Fraunhofer

ILT

FRAUNHOFER INSTITUTE FOR LASER TECHNOLOGY ILT

ANNUAL REPORT 2017

ANNUAL REPORT 2017

Fraunhofer-Institut für Lasertechnik ILT

Steinbachstraße 15
52074 Aachen, Germany
Telephone +49 241 8906-0
Fax +49 241 8906-121

info@ilt.fraunhofer.de
www.ilt.fraunhofer.de

Dear Readers,

»As for the future, your task is not to foresee the future, but to enable it«. With this thought by the French writer Antoine de Saint-Exupéry, I would like to invite you to join us in a longer-term creative process! It's about our future and this question: How can we use our technological expertise and individual creativity to come up with solutions for upcoming social and industrial challenges? What significance do the basic physical and technical elements of the respective innovation have? It was exactly these questions that we asked ourselves in 2017 during a detailed strategy meeting in which all competence areas of Fraunhofer ILT were involved.

To come to the point right away, we see many points of contact and challenges in the major issues that affect our society – from mobility and health to environment and energy, to production and digitization. Let me give you a few examples. Working closely with our industrial customers and R&D partners, we are developing high-performance LIDAR systems that significantly improve satellite-based climate research – a prerequisite for detecting sources of polluting gases such as methane. The recycling of electronic equipment will become increasingly important as congestion bottlenecks of rare earths intensify and new laser-based LIBS systems we are helping to develop will soon become integral components of completely automated sorting systems.

In the manufacturing industry, additive manufacturing processes, an important sector in our institute, will systematically spread and drive developments such as the virtual spare-parts warehouse, individualized components and co-creation processes. E-mobility – whether in vehicle technology or aircraft construction – also benefits from laser technology developments. These include some of our research projects: reliable joining processes in power electronics, laser cladding and coating processes for optimizing wear components or additive manufacturing processes for bionically structured lightweight components.

Both in terms of its resources and infrastructure, Fraunhofer ILT is well positioned to meet these upcoming technological challenges. In addition to industrial issues, we cooperate closely with the faculties of RWTH Aachen University, for example in the Digital Photonic Production research campus, to develop new basic insights and to generate innovative impulses in our laser community.

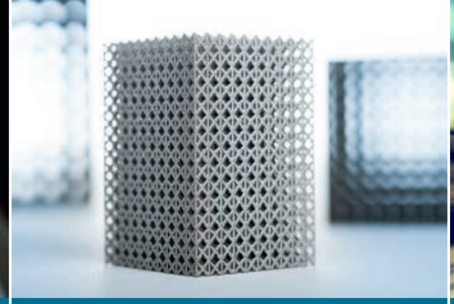
Convince yourself of the quality of our R&D work presented in the numerous projects in this annual report and do not hesitate to contact us if any of them piques your interest. We love short communication paths and direct dialog. Let us shape the future together!

Cordially

Prof. Dr. rer. nat. Reinhart Poprawe








CONTENTS

FACTS AND FIGURES

2017

DECLARATION OF PRINCIPLES

MISSION

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

CUSTOMERS

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

OPPORTUNITIES

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

FASCINATION LASER

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

STAFF

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

STRENGTHS

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

MANAGEMENT STYLE

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

POSITION

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

PROFILE OF THE INSTITUTE

SHORT PROFILE

ILT – this abbreviation stands for combined know-how in the sector of laser technology for more than 30 years. Innovative solutions for manufacturing and production, development of new technical components, competent consultation and education, highly specialized personnel, state-of-the-art technology as well as international references: these are guarantees for long-term partnerships. The numerous customers of the Fraunhofer Institute for Laser Technology ILT come from branches such as automobile and machine construction, the chemical industry and electrical engineering, the aircraft industry, precision engineering, medical technology and optics. With more than 500 employees and more than 19,500 m² of net floor area, the Fraunhofer Institute for Laser Technology ILT is among the most significant contracting research and development institutes in its sector worldwide.

The four technology areas of the Fraunhofer ILT cover a wide spectrum of topics within laser technology. In the technology area »Lasers and Optics« we develop tailor-made beam sources as well as optical components and systems. The spectrum reaches from freeform optics over diode and solid state lasers all the way to fiber and ultrashort pulse lasers. In addition to the development, manufacture and integration of components and systems, we also address optics design, modeling and packaging. In the technology area »Laser Material Processing« we solve tasks involving cutting, ablating, drilling, cleaning, welding, soldering, labeling as well as surface treatment and micro manufacturing. Process development and systems engineering stand in the foreground, which includes machine and control engineering, process and beam monitoring as well as modeling and simulation. Along with partners from life sciences, ILT's experts in the technology field »Medical Technology and Biophotonics« open up new laser applications in bioanalytics, laser microscopy, clinical diagnostics, laser therapy, bio-functionalization and biofabrication. The development and manufacture of implants, microsurgical and microfluidics systems and components also count among the core activities here. In the technology area »Laser Measurement Technology and EUV Technology« we develop processes and systems for our customers which conduct inline measurement of physical and chemical parameters in a process line. In addition to production measurement technology and material analysis, environment and safety as well as recycling and raw materials lie in the focus of our contract research. With EUV technology, we are entering the submicron world of semiconductors and biology.

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

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

RANGE OF SERVICES

The services of the Fraunhofer Institute for Laser Technology ILT are continually being adapted to the practical requirements of industry and include the solution of manufacturing problems as well as the realization of test series. In detail this means:

- development of laser beam sources
- components and systems for beam guiding and forming
- packaging of optical high power components
- modeling and simulation of optical components as well as laser processes
- process development for laser materials processing, laser measurement technology, medical technology and biophotonics
- process monitoring and control
- model and test series
- development, set-up and testing of pilot plants
- integration of laser technology into already existing production plants or measuring systems
- development of X-ray, EUV and plasma systems

DIFFERENT WAYS OF COOPERATION

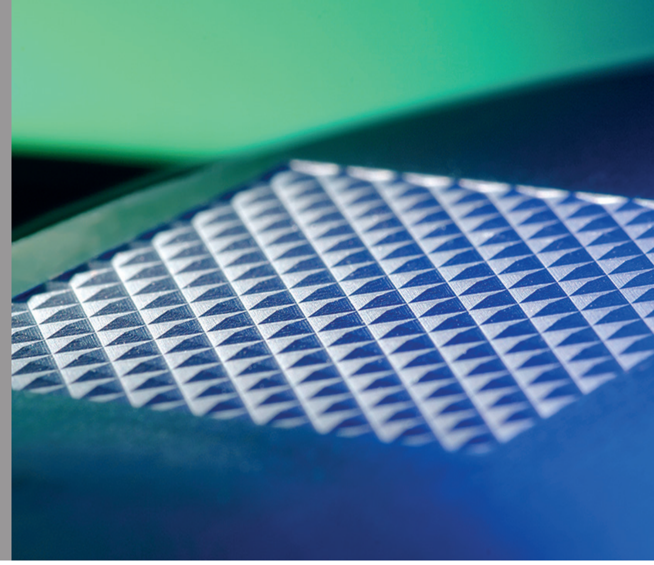
The Fraunhofer Institute for Laser Technology ILT is cooperating with R&D-partners in different ways:

- 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«

By means of cooperation with other research organizations and specialized companies Fraunhofer ILT offers solutions even in the case of interdisciplinary tasks. A special advantage hereby consists in the direct access to the large resources of the Fraunhofer Society.

HIGHLIGHTS

Laser-Based Tape-Automated Bonding (LaserTAB) for welding battery cells.



Functional surfaces: precisely and efficiently manufactured with a combination of nano- and picosecond pulses.

Ultra-precision machining of diamond lenses for laser optics.

R&D HIGHLIGHTS 2017

Selection of a fast individualized therapy by sorting molecules and cells with light

Biomolecules and cells circulating in the blood carry diagnostic information that, when analyzed, help physician provide highly effective, individualized therapies. To tap into this information, the scientists of Fraunhofer ILT have developed a microchip-based diagnostic device: The »AnaLighter« analyzes and sorts clinically relevant biomolecules and cells in a blood sample with light. A corresponding multiplex diagnosis detects up to sixteen different disease markers with only one measurement run. As a result, early diagnoses of, for example, tumor and cardiovascular diseases can be made and highly effective individualized therapies applied.

Weight savings thanks to diamond optics

Together with the Fraunhofer Institute for Applied Solid State Physics IAF in Freiburg and the Fraunhofer Institute for Production Technology IPT in Aachen, the researchers of Fraunhofer ILT have developed a new laser optic with diamond lenses. Fraunhofer IAF optimized the production of monocrystalline diamonds, while Fraunhofer IPT dealt with the ultraprecision machining of diamond surfaces. In the meantime, diamond substrates with a diameter of up to 10 mm can be produced. Thanks to its high refractive index of 2.4 and excellent thermal conductivity, diamond makes it possible to drastically reduce the dimensions of a laser optic. The laser cutting head developed at Fraunhofer ILT is 90 percent lighter than conventional components made with glass optics. A first series of application trials with diamond optics and a 1 kW fiber laser was successfully completed in 2017. Stainless steel with a thickness of 1.5 mm could be cut easily. In the future, an upgrade to higher power will be prepared.

Support-free, resin-based 3D printing

Fraunhofer ILT and Rapid Shape GmbH are jointly developing resin-based 3D printing in a ZIM project (Central Innovation Project for SMEs) funded by the Federal Ministry for Economic Affairs and Energy (BMWi). The new »T(w)oCURE« process does without supporting structures and is significantly more efficient and productive than conventional 3D printing technologies for plastic components. The joint development uses a combination of light and cold when components are built. For the novel 3D printing process, the material and the photochemical process were developed by Fraunhofer ILT, and the process and the system technology successfully implemented by Rapid Shape GmbH. The first prototype has already been set up and will soon be developed further to series maturity. The new form of plastic 3D printing was successfully tested with models for the jewelry industry.

Green light for new 3D copper printing

Scientists at Fraunhofer ILT are investigating Selective Laser Melting (SLM), also known as laser beam melting or Laser Powder Bed Fusion (L-PBF), for copper materials. SLM has already proven itself as a manufacturing process in various industries such as medical technology, turbomachinery, aerospace or automotive engineering. Currently, it is primarily used to process steels, titanium and aluminum alloys as well as nickel and cobalt alloys. Within a research project, Fraunhofer ILT is continuing to develop SLM to make it more suitable for the economical additive manufacturing of pure copper and copper alloy components. Pure copper is interesting for end users because copper alloys do not have such a comparably high electrical and thermal conductivity. The newly developed laser sources no longer work with infrared, but with green light.

Lasers retrieve valuable raw materials

One of urban mining essential aspects is automatically disassembling electronic devices that are no longer used and recovering valuable raw materials from them. The Fraunhofer-Gesellschaft is playing a pioneering role internationally in the EU project »ADIR«, Next Generation Urban Mining. In this project, nine partners from four countries are jointly exploring how to recover and re-use strategically important recyclables from old mobile phones and printed circuit boards. Special machines for automated disassembly and dismantling will combine laser technology, robotics, modern image processing and information technology in various processing stages. Fraunhofer ILT in Aachen is coordinating the project, which is funded by the European Union under the Horizon 2020 program.

Components made of pure copper: manufactured additively with green light.

Razor-thin, flexible ceramics and glass

Designed to protect portable electronics, the transparent, scratch-resistant and at the same time malleable ceramic layers of the future are only twice as thick as a typical hair, around 100 µm. The processes and process chains necessary for their production have been under development since March 2017 in the three-year research project »CeGlaFlex«. The Fraunhofer institutes IKTS, IPT, IMWS and FEP are bundling their expertise in the field of future-oriented mobile electronics in this MaVo project, which is coordinated by Fraunhofer ILT.

Clever combi-process for microstructuring

Defined surface structures for functional purposes or for appearance and haptics are in demand in various applications, for example for surfaces on the dashboard in the automotive sector or for embossing rollers in the printing industry.
Tools that generate microstructuring are often produced by photochemical etching and no longer achieve the desired precision. Ultrashort pulse lasers offer an effective alternative and can structure surfaces with high precision – but often not fast enough for industrial applications. The aim of the »eVerest« project funded by the Federal Ministry of Education and Research BMBF is to develop an easy-to-use system for the efficient production of large-format 3D forming tools for design surfaces. Together with laser manufacturers, system integrators and industrial partners, scientists at Fraunhofer ILT are developing a machine design, corresponding software and a laser process. The coarse processing is done by a productive nanosecond laser, which is combined with a picosecond laser for fine structuring in the micrometer range.

STRUCTURE OF THE INSTITUTE

BOARD OF DIRECTORS

Prof. Reinhart Poprawe
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

Dr. Bruno Weikl
IT Management

COMPETENCE AREAS

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

Dr. Arnold Gillner
Ablation and Joining

Prof. Johannes Henrich Schleifenbaum
Additive Manufacturing and Functional Layers

Prof. Reinhard Noll
Measurement Technology and EUV Sources

The 32nd Board of Trustees meeting of Fraunhofer ILT in Aachen.

BOARD AND COMMITTEES

BOARD

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

CHAIRMAN

C. Baasel, Carl Baasel Lasertechnik GmbH

MEMBERS

- Dr. R. Achatz, ThyssenKrupp Stahl AG (vice chairman)
- Dr. Norbert Arndt, Rolls-Royce plc
- Dr. Hans Eggers, BMBF
- Dr. Ulrich Hefter, Rofin-Sinar Laser GmbH
- Dipl.-Ing. Volker Krause, Laserline GmbH
- Prof. G. Marowsky, Laserlaboratorium Göttingen e.V.
- Manfred Nettekoven, Kanzler der RWTH Aachen
- Dr. Joseph Pankert, Philips Lighting B.V.
- Dr. Silke Pflueger, Direct Photonics Inc.
- Prof. R. Salathé, Ecole Polytechnique Fédéral de Lausanne
- RBe Susanne Schneider-Salomon, Ministerium für Innovation, Wissenschaft und Forschung
- Dr. Ulrich Steegmüller, Osram Opto Semiconductors GmbH & Co. OHG
- Dr. Klaus Wallmeroth, TRUMPF Laser GmbH & Co. KG

The 32nd Board of Trustees meeting was held on September 27, 2017 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:
Dr. V. Alagic-Keller MBA, Dipl.-Phys. A. Bauer, Dipl.-Ing. T. Biermann, Dr. A. Gillner, Dipl.-Ing. H.-D. Hoffmann, Prof. P. Loosen, V. Nazery Goneghany, Prof. R. Noll, Dr. D. Petring, Prof. R. Poprawe, Prof. J. H. Schleifenbaum, Prof. W. Schulz, Dr. B. Weikl, Dr. J. Stollenwerk.

HEALTH AND SAFETY COMMITTEE ASA

The Health and Safety committee is responsable for all aspects of safety and laser safety at Fraunhofer ILT. Members of this committee are: Dr. V. Alagic-Keller MBA, M. Brankers, F. Eibl M.Sc. , R. Frömbgen, A. Hilgers, Dipl.-Ing. (FH) S. Jung, F. Käfer M.Eng., A. Hajdarovice, Prof. P. Loosen, V. Nazery Goneghany, E. Neuroth, Prof. R. Poprawe, F. Voigt, Dipl.-Ing. N. Wolf, Dr. R. Keul (works doctor ILT), T. Yildirim M.Sc., S. Schoenen M.Eng. (B.A.D Gesundheitsvorsorge und Sicherheitstechnik GmbH).

SCIENCE AND TECHNOLOGY COUNCIL WTR

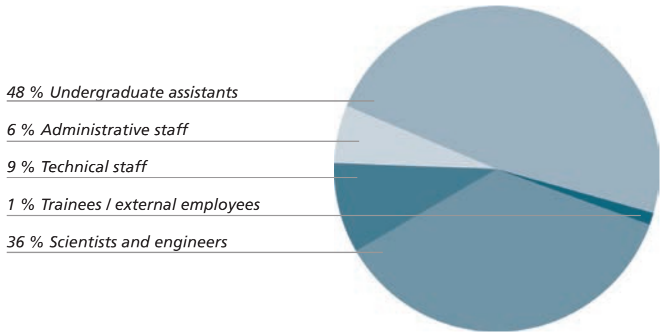
The Fraunhofer-Gesellschaft's Science & Technology Council supports and advises the various bodies of the Fraunhofer-Gesellschaft on scientific and technical issues. The members are the institutes'directors and one representative elected from the science/technology staff per institute.
Members of the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

WORKERS' COUNCIL

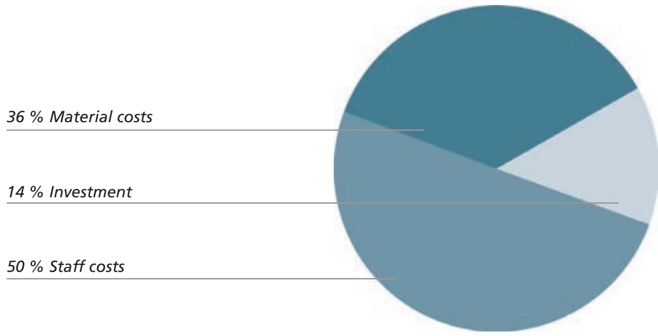
Since March 2003 there is a workers' council at Fraunhofer ILT.

THE INSTITUTE IN FIGURES

EMPLOYEES 2017	number
Personnel	**255**
- Scientists and engineers	181
- Technical staff	45
- Administrative staff	29
Other employees	**247**
- Undergraduate assistants	241
- External employees	3
- Trainees	3
Total number of employees at Fraunhofer ILT	**502**



EXPENSES 2017	Mill €
- Staff costs	20,0
- Material costs	14,4
Expenses operating budget	**34,4**
Investments	**5,5**



REVENUES 2017	Mill €
- Industrial revenues	15,8
- Additional financing from Federal Government, States and the EU	13,7
- Basic financing from the Fraunhofer-Gesellschaft	4,9
Revenues operating budget	**34,4**
Investment revenues from industry	**0,7**
Fraunhofer industry ρ_{Ind}	**48,2 %**

FACILITIES

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

TECHNICAL INFRASTRUCTURE

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

SCIENTIFIC INFRASTRUCTURE

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

EQUIPMENT

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

BEAM SOURCES

- CO_2 lasers up to 12 kW
- disc lasers up to 12 kW
- mutimode fiber lasers up to 6 kW
- singlemode fiber lasers up to 5 kW
- diode laser systems up to 12 kW
- ultra short pulse lasers up to 1 kW with pulse widths in the range of nano-, pico- and femtoseconds
- frequency-multiplied laser in visible spectral range
- excimer lasers
- broadband tunable lasers

PLANTS AND PROCESSING SYSTEMS

- three-axis processing stations
- five-axis gantry systems
- robot systems
- commercial engineering and laboratory systems for laser powder bed fusion (LPBF)
- direct-writing and laser-PVD stations
- beam guiding systems

SPECIAL LABORATORIES

- clean rooms for assembly of diode and solid state lasers as well as laser optics
- life science laboratory with S1 classification

MEASUREMENT AND SENSOR TECHNOLOGY

- sensors for process control in laser materal processing
- devices for process diagnostics and high speed video analysis
- laser spectroscopic systems for the chemical analysis of solid, liquid and gaseous materials
- laser triangulation sensors for distance and contour measurement
- laser coordinate measuring machine
- confocal laser scanning microscopy
- scanning electron microscope
- extensive equipment for beam diagnosis for high-power lasers
- Shack Hartmann sensor to characterize laser beams and optics
- equipment to produce integrated fiber lasers
- measurement interferometer and autocollimator to analyze laser optics
- measurement equipment to characterize ultra-short pulse lasers: autocorrelators, multi-GHz oscilloscopes and spectrum analyzers
- climate chambers
- equipment for vibration tests

HONOURS AND PRIZES

FRAUNHOFER PRIZE 2017

Economical, effective corrosion and wear protection with EHLA – Extreme High-Speed Laser Material Deposition

Extreme High-Speed Laser Material Deposition (EHLA), developed by the Fraunhofer Institute for Laser Technology ILT, harbors great potential: For the first time, it enables components to be protected against corrosion and wear – effectively, resource-efficiently and economically.

For numerous applications, components need to be provided with a protective layer against corrosion and wear – for example in offshore applications, where the constant contact with the salt water strongly attacks the materials. However, as far as the methods are concerned, manufacturers have so far faced a difficult choice: Since September 2017, the widely used chromium (VI) may only be used after authorization/approval. And in thermal spraying, only about half of the material used later covers the component surface, so the process is anything but efficient with resources.

ELHA – A patented process

Researchers at Fraunhofer ILT in Aachen have now developed an alternative, patented process using Extreme High-Speed Laser Material Deposition (EHLA), which eliminates the deficits of conventional processes in coating technology and repair. For the first time ever, thin layers in the range of tenths of a millimeter can be applied to large surfaces in a short time – with this new resource-efficient and economical process. In addition, it can also be used to protect or repair substrates which are sensitive to temperature or have previously been difficult or difficult to coat. For coatings based on chromium (VI), the EHLA process is an adequate, economical and sustainable replacement.

100 to 250 times faster than laser material deposition

The novel method is based on laser material deposition. Since the conventional process was too slow for large components, meaning it could therefore prevail only for wear and corrosion protection applications in certain, individual cases. Also, the high heat input into the component spoke against the process in many applications. With EHLA, the component can be coated 100 to 250 times faster than with conventional laser material deposition, and it hardly heats up. EHLA thus makes it possible to coat heat-sensitive components, which was not previously possible due to the excessive heat input. Furthermore, completely new material combinations are possible, such as coatings on aluminum or cast iron alloys.

Award ceremony at the Fraunhofer annual conference in Dresden

The importance of this development was demonstrated at Fraunhofer's annual conference on May 30, 2017 in Dresden, with which the Fraunhofer-Gesellschaft celebrated its 25th anniversary as a research partner in the new federal states of Germany: Fraunhofer President Prof. Reimund Neugebauer honored Dr. Andres Gasser, Dipl.-Ing. Thomas Schopphoven and Dipl.-Ing. Gerhard Maria Backes for the EHLA technology with the Joseph von Fraunhofer Prize, which is endowed with € 50,000.

Presentation of the Joseph von Fraunhofer Prize. From left to right: Prof. Hartmut Hoffmann, Gerhard Backes, Dr. Andres Gasser, Prof. Reimund Neugebauer, Thomas Schopphoven.

Carl Zeiss Student Paper Award

Sascha Brose received the 2nd place of the Carl Zeiss Student Paper Award at the »SPIE Photomask and EUV Lithography 2017«, which took place in Monterey, California from September 11 to 14, 2017. At the industry conference with over 600 participants, he presented the EUV-LET (Extreme Ultraviolet Laboratory Exposure Tool) nanostructuring plant. This plant was developed by researchers from the Chair for the Technology of Optical Systems TOS of RWTH Aachen University and Fraunhofer ILT. It is used to characterize photoresists, which are needed for the industrial production of semiconductor devices.

Borchers badge

Dr. Oliver Pütsch received the Borchers badge on September 16, 2017 as part of the RWTH Graduate Festival. This staff member of the Chair for the Technology of Optical Systems TOS of RWTH Aachen University was honored for his doctoral examination on the topic »Active and Adaptive Beam Forming Systems for Material Processing with Laser Radiation« at the Faculty of Mechanical Engineering.

Peter M. Baker Leadership Award 2017 to Prof. Reinhart Poprawe

Excellent leadership quality, significant enrichment of the laser community as well as decisive participation in the technological progress of photonics worldwide – this is what the »Peter M. Baker Leadership Award« of the Laser Institute of America LIA stands for. Prof. Reinhart Poprawe was awarded this prize at the 36th International Congress on Applications of Lasers & Electro-Optics ICALEO from October 22 to 26, 2017 in Atlanta, USA. He was awarded by former President of the Laser Institute of America LIA, Lin Li, on October 25, 2017 in front of more than 320 congress participants.

In this way, the LIA honored Prof. Poprawe's extraordinary commitment in the international laser industry: In 1996, Prof. Poprawe took over the management of Fraunhofer ILT and developed it into the largest facility for applied research in the field of laser technology in Europe. As Vice-Rector for Research, Structure and Young Scientists at RWTH Aachen University, he is also co-initiator of the RWTH Aachen Campus, which has since grown into one of the world's most important technology landscapes. Under his leadership, the »Photonics Cluster« has been involved in the production, shaping and use of light, in particular as a tool for industrial production, since 2010.

Prof. Poprawe is honored with the Teaching Award once again

On November 7, 2017, Professor Reinhart Poprawe was awarded the Faculty Instructor Award by the students of the Faculty of Mechanical Engineering of RWTH Aachen University. Professor Poprawe and his team received very good grades from the students for the best didactic achievements in terms of the courses offered in 2017 compared to the other university faculties. Already in 2013, 2015 and 2016, Professor Poprawe was honored with this teaching prize for his special commitment to teaching.

