Fraunhofer ILT

Annual Report 2021

Research for a sustainable future

#WeKnowHow

ANNUAL REPORT 2021

Fraunhofer-Institut für Lasertechnik ILT

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Dear Readers,

The global market for photonics was 654 billion euros in 2019, according to a study by the European Photonics21 network. It is expected to grow by about six percent, to around 900 billion euros, by 2025, despite all the restrictions imposed during the Corona pandemic. So where does this optimism in the industry come from? Certainly, the broad-based nature of the photonics industry provides a solid foundation for growth. Whether in industrial production, environmental technology, telecommunications, consumer electronics, security technology or medical technology, significant growth rates are being recorded for photonics in all these market segments.

The challenges facing our society today are addressed by the Fraunhofer-Gesellschaft in strategic research fields such as the bioeconomy, intelligent medicine, artificial intelligence, quantum technologies and resource efficiency. Fraunhofer ILT is active developing solutions in all of these fields: Indeed, "laser technology made by Fraunhofer ILT" can be found in satellite-based high-precision lasers for measuring greenhouse gases, microfilters for water purification, EUV compact battery packages, additively manufactured high-performance coatings or individualized bone implants, smart components with integrated sensor technology, all the way to laser modules for the tap-proof networking of quantum computers.

In 2021, we have successfully forged ahead with numerous projects and investments. For example, in addition to the Battery Lab, we are also setting up a Hydrogen Lab, where we will optimize and further develop laser-based manufacturing processes involving this energy source. Here we can test innovative approaches and scale them for production in close cooperation with our industrial clients.

We were also able to celebrate a very special anniversary this year: 25 years ago, one of the most important cornerstones for metal-based additive manufacturing (AM) was laid at Fraunhofer ILT with the basic patent on selective laser melting or laser powder bed fusion. While the initial phase focused on developing the manufacturing process, today we are dealing with issues such as productivity of AM systems, sustainability of process chains, prediction of properties or failure of AM-manufactured components, and international standardization. In the field of high-power ultrashort pulse lasers, we have commercialized the first multi-kW systems offering excellent beam quality, power and parallelized processing solutions. At Fraunhofer ILT, a complete application laboratory is available for companies interested in testing these new laser beam sources.

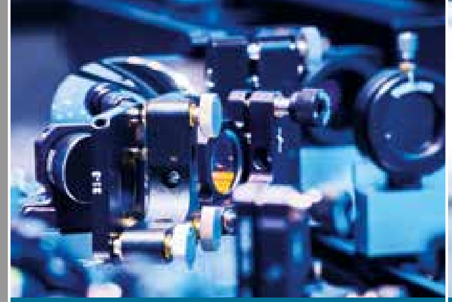
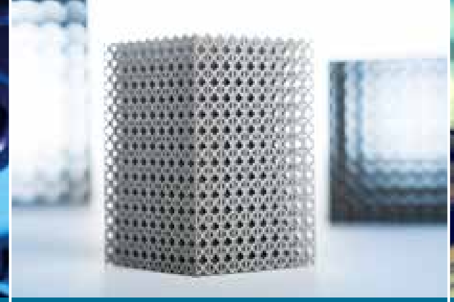
With our aerospace laser systems, we are addressing important societal applications: In addition to the LIDAR laser source for measuring greenhouse gases in the European MERLIN mission, we are launching a laser project for satellite-based detection of atmospheric wind fields using Doppler wind LIDAR technology.

To give you insight into the numerous developments of our institute, we present a selection of projects released by our clients in this annual report. If we have piqued your interest or you are curious about our future developments, please feel free to contact our experts directly. We look forward to your feedback and an inspiring exchange of ideas.

Cordially,

Prof. Dr. rer. nat. Constantin Häfner

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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

2021

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

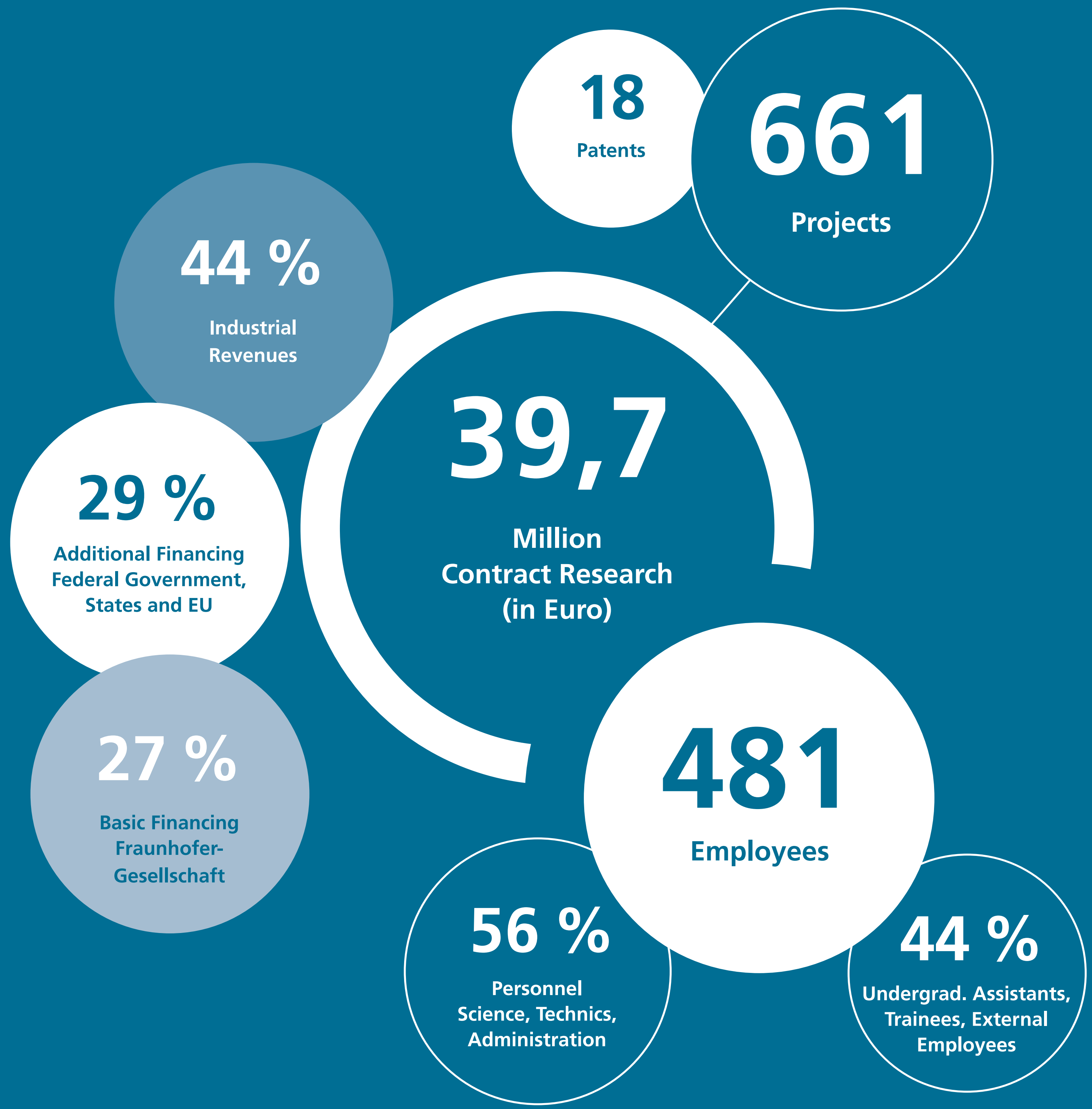
Our broad spectrum of resources enables us to offer one-stop solutions. We deliver innovative and cost-effective solutions and offer you R&D, consulting and integration. We solve our customers' tasks in multi-disciplinary teams using diverse and innovative facilities.

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

Fraunhofer 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 more than 480 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 six 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 focus »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. In the technology focus »Quantum Technology« Fraunhofer ILT offers a broad portfolio of solutions in the field of photonic beam sources and components. These include parametric photon sources and frequency converters, integrated optical components, packaging processes and application-specific system technologies. The technology focus »Digitalization« is closely linked to the activities of the other technology focuses and combines competencies in digital production around laser technologies such as design-to-production, digital twins, smart simulation, fog and edge computing and AI.

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.

DQS certified by
DIN EN ISO 9001:2015
Reg. No. 069572 QM15

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
- Solutions for digital production
- Model and test series
- Development, set-up and testing of pilot plants
- Development of X-ray, EUV and plasma systems
- Photonic components and systems for quantum technology

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

ALUMNI NETWORK AIX-LASER-PEOPLE

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 2021 alone, 122 students completed their bachelor's or master's theses at Fraunhofer ILT and 9 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.

Contact at Fraunhofer ILT

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STRUCTURE OF THE INSTITUTE

BOARD OF DIRECTORS

Prof. Constantin Häfner
Director

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

Dipl.-Ing. Gerd Bongard
IT Management

COMPETENCE AREAS

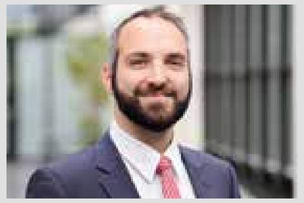
Dipl.-Ing. Hans-Dieter Hoffmann
Lasers and Laser Optics

Prof. Arnold Gillner
Ablatiion and Joining

Dr. Jochen Stollenwerk
Functional Layers and Surfaces (acting)

Dr. Achim Lenenbach
Measurement Technology and EUV Sources (acting)

Jasmin Saewe M. Sc.
Laser Powder Bed Fusion



Dr. Thomas Schopphoven
Lase Material Deposition

Board of Trustees 2021 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:

MEMBERS

- Carl F. Baasel (Chairman)
- Dr. Reinhold E. Achatz, International Data Spaces Association
- Dr. Norbert Arndt, Precision Castparts Corp.
- Dipl.-Ing. Frank C. Herzog, HZG Group
- Prof. Ursula Keller, ETH Zürich
- Dipl.-Ing. Volker Krause, Laserline GmbH
- Dipl.-Ing. Michael Lebrecht, Mercedes-Benz AG
- Prof. Gerd Marowsky, Advanced Microfluidic Systems GmbH
- Manfred Nettekoven, Chancellor of RWTH Aachen University
- Dr. Joseph Pankert, TRUMPF Photonic Components GmbH
- Dr. Silke Pflueger
- Dr. Stefan Ruppik, Coherent Hamburg
- Dr. Torsten Scheller, JENOPTIK Automatisierungstechnik GmbH
- Dr. Ulrich Steegmüller, ALEDIA
- Prof. Christiane Vaeßen, Region Aachen-Zweckverband
- Dr. Hagen Zimer, TRUMPF Laser GmbH

The 36th Board of Trustees meeting was held on November 4 and 5, 2021 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. C. Häfner, Prof. P. Loosen, Dr. V. Alagic-Keller, P. Abels, A. Bauer, T. Biermann, G. Bongard, Dr. A. Drenker, D. Esser, Prof. A. Gillner, H.-D. Hoffmann, Prof. C. Holly (since 31.5.2021), Dr. A. Lenenbach (since 3.5.2021), Prof. R. Noll (until 26.4.2021), Dr. D. Petring, J. Saewe (since 31.5.2021), Dr. T. Schopphoven (since 31.5.2021), Prof. W. Schulz, 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. C. Häfner, Prof. P. Loosen, Dr. V. Alagic-Keller, A. Bauer, M. Brankers, B. Erben, W. Fiedler, R. Frömbgen, F. Fuchs, M. Giesberts, A. Hajdarovic, M. Hesker, J. Jorzig, S. Jung, T. Kaster, K. Kohnen, D. Kreutzer, D. Maischner, V. Nazery Goneghany, B. Quilitzsch, M. F. Steiner, F. Voigt, T. Westphalen, T. Yildirim, Dr. R. Keul (Works doctor B.A.D), J. Pohl (B.A.D),

SCIENCE AND TECHNOLOGY COUNCIL WTR

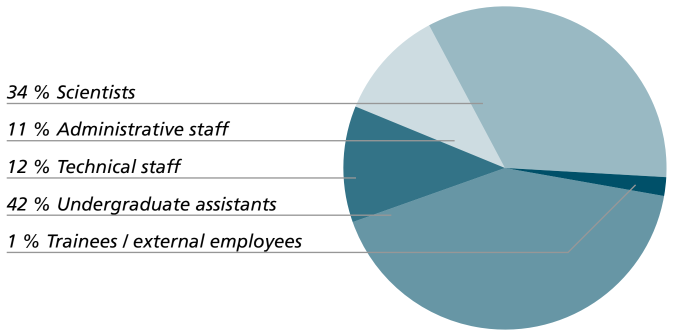
The Fraunhofer-Gesellschaft's Science & Technology Council supports and advises the various bodies of the Fraunhofer-Gesellschaft on scientific and technical issues. The members are the institutes'directors and one representative elected from the science/technology staff per institute. Members of the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

WORKERS' COUNCIL

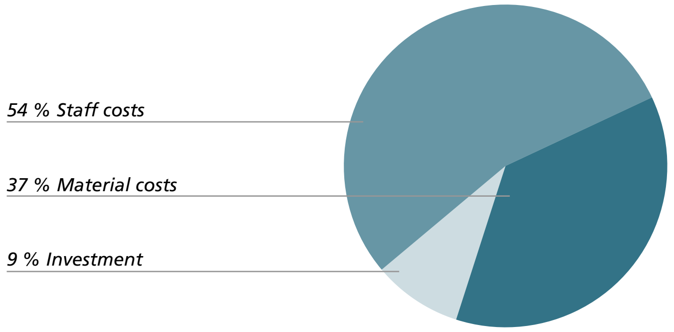
Since March 2003 there is a workers' council at Fraunhofer ILT.

THE INSTITUTE IN FIGURES

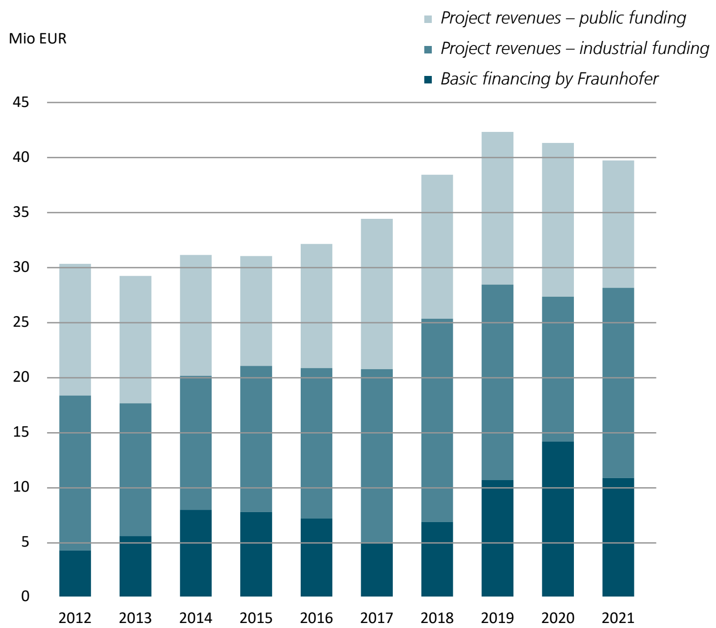
EMPLOYEES 2021	number
Personnel	**271**
- Scientists and engineers	162
- Technical staff	56
- Administrative staff	53
Other employees	**210**
- Undergraduate assistants	201
- External employees	7
- Trainees	2
Total number of employees at Fraunhofer ILT	**481**



EXPENSES 2021	Mill €
- Staff costs	23,6
- Material costs	16,1
Expenses operating budget	**39,7**
Investments	**3,9**



REVENUES 2021	Mill €
- Industrial revenues	17,3
- Additional financing from Federal Government, States and the EU	11,6
- Basic financing from the Fraunhofer-Gesellschaft	10,8
Revenues operating budget	**39,7**
Investment revenues from industry	**0,1**
Fraunhofer industry ρ_{Ind}	**43,9 %**



FACILITIES

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. The net floor area at Fraunhofer ILT amounts to 19,500 m^2.

EQUIPMENT

The equipment of the Fraunhofer 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
- Disk lasers up to 12 kW
- Disk lasers with green wavelength up to 2 kW CW and QCW
- Fiber lasers with 1.5 µm and 2 µm wavelength up to 200 W CW
- Experimental lasers with 2 µm / 3 µm wavelength (ns, ps)
- Experimental LIDAR lasers with pulse energies up to 500 mJ
- Single- and multimode fiber lasers up to 6 kW
- Diode laser systems up to 12 kW
- Multi KW ultrashort pulse lasers
- Frequency-multiplied laser in visible spectral range
- Excimer lasers amongst others with optical line systems
- Broadband tunable lasers
- MIR lasers (ps, ns) with average power > 10 W
- Laser platform for satellite-based LIDAR systems

PLANTS AND PROCESSING SYSTEMS

- Three-axis processing stations
- Five-axis gantry systems
- Robot systems including six-axis articulated robot
- Tripod system for the extreme high speed laser material deposition EHLA
- Commercial engineering and laboratory systems for laser powder bed fusion (LPBF)
- Direct-writing and laser-PVD stations
- Various powder and wire feed systems for additive manufacturing
- Printer for sol-gel-hybrid polymers and nano- to microscale dispersions

SPECIAL LABORATORIES

- ISO 5 and ISO 7 clean rooms for assembly and characterization of lasers and laser optics
- Life science laboratory with S1 classification
- Battery Lab
- Hydrogen Lab
- Application laboratories for USP applications

MEASUREMENT AND SENSOR TECHNOLOGY

- Devices for process diagnostics
- 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 USP lasers
- Equipment for vibration tests
- Climate chambers for thermal tests with continual monitoring of the optical properties
- Single photon detector (APD) for NIR lasers
- Systems to characterize powder materials
- Measurement systems for single quantum detection

AWARDS AND PRIZES

HUGO GEIGER PRIZE

Dr. Christian Kalupka receives Hugo Geiger Prize 2021

Every year, the Fraunhofer-Gesellschaft and the Free State of Bavaria award three young researchers with the "Hugo Geiger Prize for Young Scientists" for outstanding doctoral theses on application-oriented research. The prizes, endowed with 5,000, 3,000 and 2,000 euros, were presented by Hubert Aiwanger, Bavaria's Deputy Minister President and Minister of State for Economic Affairs, Regional Development and Energy, and by Andreas Meuer, member of the Fraunhofer-Gesellschaft's Executive Board responsible for Finance and Digitization, as part of the Fraunhofer-Symposium Netzwert "Resilience – Emerging Stronger from the Crisis," which took place as a hybrid event on March 23, 2021. Dr. Christian Kalupka was honored with 3rd place for his research on the interaction between ultrashort pulse laser radiation and glass. Until the end of September 2021, Dr. Kalupka led the "Glass Processing" team at Fraunhofer ILT and developed a precise method for micrometer-accurate processing of glass and other transparent materials with an ultrashort pulse laser.

Dr. Christian Kalupka with moderator Monika Jones at the award ceremony at the Fraunhofer headquarters. © Marc Müller.

In his doctoral thesis at the Chair of LLT at RWTH Aachen University "Energiedisposition von ultrakurz gepulster Laserstrahlung in Gläsern" he first investigated what exactly happens when the laser beam penetrates glass. Using a pump-and-probe microscope developed at Fraunhofer ILT, he was able to observe the complex interplay between light and matter that takes place in the range of a few hundred femtoseconds. Using this knowledge, he was able to adjust parameters such as the energy and pulse duration of the laser in such a way that glass can be processed with micrometer precision. Thanks to this development, customized processes can be designed for machining different types of glass. Put in perspective, the process can also be transferred to other materials such as silicon. In the future, it could be used to generate components for 5G technology or in the development of quantum computers.

1 Minister Hubert Aiwanger with Hugo Geiger Award winners Dr. Simon Fichtner, Dr. Annelie Schiller and Dr. Christian Kalupka. Among the well-wishers were also Fraunhofer board members Andreas Meuer and Prof. Alexander Kurz (from left to right). © Marc Müller.

Karel Urbánek Best Student Paper Award 2021 for Sophia Schröder

During the "SPIE Advanced Lithography 2021" online conference from February 22 to 26, 2021, Sophia Schröder received the "Karel Urbánek Best Student Paper Award 2021" for her paper "Using EUV spectrometry to measure photosensitive materials after EUV exposure." The EUV spectrometry process was realized in a compact laboratory setup and brought to industrial application by the researchers of the Chair for Technology of Optical Systems TOS at RWTH Aachen University and Fraunhofer ILT. Since the process is highly sensitive to nanoscale structures and optical material properties, the characterization of so-called latent images in photosensitive materials was presented. This task is currently one of the greatest challenges of metrology in industrial semiconductor manufacturing.

ICEIS "Best Student Paper Award" for Moritz Kröger

During the virtual "International Conference on Enterprise Information Systems ICEIS" from April 26 to 28, 2021, Moritz Kröger from the Chair for Laser Technology LLT at RWTH Aachen University as well as Johannes Lipp, Stefan Decker and Siyabend Sakik from the Chair of Information Systems at RWTH Aachen University/Fraunhofer FIT were awarded the "Best Student Paper Award." Their paper, "LISSU: Integrating Semantic Web Concepts into SOA Frameworks," was written within the framework of the Cluster of Excellence "Internet of Production" (IoP) at RWTH Aachen University; it shows the potential of using microservice-based architectures to improve communication standards for cloud applications. This can make work easier for users of laser systems and prevent incorrect configurations during production.

Springorum Commemorative Coin

The Springorum Commemorative Coin is awarded by proRWTH, the sponsoring association of RWTH Aachen University, to students who have received their diploma or master's examinations with distinction. Among the honorees were Julian Krauskopf – with his master's thesis on »Multidimensional model development for standardized measurement of the success of innovative ecosystems using the example of the Digital Photonic Production research campus« – and Robert Zinke – with the topic »Evaluation of a microservice-based control concept of the ultrashort pulse laser process in the context of the Fourth Industrial Revolution.« Both work at the cooperating chairs of Fraunhofer ILT in 2021.

Karel Urbánek Best Student Paper Award for Sophia Schröder.

TRAINING THE NEXT GENERATION

Girls'Day 2021: Joint digital event of the three Aachen Fraunhofer Institutes on April 22, 2021

Girls'Day 2021 took place as a virtual event on April 22, 2021 with the slogan "Experience technology and the natural sciences virtually with the Fraunhofer institutes in Aachen!" The three participating Fraunhofer Institutes in Aachen – IPT, IME and ILT – opened their doors virtually for interested girls from the 5th to the 7th grade and offered exciting insight into the institutes' daily work. The participants were able to look over the shoulders of the Fraunhofer scientists at work and ask questions via a live link. The next Girls'Day will take place on April 27, 2023.

Experiencing science live at Girls'Day 2022.

Online event #hackingforfuture from April 23 to 25, 2021 – Let's Create the Production of Tomorrow

The digital hackathon #hackingforfuture was aimed at students of computer science, engineering or a similar course of study and was organized by Fraunhofer ICNAP – International Center for Networked, Adaptive Production in collaboration with the Fraunhofer Project Center at the University of Twente in the Netherlands. Participation was free of charge and there was a varied program full of challenges, networking and exciting insights into the work at Fraunhofer. Together with employees from Fraunhofer IPT, IME and ILT as well as industry partners, the participating students formed teams to face the challenges of digital transformation in the field of production and used their programming skills, knowledge, technical skills as well as team spirit to master them. At the end, prizes were awarded to the best teams.

Participants of Girls'Day 2022.

Student University of Mechanical Engineering from July 19 to 23, 2021

In 2021, the Student University of Mechanical Engineering took place again with the participation of the Cluster of Excellence Internet of Production IoP. Owing to the Corona pandemic, the student university was held virtually via Zoom for the second time. Eighteen students spent five days virtually at the Faculty of Mechanical Engineering of RWTH Aachen University to get an initial impression of the degree program of Mechanical Engineering and its many possibilities. Thus, the participants gained insights into the fields of production, process, plastics, textile and automotive engineering as well as optics and laser technology. Then, on July 23, 2021, they discovered the world of photonics. This day was organized by Fraunhofer ILT and the associated chairs LLT and TOS of RWTH Aachen University.

Guided tours as part of the first semester event in Mechanical Engineering on October 7, 2021

For the first time in a good year and a half, guided tours of the institute were offered to students. As part of the introductory week for freshmen in Mechanical Engineering and Industrial Engineering, more than 30 students were guided through the institute in small groups under the applicable Corona regulations. They were able to gain direct insight into the working world of the chairs and the Fraunhofer ILT at four stations, experience the fascination for laser technology and exchange ideas with employees.

bonding company contact fair on November 2, 2021

For the sixth time in a row, Fraunhofer ILT in Aachen was present at the largest student-organized company contact fair: bonding. In addition to 178 other exhibitors, Fraunhofer ILT informed students and graduates from engineering, economics and natural sciences in particular about entry and career opportunities at the institute in individual discussions.

Well attended: Fraunhofer booth at bonding 2021.

MOBILITY

LASER TECHNOLOGY SOLUTIONS FOR INDUSTRY AND SOCIETY

THE SENSING COMPONENT – INTELLIGENT SENSOR TECHNOLOGY FOR TRANSPORT, TRAFFIC, AVIATION AND SPACE TRAVEL

Sensors in the chassis or in the doors of a passenger train or aircraft are state of the art. But when sensing components with built-in sensors check themselves independently and report their condition to an operator's central software system, they are much more: an intelligent and integrated solution that prevents defects before they occur.

AI-supported sensor system for rail transport

With the SenseTrAIn project, the German Federal Ministry of Economic Affairs and Climate Action BMWK is promoting a method for efficiently monitoring functions relevant to safety in rail technology. Defective components in railroads can cause so-called "delays in operations". At the same time, replacing components that are still functional at rigid maintenance intervals is not ecologically and economically justifiable in the long term. Since September 2021, researchers at Fraunhofer ILT have been working with industrial partners to develop sustainable concepts for maintenance and repair at DB Systemtechnik GmbH. The goal of the cooperation between ME-Meßsysteme GmbH, vedisys AG, DATAbility GmbH and Fraunhofer ILT is to develop an AI-supported sensor system for rail transport by 2024.

Component-integrated sensor technology through 3D printing

The additive process laser powder bed fusion (LPBF), which has proven itself over many years, is used to set the course for intelligent maintenance. The layer-by-layer buildup of a component from metal powder with laser radiation makes it possible to integrate electronic components and sensors into metallic components during 3D printing. Stopped at the right time, the process allows sensors to be integrated into the workpiece before the laser continues its work. The finished component with the integrated sensors collects significant amounts of data during later operation, which are analyzed and filtered using Artificial Intelligence (AI). Thanks to this, the component will be able to monitor itself and, thus, can signal whether, when and where replacement or repair is necessary.

Sensing tool of the future: milling head with integrated sensors for temperature and pressure measurement.

In the BMWK-funded joint project SenseTrAIn, Fraunhofer ILT and its partners are pursuing the development of an end-to-end solution for wireless and continuous condition monitoring of sensor-integrated, additively manufactured components, from sensor technology to reporting in an SAP system.

Fraunhofer ILT is also involved in a collaborative research center in the field of reusable rockets. The researchers there are working on applications for sensor integration in LPBF components for use in space.

Quickly detect and fix defects using AI

In particular, DB Systemtechnik GmbH must be able to retrofit its trains trouble-free. Among other things, this includes wireless, feedback-free data transmission, which can be realized quickly and easily with the help of 5G, for example. Possible use cases emerged from technology scouting by the project partners: Promising fields of application include door mechanics, primary and yaw dampers and, above all, wheelset bearing caps that seal off wheel bearing housings. These are particularly relevant from a maintenance perspective.

Under increased load, the temperature rises and there is a risk of wear. Temperature and acceleration sensors integrated into the cover could detect hot runners and their causes at an early stage.

The use of AI in combination with the sensors enables users to rapidly detect and correct defects, yet AI requires a large valid database. Ideally, this data would have to be generated directly on the systems to be controlled in everyday operation. To test the new sensor technology under conditions that are as realistic as possible, the SenseTrAIn project is using Deutsche Bahn's advanced TrainLab. The data obtained in this way will initially be used to train the AI. If the technology functions smoothly, it is planned to test it in operation.

Selected research results
Mobility: pages 50, 51, 56, 57, 61, 67 and 71.

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

PRODUCTION

LASER TECHNOLOGY SOLUTIONS FOR INDUSTRY AND SOCIETY

LASER CUTTING AND WELDING FASTER AND BETTER THANKS TO ARTIFICIAL INTELLIGENCE

Short development, production and delivery times, growing cost pressure and, last but not least, the desire for higher quality assurance and consistent resource savings: Producers in all sectors of industry are under great pressure. As production processes become increasingly complex, modern automation technology can play a decisive role in solving these issues.

AI in production engineering

Not only is digital transformation advancing rapidly in all areas of life, but it is also regarded as an essential key to maintaining and expanding sustainable competitiveness in industrial production technology. The focus here is on the use of artificial intelligence (AI). It can increase the autonomy and functionality of manufacturing machines and equipment to an unprecedented degree. When "well-trained" by experts, AI can detect system deviations, errors and quality defects faster and more reliably than classic monitoring and control systems. AI can analyze sensor signals for more extensive pattern characteristics previously unrecognized by experts and initiate correspondingly more intelligent system decisions such as warning messages or parameter optimization.

The potential of AI is, therefore, also increasingly being tapped for manufacturing systems. Basic AI methods and tools are available and are being continuously developed. Solutions can now be implemented as examples and tested as prototypes under realistic conditions on and in production machines in companies, thus significantly helping to increase the efficiency of the entire value chain. Laser machines are predestined for this since they are particularly fast and can be precisely controlled and regulated.

DIPOOL – Laser machines learn something new every day

The approach of the cooperative research project DIPOOL, scientifically coordinated by Fraunhofer ILT to gain autonomy and agility, consists of combining machine learning (ML) with the unique ability to temporally and spatially program and control laser tools. The project DIPOOL is funded by the German Federal Ministry of Education and Research (BMBF) under the funding measure "ProLern" (funding code 02P20A000) and supervised by the Project Management Agency Karlsruhe (PTKA). The project specifically aims at developing the automatic and robust monitoring, quality assurance and optimization of laser machines for varying production tasks. DIPOOL will demonstrate the benefits of integrating machine learning into the two most widely used laser manufacturing processes – cutting and welding – a relevant topic for the laser industry and sheet metal processing companies. To achieve its goal, Fraunhofer ILT has established an interdisciplinary consortium of research institutes, industrial system suppliers and users. This consortium covers the entire development chain up to practical testing.

Smart Data instead of Big Data

To successfully use AI and especially machine learning, industries need a sufficient amount of data with the best possible quality. In order to generate such data, Fraunhofer ILT is conducting extensive series of tests on the cutting and welding of sheet metal materials. Fraunhofer ILT's innovative, scientific approach consists of imposing "minimally invasive" laser modulation patterns on the machining process. The process responds to this continuously with particularly characteristic signals dependent upon condition, which are recorded by sensors. The motto is Smart Data instead of Big Data. The domain knowledge of experts can thus be linked with artificial intelligence. ML algorithms can be trained highly efficiently first when such response signals are made available and fused with further sensor data of the machine. This enables the AI system to draw reliable conclusions and make accurate decisions.

Productivity increase in the network

Automatic-Systeme Dreher GmbH is setting up and evaluating a demonstrator for high-speed laser cutting of molded blanks. In addition, LBBZ GmbH will demonstrate 3D welding with the same digital optimization technology in a laser robot cell. The Institute for Industrial Information Technology IIIT of the Karlsruhe Institute of Technology (KIT) is contributing the fundamentals of an efficient signal analysis for machine learning. The use of a completely new type of multispectral sensor technology from 4D Ingenieurgesellschaft für Technische Dienstleistungen mbH will additionally increase the information content of the process signals for laser-beam welding applications that can be used with ML. Precitec GmbH & Co. KG is developing the associated smart system technology and sensor technology for laser cutting systems and Marx Automation GmbH is implementing the trained ML algorithms in monitoring, decision and control modules, the so-called inference system of the laser machine control.

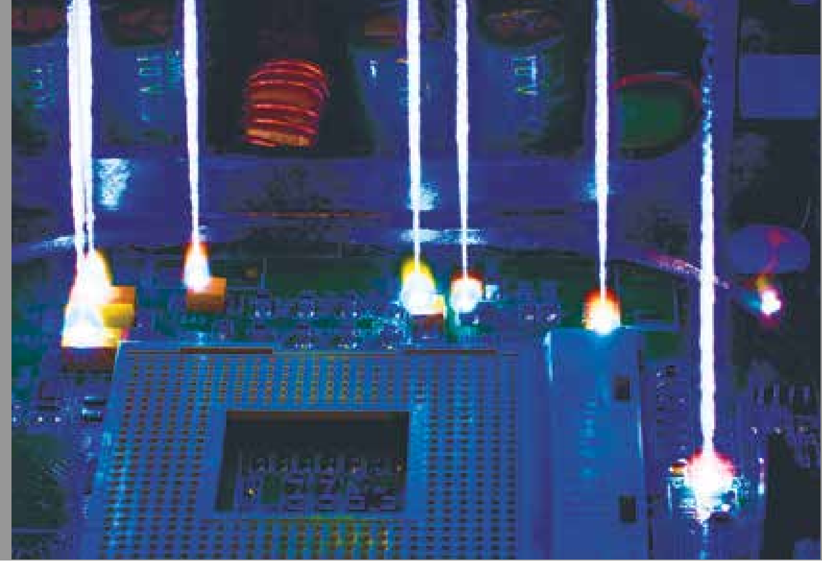
The innovations developed in DIPOOL are expected to increase the productivity of laser systems by around 25 percent, particularly for cutting and welding sheet metal materials in vehicle construction, the construction industry, the consumer goods industry and, of course, in mechanical and plant engineering. Additive and microtechnical laser applications will also benefit from further developments. Commissioning, start-up and alignment times will be shorter or eliminated altogether. The safety, stability and reliability of laser machines will improve, which will also increase product quality and resource efficiency.

Selected research results
Production: pages 46–71, 83, 92, 93 and 94.

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

DIGITALIZATION

LASER TECHNOLOGY SOLUTIONS
FOR INDUSTRY AND SOCIETY



KUBERNETES CONTROLS 100 LASERS SIMULTANEOUSLY VIA THE CLOUD

In the Cluster of Excellence "Internet of Production" (IoP), 200 scientists at RWTH Aachen University, in cooperation with Fraunhofer ILT and others, have set up a data center for controlling and monitoring industrial processes. They began by developing a control system for many lasers at Fraunhofer ILT and use the open-source software Kubernetes. With the Fraunhofer ILT software, newly installed lasers can be automatically installed and controlled remotely in just a few minutes.

Efficiently install and operate complex laser systems from the cloud

The ultrashort pulse (USP) laser is a complex system that can ablate almost any material with micrometer precision. Numerous sensors control the machine and the laser process. The software that reads the data from the sensors and controls the components must be correspondingly diverse. In industrial production, numerous laser systems are often operated in parallel. Researchers at Fraunhofer ILT have addressed the central issue of control software in such an environment. With current control systems, individual lasers can be controlled well, but conventional concepts are not sufficient for controlling 50 to 100 lasers.

A solution with open-source software

The machine control system was newly developed and programmed at the Chair for Laser Technology LLT at RWTH Aachen University in close cooperation with Fraunhofer ILT. The open-source software used offers more compatibility and development options for distributed systems. It can be used to control and optimize laser processing operations in which data from the scanner control system or from different sensor modules, as well as analysis data, must be taken into account during the ongoing process. The project started in 2018. In the meantime, the control system at Fraunhofer ILT is running stably in the beta phase. The core of the data center is Kubernetes, open-source software that can automatically upload, scale and maintain application programs on distributed computer systems. Kubernetes was originally designed by Google and is supported by leading cloud platforms such as Microsoft Azure, IBM Cloud, Red Hat OpenShift, Amazon EKS, Google Kubernetes Engine and Oracle OCI.

