

The Fraunhofer-Gesellschaft concentrates on research in the following fields:

- Health and environment
- Security and protection
- Mobility and transport
- Production and supply of services
- Communication and knowledge
- Energy and resources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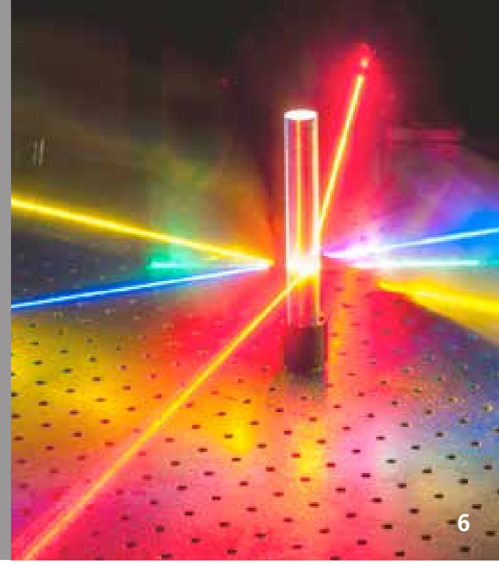
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FRAUNHOFER GROUP LIGHT & SURFACES

Competency by networking

Six Fraunhofer institutes are cooperating in the Fraunhofer Group »Light & Surfaces« in the fields of laser, optics, measurement and coating technology. Building on their basic research in the various fields of application, the institutes work together to supply fast, flexible and customer-specific system solutions in these fields. Strategy is coordinated to reflect current market requirements, yielding synergies that benefit the customer. The institutes also collaborate with their local universities to provide the full range of student education, up to and including doctoral studies. As a result, the Fraunhofer institutes are not only partners to technological development, but also a continuous source of new talents in the fields of coating technology and photonics.

www.light-and-surfaces.fraunhofer.de/en/html

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2 © Fraunhofer IOF.
3 © Fraunhofer FEP.
4 © Fraunhofer ILT.
5 © Fraunhofer IST.
6 © Fraunhofer IPM.

Core competencies of the group

The Fraunhofer institutes' competencies are coordinated to ensure that research can be quickly and flexibly adapted to the requirements of the various fields of application:

- Laser manufacturing
- Beam sources
- Metrology
- Medicine and life sciences
- Materials technology
- Optical systems and optics manufacturing
- Micro- and nanotechnologies
- Thin-film technology
- Plasma technology
- Electron beam technology
- EUV technology
- Process and system simulation

THE INSTITUTES

Fraunhofer Institute for Organic Electronics, Electron Beam and Plasma Technology FEP

Fraunhofer Institute for Organic Electronics, Electron Beam and Plasma Technology FEP works on innovative solutions in the fields of vacuum coating, surface treatment as well as organic semiconductors. The core competences electron beam technology, plasma-assisted large-area and precision coating, roll-to-roll technologies, development of technological key components as well as technologies for the organic electronics and IC/system design provide a basis for these activities. Thus, Fraunhofer FEP offers a wide range of possibilities for research, development and pilot production, especially for the processing, sterilization, structuring and refining of surfaces as well as OLED microdisplays, organic and inorganic sensors, optical filters and flexible OLED lighting. Our aim is to seize the innovation potential of the electron beam, plasma technology and organic electronics for new production processes and devices and to make it available for our customers.
www.fep.fraunhofer.de/en

Fraunhofer Institute for Laser Technology ILT

With more than 540 employees the Fraunhofer ILT develops innovative laser beam sources, laser technologies, and laser systems for its partners from the industry. Our technology areas cover the following topics: laser and optics, medical technology and biophotonics, laser measurement technology and laser material processing. This includes laser cutting, caving, drilling, welding and soldering as well as surface treatment, micro processing and additive manufacturing. Furthermore, the Fraunhofer ILT is engaged in laser plant technology, process control, modeling as well as in the entire system technology. www.ilt.fraunhofer.de/en

Fraunhofer Institute for Applied Optics and Precision Engineering IOF

The Fraunhofer IOF develops innovative optical systems to control light from the generation to the application. Our service range covers the entire photonic process chain from opto-mechanical and opto-electrical system design to the manufacturing of customized solutions and prototypes. The institute works in the five business fields of Optical Components and Systems, Precision Engineering Components and Systems, Functional Surfaces and Layers, Photonic Sensors and Measuring Systems and Laser Technology.
www.iof.fraunhofer.de/en

Fraunhofer Institute for Physical Measurement Techniques IPM

The Fraunhofer IPM develops tailor-made measuring techniques and systems for industry. In this way, the institute enables its customers to minimize their use of energy and resources, while at the same time maximizing quality and reliability. Fraunhofer IPM makes processes ecological and economical. Many years of experience with optical technologies form the basis for high-tech solutions in the fields of production control, object and shape detection, gas and process technology as well as thermal energy converters.
www.ipm.fraunhofer.de/en

Fraunhofer Institute for Surface Engineering and Thin Films IST

The Fraunhofer Institute for Surface Engineering and Thin Films IST in Braunschweig is an innovative partner for research and development in surface technology, with expertise in the associated product and production systems. The aim ist to develop customized and sustainable solutions: from prototypes, through economic production scenarios, to upscaling to industrial magnitudes – and all this whilst maintaining closed material and substance cycles. www.ist.fraunhofer.de/en

Fraunhofer Institute for Material and Beam Technology IWS

Light and layer: Fraunhofer IWS works wherever lasers and surface technology meet. The Dresden institute comes into play if the task is to deposit different materials layer by layer, to join, cut, functionalize or analyze. Services range from developing new techniques via integration into manufacturing, up to user-oriented support – in single-source responsibility. The Fraunhofer IWS is meeting the challenges of digitization with a focus on researching and developing solutions for »Industry 4.0«. www.iws.fraunhofer.de/en

STRATEGIC FRAUNHOFER-PROJECTS

FRAUNHOFER ICON-PROJECT »QFC-4-1QID«

Bringing quantum bits into the fiber optic network: Fraunhofer ICON project »QFC-4-1QID«

Transferring quantum information with glass fibers, paving the way for the quantum internet: With this goal in mind, the Dutch research center QuTech and Fraunhofer ILT launched the ICON project QFC-4-1QID on September 1, 2019. In this long-term strategic partnership between the research institutions, the scientists are initially developing quantum frequency converters for connecting quantum processors to fiber optic networks. The new technology will be used in 2022 for the world's first quantum internet demonstrator.

»ICON – International Cooperation and Networking« is a funding program the Fraunhofer-Gesellschaft launched to bring top international researchers together. Fraunhofer ILT, QuTech – the Research Center for Quantum Technologies at Delft University of Technology – and the Netherlands Organization for Applied Scientific Research TNO began collaborating within the framework of the project »Low-Noise Frequency Converters for the First Quantum Internet Demonstrator – QFC-4-1QID-«.

Quantum-frequency converter for customized photons

Quantum computers provide us with the opportunity to execute highly complex calculations and algorithms in the shortest possible time, thus revolutionizing current information technology. In the future, several quantum computers can be connected in a quantum internet in a tap-proof way and new technologies such as distributed quantum computing can be used.

In the ICON project QFC-4-1QID, the partners are developing technologies that allow the wavelength of individual photons to be converted selectively without affecting the quantum information. The aim is to subsequently transmit the photons through optical fibers with low loss and to couple qubits – the smallest computing units of a quantum computer – over long distances.

A major challenge is the design of appropriate quantum-frequency converters with a high overall efficiency. This involves converting photons from nitrogen defects in diamond at a wavelength of 637 nm. For long-distance connections with the lowest possible transmission losses, photons entangled with the qubits must be generated at wavelengths in the telecommunication bands in the range between 1500 and 1600 nm.

On the way to quantum internet

The world's first quantum internet demonstrator is to connect four cities in the Netherlands in 2022. With the QFC-4-1QID project, the Fraunhofer-Gesellschaft is helping provide the technological requirements for the first quantum internet and positioning itself as an international research partner in the field of new quantum technologies.

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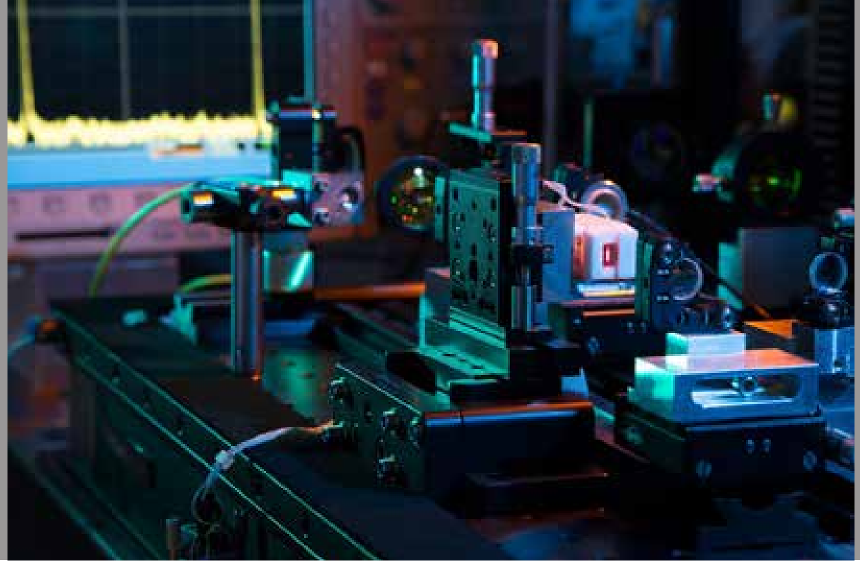
Sources and further information are available on the Internet at www.ilt.fraunhofer.de/de/technologiefelder/quantentechnologie.html (English version will follow).



ICON-Project QFC-4-1QID: OPO as concept study of a low-noise quantum frequency converter.

FRAUNHOFER LIGHTHOUSE PROJECT »futureAM«

With »futureAM«, the Fraunhofer-Gesellschaft is systematically promoting the further development of additive manufacturing of metallic components. For this purpose, six experienced institutes in the field of additive manufacturing have entered into a strategic project partnership:

- Fraunhofer Institute for Additive Production Technologies IAPT, Hamburg
- Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM, Bremen
- Fraunhofer Institute for Computer Graphics Research IGD, Darmstadt
- Fraunhofer Institute for Laser Technology ILT, Aachen
- Fraunhofer Institute for Material and Beam Technology IWS, Dresden
- Fraunhofer Institute for Machine Tools and Forming Technology IWU, Chemnitz

Strategic goals of the project partnership

1. Development of a comprehensive cooperation platform for the highly integrated cooperation and use of the distributed resources of the Fraunhofer-Gesellschaft in the field of Additive Manufacturing (AM)
2. Creation of the technological prerequisites that will increase scalability, productivity and quality of AM processes for the production of individualized metal components

Fields of activity

To ensure technological leadership, additive manufacturing will be systematically developed in four fields of activity coordinated by one institute each:

- Industry 4.0 and digital process chain
- Scalable and robust AM processes
- Materials
- System engineering and automation

There are many examples of the ambitious project goals in the four fields: novel software for automated AM component identification and optimization, a scalable SLM system design with productivity increase (factor > 10), a method and system technology for generating spatially resolved, customized multi-material properties and an autonomous manufacturing cell for the post-treatment of AM components.