Presentation of the Peter M. Baker Leadership Award.

TRAINING THE NEXT GENERATION

Photonics Academy from March 26–31, 2017

In 2017 the Digital Photonic Production (DPP) research campus in Aachen hosted the Photonics Academy of the Federal Ministry of Education and Research (BMBF) and the German photonics industry. Under the motto »We are looking for the brightest for the production of tomorrow«, 30 selected STEM students from Germany, Austria and Switzerland learned the basics of laser-based production processes – in particular 3D printing with laser technologies. In addition, they received a comprehensive overview of two interaction chains, human-machine production and Industry 4.0. Prof. Reinhart Poprawe (spokesman of the DPP research campus, director of Fraunhofer ILT and of the LLT chair of RWTH Aachen University) and Dr. Frank Schlie (Head of the Quantum Technology/Photonics Unit at BMBF) presented the students with small movable metal planetary gears in addition to their certificates of participation. These were produced overnight with a 3D laser printer at Fraunhofer ILT.

Participants of the Photonics Academy 2017.

»Girls' Day« on April 27, 2017

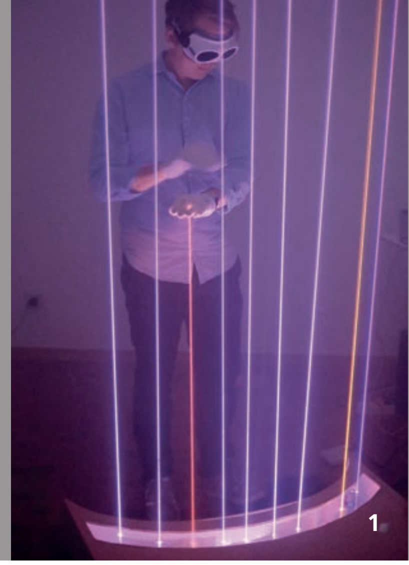
As in previous years, Fraunhofer ILT together with Fraunhofer IPT and IME participated in this nationwide career orientation day for girls between the ages of 10 and 15 years.

Students' University, Mechanical Engineering from July 24–28, 2017

In 2017 the Students' University in Mechanical Engineering again took place with the participation of the »Cluster of Excellence Integrative Production Technology for High-Wage Countries« at RWTH Aachen University. Twenty-one students from Germany, England, Portugal and Turkey spent a week here to get a first-hand impression of the Mechanical Engineering degree program and its many opportunities, both during and after graduation. On July 28, 2017, the students gained insight into the fields of lasers and optics at Fraunhofer ILT and discovered the world of photonics. Using macro lenses for the smartphone lens, they examined small structures on the 10 micrometer scale. In addition, some of them sounded rhythmic sounds on the laser harp.

10th Companies' Night on November 7, 2017

Under the motto »DOCH«, Fraunhofer ILT presented itself at the 10th »Companies' Night«, the career and job fair in Aachen. 2,000 university graduates, students and skilled workers learned how they can design their career path from the approximately 100 exhibiting companies and institutes.



Laser harp – a highlight at the Students' University, Mechanical Engineering.

Interactive event »Fraunhofer Aachen Escape Game«.

Prof. Poprawe with a miniature planetary gear for the participants of the Photonics Academy.

»5 to 12« - RWTH Science Night on November 10, 2017

The RWTH science night »5 to 12« presents science in an unusual form at an unusual time. At this event, lecturers make science understandable and tangible for all generations in a fun way with a wide range of exciting lectures, film screenings and cabaret as well as musical contributions. Dr. Nadine Nottrodt from Fraunhofer ILT gave a lecture on »3D printing – Will we soon be able to print organs?« And Georg König from the TOS chair presented the laser harp »Light to touch - making music with light«.

30th bonding on December 6, 2017

Also in 2017, Fraunhofer ILT was present in Aachen at the largest student-organized job fair - bonding. In addition to 350 other exhibitors, ILT gave personal talks to graduates from engineering, business and natural sciences on entry and career opportunities.

»Fraunhofer Aachen Escape Game« on December 12/13, 2017

With an extraordinary and interactive career event – the Fraunhofer Aachen Escape Game – the institutes in Aachen made the Fraunhofer working world tangible for selected students and graduates of engineering and natural sciences. A total of 50 people enthusiastically attended the two-day event with guided tours of the institute and networking meetings.

ALUMNI NETWORK

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 2017 alone, 85 students completed their bachelor's or master's theses at Fraunhofer ILT and 13 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 around 10 percent have founded companies. By transferring »innovative minds« into industry and science, the institute makes a direct benefit to society.

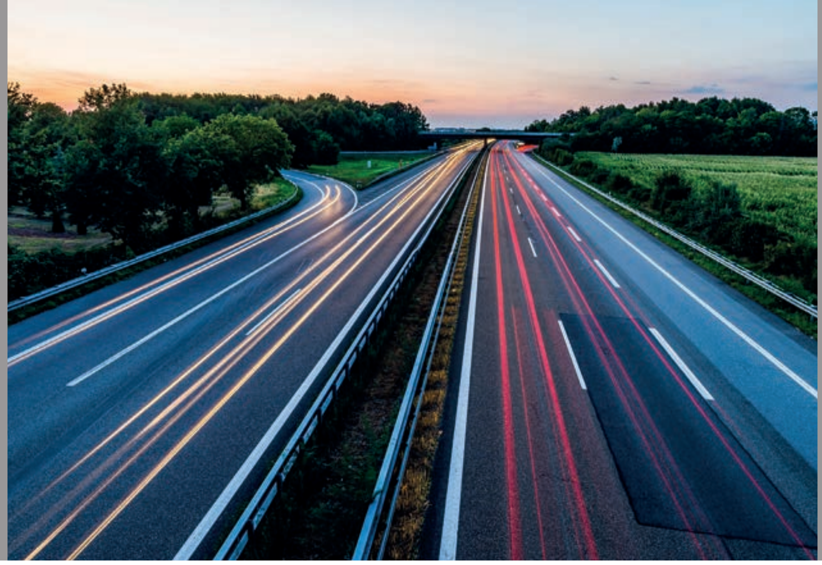
In addition to the alumni network »Aix-Laser-People«, the association »Arbeitskreis Lasertechnik AKL e.V.« bundles the thematic interests of those who continue to work in the field of laser technology. About 150 alumni, i.e. a good third, are members of the AKL e.V.

Contact at Fraunhofer ILT

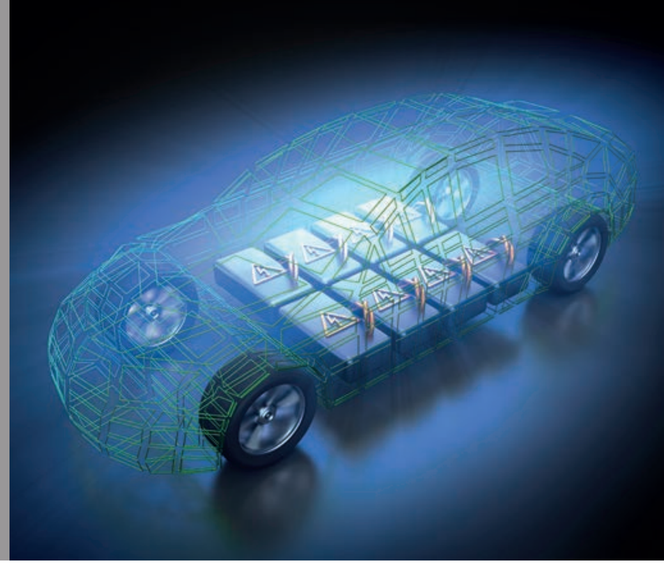
Dipl.-Phys. Axel Bauer (Alumni Manager)
Telephone +49 241 8906-194
axel.bauer@ilt.fraunhofer.de

MOBILITY

LASER TECHNOLOGY SOLUTIONS FOR INDUSTRY AND SOCIETY



© shantihesse – stock.adobe.com



© Patrick P. Palej – stock.adobe.com

LASER PROCESSES FOR ELECTROMOBILITY

The increasing trend towards electromobility is causing a significant change in the design and manufacture of automotive components. On the one hand, new lightweight concepts in body technology and chassis are gaining ground, and on the other hand, drive technology and energy storage are changing fundamentally. Both require new materials and customized manufacturing processes with the highest level of reliability, quality and productivity. Fraunhofer ILT develops manufacturing and system solutions for lightweight construction concepts in automotive technology and for the production of high-performance batteries.

Laser processes in lightweight construction

In addition to high-strength sheet metal, fiber-reinforced composites (FRP) are increasingly being used for lightweight automotive construction. Low production costs and short cycle times are a primary objective for these materials to be used in mass production. The processing of these inhomogeneous materials requires processes that are adapted to the anisotropy of the material and the laser is the ideal tool here: It is not only flexible, but is free from wear and works at high processing speeds. In the Center for Laser-Lightweight Construction, Fraunhofer ILT develops laser processes for FRP components, ones which do not change the specific properties of the materials and optimally preserve their advantages.

Thanks to its excellent temporal and local controllability, laser cutting reduces machining times and enables the automated production of FRP components. This applies to a wide variety of steps within the process chain – from cutting prepregs, tapes and organic sheets to trimming and cutting FRP components. High-speed processes or the use of short-pulse laser radiation ensures that damage to the cut edge is minimized despite the different absorption, heat conduction, melting and decomposition temperatures of the fiber and matrix.

Fraunhofer ILT also provides joining processes for plastic-metal joints with high lightweight potential. High-speed laser microstructuring creates undercuts and sponge-like, porous surfaces. In the following process, the heated plastic locks into these surfaces. A load-oriented design of alignment, shape and number of structures results in a wide range of possible hybrid structures for a variety of material combinations.

Laser processes for battery technology

To introduce competitive electric mobility batteries, the industry has to reduce their production costs significantly and increase their robustness and reliability. To accomplish this, it needs to consider all the steps from cell production to battery packaging and module production equally. Fraunhofer ILT develops laser-based technologies for the production and optimization of individual processes in cell production as well as efficient assembly and joining processes for the production of high-performance battery modules. In the production of lithium-ion cells, coating processes and subsequent drying and conditioning steps are crucial for the performance of a cell. By substituting previous conventional furnace processes by innovative laser processes, the institute is making a considerable contribution to improving the efficiency of the production as well as increasing the efficiency of the electrode and the layer stack. The drying and sintering of battery electrode layers by means of laser processes offers new possibilities for electrode production, in particular in the production of solid-state batteries.

Fraunhofer ILT offers high-speed cutting and patterning processes for the required finishing steps of a lithium-ion cell after it is coated. These processes can precisely remove active layers from the electrode without affecting the active layer material, thus replacing previous masking steps and at the same time achieving high design flexibility. By developing laser cutting processes that separate the coated battery foils without short circuits, the institute has been able to achieve a maximum yield of battery cells.

Finally, the production of battery modules and entire battery systems requires efficient assembly and joining processes, which, on the one hand, offer maximum process reliability and, on the other, are suitable for transferring high power. Fraunhofer ILT offers solutions for this. Thus, when battery cells have to be joined, laser-beam micro welding with local power modulation is used for the most part. The feed motion is superimposed with a circular oscillation movement, thus making it possible to adjust different connection geometries, current carrying capacities and mixing ratios. Thus, different materials, from aluminum-copper to copper-steel compounds, can be attached to different cell types. The welding process is designed so that the depth of penetration is reduced while maintaining the same connection width; thus, there is no damage to the active material in the battery cell. The method is suitable both for the production of electrically and mechanically safe connections from cell to cell as well as for the production of modules from cell networks and large battery packs from individual modules.

Selected research results

On lightweight design and battery technology: Pages 53–54, 56–57, 77–78, 85–88 and 92.
On mobility: Pages 40, 65–67, 69, 76, 79 and 89–90.

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

PRODUCTION

LASER TECHNOLOGY SOLUTIONS
FOR INDUSTRY AND SOCIETY

ADDITIVE MANUFACTURING OF INDIVIDUALIZED COMPONENTS

The production technology is currently facing a systematic change. While production technologies for standardized mass-produced components and the production of individualized and mostly cost-intensive individual components have each been considered separately, these two worlds will increasingly merge in the future. The need for individualized or complex components at reasonable costs in small or medium-sized quantities is growing systematically in all sectors of the manufacturing industry. Whether for individualized implants, complex injection molding tools with near-contour cooling channels or bionically engineered lightweight components for aircraft construction, additive manufacturing processes offer new opportunities to significantly reduce the unit costs of complex components made of different materials, such as metal, ceramic or plastic, in small quantities compared to conventional processes. Since the mid-90s, Fraunhofer ILT has consistently pushed forward with additive manufacturing – in particular of metallic components – and has set benchmarks with tool-free Selective Laser Melting (SLM), also known as Laser Beam Melting or laser powder bed fusion (LPBF) in production technology.

Additive manufacturing – from rapid prototyping to rapid manufacturing

Over the last few years, additive manufacturing processes have evolved from processes for prototyping and small series production to production processes for individualized series production in a wide variety of industries.

The research activities of Fraunhofer ILT cover the entire horizontal and vertical process chain of laser-based additive manufacturing.

Design and simulation

Since AM offers such geometry freedom in production, engineers can design and manufacture components with great complexity and new integrated functions. Often, the functions of entire assemblies can be integrated into one component and the component thereby manufactured monolithically with significantly reduced life cycle costs.

To assist the industry in using these process-related advantages, Fraunhofer ILT develops programs and tools for the efficient generation, simulation and validation of highly complex additive manufacturing (AM) structures. In addition to providing component design, the engineers at Fraunhofer ILT can optimize the entire digital chain, from path planning through the technology processor to integrated quality assurance and reverse engineering. This is followed by cost assessment models and strategic AM roadmaps.

Additive process chain

Fraunhofer ILT optimizes the economic efficiency of additive manufacturing processes by viewing the entire process chain in an integrated manner – from component design through SLM process control and plant engineering to final processing.

To improve robustness and reproducibility, the institute systemically determines how powder material, system components and exposure strategy influence process stability and component quality. In addition, it is developing in-line process monitoring methods for the quality assurance of SLM.

New process management strategies improve surface quality and detail resolution. To avoid cracks in difficult to weld materials and to reduce stresses and distortion, Fraunhofer ILT uses, among others, material-adapted exposure strategies and temperature control.

Plant and system technology

Users increasingly demand higher productivity in additive manufacturing and larger and more flexible installation spaces. For this reason, Fraunhofer ILT is systematically expanding the available installation space of the SLM systems, with movable processing heads, for example. The institute is able to scale productivity by using suitable beam sources, diode lasers, among others. Novel beam sources with green laser light also enable increased process efficiency and can process demanding materials, such as pure copper.

In the field of plant engineering for photopolymer 3D printing, Fraunhofer ILT is developing new machine concepts that will make it possible to produce components completely without support structures in the future. In addition, components can be arranged in the entire construction volume.

Materials

The spectrum of processable materials is being continuously expanded at Fraunhofer ILT. Thus, previously unworkable alloys, such as wrought aluminum alloys with a high risk of cracking, are systematically adapted to the specific conditions of additive manufacturing. In addition to looking at metallic materials, the institute is also doing research in new (photo) polymers for additive manufacturing. Moreover, not only does it investigate classical acrylates and epoxies, but also transparent and high-index thiol-ene photopolymers. These are suitable for constructing biocompatible implant frameworks. Finally, Fraunhofer ILT is developing 3D printing processes using living cells in a hydrogel-based ink to create artificial organ-like structures.

Selected research results
On Additive Manufacturing: pages 50–58, 62, 65 and 103.
On Production: pages 32, 34, 42, 44–47, 58, 60–61, 63–64, 66–93 and 102.

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

HEALTH
LASER TECHNOLOGY SOLUTIONS FOR INDUSTRY AND SOCIETY

INDIVIDUALIZED IMPLANTS THROUGH 3D PRINTING

Scientific research can contribute to medical care by developing individually adapted bone substitutes and replacement joints or medical implants with increased functionality, for example through integrated and defined pore structures. To produce such complex and individualized implants, the additive manufacturing process Selective Laser Melting (SLM), also known as laser beam melting or Laser Powder Bed Fusion (LPBF) has proven to be particularly suitable. Fraunhofer ILT develops manufacturing and system solutions for the additive manufacturing of individualized implants in close co-operation with medical professionals.

Challenges in medical technology

Healthcare research faces new challenges as demographics change and better medical care is required. In particular, personalized medical technology is considered a promising future field. For example, operations can be further improved when the individual medical needs of patients are carefully considered, for example in implant design or intervention planning. On the one hand, this considerably increases the well-being of the patient and, on the other, systematically reduces the costs for the healthcare system and, thus, the economy.

The use of resorbable implants as bone substitute is also setting new standards. These implants dissolve in the body of the patient and are successively replaced by the body’s own bone. “Growing” implants for children can be developed in this way, preventing unnecessary surgeries to remove an implant after bones heal or the permanent retention of an implant in the body.

Individual and functional implants

In SLM, components are built layer by layer from a fine powder by locally melting it with laser radiation according to a CAD model. Thanks to this tool-less production and the layered construction method, SLM is excellently suited for cost-effective individual production of complex components. Implants can be individually designed for the patient directly from medical image data (CT, MRI) on the computer and then manufactured cost-effectively using SLM. If required, these patient-specific implants can be provided with additional functionalities that would otherwise not be possible or only at very high cost in conventional production. For example, defined pore structures can be used to improve the ingrowth behavior and supply the implant with new tissue. In addition, SLM allows the setting of optimal mechanical properties required for each implantation site. In particular with resorbable implants, defined pore structures are a decisive advantage over non-porous implants. The amount of volume to be degraded can be significantly reduced and the degradation products effectively removed by a complete vascularization of the implant. At the same time, bone can form inside the implant.

Material diversity in 3D printing with SLM

SLM is used commercially for many metallic biomaterials such as titanium alloys, cobalt-chromium alloys or stainless steel. For applications in medical technology, Fraunhofer ILT has already put the procedure into practice several times in cooperation with partners from medicine and industry, e.g. for the individualized serial production of crowns and caps in the dental industry, for the production of joint replacements in orthopedics, and for bone replacement in oral and maxillofacial surgery. In addition to individual implants, highly specialized surgical instruments and vertebral fusion cages with enhanced functionality can also be manufactured using SLM.

The SLM components meet all the requirements of the relevant standards for mechanical properties and biocompatibility. Fraunhofer ILT also offers promising solutions for current research questions in medicine. For example, resorbable bone replacement implants with an interconnecting pore structure based on a polylactide-calcium phosphate composite material have been successfully tested for use in the low-load area of the skull in small animal experiments. Furthermore, the institute is developing the technology for the production of more resilient resorbable implants based on magnesium, iron or zinc alloys.

From the idea to the product

Fraunhofer ILT developed the SLM process in the mid-nineties and since then, in close cooperation with leading industrial companies and research institutes, has continued to refine it, taking the entire process chain into account. Thanks to their present expertise and many years of experience, the experts of Fraunhofer ILT cover the complete spectrum from the first idea through feasibility studies, process and plant development to the implementation of the results in production. In doing so, they make use of extensive plant equipment, consisting of different commercial systems, and highly flexible laboratory equipment.

Selected research results

On implants: page 99.
On medical technology: pages 33, 69 and 96–97.

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

ENVIRONMENT
LASER TECHNOLOGY SOLUTIONS FOR INDUSTRY AND SOCIETY

LASER TECHNOLOGY FOR CLIMATE RESEARCH

Fraunhofer ILT develops laser technology for satellite-based climate research and enables its clients to carry out more precise analyzes of the greenhouse effect. In this way, in cooperation with our partners, we make an active contribution to understanding the causes of climate change.

Climate change and the greenhouse effect

Since the end of the 19th century up until the present day, the world has warmed up by 0.7 °C, according to model-based calculations by the Hamburg Max Planck Institute for Meteorology. If global warming progressed as a model, a global warming of +3 °C would have to be expected by 2100, depending on the scenario. That would approximately correspond to the temperature difference from the last ice age until today. Clearly, this temperature increase would have grave repercussions on climate and vegetation. Here, there is an urgent need for action, which the acting politicians explore in the world climate conferences.

Many climatologists' predictions and simulations suggest that the temperature increases of recent decades are due to human behavior. Persistent greenhouse gases such as carbon dioxide and methane increase the so-called greenhouse effect. According to the Intergovernmental Panel on Climate Change, the concentration of carbon dioxide has increased by about 30 percent, of methane by 120 percent and of nitrous oxide by about 10 percent since the beginning of industrialization.

Climate research from space

Although it is a gas relevant to the climate, methane is not commonly discussed as much as carbon dioxide. Methane is, however, 25 times more effective per molecule in warming the earth. Still, carbon dioxide is about 200 times more abundant in the atmosphere and is, therefore, more pernicious. Nevertheless, the methane concentration in the atmosphere has been rising rapidly since 2007, without the causes of the phenomenon being truly clear.

In this context, the Franco-German »MERLIN Project« was initiated in 2010. The small satellite MERLIN (Methane Remote Sensing LIDAR Mission) is expected to be launched in 2023 and map the methane in the earth's atmosphere. The scientists want to understand in which regions methane is introduced into the atmosphere and where it is degraded. The heart of the satellite is a LIDAR system, which sends light pulses into the atmosphere and determines the methane concentration from the light scattered back from the ground.

Laser technology for space missions

The laser requirements for the MERLIN mission are extreme: The system must withstand shocks and vibrations up to 25 grms as well as thermal shock loads from -30 °C to +50 °C. In addition, organic materials such as adhesives should be avoided as completely as possible so as not to contaminate the high-purity mirror surfaces. And everything has to work smoothly after the launch for the mission period of three years.

For years now, Fraunhofer ILT has been developing technologies for space-qualified lasers for its partners such as Airbus Defence and Space or TESAT Spacecom. For LIDAR beam sources, a technology platform was designed and built on behalf of the European Space Agency ESA: FULAS – Future Laser System. Completed in 2016, the FULAS demonstrator passed thermal vacuum tests under realistic conditions and long-term tests in the laboratory of the project partner Airbus Defence and Space.

For the FULAS platform, the experts are not only developing components suitable for use in space, but also new construction technologies. For example, in the MERLIN project, all essential adjustment steps for the optomechanical components are performed by robots using the so-called Pick & Align process. Thus, the process is basically automated, thus making it interesting for other industries. The work on component development was carried out on behalf of the Federal Ministry for Economic Affairs and Energy BMWi and coordinated by the DLR Space Administration.

Laser beam sources for demanding requirements

The LIDAR laser for the MERLIN project consists of a laser oscillator with active length control, an INNOSLAB amplifier and an actively length-controlled frequency converter with two KTP crystals. Simultaneously fulfilling a multitude of requirements poses a great challenge for every developer: wavelength-switchable, bandwidth-limited, pulsed radiation, high efficiency with as little stress as possible on the optical components, high pointing stability, etc.

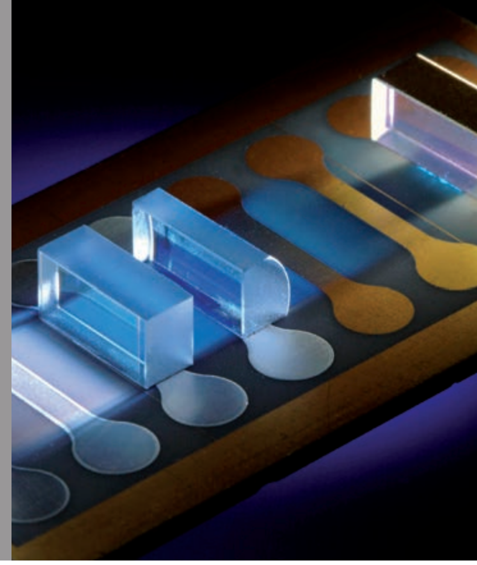
For LIDAR operation, the laser system is to deliver 9 mJ double pulses at two wavelengths around 1645 nm in single-frequency operation, whereby one of the pulses is always spectrally set exactly to a characteristic methane absorption line.

In addition to the laser systems suitable for space, the scientists of Fraunhofer ILT are also developing beam sources for aircraft- and helicopter-borne LIDAR systems, such as those used in the detection of leaks in trans-regional gas pipelines. With the innovative laser systems and the related assembly technologies, Fraunhofer ILT is making an active contribution to environmental and climate research.

Selected research results
On climate research: page 43.
On the environment: Pages 37–39, 72 and 104.

Further information on the Internet at:
www.ilt.fraunhofer.de/en.html and www.dlr.de (Project »MERLIN«)

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 and pure research.