Distributed software for the automated manufacturing of the future

The potential has been recognized at RWTH Aachen University: Fraunhofer ILT's concept for a data center at the university was adopted as early as 2019. The Cluster of Excellence "Internet of Production" is working across the board on the digitalization of manufacturing technology. Their goal here is to enhance and simplify collaboration as well as securely bundle all relevant data from many sources in real-time, all in the context of cyber-physical systems and the Fourth Industrial Revolution. More than 35 university and non-university research institutions as well as the three Fraunhofer Institutes – FIT, ILT and IPT – are involved. Over 50 companies and associations are represented on the advisory board. They come from the automotive and aerospace industries, mechanical and plant engineering, and the software sector.

Both in the data center of RWTH Aachen University and at Fraunhofer ILT, the control systems are in use and under continuous development. The software is distributed automatically and the applications in the USP laser systems can be analyzed reliably. The software and hardware connection for a new laser, including integration into the cloud-based environment, takes only five minutes. The cluster is currently conducting research on how to automatically analyze measurement data. The goal is to bring together data from as many systems as possible and prepare it graphically for users. In the future, this data will form the basis for artificial intelligence (AI) and machine learning to optimize laser processes.

When Kubernetes is used for AI management, the control software can be systematically adapted based on the data currently accumulated, which is a special feature. In this way, data acquired in a plant can be evaluated daily and used to train an AI model. Data analysts can also adapt algorithms on this basis so that the new versions can be promptly transferred to all plants using the Kubernetes software. The system thus forms a central IT infrastructure and a stable basis for the adaptive production of tomorrow.

Selected research results
Digitalization: pages 43, 46, 65 and 90–97.

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

ENVIRONMENT

LASER TECHNOLOGY SOLUTIONS FOR INDUSTRY AND SOCIETY

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RECYCLING INSTEAD OF MINING – WITH LASER-BASED SENSOR TECHNOLOGY

In order to improve raw material supply, thus strengthening the industry's ability to compete in the world's markets, the Fraunhofer Institute for Laser Technology ILT and CRONIMETFerroleg. GmbH have jointly developed a laser-based sorting process for metal scrap as part of the BMBF-funded PLUS project. A new sensor makes the recycling of metallic raw materials many times more efficient than was previously possible. The EU project REVaMP goes one step further: In this project, Fraunhofer ILT experts are also contributing their expertise in materials analysis at the European level, thus making an important international contribution to securing an efficient supply of raw materials in the long term.

Germany as a production location and, thus, also our social prosperity depend to a large extent on the availability of metallic raw materials such as chromium, nickel, copper or cobalt. Since the global demand is rising, however, these materials are becoming increasingly scarce. For this reason, material recycling plays a decisive role and has become the most important source of metallic raw materials in Germany and Europe.

Better balance – ecologically and economically

What are the advantages of material recycling? Used metal scrap that can no longer be reused, such as pipes, sheet metal, tools, old cables, electrical and electronic scrap, and old parts from households or demolition sites, can be melted down and reused without any loss of quality. Since the materials have such a high value, the process ideally pays for itself – and produces significantly less CO_2 than the primary process: Not only is the expensive, technically complex extraction of mineral resources under sometimes highly critical conditions no longer necessary, but the resources do not need to be transported to destinations around the globe.

The crux: Both the price and availability of metal scrap and its recycling rate depend on numerous factors that are mutually dependent. These include fluctuating prices on the primary market, the life cycle of products and their collection rate, losses in the process, technical recyclability and the value of the alloy in question. The global markets are correspondingly volatile. If the price of primary metals rises, the availability of scrap falls, and vice versa. This entails high risks for companies.

Higher yield through laser use

In this context, Fraunhofer ILT, together with CRONIMET Ferroleg. GmbH from Karlsruhe, Germany, has developed a novel laser-based sorting process. The sensor technology, which was developed as part of the PLUS project funded by the German Federal Ministry of Education and Research (BMBF), makes the detection and sorting of alloys in metal scrap much faster and more accurate. The pilot system was put into operation at the CRONIMET Ferroleg site in Karlsruhe – and has proven to be effective. Among other things, it is designed for processing high-speed steels, or HSS for short.

Conventional methods are limited to the laborious manual measurement of a few alloys. In contrast, Fraunhofer ILT uses laser-induced breakdown spectroscopy (LIBS), a technology that can identify more than 20 special alloys even in small scrap parts – automatically, quickly and without contact.

Future technology for Europe

As part of the EU project "Retrofitting Equipment for Efficient Use of Variable Feedstock in Metal Making Processes" (REVaMP), which was launched in 2020, Fraunhofer ILT is now also contributing its expertise in materials analysis at a European level. The project, which is scheduled to run for three and a half years and funded by the European Commission as part of the Horizon 2020 program, is being carried out by an international consortium of companies and research institutes from Spain, Poland and Germany. They aim to put the knowledge gathered in the PLUS project on a universal basis, regardless of the alloys involved. To this end, a sensor is being built that can be integrated into existing industrial plants to make the recycling process fundamentally more efficient.

The REVaMP project focuses on the following central questions: What are the composition and properties of the alloys to be recycled? How much lead does the material contain? When does a material become molten and how much energy must be added? The aim of the effort is clear: Europe is to become less dependent on global raw material markets and the resource efficiency of companies is to be significantly improved.

Selected research results

Environment: pages 37, 38, 48, 53, 54 and 80.

Further information on the Internet at:

www.ilt.fraunhofer.de/en.html

QUANTUM TECHNOLOGY

LASER TECHNOLOGY SOLUTIONS
FOR INDUSTRY AND SOCIETY

PHOTONIC QUANTUM TECHNOLOGIES FOR A STRONG INNOVATION ECOSYSTEM

Quantum technologies offer enormous potential for developing disruptive applications in areas such as imaging, metrology, communications and computing. Together with international partners from research and industry, Fraunhofer ILT is developing laser-based solutions for the implementation and application of Quantum Technologies 2.0, in which the quantum properties of microscopic systems and individual particles can be adjusted, modified and detected in a controlled manner. Through strategic initiatives and long-term collaborations, the partners are establishing and promoting a high-growth innovation ecosystem for quantum technologies locally in NRW and beyond in Germany and Europe.

The precision toolbox of science and industry can be expanded to include completely new possibilities thanks to second-generation quantum technologies. When implemented in secure communications, highly sensitive metrology, or complex computing tasks, these technologies already illustrate the disruptive potential of future applications. Moreover, they justify impressive market forecasts by recognized economic experts as well as billion-dollar investments by tech corporations and strong public funding programs by leading economies – all of which will further accelerate the technology race in these and many related areas.

Photonics is a key to quantum technology-based applications. Fraunhofer ILT scientists are investigating how microscopically limited systems can be mastered with the "tool of light" and how quantum systems can be made accessible in a controlled manner. Accomplishing this involves the practical use of the properties of individual photons, electrons or atoms as well as quantum effects such as the superposition of states and entanglement for novel applications.

Single photons can be used, for example, to transmit quantum information selectively and to interconnect quantum processors at different locations. Unlike other quantum systems, photons are stable under more than only cryogenic environmental conditions and can be transmitted over long distances without losing relevant quantum information. Lasers can be used to control or read out the state of various quantum systems (e.g. ions or atoms acting as qubits in processors). Lasers and laser processes can also be used effectively to fabricate and produce the necessary components of quantum technology, such as ion traps and micro-optical systems.

With its expertise in laser technology and optical technologies, Fraunhofer ILT is working on a broad range of topics to promote comprehensive scientific cooperation with German and international partners, achieve outstanding R&D results and open up new areas of application for quantum technologies. It is focusing on technology transfer and, in cooperation with RWTH Aachen University, talent transfer to business and industry. Strategic alliances and research clusters within and outside the Fraunhofer-Gesellschaft are being systematically expanded.

Technologies for quantum imaging, computing and information networks

With the Fraunhofer lighthouse project "QUILT", which was successfully completed in July 2021, the Fraunhofer Institutes ILT, IMS, IOF, IOSB, IPM and ITWM took quantum imaging to a new level. The Aachen scientists developed novel photon pair sources and quantum interferometers that allow high-resolution imaging in the mid-infrared (MIR) – a spectral range that was previously difficult to access. This involves imaging with non-detected photons, where the photons interacting with the sample do not need to be detected directly because the imaging is performed using entangled partner photons at a more accessible wavelength. Thus, the MIR "fingerprint" range from 1.5 to over 4.5 µm can be analyzed using sophisticated and cost-effective silicon-based camera technology in the wavelength range from 600 to 700 nm.

Quantum computers are based on so-called qubits, in which the information is stored in any number of states, in contrast to the classical binary hardware concept. For this purpose, Fraunhofer ILT is developing laser- and radiation-based fabrication techniques for ion traps and NV centers. Ultrashort pulse lasers and selective laser-induced etching can be used to precisely fabricate ultra-fine structures down to the sub-micrometer range with high geometric flexibility in glass as well as to bring about innovative packaging techniques. With these 3D-capable technologies, compact, monolithic ion traps made of glass can be manufactured as central processor elements in quantum computers. To this end, Fraunhofer ILT is developing technologies and process engineering approaches to manufacture new ion trap designs with a high potential for qubit scaling for more powerful quantum computers, among others, in the projects "IQuAN" and "ATIQ." Quantum computers can be interconnected – based on entanglement – over long distances with single photons transmitted through optical fibers. This requires quantum frequency converters (QFC) that convert photons in their wavelength efficiently, with low noise and without destroying the fragile quantum states. Fraunhofer ILT is developing such converters together with QuTech, a collaboration of TU Delft and TNO, as part of the Fraunhofer ICON project "QFC-4-1QID". At QuTech in May 2021, the experts from Aachen demonstrated a QFC architecture with world record performance in terms of both noise performance and, potentially, signal-to-noise ratio. The converter is a key component in order to demonstrate the first fully entanglement-based quantum internet at QuTech, for which qubits will soon be connected with optical fibers in Delft, Leiden, The Hague and Amsterdam.

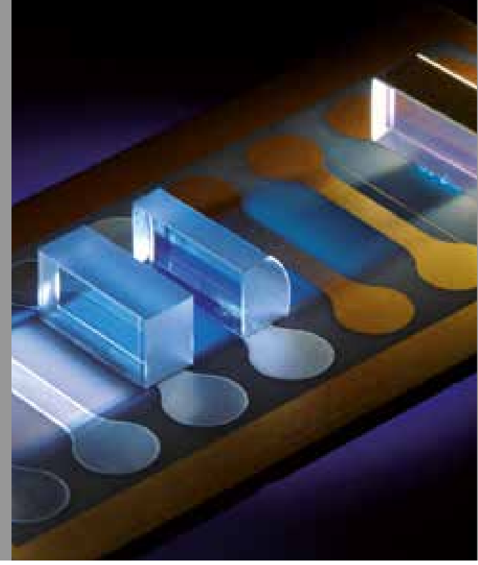
Strategic initiatives

Together with Forschungszentrum Jülich, the NRW Fraunhofer Institutes FHR, IAIS, ILT, IMS, SCAI are the driving force behind the implementation of the Center of Quantum Science and Engineering (CQSE) in the Rhineland. The center conducts market-oriented research and builds bridges between excellent basic research and companies at an early stage. Furthermore, it focuses on implementing and applying new quantum technologies, with an emphasis on system integration, engineering and production.

With an MoU for long-term cooperation, the Fraunhofer-Gesellschaft and QuTech joined forces more closely in December 2021. One of their goals is to establish a multinational quantum network in the EU. To this end, the partners will establish technology and interface standards and contribute to setting the European agenda in a coordinated manner. It is also planned to install the first German quantum internet node of a transnational and entanglement-based network at Fraunhofer ILT.

Further information on the Internet at:
www.ilt.fraunhofer.de/en/technology-focus/quantum-technology.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.

TECHNOLOGY FOCUS

DIGITALIZATION

The technology focus Digitalization is closely linked to the activities of the technology focuses Laser and Optics, Laser Material Processing, Medical Technology and Biophotonics as well as Laser Measurement and EUV Technology. It combines competencies in digital production around laser technologies: from design-to-production, digital twin and smart simulation to fog and edge computing. The comprehensive view of processes and procedures – from modeling to data integration – is a core component of the technology focus of digitalization.

The services offered in »Design to Production« include closed workflows, which are recorded completely digitally. This ensures transparent, secure and versioned documentation and handling of data. The services offered under »Digital Twin« comprise virtual models of processes with which the real data of the processes can be systematically collected and analyzed. Influencing factors can be easily identified and cause-effect relationships demonstrated without intervening in the real process.

The »Artificial Intelligence (AI) Lab« provides space for experimenting with machine learning and neural networks. The results are presented to users in a comprehensible way via visualization environments. The »Digital Light Factory« provides them with an individual and isolated development and production environment. At its core, it comprises the production technology with all desired control and automation interfaces.

QUANTUM TECHNOLOGY

Modern communication and the internet would not be possible without the first generation of quantum technologies. Now a paradigm shift is imminent, one that will enable further development towards quantum computers and the quantum internet. Whereas collective particle phenomena were in the foreground of quantum developments, researchers are currently able to manipulate and control individual photons and quantum states in a selective manner.

Together with top international researchers, scientists at Fraunhofer ILT are developing photonic solutions for quantum technology tasks. In particular, beam sources with tailored properties and precise assembly technologies for optical components and systems are of great interest for quantum technology. For example, the Aachen engineers are optimizing single photon sources with very high signal-to-noise ratios and realizing waveguides, couplers and filters in glasses and crystals for quantum imaging and fingerprint spectroscopy. They are also focusing their research on quantum frequency converters for connecting qubits to fiber optic networks, which will allow quantum computers to be connected in networks in the future.

At the Aachen location, the proximity between Fraunhofer ILT, RWTH Aachen University and Forschungszentrum Jülich ensures there is a fruitful exchange of know-how and technology. Regional and international collaborations are paving the way for research to technically implement Quantum Technologies 2.0.

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.

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Bundesministerium für Wirtschaft und Energie

Die Landesregierung Nordrhein-Westfalen

DFG Deutsche Forschungsgemeinschaft

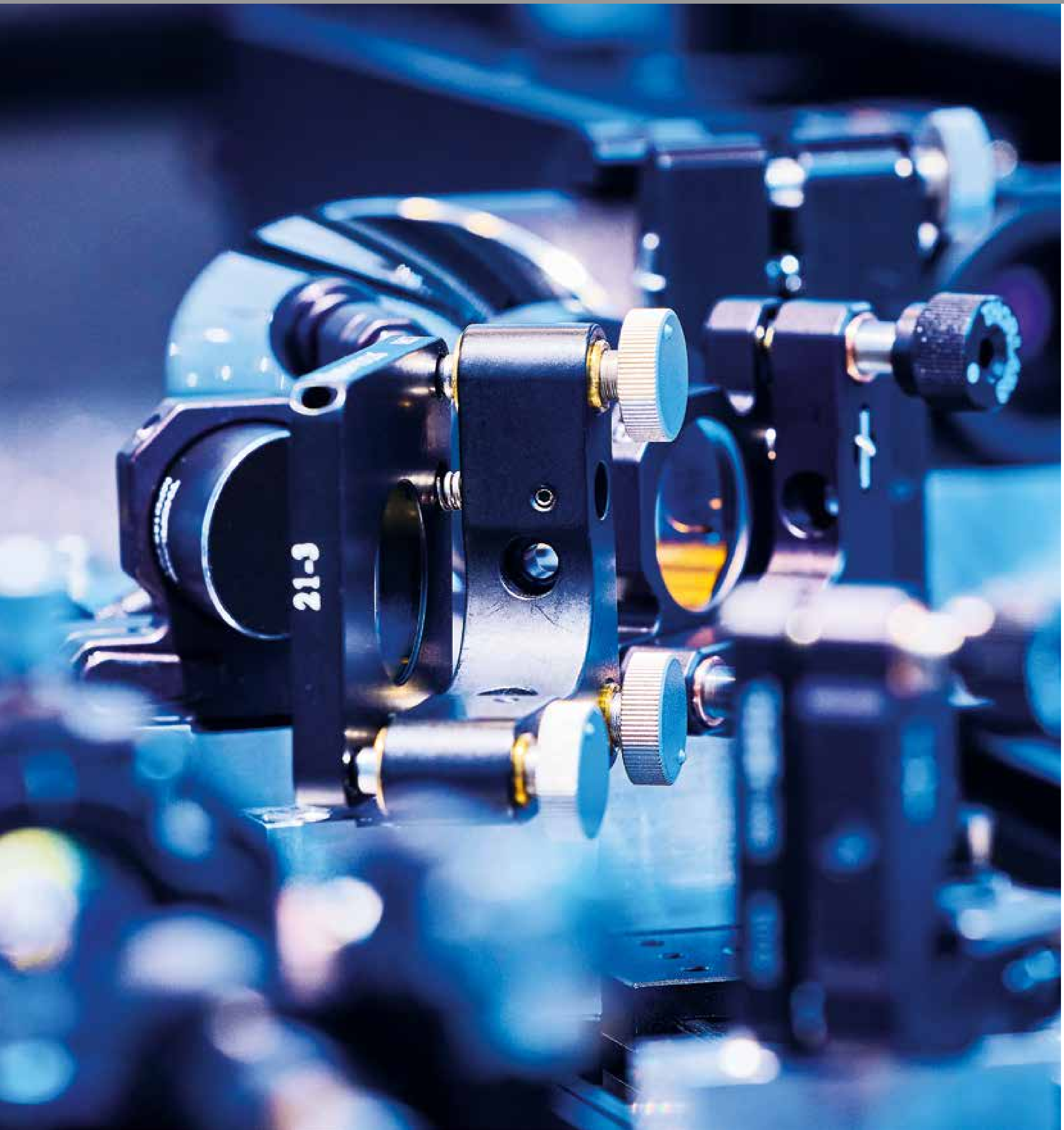
2014-2020 EFRE.NRW Investitionen in Wachstum und Beschäftigung

esa European Space Agency

EUROPÄISCHE UNION

EUROPÄISCHE UNION
Investition in unsere Zukunft
Europäischer Fonds für regionale Entwicklung

LASER AND LASER OPTICS



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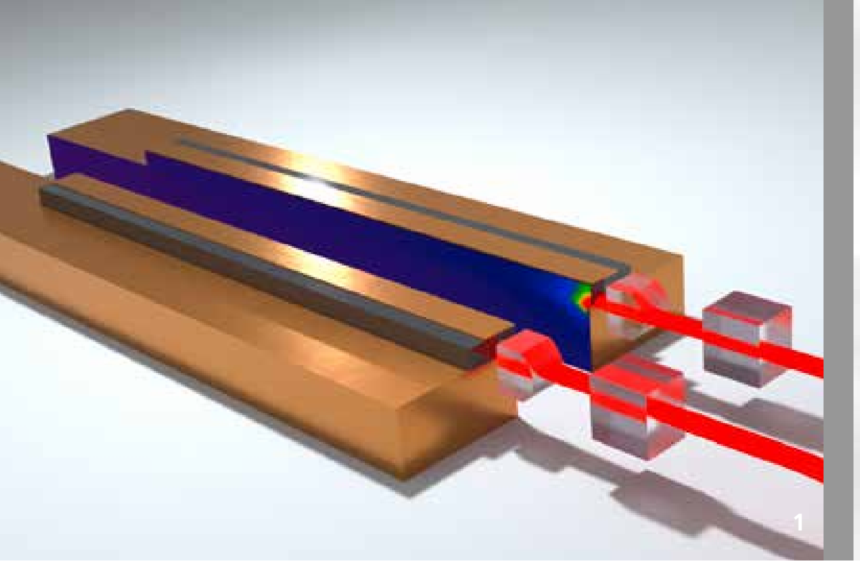

MODELING AND SIMULATION OF HIGH-POWER DIODE LASERS

Task

Diode lasers – either edge-emitting diode lasers (EEDL) or vertical-cavity surface-emitting diode lasers (VCSEL) – are the preferred laser beam source in a wide range of applications. At Fraunhofer ILT, computer simulations are used to optimize EEDLs and VCSELs with a focus on increasing output power and radiance. EEDLs are currently limited in their output power by the catastrophic optical damage (COD) threshold, while the limitations of VCSELs result from the smaller laser active volume and the reabsorption of laser radiation in the current-conducting, doped layers of the diode. Currently, Fraunhofer ILT is focusing its research on understanding the COD mechanism in EEDL as well as on increasing the light yield in VCSEL by stacking several active layers with so-called tunnel diodes.

Method

To analyze and optimize high-power diode lasers, Fraunhofer ILT is developing simulation software (SEMSIS) for the multiphysics simulation of EEDLs and VCSELs. Among other things, this software includes modules for simulating heat and electrical transport, for calculating the optical eigenmodes of the microcavities, and models for analyzing the properties of the light-amplifying quantum films. The institute is continuing to develop SEMSIS for our industrial partners. Furthermore, Fraunhofer ILT is combining it with commercial software tools for isolated or coupled simulation to identify improved heterostructure designs, contact geometries or external optical systems for partial feedback of the emitted radiation.

Results

Fraunhofer ILT has developed a more detailed understanding of the COD mechanism for free-running EEDLs as well as ECDLs (external-cavity diode laser), as compared to the state of the art. Furthermore it has identified improved designs for EEDLs with reduced slow axis beam divergence and radiance limiting factors of VCSEL single emitters with external resonators. Currently, it is helping develop a next-generation lidar system by running simulations on the electrical transport in VCSEL single emitters with tunnel diodes and on the thermomechanical properties of the VCSEL array with integrated silicon driver chip. In addition, it is designing the transmitter optics.

Applications

EEDLs with optical feedback are used as pump light sources for fiber and solid-state lasers, and VCSEL emitters are used in lidar sensors and direct material processing, among other applications.

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Dr. Martin Traub, Ext: -342
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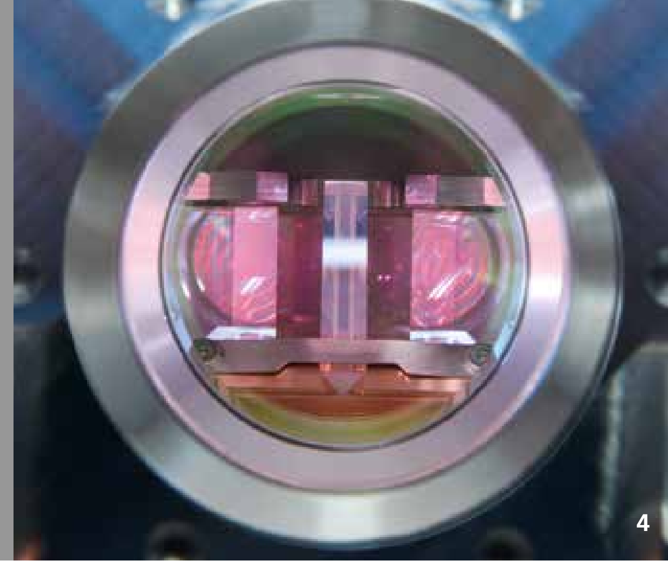
1 Edge emitting laser diodes with external cavity (ECDL).
2 Structure of a VCSEL single emitter.



LASER FLOATING ZONE SYSTEM FOR THE GROWTH OF β–GA_2O_3 SINGLE CRYSTALS

Task

Among semiconductors, β-Ga_2O_3 stands out since it has a comparatively large bandgap of approx. 4.8 eV, which predestines the material for use in high-performance electronics. In addition, Ga_2O_3 can be grown in monocrystalline form from the molten phase, in contrast to the established wide bandgap semiconductors SiC and GaN. For β-Ga_2O_3, the crucible-free floating zone method can be used; here the material is melted in a defined area with diode laser radiation (LDFZ method). Together with the Japanese National Institute of Advanced Industrial Science and Technology (AIST) and the Chair for Laser Technology LLT, Fraunhofer ILT has continued to develop the LDFZ method, scaling up the system performance into the multi-kilowatt range and increasing the crystal diameter to 1.5 to 2 inches.

Method

Using preliminary tests at AIST in the field of LDFZ crystal growth, Fraunhofer ILT developed, set up and put into operation an optical system for shaping multi-kW diode laser radiation. A fiber-coupled diode laser was used as the beam source. In addition, the institute developed, built and tested a switch box to evaluate temperature, leakage and flow sensors as well as to control the laser interlock. At AIST, the laser, the optics system and the read-out electronics were integrated into the existing crystal growing furnace and the entire system was put into operation.

Results

To generate a process-adapted intensity distribution, the laser radiation emerging from the fiber is homogenized and divided into five partial beams of equal power, which are finally guided radially to the processing point via deflection mirrors. The optical system was characterized by measuring the intensity profiles for the individual partial beams at 150 W. In addition, an endurance test with a power of 20 kW was successfully carried out. After commissioning the system, AIST conducted the first melting experiments with polycrystalline Ga_2O_3 feed rods with a diameter of 1.5 inches.

Applications

Currently, the LDFZ method is used to grow Ga_2O_3 crystals as well as other metal oxides whose suitability for applications in high-performance electronics is being investigated. In addition, the suitability of this method is being examined for other crystal materials.

This project is being funded by the Fraunhofer-Gesellschaft as part of the ICON program.

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3 Setup and commissioning of the LDFZ optical system.
4 View of the beam splitter unit through the entrance window.

LIDT MEASURING STATION FOR THE QUALIFICATION OF HIGH PERFORMANCE OPTICAL SYSTEMS

Task

Understanding the laser-induced damage threshold (LIDT) of optical components is essential for the design of efficient yet reliable laser beam sources, especially when they need to be used in aerospace applications. For the Franco-German MERLIN satellite mission – to detect methane in the Earth's atmosphere – Fraunhofer ILT is conducting LIDT measurements on representative samples (so-called "witness samples") from each manufacturing batch. The measurements are used to qualify the optical systems before they are installed in the MERLIN laser.

Method

The laser source of the LIDT measuring station is a Q-switched, longitudinal single-mode oscillator with two INNOSLAB amplifier stages using up to 500 mJ pulse energy at 1064 nm or 100 mJ at 1645 nm from a downstream frequency converter. The online destruction detection system, which uses scattered light detection, works independent of wavelength. In addition, offline detection uses differential interference contrast microscopy. Fraunhofer ILT conducted S-on-1 tests for the more than 150 different coating samples of the MERLIN laser according to ISO 11254-2 with 10,000 shots and a pass/fail test with 100,000 shots, each with defined fluences per irradiation position. For the coordinated qualification process, the institute tests the specimens at approximately 40 positions, depending on the specimen size. The angle of incidence of the test radiation is 0°, 45° or 55°, depending on the batch specification.

Results

The combination of S-on-1 and pass/fail tests was used to investigate whether the laser-induced damage threshold is higher than the load in the laser in the long term. Tests on representative samples are used to qualify batches of optical systems before they are installed in the MERLIN laser.

Applications

The laser-induced damage threshold is relevant for optical systems that need to fulfil special reliability requirements, such as in aerospace applications. In addition, accurate knowledge of the damage threshold helps engineers adapt designs of optical systems to make them less expensive and more reliable. When the setup is extended, other test parameters, such as other wavelengths or pulse durations, will be available for testing.

The work is being funded by the German Federal Ministry for Economic Affairs and Energy BMWi under grant number 50EP1601 and carried out on behalf of DLR Space Management under subcontract to Airbus Defence and Space GmbH.

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1 LIDT test setup.

FIRST MEASUREMENT CAMPAIGN WITH A COMPACT LIDAR SYSTEM BASED ON AN ALEXANDRITE LASER

Task

At the Leibniz Institute for Atmospheric Physics (IAP), mobile resonance lidar systems are used to measure wind and temperature profiles of the atmosphere up to altitudes of 110 km. By using multiple systems with overlapping observation areas, Leibniz IAP can acquire a lidar network with unrivaled resolution and coverage. These data need to be collected at remote locations under harsh environmental conditions, e.g. in polar or tropical regions, over long periods of time. Therefore, rugged lidar systems must be compact, easily transportable, and operate autonomously with low maintenance. Using novel highly efficient alexandrite lasers and innovative lidar technology, Fraunhofer ILT and the Leibnitz IAP have developed a versatile, compact lidar system (~ $1 m^3$) that could be mass-produced cost-effectively.

Method

As part of a long-term collaboration with Leibniz-IAP, Fraunhofer ILT has developed the lidar emitter based on diode-pumped alexandrite lasers, built two prototypes and integrated them into a novel highly compact lidar system. An initial two-month measurement campaign was conducted with the lidar system during the winter. The institutes developed and tested methods for controlling the emitter and data acquisition with the lidar system. For this purpose, wind profiles with high resolution were recorded using aerosols up to an altitude of 30 km and compared with reference data. In addition, the reference wavelength of potassium was addressed and the potassium layer was investigated at an altitude of up to 110 km.

Results

The operation of the lidar system under realistic conditions was successfully demonstrated. Neither was performance degradation noticeable, nor was maintenance required during more than 1000 hours of measurements. The results of the wind measurements were compared with reference data and the higher accuracy and resolution were verified. In addition, the potassium layer could be measured for the first time at an altitude of up to 110 km during daytime. Thanks to the proven design and a new pump source, the pulse energy could be increased by a factor of three in laboratory tests. Two further highly compact prototypes of the next generation are currently being built with the increased energy, but unchanged dimensions.

Applications

The resonance lidar will initially be used for ground-based measurements of temperature and wind profiles. An array of lidar systems provides large area coverage. The potential for satellite-based use is currently under discussion.

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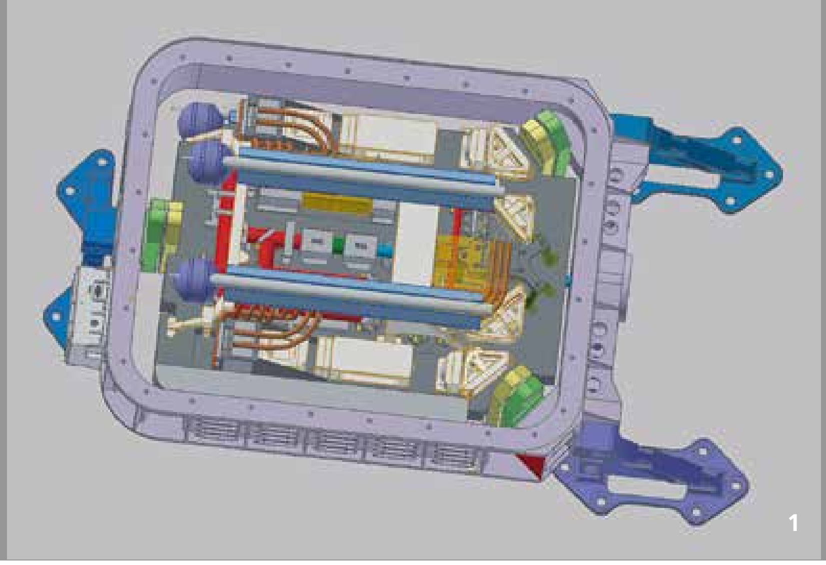
2 Alexandrite laser integrated in the lidar system.



LASER BEAM SOURCE FOR SATELLITE-BASED WIND MEASUREMENT

Task

As part of the European Space Agency's AEOLUS mission, the global wind distribution in the atmosphere is currently being measured with a satellite-based Doppler lidar instrument. For the follow-up mission AEOLUS Follow-On planned by ESA and the satellite operator EUMETSAT, a more powerful laser beam source is required – which can emit single frequency laser pulses of 150 mJ energy at a pulse repetition rate of 50 Hz and a wavelength of 355 nm. Fraunhofer ILT is currently developing an engineering model (EM) of the laser beam source in cooperation with Airbus Defense and Space.

Method

The laser concept is based on the results of the NIRLI project completed in 2016, in which Fraunhofer ILT built a laser consisting of a Q-switched oscillator and two downstream Nd:YAG INNOSLAB amplifiers based on Nd:YAG. This demonstrated more than 500 mJ of pulse energy at a wavelength of 1,064 nm. The frequency is converted to a pulse energy of 150 mJ in the UV with two LBO crystals. For AEOLUS-Follow-On, space-qualified components are available for the oscillator and the first amplifier stage. For the second INNOSLAB amplifier stage and the frequency converter, the size of the optomechanical components needs to be scaled up. Using the experience gained in the MERLIN project, the institute is developing a thermal system for dissipating the heat loss of about 300 W under space conditions. It is working on the EM design in close collaboration with Airbus Defense and Space and SpaceTech.

Results

A complete preliminary design of the laser beam source was created and accepted by ESA during a preliminary design review (PDR). In the model, the heat dissipation is efficiently conducted out of the housing by means of heat pipes so that only a small fraction of the power dissipation couples into the baseplate. This allows stable operation over a wide temperature range.

Applications

The results obtained in the project are primarily of interest for lidar laser beam sources in harsh environments such as satellites, aircraft or helicopters. The setup technology enables stable and maintenance-free operation for many years so that the findings can also be used to develop solid-state lasers suitable for industrial use or small compact beam sources.

The work is being carried out on behalf of the European Space Agency (ESA) under contract number 4000132323/20/NL/AD.

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1 CAD model of the AEOLUS follow-on transmitter.

LASER BEAM SOURCES WITH A WAVELENGTH OF 2 µm FOR GRAVITATIONAL WAVE DETECTION

Task

Gravitational wave detectors provide an alternative view into interstellar processes such as the collision of stars and black holes, which can be detected by specific signatures in the form of gravitational waves. These detectors, thus, complement other established observational methods in the exploration of the universe. In the E-TEST project, key technologies are being developed for a third-generation gravitational wave detector, also known as an Einstein telescope. To this end, Fraunhofer ILT is developing a highly stable laser with a wavelength of about 2 µm and a spectral linewidth of less than 10 kHz, which could be used within an interferometer to detect minute changes in length induced by gravitational waves.

Method

To generate radiation with a narrow linewidth at a wavelength of about 2090 nm, the institute is investigating different solid-state laser concepts. As a first approach, it will develop a unidirectional ring oscillator based on Ho:YAG crystals and – using the knowledge gained from this – a non-planar ring oscillator, which is particularly suitable for generating radiation with a low linewidth. A multistage fiber laser concept based on holmium-doped fibers will be developed to amplify the generated radiation. The extremely high stability requirements are to be met by actively controlling different actuators. Furthermore, the institute is developing highly stable thulium-doped fiber lasers at a wavelength of about 1950 nm to pump the fiber laser.

Results

After the concept was developed, the first stage of the fiber laser for amplifying radiation around 2090 nm was designed and tested experimentally. The next steps will be to actively stabilize the output power and investigate the solid-state laser experimentally.

Applications

Beam sources with wavelengths around 2 µm have other applications besides gravitational wave detectors, including those in quantum technology, medical technology and materials processing. While an improved signal-to-noise ratio of the gravitational wave detector is targeted in interferometry, in medical technology and material processing the improved absorption of the 2 µm radiation is relevant.

This project is being funded by Interreg EMR, European Regional Development Fund ERDF and by the Ministry of Economic Affairs, Innovation, Digitalization and Energy of the State of North Rhine-Westphalia.