Not only will the institutes cooperate intensively on the four fields of activity, they will also establish a »Virtual Lab«, which digitally maps the competences and resources of the project partners. Using this, all of the project partners will participate in developing technology demonstrators.

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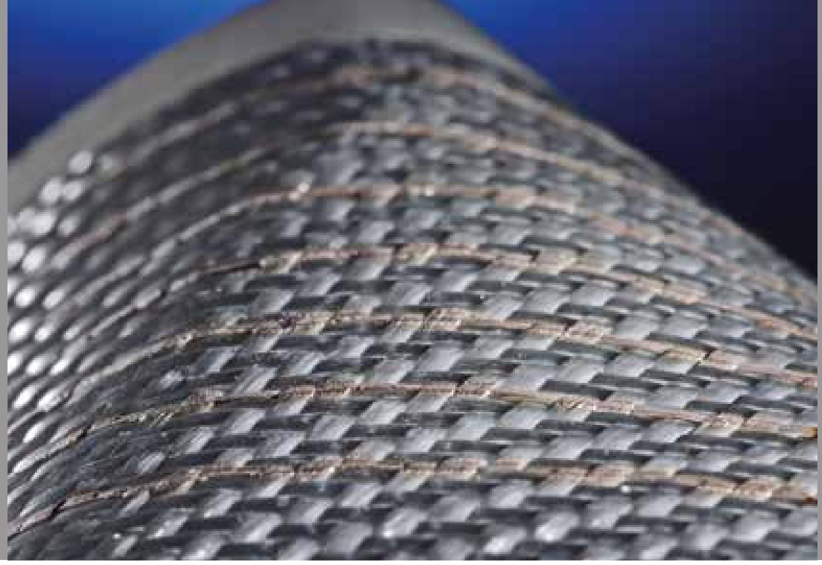
www.futuream.fraunhofer.de/en.html

FRAUNHOFER ALLIANCES AND CENTERS OF EXCELLENCE



Additive manufacturing of electrical functional layers in fiber composite componets.

FRAUNHOFER LIGHTHOUSE PROJECT »GO BEYOND 4.0«

The six Fraunhofer Institutes ENAS, IFAM, ILT, IOF, ISC and IWU have succeeded to manufacture electrical conductor patterns, sensors, and high-tech lighting modules, individually integrated into components by using digital printing and laser technologies. The result: individualization of components in mass production environments with new opportunities for design, material savings and weight reduction.

In a short video about the lighthouse project »Go Beyond 4.0« (available online: www.ilt.fraunhofer.de/en/media-center/video-audio/centers.html), the feasibility of combining digital printing, laser processing and further latest production technologies is pictured based on the three technology demonstrators »Smart Door« - manufacturing domain automotive engineering, »Smart Wing« – production domain aviation and »Smart Luminaire« – production domain lighting.

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www.ilt.fraunhofer.de/en/clusters.html

FRAUNHOFER ALLIANCES

Institutes or departments of institutes with different competences cooperate in Fraunhofer alliances in order to jointly process and market an industrially relevant business field. Fraunhofer ILT is involved in the following seven Fraunhofer alliances:

- Batteries
- Generative production
- Lightweight construction
- Nanotechnology
- Numerical simulation of products, processes
- Space
- SysWater

CENTERS OF EXCELLENCE

Centers of excellence help close the ranks between university and non-university research with the industry. Moreover, they are characterized by the participating partners following binding, continuous roadmaps in the areas of research and teaching, promotion of young researchers, infrastructure, innovation and transfer. They are an offer to politics to prioritize scientific excellence with social benefits. Fraunhofer ILT is involved in the Center of Excellence »Networked Adaptive Production«, which is coordinated by Fraunhofer IPT in Aachen and is one of 15 centers of excellence of the Fraunhofer-Gesellschaft in Germany.

Fraunhofer Center of Excellence for »Networked Adaptive Production« in Aachen

This center focuses on developing, systematically introducing and using modern digitization technologies for sustainable, industrial production systems and value chains in the context of »Industry 4.0«. As part of an overarching R&D module »Digitization and Networking«, the Center of Excellence develops the concept of fully networked, adaptive production in the fields of »Smart Manufacturing Platforms«, »Big Data«, »Adaptive Process Chains« and »Process Simulation and Modeling«. All of the developments are validated and demonstrated in six pilot lines in the fields of energy, mobility and health using representative process chains. The connection to the Fraunhofer Cloud System »Virtual Fort Knox« represents a neutral and secure platform for the storage of production data and execution of web services to analyze and optimize process chains. The close cooperation with well-known industrial companies ensures that the results can be transferred to an industrial environment.

The task of the center of excellence is to design an open research platform and test environment for the industry within a period of three years, one in which new concepts of digitalized production can be researched and tested in practice. Fraunhofer ILT is covering the following areas:

- Digital process chains for the laser-based repair of turbomachinery components
- Networking of conventional and laser-based processes in tool construction
- Model-based process development and evaluation of flexible interconnection concepts for battery module production using laser beam welding

»ICNAP« – International Community for the Development of Applications and Technologies for Industry 4.0

The work within the community of the International Center for Networked, Adaptive Production (ICNAP) aims to make demanding value chains for the production of complex and individualized products much more flexible and efficient.

The ICNAP represents a continuation of the research work in the center of excellence with the active participation of the industry. High-performance partners from IT system providers, plant manufacturers and manufacturing companies have already agreed to continue their cooperation.

The challenge is not merely the continued development of manufacturing processes. Rather, the community will demonstrate and validate the possibilities of digitization and networking for the most diverse technical products, processes and corporate networks.

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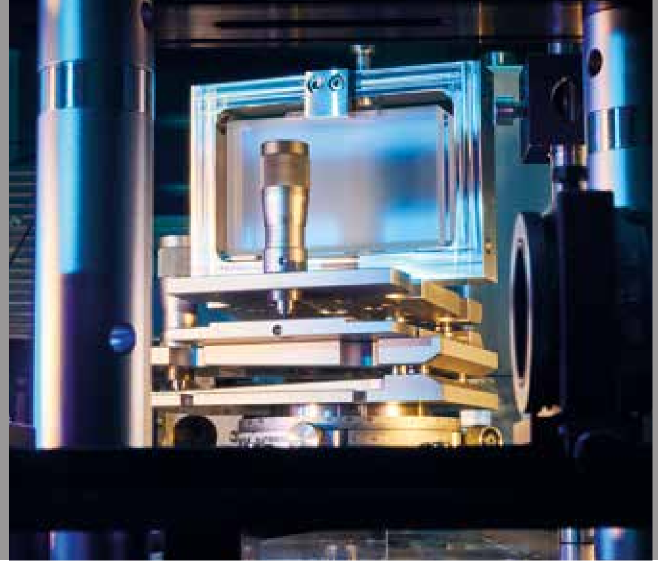
FRAUNHOFER CLUSTER OF EXCELLENCE

Setup for non-linear pulse compression.



Compression grating to generate the highest pump energies by means of CPA.

ADVANCED PHOTON SOURCES CAPS

With the Fraunhofer Cluster of Excellence »Advanced Photon Sources CAPS«, the Fraunhofer-Gesellschaft launched an ambitious project in May 2018. Its aim is to achieve international technological leadership in laser systems that achieve the highest performance with ultrafast pulses (UKP) and to research their potential applications in collaboration with Fraunhofer partners. The new systems will exceed all existing UKP lasers by one order of magnitude in average laser power. At the same time, the partners are working on the necessary system technology and possible applications in industry and research.

CAPS – a strong Fraunhofer network

At present 13 Fraunhofer Institutes jointly develop a new generation of extremely high-power ultrafast lasers. New fields of application are to be opened up, ultra-precise manufacturing processes in the industrial environment scaled and new pulse duration and wavelength ranges made available for research. The Fraunhofer Institute for Laser Technology ILT in Aachen and the Fraunhofer Institute for Applied Optics and Precision Engineering IOF in Jena coordinate the cluster.

UKP lasers for high-precision applications

UKP lasers generate extremely high intensities in the focus even at comparatively low pulse energies. For a long time, however, they were only used in basic research. The development of highly efficient, powerful pump diodes has made it possible to use new laser media, especially ytterbium-doped fibers and crystals. In recent years, UKP lasers based on this technology have achieved average laser powers and a robustness that can also be used for industrial applications.

UKP lasers have two major advantages for micro material processing applications: On the one hand, they can process practically all materials; on the other, the ablation is particularly precise and therefore gentle, as the ultrafast interaction means that hardly any heat remains in the adjacent material. This is why these lasers were interesting for medical technology at an early stage, for example for eye operations using the Femto-LASIK process.

Advanced Photon Sources – UKP lasers with beam powers in the kW range

The power of current UKP lasers in the 100 W class is often insufficient with regard to economically justifiable processing speeds when ultra-hard ceramic materials and fiber-reinforced plastics are cut. Driven by the application potential in industry and the need for basic research, the partners in the cluster have set themselves the goal of increasing the average output of the UKP sources at the Fraunhofer Institutes ILT and IOF up to the 10 kW range.

Application laboratories for industry and science

A major goal of the research cluster is the early work on various applications. For this purpose, the coordinating Fraunhofer institutes – IOF in Jena and ILT in Aachen – provide two application laboratories with several kW-USP laser sources and the necessary system technology. The application laboratory at Fraunhofer ILT, which opened on September 17, 2019, is located directly next to the laser development laboratory and equipped with a separate beam source. This allows parallel experiments to be prepared and carried out in three different rooms. In 2019, a source with 500 W, pulse energies of up to 1 mJ and pulse durations of less than 100 fs will initially be available, which will be expanded to 2.5 kW (5 mJ) by mid-2020. The laboratories of the User Facility are available to industrial partners for application studies. They can draw on the expertise of the various Fraunhofer partner institutes.