LASER MATERIAL PROCESSING

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

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

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

MEDICAL TECHNOLOGY AND BIOPHOTONICS

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

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

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

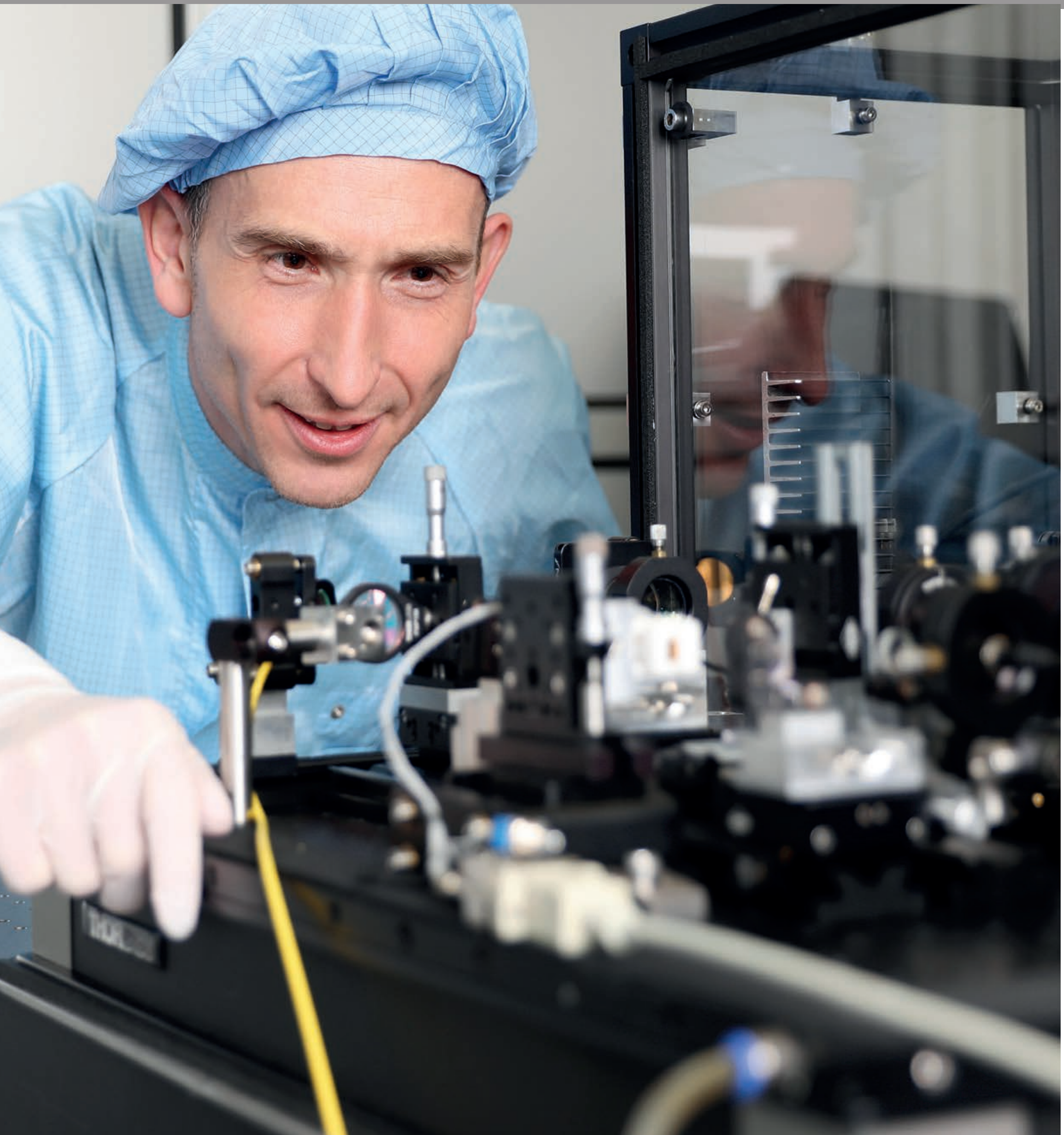
LASER MEASUREMENT AND EUV TECHNOLOGY

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

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

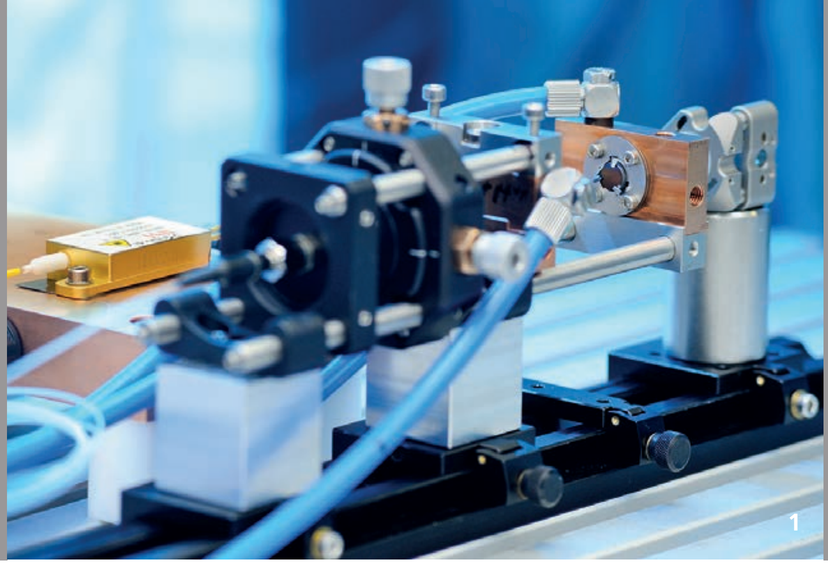
In EUV technology, Fraunhofer's experts develop beam sources for lithography, microscopy, nanostructuring or x-ray microscopy. Optical systems for applications in EUV engineering are calculated, constructed and manufactured as well.

LASERS AND OPTICS



CONTENTS

Expertise for tailored laser beam sources.



LOW-COST, COMPACT LASER WITH NS PULSE DURATION FOR MOBILE USE

Task

Fraunhofer ILT is developing a pulsed laser beam source for use in mobile laser-emission spectroscopy. The application profile specified a particular size, high stability and low manufacturing costs. The aim was to develop a compact, pulsed laser with high beam quality and repetition rates in the kHz range. Furthermore, the expected annual production costs should be less than € 1000 per piece at a batch size of 1000 pieces.

Method

The size and the energy management of mobile systems are of crucial importance for mobile systems. Usually, they contain pulsed lasers with active Q-switches such as a Pockels cell. These Q-switches require complex control electronics with high-voltage power supply and are, therefore, not suitable for low-cost handsets. For this reason, an active Q-switch will be exchanged for a passive Q-switch. Crystal-based passive Q-switches such as Cr:YAG consist of optical crystals whose transparency is dependent on intensity. This eliminates the burden on the supply- and control electronics of the Q-switch.

To reduce costs, Fraunhofer ILT has relied upon inexpensive standard components available on the market. Furthermore, the number of optical elements has been reduced to a minimum, e.g. by placing a resonator directly on the laser crystal. In addition, single-source emitter modules are used as the pump source.

Results

It was possible to construct a passive Q-switched solid state laser with a repetition rate of 1 kHz and a pulse energy of 0.7 mJ in single mode operation. Both pulse bursts and continuous pulse sequences can be generated. At a pulse duration of approx. 5 ns, the pulse peak power is about 140 kW.

Applications

The laser developed here is suitable as an excitation source in mobile laser emission spectroscopy. In addition, it can also be used in marking applications requiring high quality such as for the identification of semi-finished products in production processes or for thin-film processing.

Contact

Benjamin Erben M.Sc.
Telephone +49 241 8906-657
benjamin.erben@ilt.fraunhofer.de

Dipl.-Phys. Marco Höfer
Telephone +49 241 8906-128
marco.hoefer@ilt.fraunhofer.de

1 Passive Q-switched laser.

DIRECT GENERATION OF LASER RADIATION IN MIR

Task

As part of the project »DIVESPOT« with the Max Planck Institute for Structure and Dynamics of Matter, Fraunhofer ILT has investigated the direct generation and amplification of laser pulses in the MIR range at 3 µm output wavelength and with pulse durations between 100 ps and 1,000 ps. In addition, the institutes examined gain media that can address the wavelength range. Their goal is to develop a new precision tool for surgery.

Method

For generating laser light at a wavelength in the range of 3 µm, the chromium-doped II-VI compound semiconductor material zinc selenide was used as gain media. The pump source is a thulium solid-state laser emitting at a wavelength of 1.9 µm, which can be operated both continuously and pulsed with pulse durations of a few hundred nanoseconds. This laser was used to optically pump another resonator with Cr: ZnSe gain media. It then emits laser radiation in the wavelength range between 2.6 to 3 µm. The output wavelength can be tuned by selective elements in the resonator.

Results

Fraunhofer ILT has constructed a laser beam source that runs in continuous operation, has almost 2 W output power and an optical-optical efficiency of 21 percent. The emission wavelength was between 2.6 and 2.7 µm. In Q-switched operation, a pulse energy of 0.15 mJ was achieved at a repetition rate of 1 kHz.

Applications

Laser beam sources in the MID-IR range are suitable for use in medical technology, e.g. as a laser scalpel for soft tissue applications. Furthermore, these laser beam sources can be used for molecular spectroscopy. Another field of application is the processing of silicon.

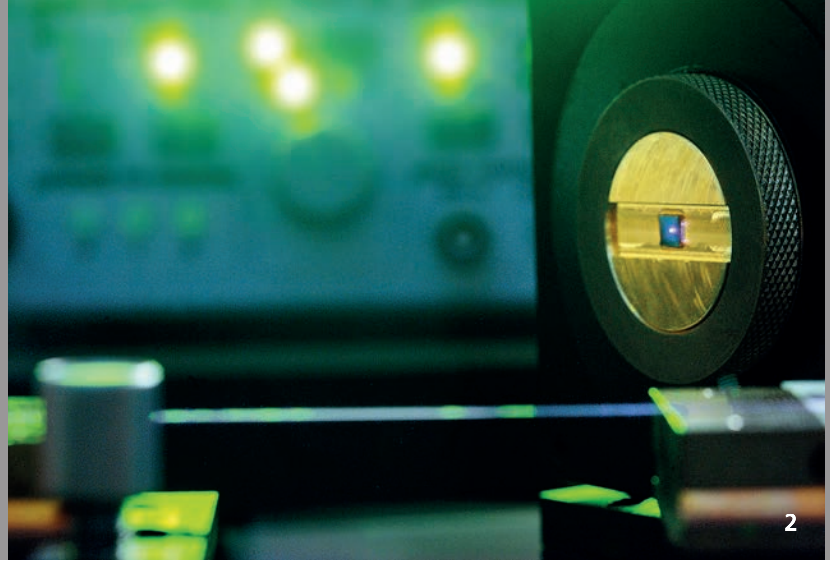
The project »DIVESPOT« has been funded within the cooperation program between the Fraunhofer-Gesellschaft and the Max Planck Society.

Contact

Benjamin Erben M.Sc.
Telephone +49 241 8906-657
benjamin.erben@ilt.fraunhofer.de

Dipl.-Phys. Marco Höfer
Telephone +49 241 8906-128
marco.hoefer@ilt.fraunhofer.de

2 Cr: ZnSe laser with Tm pump laser.
3 Cr: ZnSe laser crystal.



Q-SWITCHED MULTIMODE HIGH-POWER FIBER LASER

Task

As part of »GEWOL«, a project funded by the Federal Ministry of Education and Research (BMBF), a Q-switched, multimode high-power resonator with an output power of more than 500 W and pulse durations of less than 100 ns was developed as an alternative to pulsed fiber amplifier systems.

Method

To determine the possible operating points of a Q-switched fiber laser, Fraunhofer ILT used time-resolved simulation software it developed in house. With this software, the achievable peak power, pulse durations and repetition rates were calculated as a function of the available pump power. One result of the simulation is that a Q-switch with a particularly high contrast ratio is necessary due to the high gain in the active fiber at the targeted output power and at the repetition rates in the range of 10 to 100 kHz.

The Q-switched fiber resonator consists of an active Yb-doped XLMA fiber with a beam quality factor of $M^2 \sim 15$ and broadband mirrors. The spectrum of the laser is limited by a bandpass filter. For the Q-switch, Fraunhofer ILT used soldered Pockels cells it developed, which have a contrast ratio of > 40 dB.

Results

At a repetition rate of 60 kHz, a peak power of approx. 250 kW with a pulse duration (FWHM) of approx. 10 ns could be demonstrated at an average power of 525 W. Since the laser has not yet been limited in pump power, further power scaling (e.g. via the repetition rate) is possible.

Applications

Due to their high efficiency and robust construction, pulsed fiber laser systems are increasingly being used in industrial applications such as surface stripping. Because it is less complex compared to multi-stage fiber amplifier chains, a Q-switched high-power fiber laser offers a rugged, lower-cost alternative.

The R&D project underlying this report was commissioned by the Federal Ministry of Education and Research (BMBF) under grant number 13N12930.

Contact

Dipl.-Phys. Martin Giesberts
Telephone +49 241 8906-341
martin.giesberts@ilt.fraunhofer.de

Dipl.-Phys. Oliver Fitzau
Telephone +49 241 8906-442
oliver.fitzau@ilt.fraunhofer.de

1 Q-switched multimode fiber laser.

LOWERING THE REPETITION RATE OF MODE-LOCKED ULTRASHORT PULSE FIBER LASERS

Task

Ultrashort pulse lasers are finding an ever increasing field of application in industrial material processing. Frequently, mode-locked fiber lasers are used as a seed source for high-power systems, the repetition rate of which is typically around 50 MHz and is, therefore, too high for many applications in material processing. So that the repetition rate is reduced, actively controlled pulse pickers can be used, which, however, increase the complexity of the system and reduce its efficiency. To avoid this, a purely passive resonator was developed, which directly delivers repetition rates of about 10 MHz.

Method

First, Fraunhofer ILT conducted a theoretical investigation with a semi-analytic simulation; this took into account how dispersion, non-linear effects, gain and losses in the resonator influence the temporal and spectral properties of the pulses.

On the basis of these results, Fraunhofer ILT constructed a passive mode-locked fiber resonator which has a repetition rate of approx. 30 MHz, a pulse energy of 0.5 nJ and a pulse duration of 45 ps. To further reduce the repetition rate, the institute increased the resonator length. For this purpose, different methods were examined, and a hollow core fiber was then used to achieve a high degree of integration.

Results

Thanks to an extension of the resonator, repetition rates around 10 MHz are achieved. At the same time, the other pulse parameters are not affected.

For a single pulse, there are limits in a fiber with respect to the maximum achievable pulse peak power. These limits can be circumvented by using external amplification according to the principle of Divided Pulse Amplification (DPA). As a conceptual study, this was demonstrated for a one-step DPA.

Applications

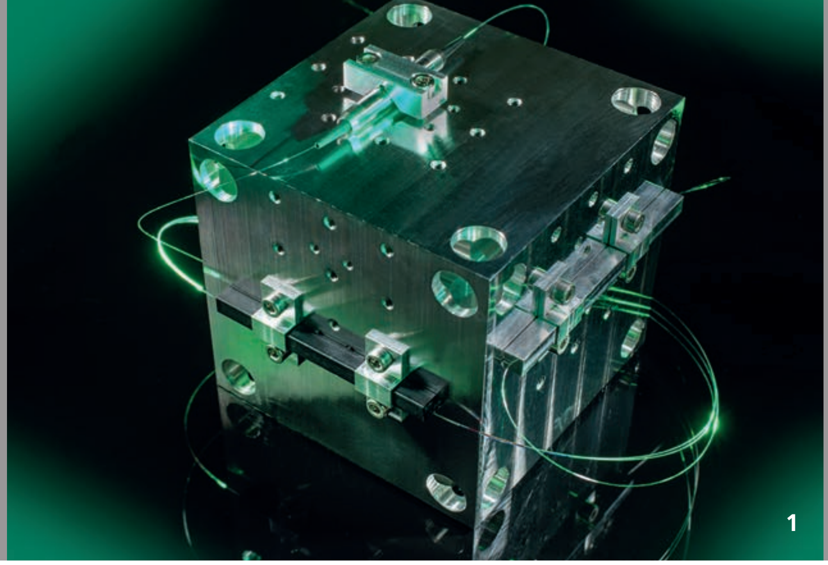
The demonstrated parameters enable efficient use of this fiber laser in micro and nano production. With the concept under examination, the repetition rate can be adapted to the respective application with efficient laser operation.

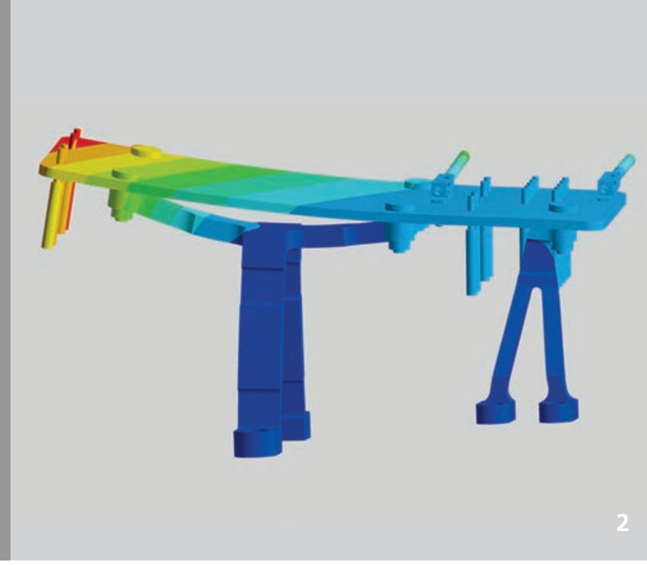
Contact

Patrick Baer M.Sc.
Telephone +49 241 8906-8251
patrick.baer@ilt.fraunhofer.de

Dipl.-Phys. Oliver Fitzau
Telephone +49 241 8906-442
oliver.fitzau@ilt.fraunhofer.de

2 Mode-locked fiber laser with saturable absorber.





ENVIRONMENTAL TESTS ON FIBER COMPONENTS FOR SPACE APPLICATIONS

Task

For a study of the European Space Agency ESA, Fraunhofer ILT developed and built a narrowband and power-stabilized fundamental mode fiber amplifier with an output power of 500 mW to measure the earth's gravitational field.

The laser amplifier, including all components, underwent environmental testing for satellite-based operation. The aims were to clarify whether the manufacturing processes and components used in space can be qualified as well as to identify weak points.

Method

The temperature fluctuations, shocks and vibrations occurring in the storage and starting phase and during the space mission were also simulated in the tests as was the cosmic radiation during the mission. For this purpose, the fiber components were subjected to the specifications of the ESA vibration, shock, thermal vacuum and irradiation tests. Before and after the environmental tests, various parameters – such as transmission, polarization and spectral properties – were used to ensure that the components function properly.

The load on the components in the sinus and random vibration tests was up to 20 g per axis. Shock tests could be performed with an acceleration of up to 1,400 g in all three spatial axes of the component. In thermal vacuum tests, the functionality of the components was investigated in a vacuum of < 1 x 10^{-5} mbar and a temperature range of -40 °C to 50 °C. Due to the expected radiation exposure during the three-year mission of the amplifier in low-earth orbit, the components were exposed to gamma and proton irradiation.

Results

To date, Fraunhofer ILT has reviewed technological maturity levels of the fiber amplifier components and identified individual deficiencies. The test results will serve as the basis for the final qualification of the fiber amplifier.

Applications

The fiber amplifier can be used for inter-satellite communication as well as to measure the static gravitational field and gravitational waves. The methodology developed here can also be applied to other difficult fields of application.

Contact

Patricia Betz M.Sc.
Telephone +49 241 8906-623
patricia.betz@ilt.fraunhofer.de

Dipl.-Phys. Oliver Fitzau
Telephone +49 241 8906-442
oliver.fitzau@ilt.fraunhofer.de

1 Test components on mounting device for vibration tests.

MERLIN – LASER OPTICAL BENCH

Task

Fraunhofer ILT is developing the Laser Optical Bench, the core element of the laser-beam source for the Franco-German-climate mission MERLIN (Methane Remote Sensing LIDAR Mission). Starting in 2022, this bench – as part of the LIDAR system – shall emit laser pulses with specific properties; these pulses will help meteorologists make conclusions about the methane content of the atmosphere by a measurement of the backscattered light between satellite and ground. Since the complex laser will be used under vibrations and temperature changes, durable and robust construction technology is required. In order not to destroy the sensitive laser optics by molecular contamination, outgassing organic materials – such as adhesives and plastic-based insulation – cannot be used at all.

Method

Fraunhofer ILT has extensively analyzed the optical, mechanical, thermal and electrical performance of the system to ensure suitability in all load cases. In addition to systematically developing the optomechanical components, the institute also developed a passive cooling structure and an arrangement for the transmission of various signals, pulsed electrical currents of up to 130 A and high voltages of about 4 kV. The final design of the Laser Optical Bench is free of any organic materials.

Results

A laboratory model of the laser was used to verify all essential beam properties of the system to be used later. The mechanical and thermal functionality of all the essential components could be demonstrated after optimization with finite element methods (FEM). Then, all components of the Laser Optical Bench were defined and arranged. Currently, the components of the laser are being procured and the Critical Design Review (CDR) prepared.

Applications

The model philosophy and the assembly concept can be transferred to other laser beam sources. This is true for both aerospace and industrial applications, where high reliability plays a crucial role.

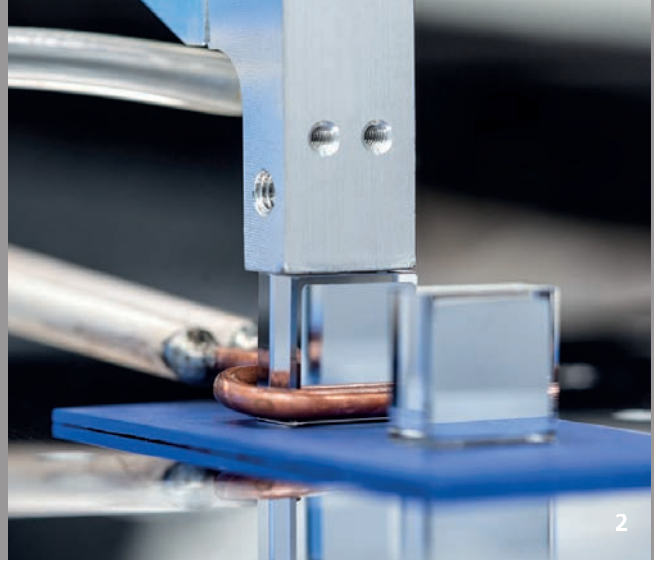
The R&D projects underlying the report were carried out on behalf of the Federal Ministry for Economic Affairs and Energy BMWi under the grant numbers 50EE0904, 50EE1235, 50EP1001 and 50EP1301. The work in »MERLIN« is being carried out on behalf of the DLR RFM, subcontracted by Airbus DS in phases C/D under the grant number 50EP1601.

Contact

Dipl.-Phys. Jörg Luttmann
Telephone +49 241 8906-673
joerg.luttmann@ilt.fraunhofer.de

2 Modal analysis of an element of the electrical harness.

3 Image of the MERLIN laser generated from the 3D model.



NEW ASSEMBLY AND ADJUSTMENT CONCEPT FOR OPTO-MECHANICAL COMPONENTS

Task

In addition to being used for space, soldering technologies are becoming increasingly important for optical components in industrial applications. In this project, Fraunhofer ILT's active soldering technology was used to connect optical components with multilayer ceramics, developed by Fraunhofer IKTS, through flux-free joining without an additional intermediate layer. An inductive heat supply heated the solder layer without contacting it and adjusted the optical components in the solder.

Method

When suitable active solders are used, metallic and non-metallic materials can be joined in an atmospheric environment. To begin with, a process wets the surface with the solder quickly and completely. To join components with very different coefficients of thermal expansion, process temperatures below 300 °C and, thus, soft solders are advantageous. The non-contact, local heat coupling by means of induction makes it possible to achieve adjustment tolerances of the optical components below 10 µrad.

Results

Fraunhofer ILT has used active soldering processes to produce assemblies of optical, ceramic and metallic components. These are characterized by a high tilting stability of < 10 µrad in the temperature range from -40 °C to +60 °C. The quality of the solder joints was verified in shear tests.

Applications

Thanks to this new assembly and adjustment concept with active soldering and inductive heat supply, the design of optical assemblies can be made more economically and efficiently. Precise adjustment of optical components enables not only robust, temperature-resistant and organically free solder joints, but also the construction of long-term stable, complex laser systems for use in industry and research.