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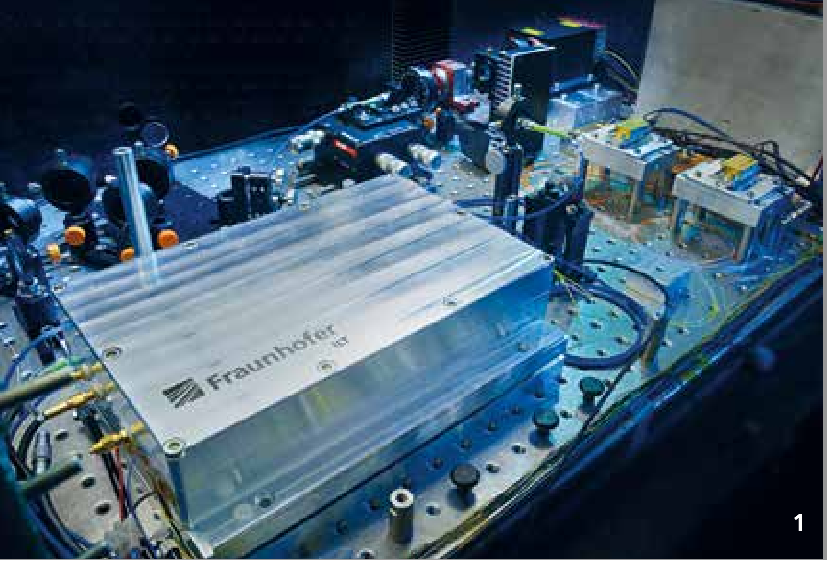
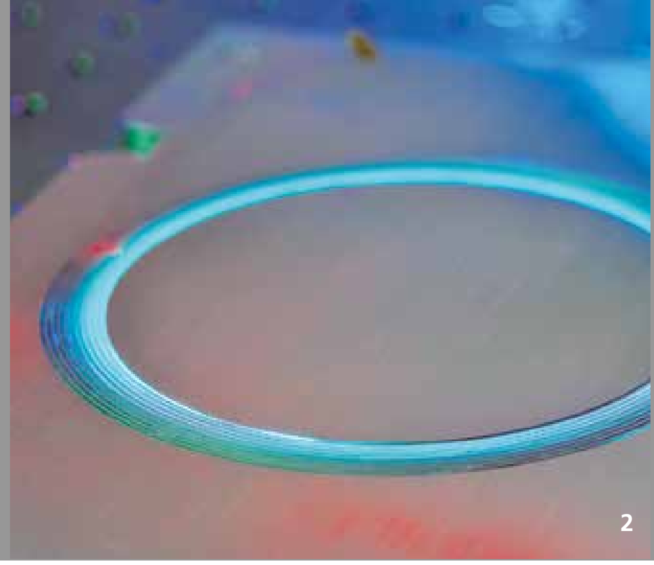
2 Thulium-doped fiber amplifier for E-TEST.





HIGHLY STABLE FIBER AMPLIFIERS FOR SATELLITE-BASED GRAVITATIONAL WAVE DETECTION

Task

Within a project of the European Space Agency ESA, Fraunhofer ILT has developed and built a power-stabilized, spectrally narrowband fiber amplifier with 10 W output power as a study for the future space-based gravitational wave detector LISA (Laser Interferometer Space Antenna). Since the requirements for the engineering model (EM) have become stricter, the institute is continuing to develop and investigate the amplifier, including stability requirements for power and phase; the EM is being implemented at a project partner in the current project phase. Furthermore, since the Technology Readiness Level (TRL) of the components has to be confirmed for the EM, Fraunhofer ILT is conducting long-term tests of the components in a vacuum.

Method

In order to meet the extreme stability requirements for the EM as well, the institute is designing and experimentally comparing different fiber amplifier concepts. One question here is whether the particularly strict requirements are technically feasible. Special measuring stations are used to measure the power stability and the phase noise. For the operational thermal-vacuum component tests, Fraunhofer ILT is developing a fiber amplifier based on the technology established for the LISA.

1 Breadboard setup of the highly stable fiber amplifier of the LISA preliminary study.
2 Active fiber of the amplifier in fiber spiral.

Results

An output power of 10 W with a spectral linewidth of < 10 kHz at a wavelength of 1064 nm could be demonstrated for the fiber amplifier concepts investigated. To the best of our knowledge, the high power stability requirements of the LISA mission could be met for the first time worldwide at Fraunhofer ILT over the entire frequency range, especially in the technically challenging low frequency range from 10^{-5} to 1 Hz. The institute also investigated the physical feasibility of the phase noise requirements, which were fulfilled for 1 W output power.

Applications

In addition to their use in gravitational wave detectors, highly stable narrowband fiber amplifiers can be used for quantum technology, satellite-based gravitational field measurement and in communications applications.

The work is being funded by the European Space Agency (ESA) under the grant number 4000119715/17/NL/BW.

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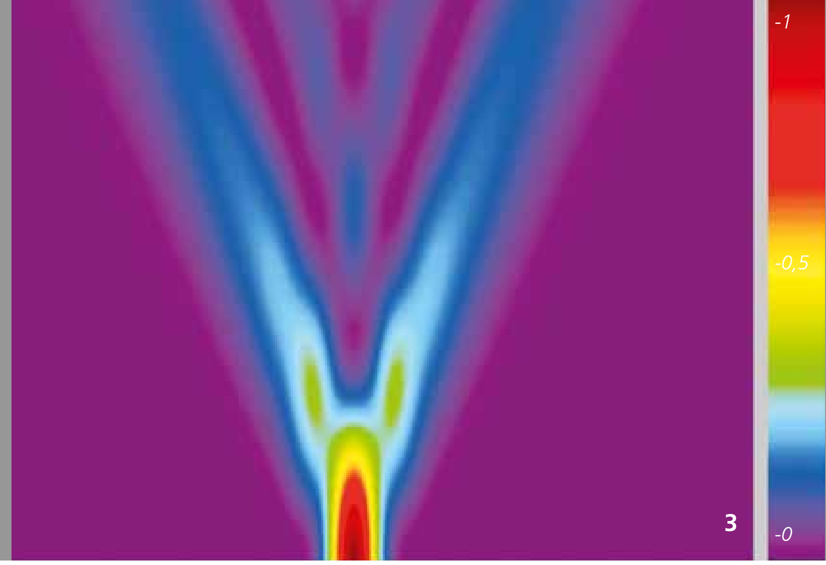

FREQUENCY COMB IN THE VACUUM ULTRAVIOLET FOR OPTICAL EXCITATION OF THE NUCLEAR TRANSITION IN 229-THORIUM

Task

229-Thorium is the only element that has a nuclear transition in the optical spectral region suitable for operating a nuclear clock. To drive this transition optically, a tunable frequency comb in the vacuum ultraviolet (VUV) will be constructed, combining a large amount of power per comb mode (nW/mode) and an extremely small linewidth (kHz). Furthermore, its spectrum shall cover the range around 150 nm based on current knowledge of the transition wavelength.

Method

The process of high harmonic generation (HHG) has a very small conversion efficiency, but allows a coherent conversion that preserves the comb modes and reaches wavelengths in the 10 - 200 nm range. Laser amplifiers with high power are available for generating the 7th harmonic of a frequency comb in the infrared (IR). To achieve the required VUV power, Fraunhofer ILT uses a laser with up to 400 W average power, a nonlinear pulse compression to about 50 fs to increase the HHG efficiency, and an enhancement resonator with a circulating power of 10 kW. One challenge this poses is the output coupling of the harmonics from the resonator, which is done geometrically here.

Results

Fraunhofer ILT has worked out and designed the concept of the VUV frequency comb with the relevant specifications in detail. It has also begun to build the setup and completed building the first components.

Applications

The laser system will be an essential building block for a thorium nuclear clock, which can achieve a much higher accuracy than previous atomic clocks. A frequency comb in the VUV or EUV will also make further applications in spectroscopy possible. In addition, spatially coherent sources in the VUV to the XUV range, which can be built with HHG, can be used in numerous applications in science and industry, for example, in photoemission spectroscopy, microscopy, lithography and metrology.

The development of the VUV frequency comb is being funded by the ERC Synergy Grant ThoriumNuclearClock within a subcontract by Ludwig-Maximilians-Universität München.

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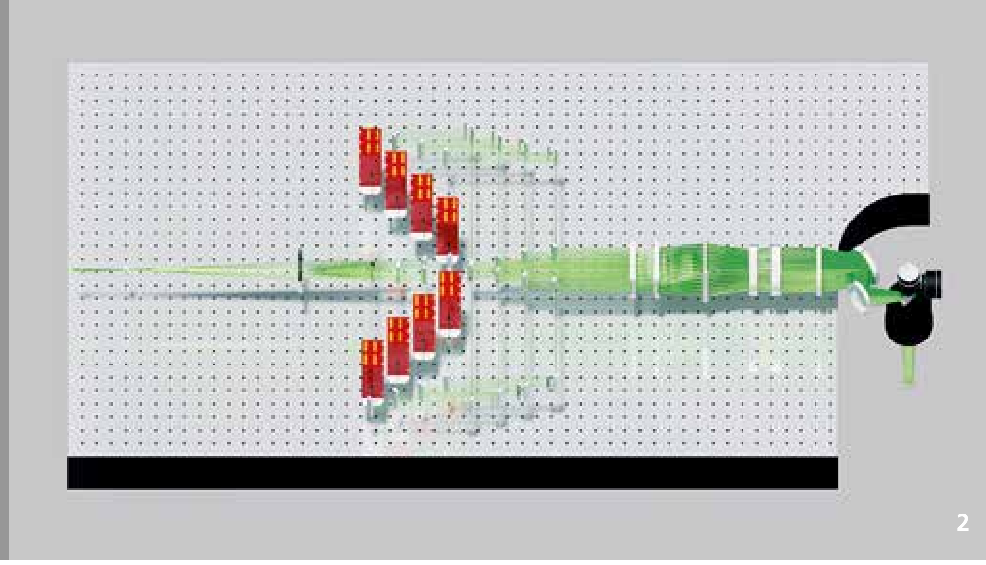
3 Simulation of the spectral intensity (abscissa) over the round trips in the MPC (ordinate) at nonlinear spectral broadening for pulse compression.



SOLDERING PROCESS DEVELOPMENT FOR CONTACTING CRYSTALS AND HEAT SINKS

Task

Ytterbium INNOSLAB crystals must be cooled in amplifier stages of ultrashort pulse beam sources due to thermal stress. They are normally cooled by contacting them with active heat sinks. Here, homogeneous and pore-free bonding with high thermal conductivity is essential so that a slab crystal package can be used in high-power lasers. Fraunhofer ILT has analyzed and continued to develop the current reflow soldering process to improve reproducibility and reliability as well as to generate an optimized interface between crystal and heat sink. The institute has also taken the scaling of the transverse dimensions into account.

Method

First, Fraunhofer ILT investigated the mechanical contact between crystal and heat sink after a reflow soldering process using computer tomography. Furthermore, it used a polarimeter to evaluate how the optical properties of the crystal changed due to the reflow soldering process. These changes include, in particular, the depolarization and the optical path difference. The results obtained here can be matched with parameters of the reflow soldering process as well as the specifications of the heat sinks and the crystal.

Results

The contacts made with previous reflow soldering processes have individual pores which are large in proportion to the soldering area. These defects can also be detected by means of polarimeter measurements. In addition, hundreds of pores that are small in relation to the solder area can also occur in the solder joint. These small inhomogeneities, however, cannot be detected with polarimeters. The institute was able to significantly increase the homogeneity of the bond by adjusting the parameters of the reflow soldering process as well as the specifications of the heat sinks and the crystal. These solder layers exhibit few or no pores in the resolution range of the CT device used. Thus, the institute can demonstrate that the prerequisites for manufacturing optimized slab crystal packages for high-power lasers have been fulfilled.

Applications

Based on the advanced soldering process, slab crystal packages for use in amplifier stages with about 5 kW pump power were built and experimentally investigated.

The R&D project underlying this report has been funded within the Fraunhofer Cluster of Excellence Advanced Photon Sources (CAPS).

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1 Slab crystal package.

4D MULTIBEAM OPTICAL SYSTEM FOR FLEXIBLE HIGH-POWER ULTRASHORT PULSE LASER MATERIAL PROCESSING

Task

Thermal accumulation and plasma formation from high pulse energy limit the usable power of ultrashort pulsed laser beam sources in industrial applications and, thus, often prevent them from being used economically. Therefore, Fraunhofer ILT is investigating how a dot-matrix printer could serve as a model to solve these issues. Here, the laser power is divided into 8x8 beams, with each beam shaped by a few optical elements, thus enabling each individual beam to be switched on and off temporally.

Method

The raw beam of an ultra-short pulsed high power laser beam source is split into a symmetric 8x8 beam matrix by a diffractive optical element. A prism stack composed of several prisms joined to form a component parallelizes the individual beams emerging at discrete angles, which are then coupled column-wise (1x8) into eight acousto-optical modulators. These switch each partial beam on or off individually by deflection. All switched-on beams are deflected and expanded by a combination of a second prism stack and a telescope, a combination that makes it possible to adjust the spot distance and the spot diameter on the workpiece. Individual lenses, or stacks of eight lens strips identical in their optical characteristics bonded into a single component, form all the beams simultaneously, which reduces complexity and cost. The spot matrix is finally positioned and focused on the workpiece using a galvanometer scanner and a plane-field lens.

Results

The novel approach based on prism and lens stacks makes it possible to fabricate compact and modular multi-beam optical systems. These scalable 4D systems overcome the limitations of common relay optical systems and fully compensate for spot matrix distortion caused by the scanner for the undeflected position. In addition to beam shaping in three dimensions, the individual temporal modulation of each partial beam enables users to structure components in any manner desired.

Applications

The main field of application is in the manufacture of functional surface structures for industry, medicine and aviation, as well as for molding, embossing and printing tools.

The work was carried out as part of the EU’s MultiFlex project under the European Union’s Horizon 2020 Research and Innovation Programme under grant number 825201.

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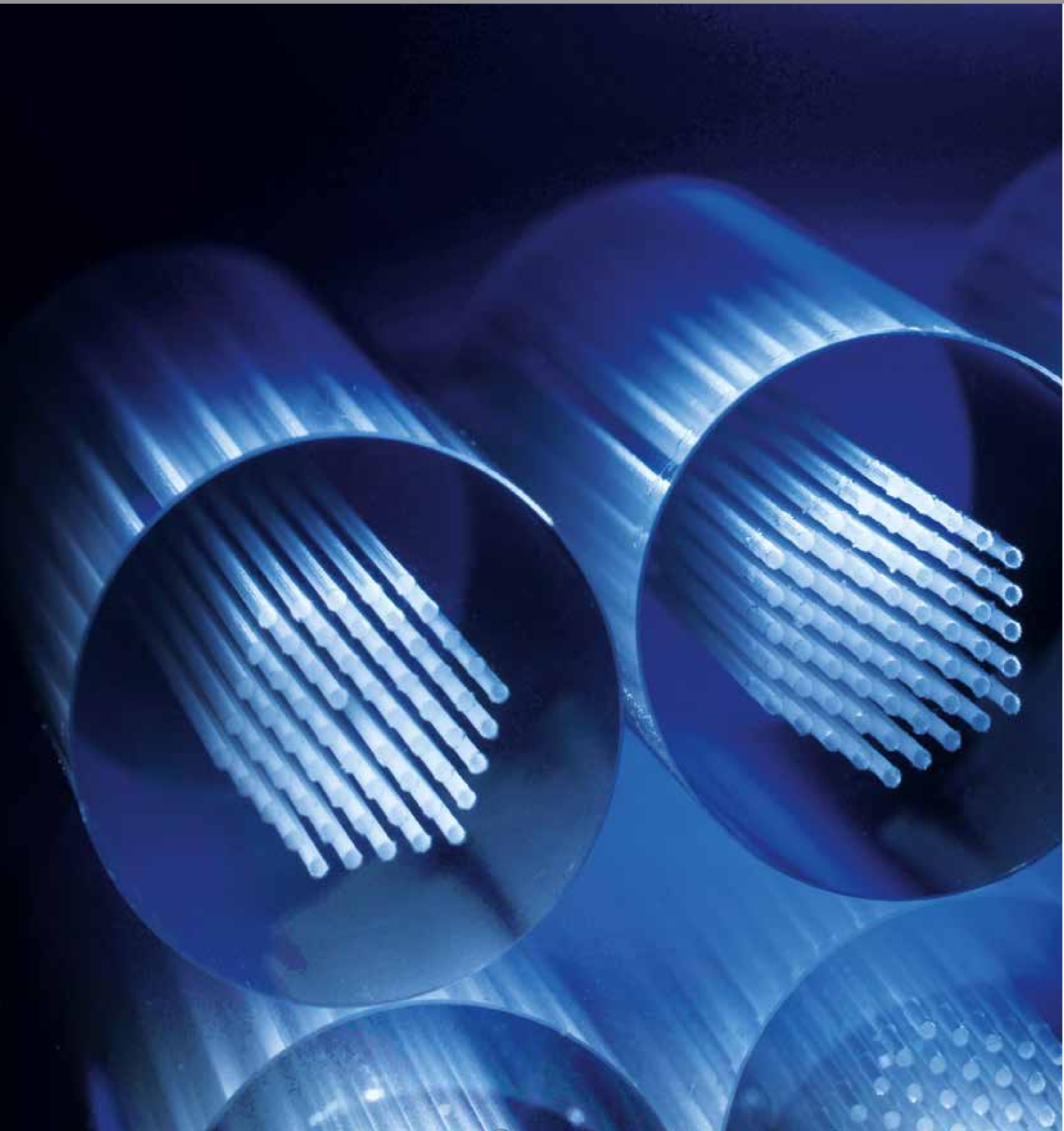
2 Designed optical system.

LASER MATERIAL PROCESSING



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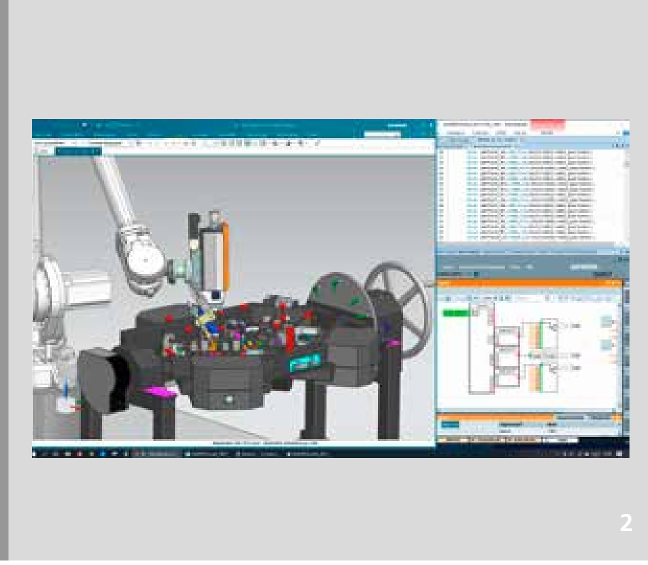

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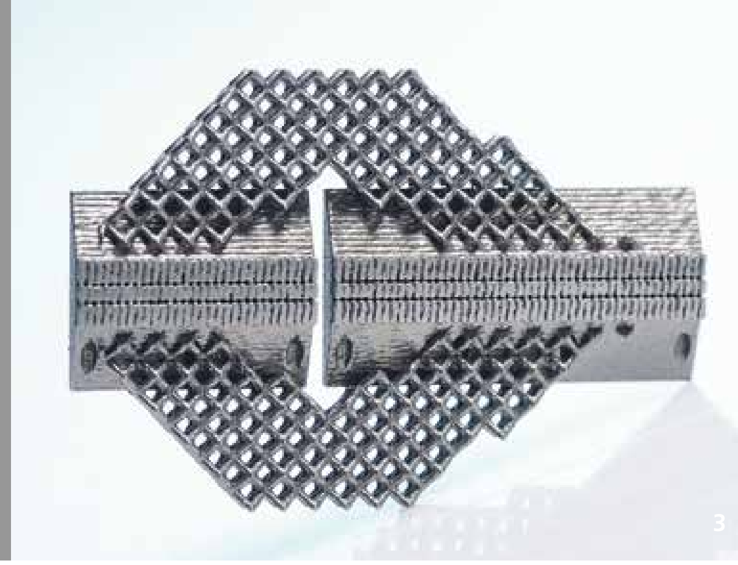

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MULTIFUNCTIONAL LASER ROBOT CELL WITH DIGITAL TWIN

Task

Multifunctional laser technology integrates different laser processes in a manufacturing cell to meet the increasing demand for agile production technology. For this purpose, Fraunhofer ILT is developing a processing head that – for the first time – masters cutting, joining and deposition welding in one robot cell without it needing to be retooled. By developing a digital twin of the overall system in parallel, the institute aims to accelerate and optimize the robotic cell engineering up to its virtual commissioning.

Method

The multifunctional laser head makes it possible to flexibly set the optical parameters for the different processes. It also provides appropriate gas supply via an autonomous nozzle and feeds consumables via an integrated wire nozzle. Setting up the digital twin required a steep learning curve, which was mastered in co-operation with the project partners and supported by the system suppliers Siemens and ABB: This included modeling the 3D mechanics in NX-MCD, behavioral model in SIMIT, PLC programming in TIA Portal, virtual control with PLCSIM Advanced, and virtual robot controller with Robotstudio.

Results

The approach described here has led to a first multifunctional laser robot cell and its digital twin. Virtual commissioning has not only facilitated the design, but also optimized the mechanics, control as well as the programming of the entire system. Communication between the control system and the components takes place in a practical combination of PROFINET and hard-wired I/Os.

Applications

With this development, Fraunhofer ILT and its partners have constructed a multifunctional laser robot cell based on a digital twin for the first time. Thanks to the virtualization model, the entire system can be commissioned more quickly, the susceptibility to errors in production preparation reduced significantly, and production planned more efficiently. Applications can be found wherever the industry requires high variant diversity, fast product changes, and systems that can be easily reconfigured. The development aims at applications for producing electric vehicles and opens up many more beyond that.

The project MultiPROmobil was funded by the European Regional Development Fund (ERDF) and the state of North Rhine-Westphalia under the grant number EFRE-0801253 in cooperation with the partners Bergmann & Steffen, CAE Innovative Engineering and the Laser Bearbeitungs- und Beratungszentrum GmbH.

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1 The real and virtual process running in parallel.
2 Virtual robot cell in the digital twin.

ADDITIVELY MANUFACTURED HEAT SINKS FOR QUANTUM TECHNOLOGY APPLICATIONS

Task

In quantum technology applications, the individual operating temperatures of optical components are precisely controlled to ensure efficient operation. This thermal control is achieved via heat sinks, which, unlike the optical components, are usually made of metallic materials. During operation, however, thermally induced mechanical stresses occur between the heat sink and the optical component because the combined materials exhibit different thermal expansions. Furthermore, there is a challenge to set the temperatures in optical components locally and selectively with minimally extended thermal transition ranges between different temperature fields.

Method

Fraunhofer ILT used the design freedom of additive manufacturing to develop a multifunctional heat sink. On the basis of thermal simulations, it incorporated innovative design features such as lattice structures and developed novel structural elements that allow local adjustment of the mechanical behavior. The heat sink was additively manufactured from the titanium alloy TiAl6V4 using laser powder bed fusion (LPBF) and subsequently stress-relieved to avoid LPBF-induced deformation.

Results

An innovative design principle was utilized to compensate for thermally induced stresses in the interface area between optical component and the heat sink. Specifically, a tailored mechanical stiffness was used to set a defined deformation during operation. Minimization of thermal transition areas was ensured by lattice structures connecting the two differently tempered areas of the heat sink. Combining necessary mechanical stability with maximum thermal insulation enables the thermal transition area to be minimized.

Applications

In particular, this heat sink design can be applied in the field of quantum technology. Moreover, the design unlocks significant potential in the field of laser applications in space, where the reliability of the optical component is a top priority. In addition, improvements can generally be achieved in technical systems that consist of different component materials and in which precise temperature control is required.

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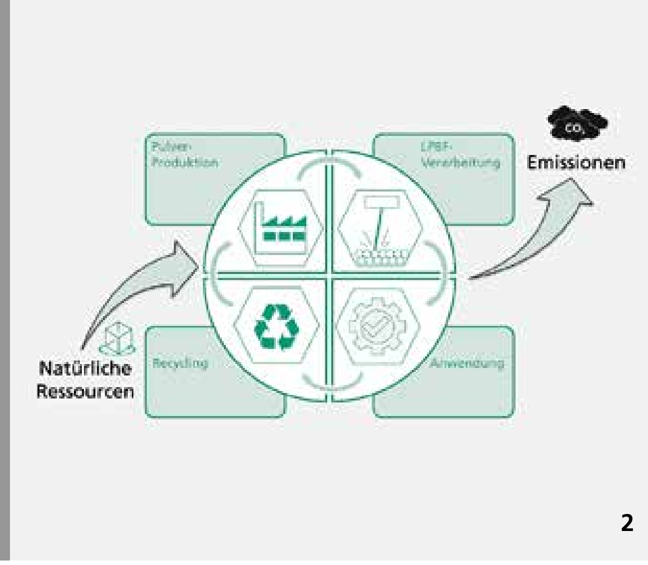
3 Additively manufactured heat sink.
4 Functional structures for thermal compensation.



LIFE CYCLE ASSESSMENT (LCA) FOR LPBF PROCESS AND SYSTEM TECHNOLOGY

Task

Additive manufacturing processes such as laser powder bed fusion (LPBF) allow the industry to produce near-net shape components on industrial scale with increased functional integration, while also reducing material usage. Additive manufacturing is, therefore, crucial for increasing the sustainability of future product developments and production chains. Although the production of components using LPBF often goes hand in hand with reduced material consumption, additional process steps – like the atomization of the needed powder – leads towards a shift in energy and resource consumption when compared to conventional manufacturing methods. For this reason, a life cycle assessment (LCA) of the entire LPBF process is necessary to evaluate its sustainability, regarding not only its final application, but also the variables influencing the upstream and downstream process steps.

Method

So that the entire life cycle of an LPBF-manufactured component can be better understood, research must investigate the essential process steps such as powder production, LPBF manufacturing and post-processing, as well as application and recycling. To this end, the process chain needs to be mapped in a digital model together with its input and output variables. However, since little reliable information is available, especially for the LPBF process in particular, these factors must be determined by means of experimental measurements on the systems.

Results

The institute has successfully developed a process chain model for components produced with LPBF. In addition, it has recorded reliable energy and mass flows for the first aerospace components as part of the EU research program CleanSky2 and implemented them in the model. Further investigations into the influence of process parameters and manipulated variables will be added to the model in the near future.

Applications

In addition to the high demand for LCA data in the aerospace sector, more and more industries are paying attention to the sustainability of their processes and products, for example the automotive industry. Furthermore, as a member of the "Additive Manufacturing Green Trade Association", Fraunhofer ILT is also involved in studies investigating the sustainability of the LPBF process.

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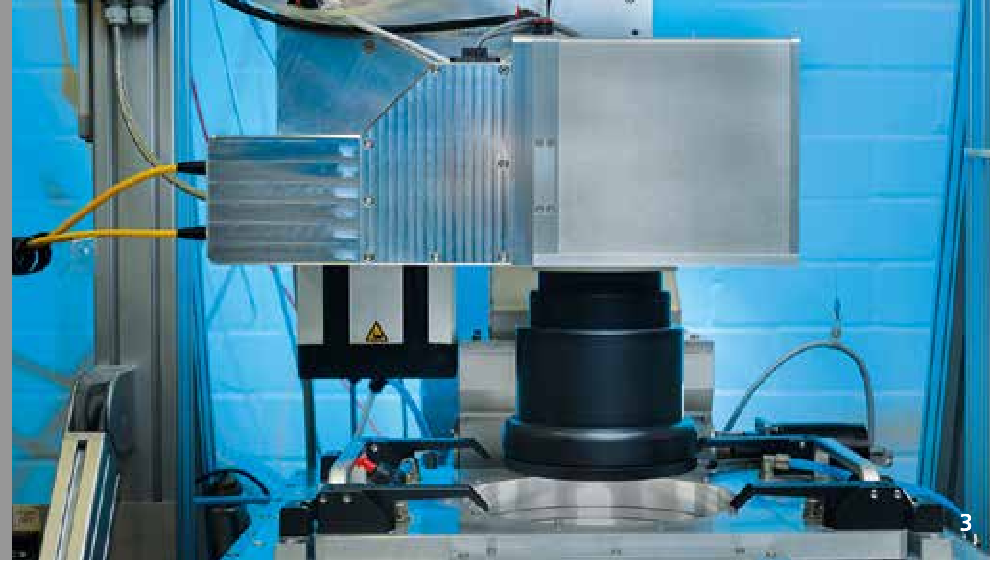
1 Advantages of the additive process using the example of a guide vane cluster from MAN.

2 LCA model for the LPBF process chain.



TEMPORAL AND SPATIAL LASER BEAM MODULATION FOR LASER POWDER BED FUSION (LPBF)

Task

The additive manufacturing process laser powder bed fusion (LPBF) makes it possible to produce functional components with almost unlimited geometric complexity. However, its comparatively low productivity inhibits broad industrial use in production. In particular, the use of small laser beam diameters with simultaneous use of large laser powers of up to 1000 W leads to large maximum intensities in LPBF and, thus, to a greater risk of component defects and process instabilities. For this reason, the industry often resorts to using multiple laser scanner systems to increase the productivity of LPBF machines. This, however, is prohibitively expensive. In order to overcome the resulting restrictions of LPBF, Fraunhofer ILT is developing alternative approaches to temporal and spatial laser beam modulation in collaboration with research and industry partners as part of the Digital Photonic Production (DPP) Research Campus.

Method

One possible solution is using a dual fiber laser array in LPBF. In contrast to conventional LPBF, the dual fiber approach uses two individually addressable single-mode fiber lasers, which are deflected via a single galvanometer scanner. With the multi-beam optical system developed at Fraunhofer ILT, the relative orientation of the laser spots can be adjusted flexibly and dynamically. This results in additional degrees of freedom that can be used to increase process productivity in LPBF.

Results

Fraunhofer ILT demonstrated the basic feasibility and potential of LPBF using a dual fiber laser array for processing AISI 316L stainless steel and analyzed it using high-speed images of the LPBF process. Relative component densities above 99.9 percent could be achieved. At the same time, this array was able to double the build-up rate compared to LPBF with a single laser beam source.

Applications

In the framework of the DPP Research Campus, Fraunhofer ILT is researching this approach to improve LPBF together with industrial partners from mechanical and plant engineering as well as users from turbo mechanical engineering.

The work is being supported by the Digital Photonic Production DPP Research Campus as part of the "Research Campus Public-Private Partnership for Innovation" research funding initiative of the German Federal Ministry of Education and Research BMBF.

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3 Multi-beam optical system for LPBF using dual fiber laser array.

IN-SITU INTEGRATION OF SENSORS WITH AM TO IDENTIFY COMPONENTS

Task

RFID chips are an effective means of protecting components against counterfeiting and make it easy to digitally track aircraft components and assign them to the correct step in the production process. By using additive manufacturing processes, the industry can reduce work steps, but also irreversibly integrate an RFID chip into the component. In order to make in-situ integration possible, however, the laser sintering process must be modified.

Method

Research needs to develop design guidelines on the chips' readout probability and investigate how this process will influence the mechanical properties of the components. This way, the RFID chips can be integrated in additively manufactured aircraft components in a space-saving, robust and secure manner. For process development, Fraunhofer ILT has determined the geometric constraints such as maximum wall thickness and size of the required cavity. In addition to sensor integration by means of geometric solutions, it has worked out how feasible in-situ integration in plastic components is and what effect the required process interruption has on the component.

Results

RFID chips can be integrated into PA 12 components both by a geometric solution after the build process and in situ. For the geometric solution, barbs are used to integrate the shuttle-receiver approach, which is flush and irreversible. The in-situ integration requires a process interruption during which the powder is extracted from a cavity inserted into the part, and the RFID chip is inserted into the cavity. The build process is then continued. The required cavity size is the chip size +1 mm. A process interruption of less than 5 min does not impair the mechanical component properties. The maximum wall thickness for reliable reading of the RFID chip for components made of PA 12 is 10 mm.

Applications

The integration of RFID chips and other sensors in additively manufactured components enables digital component tracking, which simplifies logistics and makes piracy more difficult. In addition, integrated sensors can be used to measure environmental parameters such as temperature or pressure, e.g. in medical technology and the automotive industry.

The Print&Track R&D project underlying this report was carried out on behalf of the German Federal Ministry for Economic Affairs and Energy BMWi under the grant number 20X1726D.

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1 Shuttle-receiver approach as a geometric integration solution.
2 Component after in-situ chip integration with AM-manufactured suction tip.

HYBRID ADDITIVE MANUFACTURING OF FORGED COMPONENTS BY HIGHLY PRODUCTIVE LASER CLADDING

Task

By combining conventional processes, such as casting or forging, with additive manufacturing, such as laser material deposition (LMD), research can offer the industry novel manufacturing possibilities for producing innovative components and variants. For example, additively made structural elements can be added onto conventionally produced blanks, generating a component that could not otherwise be built without additional expensive tools.

In the LuFo program, Fraunhofer ILT and its partners OTTO FUCHS, ACCESS and BTU Cottbus are researching the hybrid additive manufacturing of TiAl6V4 forged components for an aerospace application. In this context, the key challenges posed are that the additively applied material should have comparable properties to the forged base material and, at the same time, the process should reach buildup rates in the range of several kilograms per hour.

Method

To increase the buildup rate, Fraunhofer ILT developed the process parameters for the LMD process and buildup strategies for laser powers of several kilowatts. To minimize the oxygen input into the deposited volume, the institute carries out the process in an inert gas chamber. Subsequent heat treatment is performed to set the desired material properties.

Results

Demonstrators made of TiAl6V4 can be successfully produced at deposition rates of up to 4 kg/h through the targeted design of the process control, and the mechanical properties meet the stringent requirements of the aerospace industry. Additional sample parts for other applications have already been produced and finished.

Applications

In addition to titanium alloys, all technical forging alloys can be processed. Applications are mainly found where high-quality, larger components have to be manufactured in small or medium quantities, e.g. in the aerospace industry, energy technology or general mechanical engineering. In addition to additive manufacturing, these processes are also suitable for repairing and reconditioning components, thus saving expensive materials.

The R&D project underlying this report was carried out on behalf of the German Federal Ministry for Economic Affairs and Energy BMWi under the grant number 20W1719A.

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3 Additive-applied contour on a forged component.
4 Finished hybrid component.

INLINE SENSOR TECHNOLOGY FOR SCRAP-FREE LASER MATERIAL DEPOSITION

Task

Using laser material deposition (LMD), the industry can produce metallic functional components in lots from single pieces all the way to series production at the same cost per part. A challenge is posed, however, by deviations of the LMD tracks actually applied from the planning data, deviations that add up layer by layer so that the final component geometry lies outside tolerances. To minimize this resulting scrap or even to produce scrap-free, Fraunhofer ILT is aiming to better control the LMD process with an interferometric sensor system that detects the actual geometry inline.

Method

The measuring radiation of the interferometric sensor system is coaxially superimposed on the processing radiation and describes a circular path around the deposition location. The component geometry is recorded in advance and in retrospect, irrespective of the feed direction. The height information contained therein is synchronized with the position data provided by the LMD system for the respective job location and combined into 3D data records.

Results

From these time-resolved 3D data sets, the surface contour of a component can be determined as it is being built. In the next step, a model-based determination of component topography shall be carried out so as to compare it with the CAD nominal data in the data processing chain. Based on this, control actions will be established to stabilize the laser material deposition process. This real-time control based on the inline measured geometry data shall be used to implement a self-parameterizing LMD system for the rapid development of novel components made with LMD.

Applications

This innovative approach for a controlled laser material deposition system enables the industry to produce complex system components, for example, bionically optimized functional components in vehicle construction.

The R&D project underlying this report is being carried out on behalf of the German Federal Ministry for Economic Affairs and Energy BMWi under the grant number ZF4328109FH9.

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1 Powder focus with circulating measuring beam.