Broad spectrum of applications

In application development, research aims to investigate new processes and help known processes to achieve industrially relevant throughputs. Examples range from the microstructuring and surface functionalization of solar cells, ultra-hard ceramics and battery components to the cutting of glass and lightweight construction materials. In addition to breakthroughs in ultra-precise manufacturing with high productivity, the new USP sources will be used to generate coherent radiation into the soft X-ray range. The targeted photon fluxes are two to three orders of magnitude higher than those achieved so far. This is intended to establish applications in the materials sciences such as the generation and investigation of novel materials. In addition, new possibilities are opening up for the semiconductor sector, lithography or the imaging of biological samples.

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Further information on the Internet at:
www.caps.fraunhofer.de

LASER TECHNOLOGY AT RWTH AACHEN UNIVERSITY

© RWTH Aachen University / Peter Winandy.

JOINTLY SHAPING THE FUTURE

The RWTH Aachen University Chairs for Laser Technology LLT, the Technology of Optical Systems TOS and Digital Additive Production DAP as well as Nonlinear Dynamics of Laser Processing NLD represent an outstanding cluster of expertise in the field of optical technologies. This permits supercritical treatment of basic and application-related research topics. The close cooperation with the Fraunhofer Institute for Laser Technology ILT not only permits industrial contract research on the basis of sound fundamental knowledge, but also provides new stimuli for the advanced development of optical methods, components and systems. The synergy of infrastructure and know-how is put to active use under a single roof.

This structure particularly benefits up-and-coming young scientists and engineers. Knowledge of current industrial and scientific requirements in the optical technologies flows directly into the planning of the curriculum. Furthermore, undergraduates and postgraduate students can put their theoretical knowledge into practice through project work at the chairs and at Fraunhofer ILT. University courses are drawn up jointly as well. Teaching, research and innovation – those are the bricks with which the four university departments and Fraunhofer ILT are building the future.

Chair for Laser Technology LLT

The RWTH Aachen University Chair for Laser Technology has been engaged in basic and application-oriented research and development in the fields of laser measurement technology, development of beam sources, laser material processing as well as digital photonic production since 1985.

A great part of the research activities is carried out in the framework of some big projects as e.g. the Cluster of Excellence »Integrative Production Technology for High-Wage Countries«, the BMBF Digital Photonic Production Research Campus and the Collaborative Research Center SFB 1120 »Precision Melt Engineering«. Furthermore, the Chair for Laser Technology is coordinator of the »Research Center for Digital Photonic Production«.

Present topics of research:
- Interaction of ultra-short pulsed laser radiation with the material in ablation, modification, drilling or melting
- Future concepts for beam sources such as direct diode-pumped Alexandrite laser or EUV radiation by means of ultrashort pulses
- Integration of optical measuring processes for quality control in Additive Manufacturing
- New concepts for innovative laser-based processing and strategies

Prof. Constantin Häfner (Director of the chair since 1.10.2019)
www.llt.rwth-aachen.de

Chair for Technology of Optical Systems TOS

By establishing the Chair for Technology of Optical Systems in 2004, RWTH Aachen accorded recognition to the increasingly central role of highly developed optical systems in manufacturing, the IT industries and the life sciences. Research activities focus on the development and integration of optical components and systems for laser beam sources and laser devices.

Highly corrected focusing systems for a high laser output, beam homogenization facilities and innovative beam shaping systems are all key components of laser systems used in production engineering. The performance of fiber lasers and diode-pumped solid state lasers, for instance, is determined by optical coupling and pump light homogenizers. Free-form optics for innovative laser beam shaping are yet another topic of research. In the area of high-power diode lasers, micro- and macro-optical components are developed and combined to form complete systems. In addition, assembly techniques are optimized.

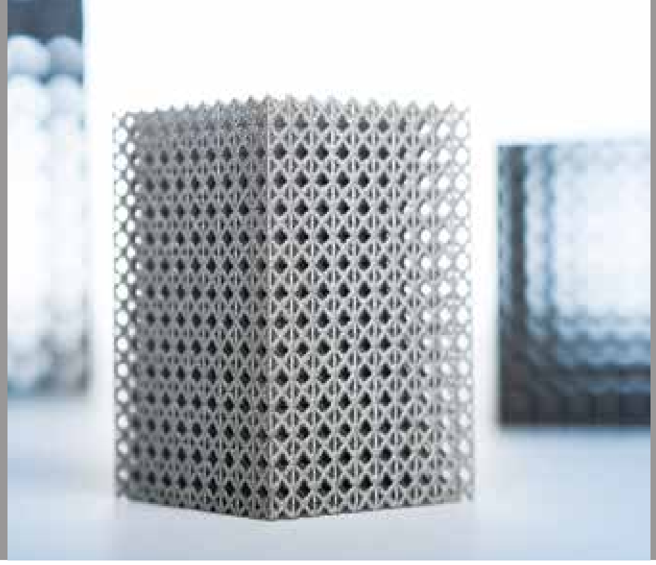
Prof. Peter Loosen (Director of the chair)
www.tos.rwth-aachen.de

Chair for Digital Additive Production DAP

The Chair for Digital Additive Production DAP together with industrial and scientific partners, researches the fundamental interrelationships of Additive Manufacturing (AM) from construction design to supply chains, production and component handling all the way to the operational properties of additively manufactured components. In addition, they focus their developments on accompanying processes such as design, quality management, mapping of the entire digital process chain and factory planning. Within the framework of basic, composite and industrial projects from a variety of industries such as automotive, aerospace, turbomachinery, life sciences, electronics, tool and mold making, as well as close cooperation with non-university research institutes, DAP has extensive expertise both in terms of software and hardware.

In addition to developing existing AM processes as well as existing machine and system technology, DAP focuses an essential part of its work on software-driven end-to-end processes. This way it can harness the advantages of additive processes, for constructing bionic lightweight components, optimizing functions for AM, designing »digital materials« all the way to validating in the real process.

Prof. Johannes Henrich Schleifenbaum (Director of the chair)
www.dap.rwth-aachen.de



Nonlinear Dynamics of Laser Processing Instruction and Research Department NLD

Founded in 2005, the Nonlinear Dynamics of Laser Processing Instruction and Research Department NLD explores the basic principles of optical technology, with emphasis on modeling and simulation in the fields of application macro welding and cutting, additive manufacturing, precision processing with ultrafast lasers and PDT in dentistry and dermatology.

Mathematical, physical and experimental methods are being applied and enhanced to investigate technical systems. The application of mathematical models is helping to achieve a better understanding of dynamic interrelationships and to create new process engineering concepts. The results of these analyses are made available to industrial partners in the form of practical applications in collaboration with the Fraunhofer Institute for Laser Technology ILT.

The main educational objective is to teach a scientific, methodological approach to modeling on the basis of practical examples. Models are derived from the experimental diagnosis of laser manufacturing processes and the numerical calculation of selected model tasks.

Prof. Wolfgang Schulz (Head of the department)
www.nld.rwth-aachen.de

Department of High Power Processes in Production Engineering and Additive Manufacturing at the FH Aachen

At the end of August 2019, Prof. Dr. Andreas Gebhardt retired from the Aachen University of Applied Sciences; he handed over his department »High Power Processes in Production Engineering and Additive Manufacturing« in the Department of Mechanical Engineering and Mechatronics to the long-standing expert for 3D printing, Sebastian Bremen, from Fraunhofer ILT on September 1, 2019. In the summer semester 2016, Sebastian Bremen received his first teaching assignments for laser technology and rapid prototyping at Aachen University of Applied Sciences and has since expanded his expertise in this field.

In 2013, Aachen University of Applied Sciences and the Fraunhofer ILT founded the Aachen Center for 3D Printing to jointly develop the future of additive manufacturing. Fraunhofer ILT and the Aachen University of Applied Sciences renewed this cooperation agreement in early 2019. Together they operate a laser powder bed fusion (LPBF) system, which is currently the world's largest commercial system for LPBF. Both institutions use this LPBF system to further develop metallic 3D printing. Prof. Bremen continues to head the Aachen Center for 3D Printing, thus continuing to foster the link between FH Aachen and Fraunhofer ILT.

Prof. Sebastian Bremen (Head of the department)
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DIGITAL PHOTONIC PRODUCTION DPP

Digital Photonic Production – the Future of Production

By taking up the topic of digital photonic production, Fraunhofer ILT is dedicating itself to a field that is central to tomorrow's production techniques. Digital photonic production permits the direct production of practically any component or product on the basis of digital data. Techniques that were developed over ten years ago for rapid prototyping are evolving into rapid manufacturing techniques for the direct production of functional components. Rapid manufacturing techniques have already been used in an initial batch of facilities for industrial production in the automotive construction and aviation industries. In the process, lasers are taking on a central role as the tool of choice thanks to their unique properties. No other tool can be applied and controlled with comparable precision.

Mass Customization

Digital photonic production goes far beyond laser-based additive manufacturing processes. New high-output ultrafast lasers, for example, can achieve very fast ablation almost regardless of material – allowing the finest of functional 3D structures to be produced down to the nanometer region. This new technology is seen by some as heralding a new industrial revolution. And the potential of this revolutionary technology lies above all in the way it fundamentally changes costing parameters in laser-based manufacturing techniques. In contrast to conventional techniques, using lasers makes manufacturing cost-effective both for small batch sizes and for the tiniest of complex products, using a wide variety of materials and featuring the most complex of geometries.

If they are to make full use of the potential of digital photonic production, industrial process chains must be considered in their entirety. These chains must be thoroughly redesigned, taking into account upstream and downstream manufacturing steps, component design, and accompanied by completely new business models such as mass customization or open innovation.

Digital Photonic Production Research Campus

The BMBF Digital Photonic Production Research Campus in Aachen enables just such a holistic view. As part of the German Federal Ministry of Education and Research BMBF's »Research Campus – Public-Private Partnerships for Innovation« funding initiative, the Aachen campus will receive lasting support in the form of up to 2 million euros in annual funding over the next 15 years.

In 2012 the Chair for Laser Technology LLT at RWTH Aachen University emerged from the national competition as one of nine winners, having coordinated a proposals consortium. This new initiative sees more than 30 companies and scientific institutes working together under one roof on questions of fundamental research, with new partners joining all the time. The Digital Photonic Production Research Campus in Aachen offers local industry and science a skilled and responsive instrument with which to shape the future of production technology.

RWTH AACHEN CAMPUS

RWTH AACHEN CAMPUS

aking its lead from the Stanford University and Silicon Valley model, the RWTH Aachen University is creating one of Europe's largest technology-oriented campuses over a total area of approximately 2.5 km², making it one of the leading national and international knowledge and research centers. It is located at the former university extension site in Aachen Melaten along with part of the Aachen Westbahnhof (Aachen West Train Station). For the first time, the core areas of the RWTH Aachen University will be connected – in the city center, in the Hörn district and in Melaten – to create an integrated campus.