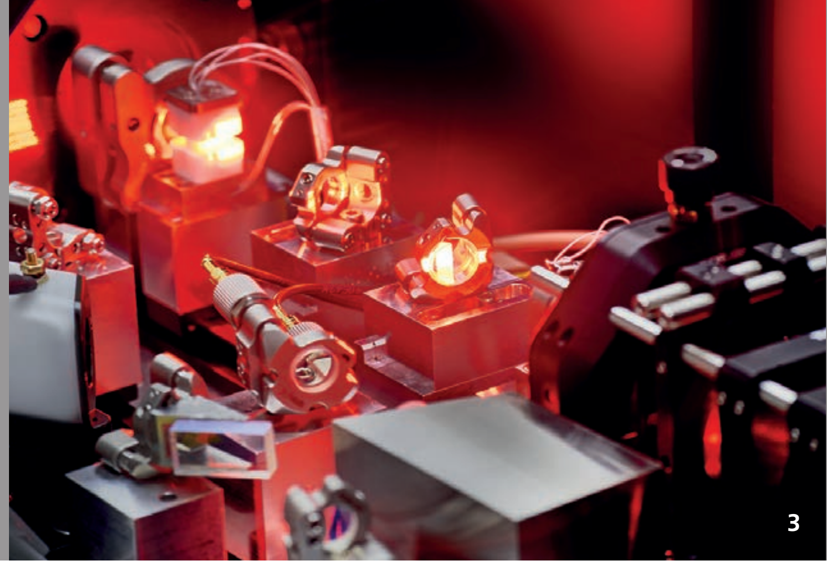
Contact

Witalij Wirz M.Eng.
Telephone +49 241 8906-8312
witalij.wirz@ilt.fraunhofer.de

Dr. Heinrich Faidel
Telephone +49 241 8906-592
heinrich.faidel@ilt.fraunhofer.de

1 Multilayer ceramic glass connection.

2 Assembly process by means of inductive heat supply.



DIODE-PUMPED ALEXANDRITE LASER FOR LIDAR MISSIONS IN THE ATMOSPHERE

Task

To measure the temperature profiles of the atmosphere at altitudes between 80 and 110 km, the Leibniz-Institute of Atmospheric Physics e.V. (IAP) uses mobile resonance LIDAR systems. For this, the Doppler width of a metal resonance line is determined spectroscopically as a measure for the temperature. The laser-emitters are flash lamp-pumped Alexandrite ring lasers in Q-switched single-frequency operation. Since the laser is operated in remote locations with partially harsh environmental conditions, both the maintenance-free operating time and plug-in efficiency need to be increased. To this end, Fraunhofer ILT has developed a technology demonstrator with which the IAP is now investigating the use of diode-pumped Alexandrite lasers in atmospheric research.

Method

The demonstrator is a Q-switched Alexandrite ring laser. Two commercial diode laser modules serve as a pump source, which can emit up to 40 W average power at 638 nm in continuous operation. Laser operation in stable single-frequency mode has been achieved by »seeding« with a narrow-band diode laser and electronically controlling the cavity length. The wavelength of the seeder is used to continuously tune the output wavelength of the Alexandrite laser in the range of potassium resonance. After completion in the laboratory, the laser was integrated into a mobile IAP lab, which, in addition to the peripheral devices of the laser, also contains the entire LIDAR technology.

Results

In single-mode operation ($M^2 < 1.2$), the laser emits pulses with an energy of 1.1 mJ at a repetition rate of 150 Hz and a wavelength of 770 nm. The pulse duration is 410 ns at a spectral bandwidth of less than 10 MHz. The laser has already successfully carried out initial measurements in the atmosphere up to altitudes of more than 100 km.

Applications

In the research project »ALISE« (grant number 50RP1605) funded by the Federal Ministry for Economic Affairs and Energy (BMWi), ILT and IAP are currently investigating the potential of such lasers for satellite-based atmospheric research with global coverage.

Contact

Dr. Michael Strotkamp
Telephone +49 241 8906-132
michael.strotkamp@ilt.fraunhofer.de

Dr. Bernd Jungbluth
Telephone +49 241 8906-414
bernd.jungbluth@ilt.fraunhofer.de

3 Diode-pumped Alexandrite ring laser.

LIDAR SYSTEM FOR APPLICATIONS IN THE AUTOMOBILE INDUSTRY

Task

Driver assistance systems are increasingly being used to partially or fully autonomously drive vehicles. Such systems must be able to detect objects and obstacles in the environment both quickly and reliably. In addition to radar sensors, LIDAR systems are increasingly being used for such purposes. These systems determine the distances to surrounding objects by time-of-flight measurements of reflected laser radiation. Conventional LIDAR systems incorporate a mechanical beam deflector (scanner), whose function and reliability may be affected by the vibrations that occur in the vehicle. In addition, the sampling rate is limited by inertia. For these reasons, a LIDAR system without moving parts is desirable, one that operates reliably, maintenance-free, at a high sampling rate, in a large ambient temperature range and under mechanical loads caused by shocks and vibrations.

For this purpose, a LIDAR demonstrator with a linear beam profile without moving parts was developed at Fraunhofer ILT in close cooperation with Fraunhofer IMS in Duisburg.

Method

In the LIDAR demonstrator, the radiation of a pulsed diode laser is horizontally expanded to approximately 40 degrees by a micro-optical system. The reflected laser radiation on objects is mapped to a line sensor with 80 pixels. The sensor was developed at Fraunhofer IMS and is based on SPAD technology, which enables high optical sensitivity at a sampling rate in the kHz range.

Results

The LIDAR demonstrator was able to detect objects at a distance of up to 30 meters at a field of view of 40 degrees. The sampling rate is currently 10 kHz.

Applications

The LIDAR system serves as a sensor-based component for driver assistance systems and can, for example, be used in the field of autonomous driving. Objects in the roadway area, such as obstacles or vehicles in front, can be reliably detected even under harsh environmental conditions.

Contact

Dr. Thomas Westphalen
Telephone +49 241 8906-374
thomas.westphalen@ilt.fraunhofer.de

Dipl.-Ing. Dipl.-Wirt.Ing. Martin Traub
Telephone +49 241 8906-342
martin.traub@ilt.fraunhofer.de

1 LIDAR demonstrator.

LASER-BASED FORCE SENSOR

Task

High-precision force sensors play an important role in many areas of production and quality assurance. Kistler Instrumente AG is the world market leader in the field of piezoelectric sensors for the measurement of pressure, force, torque and acceleration. In piezoelectric sensors, the stress generated by deformation of a crystal is analyzed, allowing highly accurate relative measurements. A direct absolute measurement of the force is, however, not possible owing to the principles involved. In close cooperation with Kistler, Fraunhofer ILT investigated a laser-based method for high-precision force measurement, which also enables absolute measurements. The force acting on the laser crystal is determined by a frequency measurement of this laser.

Method

A flexible laboratory setup was developed to investigate the different influencing factors on the measurement and to identify suitable components. For this purpose, ILT developed the optical design of the laser, the pump and analysis optics, the selection of suitable components and FEM analyzes to determine the resulting stresses in the crystal. In addition, the potential of the process was analyzed in extensive laboratory investigations. The studies focused on essential questions for potential product implementation, such as accuracy, reproducibility and long-term stability.

Results

Key influencing factors were identified, and absolute adjustments of 0.5 ‰ and reproducibility of 0.1 ‰ could be achieved by adapting the structure. Even over a larger temperature range up to 70 °C, the deviations were below 3 ‰.

Finally, two demonstrators were constructed to further investigate the potential of the technology on Kistler's premises. The demonstrators were built on the basis of commercially available components with a flexible and high-precision mounting method in a customized housing and have dimensions of 150 x 45 x 30 mm³.

Applications

With this technology, high-precision measurements of absolute forces can be made for use in calibration and reference measuring systems.

Contact

Dr. Michael Strotkamp
Telephone +49 241 8906-132
michael.strotkamp@ilt.fraunhofer.de

Dr. Bernd Jungbluth
Telephone +49 241 8906-414
bernd.jungbluth@ilt.fraunhofer.de

2 Demonstrators of a laser-based force sensor.

2 µm ULTRASONIC PULSE LASER WITH SUBPICO SECOND PULSE DURATION

Task

The use of ultrashort pulse (USP) lasers with pulse durations < 1 ps makes the cold processing of a wide range of materials possible, with virtually no heat input into the workpiece. Industrial ultra-short pulse lasers are currently mainly limited to the wavelength range around 1 µm and below. With the help of optical parametric frequency conversion, however, the addressable wavelength can be extended to the IRB range (1.5 to 3.0 µm).

Method

Based on a commercial laser (Trumpf TruMicro 5070 Femto Edition) at 1030 nm, the system presented here generates laser light with a wavelength of 2.06 µm in a two-stage process. First, in an optical parametric generator (OPG), part of the pump power is converted into the longer wavelength signal and idler field ($\lambda_{signal} = \lambda_{idler} = 2.06$ µm). In an optical parametric amplifier (OPA), this field is further amplified with the remaining pump power. An optional seeding with a narrow-band diode laser can be used to specifically influence the output bandwidth.

Results

Output powers of more than 28 W were generated from approximately 80 W input power. This corresponds to a total conversion efficiency of more than 35 percent. The pulse duration at 2 µm at this operating point is about 600 fs at a pump pulse duration of 900 fs and a repetition rate of 800 kHz. At an optimized operating point, the beam quality M^2 is 1.8 in the horizontal and 2.0 in the vertical direction. In this case, an output power of about 19.5 W was generated.

Applications

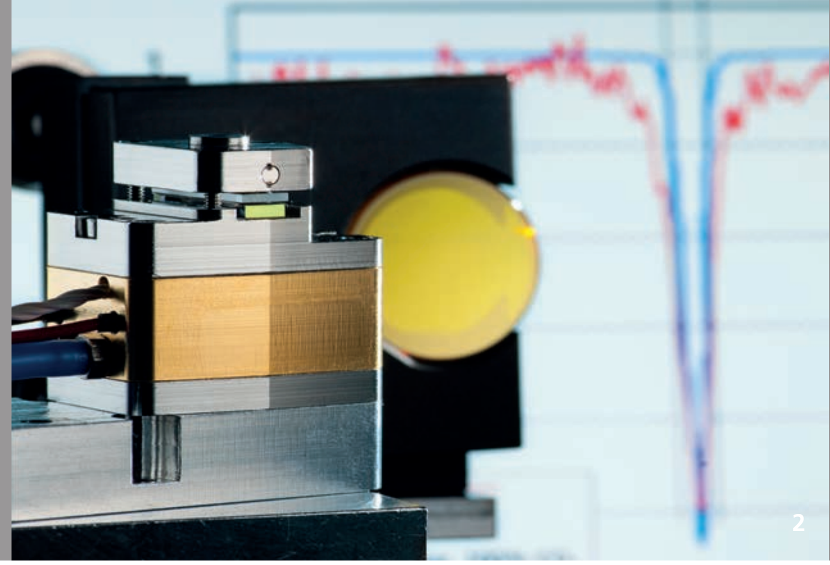
The concept presented here demonstrates that efficient high-power frequency conversion of industrial USP lasers is possible with pulse durations < 1 ps in the range of 2 µm. This can be applied to the entire spectral range of 1.5 to 3.0 µm. Thus, USP beam sources can be built, making it possible to process materials with application-specific optimized wavelengths.

Contact

Florian Elsen M.Sc.
Telephone +49 241 8906-224
florian.elsen@ilt.fraunhofer.de

Dr. Bernd Jungbluth
Telephone +49 241 8906-414
bernd.jungbluth@ilt.fraunhofer.de

1 Laboratory setup for frequency conversion to 2 µm.



OPGaAs-OPO WITH 10 µm WAVELENGTH

Task

The mid-infrared (MIR) spectral region is of great importance because many atoms and molecules exhibit high and specific absorption in MIR. Where applications place special demands on the spectral and temporal characteristics of the emission, the CO_2 and quantum cascade lasers currently available in this wavelength range often reach their limits. Optically parametric oscillators (OPO), however, can cover such needs.

Method

If orientation-patterned gallium arsenide (»OPGaAs« for short) is used as the nonlinear medium, OPOs can generate radiation at wavelengths of more than 15 µm. OPGaAs is characterized by its broadband transparency in MIR, its high effective nonlinearity and resistance to destruction.

The OPO implemented here is pumped with a pulsed thulium fiber laser. At the crystal, the laser provides an average input power of up to 13.5 W at a repetition rate of 50 kHz and a pump pulse duration of 150 ns. The OPO converts the wavelength of the laser radiation from 1.95 µm into the spectral range between 10 µm and 11 µm (idler radiation). The exact output wavelength is set by the temperature of the OPGaAs crystal.

The bowtie cavity of the OPO is resonant only for the signal wavelength generated simultaneously in the crystal (about 2.4 µm). Pump and idler waves are coupled out at the first resonator mirror behind the crystal and then separated with a dichroic mirror.

Results

The OPO achieves an average idler power of up to 1.07 W. The beam quality M^2 – 1.42 and 1.62 in the horizontal and vertical directions, respectively – is slightly higher than the values of the pump beam. The duration of the idler pulses is 130 ns. The measured values correspond to a conversion efficiency of pump to idler power of approx. 8 percent. The corresponding quantum conversion efficiency is calculated to 43 percent, the corresponding power of the signal wave to about 5 W at 2.4 µm.

Applications

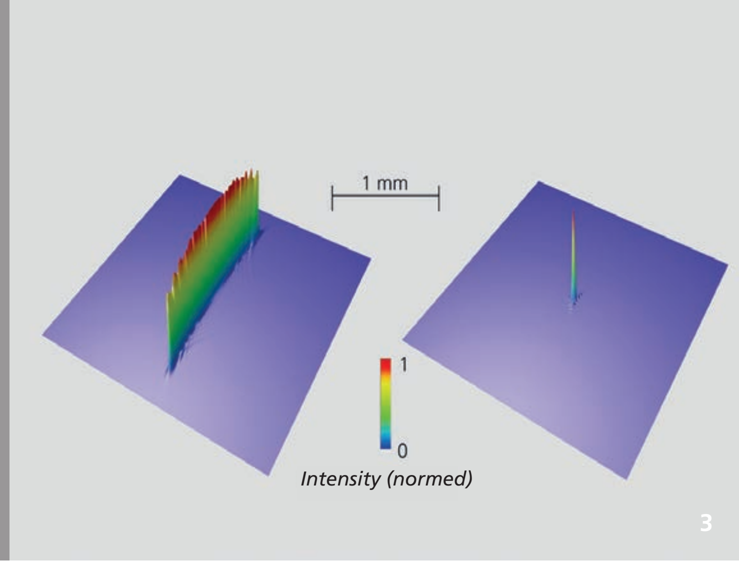
Based on the design presented here, output wavelengths between about 2 µm and 15 µm can be generated when adapted components are used. This enables a range of metrological applications, for example in environmental analysis or atmospheric research, but also in material processing.

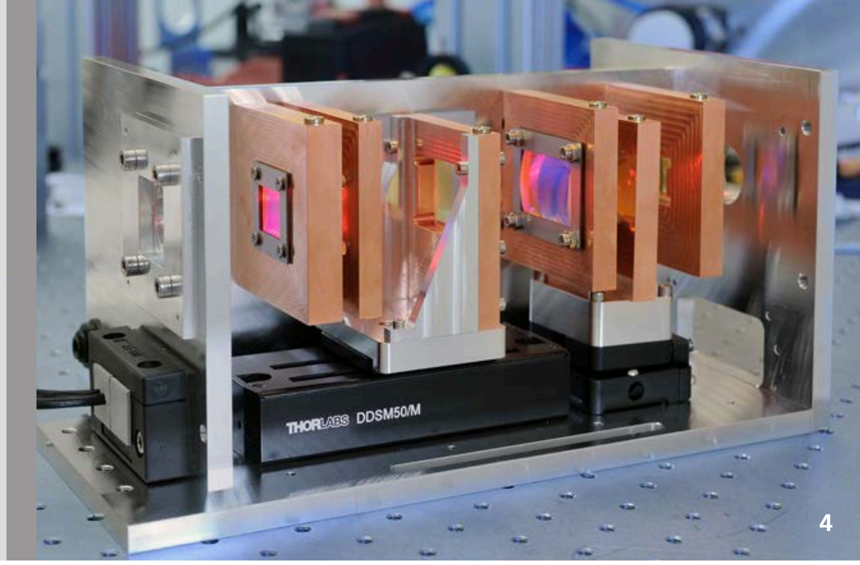
Contact

Dr. Jochen Wüppen
Telephone +49 241 8906-8020
jochen.wueppen@ilt.fraunhofer.de

Dr. Bernd Jungbluth
Telephone +49 241 8906-414
bernd.jungbluth@ilt.fraunhofer.de

2 Crystal oven with OPGaAs crystal.





COMPACT LASER CUTTING HEAD WITH HIGH-POWER OPTICS MADE OF SYNTHETIC MONOCRYSTALINE CVD DIAMONDS

Task

Highly dynamic cutting applications require compact machining heads for medium laser power in the kW range. Conventional optical materials such as quartz or optical glass have only limited suitability for these applications. Compared to established materials, monocrystalline synthetic CVD diamond has a variety of outstanding properties, such as high hardness, thermal conductivity and a high refractive index. Since diamond has such advantageous thermal properties, the optics can be efficiently cooled even at very large power densities. Moreover, the high refractive index makes it possible to build optical systems with significantly fewer lenses. Compared to polycrystalline diamond, monocrystalline synthetic diamond is better suited for the low-loss shaping of laser radiation at a wavelength of 1 µm.

Method

The research presented here focused on reducing the size and weight of the cutting head by optimizing its mechanical and optical design. So that the installation space could be minimized, the fiber end is imaged onto the workpiece with an optical group instead of a conventional arrangement consisting of collimator and focusing unit. The diamond lenses have an anti-reflective coating, and the lens mount is water-cooled, allowing reliable lens operation even at high power densities.

Results

This cutting head is more than 90 percent lighter than conventional compact cutting heads. In the first application trials, a stainless steel sheet with a thickness of 1.5 mm was cut with diamond optics and a single-mode 1 kW fiber laser.

Applications

In addition to the demonstrated application of diamond optics in the field of laser-beam cutting, this optical system can be used in all applications in which compact machining systems are advantageous with high laser power in the multi-kW range. These include additive manufacturing processes such as laser material deposition.

Contact

Dipl.-Ing. Dipl.-Wirt.Ing. Martin Traub
Telephone +49 241 8906-342
martin.traub@ilt.fraunhofer.de

Dipl.-Ing. Hans-Dieter Hoffmann
Telephone +49 241 8906-206
hansdieter.hoffmann@ilt.fraunhofer.de

1 Synthetic monocrystalline diamond lens.
2 Laser cutting test with the machining head.

OPTICAL SYSTEM FOR VARIABLE BEAM SHAPING

Task

As an important process parameter, the intensity profile of the laser beam significantly influences the machining result of laser-assisted machining processes. The often Gaussian intensity profile emitted by a laser beam source is transformed into process-adapted intensity profiles in many applications by means of optical beamforming elements. However, the intensity profiles thus formed are static, and a dynamic adaptation to the process is not possible. Therefore, an optical system has been developed that provides a rotationally symmetric, Gaussian or a homogeneous, linear spot in the working plane.

Method

So that the Gaussian input beam could be formed into a homogeneous, linear spot in the working plane, an optical system consisting of cylindrical lenses has been designed. The process, patented by Fraunhofer ILT, will adjust the system so that it will be possible to vary the degree of homogenization.

Results

Thanks to the developed optical system, a linear intensity distribution with an aspect ratio of 30:1 can be generated in addition to a rotationally symmetric intensity distribution with Gaussian profile. The linear intensity distribution has a high homogeneity in the longitudinal axis. During the switching process between the intensity profiles, the working distance is not changed. To change to another intensity profile, the system needs < 0.2 s. Furthermore, the quartz glass cylindrical lenses also allow the use of laser powers up to 2 kW.

Applications

In principle, all laser material processing methods that currently homogenize the intensity profile in the working plane can benefit from the new possibility of variable beam shaping. Thanks to the newly gained degree of freedom, Gaussian profiles can also be used. This opens up new possibilities in these processing methods for machining strategies that will have a positive effect on the processing time and quality.

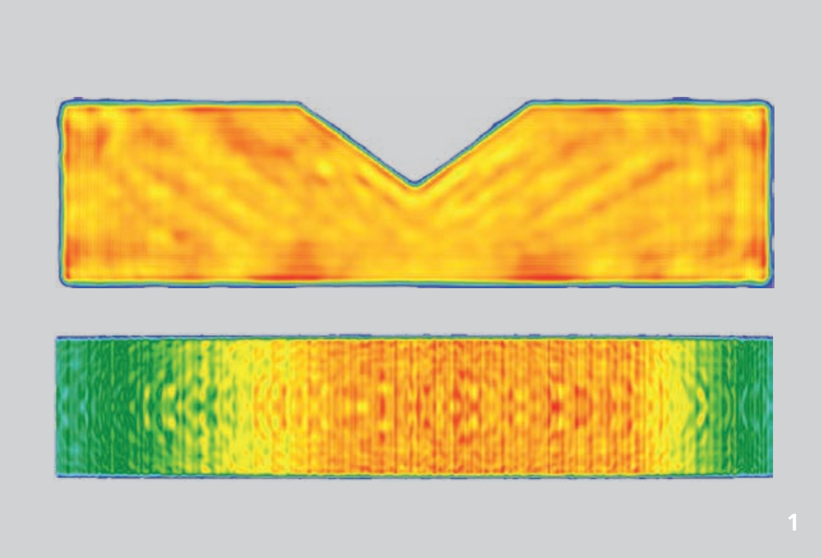
The R&D project underlying this report has been carried out as part of the research campus »Digital Photonic Production« under grant number 13N13710.

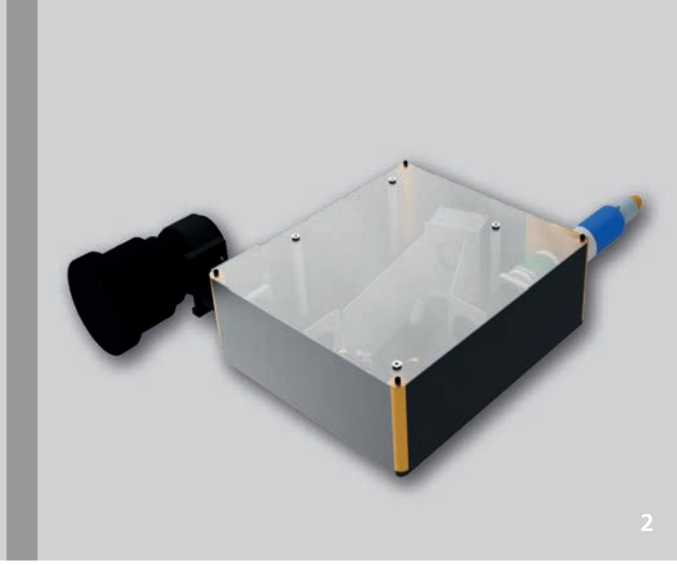
Contact

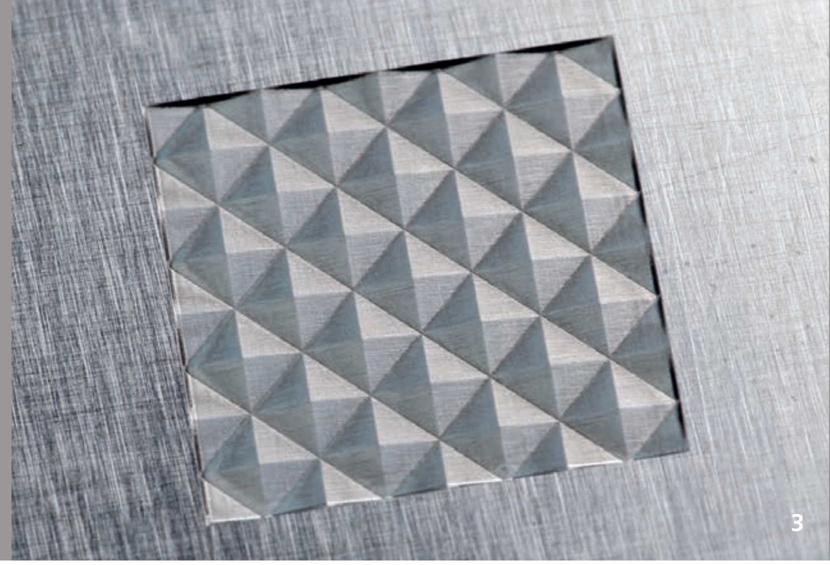
Dipl.-Ing. Georg König
Telephone +49 241 8906-614
georg.koenig@ilt.fraunhofer.de

Dr. Jochen Stollenwerk
Telephone +49 241 8906-411
jochen.stollenwerk@ilt.fraunhofer.de

3 Adjustable intensity profiles (simulation).
4 Prototype of line optics.







HIGHLY DYNAMIC ADAPTATION OF INTENSITY DISTRIBUTIONS FOR 3D LASER MATERIAL PROCESSING

Task

Laser-based surface processing methods, such as polishing or the functionalization of thin layers, either have too low processing speeds or are restricted to flat workpiece surfaces, both of which currently limit their broad industrial application. Application-adapted intensity distributions allow the temperature profile to be adapted to the process control in order to increase the processing speed. In addition, the processing of 3D surfaces requires intensity distributions to be dynamically adapted, which cannot be done with the previous approaches or only with insufficient dynamics.