2 Robot-guided laser material deposition optics with integrated coaxial measuring beam guidance.

DEVELOPMENT OF A REPAIR PROCESS CHAIN FOR THE CIRCULAR ECONOMY

Task

Heavy-duty components often fail due to local surface damage as a result of wear or corrosion, but the damaged areas are small compared to the overall size of the component. Currently, defective components are usually replaced with new components in a process that uses a great deal of resources. Moreover, recycling metallic precision components also places a heavy burden on the environment, despite certain resource and energy savings compared with primary extraction (such as energy-intensive smelting processes). Not only are countries economically dependent on imports, but the industry also increasingly needs scarce raw materials, causing a significant environmental footprint due to the CO_2 emissions generated in the manufacturing process. Much more sustainable in this context is repairing the damaged components by processing the damaged areas locally.

Method

The components are repaired with an automated, hybrid process chain: First, the damaged areas on the component are detected, removed by a turning process and converted into a defined groove, which is then additively filled again by laser material deposition. This pre- and post-machining of the repair area can restore the component's required profile, and the component can be put back into operation.

Results

The individual production steps are supported by software that combines machine-integrated geometry acquisition, automated path planning and program generation. Thanks to an open machine design, the system can be used on different industrial machine concepts. The process chain, developed and qualified for the repair of metallic precision components, significantly increases not only resource and energy efficiency, but also decisively reduces the burden on the environment. A company needs fewer raw materials, is less dependent upon suppliers and, thus, more competitive.

Applications

The process chain can be used to repair rotationally symmetrical metal components. In addition to unfinished components, coated components made out of similar or dissimilar materials can also be repaired. In particular, resource and energy savings can be expected in the repair of large-volume components.

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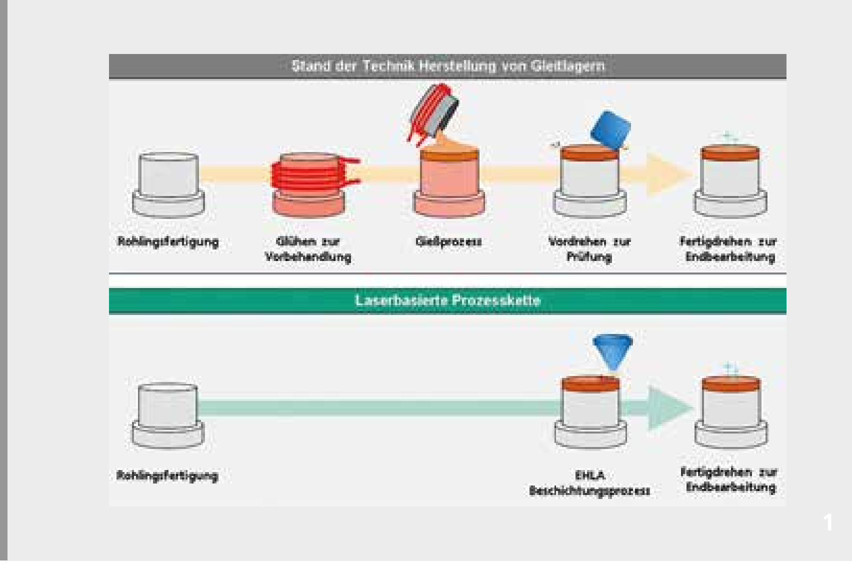
3 Principle hybrid process chain for the circular economy.

4 Additive repair using extreme high-speed laser material deposition.



ENVIRONMENTALLY FRIENDLY PRODUCTION OF TRIBOLOGICALLY HIGHLY STRESSED SLIDING BEAR-INGS BY MEANS OF EHLA

Task

Next to the rolling bearing, the sliding bearing is the most frequently used bearing type in machine and equipment construction. Approximately ten billion bearings (rolling and sliding bearings) are manufactured worldwide every year. In vehicles, five percent of fuel consumption is caused by mechanical losses, and one fifth is due to bearing resistance. In sliding bearings, the two parts moving relative to each other are in direct contact and slide on each other against the resistance caused by sliding friction. Self-lubricating lead-bronze alloys are commonly used as sliding materials to reduce frictional resistance. Since the EU has imposed restrictions on using lead (e.g. Regulation (EU) 2015/628 and the REACH list [4-6]), lead-free sliding materials will be required in the long term to protect people and the environment. Further savings potential can be unlocked by replacing the energy- and resource-intensive composite casting process used for processing the lead layers.

Method

Fraunhofer ILT has developed and qualified extreme high-speed laser material deposition (EHLA) to economically produce sliding bearings from lead-free sliding materials. In addition to a metallographic evaluation, the institute has analyzed tribological properties of these materials.

Results

The laser-based manufacturing process involves significantly fewer process steps than previous conventional process chains. The required use of energy and resources can be drastically reduced, thus achieving decisive ecological and economic advantages. In addition, EHLA achieves significantly higher process stability than the composite casting process. The sliding materials applied, such as copper-aluminum bronzes, have a metallurgical bond to the base body and a heat-affected zone of only a few micrometers.

Applications

The EHLA process chain demonstrated here is suitable for numerous other applications where highly stressed surfaces need to be protected, such as in bearing components in automotive, wind turbine, aerospace, agricultural, mining, railroad, marine and offshore applications, hydraulic motors and especially the axial piston pumps sector.

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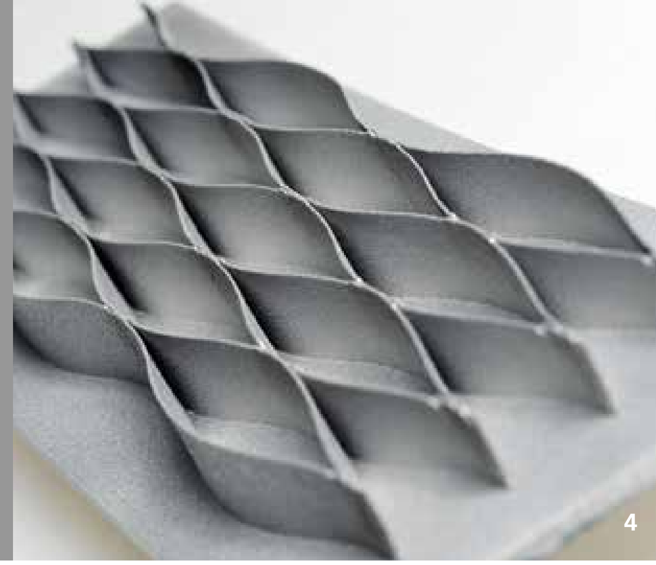
1 Process chain comparison.

2 Coating process of the mating surface of a plain bearing using EHLA.



EHLA 3D FOR THE ADDITIVE MANUFACTURING OF LIGHTWEIGHT ALUMINUM COMPONENTS

Contact

Additive manufacturing with extreme high-speed laser material deposition (EHLA 3D) has numerous unique technological features and advantages over conventional laser material deposition processes: significantly greater precision and resolution of the manufactured structures combined with high build-up rates. Such advantages can unlock great potential in innovative lightweight applications with aluminum materials. Processing aluminum alloys with laser-based methods is challenging, however, since they have a low absorption coefficient and high thermal conductivity. Thus, the process control needs to be adapted to these specific material properties.

Method

To implement the required high feed rates in all spatial directions for the production of complex structures, Fraunhofer ILT cooperated with Ponticon GmbH to develop and set up a highly dynamic tripod kinematic system for feed rates of up to 200 m/min and high accelerations of up to 50 m/s². Based on investigations and findings on EHLA 3D for iron- and nickel-based materials, Fraunhofer ILT identified process parameters for the materials AlSi12 and AlSi7Mg0.6 experimentally. In addition to a metallographic evaluation, it determined the mechanical properties of additively manufactured three-dimensional structures.

Results

Additive manufacturing of aluminum structures succeeds at process powder efficiencies of over 95 percent and reaches a relative component density of over 99 percent. Tensile tests show that the mechanical properties are on a par with non-additive material samples. In addition, thin-walled structures with web widths of less than 1 mm for lightweight aluminum components, e.g. for ribbing structures of sandwich components, can be applied additively to aluminum components. It is also possible to produce overhangs of up to approx. 40° without having to line up the component laterally with the powder nozzle.

Applications

By identifying suitable process parameters and build-up strategies for basic geometric elements, the project partners are ready to transfer the results to complex, industrially applicable aluminum components. Since it can be used to combine materials that are difficult to weld, EHLA 3D opens up a wide range of new possibilities. The first industrial applications are expected for high-strength, corrosion-resistant component coatings, such as in toolmaking or aerospace. The work was partially financially supported by the Fraunhofer-Gesellschaft as part of the "HIGHLIGHT – Light Materials 4 Mobility" project.

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3 EHLA 3D process with stationary powder feed nozzle and moving component.

4 Lightweight honeycomb structure manufactured using EHLA 3D for the production of aluminum sandwich components.

LASER-BASED PRODUCTION OF POLYMER MULTIFUNCTIONAL COATINGS FOR LIGHTWEIGHT CONSTRUCTION

Task

Replacing conventional materials by lightweight alloys continues to be an increasing trend in the automotive and aerospace industries, but the requirements for corrosion, friction and wear protection often exceed the performance of these lightweight materials. These requirements can be met if the surface is suitably modified. Coatings based on high-performance polymers such as polyetheretherketone (PEEK) have great potential to fulfil the necessary requirements thanks to their excellent properties: high temperature resistance and effective corrosion and wear protection. However, conventional oven-based processing of microparticulate PEEK coatings at temperatures above 340 °C is not suitable for many temperature-sensitive substrate materials, as both the coating and the substrate are heated to the same temperature.

Method

Fraunhofer ILT has developed a laser-based melting process including plant technology that makes it possible to apply adhesive and dense PEEK coatings onto lightweight components. By additivating the powder, the institute can increase the performance of the coating in terms of corrosion protection, wear protection and lubricant film formation. The individual layers can be applied on top of each other with print or spray processes and laser post-treatment, producing discrete multilayer systems with application-adapted properties.

1 PEEK layer on an aluminum engine piston.

2 Multi-layer system consisting of corrosion protection, wear protection and sacrificial layer on a laser-pretreated metal surface.

Results

The laser-based process presented here can be used to produce adhesive and dense PEEK multilayer systems on aluminum and magnesium, but also on hardened steel. The system shown in Figure 2 – consisting of a corrosion protection layer, wear protection layer and sacrificial layer – does not exhibit any intermixing of the individual layers. Investigations of the coating system using a pin-on-disc tribometer show significantly longer lifetimes than those of conventional bonded coatings.

Applications

The technology can be used for all components in general mechanical engineering that are in constant frictional contact with other components. The coatings produced are particularly relevant for lightweight components, e.g. in the automotive and aerospace industries.

The ATSM R&D project underlying this report was carried out with ELB Eloxalwerk Ludwigsburg and Pulsar Photonics on behalf of the German Federal Ministry of Education and Research BMBF under the grant number 01LY1824.

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LASER SINTERING OF PRINTED CERAMIC SOLID-STATE BATTERY LAYERS FOR ELECTROMOBILITY

Task

Electromobility is regarded as a climate-friendly and sustainable concept. Requirements for corresponding battery systems are, for example, high energy densities to achieve long ranges with high safety standards. Compared to conventional lithium-ion batteries (LIB), ceramic solid-state batteries have a higher theoretical energy density and do not need organic liquid electrolytes. Thus, they are of considerable relevance and show great potential for the future of electromobility. Possible ceramic materials include lithium cobalt oxide (LCO) as a cathode material, and lithium lanthanum zirconate (LLZ) as an electrolyte material. Thin-film battery cells based on these materials cannot be sufficiently functionalized in the furnace due to long interaction times, the resulting diffusion effects as well as temperature incompatibilities of the materials.

Method

Fraunhofer ILT is developing a laser-based process for sintering particulate ceramic thin films from LCO and LLZ in the µm range. By combining screen printing and laser processes, the institute is building a battery half cell consisting of a metallic current collector, a mixed cathode layer (LCO and LLZ) and an electrolyte layer (LLZ). The short-time high-temperature laser sintering (approx. 1000 °C process temperature) has to generate adhesive layers as dense as possible while at the same time maintaining the electrochemical layer properties. Line laser beam sources make it possible to scale up the inline process.

Results

Laser radiation can be used to adhesively sinter printed mixed cathode layers (< 10 µm) on metallic current collectors, which, in contrast to oven-processed layers, show a high crystallinity of the base materials. They also exhibit a reduction of the minor phases and are, thus, the necessary prerequisite for use in a battery cell.

Applications

In addition to its use for battery cell production in the mobile energy storage sector, the process presented here can also be applied to sinter other microparticulate layers.

The OptiKeraLyt R&D project underlying this report was carried out together with the partners Forschungszentrum Jülich GmbH, TANIOBIS GmbH and LIMO GmbH on behalf of the German Federal Ministry for Economic Affairs and Energy BMWi under the grant number 03ETE016D.

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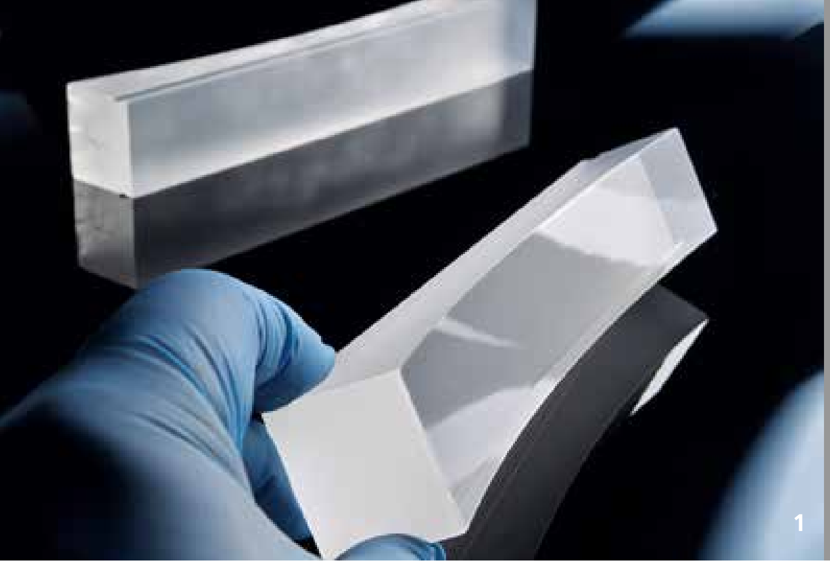
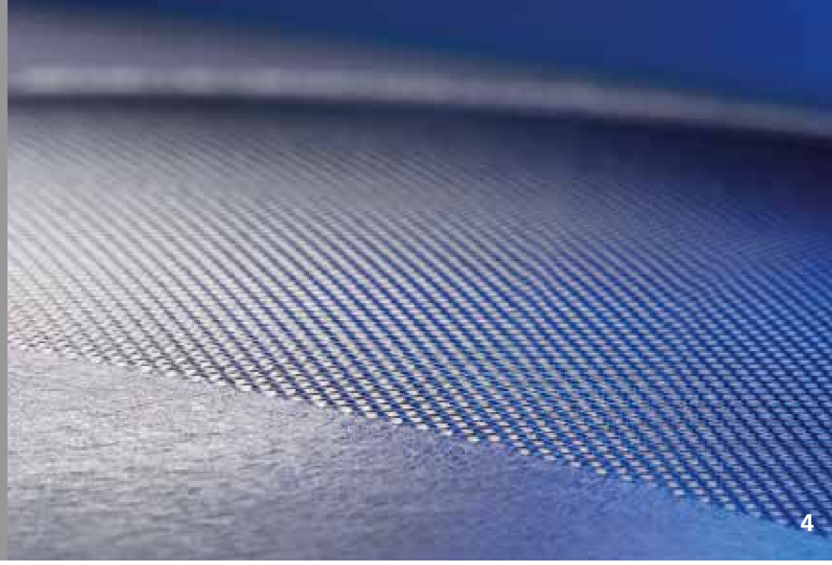
3 Laser sintering of a mixed cathode layer on a current collector foil using a line laser beam source.





INCREASING THE SHAPE ACCURACY OF LASER POLISHING OF GLASS LENSES

Task

Laser polishing of optical glass such as N-BK7 is a thermal process: By interacting with the laser radiation, the surface of the glass is heated in a thin edge layer and thus softened. Thanks to the surface tension, the glass surface is smoothed without material being removed. However, the high local temperature gradients lead to thermal stresses in the glass, which can result in permanent deformation of the glass substrate. For example, the shape in lenses made of N-BK7 (center thickness 15 mm, diameter 30 mm) can deviate in peak to valley by up to 30 µm.

Method

In addition to looking at strategies such as polishing on both sides with adapted process parameters, Fraunhofer ILT is investigating whether shape defects can already be corrected in the preceding machining step. The institute aims to achieve improved shape accuracy after laser polishing by adjusting the initial shape prior to laser polishing. For this purpose, the shape distortion of the target geometry after laser polishing is systematically recorded in a first development step, and then characterized in order to subsequently be able to grind blanks with a deliberate shape offset. The spherical component, which dominates the shape distortion after laser polishing, can thereby be adjusted without additional time or machine expenditure.

Results

When the N-BK7 lenses (diameter 30 mm, radius of curvature 100 mm) are ground as R 98 mm lenses, a radius of curvature of R 99.6 ± 0.5 mm can be achieved after laser polishing. Thereby, the sagitta error is reduced from over 22 µm to below 4 µm compared to the non-adjusted initial geometry. Thus, the shape deviations after laser polishing on these lenses lie in an order of magnitude comparable to fused silica for the first time.

Applications

The results shown here demonstrate that laser polishing of optical glass is technically feasible. This can reduce the complexity of the process chains in optics manufacturing and thus cut throughput times and unit costs.

The R&D project HyoptO underlying this report was carried out on behalf of the German Federal Ministry for Economic Affairs and Energy BMWi under the grant number IGF-20308 N.

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1 Laser-polished freeform mirror blank 230 x 35 mm².

2 Laser polished lens Ø 30 mm with initial state.

WAVESHAPE PROCESS FOR LIGHT GUIDE TOOLS

Task

Light guides for guiding and shaping LED light are often manufactured by means of plastic injection molding. On the one hand, the surfaces of the molds used for this purpose must be polished so that the light can be guided by total reflection with as little scattering and, thus, as little loss as possible. On the other hand, decoupling structures are used locally to distribute the point-shaped LED light in the light guides, which distribute the light specifically in a linear or planar manner. One application for these guides can be found in the automotive industry, where increasingly complex designs are required for ambient lighting. Together with Prof. Bordatchev from the National Research Council of Canada (NRC), Fraunhofer ILT researchers have investigated whether the Waveshape process developed at the institute is suitable for creating efficient outcoupling structures for light guides.

Method

Based on optical ray tracing simulations of the NRC, wave structures of different structural wavelengths (around 500 µm) and heights (50 - 150 µm peak to valley) were generated at Fraunhofer ILT. The institute used surface structuring by laser remelting (Waveshape) to structure the surface of the tool steel 1.2343, commonly used for plastic injection molds. The area rate was 0.5 to 0.125 cm²/min, depending on the structure height. The main advantage of the Waveshape process is that the structures have a polished surface, meaning that optical behavior of the structures results only from their geometry and not from scattering effects from their surface roughness. Thus, the optical effect can be easily calculated. The surfaces created in this way were subsequently molded in transparent plastic; then the institute examined if they could distribute light irradiated at the short edge homogeneously and over a wide area.

Results

The structures produced have a low manufacturing tolerance (< 10 percent in the structure height) and low roughnesses (Sa 0.2 µm), as required for practical optical applications. The scattering pattern agrees well with the simulations and is already mostly homogeneous in this first experiment without any optimization.

Applications

The results show that the Waveshape process is suitable for manufacturing outcoupling structures in tools for light guides. Possible applications are wherever concentrated LED light is to be distributed in a linear or planar manner.

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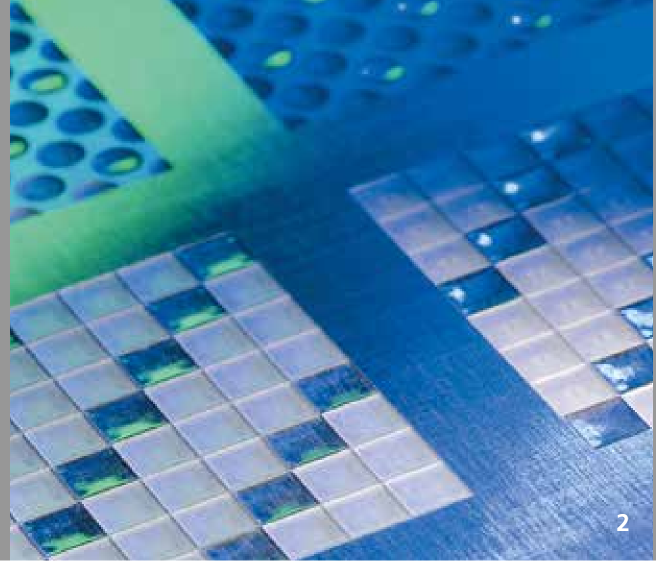
3 Wave and nap structures created with Waveshape.

4 Burled structure on curved surface.



SELECTIVE POLISHING USING ULTRASHORT PULSED LASER RADIATION

Task

High-quality surfaces with sub-µm roughness and locally adapted design and functional structures are becoming increasingly important in a wide range of industrial applications. To produce e.g. micro-holes and micro-structures, ultrashort pulsed (USP) laser radiation is used since it is so precise. Often a downstream polishing step as a surface finishing, however, is necessary for the surfaces to reach corresponding gloss levels. Laser polishing has proven to be suitable for complex structures, but also because it offers ecological and automation advantages. Currently, industrially used laser polishing processes are based on the use of cw or short pulsed laser radiation. By developing a USP polishing process, Fraunhofer ILT aims to integrate a polishing step into a fully digital photonic USP process chain, thus enabling users to polish new design and functional surfaces at high spatial resolution.

Method

Various process strategies for polishing using USP laser radiation have been developed to generate a roughness < 100 nm. By using a high pulse repetition rate of 50 MHz with correspondingly low pulse energy, Fraunhofer ILT has developed a process that can generate targeted melt film and prevented material evaporation. Tailored pulse bursts with repetition rates in the 100 kHz range enable a controlled melting and solidification process. The high feed rates of up to 8 m/s result in high cooling rates, reducing oxidation of the melt and make an inert gas atmosphere during USP polishing unnecessary.

Results

Different melt depths and surface qualities can be flexibly combined on one workpiece surface with a combination of different process strategies. Common melt depths in USP polishing are < 15 µm. A roughness of Ra < 80 nm can be produced at area rates of 7–15 cm^2/min. Moreover, the system can polish locally at high-precision and selectively, in addition to processing large areas in a normal ambient atmosphere.

Applications

USP polishing is particularly relevant as a sub-process in a USP-based photonic process chain to produce different functional surfaces, especially in tool making for the automotive and consumer goods industries.

The R&D project underlying this report was carried out on behalf of the German Federal Ministry for Economic Affairs and Energy BMWi under the grant number ZF4328108LT9.

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1 Large-area USP polishing of a vacuum huck plate with microholes.

2 Selective polishing of three-dimensional USP structures.

ROBOT-BASED USP STRUCTURING ON FREEFORM SURFACES

Task

Functional laser-based surface structuring is currently usually performed using high-precision 5-axis CNC machines and mirror-guided laser radiation, although 6-axis robots are a cost-effective alternative whenever a wide range of products need to be processed flexibly. However, since the commercial robots have low absolute accuracy, a sensor-based compensation strategy is required for microstructuring with accuracy requirements < 10 µm. Another challenge is posed by the fiber guidance of the ultrashort pulsed laser radiation used for precision processing in the robot system.

Method

When large 3D components are structured, the surface is mathematically divided into 2D patches, which are removed layer by layer. To produce a texture without visible patch boundaries, the patches in each layer must be positioned with < 10 µm repeat accuracy. To compensate for the insufficient robot accuracy, Fraunhofer ILT developed a sensor system for position measurement and correction. For this purpose, the system was equipped with a global measurement system and a local coaxial camera integrated into the laser beam path. Optical flow algorithms are used to calculate a displacement vector between the target and actual positions from the camera images and to compensate for this by correcting the robot position and scan vectors. Furthermore, the institute uses a real-time capable EtherCat PLC to synchronize the robot, the laser scanner and the sensors temporally.

Results

Fraunhofer ILT has developed modular software for overall machine control and communication between the individual systems. This software can be used to reorient the robot and recalculate the scan vectors to compensate for position deviations. With the camera and illumination system, specified displacements in the recorded image data could be reproducibly measured with a repeatability of < 1 µm in a test setup.

Applications

3D surface structuring is used in toolmaking, e.g. to produce design structures or microstructures for surface functionalization. In the automotive sector, the process can be utilized to apply optical and haptic design structures to the fittings in the vehicle interior.

The work is being carried out as part of the NRW project FOCUS under the grant number EFRE-0801603.

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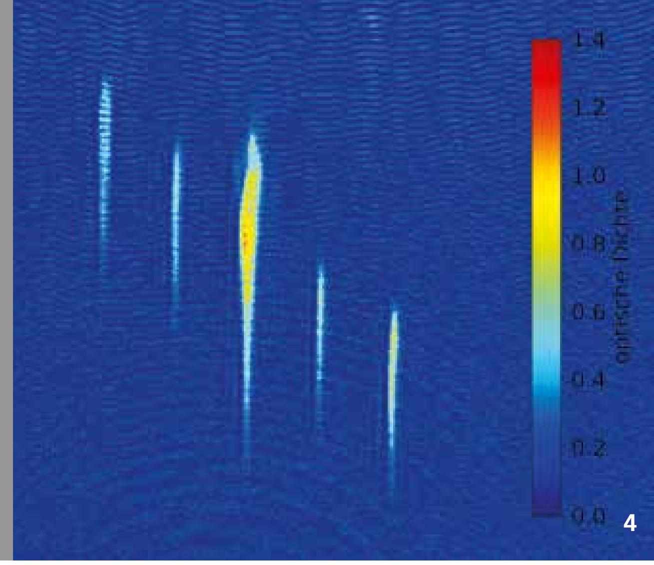
3 Industrial robot with laser scanner and coaxially integrated sensors (camera and external illumination 808 nm).

4 Structured surface textures.

1

2

3



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HIGH-RATE USP SURFACE STRUCTURING IN ROLL-TO-ROLL PROCESSING

Task

Ultrashort pulsed laser radiation (USP) enables the industry to precisely generate microstructures on a wide range of materials, but it cannot be transferred to large-scale industrial production processes since its productivity is still too low. Multi-beam systems are a key technology to fully exploit the potential of high-power USP laser sources. Beam splitting via diffractive optical elements can parallelize USP processes, increase the total power that can be converted, and significantly boost productivity.

Method

To increase productivity, Fraunhofer ILT has developed a continuous USP multi-beam machining process with a 160 W USP laser source in a roll-to-roll system. The optical multi-beam module splits the laser beam into a total of 4 x 6 partial beams, with each of the 6 partial beam bundles simultaneously guided over the strip by a total of 4 galvo-scanner systems. Sensors are used for process and quality monitoring, which, for example, precisely record the strip position and can validate the structures produced inline. By combining continuous feed of the strip material and a system technology for parallelized, large-area processing, the institute has developed a system that can utilize greater laser power and, thus, significantly increase the productivity of USP laser material processing.

1 Structuring module and roll-to-roll plant.
2 Structured electrode tape material.

Results

Thanks to the multi-beam structuring module, the number of structures introduced per unit of time and area can be increased by one order of magnitude compared to the conventional single-beam process. This USP multi-beam module makes it possible to process to 1.2 million structures per minute. In addition, a continuous USP structuring process has been developed, which is regulated with inline sensor technology.

Applications

Applications can be found in any roll-to-roll manufacturing process (e.g. battery, hydrogen, photovoltaics). The institute's current work focuses on the production of battery electrodes for lithium-ion batteries with liquid electrolytes. Its goal is to increase the power density and lifetime of the cells by introducing periodic hole structures into the battery electrodes.

The R&D project underlying this report was carried out on behalf of the German Federal Ministry of Education and Research BMBF under grant number 03XP0316C.

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FLEXIBLE MULTIBEAM PROCESSING IN SELECTIVE LASER-INDUCED ETCHING

Task

The selective laser-induced etching (SLE) process can be used to produce microcomponents made of fused silica with almost any desired geometrical shape and a high degree of customization. Currently, process times for the SLE method are limited, however, due to the high level of precision. Applying multi-beam intensity distributions should shorten the process time and reduce the process cost, and using flexible beam shaping allows the quality and geometry freedom of the processing to be maintained.

Method

Together with the project partner LightFab GmbH, Fraunhofer ILT has used a spatial light modulator (SLM) in the ZIM project MB-SLE4MF to implement flexible beam shaping during processing. For this purpose, an SLM was added to an existing microscanner, and an iterative algorithm is used to generate predefined multi-beam intensity distributions in the focal plane. The beam profile is controlled by camera feedback and the intensity distribution dynamically adjusted in each step.

Results

This approach has demonstrated that the SLE process works well with seven parallel partial beams and significantly increases the process speed. At the same time, the selectivity and scan field size could be maintained compared to single-beam processing.

Applications

So far, the SLE process has been used, for example, to manufacture microfluidics for lab-on-a-chip applications in medical technology, for micromechanics, for components in quantum technology or for ion traps in quantum computing. By scaling the SLE process, research can reduce component costs. Multi-beam processing enables the SLE process to be scaled in different areas. The system technology presented here will allow the industry to fabricate almost any 3D geometrical shape with high precision and high degree of customization.

The R&D project underlying this report is being carried out on behalf of the German Federal Ministry for Economic Affairs and Energy BMWi under grant number 16KN070939.

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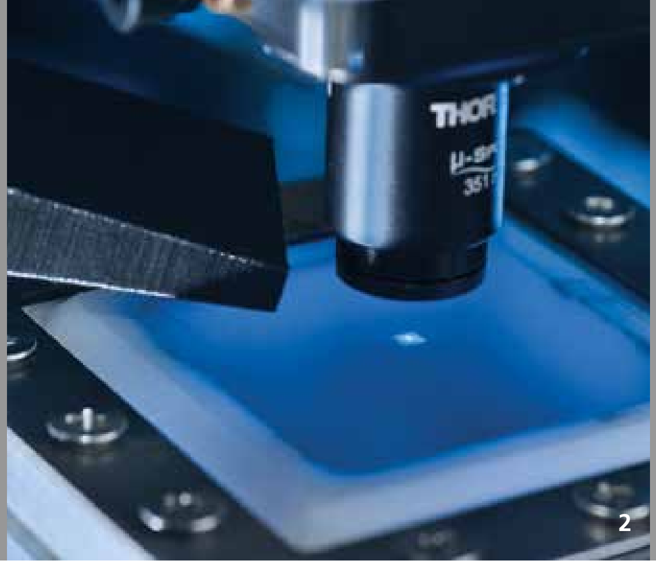
3 Microstructuring system with SLM for flexible beam shaping.
4 In-situ analysis of the beam distribution in the glass volume.



SUB-MICROMETER DRILLING IN PLASTICS

Task

Laser material processing using ultrashort pulsed laser radiation can be used to produce microholes with the highest precision in almost all materials. Holes with diameters larger than 0.7 µm can, thus, be made in metal membranes for various filter applications and leakage tests. For plastics in particular, the demand is growing for precision holes with diameters smaller than 1 µm. Here, the low absorption of plastics in the infrared and visible wavelength range results, however, in thermal loads and limits the precision and reproducibility achievable. As the microholes have to meet strict geometrical requirements, the thermal impact must be reduced and the process needs high-precision system technology.

Method

Fraunhofer ILT has developed a special UV microscanner to generate micro- and nanoscale structures and holes in different materials with great flexibility. The shorter wavelength of 343 nm is not only advantageous due to the higher absorption, especially in plastics, but also allows a significant reduction of the laser focus diameter. Indeed, focus diameters with a size of down to the sub-µm range can be generated when the suitable focusing objective is selected. The high-precision processing station is complemented by a linear axis system and a chromatic-confocal distance measurement sensor, each with sub-µm accuracy.

Results

With the UV microscanner, micro- and nanoscale through holes can be produced in various polymer films (such as PC, PE, PI and PP). Holes up to 800 nm in size can be reproducibly generated with a tolerance of less than 10 percent. By flexibly selecting the focusing objective and path guidance, the institute can use the drilling process for plastics with a material thickness of more than 500 µm. It can even achieve a high hole density in thermally sensitive material with a material thickness of 12.5 µm without thermally induced material distortion.

Applications

Precisely reproducible holes in plastics with diameters in the single-digit and sub-µm range are required in numerous applications: for example, in medical technology, filter technology, microsystem technology or in the pharmaceutical industry.

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1 Process development on the UV microscanner.

2 Drilling with a focus diameter of 1 µm.

AI-BASED PROCESS ANALYSIS IN ABSORBER-FREE LASER TRANSMISSION WELDING

Task

In absorber-free laser transmission welding of plastics, pyrometry is used to measure the temperature to monitor the process. However, the measurement signal is merely an indicator of the temperature, so while thermal damage is recorded as signal peaks, conclusions cannot be drawn about the type of damage, such as bubble formation or burning. Furthermore, since the emitted thermal radiation is spectrally attenuated by various optical components, detecting the radiation is more challenging as the weld becomes smaller.

Method

Imaging techniques are used to extend 1-dimensional pyrometry. Images or objects captured by cameras can be automatically identified and classified with multilayer convolutional neural networks. For this, a camera was first coaxially integrated into the beam path of the processing optics and used to take images of the welding process at different welding parameters to generate the data set. Semantic segmentation was used to analyze the images. Here, each image pixel is evaluated and assigned to a class defined at the beginning. In this way, both the weld seam and damage in the component can be identified and evaluated in the camera image. Subsequently, suitable network architectures were selected and trained with the data set.

Results

The work carried out illustrates the great potential of an AI-based process analysis. The trained convolutional neural network is able to reliably classify thermal damage such as burns or bubble formation. All examined models show an intersection-over-union (IoU) value > 0.9. In addition to classifying the welds, the system can also be used to determine the seam width or the size of the thermal damage.

Applications

Absorber-free laser welding of plastics is particularly suitable for applications in which transparent plastics are to be joined in a selective, contact-free and reproducible manner. Typical applications are medical technology or biotechnology. However, AI-based process analysis can also be implemented in other applications, such as in the laser welding of metals.

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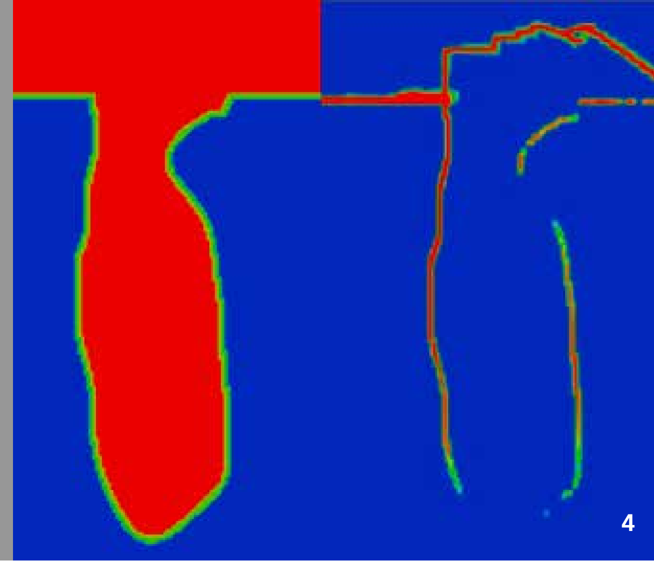
3 Weld seam with blistering.