Research catalyst and innovation generator

The RWTH Aachen Campus offers a groundbreaking symbiosis between industry and university education in the form of »university enrolment« for staff at locally based companies – an unrivalled combination in Germany. This enables companies to actively participate in centers which demonstrate the operative units of the cluster to cooperate in their areas of interest in an interdisciplinary and consortial way. At the same time, it ensures access to qualified young staff and facilitates accelerated and praxis-based PhD programs.

Interested companies can relocate to the RWTH Aachen Campus by leasing or building their own space. This proximity generates a unique, more intensive form of collaboration between university and business; no other university in Europe currently boasts a greater number of major application-oriented institutes than the RWTH Aachen University. An integrated concept underpins the entire project: research, learning, development, living.

The RWTH Aachen Campus creates an ideal, prestigious working environment for more than 10,000 employees, with research institutions, offices and training centers. The campus also offers a superb quality of life, through hotel and living accommodations, top-class restaurants, shopping facilities, childcare facilities and a range of service and relocation organizations.

Development and timetable

The RWTH Aachen Campus will be created in several stages. The first stage was started in 2010 with the development and construction of Campus Melaten with its six clusters – one is the Photonics Cluster coordinated by Fraunhofer ILT. In detail the clusters are:

- Bio-Medical Engineering Cluster
- Sustainable Energy Cluster
- Photonics Cluster
- Production Technologies Cluster
- Heavy Duty & Off-Highway Powertrain Cluster
- Smart Logistics Cluster

At the moment, the university is concentrating on the next thematic cluster, which will see the development of Campus Westbahnhof with four clusters and focus on the growth of 16 clusters in Melaten and the Westbahnhof. The infrastructure, for example, will be upgraded by the construction of a congress hall, library and hotels. The relevant future topics for industry and society will be tackled in all 16 clusters.

Further information can be found at: www.rwth-campus.com/en

PHOTONICS CLUSTER

The Photonics Cluster, one of six initial research clusters on the RWTH Aachen Campus, researches and develops methods to produce, shape and use light, in particular as a tool for industrial production. In comparison to other tools, the laser beam can be more precisely modulated and controlled. The Photonics Cluster was initiated by Prof. Poprawe (Director of Fraunhofer ILT until the end of September 2019). The cluster's large premises offers sufficient space for, on the one hand, scientific institutions to cooperate in an interdisciplinary manner and, on the other, for companies to strategically collaborate with Fraunhofer ILT and the associated chairs of the RWTH Aachen University. In this respect, the Photonics Cluster is the consequent development of the Fraunhofer ILT User Center, which has existed since 1988; in it around 10 companies, as guests, worked in close collaboration with Fraunhofer ILT in their own offices and laboratories.

The first building in the Photonics Cluster – the Industry Building Digital Photonic Production – was ceremoniously inaugurated during the International Laser Technology Congress AKL'16 on April 28, 2016, with more than 500 experts from laser technology and 100 guests from science, business and politics. The keys were handed over between the private-sector investor Landmarken AG with the KPF architects team and Fraunhofer ILT. The guests were able to visit the new DPP building with about 7,000 square meters of research and office space. The building had already been occupied by about 20 companies as well as R&D teams of Fraunhofer ILT and the Chair for Laser Technology at RWTH Aachen University.

2019 saw a further infrastructure project open: the Research Center Digital Photonic Production DPP, funded by the federal government and the state of NRW for interdisciplinary cooperation in the field of digital photonic production. The topping-out ceremony of the new building took place on May 24, 2016 in the presence of Thomas Rachel, congressman and state secretary of the Federal Ministry of Education and Research (BMBF) and Prof. Ernst Schmachtenberg, the former rector of RWTH Aachen University. On an area of 4,300 square meters, 16 institutes of the RWTH Aachen University from 6 faculties tackle the interdisciplinary and integrated research of digital photonic production chains.

The two buildings, the Research Center Digital Photonic Production and the Industry Building Digital Photonic Production, form the basis for the BMBF funded Research Campus DPP. At the moment more than 20 partners from industry can do research under one roof at the Research Campus DPP. These include large companies such as TRUMPF, MTU or Siemens as well as medium-sized companies and spin-offs of Fraunhofer ILT. The Photonics Cluster is thus the ideal spring board for research and development, education and training, innovation and networking in the field of optical technologies.

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1 3D sketch of the Photonics Cluster building (source: KPF, New York).

PHOTONICS CLUSTER

RESEARCH CENTER DPP

Research Center Digital Photonic Production

Inter- and transdisciplinary networking of different research areas is key to shortening innovation cycles. Here, the Excellence Cluster »Integrative Production Technology for High-Wage Countries« was already a major step forward. Scientists from various institutes and professorships at RWTH Aachen University research different topics for a common goal over a relatively long period of time. The scientists and infrastructure are located at the respective institutes and chairs, and at present, they exchange information and results in temporary intervals. However, in order to allow an even more effective networking of the different research disciplines and the scientists involved, they should be located in a common place for a longer period of time.

In 2014, institutes and chairs from six faculties at RWTH Aachen University, headed by the Chair for Laser Technology LLT, received funding for the construction of the »Research Center Digital Photonic Production RCDPP«. Construction, first-time installation and large-scale equipment with a total volume of approx. 55 million euros have been financed by the federal government and state of North-Rhine Westphalia, each covering 50 percent.

In the building of the Research Center DPP scientists are able to conduct basic research in the field of photonics on about 4,300 square meters of usable floor area, including 2,800 square meters of laboratory, clean room and hall areas.

The institutes and chairs currently involved are from six faculties at RWTH Aachen University: Engineering, Mathematics, Computer Science and Natural Sciences, Electrical Engineering and Information Technology, Geo Resources and Materials Engineering, as well as Medicine and Economics. This way, project-related interdisciplinary working groups can form and research, for example, new materials for 3D printing. Material scientists, together with experts for laser processes, beam sources or plant engineering, can coordinate the relevant building blocks in joint experiments and shorten innovation cycles.

Other key areas include, among others, adaptive manufacturing of complex optical systems, direct photonic ablation with high ablation rates, ultra-precision processing, EUV beam sources, high-performance ultra-short pulse lasers, medical technology, biotechnology and quantum technology.

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INDUSTRY BUILDING DPP

Industry Building Digital Photonic Production

In the immediate vicinity of the Fraunhofer Institute for Laser Technology ILT and the associated chairs – LLT, TOS, DAP and NLD – at the RWTH Aachen University, companies in the Industry Building Digital Photonic Production can set up strategic partnerships to develop new components, systems, process chains or business models in the field of optical technologies, especially for production technology. Joint research and development forms the basis for these long-term cooperations. Here, it does not matter whether a company as a legal person, a specifically selected R&D team or several doctoral students from within its own ranks set up shop on this location. Facilities such as laboratories and offices can be rented by private operators, who benefit from this cooperation due to the proximity to the experts of Fraunhofer ILT and the associated RWTH Aachen University chairs, which also have their own premises on site. In open-space structures and shared labs, mixed teams from industry and science can interact and inspire each other. The »enrollment of companies« at the RWTH Aachen University is also a very efficient way of providing initial and further education as well as access to on-site scientific events.

In addition to individual companies, major initiatives such as the Research Campus DPP, funded by the Federal Ministry of Education and Research (BMBF) or centers of the Photonics Cluster such as ACAM – Aachen Center for Additive Manufacturing – are located in the Industry Building DPP with approx. 7,000 square meters of usable floor space. For example, in the Research Campus DPP, companies can develop new processes for additive manufacturing or nanostructuring of smart products, in close coordination with the players involved, or carry out process optimization for 3D printing technologies, which they test in pilot plants..

Partners from Industry

- Access e.V.
- AixPath GmbH
- AMPHOS GmbH
- BMW AG
- EdgeWave GmbH
- Exapt Systemtechnik GmbH
- EOS GmbH
- Innolite GmbH
- LightFab GmbH
- ModuleWorks GmbH
- MTU Aero Engines AG
- Pulsar Photonic GmbH
- Siemens AG
- SLM Solutions GmbH
- TRUMPF Laser- und Systemtechnik GmbH
- TRUMPF Photonic Components

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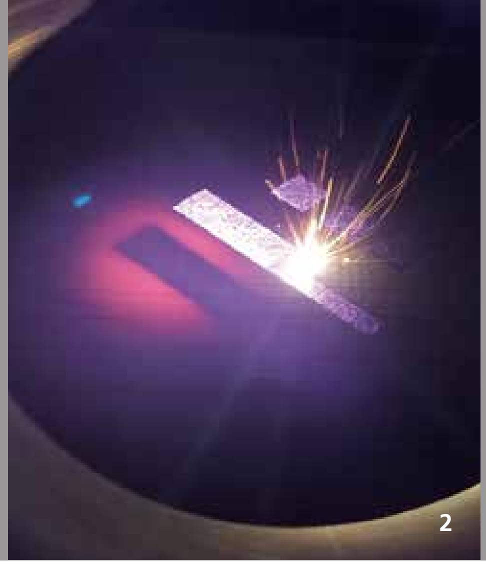
1 Research under one roof: Research Center Digital Photonic Production RCDPP, sketch: Carpus+Partner.

2 Industry Building DPP in the Photonics Cluster on the RWTH Aachen Campus.

RESEARCH CAMPUS DPP



RESEARCH CAMPUS DIGITAL PHOTONIC PRODUCTION DPP

Goals and tasks

The Research Campus »Digital Photonic Production DPP« in Aachen is a location where scientists can explore new methods and basic physical effects in order to use light as a tool in the production of the future. Thanks to the BMBF funded Research Campus DPP, RWTH Aachen University, the Fraunhofer-Gesellschaft and industry can establish a new form of long-term and systematic cooperation that aims to concentrate the various resources under one roof for joint, complementary application-oriented basic research. This is made possible by a new building on the RWTH Aachen Campus: the Industry Building DPP. Here the partners from business and science can research together on about 7,000 square meters of office and laboratory space under one roof as part of the Research Campus DPP.

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Road mapping process

The collaboration of the two Fraunhofer Institutes ILT and IPT and the around 20 industrial companies is defined in jointly agreed technology roadmaps. Alongside the technology roadmaps, the partners are exploring basic aspects of light generation (e.g. modeling of ultra-short pulse resonators), new possibilities of light guiding and shaping (e.g. modeling of free-form optics) and physical models for the interaction of light, material and functionality (e.g. modeling of load-optimized additively manufactured structures).