Method

First, a static intensity distribution is generated by means of a diffractive optical element (DOE). With a piezoelectric, continuously deformable mirror, the phase front of the laser beam is then highly dynamically modulated (switching times < 5 ms) so that the desired intensity distribution can be established after the laser beam is focussed. In addition, the deformable mirror compensates for the distortion effects of the scanner-based beam deflection on the intensity distribution. Additionally, the intensity distribution can be adapted depending on its position when surface data of the workpiece are taken into account.

Result

The developed optical system enables 3D surfaces to be processed at an angle of incidence of up to 60 degrees while maintaining a distortion-free intensity distribution. All optical components are designed for laser powers up to 2 kW.

Applications

The generation of a constant, distortion-free intensity distribution during the processing of 3D surfaces creates the prerequisite for transferring a large number of laser-based processes to the processing of 3D surfaces.

The work was carried out as part of the EU project »ultra SURFACE« under grant number 687222.

Contact

Oskar Hofmann M.Sc.
Telephone +49 241 8906-395
oskar.hofmann@ilt.fraunhofer.de

Dr. Jochen Stollenwerk
Telephone +49 241 8906-411
jochen.stollenwerk@ilt.fraunhofer.de

1 Application-adapted intensity distributions for laser polishing.

2 3D model of the optical system (Source: Pulsar Photonics).

OPTICS FOR FLEXIBLE MULTI-BEAM PROCESSING

Task

Due to its very short light-matter interaction times, ultrashort pulsed (USP) laser radiation enables high-precision material processing with negligible thermal influence. While the quality for cutting or ablation processes is excellent, the productivity is still too low for many applications. Although USP beam sources with power up to the kW range are available, these power levels cannot easily be converted into productive processes. Since the power per laser focus is limited to a few watts of average power for reasons of quality, the power of a high-power beam source is split into multiple sub-beams by diffractive optical elements, and the productivity is scaled up by parallel processing with these multi-beams. The big deficit of these approaches is their low flexibility because the partial beams can only be switched together and the lateral distance is generally determined statically by the optics used. For this reason, only periodic structures can be generated.

Method

Fraunhofer ILT has developed an optical system that can selectively control and modulate the power of the individual partial beams. In combination with an FPGA-based control system, any structures, even non-periodic structures, can be produced efficiently.

Results

As a prototype, Fraunhofer ILT constructed an optic that generates four partial beams, each of which can be switched separately. The total efficiency is over 80 percent and the deviation of power between the partial beams is less than 1 percent. The individual partial beams are arranged linearly at a distance of 1 mm and the arrangement of the partial beams can be rotated by any angle. When the existing optics are extended, the number can be increased to eight partial beams.

Applications

The application addressed here is the precise, efficient production of non-periodic surface structures for tool and mold making. In principle, the optics can also be used to increase productivity for other USP applications such as cutting, drilling or thin-film ablation.

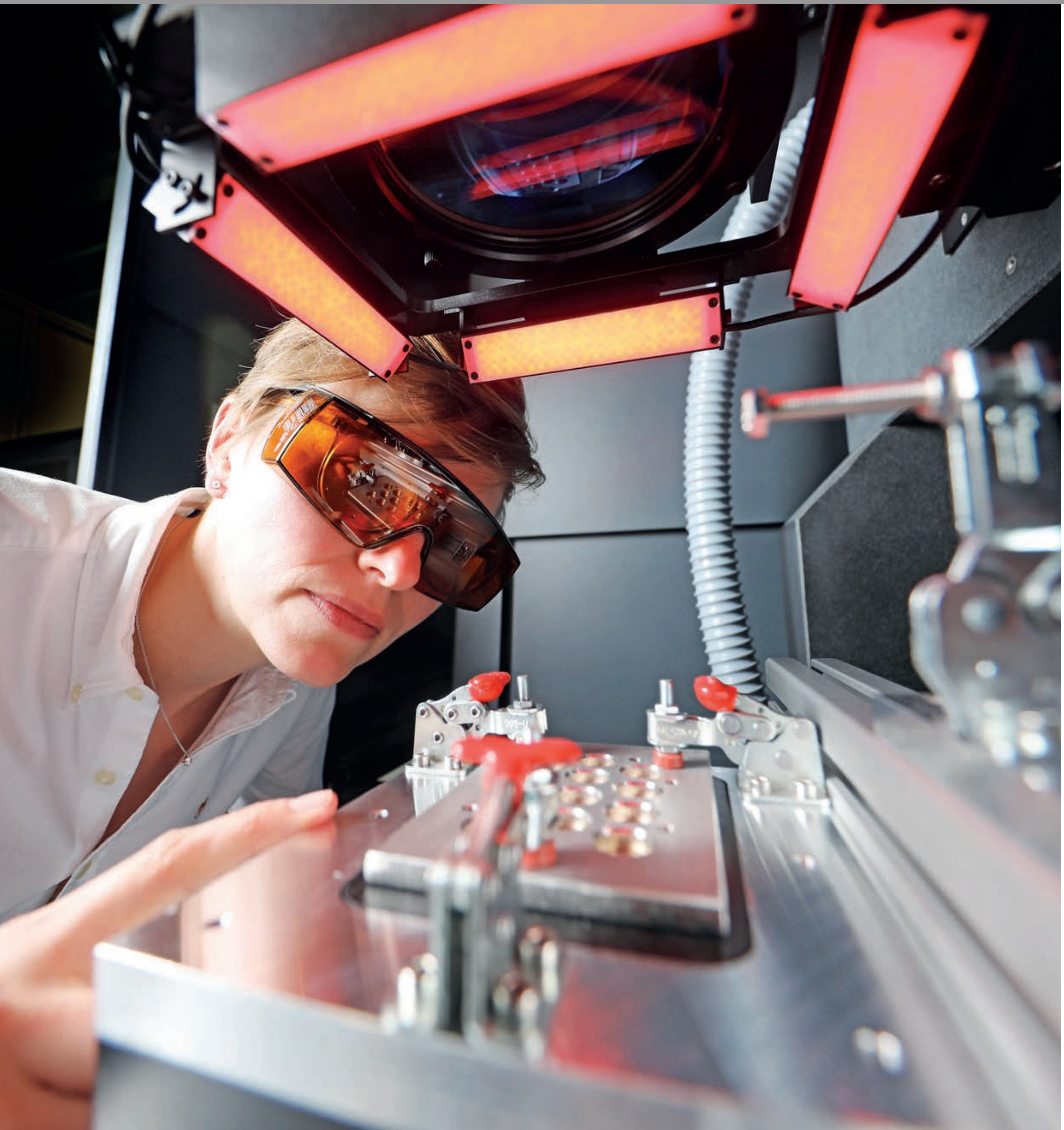
Contact

Dr. Johannes Finger
Telephone +49 241 8906-472
johannes.finger@ilt.fraunhofer.de

Dipl.-Phys. Martin Reininghaus
Telephone +49 241 8906-627
martin.reininghaus@ilt.fraunhofer.de

3 Surface texture generated by a USP laser.

LASER MATERIAL PROCESSING



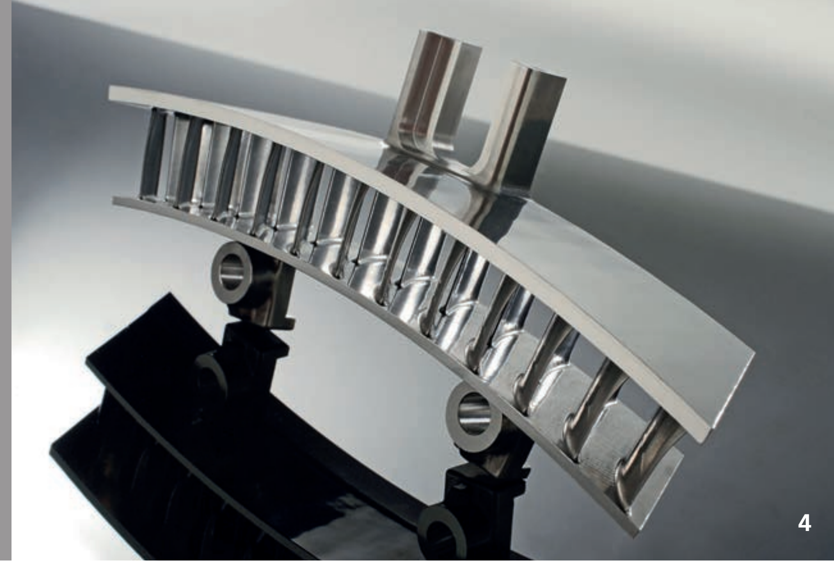
CONTENTS

Laser micro welding of battery cells for electrical drives.

1

2

3



4

»T(w)oCURE« SUPPORT-FREE IN PHOTO-POLYMER 3D PRINTING

Task

Many additive manufacturing processes have a considerable disadvantage: They need support structures (supports), which the user has to plan in the design, to additionally build in the process and then to laboriously remove from the product. This also applies to processes based on photopolymers.

Method

Together with Rapid Shape GmbH, Fraunhofer ILT has developed a hybrid technology in which a liquid photopolymer is solidified chemically by light and thermally by cold. The material is applied while warm and then irreversibly cured by light. At the same time, the cooled space ensures that the layered thermoset component freezes into a block with the waxy, solidified resin. Because two hardening processes are used, the process, still in the development stage, is called »T(w)oCURE«. After printing, the user has access to the components by heating the block slightly, so that the supporting material flows off (Fig. 1). What remains are the 3D-printed components, which are only briefly cleaned and post-cured.

Results

The novel method not only does not require supports, but also enables the components to be positioned without being connected to a construction platform. Three-dimensional objects can be set up anywhere in the installation space. Because the entire installation space is used more efficiently, significantly more parts can now be produced per 3D print job. Furthermore, this procedure makes it possible to run additive manufacturing continuously, thus constituting an initial step towards additive production of polymer parts.

Applications

The new form of plastic 3D printing has been successfully tested on models for the jewelry industry. Until now, the jewelry manufacturers have been producing models with support structures and then removing them with great effort and smoothing the surface. These last two steps are expensive and unnecessary. Due to the new procedure, they can be dispensed with in the future. In addition to lost molds for casting, current development of new materials is addressing functional polymer parts.

The R&D project underlying this report was commissioned by the Federal Ministry for Economic Affairs and Energy BMWi as part of the »ZIM project« (Central Innovation Program for SMEs) under grant number KF2118111WO4.

Contact

Dipl.-Chem. Holger Leonards
Telephone +49 241 8906-601
holger.leonards@ilt.fraunhofer.de

1 Melt of the frozen phases at room temperature and release of the printed structures.
2 Rings printed with »T(w)oCURE«.

ADDITIVE MANUFACTURING OF A GUIDE VANE CLUSTER BY SLM TO TECHNICAL MATURITY

Task

The additive manufacturing process Selective Laser Melting (SLM) – also known as laser beam melting or Laser Powder Bed Fusion (LPBF) – has great potential, especially for the turbomachinery sector, since the process can manufacture components with nearly any geometrical form. In 2012, together with the project partner MAN Diesel & Turbo SE, Fraunhofer ILT identified a gas turbine guide vane cluster as a component which can be used to test SLM's ability to both increase component functionality and reduce production costs. This resulted in the task of developing and qualifying the component under design and the manufacturing aspects for additive series production.

Method

The development took place along the entire process chain. The central topics of design, SLM process as well as post-processing were continuously adapted and optimized in detail as well as to each other. In the first phase of product development, the focus was on the SLM component complying with the component requirements (mechanical properties, dimensional accuracy and surface quality). In particular, maintaining the required surface roughness and profile tolerances in the flow channel posed a challenge for additive production. Since the blade area has limited accessibility, only tool-bound post-processing was possible. As a flow-based process was chosen to reduce the surface roughness and the additive manufacturing process was well coordinated with the surface treatment, the component requirements could be adhered to overall. In the second phase of product development, the developments were successfully transferred to two production service providers as future series suppliers.

Results

As a result of this long and intensive process, MAN Diesel & Turbo SE has approved the vane cluster for series production with SLM.

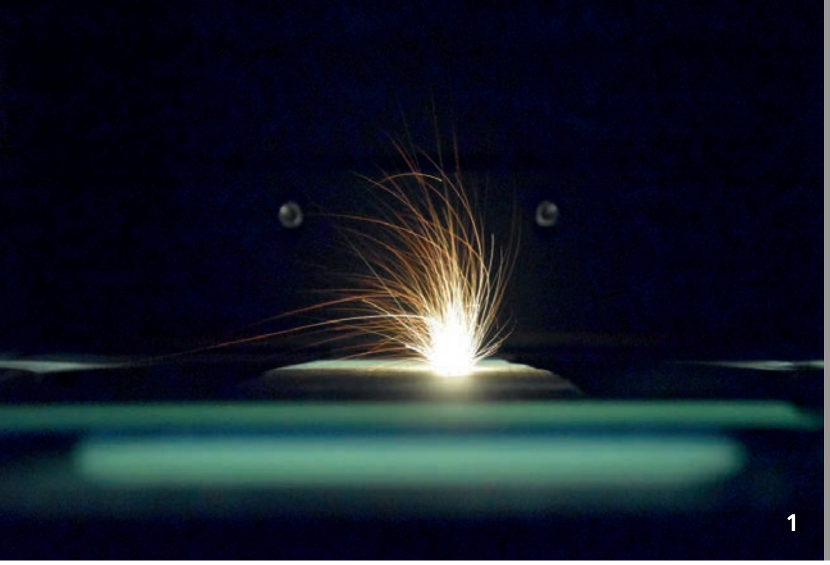
Applications

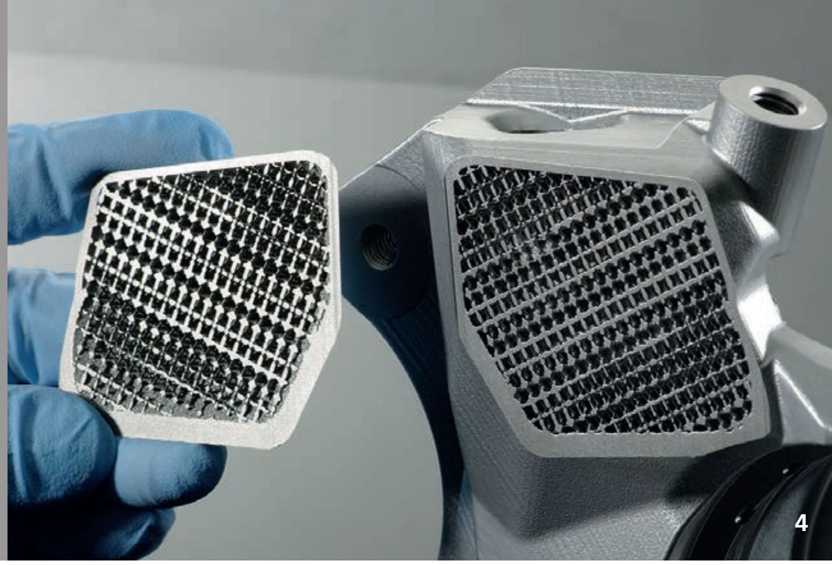
The work described here addresses the production of turbomachinery components with SLM. The methods developed for additive product development can be transferred to other sectors (e.g. the aviation industry).

Contact

Dipl.-Ing. Anders Such
Telephone +49 241 8906-511
anders.such@ilt.fraunhofer.de

3 Additively manufactured MAN logo.
4 Additively manufactured guide vane cluster released for series production.





PROCESSING HIGH CARBON STEELS BY SELECTIVE LASER MELTING (SLM)

Task

The additive manufacturing process Selective Laser Melting (SLM), also known as laser beam melting or Laser Powder Bed Fusion (LPBF), is already being used in many industrial sectors, such as turbomachinery and automotive engineering, for a wide range of applications. In mechanical and plant engineering as well as toolmaking, wear-resistant steel materials with high hardness are often required, but these steels are considered to be only partially weldable, which is why processing with SLM leads to cracking. Rolling bearings, in particular, require a higher material hardness in order to achieve a long service life. The goal of the project »NeuGenWälz« is to develop a material with a higher carbon content (> 1 wt.-%), which fulfills the requirements of high hardness and can be processed by SLM.

Method

The local melting and solidification during the SLM process causes cracks in the material. So that steels with increased carbon content can be processed crack-free, therefore, a suitable process control was tested with and without preheating the working plane.

For this purpose, a material tailored to the requirements of rolling bearings, which have a carbon content of 1.38 wt.-%, was developed with reproducible properties. The focus here is on industrial application, for which processing such material with SLM plants should be made possible. To accomplish this, laser powers of ≤ 400 W and preheating temperatures of ≤ 500 °C were used.

Results

Thanks to suitable process control, SLM with preheating can be now used to produce an alloy with a carbon content of 1.38 wt.-%) without cracks, with a density of more than 99.95% and a hardness of more than 60 HRC.

Applications

The possible fields of application of SLM-manufactured components made of steels with high hardness are mechanical and plant engineering as well as toolmaking.

This project was carried out with the support of the European Regional Development Fund ERDF under grant number EFRE-800665.

Contact

Jasmin Saewe M.Sc.
Telephone +49 241 8906-135
jasmin.saewe@ilt.fraunhofer.de

Dr. Sebastian Bremen
Telephone +49 241 8906-537
sebastian.bremen@ilt.fraunhofer.de

1 Exposure of specimens made of high-carbon steel.
2 Etched cross section of a high-carbon steel component.

TOPOLOGY-OPTIMIZED WHEEL KNUCKLE WITH INTERNAL GRADED LATTICE STRUCTURES

Task

In the face of climate change, reducing fuel consumption and reducing emissions in the automotive sector are imperative. Weight-reduced lightweight components, for example, have great potential for saving natural resources. With the help of Selective Laser Melting (SLM), also known as laser beam melting or Laser Powder Bed Fusion (LPBF), it is now possible to build such lightweight components by exploiting the increased design freedom this process provides. In the context of the research project »ToPoLight«, Fraunhofer ILT developed, manufactured and successfully tested a load-adapted wheel knuckle made of the tempered steel 1.7734 with reduced volume for a prototype racing vehicle.

Method

For the manufacture of the wheel knuckle, the institute has continued to refine the entire process chain, starting with powder development through design adaptation and SLM process development to final processing. Fraunhofer ILT has engineered both a process control for the processing of 1.7734 as well as process-specific design guidelines and manufactured the wheel knuckles.

Results

Thanks to the load-adapted design, the volume of the wheel knuckle could be reduced by about 25 percent compared to the original. By adapting the outer structure and integrating load-adapted graded lattice structures, ILT was also able to increase the rigidity. In addition to installation in the prototype race car, the wheel knuckle has already been successfully tested on the test bench.

Applications

The developed manufacturing chain for structural lightweight construction through topology optimization and the use of load-adapted graded lattice structures can also be adapted to automobile prototype construction and can thus contribute to a reduction in development times.

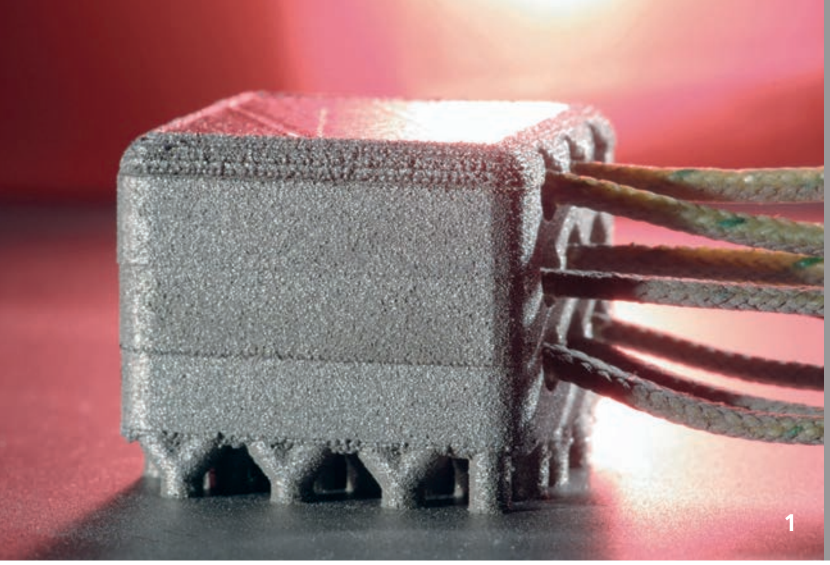
The R&D project underlying this report was carried out on behalf of the Federal Ministry of Education and Research BMBF under grant number 033RK020D.

Contact

Tobias Schmithüsen M.Eng.
Telephone +49 241 8906-568
tobias.schmithuesen@ilt.fraunhofer.de

Dr. Sebastian Bremen
Telephone +49 241 8906-537
sebastian.bremen@ilt.fraunhofer.de

3 Wheel knuckle (cut open) with internally graded grid structure.
4 Detailed view of lattice structure.



SENSOR INTEGRATION BY MEANS OF SLM

Task

Intelligent components that provide data on their production status and condition in the field of application are a central component of current developments in Industry 4.0. Additive manufacturing can be used to break new ground for the production of such »smart parts« with integrated electronics and sensors. The layer-by-layer manufacturing process, for example, allows sensors to be integrated and positively bonded at almost any point in the component's volume during the build process.

Method

Fraunhofer ILT develops process chains for the integration of sensors that measure temperatures and mechanical stresses in metallic components during assembly with the additive manufacturing process Selective Laser Melting (SLM), also known as laser beam melting or Laser Powder Bed Fusion (LPBF). For this purpose, the process is interrupted at a certain height and the sensor placed manually in a prefabricated cavity in the component. The sensor data is transmitted via cable. The cables are routed to the outside through channels located in the component. The sensor is connected metallurgically and positively to the component by the process laser beam source. Subsequently, the construction process is continued, whereby the cavity is closed and the sensor is completely integrated into the component.

1 Additively manufactured demonstrator with integrated thermosensors.

2 Additively manufactured bending beam with integrated pressure sensor.

Results

The developed method enables sensors to be integrated in SLM-built components both in a position-correct and process-reliable manner. This has been successfully tested for temperature and pressure measurements. Especially for temperature measurement, a shorter response time compared to conventionally introduced temperature sensors could be detected. In addition, the fully integrated sensors are better protected against external influences. The knowledge gained here forms the technical basis for the integration of further electronics, e.g. for component identification (RFID chips).

Applications

The combination of additively manufactured components with complex geometries in small numbers and integrated sensors is particularly interesting for the production of prototypes and experimental components, e.g. for tool making as well as for turbomachinery and internal combustion engines. This way, the condition data of the components can be recorded and significantly extended in test bench operation.

The R&D project underlying this report was conducted on behalf of the Federal Ministry of Education and Research (BMBF) under grant number 13N13587.

Contact

Dipl.-Ing. Simon Vervoort
Telephone +49 241 8906-602
simon.vervoort@ilt.fraunhofer.de

Dr. Sebastian Bremen
Telephone +49 241 8906-537
sebastian.bremen@ilt.fraunhofer.de

MEASUREMENT OF ABSORPTION IN THE SLM PROCESS

Task

Selective Laser Melting (SLM), also known as Laser Beam Melting or Laser Powder Bed Fusion (LPBF), is a relatively new technology whose physical sub-processes have not been fully explored and understood. One such sub-process is the absorption of laser radiation during the LPBF process. For it, different process regimes (heat conduction or keyhole regimes) and different material states (absorption of the laser radiation in the substrate, component, in the powder layer and melt) must be considered. This results in different relevant and effective absorptance for the LPBF process, depending on the materials phase.

Method

The core of the experimental set-up is an integrating sphere placed in an industrial LPBF system, which allows experimental measurements of the diffuse and directed reflection for the different material (Ti6Al4V) states as well as for the overall process. Since this method has not been tested for the LPBF process, the measurement accuracy of the system was first examined. The measured values for substrates and powder layers were determined experimentally with the integrating sphere and compared with existing literature values. After the experimental setup was validated, the absorption behavior during the LPBF process was analyzed.