4 Classification by neural network.



LASER-BASED MANUFACTURE OF COMPRESSION SEALS FOR MULTILAYER CERAMIC FEEDTHROUGHS

Task

Compressed glass feedthroughs are reliable elements for contacting electronic components and electrical assemblies in hermetically sealed housings. The current standardized manufacturing process for the metal-to-glass connection is a time-consuming oven-based process that lasts for several hours. All necessary components of the feedthrough, such as the metallic mount and the electrical contacts, are heated to the melting temperature of the sealing glass. Usually, the melting temperature of sealing glass is above 400 °C. As developments in multilayer ceramic substrates advance – which enable the construction of three-dimensional interconnected multilayer boards – high temperatures can damage the circuits on the boards and cause the integrated electronics to fail. Oven-based fabrication of compressed glass feedthroughs for multilayer ceramic elements is thus problematic, indicating that a manufacturing process with localized energy input is necessary.

Method

The laser-based process developed by Fraunhofer ILT, which focuses the laser radiation on the metallic mount, exploits the advantages of locally defined energy input and local temperature rise typical of laser processes. The radiation energy absorbed there is converted into thermal energy, which increases the temperature of the irradiated area rapidly. Via thermal conduction, the heat flows into the glass body. As soon as the glass body melts, the molten glass wets the mount wall and the multilayer ceramic in equal measure.

Results

Within 70 seconds, laser radiation produces a helium-tight pressurized glass joint between the mount made of Inconel 718 and the LTCC multilayer ceramic element. The measured leakage rate of the joint is in the range of 2.2 x 10^{-9} mbar l/s.

Applications

Vacuum-tight feedthroughs for multilayer ceramic elements with integrated electronics are used in the field of sensor and measurement technology.

This project has been financially supported by the Fraunhofer-Gesellschaft and funded by the German Federal Ministry for Economic Affairs and Energy BMWi based on a resolution of the German Bundestag.

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1 Laser-based manufactured compressed glass feedthrough for an LTCC board.

2 Compressed glass feedthrough welded into a housing component.

TAILOR-MADE JOINTS FOR PLASTIC-METAL HYBRID COMPONENTS

Task

Manufacturing multi-material components requires reliable bonding technologies since dissimilar materials need to be joined. Laser-based joining of plastics and metals is an innovative approach to do this quickly and permanently. To optimize the components in a load-adapted manner, however, designers and developers need sufficient knowledge of the joining properties when the component is designed and dimensioned: in other words, guidelines and tools for implementing hybrid joining technology.

Method

The laser-based process chain for joining consists of two process steps. In the first process step, microstructures are introduced into the metal surface, and in the subsequent joining process these structures are then filled with molten plastic. Depending on the strength and load requirements, the joining properties can be specifically influenced by load-adapted laser microstructuring. This opens up extended possibilities for optimizing components during design and component layout. So that characteristic values can be determined, laser-structured metal inserts are injected into a hybrid injection molding process to produce hybrid test specimens, which are then tested under various loads.

Results

The strength parameters for shear, tensile and peel loads from the component test serve as the basis for simulations of the joining zone at micro level and for component design at macro level. By adapting the structures depending on the load case, Fraunhofer ILT can optimize components and minimize process times. The institute aims to derive design methods for hybrid components and transfer them to demonstrators and real components.

Applications

Plastic-metal hybrid components are used in almost all areas of life. High demands are placed on the performance of structural components, particularly in the automotive and aerospace industries.

The R&D project underlying this report was carried out on behalf of the German Federal Ministry of Education and Research BMBF under the grant number 03XP0277E.

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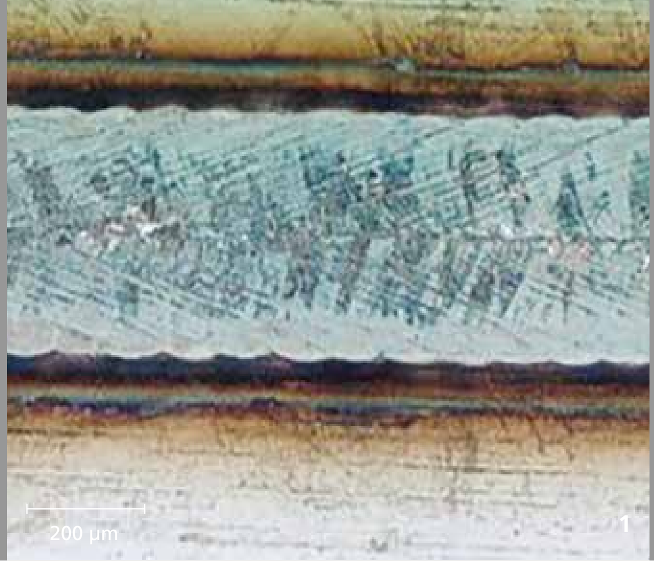
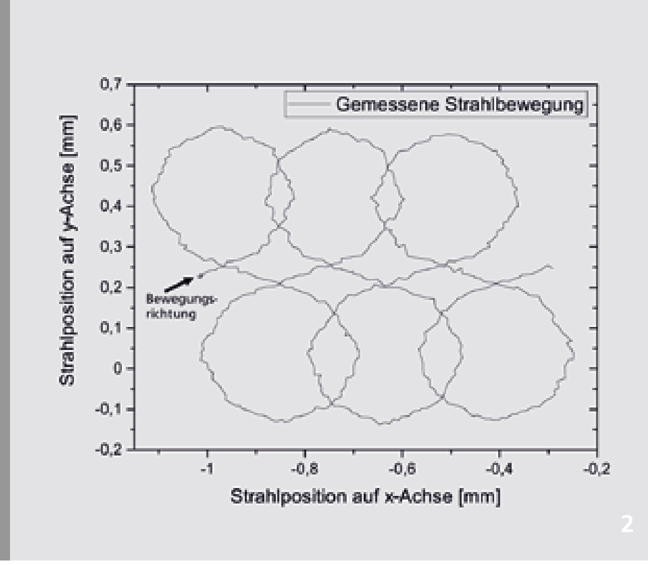
3 Hybrid rib test specimen for characteristic value determination.

4 Simulation of the joining zone.





NOVEL LOCAL POWER MODULATION FOR LASER MICROWELDING

Task

Innovative process approaches are needed to reduce metallurgical defects when dissimilar materials or aluminum alloys susceptible to hot cracking are welded together. In these cases, temporal and spatial power modulation can be used to control energy input in the joining zone, thus enabling a precise and efficient welding process.

Method

To reduce hot cracking during welding of aluminum alloys, for example, the magnesium mass fraction in the melt pool must be adjusted. Targeted local beam modulation can be used to set different heat distribution and accumulation in the joining zone. In this way, the evaporation of magnesium in the melt can be reduced or increased. For this purpose, the function of galvanometric scanner is advanced in such a way that it can trace a 360° rotatable geometric form of a digit “8.”

Results

The novel local power modulation extends the degree of freedom of conventional local power modulation with circular oscillation (wobble) by additional adjustment factors: The two separately adjustable amplitudes and rotational speeds of the individual circuits of the “8” influence the melt pool dynamics and the temperature distribution.

Applications

This local power modulation can be used for different welding tasks for batteries as well as capacitors. In particular, mixed joints can be improved using this approach.

The work is being carried out as part of the EU project TopLamp under the grant number 01 QE2009B.

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1 Weld seam made with novel local power modulation.

2 Measured beam modulation by means of PSD measurement.

NEW POTENTIAL TO OPTIMIZE LASER BEAM CUTTING THROUGH BEAM FOLDING

Task

In laser beam cutting, efficiency and cut quality are significantly determined by the amount and distribution of the beam energy absorbed in the cut kerf as it forms throughout the process. The innovative type of laser beam shaping presented here – beam splitting and folding – can be used to selectively target and adjust the lateral and axial intensity distribution of the laser beam in the cut kerf. This can significantly increase process stability and efficiency.

Method

The new optical system design makes it possible to split the laser beam into two partial beams and to adjust the relative distance, orientation and shape of the partial beams. Sub-processes that characterize burr and striation formation can, thus, be specifically influenced within the interaction zone, which reaches from the cutting front to the cutting flanks. Supported by simulation and based on a sound understanding of the process, Fraunhofer ILT identified how the beam folding impacts the process, and determined suitable parameter sets for carrying out the experimental analysis. An optical design was derived and transferred to a variable prototype of the optical system. The beam shaping design was tested on a laser cutting unit equipped with a 6 kW disk laser. Stainless and mild steel plates with thicknesses of 10 and 12 mm were used for the experimental tests.

Results

With appropriately adapted beam folding, Fraunhofer ILT was able to produce nearly burr-free cuts right away at process speeds just below the intrinsic cut-off limit and exceeding conventional maximum cutting speeds. In addition, a high quality of the cut was maintained over a wide range of parameters. In particular, this new technology can significantly reduce the well-known strong dependence of the cut quality on the focus position and the process speed. These are the first promising indications that this new type of beam shaping, derived from a well-founded understanding of the process, has considerable potential.

Applications

The concept of laser beam folding offers new chances to reliably produce high-quality cuts at high process speeds. It also represents a solution for static laser beam shaping that can be integrated in a modular way and can unlock previously unimagined potential to optimize not only cutting thick sheets, but also deep welding processes.

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3 Cutting of 10 mm thick stainless steel plate by folded laser beam profile.

USE OF ACOUSTIC RESONANCES IN LASER BEAM CUTTING – THE "CUTTING WHISTLE"

Task

Using high-speed video analyses of the melt film on the cutting front, research has identified acoustic resonances of the gas column in the cutting kerf for the first time. It was recognized that the cut edges produced have the lowest roughness depth precisely in the areas where the melt film exhibits high-frequency waves. By understanding of this positive effect, Fraunhofer ILT could develop an innovative approach to improve the cut edge quality by acoustic amplification of high-frequency melt waves. For this purpose, the institute should develop an acoustically tuned cutting nozzle design – a so-called "cutting whistle."

Method

The cutting whistle is based on a cavity-induced supersonic flow. The cavity formed at the nozzle exit side enables the generation of sharp high-frequency spectral peaks whose resonance frequency can be finely tuned as a function of the cavity length. The resonances are validated by Schlieren optics as well as by an optical microphone. Cuts are made on 6 mm thick stainless steel sheets using a disk laser at 6 kW output power to evaluate how the newly developed nozzle design influences the resulting cutting edge quality.

Results

The high-frequency oscillations of the nozzle flow are detectable in both the microphone measurements and the Schlieren recordings. In addition, a correlating stabilization of the melt flow can be detected on the basis of the diagnosed more uniform streak recordings. Accordingly, the institute produced high-quality cut edges with roughness depths and dross lengths of only 20 µm. In the future, it aims to specifically tune the acoustic resonances of the process gas flow to the kerf geometry.

Applications

The use of acoustic resonances in laser-beam fusion cutting is just one example of the potential that simulative, diagnostic and practical consideration of acoustic effects offers for improving laser material processing operations.

The project is being funded by the German Research Foundation (DFG) within the framework of the Collaborative Research Center SFB 1120 "Precision from Melt."

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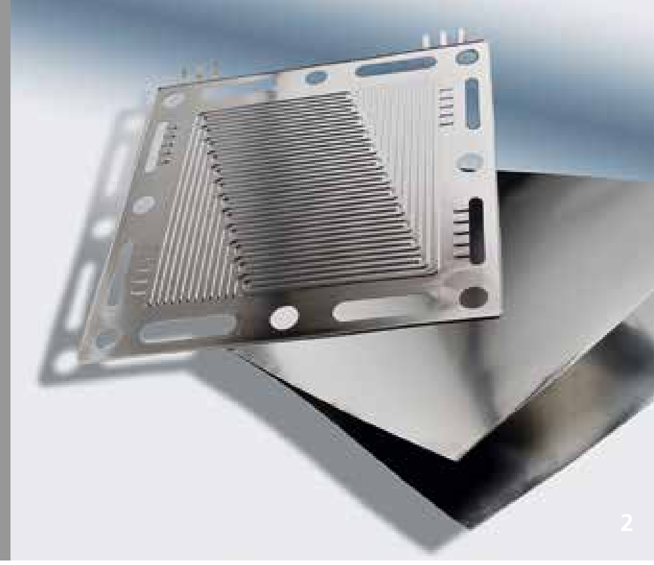
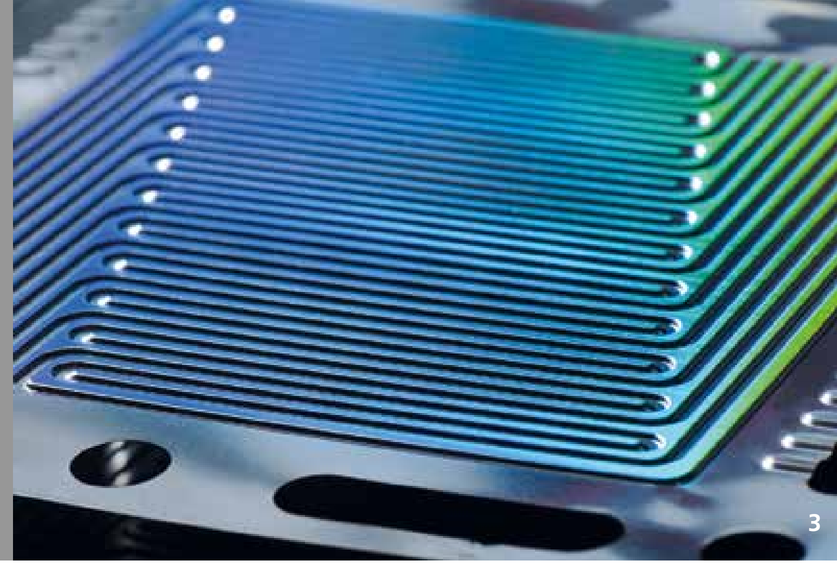
1 An acoustically tuned cutting nozzle design to improve cutting edge quality.





LASER MEETS HYDROGEN – THE HYDROGEN LABORATORY AT FRAUNHOFER ILT

Task

In addition to battery-based electric mobility, using green hydrogen in fuel cells is also a way out of our dependence on fossil fuels and towards sustainable mobility. The production costs of fuel cell systems, however, are still too high for the mass market. Currently, the bipolar plate (BPP) is the second most costly component of a fuel cell after the membrane electrode assembly (MEA). A bipolar plate usually consists of two stamped sheets that are welded together and then coated with corrosion protection. To reduce the production cost of the bipolar plate, the industry needs new high-rate cutting, welding and coating processes.

Method

As it develops innovative laser processes and equipment technology, Fraunhofer ILT provides solutions for the cost-efficient and, at the same time, flexible production of high-quality and functionalized BPPs. On the one hand, processes under examination are BPP laser-beam welding and cutting with a focus on increasing the process speed while maintaining the quality. On the other, the institute is investigating processes for functionalizing bipolar plates with USP laser microstructuring as well as the wet-chemical application of corrosion protection layers with coupled thermal laser post-treatment. In addition, it is developing laser-based MEA thin film fabrication.

Results

To investigate these novel laser-based manufacturing processes for the production of BPPs, the Fraunhofer ILT has established a hydrogen laboratory with the help of a strategic investment. Thanks to a total volume of more than € 1.7 million, the new laboratory will be equipped with state-of-the-art machine technology specifically designed to increase the productivity of laser-based manufacturing processes for fuel cell production. From the beginning of 2022, laser processes will be developed here and the bipolar plates produced will be installed and tested in fuel cells.

Applications

The Fraunhofer ILT's hydrogen laboratory provides a development platform for customers from industry and research. Since it is equipped with laser-based machine technology that goes beyond the state of the art, researchers can develop future laser processes in the context of fuel cell production and evaluate how they influence functionality and performance using prototype fuel cells.

The hydrogen laboratory was financed with strategic funds of the Fraunhofer-Gesellschaft.

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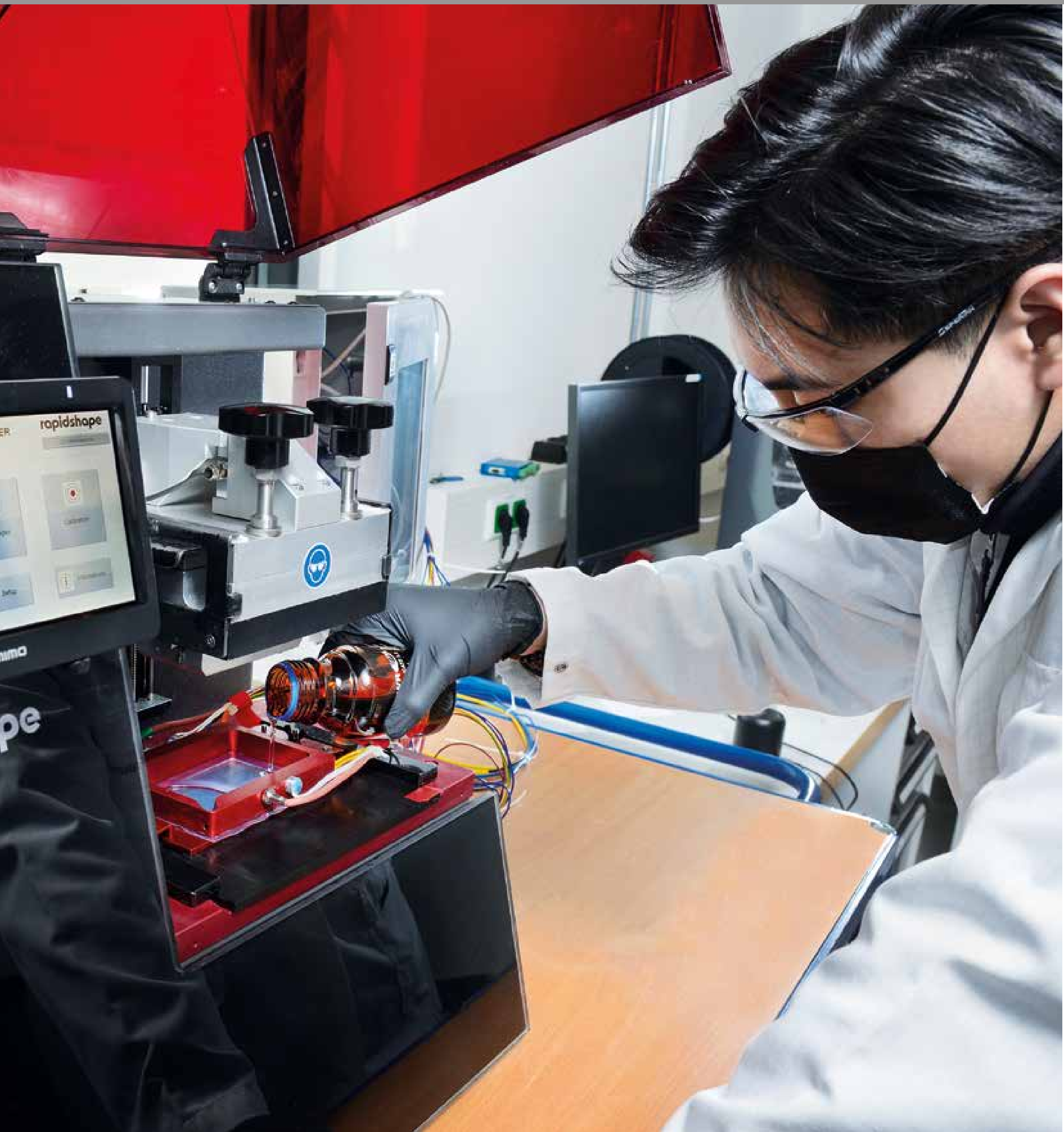
2 Laser-welded bipolar plate (bipolar plate design: Dana Victor Reinz).

3 Bipolar plate functionalized by USP laser microstructuring (bipolar plate design: Dana Victor Reinz).

MEDICAL TECHNOLOGY AND BIOPHOTONICS



CONTENTS

COLD LASER ABLATION FOR NON-CONTACT CRANIOTOMY DURING AWAKE SURGERY

Task

Recent successes in the therapy of movement disorders – e.g. in Parkinson's patients, as well as in the resection of tumors in eloquent regions of the brain – improve patients' quality of life and increase their survival rate. In these surgical procedures the skull must be opened while the patient is awake so that complex brain functions can be checked during the operation. During this procedure, the skull is opened mechanically with a drill or a burr, which causes extreme psychological stress in the affected patients.

Method

To reduce this stress, Fraunhofer ILT is developing an efficient and safe laser cutting process to replace conventional surgical drills and milling cutters. This cutting process features inline monitoring of the residual bone thickness based on optical coherence tomography (OCT). This real-time monitoring allows the laser process to be controlled and makes it impossible for the system to injure the brain tissue lying beneath the skull bone. The ablation is performed with a Q-switched CO_2 laser at repetition rates between 20 and 100 kHz. A water spray system ensures continuous wetting of the bone surface and thus prevents the bone from drying out during the cutting process. This guarantees that the hard tissue is removed efficiently and is free of carbonization.

Results

In laboratory experiments, parameter studies on the cutting process were carried out on bovine bone samples. A maximum removal rate of more than 5 mm³/s was achieved at a cutting width of 2 mm and a cutting depth of 3.7 mm. A maximum cutting depth of 7 mm was achieved with a cutting width of 2 mm. Defined residual bone thicknesses between 50 and 350 µm have been reliably measured with the OCT system while the bone surface was wetted.

Applications

Applications for laser craniotomy are stereotactic implantations of electrodes for deep brain stimulation for the treatment of complex movement disorders. Other applications include craniotomies on awake patients for removal of low-grade gliomas (brain tumors) in eloquent regions of the brain. Here, awake surgery assists operating doctors in making the crucial distinction between malignant and functional tissue.

The project is being funded by the Fraunhofer-Gesellschaft within the research program ATTRACT under the project name STELLA.

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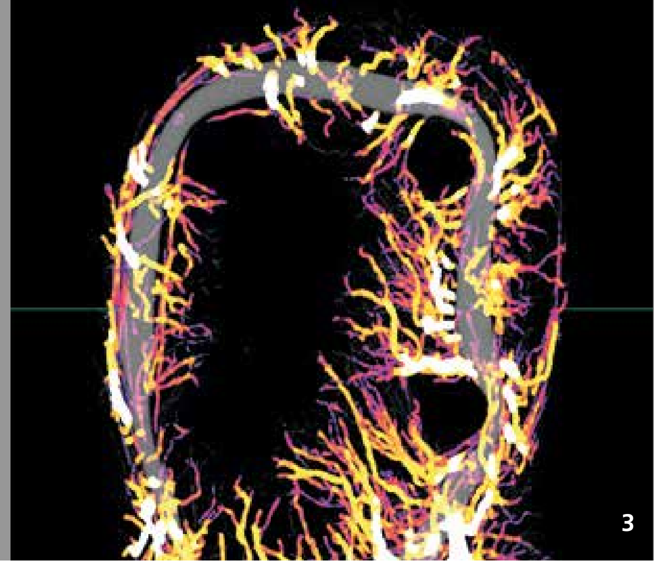
1 Laser cutting process on bone with Q-switched CO_2 laser.

2 Laser sections on a bovine bone specimen.



GENERATION OF PATIENT-SPECIFIC AND TRANSPLANTABLE CONNECTIVE TISSUE FLAPS

Task

In reconstructive surgery, flap plasty is used to reconstruct larger defects, but this technique reaches its limits if no autologous material is available. One approach to compensate for this problem is the cultivation of patient-specific and transplantable tissue flaps, using the so-called AV loop technique. Here, perfused tissue flaps can be grown from the patient's own cells in implantable plastic chambers. To ensure that defects are reconstructed specific to a patient, individualized plastic chambers are to be produced by means of 3D printing, thereby generating customized flap plasties.

Method

Fraunhofer ILT is developing a process to additively manufacture these plastic chambers, which should be flexible and biocompatible. Various combinations of photo resins and lithography-based 3D printers have been tested for this purpose and verified by in vitro cell tests. Fraunhofer IAP helped by analyzing the mechanical properties of these chambers and how well the flaps can be sewn. In addition, ILT is continuing to develop the chamber design. The process is being validated with in vivo test at the BG Klinik Ludwigshafen.

Results

The project has identified conditions the chambers need so that all requirements for mechanical, optical and cell biological properties are taken into account. The material is based on (meth)acrylated monomers with a high polyurethane content. The printer uses LCD technology. The original chamber design was iteratively refined to create a chamber that closes flush, can be sewn well, and results in minimal friction with the patient's skin during implantation.

Applications

In the future, the production of more complex vascularized tissue flaps is envisaged. Complex skin models could be produced to test active substances or also for implantation, in combination with methods for making skin replacement tissue.

The Flexloop R&D project underlying this report was carried out on behalf of the German Federal Ministry of Education and Research BMBF under the grant number 03VP05962.

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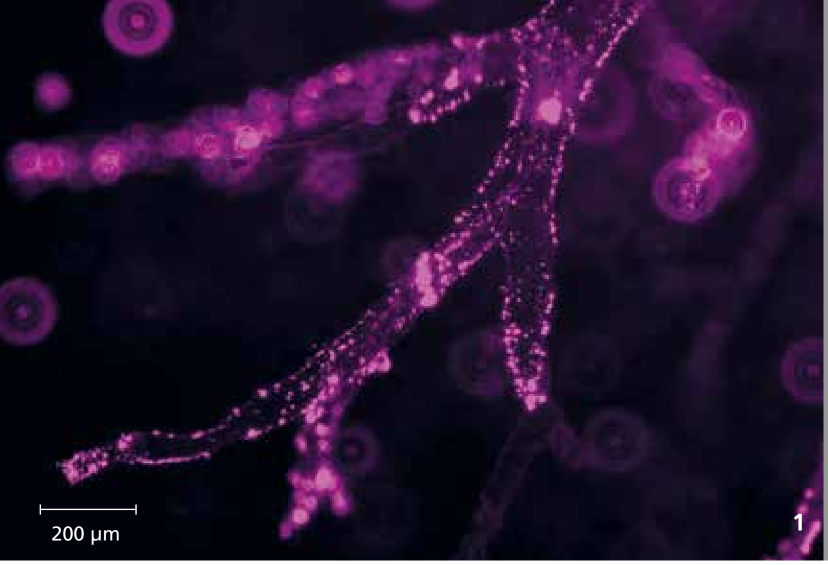
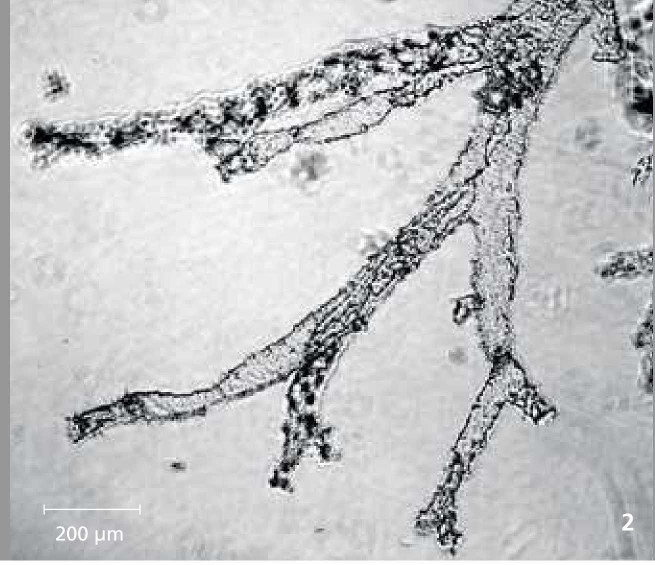
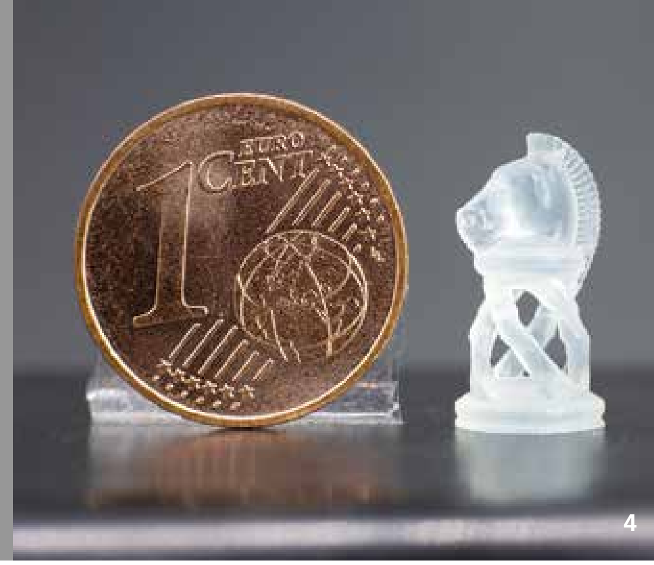
3 µCT of angiogenesis.

4 Individualized chambers with different closure mechanisms and geometries.







LASER-BASED FABRICATION OF SCAFFOLDS FOR VASCULARIZED, BIOARTIFICIAL HEART MUSCLE

Task

Along with stem cell technology, bioartificial tissue production plays a key role in the treatment of cardiovascular diseases. Today, cardiac myocytes can be generated in vitro from human induced pluripotent stem (iPS) cells. The main obstacle for using bioartificial tissues is the lack of a functional blood vessel structure, which is essential for the supply of the cells at layer thicknesses greater than a few 100 µm. Fraunhofer ILT and partners aim to fabricate vascularized cardiac muscle tissue in vitro. This will be an important step towards fully functional artificial tissues and organs.

Method

The approach pursued in this project combines bottom-up and top-down processes to inscribe blood vessels into biocompatible polymers – tailored hydrogels, to be more precise – by means of laser radiation. Furthermore, it is used to build up three-dimensional scaffolds that are seeded with vascular cells from human iPS cells. As part of the process development, the institute has determined the optimal process parameters such as wavelength, laser power and processing speed for different hydrogels. Furthermore, it is investigating suitable methods for biological and chemical analysis and visualization of the processing results.

Results

In this project, Fraunhofer ILT has been collaborating with several partners: LightFab GmbH, Miltenyi Biotec B.V. & Co. KG, Taros Chemicals GmbH & Co. KG, University Hospital Cologne and the Department of Chemistry at the University of Cologne. With them, Fraunhofer ILT has developed a process that can inscribe vascular structures in a hydrogel using ultra-short pulse (USP) laser radiation. To prove that the generated channels are open, fluorescent nanoparticles were passed through them. In the further course of the collaboration, the partners plan to colonize suitable cells.

Applications

The anticipated product is expected to enable cardiologists to replace damaged heart muscle tissue. The materials and manufacturing processes developed offer improvements for a wide range of tissue engineering areas, especially where vascular structures are required, and thus represent a key to fully functional artificial tissues and organs.

This project is being funded by the European Regional Development Fund (ERDF) under the grant number ERDF-0801776.

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1,2 Fluorescence and phase contrast micrograph of a laser-generated vascular structure with dimensions in the µm range.

3D PRINTING OF HIGH VISCOSITY OR SOLID PHOTO RESINS WITH A TEMPERATURE CONTROLLED PROCESS CHAMBER

Task

Additive manufacturing processes are developed to produce functional components defined by their mechanical, thermal and optical properties. For so-called 4D printing, the requirements are extended to include further properties such as thermo-responsiveness or self-healing. To achieve these material properties, research can use starting materials with high molecular weights. However, the viscosities of these materials (>> 1000 mPas) have led to considerable problems in stereolithography printers, such as component deformation due to high shear forces or significantly increased printing times. By controlling the temperature of the process chamber, Fraunhofer ILT has been able to reduce the viscosity of the resins since it decreases with increasing temperature.

Method

Based on a commercially available 3D printer, Fraunhofer ILT supplemented and redesigned relevant assemblies. The institute has focused on implementing a temperature control system for the photo resin bath and the build platform. In addition to designing the heating elements, it has integrated a control system and insulated the process area, and made safety-relevant additions. The exposure source (385 nm), exposure direction (constrained surface approach) and beam shaping method (digital light processing) were retained.

Results

The selected measures enable a process window for processing photo resins between 20 and 80 °C. The temperature can be maintained to within ±1 °C in the stable state. It is thus possible to process highly viscous starting compounds as well as TwoCure® materials, which are solid at room temperature.

Applications

With this approach, high-molecular-weight prepolymers and oligomers can be incorporated with their versatile properties into photo resin development. The aim of the application is primarily the production of dental and otoplastic components. At the same time, starting materials can be investigated for their suitability and influence in photo resin formulations in a time-efficient manner.

This project was carried out with funding from the European Regional Development Fund (ERDF) as part of the NRW-funded AlPhaMat project under grant number 0801505.

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3 DLP plant with temperature-controlled process chamber for processing high-viscosity photo resins.

4 Printed structure made of TwoCure® photo resin, © Nick Hüdepohl.

LASER MEASUREMENT AND EUV TECHNOLOGY

CONTENTS

LIBS SENSOR TECHNOLOGY FOR THE ANALYSIS AND CONTROL OF SCRAP FLOWS FOR METAL RECYCLING

Task

Metals can be recycled as often as required – without any loss of quality – simply by remelting them. Used in a variety of alloys with various alloying elements in specific concentrations, they are produced as such in furnace processes. In contrast, the metal scrap available for recycling is usually widely mixed and only roughly prequalified. In addition, low-quality scrap should increasingly be used in order to increase the recycling rate, which further reduces the metal purity. To process these metals in an energy- and raw material-efficient manner, the industry needs precise knowledge of the chemical composition of the materials. Therefore, a method is needed to determine the chemical composition of metal scrap before it is fed into the furnace.

Method

A three-dimensional scanning laser measurement process is used to analyze the delivered metal scrap and determine the chemical composition of the individual scrap parts. The analysis is performed by laser-induced breakdown spectrometry (LIBS) and provides a large number of multi-element analyses per minute. The composition of the scrap parts is transmitted to the recycling plant's control center so that the furnace can be charged in a defined manner. Depending on the application, the individual parts are sorted into pure alloys, or entire scrap streams are controlled on the basis of a representative average value of the analysis. Before each measurement, a laser pulse at the measurement location cleans the contaminated parts according to a patented process and exposes the material to be measured. For this purpose, the surface contour of the scrap is recorded by a laser-light section measurement, which provides the 3D coordinates for the laser focus of the LIBS measurement.

Results

In cooperation with industry and research partners, Fraunhofer ILT has developed a universal concept for a measuring device that can analyze both individual scrap parts on conveyor belts and batch loads as a whole. The measuring process has been tested in the laboratory on different materials and will be tested in the further course of the project in various recycling plants for steel, aluminum and lead.

Applications

In addition to evaluating scrap streams, the sensor technology can also be used for sorting mixed metal scrap. However, the LIBS measurement process is not limited to metallic materials; mineral or mixed material streams in the raw materials industry can also be analyzed. The inline measurements map the chemical composition of the material in real time and provide the data basis for process control and management. The work is being carried out as part of the EU project REVaMP under grant number 869882.

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1 LIBS analysis of a stream of metal parts on a conveyor belt.

OPTICAL INLINE PARTICLE ANALYSIS FOR MONITORING DISPERSION PROCESSES IN PRODUCTION

Task

For monitoring dispersion processes, Fraunhofer ILT is developing new tools for optical inline particle analysis in cooperation with international partners from industry and research. Their focus is on monitoring production processes in the pharmaceutical, dyestuffs and fine chemicals industries. Based on the needs of users, the partners are developing laser measurement processes for characterizing the size distribution and chemical composition of dispersions and testing them in industrial applications.

Method

Dynamic light scattering (DLS) is a suitable method for analyzing nanoparticles. So that the process can work inline, for example in a chemical reactor, Fraunhofer uses a probe equipped with an inline probe head to carry out the optical measurement. This probe head isolates a small amount of a sample so that undisturbed diffusion can be observed. The DLS method is based on the time-resolved detection of singly scattered photons from a small volume (a few picoliters), which roughly corresponds to the laser focus. So that the method can be used for high particle concentrations, multiple scattered photons have to be suppressed, since they distort the measured value. This is achieved by cross-correlating two identical scattering experiments. For this purpose, miniaturized optical assemblies with two excitation and two detection channels each are integrated into an immersion probe.