Joint working groups

The cooperation at the Research Campus DPP is organized along the technology roadmaps in joint working groups with scientists from the scientific community and the industry. The following five working groups have been established:

- DPP Direct
- DPP Femto
- DPP Nano
- DPP MaGeoOptics
- DPP Digital Photonic Process Chain

DPP Direct

The additive manufacturing process Laser Powder Bed Fusion (LPBF) allows the direct, tool-free production of functional components with serial-identical properties. In addition to the high resource efficiency, the tool-less production of complex components is particularly noteworthy. They can be produced quickly and comparatively inexpensively in small numbers. Likewise, functionally and weight-optimized components for new products with improved properties can be built cost-effectively. The LPBF process is increasingly used in industries such as dental technology, toolmaking, power engineering, automotive engineering and aircraft construction.

DPP Femto

With the relatively new ultra-short pulse lasers (UKP lasers), new functionalities can be created on components made out of different materials. However, the fundamental connections between the interaction between UKP laser light and modern functional materials of the digital world have not yet been sufficiently researched. The partners in the network project DPP Femto aim to analyze these complex relationships in detail and, thus, open up new horizons for this laser technology in the processing of electronic components, such as in display making or the production of modern LEDs.

DPP Nano

In order to carry out localized, timed, precisely applied heat treatment, researchers have been developing and testing new laser beam sources (such as, for example, VCEL lasers), optical systems and algorithms. Their aim is to produce tailor-made, material-matched light distributions. These new applications are being developed in the industry (e.g. by the functionalization of surfaces based on nanoparticulate materials), which increases the productivity of heat treatment processes (e.g. laser hardening) as well as the application spectrum (e.g. the production of complex components from composites).

DPP MaGeoOptics

The aim of the research project »MaGeoOptics« is to significantly increase the performance of current beam guidance systems by using high-quality optics, novel materials and more complex geometries. For this purpose, research is designing and qualifying new pressing processes for quartz glass, developing software and processes with innovative machining kinematics for diamond optics and using suitable metrological methods of non-contact optical inspection. As a result, complex geometries – for example, array structures with aspherical individual geometries – can be produced in quartz glass cost effectively.

DPP Digital Photonic Process Chain

The high energy density in the laser focus can be used to either selectively ablate or melt material. Thus, the smallest structures can be inserted into the surface of components for technical functions or design purposes. Modeling the sophisticated structures is very complex, thus costly, with common CAD/CAM systems. Therefore, a digital infrastructure has been created to utilize procedurally described structures for photonic manufacturing processes. The results are implemented in CAx libraries for path calculation and then integrated into conventional CAM software products.

Start of the second funding phase in 2020

The development of the Research Campus DPP has been supported by the Federal Ministry of Education and Research since 2014 within the funding initiative »Research Campus - Public-Private Partnership for Innovation«. At the end of 2019, the Research Campus DPP was evaluated by an independent jury and recommended for a second five-year funding phase. From spring 2020, the research campus will enter the second funding phase with 31 partners and continue using its advanced and agile management system.

1 Meeting space in the light-flooded atrium of the Industry Building DPP.
2 DPP Nano: Selective preheating by means of VCSEL in Laser Powder Bed Fusion (LPBF).

SPIN-OFFS

Networks and infrastructure

Together with the Digital Photonic Production Research Campus, funded by the Federal Ministry of Education and Research (BMBF), and the RWTH Aachen Campus, Fraunhofer ILT offers an ideal environment for setting up a company in the field of photonic production. Fraunhofer ILT acts as a know-how partner, who is more or less – depending on the cooperation agreement – involved in the development of new technologies. Through appropriate license agreements, the spin-offs also have access to those patents that, for example, the founders have themselves obtained while at Fraunhofer ILT.

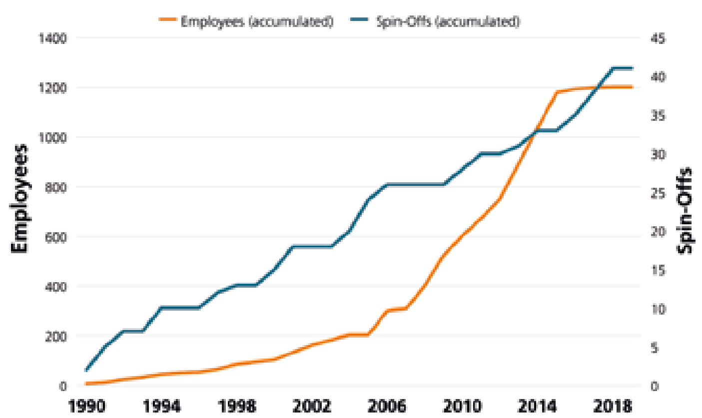
The DPP Research Campus forms the platform for intensive exchange with companies, institutes and consultants involved in the field of photonic production. Co-creation areas and open innovation concepts are also used at the research campus when required. In the DPP Industry Building on the RWTH Aachen Campus site, founders can rent their own offices and laboratories on 7,000 square meters of floor space. Thirty companies have already established themselves here, including research groups from major corporations such as Siemens, TRUMPF or MTU. The entire environment of the campus acts as an incubator for successful business spin-offs.

Supporting services

In addition to the publicly funded programs, spin-offs have direct access to regional counseling services such as from AGIT, a regional business development company, or IHK Aachen, the city's chamber of commerce and trade. The latter also coordinates the approximately 200-member volunteer AC² advisory network.

Alongside the regional players, the Fraunhofer Venture, a division of the Fraunhofer-Gesellschaft, supports scientists in developing and implementing their ideas all the way to market readiness. The diverse range of services extends from advising and optimizing a business plan, to supporting legal and organizational design, to arranging investors and preparing for possible participation by the Fraunhofer-Gesellschaft.

Spin-offs since 1990



SPIN-OFFS OF FRAUNHOFER ILT

Intensive spin-off culture at Fraunhofer ILT

The Fraunhofer Institute for Laser Technology ILT has maintained an intensive spin-off culture since the early 1990s. This is essentially the case because it recognized that an efficient way of introducing a new technology into the market is the entrepreneurial activity of the relevant promoters of the respective technology. Founders are deeply convinced of their idea and are rarely slowed down by skeptics or administrative hurdles. At the same time, they have to be flexible enough to constantly adapt their business model to the needs of the market, but without abandoning their core idea. Innovative founders, thus, generate impulses in the industry for new technological solutions and perspectives, but there are also classic entrepreneurs who need to keep an eye on sustainable business development.

These characteristics are shared by the founders with the namesake of the Fraunhofer-Gesellschaft: Joseph von Fraunhofer emerged as a researcher, inventor and entrepreneur at the beginning of the 19th century. His activities ranged from discovering the Fraunhofer lines, later named after him, in the solar spectrum to developing new processing methods for the lens production all the way to managing a glassworks. In this respect, Fraunhofer ILT continues this entrepreneurial tradition by supporting employees willing to start a spin-off. And that since the institute was founded.

Spin-offs generate added value for the laser industry

In retrospect, one to two companies have been created per year over the past 25 years. Thus, the spin-off frequency of the institute is above the average of the Fraunhofer-Gesellschaft. Around 40 so-called spin-offs operate in laser technology and not only generate new sales, but also expand the market potential of the industry. They contribute directly to economic growth.

In addition to this financial aspect, the spin-offs are attractive employers as they move in an industry that has been experiencing outstanding growth for years. Of course, the spin-offs also provide added value for large established cmpanies, which rely on the new technologies when needed. Whether it is about new cleaning methods, custom-made additively manufactured implants, new high-power diode lasers or high-performance ultrashort pulse lasers, the roughly 40 spin-offs of Fraunhofer ILT cover a broad spectrum.

1 Domicile of the spin-off EdgeWave GmbH in Würselen, © EdgeWave GmbH.

INITIATIVES

ACAM

ACAM Aachen Center for Additive Manufacturing

Together with partners from science, the Fraunhofer Institutes for Laser Technology ILT and for Production Technology IPT founded the ACAM Aachen Center for Additive Manufacturing in 2015. The aim of ACAM is to help manufacturing companies implement additive manufacturing in their production processes. The Center for Additive Manufacturing is run by Prof. Johannes Henrich Schleifenbaum (Fraunhofer ILT) and Kristian Arntz (Fraunhofer IPT).

ACAM bundles the competencies of different research institutes in their services on the RWTH Aachen Campus Melaten. ACAM brings together an expert community that deals with additive manufacturing and continues to systematically develop its know-how in this area. The existing expertise is made directly accessible to the users.

ACAM Community meeting on February 20, 2019 at Oerlikon AM in Feldkirchen, © Oerlikon AM.

In terms of training, ACAM offers tailor-made seminars. Interested companies can participate in the ACAM community for a fee. If required, the partner companies can also establish their own resources directly on the campus. The employees of these companies can also take part in training and further education programs offered by RWTH Aachen University and are involved in the university environment.

Strategic partners of ACAM

- Fraunhofer Institute for Laser Technology ILT
- Fraunhofer Institute for Production Technology IPT
- Access Technology GmbH
- KEX Knowledge Exchange AG
- Institute for Tool-free Production IwF, an institute associated to the FH Aachen University of Applied Sciences

RWTH Aachen University
- Chair for Laser Technology LLT
- Chair for Digital Additive Production DAP
- Chair of Production Engineering of E-Mobility Components PEM
- Nonlinear Dynamics of Laser Processing Instruction and Research Department NLD
- Chair and Institute of General Design Engineering of Mechanical Engineering ICT
- Machine Tool Laboratory WZL
- Institute for Automotive Engineering IKA
- Institute of Plastics Processing IKV
- Institute for Material Applications in Mechanical Engineering IWM

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AACHENER CENTER FOR 3D PRINTING

The Aachen Center for 3D Printing is a joint research group of Fraunhofer ILT and the FH Aachen University of Applied Sciences, and aims to give small and medium-sized companies access to the entire process chain in the field of additive manufacturing (AM). This way, they can exploit the economic and technological opportunities offered by this innovative technology.

As small and medium-sized businesses screen their own applications, they increasingly see the economic and technological opportunities of AM in their production environments. Often, however, they shy away from investment risks; most of all, they seldom have qualified 3D printing specialists and skilled workers. This is where the closely cooperating team of experts from Fraunhofer ILT and FH Aachen comes in.

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Further information at: www.ilt.fraunhofer.de/en.html and www.fh-aachen.de/en

ICTM AACHEN

ICTM – International Center for Turbomachinery Manufacturing

The Fraunhofer Institutes for Production Technology IPT and Laser Technology ILT as well as the Machine Tool Laboratory WZL and the Chair for Digital Additive Production DAP of RWTH Aachen University started the »International Center for Turbomachinery Manufacturing – ICTM« on October 28, 2015 in Aachen with 19 renowned industrial partners.