Results

The experimentally determined absorptance for the substrate and the powder layer are consistent with comparable calorimeter-based results from the literature and have a relative error of less than 3.2 percent. The measuring method was then used to determine the absorption of the laser radiation in the liquid phase $A_{liq} \approx 63$ percent as well as for the overall LPBF process. In addition, it was determined that the absorptance correlated with the process regimes Keyhole $A_{Keyhole}$ to ≈ 70 to 80 percent and with heat conduction A_{heat} to ≈ 50 percent. Since the design limits the maximum usable laser power (about 30 to 50 percent of the power commonly used) and the process-relevant inert gas flow, the results cannot be transferred to the LPBF process until confirmed by further investigations.

Applications

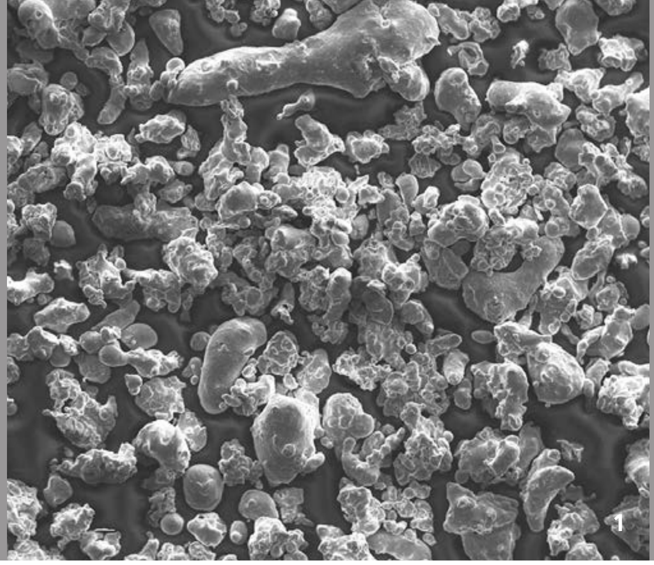
The experiments determined effective absorptance of the various process regimes and material states as well as the overall process, all of which are relevant input variables for simulations of the LPBF process. In addition, these measurements serve to expand the general understanding of the process.

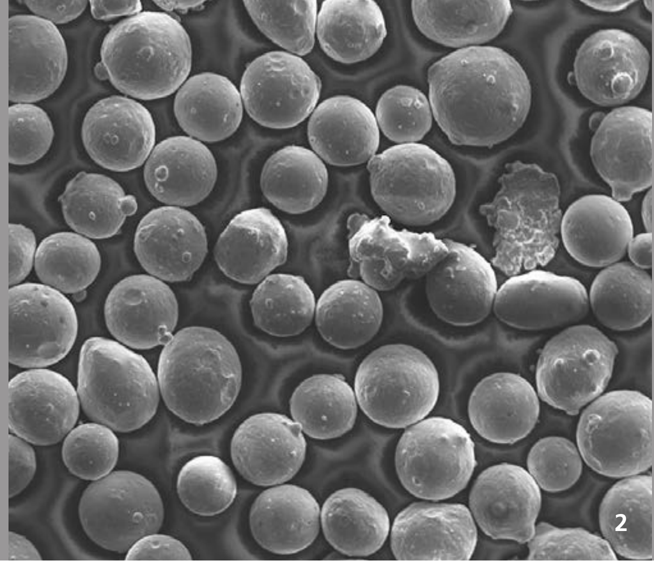
This project was funded by the European Union's »Horizon 2020« Research and Innovation Program (Grant Agreement No. 690725 EMUSIC).

Contact

Jonas Zielinski M.Sc.
Telephone +49 241 8906-8054
jonas.zielinski@ilt.fraunhofer.de

3 Long exposure photograph of the LPBF process.





PROCESSING ALTERNATIVELY MANUFACTURED POWDER MATERIALS WITH SLM

Task

When compared to conventional manufacturing, Selective Laser Melting (SLM), also known as Laser Beam Melting or Laser Powder Bed Fusion (LPBF), still generates high component costs, which constitute an industry-wide hurdle for it to spread further into series applications. Although SLM systems are becoming more and more productive, the cost of powder material, in addition to machine costs, also plays an increasingly important role. Two factors are regarded as cost drivers in powder production: first, production by gas atomization and, second, the relatively narrow specification limits of the powder particle sizes, the latter of which currently only make use of a very small proportion (in part less than 20 percent) of the atomized material in the SLM process.

Method

In this context, Fraunhofer ILT is investigating the extent to which powder particle size can be expanded and more favorable powder production methods used, such as water atomization, using material 1.4404 as an example. For this purpose, it has carried out investigations into characterizing the powders in terms of chemical composition, flowability and particle morphology, as well as analyzes of applicability and the nature of the applied powder layers. Furthermore, the investigations are looking into determining SLM process parameters to achieve relative component densities of at least 99.5 percent.

Results

The institute successfully demonstrated that water-atomized powders of 1.4404 in the particle size range of 0 to 74 µm can be applied and processed within the scope of the investigations. Despite the reduced build rate in the processing of the water-atomized powder with erratic particle morphology, component costs could be reduced by more than 30 percent, demonstrated by a profitability analysis.

Applications

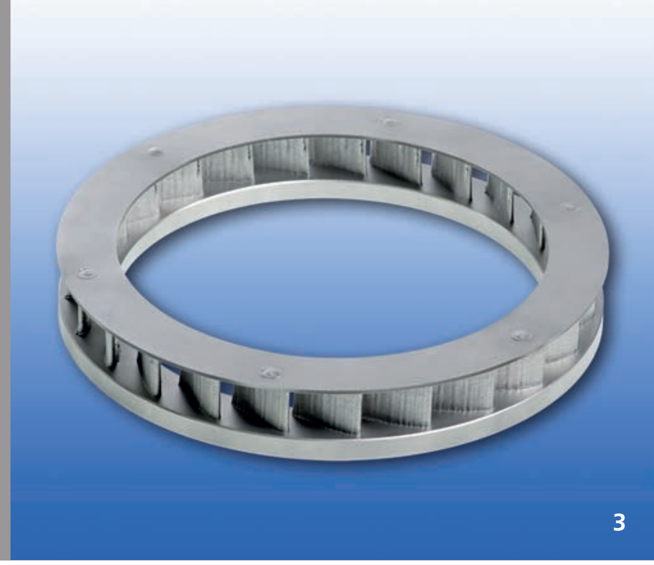
The powders tested here can be used in any SLM plant in many different industries. They are particularly interesting for applications with strict targets in terms of component costs such as in automotive mass production.

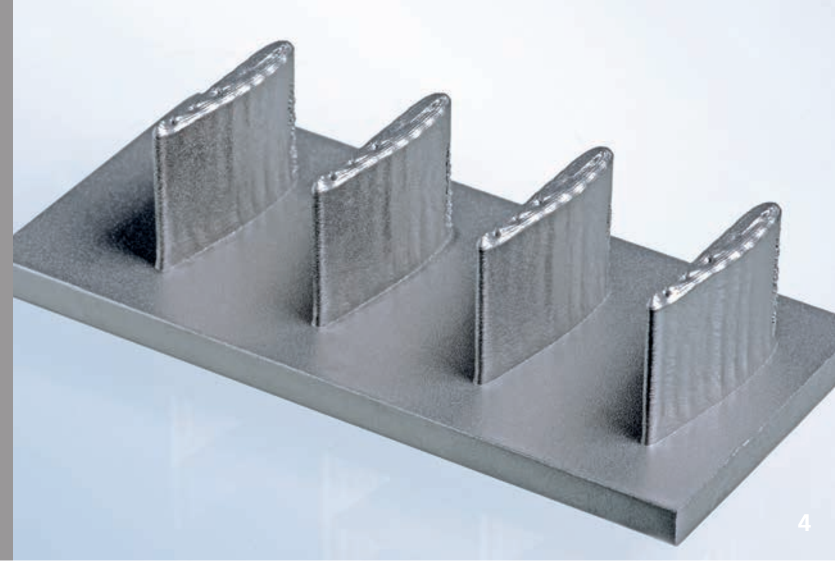
The R&D project underlying this report was conducted on behalf of the Federal Ministry of Education and Research (BMBF) under grant number 13N13710.

Contact

Tobias Pichler M.Sc.
Telephone +49 241 8906-8360
tobias.pichler@ilt.fraunhofer.de

1,2 SEM images of gas (l) and water-atomized (r) powder made of stainless steel 1.4404.





ADDITIVE MANUFACTURE OF A TURBOCHARGER COMPONENT WITH LASER MATERIAL DEPOSITION

Task

As part of the EU project »HyProCell«, Fraunhofer ILT is studying additive manufacturing by laser material deposition (LMD) as a technology in hybrid production cells. The demonstrator component for this project is a turbocharger nozzle ring commonly used in turbochargers for marine diesel engines. Turbocharger nozzle rings are manufactured conventionally in a very wide variety (> 1000 models). The hybrid production cell (machining and LMD-based production) makes it possible to customize numerous variants with one machine. The decisive criterion for industrial application is the economic viability of hybrid production cells, in addition to technological aspects. Both aspects will be examined in the EU project »HyProCell«. For this purpose, Fraunhofer ILT is developing the LMD process for the additive production of the turbocharger nozzle ring. Together with the project partners, the LA process will be transferred to a hybrid production cell and the profitability of this production route evaluated.

Method

The turbocharger nozzle ring is made of a stainless steel alloy. The CAD data provide the starting point for the production of the turbocharger. For the design of the LMD process, a suitable build strategy for the vanes was developed. The CAD data was used to implement near-net-shape path planning for the construction of the vanes using the software »LMDCAM«. The structure of the vanes took place on a prefabricated base ring. After the wings were manufactured with LMD, the upper vane surface was machined, and, subsequently, the upper ring joined to it with a laser.

Results

The turbocharger nozzle ring was manufactured with the elaborated parameters and the developed build strategy and its dimensional accuracy checked. The material allowance of the vane side walls is a maximum of about 800 µm. The LMD process will be transferred to the hybrid production cell, and the cost-effectiveness of the production route will be determined for various post-processing strategies.

Applications

The investigations are primarily focused on applications in turbomachinery. However, the know-how gained can also be used in other sectors, such as in tools and automotive engineering.

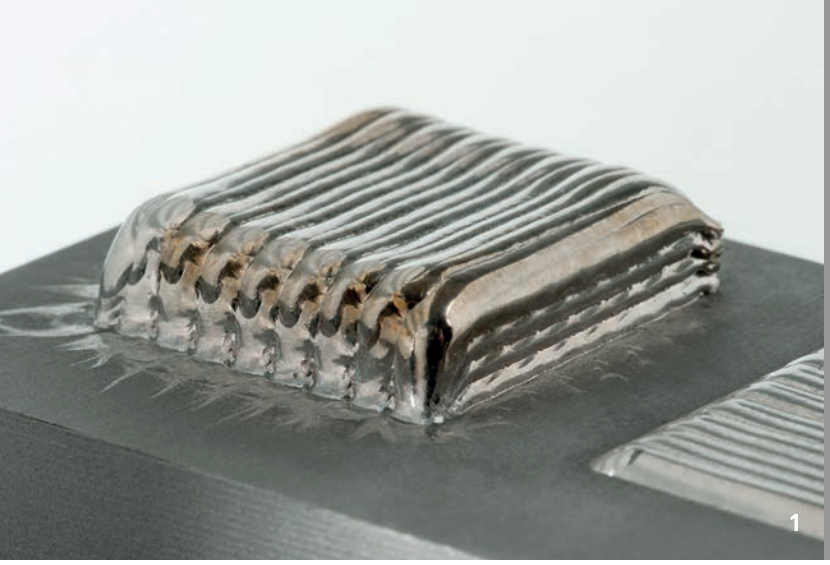
The work presented here was carried out as part of the EU project »HyProCell« under grant number 723538.

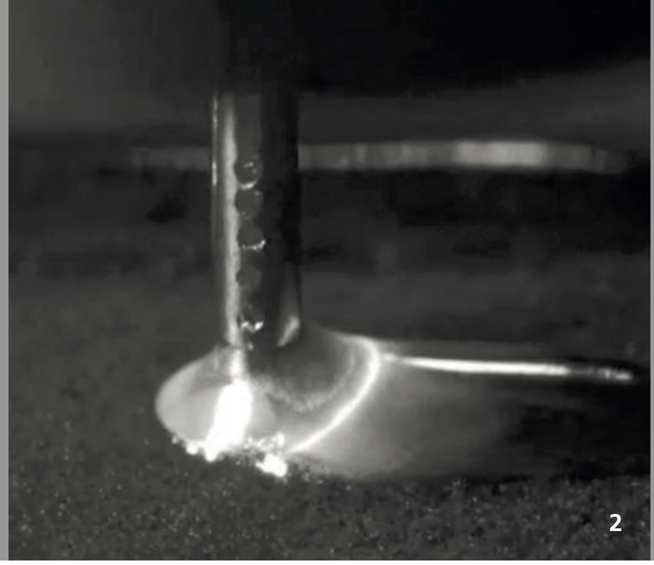
Contact

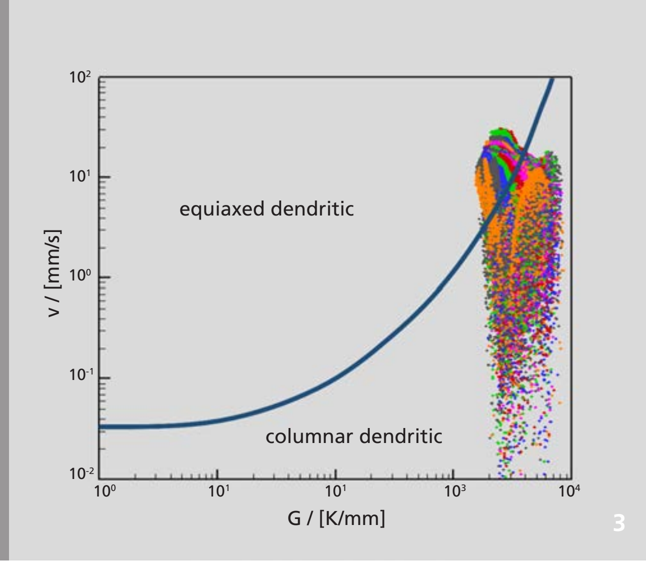
Dipl.-Ing. Moritz Alkhayat
Telephone +49 241 8906-445
moritz.alkhayat@ilt.fraunhofer.de

3 Turbocharger nozzle ring made with LMD, (CAD data: ABB Turbo Systems AG).

2 Single vane geometric forms to evaluate the geometric accuracy, (CAD data: ABB Turbo Systems AG).







LASER MATERIAL DEPOSITION WITH COAXIAL WIRE FEEDING

Task

Fraunhofer ILT has developed a light-weight and compact processing head for laser material deposition (LMD). Weighing five kilograms, the head enables 3D machining independent of direction with coaxial wire feed. This processing head is being used in various projects for the deposition of iron-, aluminum-, nickel- and titanium-based alloys. Within the scope of the International Center for Turbomachinery Manufacturing (ICTM) Aachen, process development has been carried out for the nickel- and titanium-based alloys, IN718 and TiAl6V4, which are relevant in turbomachinery applications. The overall objective is to determine the geometric, mechanical and microstructural as well as macrostructural properties of volume structures produced by wire LMD. In a first step, the required system technology (wire feed systems and coaxial wire head) has been qualified for turbomachinery applications.

Method

First of all, various wire feeding systems have been tested since wire diameters of less than 0.5 mm, required to produce smaller structures, place special demands on the wire feed (conveying speeds below 10 mm/s and conveying and straightening thin wires). For process development, suitable process parameters have been identified, application strategies developed and samples produced and analyzed. By using a high-speed camera (Figure 2), Fraunhofer ILT has monitored the laser material deposition welding process to gather insight into process and wire feeding behavior. Based on these observations, process parameters and wire feeding were improved.

Results

The coaxial wire processing head was used to additively produce various metallographic test specimens (Figure 1). Suitable process parameters could be determined for the materials IN718 and TiAl6V4; the maximum laser power used is 1 kW. A coaxial shielding gas system has made it possible to produce virtually oxide-free volume structures. The metallographic analysis shows extremely low porosity and good metallurgical bonding of the layers.

Applications

The developed processing head can be used for LMD with wire-shaped filler materials for coating, repair applications and additive manufacturing. The system weight and size allow it to be used on systems with low load capacity and/or high dynamics.

Contact

Jana Kelbassa M.Sc.
Telephone +49 241 8906-8331
jana.kelbassa@ilt.fraunhofer.de

Dr. Andres Gasser
Telephone +49 241 8906-209
andres.gasser@ilt.fraunhofer.de

1 Cube form (20 x 20 x 5 mm³) made of TiAl6V4 with wire LMD.

2 High speed image of the wire LMD process with IN718.

LASER MATERIAL DEPOSITION WITH OSCILLATING LASER BEAM

Task

There is a high demand for repair deposition welding for components made of heat-resistant Ni- or Fe-based alloys. Selected high-temperature alloys can be processed with laser material deposition (LMD) at room temperature with a technically crack-free microstructure, but only at very low deposition rates. When the application rates are increased, solidification conditions result in a grain structure over multiple layers with cracks along the grain boundaries. The aim is to develop a process strategy with increased deposition rates, which can prevent this grain structure along the build direction and, thus, the resulting cracks from forming.

Method

In order to achieve a fine-grained structure, the solidification conditions must be adjusted so that equiaxed dendritic growth is preferred. For this purpose, a simulation tool was used to determine the resulting local solidification rates and cooling rates in advance as a function of the process parameters for a laser beam oscillating perpendicular to the direction of travel. The results were entered in a solidification diagram (Figure 3) and the areas identified for a preferably equiaxed dendritic growth. The experiment was implemented with scanner optics, which deflects the laser beam perpendicular to the direction of travel.

Results

The use of scanner optics for LMD leads to an oscillating solidification front with solidification conditions that prevent larger grains from forming in the build direction due to preferably equiaxed dendritic solidification (Figure 4). With the process developed here, significantly higher deposition rates can be reached with the same quality of deposition compared to the state of the art.

Applications

This method is suitable for all applications in which high-temperature materials susceptible to cracking must be processed with LMD, such as those in turbomachinery.

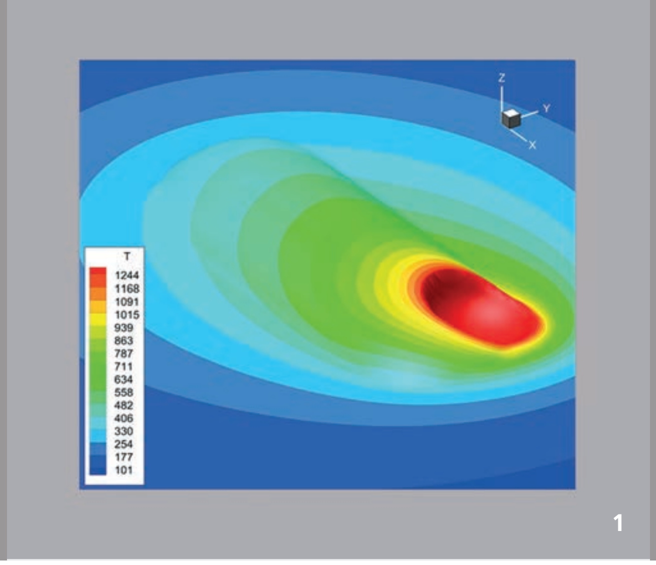
Contact

Dipl.-Ing. Stefanie Linnenbrink
Telephone +49 241 8906-575
stefanie.linnenbrink@ilt.fraunhofer.de

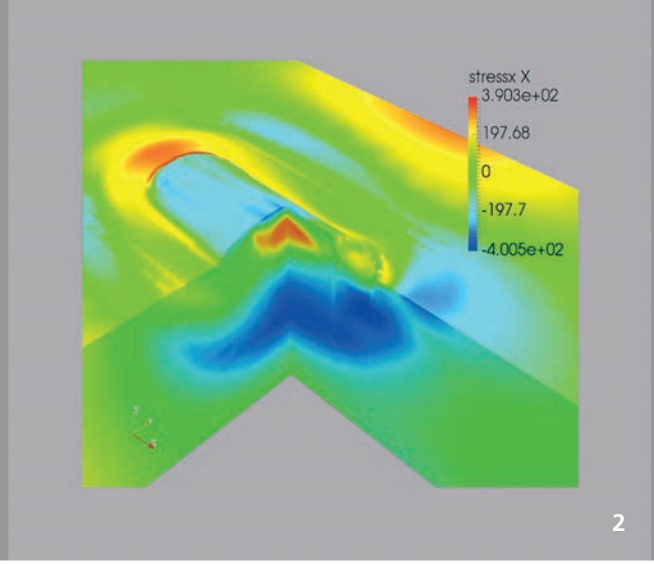
Dr. Andres Gasser
Telephone +49 241 8906-209
andres.gasser@ilt.fraunhofer.de

3 Calculated solidification and cooling rates on the solidification front at different points in time, as well as the resulting micro structure.

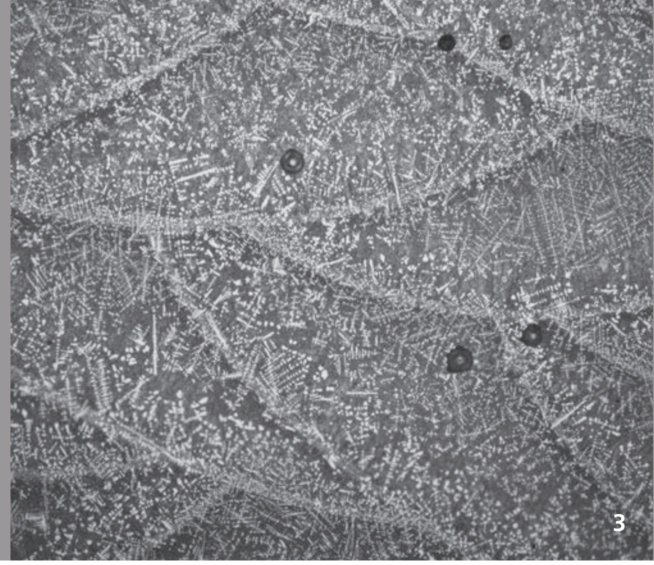
4 Cross-section of a 3D structure with an oscillating laser beam and out of a nickel-based alloy susceptible to cracking.



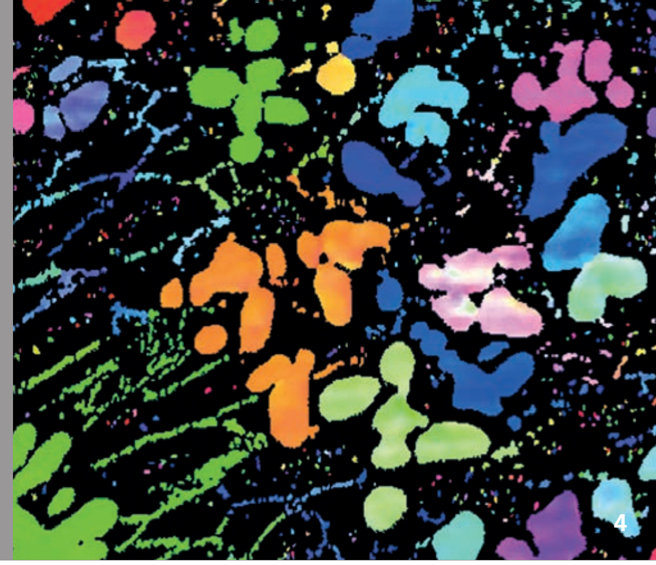
1



2



3



4

DISTORTION AND INTERNAL TENSION DURING LASER MATERIAL DEPOSITION

Task

For laser material depositon (LMD), a simulation tool was created with which the user can simulate the process for specific tasks, different process strategies and parameter settings. Adapted process control is intended to reduce stresses and distortion and thus to expand the process limits for LMD.

Method

Mathematically, LMD represents a free boundary value problem whose solution is based on integrating the transient heat conduction equation and the pressure balance equation, while taking into account a mass balance or the powder particles absorbed in the melt per unit time. The simulation is carried out with the finite element method (FEM) on moving network points in order to realize contour-matched networking. For structural mechanics, the melt is extracted from the model at each time increment, so that the stresses are calculated only in the solid phase. The solvent for structural mechanics is massively parallelized and distinguishes itself in large systems of equations by requiring little memory and having high computing speed.