Results

Fraunhofer ILT set up and tested the inline probe head with integrated measuring probe on mono- and polydisperse solutions in the laboratory. For the cross-correlation measurement process, both scattering experiments have to take place in the same sample volume. This is achieved without adjustment by using a high-precision glass component to accommodate four fibers and collimating lenses. This component was manufactured by selective laser-induced etching (SLE).

Applications

Nanoparticles play an important role in a wide variety of chemical, pharmacological and biotechnological processes. In the present PAT4Nano project, the focus is primarily on dispersion processes. Applications can be found in the grinding of crystalline pharmacological active ingredients, the production of ink from color pigments, and the production of nanoparticulate fine chemicals, e.g. for catalysts or batteries.

The PAT4Nano project is being funded by the EU under the Horizon 2020 call DT-NMBP-08-2019.

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2 Inline probe head.

3 Quartz block as optics holder with inserted fiber ferrule.

ANGLE-RESOLVED INLINE PARTICLE ANALYSIS WITH A WAVEGUIDE PROBE

Task

According to the current state of the art, no suitable inline measurement systems are available to measure particle sizes while chemical and biological processes are running. However, particle sizes and size distributions can be determined offline by angle-resolved scattered light measurements. This process, static laser-light scattering, analyzes particles between tens of nanometers and hundreds of micrometers in size with laboratory equipment. However, the method is not suitable for real-time, process-analytical immersion probes since the measuring systems are too large. In a research project with partners from industry, Fraunhofer ILT is developing a miniaturized, inline-capable immersion probe in which the angular distribution of the scattered light is measured with a diagnostic chip that has integrated waveguides.

Method

Optical waveguides are written into a glass chip with a short pulse laser. These optical waveguides are radially aligned with a sample aperture and guide the scattered light from different directions to a light-sensitive sensor chip, which quantitatively detects the scattered light signal. Since each waveguide corresponds to a known scattering angle, an angle-resolved scattering intensity can be determined from the intensity distribution of the individual waveguides. From this intensity distribution, the particle size can be calculated. Since the waveguides can be placed in a compact glass chip with an edge length of a few centimeters, the measurement method is suitable for integration in a compact immersion probe.

1 Immersion probe for angle-resolved laser scattered light measurement.

2 Glass chip with laser switched on for scattered light measurement (sample opening see center of image).

Results

Fraunhofer has developed and tested the first version of an immersion probe for angle-resolved laser light scattering. Scattered light signals from particles in solution can be detected with angular resolution, analyzed and used to determine particle sizes.

Applications

The scattered light probe can be used to measure the size of particles in the range of a few tens of nanometers to several micrometers. It can be used in applications for chemical process and bioprocess analysis. Growth processes in biofermenters, particle formation in chemical crystallizations or polymerizations as well as dispersion processes can be recorded inline during an ongoing process.

The R&D project underlying this report was carried out on behalf of the German Federal Ministry of Education and Research (BMBF) together with small and medium-sized enterprises (SMEs) under the grant number 13N14176.

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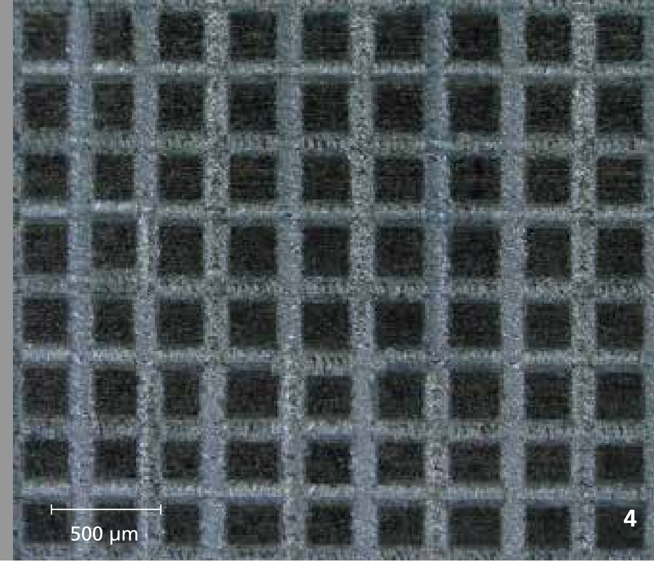

SCANPLEX – COMPACT SCANNER-ARRAY FOR MULTIBEAM PROCESSING

Task

To increase productivity, research in laser material processing is pursuing multi-beam approaches that increase the production speed in proportion to the number of laser beams used.
To ensure a high degree of design freedom in multi-beam processing, the laser beams must be guided independently of one another across the processing field. This requires an array technology consisting of compact 2D scanner elements and having significantly reduced dimensions compared to conventional galvanometer scanners. The smaller the space required by a scanner element for a given aperture and scan angle, the higher the degree of parallelization that can be achieved per area and thus the higher the productivity of the process.

Method

Therefore, Fraunhofer ILT has developed a scanner array that combines four 2D deflection units for parallelized laser material processing in a housing the size of a conventional 2D processing head. The scanner drives are based on a planar galvo scanner technology developed and patented at Fraunhofer ILT, a technology that combines a small construction volume with a large aperture. By using the scanner array and compact F-theta lenses, the institute is able to process an area of 120 x 120 mm^2 in parallel with four separate laser beams.

Results

The institute set up and characterized the scanner array demonstrator with four 2D deflection units and one F-theta lens per deflection unit. Demonstration tests were carried out with laser powers of up to 150 W per scan head for the application fields of laser marking and engraving and showed the potential of Scanplex technology for a significant increase in productivity.

Specifications of Scanplex scanner array

Dimensions L x W x H	140 x 140 x 90 mm^3
Focal length f	160 mm
Scan field size A	120 x 120 mm^2
Scanning speed v_s	≤ 8 m/s
Aperture D	7 mm
Irradiance E	≤ 500 W/cm^2
Tracking delay t_s	200 µs
Position resolution	16 bit
Interface	XY2-100

Applications

- Laser marking and engraving
- Additive manufacturing
- Microprocessing

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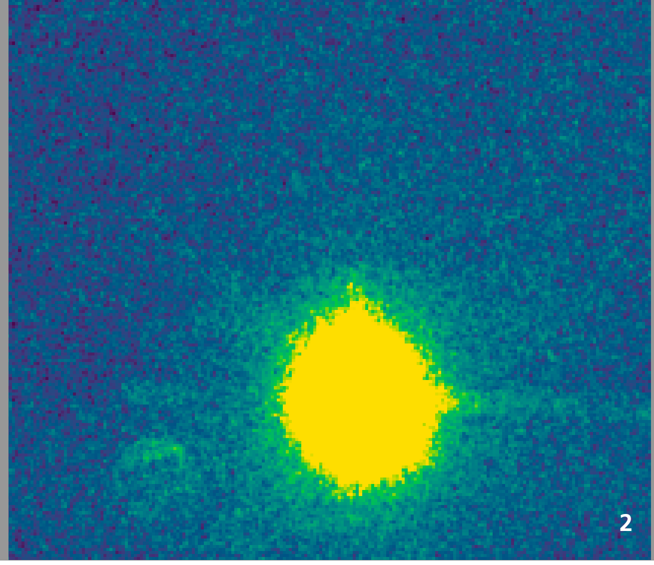
3 2x2 Scanplex scanner array.

4 Laser engraving in aluminum created with Scanplex.



LABORATORY-BASED CHARACTERIZATION OF THE SCATTERING BEHAVIOR OF EUV-PELLICLES

Task

Used in industrial semiconductor manufacturing, pellicles are membranes with thicknesses in the nanometer range. They serve to protect the nanostructured mask from particles in the lithography process. To ensure high imaging quality and throughput, the industry must carefully optimize the transmission and scattering behavior of pellicles. Especially for modern lithography processes in the extreme ultraviolet (EUV) radiation range, this optimization places high demands on the fabrication and analysis of the pellicles.

Method

Fraunhofer ILT uses the broadband EUV radiation of a discharge produced plasma source to characterize the scattering behavior of nanoscale pellicles at the wavelength mainly used by industry, 13.5 nm. With suitable thin-film filters and a multilayer mirror, the radiation is spectrally filtered so that a main wavelength of 13.5 nm with a relative spectral bandwidth of 4 percent is available for the measurements. The pulse energy of the source is continuously measured with a dose monitor during the measurements to ensure their results can be reproduced. An aperture is used to illuminate a portion of the pellicle, and the transmitted and scattered light is measured with a CCD camera (charge-coupled device). To increase the number of photons available within a measurement, a beam blocker can be introduced into the beam path to shield the directly transmitted part of the radiation.

Results

Using this laboratory setup, Fraunhofer ILT was able to characterize different EUV pellicles of the latest generation with respect to the scattering behavior at a wavelength of 13.5 nm. Different material compositions and coatings were flexibly tested for their suitability for use in modern lithography processes. The measured results show high agreement with reference measurements and simulation results.

Applications

The setup and the developed measurement method can be used to characterize nanoscale membranes (pellicles) for use in lithography with extreme ultraviolet radiation.

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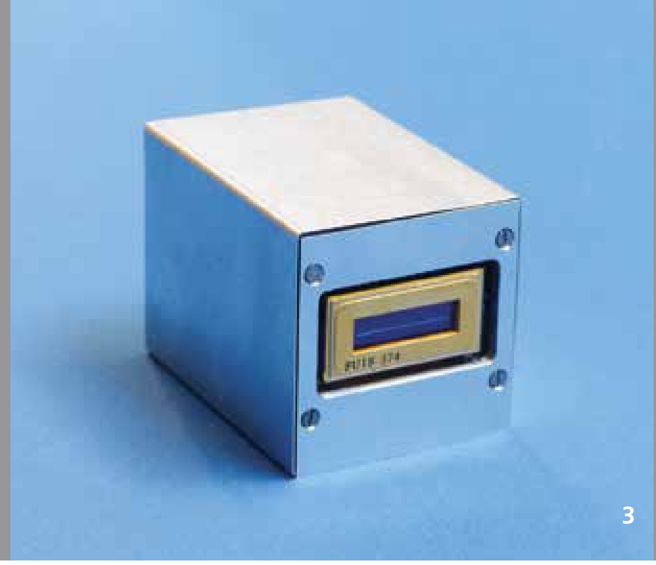
1 The experimental setup.

2 Scattered light image of a CCD camera.



DEVELOPMENT OF VACUUM COMPATIBLE COMPACT CAMERAS FOR EUV/SXR APPLICATIONS

Task

Extreme ultraviolet (EUV) and soft X-ray radiation (SXR) are applied in lithographic and metrological processes, and also widely used in the semiconductor industry or in nanoscience applications. The use of this short wavelength radiation (2 - 50 nm) offers advantages both in terms of achievable structure size and measurement sensitivity. However, since this radiation experiences strong absorption in any matter as well as in the atmosphere, technical setups must be used in a vacuum environment. In such setups, compact and vacuum-compatible camera systems are extremely important as they can be flexibly positioned in the limited installation space of the vacuum chambers for measurement and alignment tasks. In addition, sensitivity to EUV/SXR radiation should be ensured. However, commercially available in-vacuum cameras for the given radiation range are only available from a few manufacturers and usually not compact enough to be placed in vacuum chambers with sufficient room to move.

Method

In cooperation with the company khs-instruments, the Chair for Technology of Optical Systems (TOS) at RWTH Aachen University is developing a compact in-vacuum camera for EUV and soft X-ray radiation. Based on the special requirements of the vacuum environment, it has developed a prototype of the camera, which is being tested and optimized in a vacuum and EUV test station.

Results

In the first year of the project, TOS and khs-instruments developed a compact prototype of the camera, including control technology. With a vacuum and EUV test stand, the prototype is being tested for vacuum compatibility, thermal stability and sensitivity to EUV radiation.

Applications

The developed camera can be used in technical systems for the detection of EUV and SXR radiation for measurement and alignment tasks. Examples are EUV lithography systems or metrological systems.

The work is being funded by the German Federal Ministry for Economic Affairs and Energy (BMWi) as part of the "Central Innovation Program for Small and Medium-Sized Enterprises" under grant number ZF4109603SY9.

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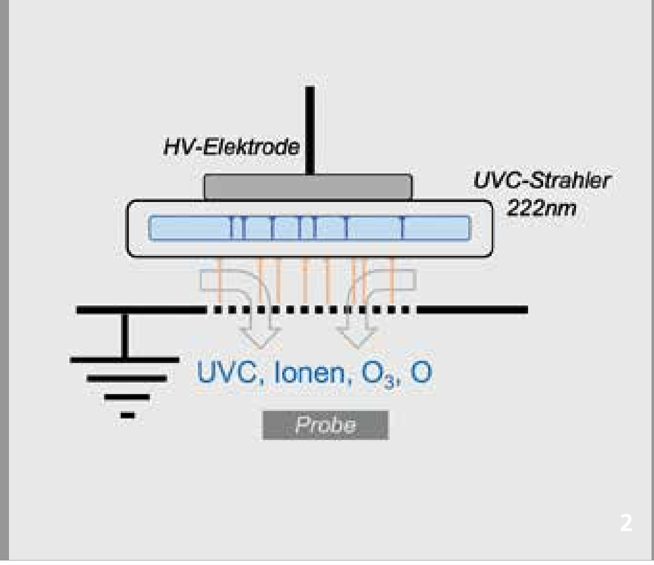
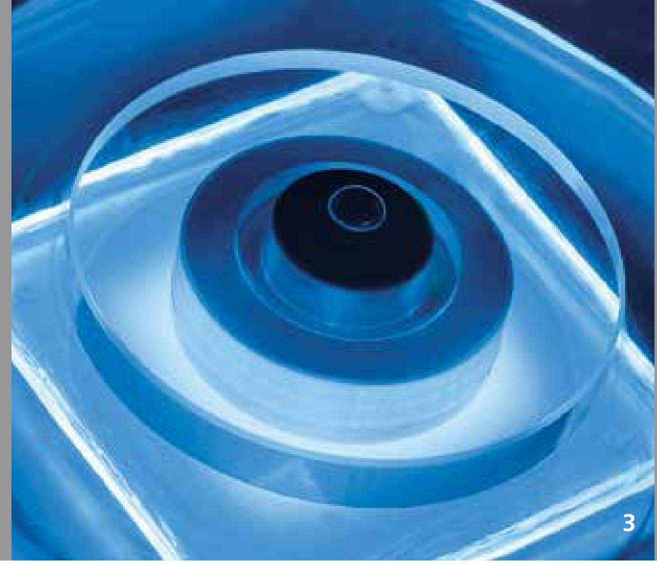
3 Prototype of the EUV camera, © khs-instruments.





IRRADIATION SYSTEM FOR THE DEVELOPMENT OF OPTICAL COMPONENTS IN THE EXTREME ULTRAVIOLET

Task

The development of optical systems and components for extreme ultraviolet lithography (EUVL) requires lifetime tests at the operating wavelength around 13.5 nm and intensities that also occur during operation of the lithography systems. The thermal load capacity or the wear caused by EUV-induced contamination of the components can thus be determined and improved or reduced by suitable measures such as special coatings.

Method

The main components of the testing system are an EUV radiation source developed by Fraunhofer ILT, which is based on a xenon gas discharge, and a grazing-incidence collector with the sample to be irradiated at the focal point. When dimensioning the collector, Fraunhofer ILT had to take several requirements into account: spot size, average power, peak intensity and incidence angle as well as the volumetric emission properties of the beam source. Unbiased experimental conditions need a suppression of the working gas flow into the irradiation chamber to about 10^{-5} mbar l/s. Supported by Monte Carlo simulations of molecular flow in vacuum, the institute developed a differential pumping system to achieve this goal. The radiation source has an average EUV power of up to 700 W/2πsr in a spectral range of 10–18 nm (broadband). Of this, a radiation power of up to 40 W/2πsr is emitted in the region of particular interest for EUV lithography, around 13.5 nm in a spectral bandwidth of 0.27 nm (inband). The pulse repetition rate of the EUV source is up to 2500 Hz.

Results

The developed system consisting of source, collector module and pressure stage delivers an average irradiation power of up to 40 W/cm^2 (broadband) and about 4 W/cm^2 (inband) around a central wavelength of 13.5 nm with a spot diameter of 1.6 mm. A modified optical system allows the approximately homogeneous irradiation of an area with a diameter of about 4 mm at a correspondingly lower intensity. With differential pumping, a pressure of less than 10–7 mbar can be achieved at the sample position, minimizing interfering influences from residual gas contamination during the examination.

Applications

A spectral range from about 2 nm wavelength to the extreme ultraviolet at about 20 nm is covered when the operating parameters of the source and the collector are adjusted. The main field of application currently lies in lifetime tests of components for EUV lithography using an irradiation around a central wavelength of 13.5 nm.

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1 Source-collector system for irradiation experiments in the extreme ultraviolet.

COMBINED UV-PLASMA TREATMENT FOR SURFACE DISINFECTION

Task

UV radiation and plasmas are used today to disinfect and sterilize surfaces, respectively. However, there are limitations to both methods. In the case of UV radiation, there are losses due to shading of rough surfaces or the effectiveness is insufficient with certain types of pathogens. In the case of pure plasma treatment, the applications are restricted by the high energy required to generate the plasma and the high irradiance levels needed.

Method

To combine the advantages of both processes in one device, Fraunhofer ILT has built a demonstrator for a combined UV-plasma treatment. In a cascaded barrier discharge (Fig. 2), both UVC radiation at a wavelength of 222 nm and an air plasma are efficiently generated by applying an alternating high voltage. A continuous air flow is used to direct the reactive substances generated in the plasma – such as radicals, ozone and also atomic oxygen, as well as the UVC radiation itself – through a mesh electrode onto the surface to be cleaned. The electrical power consumption related to the surface of the UVC radiator is about 0.8 W/cm^2. The irradiance of the UVC component on the sample is 2 mW/cm^2.

Results

In initial experiments with E. coli and Bacillus subtilis, vital germs were reduced by up to five orders of magnitude with an electrical energy per radiator area of 3 J/cm^2. Germs were reduced by one order of magnitude to 10 percent with an irradiation of 10 mJ/cm^2 for the spectral UVC component. The concept can be scaled to smaller modules with a power consumption of a few watts and a small size, making this technology suitable for mobile use.

Applications

Possible applications for mobile use are in disinfection systems for clinics and medical facilities. Large-scale applications include the production of sterile packaging for medical devices and the sterilization of heat-sensitive equipment.

The developments were carried out as part of the joint project “MobDi – Mobile Disinfection” via the Anti-Corona Program of the Fraunhofer-Gesellschaft under grant number 840264.

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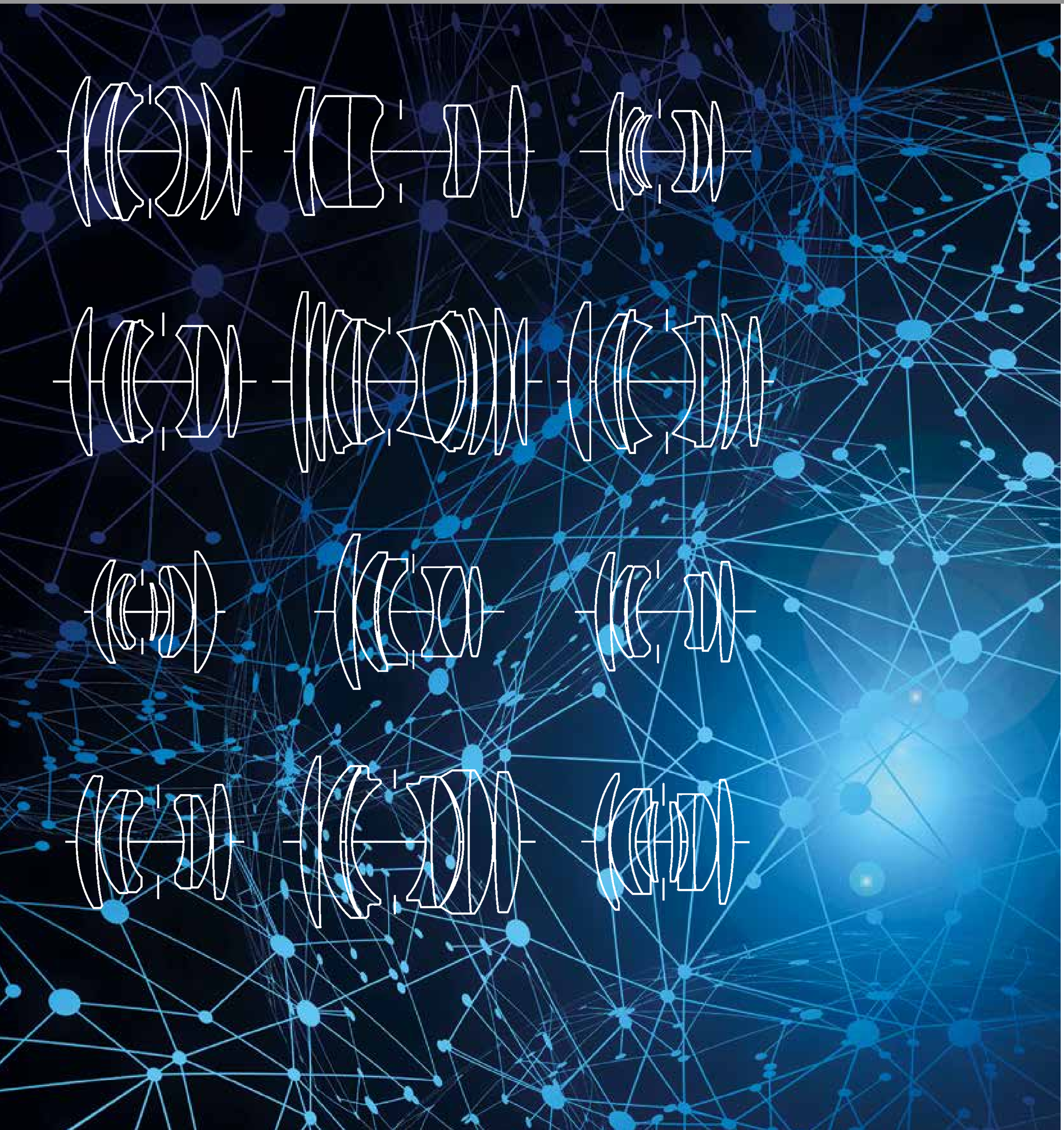
2 Principle of combined UV plasma treatment.

3 UVC lamps in the demonstrator.

DIGITALIZATION



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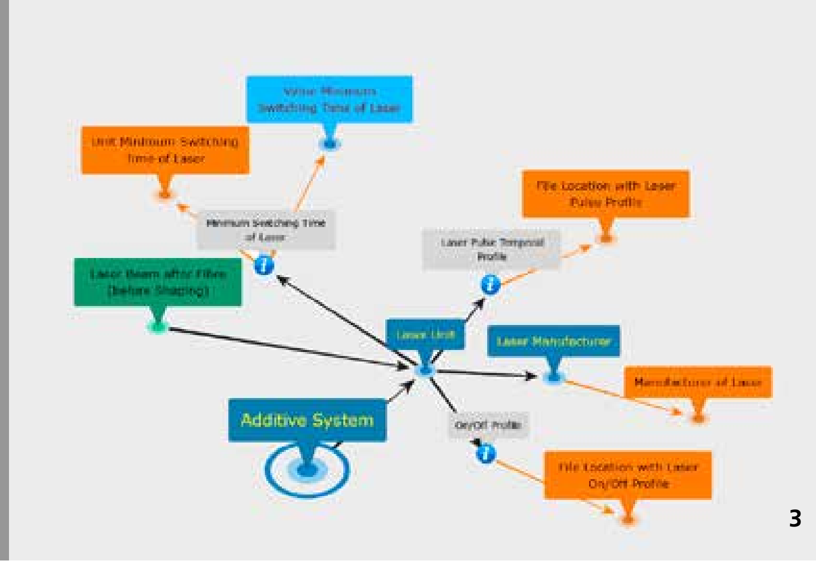

AMABLE – PLATFORM FOR DEVELOPMENT SUPPORT

Task

When a company considers using additive manufacturing for a new product development, it is confronted with a large number of options in all areas from design to production. Decisions in mechanical design, for example, can mean that excess powder material can no longer be removed in downstream production steps, or that the dimensional tolerances of a product cannot be maintained since thermal influences impair the construction process. Ideally, such problems are detected at an early stage and prevented using appropriate measures. However, there is often a lack of on-site knowledge in the specific application. The search for suitable expertise is also time-consuming and cost-intensive.

Method

In additive manufacturing, engineers are constantly gaining new insights into product design and process control, many of them in the laboratories of leading research institutes. For example, if they are designing a new lightweight heat exchanger to withstand high pressure and temperature stresses, they need access to current findings in material development. If the choice of material influences the dimensional accuracy of the manufactured product, knowledge of process control is also essential.

Comprehensive competence along the product development chain is ideally covered by combining the know-how of many experts from the various sub-disciplines. The AMable platform offers precisely this pool of expertise through its partners from Europe's leading research institutes, thus creating a unique resource for SMEs and industrial users. AMable is a true one-stop "shop" for quick solutions. Once the user has formulated the question, a suitable and available expert is found within a short time to provide concrete support in finding a solution. The entire process from inquiry to solution remains under one roof and can also include the production of prototypes.

Results

AMable offers dedicated support for the development of additively manufactured products in its "Services Arena". SMEs and industrial users can use services such as "Design for AM" or "Materials for AM" to draw on external expertise for their development throughout Europe. Users can decide for themselves whether they want to use the services as training or as outsourcing.

Applications

The AMable platform supports additive manufacturing users in all phases of product development - from design to manufacturing – with all materials and processes.

This project has received funding from the European Union Horizon 2020 Research and Innovation Programme under grant number 768775.

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1 Design process using the AMable platform.
2 Heat exchanger realized with AMable,
© Ramem, Epsilon.

ONTOLOGIES FOR DIGITIZED VALUE CHAINS IN ADDITIVE MANUFAC-TURING PROCESSES

Task

To continuously improve additive manufacturing processes, engineers must integrate them into digital value chains within the principles of the Fourth Industrial Revolution. In particular, to continuously improve both additive manufacturing processes and the quality of the manufactured components, the inclusion of all influencing factors of the process must be consistent, traceable and transparent. For this purpose, data generation, data storage, data evaluation and the corresponding data streams along the process chain must be known, semantically comprehensible and merged.

Method

Suitable tools for this kind of merging are ontologies. These enable engineers to create a unified vocabulary, to map and index logical relationships and to generate knowledge graphs for linking the data, which can be stored in a standardized file format (RDF, resource description framework), imported into databases, and searched using a standardized query language.

Results

Fraunhofer ILT is using its expertise in the laser-based additive manufacturing processes laser material deposition (LMD) and laser powder bed fusion (LPBF) to create a digital knowledge base, which has been built up over many years. In this, the data along the process chain are networked with regard to the powder material, the process, the machine used and the product. The ontologies developed serve as a template for transfer to databases and can be supplemented with application-specific measurement and process monitoring data, as well as simulations.

Applications

The ontologies for additive manufacturing processes can be applied independently of industry and application and can be extended as required. The work is funded by the Fraunhofer-Gesellschaft as part of the ADAM project. It focuses on developing ontologies as a basis for SME-oriented data-driven value creation through data ecosystems.

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3. Ontologies for digitized value chains in additive manufacturing processes.

SPATIALLY RESOLVED PROCESS MONITORING FOR ADDITIVE MANUFAC-TURING WITH LASER MATERIAL DEPOSITION

Task

To qualify additively manufactured components, process monitoring is necessary to detect even the smallest deviations during the manufacturing process. In laser material deposition, coaxially integrated, camera-based sensors for detecting the thermal signature of the melt pool are state of the art. Data acquisition is predominantly time-resolved. The process monitoring data for individual component cross-sections are required, above all, with local resolution to enable users to localize process anomalies during the layered buildup of solids and to assign ex-situ detected component properties to in-situ recorded sensor signals for complex component geometries.

Method

A software solution developed at Fraunhofer ILT records and synchronizes not only the data of several sensors using a timestamp but also the tool center point coordinates of the machine tool, both of which make it possible to localize the measurement data. The machine data is recorded using the OPC UA standard. With an additionally implemented image processing pipeline, features extracted from melt pool images, such as the melt pool surface or detectable spatter, can also be recorded and localized in the component, in addition to pyrometer temperatures.

Results

By synchronizing different measured variables of the process monitoring with weld tracks of the laser material deposition process, Fraunhofer ILT has been able to investigate, in spatial resolution, a correlation of abnormalities in the images with quality characteristics such as volume defects and shape accuracies of the manufactured component.

Applications

The concept is currently being tested and validated on use cases from the aerospace industry. However, testing can be carried out independently of the industry for any use case in additive manufacturing, repair, component individualization or coating. With the open communication standard OPC UA, users can apply the data acquisition concept independently of machines and controllers.

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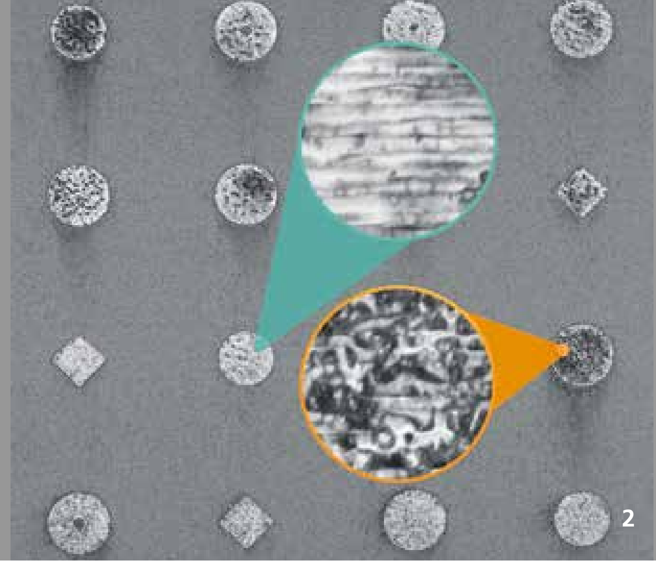
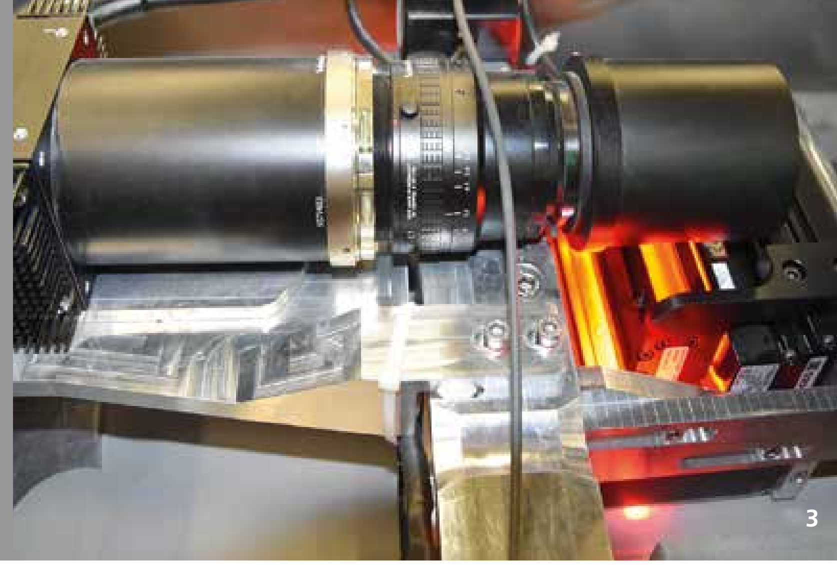
1 Hybrid-additively manufactured BLISK with representation of the process measurement data.





QUALITY ASSURANCE IN ADDITIVE MANUFACTURING BY MEANS OF DIGITAL IMAGE PROCESSING

Task

The properties of components made with laser powder bed fusion (LPBF) are unknown while they are being manufactured. In particular, internal defects as well as the actual part geometry can only be determined afterwards by taking additional steps in external quality control. At the same time, the cyclic character of the LPBF process could be used for layer-by-layer process monitoring. Existing approaches to this are already focused on observing thermal emissions.

Method

Fraunhofer ILT has developed a process monitoring system with a line sensor, which uses the inherent movement of the powder application unit to record images of the cooled process zone layer by layer and line by line. The institute has also developed application-specific image processing algorithms and tested them to identify process deviations and possible defects from the image data.

Results

Thanks to the detailed resolution of the system, the institute can identify individual solidified melt paths as well as estimate their textures that are closely linked to the resulting component quality. A material-specific “fingerprint” can be extracted from the sensor data; the deviation from the nominal value can be used to infer critical process conditions. By means of machine learning, certain process deviations (e.g. the “balling effect”) can also be detected directly from the image data. The detection of the actual component geometry is made possible by a specially developed approach to image segmentation. In principle, a large number of process deviations can be detected, both inside the part and in the contour area.

Applications

LPBF is currently used primarily for the production of complex and heavy-duty components, e.g. in medical technology and aviation. Initially, the in-process recording of the process behavior can reduce costly downstream quality controls. In the future, the system could also be used as a basis for the in-situ adjustment of process parameters in order to sustainably increase component quality and to repair or prevent potential defects while the process is still in progress.

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2 Slice image acquired with the system.
3 Line scan camera system integrated in laboratory plant.

CLOUD NATIVE USP LASER PROCESSING

Task

An ultrashort pulse (USP) laser is a complex system that can ablate any material with micrometer precision. To accomplish this, numerous sensors are used to control the machine and the laser process. The software that controls the components and reads the data from the sensors is correspondingly diverse. In industrial production, many such systems are used in parallel. Fifty systems running side by side is not unusual here. But how can they be installed efficiently and controlled centrally?

Method

Conventional concepts are no longer able to control 50 and more lasers simultaneously, install new software for these systems and evaluate sensor data in real time. For this reason, Fraunhofer ILT redeveloped the entire control and analysis software while taking into account the RAMI4.0 specifications. The institute placed particular emphasis on integrating it in data centers and making the system easy to scale. The software is thus “cloud native” and can be installed very quickly on production computing clusters. “Kubernetes”, open source software, operates at the core of the data center. It can automatically install, scale and maintain application programs on distributed computing systems. Kubernetes was originally designed by Google and is supported by leading cloud platforms such as Microsoft Azure, IBM Cloud, Red Hat OpenShift, Amazon EKS, Google Kubernetes Engine and Oracle OCI.

Results

The Chair for Laser Technology LLT at RWTH Aachen University has co-developed cloud native control software that is administered by Kubernetes. The entire management software stack used is open source and allows for extensive customization of the processes. In addition to automation routines, condition monitoring and other analysis algorithms, the control algorithms can now be centrally hosted, administered and updated on the shop floor. This centralized control level creates economies of scale that make software management of hundreds of plants possible in parallel. In addition, by using Kubernetes, developers can provide external computing capacity to the plant algorithms “on demand” at any time. For example, through cloud providers or on-premises data centers, the computing capacity can be individually adapted to the current operational load.

Applications

The control software is primarily designed for use in laser systems. The framework used here scales very well for hundreds of simultaneously operated systems, for example in a job store, as well as for individual systems that need to be continuously adapted. The modularity favors easy adaptation to other processes such as LPBF.