At present, the network's 32 industrial partners are big and medium-sized companies in the fields of turbomachinery building, mechanical and automation engineering, machining as well as additive manufacturing. The center focuses on research and development around the production and repair of turbomachinery components which are covered by the partners in all areas. The research center was founded without any state funding and is thus one of the few independent networks that emerged from the Fraunhofer innovation clusters »TurPro« and »ADAM«. The ten-member steering committee comprises representatives of the participating industrial companies and research institutes.

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1 Additive-manufactured letters with integrated lightweight structures.

COOPERATIONS AND ASSOCIATIONS

The Fraunhofer Institute for Laser Technology ILT has partnerships with domestic and foreign research centers, universities, clusters and companies so that it can offer its customers solutions from a single source. Fraunhofer ILT also maintains close contacts to associations, chambers of commerce and trade, testing institutes and ministries.

REGIONAL NETWORKS

At the local level, Fraunhofer ILT cooperates with RWTH Aachen University, the FH Aachen University of Applied Sciences and Forschungszentrum Jülich in many fundamental issues. At the Aachen Center for 3D Printing – a cooperation between FH Aachen and Fraunhofer ILT – medium-sized companies, in particular, can receive support in all aspects of additive manufacturing. In the life sciences too, Fraunhofer ILT is well networked via the MedLife e.V. The trade association IVAM e.V. allows ILT access to numerous experts in microtechnology. In the NanoMicroMaterialsPhotonic.NRW state cluster, Fraunhofer ILT is involved in the fields of nanotechnology, photonics and microsystem technology.

NATIONAL COOPERATIONS

Together with around 70 other research institutes, Fraunhofer ILT is embedded in the Fraunhofer-Gesellschaft, the largest organization for application-oriented research in Europe. Our customers benefit from the combined expertise of the cooperating institutes.

The networking of laser users, manufacturers and researchers at the national level succeeds, among others, in the Arbeitskreis Lasertechnik e.V., in the Wissenschaftliche Gesellschaft Lasertechnik e.V. (Scientific Society of Laser Technology) and in various industry associations such as DVS, SPECTARIS or VDMA. The national initiatives such as the »go-cluster« of the Federal Ministry of Economic Affairs and Energy (BMWi) or the research campus of the Federal Ministry of Education and Research (BMBF) actively support Fraunhofer ILT. In all committees, ILT employees provide impetus to further develop the field of laser technology as well as forms of cooperation between science and industry for the benefit of society.

NETWORKED INTERNATIONALLY

Fraunhofer ILT carries out bilateral projects as well as joint projects with foreign companies and branches of German companies abroad. In addition, the Fraunhofer-Gesellschaft maintains liaison offices in numerous countries. To support international developments of fields relevant to Fraunhofer ILT in a timely manner, employees are actively engaged in selected associations and networks such as the European Photonic Industry Consortium EPIC and the technology platform Photonics21 at the European level or the Laser Institute of America LIA at the transatlantic level. Numerous scientific lectures at international conferences complete the picture.

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ARBEITSKREIS LASERTECHNIK E.V.

AKL
ARBEITSKREIS LASERTECHNIK e.V.

The Arbeitskreis Lasertechnik AKL e.V. (AKL e.V. for short) was founded in 1990 in order to make the fascinating possibilities that the laser opens up – with regard to precision, speed and economy – useful for the industry by intensifying the level of information and education. While many laser-based applications are known today, new laser beam sources and laser processes are constantly being developed, which lead to innovative prospects in industrial production. In this rapidly changing discipline, a network of laser experts supports ongoing innovation processes and AKL e.V. serves exclusively and directly to promote scientific goals.

Tasks of the AKL e.V.

- Promoting scientific work in the field of laser technology by stimulating and supporting research projects carried out at research institutes as well as cooperating with other research associations and scientific institutions.
- Promoting the dissemination of laser technology in industry and supporting the scientific exchange of ideas with persons, companies, associations, authorities and offices of all kinds, in particular through funding and organizing research projects, lectures, conferences, meetings and symposiums. In this context, AKL e.V. also organizes the seminars and events of the alumni network »Aix-Laser-People«.

The AKL e.V. has about 180 members. Personal communication between the members forms the backbone of the association. Dr. Hartmut Frerichs (managing director), chairman Ulrich Berners and Dr. Bernd Schmidt (treasurer) are also represented on the board of AKL e.V. Since Prof. Reinhart Poprawe's departure, the new head of the Fraunhofer ILT, Prof. Constantin Häfner, has been acting as deputy chairman.

Innovation Award Laser Technology

Every two years the associations Arbeitskreis Lasertechnik e.V. and the European Laser Institute ELI e.V. award the Innovation Award Laser Technology, which is endowed with € 10,000. This European prize for applied science is aimed at both individuals and project groups whose skills and commitment have led to outstanding innovation in the field of laser technology. Potential participants are also people working in industry, universities or independent research centers in Europe who have successfully conceived and implemented an innovative idea in the field of laser technology. In essence, the work should deal with the use and generation of laser light for material processing and lead to an economic benefit.

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Further Information at: www.akl-ev.de

EVENTS AND PUBLICATIONS

PATENTS

PATENTS GERMANY

DE 102015201140.2 Bearbeitungskopf für die Materialbearbeitung

DE 102013017288.8 Verfahren und Vorrichtung zum Justieren eines Paars mittels elektromagnetischer Strahlung messender Messköpfe

DE 102014200633.3 Bearbeitungsvorrichtung und -verfahren zur Laserbearbeitung einer Oberfläche

DE 102013005137.1 Verfahren zum Abtragen von sprödhartem Material mittels Laserstrahlung

DE 102007024700.3 Verfahren zur Materialbearbeitung mit Laserstrahlung sowie Vorrichtung zur Durchführung des Verfahrens

DE 102017210241 Optische Anordnung zur Umformung des Intensitätsprofils eines optischen Strahls

DE 102015014060.4 Verfahren zum Fügen von zwei Bauteilen im Bereich einer Fügezone mittels mindestens einem Laserstrahl sowie Verfahren zum Erzeugen einer durchgehenden Fügenaht

PATENTS EUROPE

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EP 08758722.6 Verfahren zur Materialbearbeitung mit Laserstrahlung sowie Vorrichtung zur Durchführung des Verfahrens

EP 15722192.0 Verfahren und Anordnung zur spektralen Verbreiterung von Laserpulsen für die nichtlineare Pulskompression

47
Bachelor theses in 2019

PATENTE
14 patents, 24 patent applications in 2019

113
Scientific lectures in 2019

61
Master theses in 2019

107 Publications

PATENTS

PATENTS CHINA

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2017-512418 Verfahren und Anordnung zur spektralen Verbreiterung von Laserpulsen für die nichtlineare Pulskompression

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102019130378.8 Verfahren zum Fügen einer elektrischen Zelle und elektrischer Speicher

102019210295.6 Verfahren zum Beschichten einer Oberfläche eines Substrates durch Laserauftragschweißen

102019004260.3 Verfahren zum Bohren oder Schneiden durch Abtragen von schmelzfähigem oder verdampfungsfähigem Material eines Werkstücks

102019125951.7 Verfahren und Vorrichtung zur Bahngenauigkeitsbestimmung einer stationären Bearbeitungsmaschine

102019212818.1 Abtastmodul zur zweidimensionalen Abtastung einer Zielebene mit einem oder mehreren Laserstrahlen

102019207421.9 Verfahren und Vorrichtung zum Glätten einer Oberfläche eines Bauteils durch Bearbeitung mit energetischer Strahlung

102019124 856.6 Werkstoffzuführungsvorrichtung

102019209133.4 Verfahren zum Testen neuer Werkstoffzusammensetzungen für das pulverbettbasierte Laserschmelzen sowie dafür ausgebildete Vorrichtung

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102019116214.9 Vorrichtung und Verfahren zur Referenzierung und Kalibrierung einer Laseranlage

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102019205222.3 Verfahren zur Terminierung optischer Strahlung sowie dafür ausgebildete optische Strahlfalle

102019201573.5 Verfahren und Vorrichtung zur interferometrischen Abstandsmessung, insbesondere bei der Lasermaterialbearbeitung

102019205289.4 Anlage zur Herstellung elektrischer Kontaktelemente mit selektiv veredelten elektrischen Kontaktflächen

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102019202222.7 Ablenkspiegel aus Diamant sowie Verfahren zur Herstellung

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PCT/EP2019/078054 Radar- und Lichtausstrahlungsanordnung für Fahrzeuge zum Ausstrahlen von Licht und Radarstrahlung sowie Verfahren und Verwendung

PCT/EP2019/081335 Vorrichtung und Verfahren zur Elementanalyse von Materialien

PCT/EP2019/075528 Verfahren zum Glätten der Oberfläche eines Kunststoffbauteils

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PCT/EP2019/064334 Vorrichtung zur Laserbearbeitung schwer zugänglicher Werkstücke

PCT/EP2019/000186 Verfahren und Vorrichtung zum Bohren von Bauteilen

PATENT APPLICATIONS TAIWAN

108137484 Radar and Light Emitting Arrangement for Vehicles for Emitting Light and Radar Radiation as well as Method and Use

DISSERTATIONS

DISSERTATIONS

15.2.2019 – Tobias Bonhoff (Dr. rer. nat.)
Multiphysikalische Simulation und Kompensation thermo-optischer Effekte in Optiken für Laseranwendungen

18.2.2019 – Christian Kalupka (Dr. rer. nat.)
Energiedeposition von ultrakurz gepulster Laserstrahlung in Gläsern

5.4.2019 – Jeroen Risse (Dr.-Ing.)
Additive manufacturing of nickel-base superalloy IN738LC by Laser Powder Bed Fusion

15.4.2019 – Carlo Holly (Dr. rer. nat.)
Modeling of the lateral emission characteristics of high-power edge-emitting semiconductor lasers

30.4.2019 – Alp Özmert (Dr.-Ing.)
Evaluation of multidimensional data from optoelectronic sensors for the determination of the penetration depth in laser welding

28.5.2019 – Sabrina Vogt (Dr.-Ing.)
Lokale Laserentfestigung von Halbzeugen und Bauteilen aus hochfesten Stählen

10.7.2019 – Sebastian Nyga (Dr. rer. nat.)
Kontradirektionale Modenkopplung in pumpüberhöhten optisch-parametrischen Ringoszillatoren

16.7.2019 – Chongliang Zhong (Dr.-Ing.)
Prozessführung, Mikrogefüge und mechanische Eigenschaften beim Laserauftragschweißen von Inconel 718 mit hohen Auftragsraten