Results

The simulation tool was applied to powder bed-based laser melting and powder-based LMD. Calculated trace geometries (Figure 1) during LMD could be validated by comparison with experiments. The temporally and spatially resolved development of the residual stresses was analyzed for single tracks, overlapping tracks and multilayers for different process strategies (Fig. 2).

Applications

The developed simulation tool can be used to calculate process temperatures and distortion in LMD and Selective Laser Melting (SLM), also known as laser beam melting or Laser Powder Bed Fusion (LPBF). An application is currently being planned for other machining processes such as welding or drilling.

Contact

Dr. Norbert Pirch
Telephone +49 241 8906-636
norbert.pirch@ilt.fraunhofer.de

Dr. Markus Nießen
Telephone +49 241 8906-8059
markus.niessen@ilt.fraunhofer.de

1 Track geometries and temperature distribution during LMD.
2 Stress distribution during LMD.

LASER MATERIAL DEPOSITION OF MO-SI-B ALLOYS FOR HIGH-TEMPERATURE APPLICATIONS

Task

By forming intermetallic phases, molybdenum-silicon-boron alloys combine high resistance to thermocyclic stress with great high-temperature strength and oxidation resistance. Therefore, they are interesting materials for increasing the operating temperature of turbines up to 1300 °C (with nickel basis, the maximum is 1100 °C). Processing Mo-Si-B alloys, however, is extremely demanding because of its very high melting temperatures of over 2000 °C and the complex solidification behavior; moreover, to date, it has only been possible in a multi-stage powder metallurgy process. An alternative production route does not yet exist. Laser material deposition (LMD), as an additive manufacturing process, has already been successfully tested for the consolidation of complex intermetallic materials, e.g. Fe-Al or TiAl. The great brittleness of Mo-Si-B poses a particular challenge in the development of this alloy.

Method

As part of »LextrA« (03XP0094), a project for the Federal Ministry of Education and Research (BMBF), the powder- and laser-based additive manufacturing processes laser material deposition (LMD) and selective laser melting (SLM), also known as laser beam melting or Laser Powder Bed Fusion (LPBF), have been in development since the beginning of 2017. Together with partners from the industry (Nanoval, KEG, Siemens) and research (IFKorr, OvGU), Fraunhofer ILT has been using these processes to develop Mo-Si-B alloys. Fraunhofer ILT is developing the process control of LMD to produce crack-free, dense 3D structures. For this purpose, suitable process parameters were determined in the first step. In the following, the partners will adapt deposition strategies for the production of test specimens and demonstrators.

Results

For the first time, a near-eutectic Mo-Si-B alloy could be processed with the additive manufacturing process LMD and generated crack-free test specimens (10 × 1 × 5 mm³) at preheating temperatures of min. 900 °C. The microstructure consists of a primary solidified Mo-mixed crystal phase (MoSS), secondary Mo_3Si-Mo_5SiB_2 eutectic, and MoSS-Mo_3Si-Mo_5SiB_2 ternary regions. Ongoing investigations shall determinate the alloy's mechanical properties.

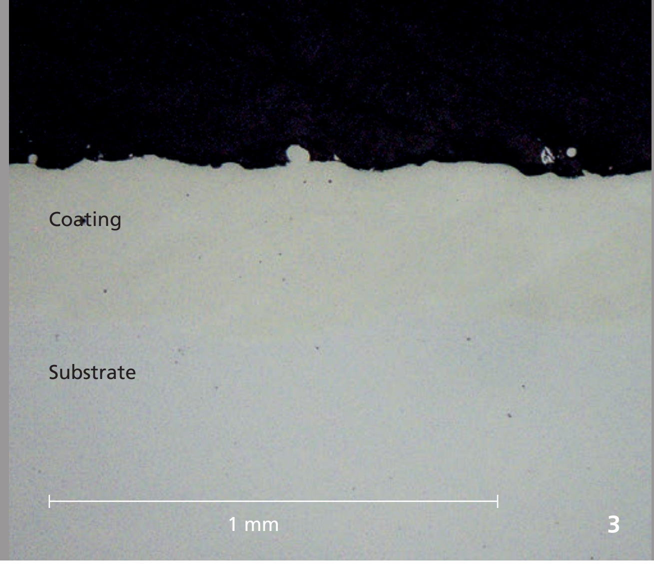
Applications

The focus is on the development of additive processing technologies of the molybdenum silicide alloy group. Future applications can be found in aerospace as well as in power generation.

Contact

Silja-Katharina Rittinghaus M.Sc.
Telephone +49 241 8906-8138
siljakatharina.rittinghaus@ilt.fraunhofer.de

3 Mo-Si-B microstructure after laser material deposition.
4 Electron backscatter diffraction (EBSD) orientation overview of Mo, IPF (source: Dr. Egbert Wessel, Research Center Jülich on behalf of OVGU Magdeburg).



HIGH-ENTROPY MATERIALS FOR THE ADDITIVE MANUFACTURING OF MOLDING TOOLS

Task

High-entropy alloys are a new alloy class that combines high heat resistance with good ductility. They are, therefore, particularly suitable for components that have to withstand, both mechanically and thermally, substantial loads. For example, press hardening tools are subject to these stresses and also require the integration of complex channel structures to effectively cool the tool. Within a collaborative research project, Fraunhofer ILT has developed a high-entropy alloy that can be processed using Selective Laser Melting (SLM), also known as laser-beam melting or Laser Powder Bed Fusion (LPBF).

Method

On the basis of the AlxCoCrFeNi alloy system, promising alloy compositions were first identified. The process used was laser material deposition (LMD), which, in contrast to SLM, enables a rapid screening of many alloy compositions with small amounts of powder mixtures. First, the aluminum content was adjusted to produce a bimodal microstructure representing the best possible compromise between high strength and sufficient ductility. Through further additives as well as adaptation of the process control, the thermal stability of the microstructure was improved by grain refining and increasing the strength.

Results

LMD was used with an Al0.7CoCrFeNi alloy and, through adaptation of the process control, extremely fine-grained microstructures were produced which reach a substantial hardness through alloying additives: up to 800 HV0.1. However, the microstructures produced still have a high crack sensitivity, which makes it necessary to use preheating in the process.

Applications

The process can be applied in additive manufacturing where, in particular, the highest demands are placed on design and material properties. In addition to tool making, applications can be found in turbomachinery and the aerospace sector.

This project is being carried out for the state of North Rhine-Westphalia through the use of funds from the »ERDF Regional Operational Programme 2014-2020« under grant number EFRE-0800627.

Contact

Markus Benjamin Wilms M.Sc.
Telephone +49 241 8906-567
markus.benjamin.wilms@ilt.fraunhofer.de

Dr. Andreas Weisheit
Telephone +49 241 8906-403
andreas.weisheit@ilt.fraunhofer.de

1 Solid body made out of Al0.7CrCoFeNi with LMD.

2 Nanoscale microstructure of a specimen made with LMD (source: ACCESS e.V.).

EXTREME HIGH-SPEED LASER MATERIAL DEPOSITION FOR MASS PRODUCTION IN THE OIL AND GAS INDUSTRY

Task

Components in the oil and gas industry are used under extreme conditions, which cause high wear and corrosion. The use of wear- and/or corrosion-resistant coatings can improve the service life of these components, thereby reducing the risk of time-consuming and costly production downtime. Typically needed for quantities of more than 100,000 per year, the coating processes used must be fast, robust and resource-efficient.

Method

In cooperation with Tenaris S.A., an international company in the oil and gas industry, Fraunhofer ILT developed a tailor-made process for the production of wear-resistant coatings by means of extreme high-speed laser material deposition (German acronym: EHLA). EHLA is a novel variant of laser material deposition (LMD), which is widely used for repair applications and for the production of wear protection layers with layer thicknesses in the millimeter range. With a process speed 10 to 100 times faster than LMD, EHLA can produce thin layers with layer thicknesses in the range of 25 to 350 µm. Compared to other coating processes, EHLA does not use chemicals nor does it require complex surface preparation. In addition, the EHLA process is resource-efficient: Approx. 80 to 90 percent of the additive metal powder applied is used to form the coating.

Results

Different coatings were produced at Fraunhofer ILT and tested by Tenaris S.A. The coatings produced are dense, crack-free and metallurgically bonded to the substrate; furthermore, they can withstand the high stresses found in the industry. At the same time, the process is economical so that the aforementioned quantities can be readily made for mass production.

Applications

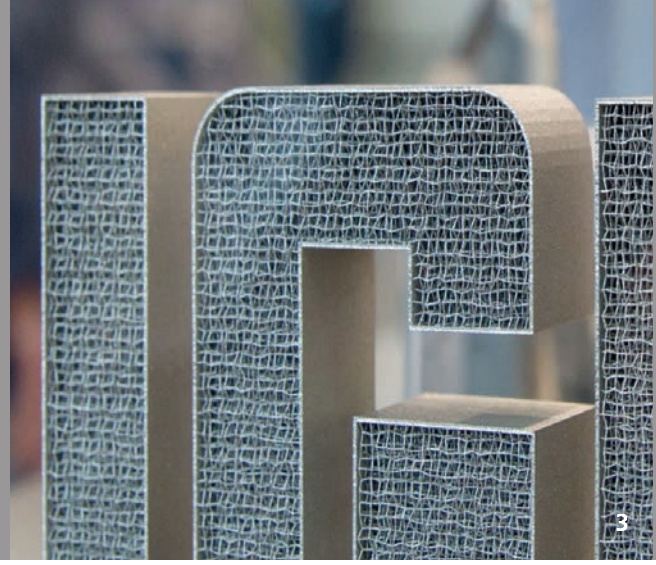
To develop tailor-made EHLA processes, Fraunhofer ILT has several EHLA systems for component lengths of up to 1.5 m and revolutions of up to 2,000 rpm. In close cooperation with various laser beam source and machine tool manufacturers, Fraunhofer ILT offers support in the form of consulting, commissioning and on-site training in setting up production processes.

Contact

Dipl.-Ing. Thomas Schopphoven
Telephone +49 241 8906-8107
thomas.schopphoven@ilt.fraunhofer.de

3 Cross-section of an approx. 350 µm thick wear protection layer.

4 Photograph of the EHLA process.



ADDITIVE PRODUCTION BY LASER MATERIAL DEPOSITION WITH HIGH DEPOSITION RATES

Task

Since many components made out of Inconel® 718 (IN718) in the aerospace industry are manufactured in small batch sizes or must have large amount of material ablated, there is a great need to manufacture these components additively. One of the disadvantages of the powder bed-based additive process, however, is its comparatively low productivity since the deposition rate is still very low. Typical deposition rates in laser material deposition (LMD) of IN718 are currently less than 0.5 kg/h. In order to increase the productivity of the process, Fraunhofer ILT is conducting investigations to increase the deposition rate by using higher laser power.

Method

Initially, the institute carried out fundamental investigations on the LMD process with higher laser powers (up to 4 kW). In order to set variable track widths, it used a zoom lens. For the powder feed, a coaxial powder nozzle was modified in such a way that high powder mass flows (up to 3 kg/h) can be processed and the powder nozzle can withstand the high laser powers. So that large components can be protected from oxidation during production, a precise adjustment of the process conditions is required. For this purpose, a local inert gas shielding was developed and built.

Results

The developed process can reach deposition rates of up to 2 kg/h. The mechanical properties (tensile strength, yield strength and elongation) of the deposited specimen meet the relative requirements of AMS5596. Various demonstrator models were produced with adapted system technology and the developed process parameters. Demonstrator 1 is a real aerospace component (engine mount) manufactured at an application rate of 0.6 kg/h and 85 percent powder efficiency. The demonstrator component 2 was produced with a deposition rate of about 1.2 kg/h at a powder efficiency of about 60 percent.

Applications

Potential for the additive manufacturing can be found in all components that have a high volume to be machined, e.g. components from the aerospace industry or turbine parts made of high-performance materials for energy production.

The work presented here was carried out within the EU project »AMAZE« under grant number 313781.

Contact

Dr. Chongliang Zhong
Telephone +49 241 8906-8053
chongliang.zhong@ilt.fraunhofer.de

Dipl.-Ing Jochen Kittel
Telephone +49 241 8906-136
jochen.kittel@ilt.fraunhofer.de

1 LMD demonstrator 1: Pylon bracket segment (496 x 65 x 60 mm³).

2 LMD demonstrator 2: Cylinder geometry with flanges (150 x 150 x 185 mm³).

»AMable« – SERVICES IN THE DIGITAL DATA SPACE FOR ADDITIVE MANUFACTURING

Task

Companies interested in additive manufacturing (AM) face a great number of challenges when they use AM processes. For example, already when the first ideas are formulated, confidentiality needs to be safeguarded and when various partners have to discuss the options in order to evaluate the feasibility. Dissolving these potential conflicts requires interdisciplinary expertise and a secure data space.

Method

Fraunhofer ILT has initiated a network of competence centers at the European level, offering interested SMEs and mid-caps a variety of services. Companies can work together with experts to develop a first design for their idea and digitally document it. In the same way, a company can have a simulation performed to clarify the loading capacity of a mechanical solution, for example. The offers in the so-called »Services Arena« range from support for elaborating the idea to examining the finished product, all tailored to a company's needs.

At the data owner's premises, data management is combined in a novel way through implementing an »industrial dataspace« relevant to AM. All quality and safety relevant content is linked into data block shadows with cryptographic certificates of authenticity by the first AM blockchain – this forms the basis for the consistent documentation of design data and manufacturing information. The resulting system of service and data management matches the needs of the AM users in terms of flexibility, variability and individuality.

Results

The team of technology providers and business consultants will make »AMable« a Digital Innovation Hub (DIH), a one stop location for companies that are looking for premium technical expertise and first class business support in additive production and in a secure data and solution space.

Applications

Designed for the diverse challenges of additive manufacturing, the principle of local data storage and linked authenticity certification is suited to a variety of processes in industrial manufacturing.

The work is being carried out as part of the EU project »AMable« under grant number 768775.

Contact

Dipl.-Ing. (FH) B. Eng. (hon) Ulrich Thombansen M.Sc.
Telephone +49 241 8906-320
ulrich.thombansen@ilt.fraunhofer.de

3 Additive manufacturing of filigree structures.

4 Digital data chain for AM data from the idea to the product.

LASER POLISHING OF ADDITIVELY MANUFACTURED PLASTIC COMPONENTS

Task

As demands on individualized products increase, new manufacturing processes, especially additive manufacturing, are conquering the market. For plastics, common additive processes are Selective Laser Sintering (SLS) or Fused Deposition Modeling (FDM). Despite their great potential for individualization, they have the particular disadvantage that the surface roughness after the process is too high for many applications; therefore, surface finishing is often necessary. Current finishing procedures are, for example, vibratory or manual grinding. However, these have deficits such as edge rounding, high costs or incorporation of abrasives in the component. Therefore, Fraunhofer ILT is developing a non-contact, laser-based polishing process for additively manufactured plastic components.

Method

When plastic surfaces are irradiated with laser radiation, the material can be melted close to the surface without affecting the component geometry. In the molten state, cracks and pores on the surface are closed. Furthermore, the roughness of the surface is reduced by acting surface tension forces. The surface then resolidifies in the smoothed state.

Results

Investigations on the materials PA6 and PA12 show that the surface roughness can be significantly reduced and the gloss of the surface increased by laser polishing of SLS components. With PA12, the roughness can be reduced by laser polishing with continuous CO_2 laser radiation, for example by a factor of 10 from the starting roughness (after SLS), i.e. from Sa = 10 µm to Sa = 1 µm. Not only is the roughness reduced, however, but pores on the surface can also be closed to a great extent. Furthermore, other materials can be laser polished, for example, PMMA, PEEK and PC.

Applications

The laser polishing of additively manufactured plastic components can be employed wherever a surface finish is necessary. Examples can be found in medical technology or the automotive industry.

Contact

Karsten Braun M.Sc.
Telephone +49 241 8906-645
karsten.braun@ilt.fraunhofer.de

Dr. Edgar Willenborg
Telephone +49 241 8906-213
edgar.willenborg@ilt.fraunhofer.de

1 Laser-polished, SLS-made plastic component made of PA12 (left) and initial state after the SLS process (right).

LASER-BASED DEBURRING AND POLISHING OF SHEETS AND THIN GLASS

Task

When metallic sheet metal parts as well as glass panes or thin glass are cut or separated, burr- and defect-free edges often cannot be achieved. Due to different requirements with regard to appearance, haptics and strength, the edges must be deburred or rounded in a subsequent process.

Method

The deburring and edge rounding of glass and metals with laser radiation is based on the absorption of the laser radiation in a thin surface layer of the workpiece so that a thin surface layer is melted. In the liquid state, the roughness can flow out due to the surface tension and is smoothed. By a suitable choice of the process parameters, a defined rounding of the edge can also be set.

Results and Applications

When CO_2 laser radiation is used for rounding the edges of glass, the melting process not only rounds off the edge, but also heals micro-cracks and sub-surface damage. Glass panes with thicknesses down to 50 µm can be processed in order to increase their strength. Thanks to contactless processing, which prevents new defects from emerging in the glass edge, processing speeds of up to 100 mm/s have been achieved.

In addition to some cover glass, many other kinds of glass and optical glass, such as fused silica or N-BK7, can be processed, e.g. for deburring blank-molded components.

When metals are polished with laser radiation, the radius of the edge rounding can be adjusted as defined, but, as with the polishing of glass, the roughness can also be reduced and micro-defects removed. For example, laser polishing has increased the fatigue strength of push link chains in CVT transmissions by up to 200 percent, allowing for higher torques or, alternatively, smaller gears. The previous investigations were carried out on sheets with thicknesses from 100 µm up to 1.5 mm. Depending on the material, processing speeds of a few 100 mm/s are possible. The laser-based edge polishing of metals is already being used in the automotive industry.

A part of this project has been financed by the Fraunhofer-Gesellschaft.

Contact

Dipl.-Phys. Judith Kumstel
Telephone +49 241 8906-8026
judith.kumstel@ilt.fraunhofer.de

Christian Weingarten M.Sc
Telephone +49 241 8906-282
christian.weingarten@ilt.fraunhofer.de

2 Partially laser-rounded sheet edges made of stainless steel (sheet thickness 1.5 mm).

3 Initial state (left) and laser-rounded (right) thin glass (glass thickness 100 µm).

ADDITIVE LASER-BASED MANUFACTURE OF THICK-LAYER SENSORS FOR COMPONENT MONITORING

Task

The service life and the function of mechanical components are impaired, in particular, by influences such as super-elevated temperatures or static as well as dynamic overloads. To prevent greater damage to massive structural components, such as wind turbine bearings or turbine blades, Fraunhofer ILT is developing printed and laser-functionalized sensor systems for structural health monitoring (SHM) of solid, metallic components in temperature ranges of up to 500 °C. The project is part of the Fraunhofer joint project »INFUROS« in cooperation with Fraunhofer Institutes IKTS (responsible for material development) and IZM (responsible for electronics development).

Method

The metallic structural components are cleaned in a first step by means of laser pretreatment in order to adapt the surface properties for the subsequent coating process. Furthermore, the mechanical and chemical adhesion properties are improved by surface roughening and by local surface oxidation, respectively. In the next step, the thick-film paste is applied with layer thicknesses of 10 to 40 µm for the production of the first electrical insulation layer. The layer is then selectively post-treated by laser radiation to create an adhesive and electrically insulating layer. Subsequently, the steps of deposition and laser post-treatment of further insulation, conductor, resistor or piezoelectric layers are repeated until the multi-layer sensor structure is completed.

Results

In addition to reducing process times to a few seconds per pass – compared to conventional furnace-based post-treatment processes from several minutes to hours – this new process can now be used to additively produce multilayer-based sensor structures. These include strain gauges on rolling bearings, also on previously non-processable temperature-sensitive steels (hardened, e.g. 100Cr6).

Applications

The additive, inline-capable approach makes it possible to provide massive structural components with thick-film sensors. Areas of application include temperature, strain or body sound sensor monitoring of temperature-sensitive, or high-temperature structural components (e.g. wind turbine bearings or turbine blades).

Contact

Dr. Christian Vedder
Telephone +49 241 8906-378
christian.vedder@ilt.fraunhofer.de

1 Rolling bearing with printed and laser-functional strain gauges in different finishing stages.

2 Additively manufactured piezo body sound sensor under construction.

ADDITIVE MANUFACTURING ELECTRICAL FUNCTIONAL LAYERS ON 2D AND 3D COMPONENTS

Task

As the demand for individualized industrial products grows, manufacturing processes are required to efficiently fulfil individual requirements for a product in terms of production technology. Until now, the electrical supply of individual features within an automobile has been ensured by the manual assembly and integration of cable harnesses. Likewise, structural health monitoring (SHM) of components is made possible through manually applied strain gauges. Lock in and lock out as well as manual production processes constitute a major cost factor for the customization of mass-produced products. Digital printing and laser processes offer great potential for cost-effective acceleration of these processes through inline-compatible, reproducible automation. Furthermore, completely new functions can be integrated into a product.

Method

To integrate such functionality into products, Fraunhofer ILT has developed laser processes that, in combination with digital printing processes (e.g. dispensing, ink or aerosol jetting, etc.), make it possible to apply sensors, actuators and conductors on 2D and 3D components. The substrates used are made from metals, optical materials as well as fiber composites. After laser pretreatment to adapt the surface properties, pastes or inks filled with functional particles are deposited onto the component with digital printing methods and then thermally treated using selectively applied laser radiation, resulting in curing, melting or sintering of the previously deposited functional material.

Results

Thanks to digital printing and laser processes, mass-produced products can be customized with functional electrical layers such as insulators or conductors. Compared to those treated in furnace processes, the layers produced have the same or better electrical properties while placing less thermal impact on the substrate material.

Applications

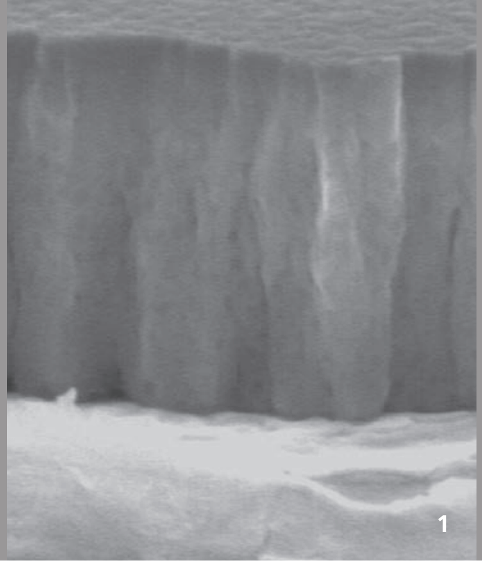
The functional layers produced with digital printing and laser processes can be used in a wide variety of sectors (e.g. automotive, aerospace). Particularly relevant are functional layers for individualized smart products within the scope of the »Internet of Things« as well as »Structural Health Monitoring«. The research presented here is part of the Fraunhofer lighthouse project »Go Beyond 4.0«.