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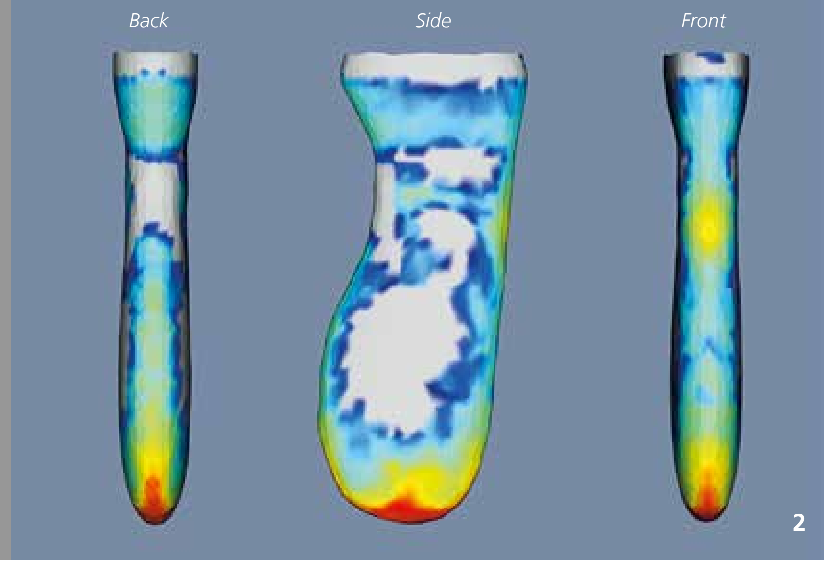
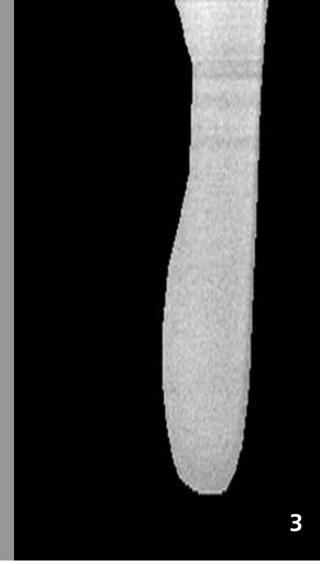
1 USP laser processing.





SIMULATION OF THE ABSORPTION DISTRIBUTION IN LASER BEAM MICRO-WELDING OF METALS

Task

Laser welding of metallic materials on the submillimeter scale is used to produce electronic components in the electromobility industry. The small spatial scales as well as the large thermal conductivities of copper and aluminum materials pose challenges for process stability, however. With the experimental diagnostics and numerical simulation, research can analyze causes of instabilities and derive measures for improving the quality of the weld seam.

Method

The laser welding process is conducted by scientists from Fraunhofer ILT and RWTH Aachen university LLT in an adapted setup at the German Electron Synchrotron (DESY) and exposed in-situ with high-brilliance X-rays from the PETRA III beam source. At RWTH Aachen University (NLD), the acquired contrast images are used to construct the three-dimensional shape of the weld capillaries. A GPU-parallelized ray tracing algorithm developed at NLD is used to calculate the radiation propagation and absorption.

Results

The temporal course of the calculated absorption distribution shows a predominantly uniform illumination of the capillary base. The dynamic variation of the capillary shape is mainly expressed by absorption fluctuations in medium depth regions as well as in the detection of the back-reflected light. Thanks to the process understanding gained from analyzing the time course of absorption distribution and capillary shape, Fraunhofer ILT has developed approaches for reducing pore formation and surface roughness.

Applications

The modeling and numerical simulation developed here can be applied in the process development of laser microwelding for metallic materials, especially for components of the electric vehicle industry (battery packs, fuel cells) and power electronics (direct bonded copper substrates).

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2 Calculated absorption distribution on the surface of a welding capillary reconstructed from X-ray images.
3 Masked radiograph of a sweat capillary.

ALGORITHM DEVELOPMENT FOR THE RIGOROUS SIMULATION OF WAVE OPTICAL ELEMENTS

Task

As components become smaller and smaller, and more precise manufacturing processes are developed, optical elements in production engineering and other applications are also becoming more and more compact. If their structure sizes are in the order of magnitude of the wavelength used, wave-optical effects occur. Since these effects enable a functionality that cannot be achieved with conventional optics, they open up novel possibilities for beam shaping. For example, in so-called meta-optics, these effects can be used to create a very short focal length or an unexpected beam deflection at perpendicular beam incidence. However, since the physical principles for these optical systems are more complex than for conventional optics, innovative methods are necessary to design corresponding optical elements, also for near-application, macroscopic situations.

Method

For the simulation of wave-optical elements, the Chair for Technology of Optical Systems (TOS) at RWTH Aachen University has developed algorithms that rigorously solve the underlying physical equations on a microscopic level and simultaneously couple these with macroscopic computational methods. The latter are, for example, methods for analyzing overall optical systems or for rendering complex scenarios. In the future, these methods will be coupled with optimization algorithms so that the systems can not only be analyzed, but also designed.

Results

With the methods developed, the institute could simulate illumination scenarios even for complex configurations. The method was validated by comparison with experimentally taken photographs.

Applications

The methods developed here have multiple applications in areas such as beam shaping for laser material processing, in AR applications such as near-eye displays, or for the generation of structural color.

This work is being partly funded by the German Research Foundation (DFG) under the Excellence Strategy of the German Federal and State Governments – EXC-2023 Internet of Production – under grant number 390621612.

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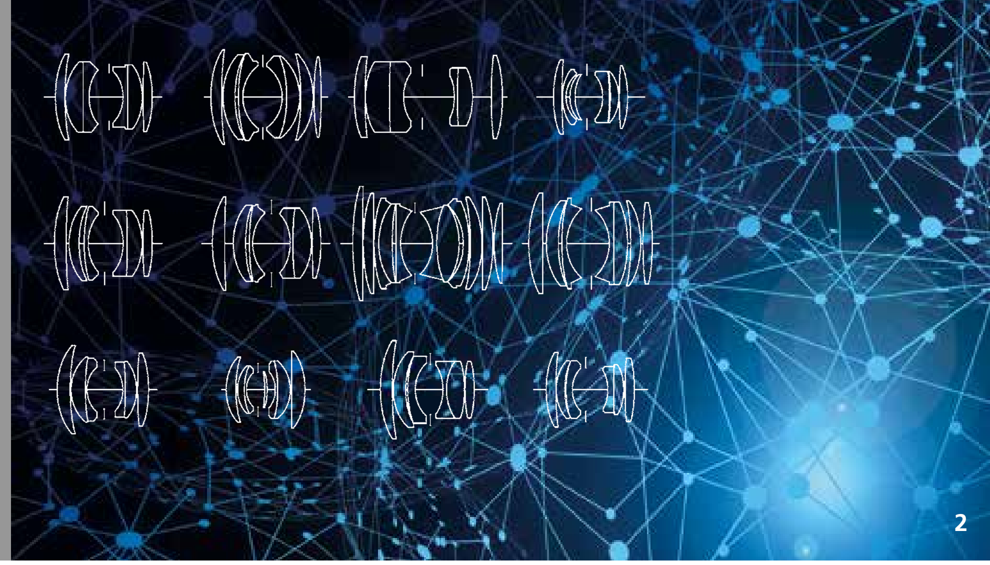
1 Result of a wave-optical simulation of an illumination scene with two CDs.



REINFORCEMENT LEARNING FOR AUTOMATED DESIGN OF OPTICAL SYSTEMS

Task

Optical systems are currently designed using ray or wave optical simulation software. The optical system is optimized in terms of required target functions, which results from iterative modifications that the designer makes and the automated optimization of variable parameters. For research purposes, the question now arises whether this design and optimization strategy can be executed by a reinforcement learning approach. In this approach, an agent takes over the task of the optical designer, modifying and optimizing the optical system based on a ray-tracing program.

Method

An agent is trained for different use cases using a reinforcement learning algorithm. By evaluating a target function, which measures the optical aberrations of the system, for example, the agent independently learns the effects that various actions have on the system. In the process, for example, lens radii or the distances between lenses are modified. The agent's goal is to obtain a desired focal length or to minimize the optical aberrations.

Results

In a proof-of-concept, the Chair for Technology of Optical Systems at RWTH Aachen University used a two-lens system to design the lens bending in such a way that the spherical aberration is minimized for the given focal length. A neural network is trained using the proximal policy optimization approach. After a successful training phase, the approach can be used to automatically optimize the two-lens system. In another proof-of-concept, the lens spacings of a three-lens lens are varied to produce a desired target focal length for the optical system. In both examples, the objective function can be achieved within a few seconds.

Applications

The automated design of optical systems can be applied to the development of laser or imaging systems. Such a method is particularly advantageous for agile product development.

This project is being funded by the German Research Foundation (DFG) as part of the Excellence Strategy of the Federal and State Governments – EXC-2023 Internet of Production – under grant number 390621612.

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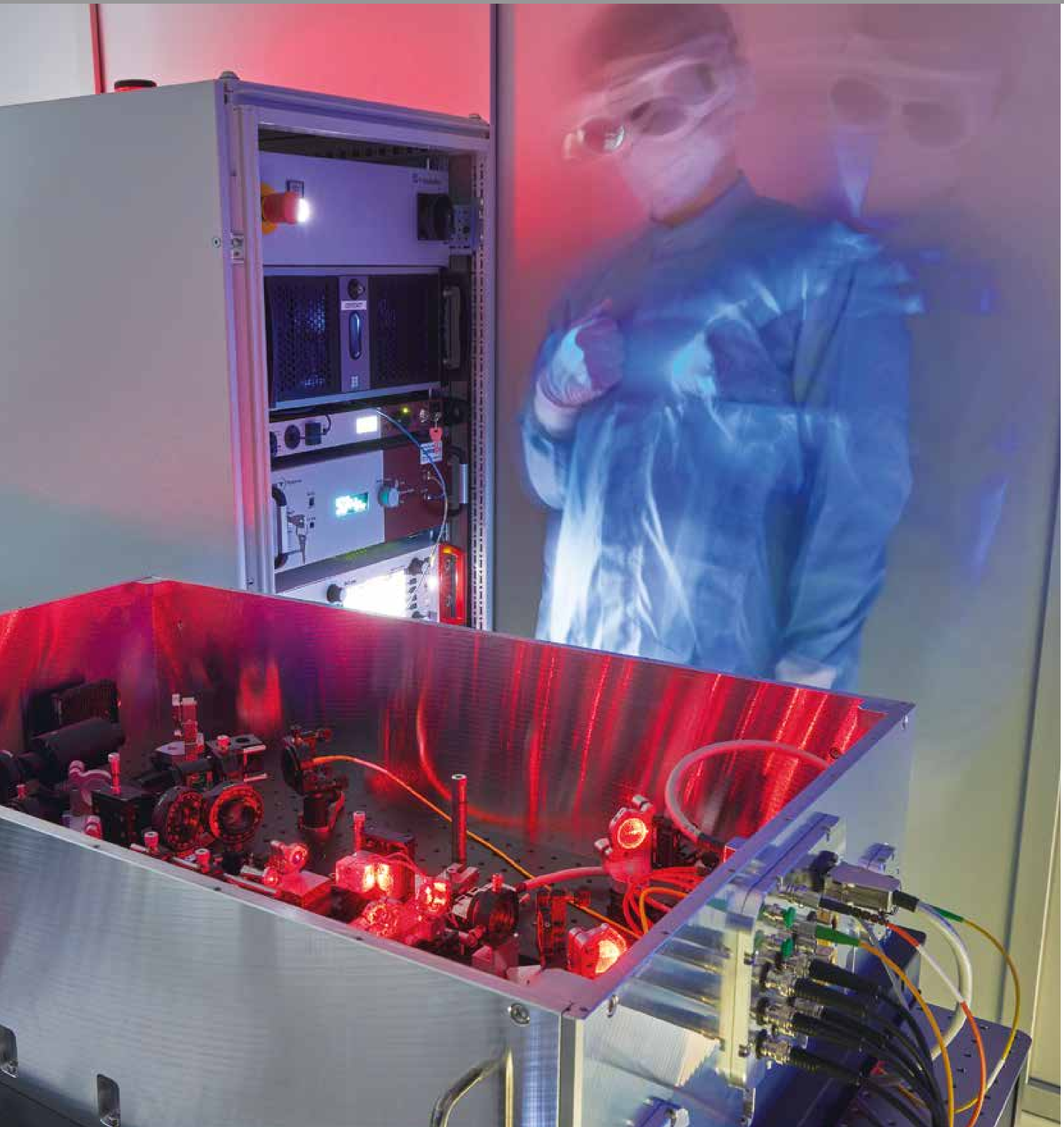
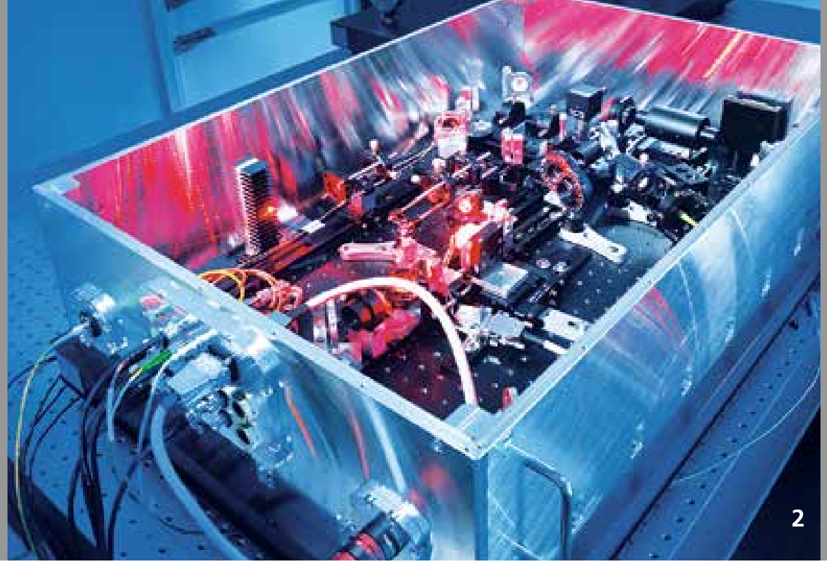
2 Reinforcement learning for optics design.

QUANTUM TECHNOLOGY



CONTENTS



QUANTUM COMPUTING IN PHOTONICS

Task

In the field of photonics, there is a multitude of different optimization problems with a large number of degrees of freedom. According to the current state of the art, such problems can only be solved approximately by means of classical, CPU- and GPU-based optimization processes. As a result, research cannot fully exploit the potential of the underlying photonic technologies. In the future, this problem could be solved by the ongoing development of quantum computers and annealers. Especially for discrete, combinatorial optimization problems, using quantum computers and annealers promises to shorten the required runtime and to increase the quality of the obtained solution. In order for quantum computers to solve photonics problems, however, these problems have to be transformed into a special mathematical formulation (quadratic unconstrained binary optimization, QUBO).

Method

The Chair for Technology of Optical Systems (TOS), in cooperation with Fraunhofer ILT is working out the transformations and validating the resulting advantages using state-of-the-art quantum computers. In addition, it is analyzing how to scale up optimization problems on future generations of quantum computers. In the context of preliminary investigations, the institute has identified various use cases from photonics for this purpose, cases that are particularly suitable, due to their problem structure, for the use of quantum computers and annealers. These use cases are expressed in the form of a QUBO problem, solved on a D-Wave Advantage quantum annealer, and the TOS is investigating the optimization quality for different problem sizes.

Results

Scientists at TOS have verified the correct QUBO formulations for the two use cases "Combinatorial selection of catalog lenses for automated design of optical systems" and "Design of free-form optical systems" using sample problems. They were able to identify the limitations of current generation quantum annealers and to formulate resulting requirements for suitable problems (among others avoiding densely populated QUBO matrices).

Applications

The investigations presented here make it possible to systematically assess the advantages of using quantum computers in optimization problems in photonics, such as optical design and industrial laser-based manufacturing (e.g., LPBF).

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1 Topography of a quantum annealer.

NOISE-REDUCED FREQUENCY CONVERTERS FOR THE QUANTUM INTERNET

Task

The development and construction of a quantum internet are overarching goals of the European quantum technology roadmap. To achieve this, quantum processors, sensors and network nodes must be interconnected over large distances to share information efficiently and securely, and to increase the performance and potential applications of quantum computers. A basis for implementing such networks is the low-loss transmission of quantum information encoded in single photons throughout an optical channel, e.g. optical fiber. In order to establish networks of heterogeneous nodes and to use wavelengths in the telecom band, the photon wavelength must be efficiently converted while maintaining the photon's quantum state. In the conversion process, the number of noise photons introduced by the converter setup must be minimized to optimize the signal-to-noise ratio.

Method

For efficient conversion, so-called quantum frequency converters (QFC) are used, which are based on nonlinear optical frequency conversion. In state-of-the-art devices, periodically poled crystals with waveguides are used, with which conversion efficiencies of up to over 90 percent can be achieved. However, these systems also generate high rates of noise photons.

Within the Fraunhofer ICON QFC-4-1QID project, Fraunhofer ILT and QuTech in Delft, the Netherlands, are developing novel low-noise QFCs. These converters are based on using nonlinear crystals without periodic poling and without waveguides in an enhancement cavity. With this approach, the basic physical process of introducing noise photons (spontaneous parametric down-conversion) can be effectively suppressed.

Results

A technology demonstrator of the converter was implemented as a compact, mobile and stable system and tested in a measurement campaign at QuTech in Delft. The converter achieves an internal photon conversion efficiency of about 50 percent, with the rate of noise photons reduced by a factor of four compared to the previous state of the art.

Applications

Efficient, low-noise frequency converters are a key component for a future quantum internet, for quantum networks and for quantum repeaters.

The work is being financially supported by the Fraunhofer-Gesellschaft as part of the ICON project QFC-4-1-QID.

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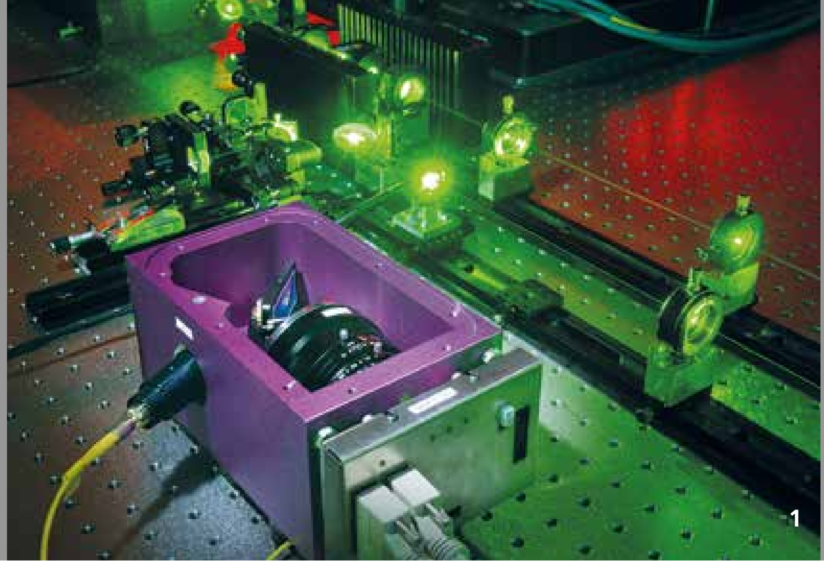
2 Demonstrator for an efficient, low-noise QFC.



QUANTUM OCT

Task

Optical coherence tomography (OCT) is a powerful and widely used method for the non-destructive 3D imaging of layered systems. While previous OCT systems work in the visible or near-infrared range, the penetration depth in scattering materials can be significantly increased if the system uses light with longer wavelengths – in the mid-infrared (MIR). At the same time, however, the complexity and cost of appropriate detectors and light sources increase, which is why such MIR OCT systems have not yet been commercially implemented. This circumstance can be circumvented if the sample measurement and the detection are examined at different wavelengths, using a so-called measurement of undetected photons.

Method

In a quantum OCT, entangled photon pairs are used in which the wavelength of one photon is in the visible or near-infrared range and the second in the MIR range. While measurements are made in the MIR, detection in the visible or near-infrared wavelength range is done with low-cost and low-noise silicon detectors. The Fourier transform of the interference signal is used to evaluate the depth information of the sample. The Fraunhofer ILT is developing an adapted spectrometer as well as a nonlinear interferometer. The latter is essentially a Michelson interferometer, whereby the entangled photon pairs are generated in a nonlinear crystal (here, a periodically poled lithium niobate: PPLN), which is located in the input and output of the interferometer. A commercially available laser at 532 nm is used as pump source.

Results

Fraunhofer ILT built and tested the nonlinear interferometer in a laboratory setup. The principle function was first demonstrated at a measurement wavelength in the near infrared at 1485 nm and a detection wavelength of 829 nm. Furthermore, the setup was converted for MIR measurement wavelengths, which could be adjusted between 4 and 5.7 µm, a range that is within the limit of what the PPLN crystal can transmit. Detection is performed accordingly between 586 nm and 613 nm. The recorded interference signals also show that the quantum OCT principle works. Depending on the wavelength selected, the spectral width allows axial resolutions in the range of 10 µm.

Applications

One application is the 3D investigation of ceramic functional components and coatings. In the future, the quantum OCT system will be able to detect pores, cracks and fluctuations in coating thicknesses during the production cycle and be used to increase component quality and control manufacturing processes.

This project was financially supported by the Fraunhofer-Gesellschaft.

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1 Nonlinear interferometer (background) and spectrometer (foreground).

HIGH-RESOLUTION QUANTUM IMAGING IN MIR WITH NON-DETECTED PHOTONS

Task

Quantum imaging uses non-classical photon states to overcome the limitations of classical imaging. For example, wavelength-shifted entangled photon pairs can be used to separate the measurement and detection wavelengths in imaging processes and to independently optimize them for the particular measurement required. Samples scanned in difficult-to-access but highly interesting spectral regions such as the mid-infrared can be investigated, while image information is generated in the easily detectable visible spectral range of light. One process to achieve this is "non-detected photon imaging", where the photons interacting with the sample do not need to be detected and images are acquired interferometrically using only the entangled partner photons.

Method

Fraunhofer ILT has developed photon sources and quantum interferometers within the Fraunhofer QUILT lighthouse project, which allow high-resolution imaging analyses in the mid-infrared. Here, measurement wavelengths in the range from 1.5 to greater than 4.5 µm could be demonstrated, with the detection wavelength lying in the range around 600–700 nm. With this wavelength, both photons can be detected efficiently and with low noise using low-cost and sophisticated silicon-based cameras. A large-aperture lithium niobate crystal pumped at 532 nm is used to generate the photon pairs. By building the interferometer in a special long-pass configuration with broadband-coated optics, the institute can probe the entire wavelength range of the sources with a single setup.

Results

Non-polarized, large aperture crystals can be used to acquire very detailed images in the mid-infrared compared to the state of the art. The number of resolvable pixels is about 12,000 at a resolvable structure size of 70 µm and an image field diameter of more than 7 mm, which is an order of magnitude higher than previous results in this wavelength range. The institute is continuing to improve the process.

Applications

The developed setup forms the basis for investigating novel applications of quantum imaging in the life sciences and materials testing. The lower cost of the image sensor and the operation at room temperature may make it applicable in a wide range of commercial settings.

The work was funded by the Fraunhofer-Gesellschaft as part of the QUILT lighthouse project.

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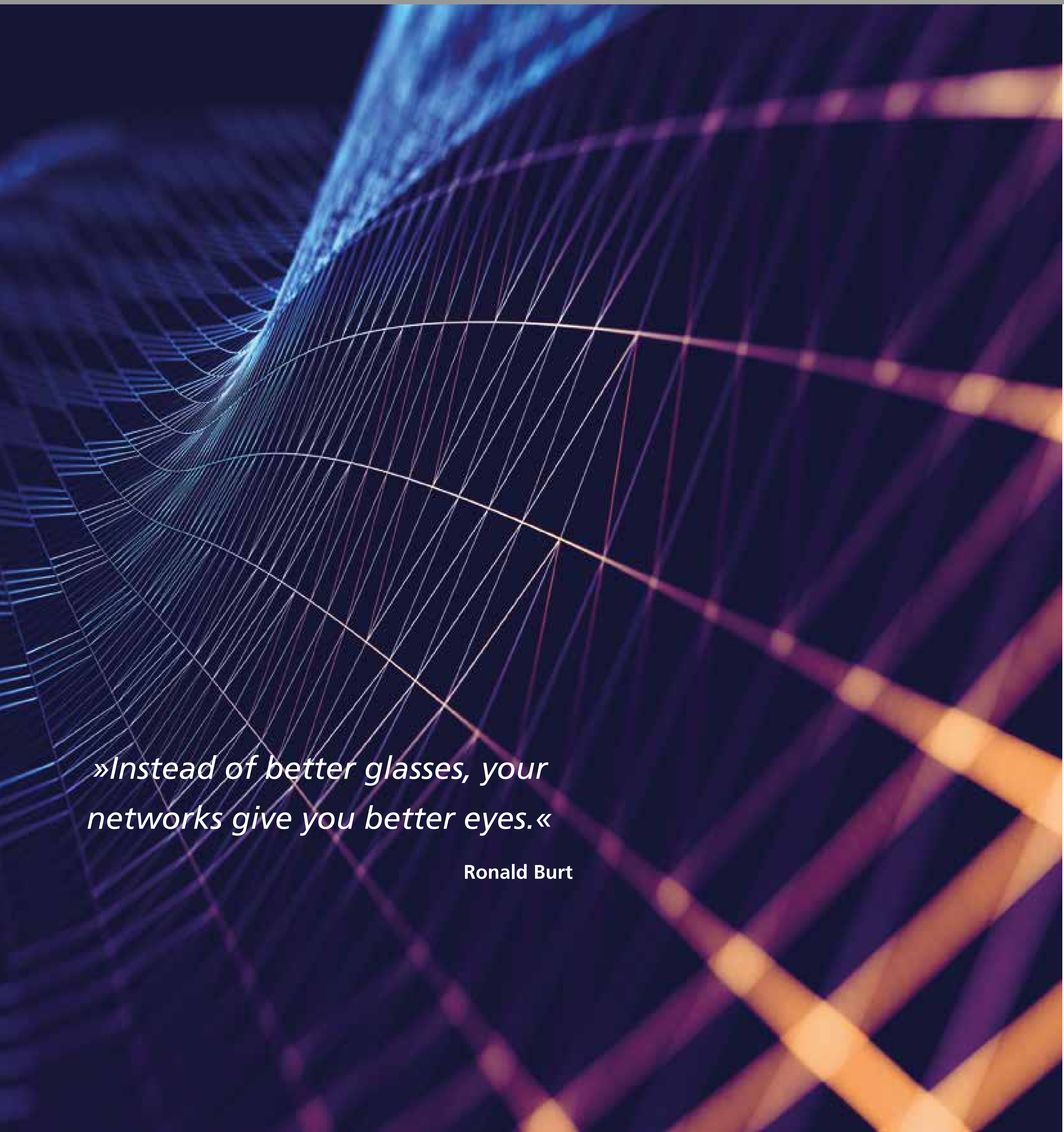
2 Image of the test object with measuring wavelength 3.4 µm.

3 Transmission object for the quantum interferometer.

NETWORKS AND CLUSTERS



»Instead of better glasses, your networks give you better eyes.«

Ronald Burt

THE FRAUNHOFER-GESELLSCHAFT AT A GLANCE

THE FRAUNHOFER-GESELLSCHAFT

The Fraunhofer-Gesellschaft based in Germany is the world's leading applied research organization. Prioritizing key future-relevant technologies and commercializing its findings in business and industry, it plays a major role in the innovation process. It is a trailblazer and trendsetter in innovative developments and research excellence. The Fraunhofer-Gesellschaft supports research and industry with inspiring ideas and sustainable scientific and technological solutions and is helping shape our society and our future.

The Fraunhofer-Gesellschaft's interdisciplinary research teams turn original ideas into innovations together with contracting industry and public sector partners, coordinate and complete essential key research policy projects and strengthen the German and European economy with ethical value creation. International collaborative partnerships with outstanding research partners and businesses all over the world provide for direct dialogue with the most prominent scientific communities and most dominant economic regions.

Founded in 1949, the Fraunhofer-Gesellschaft currently operates 76 institutes and research units throughout Germany. Over 30,000 employees, predominantly scientists and engineers, work with an annual research budget of € 2.9 billion. Fraunhofer generates € 2.5 billion of this from contract research. Industry contracts and publicly funded research projects account for around two thirds of that. The federal and state governments contribute around another third as base funding, enabling institutes to develop solutions now to problems that will become crucial to industry and society in the near future.

The impact of applied research goes far beyond its direct benefits to clients: Fraunhofer institutes enhance businesses' performance, improve social acceptance of advanced technology and educate and train the urgently needed next generation of research scientists and engineers.

Highly motivated employees up on cutting-edge research constitute the most important success factor for us as a research organization. Fraunhofer consequently provides opportunities for independent, creative and goal-driven work and thus for professional and personal development, qualifying individuals for challenging positions at our institutes, at higher education institutions, in industry and in society. Practical training and early contacts with clients open outstanding opportunities for students to find jobs and experience growth in business and industry.

The prestigious nonprofit Fraunhofer-Gesellschaft's namesake is Munich scholar Joseph von Fraunhofer (1787–1826). He enjoyed equal success as a researcher, inventor and entrepreneur.

STRATEGIC FRAUNHOFER PROJECTS

FRAUNHOFER-GROUP LIGHT & SURFACES

Competence by networking

The Fraunhofer Group for Light & Surfaces brings together the Fraunhofer-Gesellschaft's scientific and technical expertise in the areas of laser, optical, measurement and surface technology.

Members are the Fraunhofer Institutes for:

- Organic Electronics, Electron Beam and Plasma Technology FEP, www.fep.fraunhofer.de/en.html
- Laser Technology ILT, www.ilt.fraunhofer.de/en.html
- Applied Optics and Precision Engineering IOF, www.iof.fraunhofer.de/en.html
- Physical Measurement Techniques IPM, www.ipm.fraunhofer.de/en.html
- Surface Engineering and Thin Films IST, www.ist.fraunhofer.de/en.html (associated)
- Material and Beam Technology IWS, www.iws.fraunhofer.de/en
- Telecommunications Heinrich Hertz Institute, www.hhi.fraunhofer.de/en (associated)
- Optronics, System Technologies and Image Exploitation IOSB www.iosb.fraunhofer.de/en.html (associated)

With a total of approximately 1900 employees, the Fraunhofer Institutes in the Group work together to solve complex, application-oriented customer inquiries at the cutting edge of science and technology.

But the Fraunhofer Institutes are not only partners in innovation. They also work to produce new generations of scientific and technical experts. In cooperation with the local universities, the young scientists at the Fraunhofer Institutes bring together academic research and industry.

Core competencies of the group

1. Optics and photonic components and systems
2. Layer and surface processing
3. Production technology
4. Measurement and testing technology
5. Quantum technology

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2 © Fraunhofer IPM.
3 © Fraunhofer IOF.

FRAUNHOFER ICON PROJECT "QFC-4-1QLD"

Connecting quantum computers via optical fibers

Fraunhofer ILT and the Dutch research center QuTech are working closely together in quantum communication and quantum information networks. In September 2019, they launched the ICON project "QFC-4-1QID – Low-Noise Frequency Converters for the First Quantum Internet Demonstrator". Their goal is to develop efficient and low-noise quantum frequency converters (QFC) for connecting quantum processors to fiber optic networks and for building what is expected to be the world's first quantum Internet demonstrator. Together, the partners are developing technologies for an entanglement-based link between two quantum processors in Delft and The Hague – the first implemented link in a larger national quantum network. QFCs with high efficiency and, at the same time, low noise in the output signal are important key components. They allow the wavelengths of individual photons to be specifically modified so that they lie in the range of the optical telecommunication bands (1,500–1,600 nm); this way the photons can be transmitted with as little loss as possible via optical fibers and without compromising crucial quantum information.

On the way to the quantum internet

In October 2021, the project partners and the industrial advisory board met for the mid-term meeting at Fraunhofer ILT to discuss new results and the further roadmap. QuTech, an alliance of Delft University of Technology and the Netherlands Organization for Applied Scientific Research TNO, is one of the world's leading institutions in the fields of quantum communications and the Internet. With TRUMPF Photonics Components, Menlo Systems and ADVA from Germany as well as QuiX and OPNT from the Netherlands, renowned companies are also involved in the project as an industrial advisory board, supporting the developments and contributing their experience when the project's results will be commercially implemented.

The benefits of the fruitful collaboration are reflected in the development of a quantum frequency converter (QFC) architecture, which was demonstrated by Fraunhofer ILT in May 2021 at QuTech in Delft and set a world record. Compared to the state of the art, the new converter reduces noise by almost an order of magnitude and generates a potentially much better signal-to-noise ratio, as well as a higher photon rate for the entanglement of the two nodes. This will thus greatly facilitate further development towards making the quantum Internet a reality. In a next step, a second QFC system will be developed and optimized based on the first one, which will later be tested at QuTech with qubits (NV centers in diamond with an emission wavelength of 637 nm). With the QFC-4-1QID project, the partners are positioning themselves as leading organizations that develop and transfer quantum technologies together to strengthen Europe's innovative power and pave the way for the quantum Internet.

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www.ilt.fraunhofer.de/en/technology-focus/quantum-technology.html

CENTERS OF EXCELLENCE AND LIGHTHOUSE PROJECTS

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 build up an open research platform and test environment for the industry, one in which new concepts for a 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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Further information on the Internet at:
www.vernetzte-adaptive-produktion.de/en.html

New compact sensors for industrial processes in harsh environments.

FRAUNHOFER LIGHTHOUSE PROJECT "eHarsh"

As key elements for recording environmental properties, sensor systems are used in the industrial sector to intelligently control processes, especially within the context of the Fourth Industrial Revolution. Standard electronics cannot be used for such systems when they have to operate under harsh conditions such as high temperatures, high mechanical stress or aggressive environments.

Eight Fraunhofer institutes have pooled their expertise in the fields of sensor technology, microelectronics, assembly, circuit board design, laser applications and reliability analysis. These institutes have formed a consortium to develop and provide a technology platform on the basis of which sensor systems, consisting of sensor technology and electronics, can be developed and manufactured for use in extremely harsh environments. To implement such systems, interdisciplinary competencies are needed, starting with the selection of appropriate materials and technologies, through various development competencies, system integration for the application, to the evaluation and prediction of reliability and operational behavior.

The work at Fraunhofer ILT will focus on hermetic interconnection technology for the assembly of sensor elements and the design of the associated housing technology. It is using laser-based processes such as laser-based glass soldering and laser-beam welding.

The lighthouse project will develop and provide the following technologies and competencies:
- Robust sensors, e.g. pressure and temperature sensors for use up to 500 °C and MEMS sensors for use up to 300 °C
- Integrated circuits and system components for use up to 300 °C
- Hermetically sealed encapsulations allowing simultaneous media access to the sensors
- 3D integration and encapsulation at the system level as a "system scaled package"
- Analytics and test methods for the various loads, also in their combination
- Understanding of material usage behavior with regard to defect risks and degradation mechanisms
- Advanced reliability analysis and models

The technologies and competencies are exemplified by two characteristic and extremely sophisticated demonstrators from the fields of jet engine/turbine monitoring and geothermal energy. Thanks to the technologies and demonstrators it has developed, the lighthouse project provides users with the opportunity to selectively develop and expand their markets in the field and establish unique selling points. Furthermore, this project displays Fraunhofer technology leadership in the area of "sensor systems in extremely harsh environments".