19.7.2019 – Frank Zibner (Dr.-Ing.)
Robustheitsanalyse des Laserstrahlwendelbohrens

12.8.2019 – Ansgar Meissner (Dr. rer. nat.)
Untersuchung von Laserstrahlquellen mit Erbium-dotiertem YLuAG für Lidar-Systeme zur CH4-Detektion

13.9.2019 – Oliver Fitzau (Dr. rer. nat.)
Fasergekoppelte optische Isolatoren für Hochleistungs-Faserlaser

17.9.2019 – Martin Traub (Dr.-Ing.)
Erzeugung prozessangepasster Leistungsdichteverteilungen für die Lasermaterialbearbeitung

19.9.2019 – Jochen Vieker (Dr. rer. nat.)
Einflussfaktoren auf die Emissionseigenschaften einer EUV-Strahlungsquelle im Langzeitbetrieb

7.11.2019 – Holger Leonards (Dr.-Ing.)
Direktinitiierung von Thiol-En Photopolymeren in der Stereolithographie

22.11.2019 – Thomas Schopphoven (Dr.-Ing.)
Experimentelle und modelltheoretische Untersuchungen zum Extremen Hochgeschwindigkeits-Laserauftragschweißen

28.11.2019 – Chen Hong (Dr.-Ing.)
Laser Additive Manufacturing of nickel superalloy based composites

You will find a list of Fraunhofer ILT's scientific publications and lectures as well as bachelor and master theses online in our media center on the Internet at:
www.ilt.fraunhofer.de/en/media-center.htmlt

EVENTS

Joint Fraunhofer booth at LASER WORLD OF PHOTONICS 2019: 70 years Fraunhofer – 70 years future.

LASER WORLD OF PHOTONICS 2019

Quantum technologies, metallic 3D printing and electromobility – latest developments from Aachen

From June 24 to 27, 2019, the laser community met for the trade fair in Munich. Thanks to around 34,000 visitors and 1325 exhibitors, LASER World of PHOTONICS set two new records in 2019. Fraunhofer ILT was again represented with more than 50 exhibits from the different areas of applied laser technology and beam source development.

Ultrafast lasers go on the offensive with kW systems

In the Fraunhofer Cluster of Excellence Advanced Photon Sources CAPS, under the leadership of Fraunhofer ILT and IOF experts from 11 other Fraunhofer institutes are working on laser and process technology for the next generation of ultrafast laser systems (see page 122–123). The booth showed how high precision and high productivity with ultrafast lasers work in large-scale machining on an aircraft wing of industrial partner Sonaca: The ultrafast laser can be used to drill tiny holes over a large area, for example, in aircraft wings. This reduces air resistance and enables fuel savings of up to 15 percent. In addition, a multi-pass cell was on display as an eye-catcher, with the help of which the pulse durations of high power ultrafast lasers can be efficiently shortened.

Laser technology for e-mobility

»No e-mobility without laser technology« was an important motto of the laser trade fair: in Munich, the »eace05« electric racing car from the Ecurie Aix – Formula Student Team at RWTH Aachen University served to demonstrate how this motto could be put into practice. For the ultra-light body of the racing car, which weighs almost 180 kilograms, CFRP parts were laser-cut and the battery cells laser-welded. The engine and wheels contain parts produced from metal powder by a 3D laser printer.

At the booth, Fraunhofer ILT also demonstrated how battery cells can be welded with robot support. In this process, Laser-Based Tape-Automated Bonding (LaserTAB), they showed how robots, laser scanners and process monitoring work together.

Laser structuring at triple the productivity

Car makers currently use a variety of methods to emboss plastic panels for vehicle interiors. However, manufacturing the tools required for this purpose is an extremely time-consuming process. This situation can be improved using a new laser machine that triples the rate at which these tools are produced while facilitating even more complex structures. At LASER World of PHOTONICS 2019, the results developed in the BMBF research project eVerest were presented: radically improved laser structuring technology with resolutions in the micrometer regime.

To optimize the processes, the engineers started out by examining the efficiency of all the components. Lasers with ultrashort pulses (USP) are known for their precision in the nanometer regime. The eVerest team therefore decided to incorporate a USP source in addition to the standard nanosecond (ns) laser. USP lasers have traditionally been criticized for their low productivity. In this case, however, the Fraunhofer ILT process engineers employed a particularly powerful, actively cooled fiber-coupled USP laser from Amphos GmbH to obtain the same ablation rate per watt as that offered by the ns laser. The USP laser makes it possible to reduce surface roughness to less than 0.5 µm.

Clever combi-head for three different laser processes

Today, lightweight construction and e-mobility are almost synonymous with the demands for more flexibility and efficiency. In the North Rhine-Westphalian lead market project MultiPROmobil it was analyzed how classical and future machining processes can be performed with just one laser head. The result was a combi-head that can not only cut and weld with the laser, but also generate additive layers.

The project partners are currently working on optimizing the combi-head so that it can carry out all three processes in a production plant in a »flying change« – without having to change optics or nozzles. The project also developed simulation software that maps machines, processes and components using digital twins, thus enabling the process to be better controlled and optimized.

Further information at:
www.ilt.fraunhofer.de/de/messen-und-veranstaltungen.html

New possibilities with laser technology for lightweight construction and e-mobility: the »eace05« electric racing car.

futureAM – factor 10 faster for additive processes

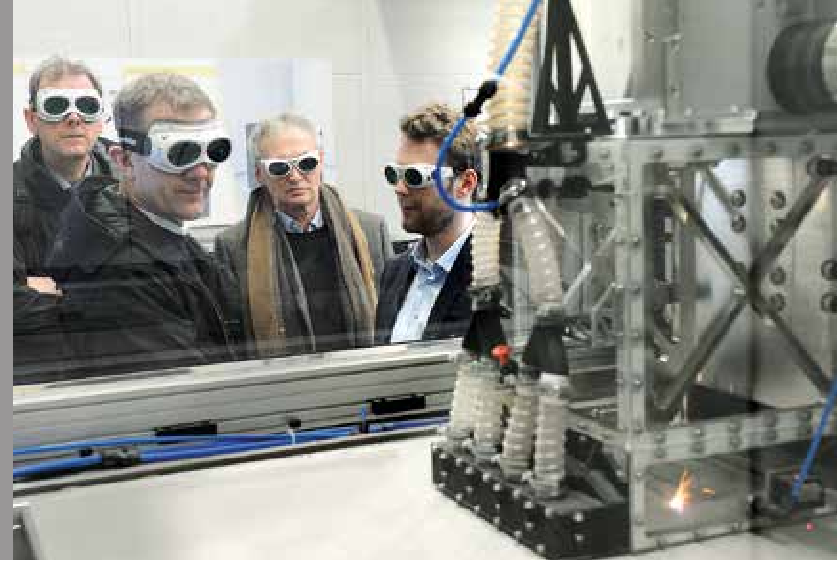
The additive manufacturing of metal components has great potential for completely new design solutions. However, one of the inhibiting factors for industrial use so far has been low productivity. This is why six Fraunhofer institutes joined forces in 2017 to form the Fraunhofer lighthouse project »futureAM – Next Generation Additive Manufacturing«, which aims to accelerate the additive manufacturing process for metal components (metal AM) by a factor of ten. The work focuses on the entire process chain, from order processing through design and simulation to production in the machines.

Building blocks for quantum technologies

For the processes of quantum imaging, quantum communication and quantum computing to make their way into marketready applications, however, highly integrated photonic components must become available. That is why Fraunhofer ILT is developing process technologies to produce waveguides, couplers and filters in glasses and crystals. High-power ultrafast laser systems serve as the basis.

Among other things, Fraunhofer ILT is currently working on processes for quantum imaging, but also on the optical interface for the quantum internet of the future.

Dr. Oliver Nottrodt (Fraunhofer ILT) at the Laser Symposium Electromobility LSE 2019.



Laboratory tour as part of the 5th ICTM conference at Fraunhofer ILT.

EVENTS

February 6-7, 2019, Aachen
5th Conference of the ICTM International Center for Turbomachinery Manufacturing
The aim of the »5th Conference of the ICTM International Center for Turbomachinery Manufacturing Aachen« was to accelerate technological innovations and transfer them to industrial applications. The conference demonstrated the excellent research and development for turbomachinery manufacturing and networked representatives from industry and science. Topics included the highly productive and environmentally friendly manufacture of turbomachinery.
- Around 200 participants from 18 countries
- Organization: Fraunhofer ILT and Fraunhofer IPT

February 20, 2019, Aachen
Laser Symposium Electromobility LSE 2019
As more and more automobiles are powered by electricity, the demand for powerful energy storage systems is increasing. To meet the constantly growing challenges, the industry needs new manufacturing methods to produce battery modules and packs. Already today, highly efficient laser processes are essential for the entire process chain and the share of laser technology in production will continue to increase. These topics were highlighted by ten speakers from industry and research at the first Laser Symposium on Electromobility LSE 2019.
- Organization: Fraunhofer ILT

April 10-11, 2019, Aachen
5th USP Workshop: Ultrafast Laser Technology
The 5th USP Workshop presented the basics of ultrashort pulse laser technology as well as an overview of current developments in the field of beam sources and the necessary system technology. The workshop focused on suitable beam shaping solutions for individual processes. The latest laser-based applications and processing methods were presented, both of which extend the limits of previous technologies in terms of processing speed, quality and material bandwidth.
- More than 20 lectures on the topic of ultrashort pulse laser applications and processing methods
- Over 170 participants from 14 countries
- Organization: Fraunhofer ILT, Conference venue: Aachener Tivoli

November 6-7, 2019, Aachen
AI for Laser Technology Conference
The first »AI for Laser Technology Conference« provided industrial users with practical basic knowledge and orientation for the application of artificial intelligence (AI) processes in laser technology. The approximately 70 participants learned how AI can be used to arrive at clear conclusions from process data in order to increase quality, efficiency and flexibility in laser technology.
- Organization: Fraunhofer ILT

Networking at the Aix-Laser-People meeting at the Seehaus in Munich.

Well attended: Joint Fraunhofer stand at the K 2019 in Düsseldorf.

AIX-LASER-PEOPLE

June 26, 2019, Munich
58th Aix Laser People Meeting on the occasion of LASER World of PHOTONICS

The alumni meeting took place for the tenth time during LASER World of PHOTONICS in Munich. Around 170 participants – 65 of whom were AKL e.V. members and alumni of Fraunhofer ILT and the cooperating chairs of RWTH Aachen University – gathered in the Seehaus of the English Garden. Managing Director Dr. Hartmut Frerichs took the opportunity to thank the former head of Fraunhofer ILT, Prof. Poprawe, on behalf of the entire AKL e.V. and to bid him farewell as a long-standing member of the board. At this year's Business Speed Dating, 20 laser experts from various industries and scientists from Fraunhofer ILT environment exchanged ideas in the »Industry meets Industry« and »Industry meets Science« groups. The concluding get-together in a relaxed atmosphere provided everyone with the opportunity for further networking.