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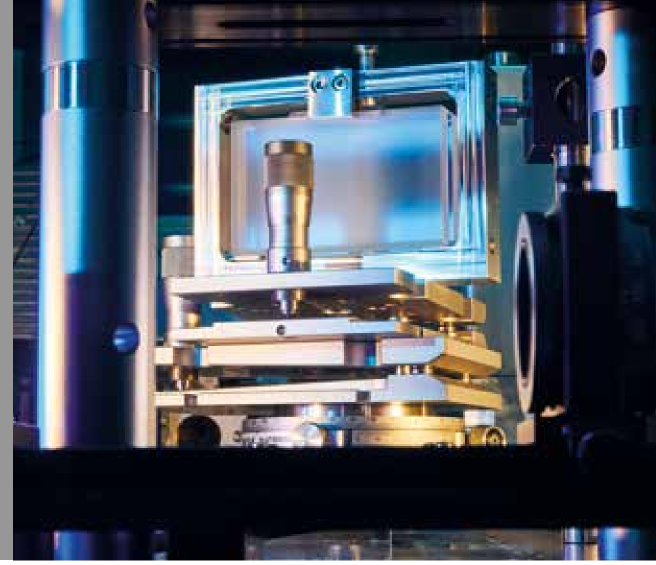
FRAUNHOFER CLUSTER OF EXCELLENCE

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 January 2018. Its aim is to achieve international technological leadership in laser systems that achieve the highest performance with ultrashort pulses (USP) and to research their potential applications in collaboration with Fraunhofer partners. The new systems will exceed all existing USP 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 applications for a new generation of extremely high-power ultrashort lasers. New fields of application are 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 CAPS.

USP lasers for high-precision applications

USP 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, USP lasers based on this technology have achieved average laser powers and a robustness that can also be used for industrial applications.

USP lasers have two major advantages for micro material processing applications: On the one hand, they can process practically all materials; on the other hand, 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 – USP lasers with beam powers in the kW range

The power of current USP lasers in the 100 W class is often insufficient with regard to economically relevant processing speeds when ultra-hard ceramic materials, metal foils, glass substrates or fiber-reinforced plastics are structured. 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 CAPS 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 was initially available, which was expanded to a second source with 1.5 kW up to 10 mJ in 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 precise localized generation of NV-centers in diamant. In addition, new possibilities are opening up for the semiconductor sector, lithography or the imaging of biological samples.

Furthermore, the sources developed in CAPS open up new possibilities for the imaging of biological samples as well as for the semiconductor and lithography sectors. The scaling of laser power is also interesting for basic research. In the future, laser particle accelerators will become much more compact and can, thus, even be integrated into existing laboratories. These so-called “secondary sources“ can significantly boost growth in areas such as materials research and medical technology.

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LASER TECHNOLOGY AT RWTH AACHEN UNIVERSITY

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JOINTLY SHAPING THE FUTURE

The RWTH Aachen University Chairs for Laser Technology LLT and Technology of Optical Systems TOS 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 three university departments and Fraunhofer ILT are building the future.

Carlo Holly takes over as head of the Chair for Technology of Optical Systems TOS

On February 26, 2021, Prof. Peter Loosen officially retired from RWTH Aachen University as Head of the Chair for Technology of Optical Systems TOS. He was succeeded by Prof. Carlo Holly effective May 1, 2021. Prof. Holly studied mechanical engineering and physics at RWTH Aachen University and worked at Fraunhofer ILT and the Chair for Laser Technology LLT in the field of optics design and diode lasers from 2012 to 2017. In April 2019, he received his PhD from the RWTH Chair for Laser Technology LLT with the dissertation entitled "Modeling of the Lateral Emission Characteristics of High-Power Edge-Emitting Semiconductor Lasers." After leaving Fraunhofer ILT, Prof. Holly worked at TRUMPF Photonics in Princeton, USA, in the field of semiconductor laser development. He then worked as Head of R&D Photonics at DiaMonTech AG in Berlin, where he developed non-invasive glucose measurement devices.

He was appointed professor at RWTH Aachen University on April 22, 2021. Since the summer semester of 2021, Carlo Holly has taken over the lectures of the TOS chair, which has been cooperating intensively with the Fraunhofer ILT for years.

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 "Internet of Production", 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
- New concepts for innovative laser-based processing and strategies

Prof. Constantin Häfner (Director of the chair)
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. These include adaptive optics and free-form optics for innovative beam shaping for process-adapted intensity distributions. The chair develops micro- and macro-optical components for high-power diode lasers and combines them to form systems. It also investigates lithography and material analysis with resolutions smaller than 50 nanometers in the field of EUV technology.

Prof. Carlo Holly (Director of the chair since 1.5.2021)
www.tos.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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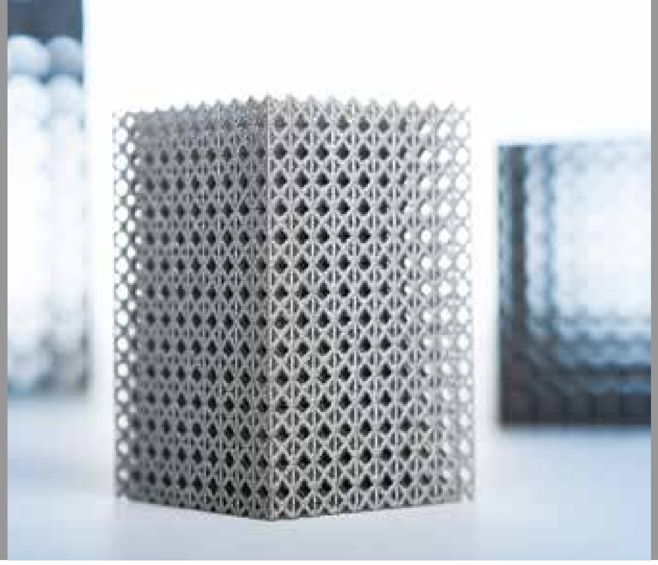

DIGITAL PHOTONIC PRODUCTION DPP

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 have been evolving into rapid manufacturing techniques for the direct production of functional components. Rapid manufacturing techniques have already been used in a lot of facilities for industrial production in 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. 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.

RESEARCH CAMPUS DPP AND RWTH AACHEN CAMPUS

Industry Building DPP (r.) and Research Center DPP (l.) at the Photonics Cluster, © Forschungscampus DPP, Aachen.

Entrance of the Industry Building DPP in the Photonics Cluster, © Forschungscampus DPP, Aachen.

RESEARCH CAMPUS DIGITAL PHOTONIC PRODUCTION

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 since 2014 BMBF funded Research Campus DPP, RWTH Aachen University, the Fraunhofer-Gesellschaft and industry can establish a new form of longterm and systematic cooperation that aims to concentrate the various resources under one roof for joint, complementary application-oriented basic research.

Road mapping process

The collaboration of the two Fraunhofer Institutes ILT and IPT, the chairs of RWTH Aachen University and the around 30 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). The systematic collaboration takes place in three competence areas and two application areas:

Digital competence area

- Digital process chain
- Digital shadow
- Artificial intelligence
- Automated algorithmic design
- The Fourth Industrial Revolution and cloud-based production

Photonics competence area

- Novel scanner concepts
- Multi-beam systems
- Application-adapted, local and temporal intensity distributions
- Process sensor technology

Production competence area

- Systematic cost and benefit assessment
- Material development

Additive production and subtractive production application areas

- Interaction
- Scaling

Agile project management on the research campus

Currently, 17 interdisciplinary sprint teams, each consisting of three to eight employees from science and business, meet every two weeks to implement the goals set every six months. The sprint teams draw on resources from the competence and application fields. At the plenary meetings of the DPP research campus, the results are presented to all partners at the "marketplace of opportunities".

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RWTH AACHEN CAMPUS

On a total area of approx. 2.5 km², RWTH Aachen University is creating one of the largest technology-oriented campuses in Europe and, thus, an internationally significant knowledge and research landscape. The sites for the cluster are located in close proximity to several major research institutes and facilities. By offering "company enrollment," the RWTH Aachen Campus promotes a new form of exchange between industry and university. It enables companies to collaborate on priority topics in an interdisciplinary manner as a consortium, while ensuring access to qualified young talent at the same time. It also facilitates rapid, practice-oriented doctoral studies. Interested companies can set up shop on the RWTH Aachen Campus either by renting an investor building or by owning their own. The RWTH Aachen Campus is developing in several stages. The first stage was launched in 2010 with the development and construction of the Campus Melaten with six thematic clusters – including the photonics cluster coordinated by Fraunhofer ILT.

Photonics Cluster

The Photonics Cluster researches and develops methods to produce, shape and use light, in particular as a tool for industrial production. The cluster's large premises offer sufficient space for, on the one hand, scientific institutions to cooperate in an interdisciplinary manner and, on the other hand, 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.

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. The keys were handed over between the private-sector investor Landmarken AG with the KPF architects team and Fraunhofer ILT.

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. On an area of 4,300 square meters, 16 chairs 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.

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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" as well as the actual Excellence Cluster "Internet of Production" were 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.

The DPP Research Center, which opened in 2019 and became fully operational in 2020, offers scientists space for basic research in the field of photonics on approximately 4,300 square meters of floor space – including 2,800 square meters of laboratory, clean room and hall space.

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 ultrashort 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 cooperating chairs – LLT, TOS 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 terchnology. The DPP Industry Building thus provides the necessary infrastructure for long-term, strategic cooperation within the framework of the DPP Research Campus. Premises such as laboratories and offices can be rented as needed through the private operator. This cooperation benefits from 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.

Partners from Industry in the Research Campus DPP

- ACAM Aachen Center for Additive Manufacturing GmbH
- Access e.V.
- Aconity 3D GmbH
- AixPath GmbH
- Amphos GmbH
- BeAM S.A.S.
- BUSCH Microsystems Consult GmbH
- Conbility GmbH
- EdgeWave GmbH
- EOS GmbH Electro Optical Systems
- ESI Group
- EXAPT Systemtechnik GmbH
- Ford-Werke GmbH
- GKN Sinter Metals Engineering GmbH
- Hegla GmbH & Co. KG
- Innolite GmbH
- LightFab GmbH
- MDI Advanced Processing GmbH
- ModuleWorks GmbH
- MTU Aero Engines AG
- Oerlikon Metco Woka GmbH
- Saint-Gobain Sekurit Deutschland GmbH & Co. KG
- SCANLAB GmbH
- Siemens Energy AG
- SLM Solutions Group AG
- TRUMPF Laser- und Systemtechnik GmbH
- TRUMPF Photonic Components GmbH

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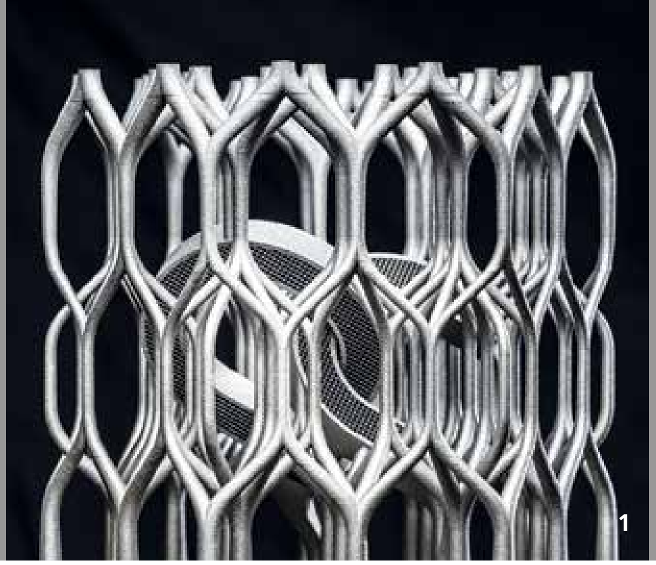
1 Research under one roof: Research Center Digital Photonic Production RCDPP, sketch: Carpus+Partner.

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

SPIN-OFFS

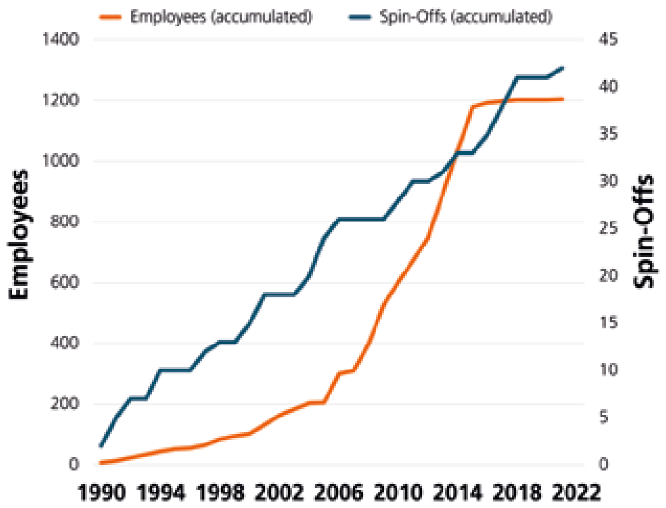


Networks and infrastructure

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.

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 which resolved in more than 40 new companies in the last 30 years. Innovative founders 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 and saveguard jobs.

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.

Spin-offs generate added value for the laser industry

More than 40 so-called spin-offs of Fraunofer ILT 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 companies, 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 spin-offs of Fraunhofer ILT cover a broad spectrum.

One of these spin-offs is Aconity3D GmbH, which was founded in 2014. The company focuses on building special machines for laser-based 3D printing of metals for customers in the research, turbomachinery, automotive and aerospace sectors.

1 Titanium lattice structure produced with the AconityMIDI machine, © Aconity3D GmbH.
2 Detailed view of the AconityMINI machine, © Aconity3D GmbH.

REGIONAL INITIATIVES

Laser welding system for the production of battery modules.

Additive-manufactured letters with integrated lightweight structures.

BATTERY LAB

Fraunhofer ILT operates a Battery Lab in the laser plant park on an area of just under 140 square meters. Here, our researchers have access to a wide range of equipment for laser-based battery production. For example, they can test processes and further develop them for the production of lithium-ion batteries with liquid electrolytes, which are common today, and future solid-state batteries. To this end, around 3 million euros from the European Regional Development Fund (ERDF) have been invested in this new laboratory.

Next generation batteries

ERDF has already been funding the project "NextGenBat - Research Infrastructure for Future Battery Generations" since 2018 with the aim of strengthening the infrastructure in Aachen and Jülich in the field of battery research. The research infrastructure already in place in NRW will be expanded to create optimal conditions for regional companies to research and develop next-generation batteries. In addition to Fraunhofer ILT, other research institutes at RWTH Aachen University and Forschungszentrum Jülich are collaborating in this area.

More powerful batteries through roll-to-roll laser processes

Laser-based production processes in battery technology, such as the drying of electrodes and subsequent structuring, only realize their potential when integrated in roll-to-roll processes. An enlarged electrode surface in this way improves various properties of the lithium-ion cell, such as capacity, fast-charging capability and service life. At the end of 2020, such a system was put into operation. Furthermore, the Battery Lab has an argon-fueled GloveBox system that integrates state-of-the-art PVD coating technology and a high-temperature furnace. In this way, the partially air-sensitive solid-state cell materials processed by laser processes can be coated with metallic lithium, for example, and then assembled into test cells.

With laser technology from the electrode to the battery pack

Cutting and welding of battery components are further possible applications of laser technology to replace conventional production processes. USP lasers also enable damage-free processing of electrode foils directly in the roll-to-roll system in preparation for further production steps. In the end, battery cells are interconnected to form battery modules, modules in turn to form battery packs. An innovative plant technology for welding is available for making the necessary electrical connections using copper and aluminum conductors. Since two laser beam sources and intelligent image processing are integrated in it, it can compensate for the tolerances in the positioning of the battery cells that occur during the assembly of battery modules.

The Battery Lab is also equipped with various electrical and mechanical test benches that allow direct evaluation of the laser processes on the performance of the cell and module under thermal and electrical load.

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AACHEN 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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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 28 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 twelve-member steering committee comprises representatives of the participating industrial companies and research institutes.

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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 Fraunhofer ILT access to numerous experts in microtechnology. In the NanoMicroMaterialsPhotonic.NRW state cluster, Fraunhofer ILT is involved in the fields of nanotechnology, photonics, microsystem technology areospace and quantum 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, Fraunhofer 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.

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. Markus Kogel-Hollacher (managing director), chairman Ulrich Berners and Dr. Claus Schnitzler (treasurer) are also represented on the board of AKL e.V. The 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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EVENTS AND PUBLICATIONS

PATENTS

PATENTS GERMANY

DE 102020200237 Verfahren zur Herstellung eines piezoelektrischen Mehrschicht-Sensors und/oder Aktuators

DE 102019205222 Verfahren zur Terminierung optischer Strahlung sowie dafür ausgebildete optische Strahlfalle

DE 102019205289 Anlage zur Herstellung elektrischer Kontaktelemente mit selektiv veredelten elektrischen Kontaktflächen

DE 102018128754 Vorrichtung und Verfahren zur Elementanalyse von Materialien

DE 102019204032 Vorrichtung und Verfahren zur Erzeugung von räumlich modulierbaren Leistungsdichteverteilungen u. a. für parallelisierte Lasermaterialbearbeitungsprozesse

DE 3326021 Anordnung und Verfahren zur verzeichnungsfreien zweidimensionalen Ablenkung von räumlich ausgedehnten Intensitätsverteilungen

DE 102014108630 Vorrichtung und Verfahren zur Durchführung optischer Messungen an fluiden Substanzen in Gefäßen mit einer Längsrichtung

DE 102014010412 Verfahren und Anordnung zur generativen Fertigung von Bauteilen

DE 102015208181 Anordnung und Verfahren zur Reflektometrie

DE 102014006151 Verfahren zur Messung des Rundlaufs einer Werkzeugmaschine sowie für die Durchführung des Verfahrens ausgebildete Werkzeugmaschine

DE 102014001666 Verfahren zur Homogenisierung der Oberflächentopologie bei der Trocknung einer Beschichtung

DE 102013001940 Strahlungsquellen im Extremen Ultraviolett und weichen Röntgenbereich durch Anregung von Pinchplasmen mit Elektronenstrahlen

DE 102007028789 Verfahren zum Fügen von Hybridbauteilen

56
Bachelor theses in 2021

PATENTS
18 Patents, 18 Patent applications in 2021

135
Scientific publications in 2021

66
Master theses in 2021

PATENTS

PATENTS EUROPE

EP 3450083 Vorrichtung und Verfahren zur Materialbearbeitung

EP 3576898 Verfahren zum Fügen von Bauteilen auf eine Trägerstruktur unter Einsatz von elektromagnetischer Strahlung

PATENTS GREAT BRITAIN

GB 2664220 Optischer Resonator mit direktem geometrischem Zugang auf der optischen Achse

PATENTS JAPAN

JP 6861706 Verfahren zum Fügen von zwei Bauteilen im Bereich einer Fügezone mittels mindestens einem Laserstrahl sowie Verfahren zum Erzeugen einer durchgehenden Fügenaht

PATENTS KOREA

KR 10-2208818 Laser processing apparatus

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

PATENT APPLICATIONS GERMANY

502016012310.1 Anordnung und Verfahren zur verzeichnungsfreien zweidimensionalen Ablenkung von räumlich ausgedehnten Intensitätsverteilungen

102019205289 Anlage zur Herstellung elektrischer Kontaktelemente mit selektiv veredelten elektrischen Kontaktflächen

102018128754 Vorrichtung und Verfahren zur Elementanalyse von Materialien

502017010046.5 Vorrichtung und Verfahren zur Materialbearbeitung

102014001666 Verfahren zur Homogenisierung der Oberflächentopologie bei der Trocknung einer Beschichtung

102015208181 Anordnung und Verfahren zur Reflektometrie

102014108630 Vorrichtung und Verfahren zur Durchführung optischer Messungen an fluiden Substanzen in Gefäßen mit einer Längsrichtung

102014006151 Verfahren zur Messung des Rundlaufs einer Werkzeugmaschine sowie für die Durchführung des Verfahrens ausgebildete Werkzeugmaschine

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102013001940 Strahlungsquellen im Extremen Ultraviolett und weichen Röntgenbereich durch Anregung von Pinchplasmen mit Elektronenstrahlen

102019205222 Verfahren zur Terminierung optischer Strahlung sowie dafür ausgebildete optische Strahlfalle

102020200237 Verfahren zur Herstellung eines piezoelektrischen Mehrschicht-Sensors und/oder Aktuators

PATENT APPLICATIONS EUROPE

PCT/EP2021/3326021 Anordnung und Verfahren zur verzeichnungsfreien zweidimensionalen Ablenkung von räumlich ausgedehnten Intensitätsverteilungen

PCT/EP2021/ 3450083 Vorrichtung und Verfahren zur Materialbearbeitung

PCT/EP2021/ 2664220 Optischer Resonator mit direktem geometrischem Zugang auf der optischen Achse

PCT/EP2021/ 3576898 Verfahren zum Fügen von Bauteilen auf eine Trägerstruktur unter Einsatz von elektromagnetischer Strahlung

PATENT APPLICATIONS JAPAN

PCT/EP2021/06861706 Verfahren zum Fügen von zwei Bauteilen im Bereich einer Fügezone mittels mindestens einem Laserstrahl sowie Verfahren zum Erzeugen einer durchgehenden Fügenaht

PATENT APPLICATIONS KOREA

KO-10-2208818 Laser processing apparatus

DISSERTATIONS

DISSERTATIONS

4.3.2021 – Lukas Fabian Bahrenberg (Dr.-Ing.)
Charakterisierung nanoskaliger Gitter mittels Spektrometrie im Extrem-Ultraviolett

15.4.2021 – Viktor Mamuschkin (Dr.-Ing.)
Laserdurchstrahlschweißen transparenter Thermoplaste ohne Strahlungsabsorber

21.5.2021 – Tobias Schmithüsen (Dr.-Ing.)
Untersuchungen zur nass-chemischen Stützenentfernung bei LPBF-gefertigten Bauteilen aus Aluminiumlegierungen

26.5.2021 – Robert Lange (Dr. rer. nat.)
Erhöhung der Fluenz gütegeschalteter Einzelfaserlaser der kW-Leistungsklasse

27.5.2021 – Andreas Brenner (Dr.-Ing.)
Sequentielle Ultrakurzpuls-Laserbearbeitung zur effizienten Oberflächentexturierung

28.5.2021 – Georg König (Dr.-Ing.)
Automatisierte Auslegung optischer Systeme aus Kataloglinsen

16.6.2021 – You Wang (Dr.-Ing.)
Reduced modelling for laser drilling process in melt expulsion regime

26.11.2021 – Georg Meineke (Dr. rer. nat)
Opto-kalorisches Schalten zur Sortierung fluoreszenzmarkierter Partikel in Mikrofluidiken

8.12.2021 – Christoph Gayer (Dr.-Ing.)
Selektives Lasersintern von Polylactid-basierten Kompositwerkstoffen

EVENTS

Nothing left to chance: Technology check for LKH_2 (online).

Live lab tour at AI for Laser Technology (online).

EVENTS

January 19–20, 2021, online
LSE – Laser Symposium Electromobiliy
As more and more automobiles are powered by electricity, the demand is increasing for high-performance energy storage systems. In order to meet the constantly growing challenges, the industry needs new manufacturing methods to produce such battery modules and packs. Already today, highly efficient laser processes are essential for the entire process chain.

The following topics were highlighted at the third Laser Symposium Electromobility LSE'21 organized by Fraunhofer ILT and presented by speakers from industry and research:
• Laser processes in battery production
• Laser-beam sources in electromobility
• Production equipment in laser material processing
• Process monitoring for laser manufacturing processes
• Treatment and processing of solid batteries

April 21–22, 2021, online
6th UKP Workshop: Ultrafast Laser Technology
For the first time virtually, the 6th UKP workshop initiated by Fraunhofer ILT presented, in addition to the basics of UKP technology, an overview of current developments in the field of beam sources as well as the necessary system technology. The latest laser-based applications and processing methods were also presented, which extend the limits of previous technologies in terms of processing speed, quality and material bandwidth. In addition to individual and optimized beam shaping solutions, the workshop addressed the latest laser-based applications and methods regarding their processing speed, quality, precision and material bandwidth.
• 15 lectures on 5 different topics
• Over 95 participants from 8 countries

September 15–16, 2021, online
LKH_2 – Laser Colloquium Hydrogen 2021
The use of hydrogen by fuel cells is – as part of the global challenges of climate change and the associated energy transition – the focus of much future-oriented research and development. To efficiently and economically produce fuel cells, the industry can take advantage of the high efficiency of laser-based processes since they are not only very flexible, but can be automated to a high degree. The following topics were highlighted at the second Laser Colloquium Hydrogen LKH_2 2021, organized by Fraunhofer ILT:
• Continuous production of metallic bipolar plates
• Compound plates
• Industrial production of metallic bipolar plates
• Fuel cell production in the German research landscape
• Functionalizing and coating of surfaces

September 21, 2021, online
"SiCellNet" Workshop
As a virtual research campus, "SiCellNet" aims to be a one-stop-shop and single exchange point for SMEs active in the medical and pharmaceutical sectors. In these sectors, the cluster provides suitable process steps with targeted development capacities and infrastructures. It does feasibility studies on single-cell printing and validation projects for chip-based analysis, which round out the cluster's capabilities. The Fraunhofer Institutes IMS, ILT, IMM and EMB together form the project partnership of the current joint project.

September 28–29, 2021, online
AI for Laser Technology Conference
For the second time, scientists met at the virtual "AI for Laser Technology Conference" to exchange information on the current state of the art in the application of artificial intelligence in laser materials processing. The focus was on the acquisition and processing of data from production processes such as from laser welding and AI-based control processes. In addition to giving technical presentations, Fraunhofer ILT also opened its laboratories for virtual tours.

October 12/November 10/December 16, 2021, online
In demand – Fraunhofer ILT in dialog
For the first time, interested scientists have the opportunity to look behind the research scenes of Fraunhofer ILT free of charge. This new online lecture series is intended to link industry and science more closely and open up a discourse between the audience, our researchers and an external guest from industry. The series was launched with the topic "Laser Powder Bed Fusion": In October, ILT's Jasmin Saewe moderated a discussion with around 35 participants on multilaser systems for the production of large components using LPBF. This was followed by the talk rounds in November and December.
• October: Laser powder bed fusion / guest: Ole Geisen, Siemens Energy AG
• November: Laser material deposition / guest: Tobias Stittgen, ponticon GmbH
• December: Polishing with laser technology / guest: Prof. Rolf Rascher, PanDao GmbH

February 24, November 16, 2021, online
Digital Aachen Polymer Optics Days
In cooperation with Fraunhofer IPT, Fraunhofer ILT organized quarterly online sessions on the topic of plastic optics from December 2020 to November 2021. In addition to hearing numerous technical presentations, participants from science and industry benefited from networking and discussions. In 2021, the online sessions were held quarterly on the following topics:
• Materials in optics manufacturing (February 24, 2021)
• Tool and mold making for optical applications (May 18, 2021)
• Metrology for optical components (September 1, 2021)
• Optical systems (November 16, 2021)

The Digital Aachen Polymer Optics Days series is a joint event of these three research institutions:
• Fraunhofer Institute for Production Technology IPT
• Fraunhofer Institute for Laser Technology ILT
• IKV Institute for Plastics Processing in Industry and Trade at RWTH Aachen University

November 29 – December 3, 2021, online
eHarsh
Sensor systems are key elements for recording environmental properties and are used in the industrial sector, especially for the intelligent control of processes needed in the Fourth Industrial Revolution. Over five days, eight Fraunhofer institutes showcased their expertise in live demonstrations on sensor development, manufacturing technology and simulation and reliability testing for the construction of high-temperature electronics.

FAIRS AND EXHIBITIONS

February 17–18, 2021, online
PHOTONICS + Virtual Exhibition and Conference
Networking event for the photonics industry
The PHOTONICS + Virtual Exhibition and Conference is a new networking event for the photonics industry in cooperation with the European Photonics Industry Consortium (EPIC), which took place virtually in February 2021. Here, Fraunhofer ILT scientists presented the main topic "UKP lasers and their applications" at a digital booth.

March 6–11, 2021, online
Photonics West 2021, San Francisco, USA
International Trade Fair for Optics and Photonics
Fraunhofer ILT was present at the joint online booth of the German Federal Ministry of Education and Research BMBF with the following presentations and highlights:

- Modeling of the impact of current crowding on catastrophic optical damage in 9xx-nm high power laser diodes
- Efficient difference frequency generation for quantum frequency conversion in a multimode PPLN-waveguide
- Automated spatial period variation for Direct Laser Interference Patterning
- Laser powder bed fusion of stainless steel 316L using a combination of a high-power diode laser and galvanometer scanner

Further information on the Internet at:
www.ilt.fraunhofer.de/en/fairs-and-events.html

Fraunhofer ILT at Laser China represented by partner ACunity GmbH.

- Investigation of the laser-based joining technique for PCBs with locally thickened layers using a cold gas spraying process
- Combined laser beam soldering and welding process for electrical contacting
- Laser ablation of bone tissue with Q-switched infrared laser sources for neurosurgical applications

Prof. Constantin Häfner gave the welcoming speech and, thus, kicked off the event.

March 17–19, 2021, Shanghai, China
LASER World of PHOTONICS China
International Trade Fair for Optics and Photonics
Our latest technological developments and trends in laser technology were presented by our strategic partner ACunity GmbH at a joint booth in China.

March 25, 2021, online
Hydrogen Workshop
The Fraunhofer ILT's interactive workshop platform on the topic of "Laser Processes for Hydrogen Technology" answered visitors' questions about the industrial production of metallic bipolar plates and compound plates as well as fuel cell manufacturing. Fraunhofer ILT also participated in a presentation of the workshop accompanying the exhibition.

April 12–16, 2021, online
Hannover Messe 2021
At the virtual Hannover Messe 2021 Digital Edition, Fraunhofer ILT presented solutions in the field of printed electronics as well as further information on the thin-film process. Highlights also included the sensing component from the printer and the printed piezo multilayer actuators.


Fraunhofer ILT booth at COMPAMED 2021 in Düsseldorf, Germany.

April 21–23, 2021, online
NRW Nano Conference
The conference featured the interdisciplinary exchange on trends and solutions in the field of new materials, nanotechnology and quantum technology. At the virtual and interactive Fraunhofer ILT booth, the latest technological developments from the following areas were exhibited alongside the exhibit "QFC4 – Technologies for Quantum Networks":

- Quantum technology
- Quantum imaging
- Quantum communication
- Quantum computing

April 27–29, 2021, online
Battery Conference "ADVANCED BATTERY POWER – the Battery as a Power Plant"
Participants and exhibitors met in a virtual space and found an interesting marketplace for products and developments for the energy industry, with the spectrum of topics ranging from battery chemistry to AI integration. Fraunhofer ILT participated in the online exhibition accompanying the conference and presented several posters on the topic of laser processes for the efficient production of energy storage devices and for laser-based contacting of batteries and power electronics.

May 4–6, 2021, online
Sensor + Test
The Measurement Fair
The demands placed on component-integrated electronics have risen sharply in many industries in recent years and can often no longer be met with conventional electronic components. Printed electronics are gaining ground as an alternative.

Interactive exhibition booth of Fraunhofer ILT at LIPA 2021.

Fraunhofer ILT experts presented their approaches to solve these issues at the digital Sensor + Test 2021 and virtually presented the following exhibits:

- The sensing component from the printer
- Printed piezo multilayer actuators
- In-volume light shading structures
- Selective contact gold plating
- Contacting for power electronics
- Laser crystallization silicon wafer

May 11, 2021, online
LIPA – Laser Innovation Production Aachen
The "WIR! alliance LASER.region.AACHEN" is aimed at helping companies that seek laser technology solutions for their individual applications. Located at the edge of the largest lignite mining area in Europe, this technology alliance offered interesting information about laser technology in virtual and compact presentations. During the conference, Fraunhofer ILT presented new approaches in additive manufacturing and provided visitors with insights into the current state of research on the following topics via a virtual booth:

- Laser and optics
- Laser material processing
- Medical technology and biophotonics
- Laser measurement and EUV technology

June 7–9, 2021, online
Wiley Industry Days
Fraunhofer ILT was present at the digital and conference exhibition, which was a part of the Wiley Industry Days.
To help the industry gain new insights into laser development, Christian Knaak represented the institute by giving a talk on digitalization and machine learning in laser-based manufacturing.

Presentations of the Fraunhofer ILT film project "25 years LPBF" at formnext 2021 in Frankfurt.

June 21–24, 2021, online
World of PHOTONICS Congress & Industry Days
The World of PHOTONICS Congress was opened by Prof. Peter Loosen on June 21, 2021. At the parallel World of PHOTONICS Industry Days, participants could exchange ideas with Institute Director Prof. Constantin Häfner during his presentation at a digital roundtable. Furthermore, a large number of scientists participated at the LiM, which took place in parallel, and gave presentations about different areas where laser technology can be applied.

September 29, 2021, Aachen, Germany
15th German Day of the Aerospace Regions
For the 15th time, the German Aerospace Industries Association organized the Day of the German Aerospace Regions. In addition to the main theme of the event – »Mastering the Corona Crisis - Focusing on the 'New Normal'« – companies and research institutions such as Fraunhofer ILT were given the opportunity to provide information about their company at exhibition stands and to give presentations. At the Fraunhofer ILT booth, visitors could obtain information on laser technology used in the aerospace industry.

November 15–18, 2021, Düsseldorf, Germany
COMPAMED 2021
High-Tech Solutions for Medical Technology
At COMPAMED 2021, Fraunhofer ILT was presented at the joint booth along with IVAM, the Microtechnology Network, in Düsseldorf with the following exhibits:
- Generator for UV plasma sterilization
- Opto-caloric sorting chip
- Droplet generator chip
- Microfluidic chip support
- Flow cell holder
- Compact capillary holder

November 16–18, 2021, Bremen, Germany
Space Tech Expo Europe 2021
Fraunhofer ILT was present at this year's Space Tech Expo Europe on the joint Fraunhofer Space Alliance booth. The event is Europe's largest event specifically focused on the supply chain and technical services for manufacturing, designing and testing spacecraft, subsystems and space-qualified components. The exhibition and conference attracted thousands of industry leaders, decision makers, engineers, planners and buyers who wanted to meet manufacturers from across the commercial, government and military space supply chain. Fraunhofer ILT presented laser solutions for rocket engines.

November 16–19, 2021, Frankfurt, Germany
formnext 2021, Trade Fair for Additive Manufacturing
In 2021, visitors to formnext were once again able to meet experts from Fraunhofer ILT at the joint Fraunhofer booth. The following innovative results were exhibited:
- Additive manufacturing of large components using the novel LPBF system concept with movable multi-scanner processing head
- The "sensing" component, which can be produced using laser-based additive manufacturing processes
- Anniversary film celebrating 25 years of LPBF at Fraunhofer ILT

In addition, Tim Lantzsch participated in the conference accompanying the exhibition with a presentation on "Laser powder bed fusion of nickel-base alloy 625 using a ring-mode laser intensity distribution".

REFERENCES

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AIRBUS, BOSCH, Heraeus, LEYER & KIWUS, ponticon, Techspace Aero
arnold RAVENSBURG, BRAUN, HONDA, manroland | GOSS, POSSEHL ELECTRONICS, voestalpine
Aurubis, COHERENT, Huf, MARQUARDT, PRECITEC, TESAT
Bartels mikrotechnik, DILLINGER, igm, MBRAUN, Radium
BASF, IMA SCHELLING GROUP, MTU Aero Engines, Raufoss, TRUMPF
BCT., EMERSON, INOVAN, Mubea, rofin, Valeo
BEGO, eos, JENOPTIK, MULTEK, Rolls-Royce, VYCON
Berlin Heart, EVONIK, karcoma, OTTO FUCHS, SIEMENS, ZWIESEL GLAS
BILSTEIN, FEV, KISTLER
BMW GROUP, GE Additive, KUKA

The companies listed here represent a selection of the Fraunhofer ILT's many clients, as at December 2021. Printed with the kind permission of our partners.

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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