Farewell to Prof. Reinhart Poprawe (center) by Ulrich Berners (left) and Dr. Hartmut Frerichs (right) in Munich.

December 19, 2019, Geilenkirchen
59th Aix Laser People Meeting at the Laser Processing and Consulting Centre GmbH (LBBZ)

At the end of the year the Arbeitskreis Lasertechnik e.V. invited its members to the alumni meeting in the Laser Processing and Consulting Centre (LBBZ) in Geilenkirchen. The LBBZ has been dealing with the industrial application of laser technology and other modern production processes since 1991. At the meeting, LBBZ's team not only reported on the company's positive developments in recent years, but was also able to present its own production system for manufacturing chassis for electromobility applications. The welcoming address by Dr. Hartmut Frerichs and Managing Director Ulrich Berners was followed by three exciting presentations outlining the subject of electromobility and the challenges it presents. This was followed by a tour of the production processes on site and a concluding discussion.

In the evening, the event continued with a convivial meeting at Fraunhofer ILT, where the focus was on networking as well as professional exchange.

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Further Information at: www.akl-ev.de

COLLOQUIUM LASER TECHNOLOGY AT RWTH AACHEN

January 10, 2019 – Chair for Laser Technology LLT
Prof. Thomas Dekorsy, DLR / Fakultät für Luft- und Raumfahrt und Geodäsie der Universität Stuttgart
»Laserbasierte Detektion und Reduktion von Weltraumschrott«

February 27, 2019 – Chair for Laser Technology LLT
Prof. Christoph Becher, Universität Saarland
»Quantum frequency conversion of single photons as toolfor quantum networks«

April, 25, 2019 – Chair for Laser Technology LLT
Dr. Thomas Metzger, TRUMPF Scientific Lasers GmbH & Co. KG
»Ultrafast thin-disk amplifiers«

October 22, 2019 – Chair for Laser Technology LLT
David Sebastian Voigt, M. Sc., Deutsches Zentrum für Luft- und Raumfahrt e.V.
»Molecular emissions and spatial characterization of the LIBS plasma in Martian conditions«

November 14, 2019 – Chair for Laser Technology LLT
Prof. Clara Saraceno, Ruhr Universität Bochum
»High-power ultrafast thin-disk oscillators for Terahertz science«

TRADE FAIRS

February 5–7, 2019, San Francisco, USA
SPIE Photonics West 2019
International Trade Fair for Optics and Photonics
Fraunhofer ILT was represented at the joint booth of the Federal Republic of Germany and showed exhibits on the following topics:

- Diamond Optics for High-Power Laser Applications
- Spaceborne Optical Parametric Oscillator
- Highly Stable Fiber Amplifier for Gravitational Measurements

At the accompanying LASE Conference, Fraunhofer ILT experts gave eight presentations.

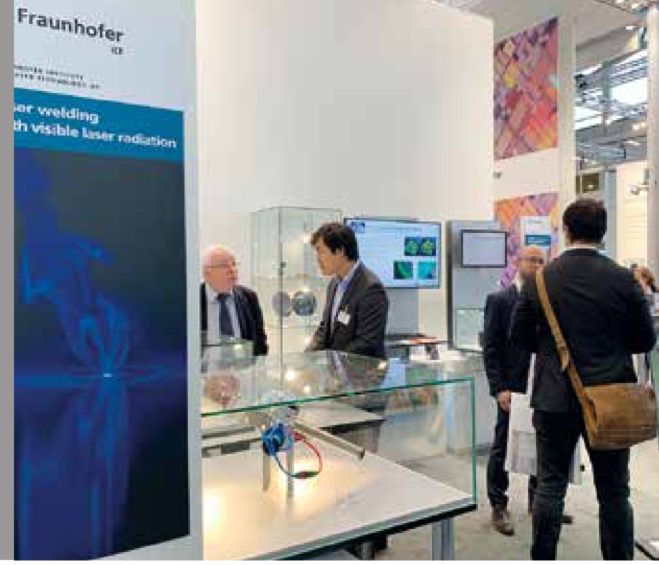
March 12–14, 2019, Paris, France
JEC World 2019
The Leading International Composites Show
Fraunhofer ILT presented laser-based technologies for the industrial processing of fiber-reinforced plastics at the joint booth of the Aachen Center for Integrative Lightweight Construction (AZL):

- Multi-material roof bow demonstrator (HyBriLight project)
- Cutting of GFRP-CFRP mixed components
- High-speed microstructuring of metals for plastic-metal hybrid joints

March 20–22, 2019, Shanghai, China
LASER World of PHOTONICS China
International Trade Fair for Optics and Photonics
Fraunhofer ILT presented new ideas for industrial laser applications at LASER World of PHOTONICS China.

Joint Fraunhofer stand at the Hannover Messe 2019.

Fraunhofer ILT at formnext 2019 in Frankfurt.



Fraunhofer ILT with innovative processes for laser microwelding at productronica 2019.

The top topics of Fraunhofer ILT at LASER China were as follows:

- Material Ablation Using Ultrashort Pulsed Lasers
- High Precision Laser Drilling and Laser Cutting with Helical Optics
- High Power Multi Beam Processing with Ultrashort Laser Pulses
- Laserfact Combi-Head: Cutting, Cladding, Welding
- Extreme High-Speed Laser Material Deposition EHLA

Experts from the Fraunhofer ILT also gave lectures at the 14th International Laser Processing and Systems Conference LPC 2019.

April 1–5, 2019, Hanover
HANNOVER MESSE 2019
The world's leading trade fair for industry

Fraunhofer ILT presented exhibits at the joint Fraunhofer stand on the subject of »Functional Layers for Electronic Applications«. The focus was on directly printed strain gauges and locally gold-plated contacts.

May 7–10, 2019, Stuttgart
Control 2019
International trade fair for quality assurance

At the joint stand of the Fraunhofer VISION Alliance, Fraunhofer ILT presented a plant-integrated system for camera-based joint tracking and process monitoring for laser beam and MIG hybrid welding. The combination of imaging measurement technology and a suitable illumination method enables the system to determine the joint geometry and laser focus in real time using a texture-based method and to adaptively minimize the offset between the interaction point and the joint center.

June 17–23, 2019, Paris
Paris Air Show 2019

At the Paris Air Show, the Fraunhofer ILT showed an exhibit processed with extreme high-speed laser material deposition (EHLA) at the Fraunhofer joint stand: EHLA was used to coat a cylinder used in aerospace applications with a corrosion-resistant nickel alloy (Inconel 625), demonstrating the technology's strengths as compared with conventional coating processes such as thermal spraying or electroplating.

June 25–27, 2019, Erfurt
Rapid.Tech 2019
International Hub for Additive Manufacturing

The Aachen Center for 3D Printing presented itself at the booth of ACAM GmbH. The Aachen Center for 3D Printing is a joint project between Fraunhofer ILT and the Aachen University of Applied Sciences and aims to give small- and medium-sized companies access to the integrated process chain in the field of additive manufacturing. Fraunhofer ILT was also represented with lectures in the »Plastics« forum and the »AM Science« forum.

September 10–13, 2019, Frankfurt am Main
IAA 2019
International Motor Show

Fraunhofer ILT presented exhibits at the joint Fraunhofer stand on the following topics:

- Wear and corrosion protection coatings on brake disks, car doors and on and in FVK components
- Directly printed strain-gauge sensors
- Local gold-plated contacts
- 3D printed components and other applications for automotive parts

October 8–10, 2019, Karlsruhe
Deburring EXPO
Leading trade fair for deburring technologies and precision surfaces

Fraunhofer ILT presented current developments in the fields of laser deburring and polishing in the research pavilion. The focus was on laser processes for tribologically loaded surfaces, sealing surfaces and sheet metal edges.

October 16–23, 2019, Düsseldorf
K 2019
Fair of the plastics and rubber industry

Fraunhofer ILT presented the following topics at the joint Fraunhofer stand:

- Laser transmission welding of transparent plastics
- Joining of hybrid plastic-metal compounds
- Cutting and ablation of plastics using laser radiation
- Laser based encapsulation of polymeric multilayer films in a roll-to-roll process

The highlight was the presentation of a laser-based process chain for the production of a microfluidic chip.

November 12–15, 2019, Munich
productronica 2019
World's leading trade fair for the development and production of electronics

At the joint Fraunhofer stand, Fraunhofer ILT presented laser microwelding with blue laser radiation:

- Self-developed optics for demanding welding tasks
- Precise control of energy coupling through increased absorption in copper materials
- Flexible seam design through combination with a galvanometric laser scanner
- Enabling new and further developed joining processes

November 18–21, 2019, Düsseldorf
COMPAMED 2019
High-Tech Solutions for Medical Technology

At COMPAMED, Fraunhofer ILT presented itself at the joint IVAM stand and had exhibitions on the following topics:

- Compact application-specific µFACS systems
- High throughput screening
- 3D microfluidics out of fused silica
- OptisCell – Process chain for automated cell isolation and laser based cell picker

The highlight was the laser-based process chain for manufacturing a microfluidic chip. In addition, Maximilian Brosda from Fraunhofer ILT gave a presentation in the session »Laser and Photonics Applications - EPIC Tech Watch« at the COMPAMED High-Tech Forum by IVAM.

November 19–22, 2019, Frankfurt am Main
formnext 2019
International Exhibition and Conference on the Next Generation of Manufacturing Technologies

At formnext 2019, Fraunhofer ILT presented innovative results at the joint Fraunhofer stand:

- Infrared (NIR) preheating in laser powder bed fusion (LPBF)
- Additive manufacturing of high-purity copper components with »green« and »blue« light
- 3D printing of large components with wire laser material deposition (LMD)
- Analysis of powder gas flows with the Powder Jet Monitor
- Fraunhofer lighthouse project futureAM

Further information on our trade fairs and events can be found on the Internet at:
www.ilt.fraunhofer.de/en/fairs-and-events.html

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BEGO · Berlin Heart · BMW · BOMBARDIER · BOSCH

BRAUN · COHERENT · CONCEPTLASER · DILAS · DILLINGER HÜTTE

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INFORMATION

For more information about Fraunhofer ILT please visit our website or follow the social media channels mentioned below.

→→ www.ilt.fraunhofer.de

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