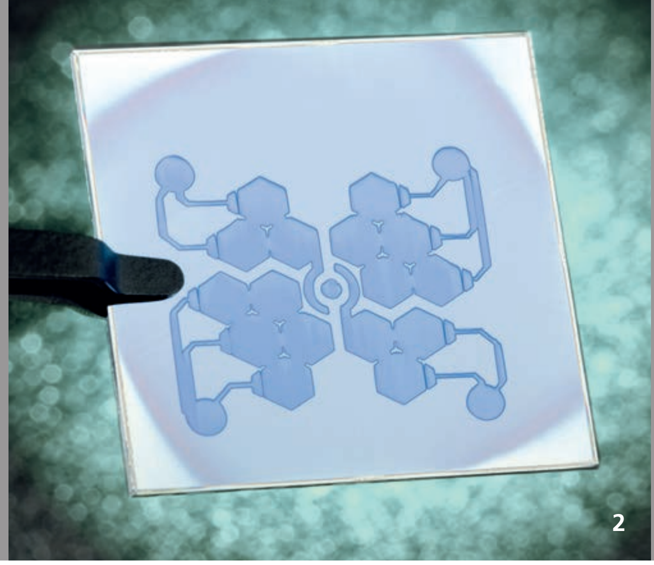
Contact

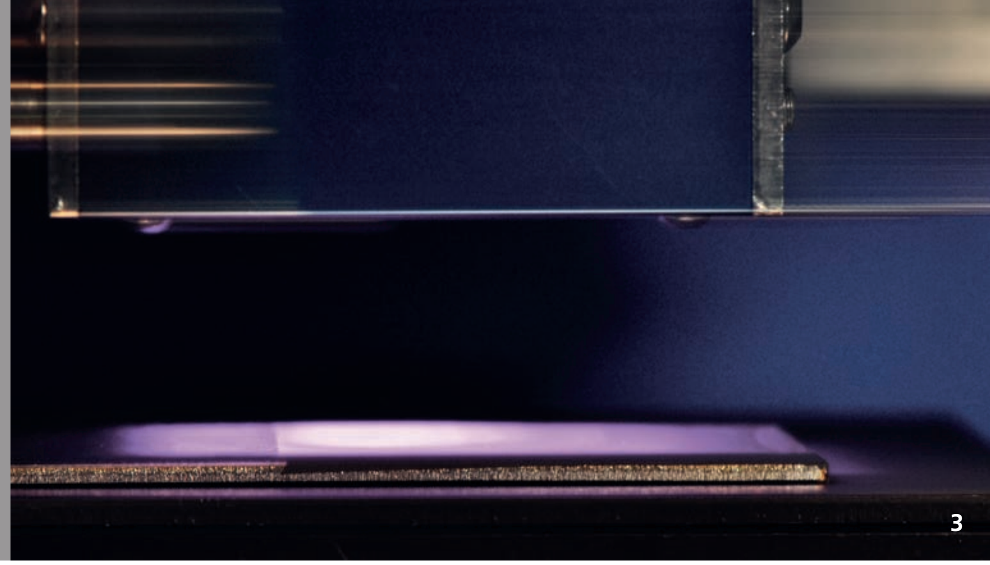
Jonas Mertin M.Sc.
Telephone +49 241 8906-8308
jonas.mertin@ilt.fraunhofer.de

Dr. Christian Vedder
Telephone +49 241 8906-378
christian.vedder@ilt.fraunhofer.de

3 Functional layers on a metal ball produced by means of printing and laser processes.







ADDITIVE, LASER-BASED MANUFACTURE OF PIEZOELECTRIC LAYERS

Task

In the course of miniaturization and the increasing integration of electrical circuits, microelectromechanical systems (MEMS) continue to become more important. Piezoelectric materials are used for microactuators; these materials mechanically deform when an electric field is applied. Sol-gel-based systems out of lead zirconate titanate (PZT) are characterized by their pronounced dielectric and piezoelectric properties with thinly applicable layer thicknesses, but have to be crystallized by means of thermal post-treatment. In contrast to conventional furnace processes, laser processes can heat small volumes for a short period of time in a location-selective manner, thus reducing the thermal impact on the coated substrate.

Method

Sol-gel-based PZT precursor solutions are spin-coated onto specially prepared silicon wafers. Subsequently, in a laser-based process, the organic components are removed (pyrolysis) and the layers crystallized (functionalization). Wet-chemical application and laser post-treatment are performed several times to obtain thicker layers. The process development is supported by simulations of the laser-induced time-temperature sequences.

Results

Laser radiation can be used to crystallize single layers with thicknesses of about 50 nm as well as multiple layers with a total thickness of up to 200 nm. The columnar microstructure can be controlled by adjusting the laser process parameters. The laser-crystallized layers show almost the same ferro- and piezoelectric properties ($2P_r \approx 60$ µC/cm², $d_{33} \approx 100$ pm/V) as those from the furnace process.

Applications

The applications of highly efficient piezoelectric layers range from sensor technology, for example, to measure structure-borne noise, and actuator technology in micropumps and relays, to inkjet printers all the way to use in communications technology.

The R&D project underlying this report is being carried out on behalf of the Federal Ministry of Education and Research BMBF under grant number 03VPP02223.

Contact

Samuel Fink M.Sc.
Telephone +49 241 8906-624
samuel.fink@ilt.fraunhofer.de

Dr. Christian Vedder
Telephone +49 241 8906-378
christian.vedder@ilt.fraunhofer.de

1 SEM image of the fractured edge of a laser-crystallized PZT layer.

2 Laser-crystallized PZT structures on a silicon substrate.

VCSEL-BASED LACQUER CURING IN AN INLINE PROCESS

Task

Increasing demands on wear protection and corrosion resistance, low friction and high hardness often exceed the limits of current state of the art base materials. Hence, thin films are applied onto the base material to ensure reliable and enduring performance. For the thermal post-treatment, which is often necessary after coating, laser-based solutions offer advantages over conventional methods, in particular with regard to local and temporal control of the temperature profile both in the workpiece and in the coating. Thanks to Vertical Cavity Surface Emitting Lasers (VCSEL), it is possible to individually adjust the intensity distributions according to the application.

Method

Currently, Fraunhofer ILT is using a VCSEL module with a maximum output power of 2.2 kW, a beam exit area of 40 x 55 mm² and a total of twelve individually controllable emitter rows to dry and cure thermosetting lacquers on stainless steel substrates. The intensity profile is calculated in advance and the material feed rate adjusted individually so that the lacquer cures as quickly as possible, without damaging the coating or the substrate material.

Results

Application-adapted intensity distributions of VCSEL modules make the hot curing of lacquers and the drying of wet-applied pastes possible in dynamic continuous processes, providing uniform processing quality of the coating; this shows that the process is inline capable. Both the wear coefficient and the hardness of the layers can be improved over conventional methods and the duration of the post-treatment can be reduced by a factor of 100 compared to furnace methods.

Applications

The VCSEL-based functionalization is particularly suitable for thin, large-area applied layers, which are to be dried or cured by the application of heat. Application fields are, among others, wear and corrosion protection, tribology and electronics.

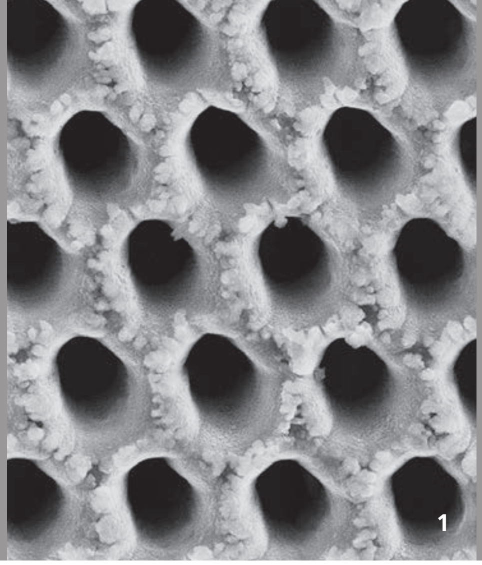
The R&D project underlying this report is being carried out on behalf of the Federal Ministry of Education and Research BMBF under grant number 13N13476.

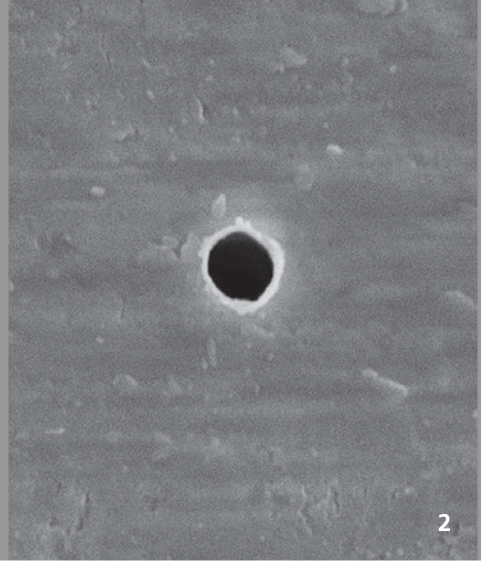
Contact

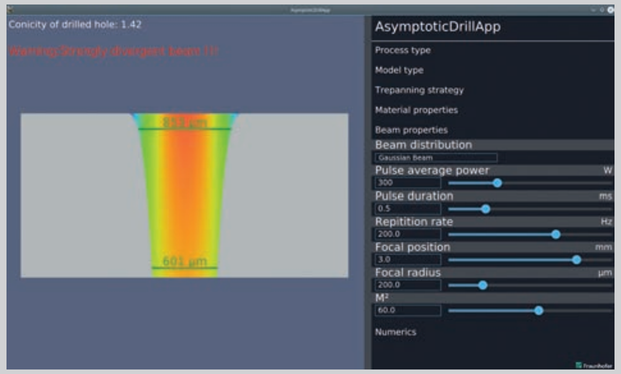
Susanne Wollgarten M.Sc.
Telephone +49 241 8906-372
susanne.wollgarten@ilt.fraunhofer.de

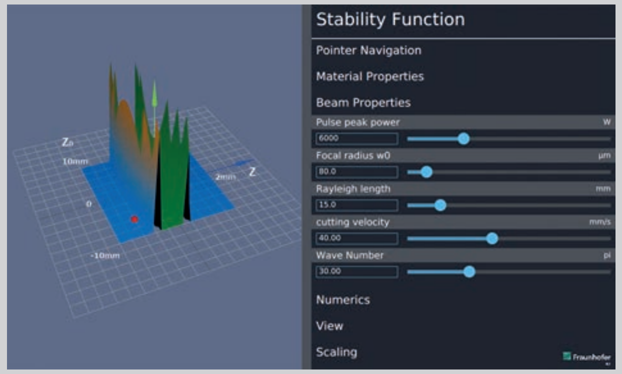
Dr. Jochen Stollenwerk
Telephone +49 241 8906-411
jochen.stollenwerk@ilt.fraunhofer.de

3 Dynamically moved VCSEL module during lacquer curing (side view).









LASER DRILLING OF MICROFILTERS

Task

Mechanically stable surface filters are commonly used to treat wastewater, fuel or for applications in the food and cosmetics industry. These filters are characterized by their low material thickness and large number or density of holes. Yet the industry faces a great technical challenge in producing filters with pore sizes in the single-digit micron range and large open area.

Method

In this context, Fraunhofer ILT is employing a percussion drilling process using ultrashort pulsed (USP) laser radiation. The process uses laser radiation with a wavelength of 532 nm (green) or 355 nm (ultraviolet), which enables precise machining since it has a focus diameter of less than 10 µm. Due to its very short light-matter interaction times, USP laser radiation makes it possible to process material not only with high-precision, but also with negligible thermal influence in the workpiece. Thus, very small holes can be precisely drilled in fields, thus creating a thin webbed structure. At the same time, the high intensity of the ultrashort pulses allows an almost material-independent ablation, which makes it possible to produce tight drill patterns in plastics, metals, ceramics or glass.

Results

The process presented here can be used to generate individual holes as well as hole patterns with customized hole size, geometry and pitch (hole-to-center distance). The open area can be set tailored to a specific application. Due to the reduced heat input into the workpiece, the process can reproducibly drill hole sizes with a diameter of up to 2 µm in the exit and a maximum open area of approx. 20%. The USP laser percussion drilling is almost independent of material and can be used for workpieces with a thickness of up to 500 µm.

Applications

Such a dense hole matrix, consisting of holes with a diameter of less than 10 microns, can be used to produce perforated foils or filters for the separation of particles from liquids or gases. Possible applications are the filtration of food, such as beer filtration, whey separation and juice production, the separation of microplastics or the treatment of wastewater and fuels. Furthermore, emulsions can be produced with such fine-pored filters.

Contact

Dipl.-Ing. Stefan Janssen M.Sc.
Telephone +49 241 8906-8076
stefan.janssen@ilt.fraunhofer.de

Dipl.-Phys. Martin Reininghaus
Telephone +49 241 8906-627
martin.reininghaus@ilt.fraunhofer.de

1 Entry side of a hole grid with sub-10 µm drill holes.

2 Hole exit with a diameter of 2 µm in 50 µm thick titanium foil.

SIMULATION TOOLS FOR THE USAGE IN INDUSTRIAL EVERDAY TASKS

Task

In the face of ever-increasing market demands and the associated increasingly complex processes, process simulations have become an indispensable tool for industrial process design and process optimization. This applies in particular to laser processing methods. Due to excessive calculation times, however, only a small part of the parameter range can usually be examined with currently available simulation tools. For this reason, integration of process simulations into everyday industrial life, such as digital support at the manufacturing level, is not yet in sight. The task in the development of future simulation tools is thus to enable in particular the non-simulation expert easy use and at the same time to ensure a profitable use in everyday industrial life due to low calculation times and resource requirements.

Method

Based on model reduction approaches, the Fraunhofer ILT has developed »fast« process simulations, which allow to study much larger areas of the parameter space on economically reasonable time scales. In order to make the most intuitive use possible, the simulation tools are equipped with a graphical user interface (GUI). The values of individual process parameters can be set using sliders, while the simulation result is displayed online in an adjacent window.

Results

The first applications that have been developed are reduced models for drilling metallic materials with long pulsed laser radiation and for describing the stability properties of the melt film and the associated ripple formation during fusion cutting. The models were implemented in the real-time simulation apps » AsymptoticDRILL« (Figure 1) and »StabCUT« (Figure 2). The apps can be executed on both classic end devices and smart devices such as tablets or smartphones, and are offered as licensed software by the Fraunhofer ILT.

Applications

The methodology of reduced modeling is applicable to all processes. Future fields of application include drilling with ultrashort pulsed laser radiation or additive manufacturing.

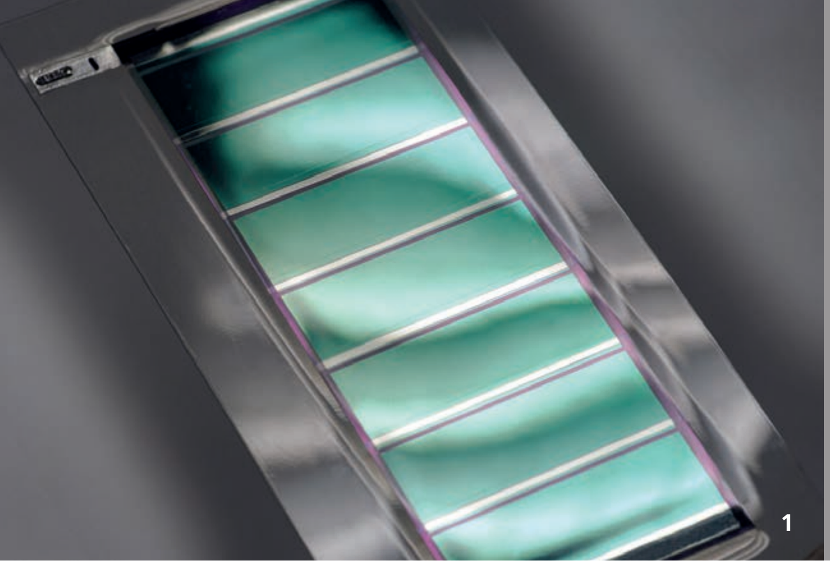
Contact

Dr. Torsten Hermanns
Telephone +49 241 8906-8367
torsten.hermanns@ilt.fraunhofer.de

You Wang M.Sc.
Telephone +49 241 8906-163
you.wang@ilt.fraunhofer.de

3 GUI of AsymptoticDRILL. Slider for parameter adjustment (ri.), simulated hole shape (le.).

2 GUI of StabCUT. Slider for parameter adjustment (ri.), stability of the melt film over the cutting depth and the focal position (le.).



LASER STRUCTURING IN ROLL-TO-ROLL PROCESS

Task

The roll-to-roll production process is ideal for the efficient processing of thin and flexible materials. As a result, cost-efficient products can be manufactured for a wide range of applications, as both inexpensive substrate materials and a highly productive process are used. In particular, products from polymer electronics can be manufactured this way. Since conventional structuring methods such as lithography can only be implemented to a limited extent in a roll-to-roll production chain, laser-based processes are used for the parallelized structuring of surfaces and for the galvanic separation of functional thin layers. The use of ultrashort pulsed laser radiation (USP) makes it possible to process nearly independent of the material as well as to significantly increase spatial resolution.

Method

By combining highly repeating USP laser radiation with tailor-made optical systems for beam shaping and parallelization, Fraunhofer ILT has integrated powerful process components into a roll-to-roll production system. Thanks to adapted ablation strategies as well as temporal and spatial energy modulation, the system can reach high process speeds and selective laser ablation of thin layers on metallic and polymer substrates.

Results

Fraunhofer ILT has developed a system for the continuous, laser-based structuring of semiconducting layers in the field of thin-film photovoltaics. The implemented optical system allows a parallelized, selective material ablation with a continuous feed of the tape material. In addition to sensory monitoring the tape to be processed in conjunction with the use of galvanometer scanners, the system can also process geometrically flexible contours as well as incorporate process monitoring and control. The combination of parallelization and process control enables high-precision material processing at high throughput rates.

Applications

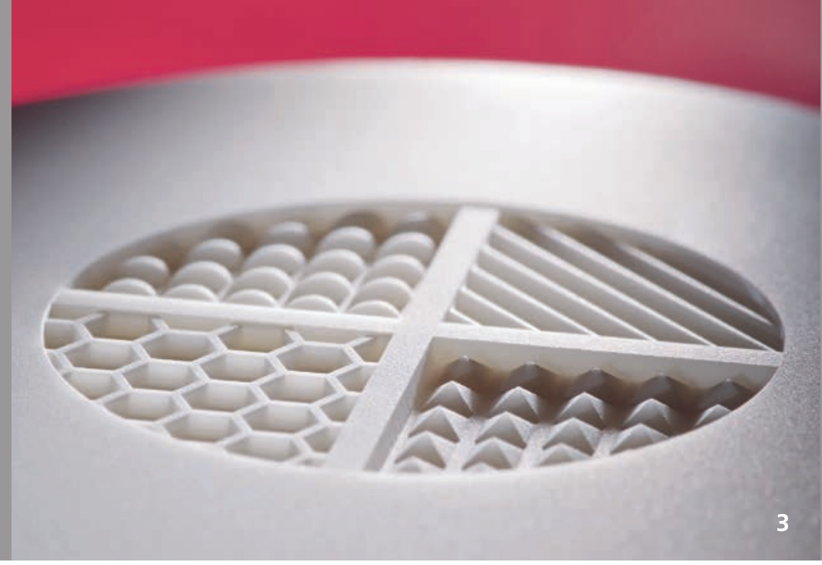
The know-how gained from thin-film photovoltaics can be transferred to the production of flexible OLED displays, solid-state batteries, electronic circuits as well as RFID and sensor applications.

The work is being carried out as part of the »ERDF Program 2014-2020« for North Rhine-Westphalia under funding code EU-1-1-078.

Contact

Dipl.-Ing. Christian Hördemann
Telephone +49 241 8906-8013
christian.hoerdemann@ilt.fraunhofer.de

1 Organic solar cell with laser-structured electrodes.
2 Parallelized inline structuring.



LASER PROCESSING OF HIGH PERFORMANCE CERAMICS

Task

Due to their outstanding thermal, mechanical, electrical and chemical properties, ceramic materials are increasingly being used in areas such as medical technology, bearing and seal construction, turbomachinery construction and high-performance electronics. However, owing to their high hardness and strength in connection with low fracture toughness ceramics are difficult to process with conventional manufacturing processes. Indeed, challenges lie in the short tool life and the generation of unwanted microcracks during machining.

Method

Fraunhofer ILT is investigating the use of short (nanoseconds) and ultrashort (picoseconds) pulsed laser radiation (USP) for the processing of various technical ceramics. The decisive advantage over conventional methods lies in the quasi wear-free tool and contactless processing.

Results

USP laser radiation can be used to process various ceramics such as zirconium oxide, aluminum oxide or silicon carbide without inducing cracks. Moreover, high power USP laser sources can achieve comparatively high volume ablation rates of up to 250 mm³/min. This allows ceramics to be productively and precisely separated, drilled or patterned. In comparison with nanosecond pulses, picosecond pulses not only enable better machining qualities, but also higher ablation rates at the same laser power.

Applications

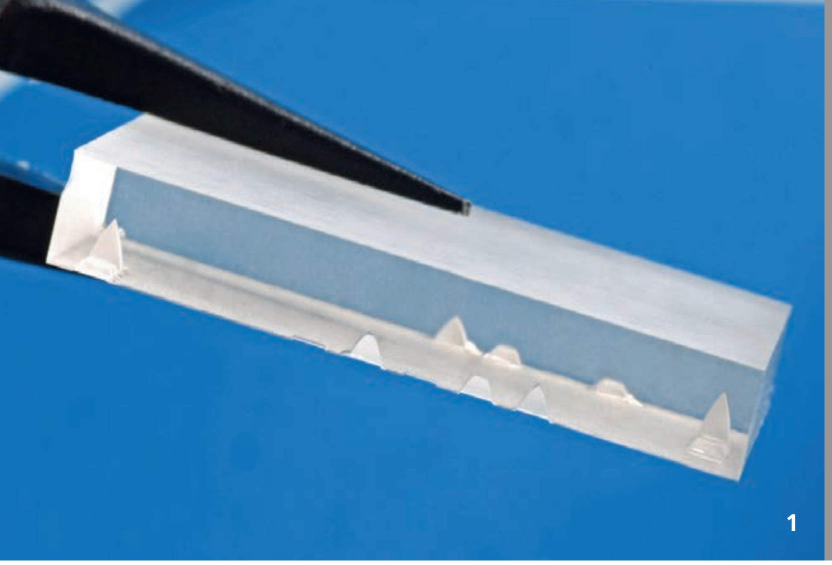
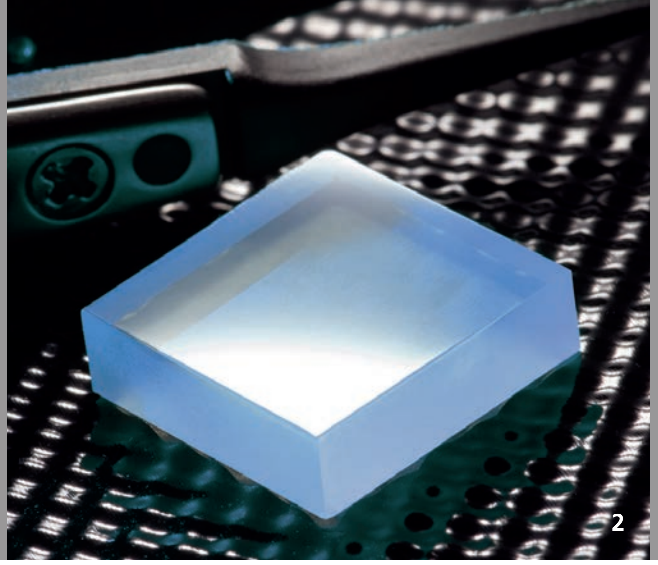
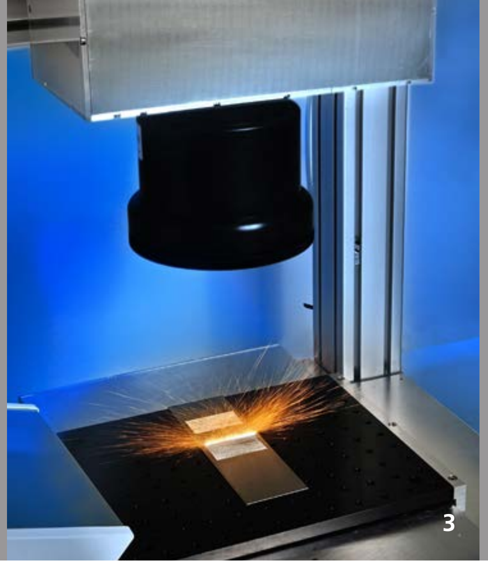
This process can be used, for example, to produce functional surface structures for ceramic sleeve bearings or seals, to insert high-precision through-holes or blind-hole bores for applications in high-performance electronics or to process ceramic cutting tools.

Contact

Dr. Johannes Finger
Telephone +49 241 8906-472
johannes.finger@ilt.fraunhofer.de

Dipl.-Phys. Martin Reininghaus
Telephone +49 241 8906-627
martin.reininghaus@ilt.fraunhofer.de

3 Surface structure on oxide ceramics produced with USP laser radiation.
4 Drilling grid on oxide ceramics produced with USP laser radiation.


PRECISION PROCESSING OF TRANSPARENT CERAMICS WITH ULTRASHORT PULSE RADIATION

Task

Novel processes enable the production of transparent ceramics that transmit light at 85 percent. Thanks to suitable powdered raw materials, it is now possible to produce mechanically high-strength, transparent ceramics with material thicknesses ranging from less than 100 µm up to several millimeters. The unique mechanical, optical and thermal properties of this class of materials require, however, machining and packaging technologies that can process high quality and high productivity materials for specific applications.

Method

Fraunhofer ILT is investigating and developing processes for structuring and separating novel transparent ceramics using ultrashort pulsed laser radiation (USP). Pulse durations shorter than 10 ps make it possible – by selectively focusing the laser radiation – to process surface and volume structures precisely, contact-free, with accuracies of 1 µm and without damaging them. In addition, a suitable system technology is used to adjust the spatial and temporal energy deposition exactly to the absorption properties of the transparent ceramics for a productive separation or processing result.

Results

To develop an effective laser ablation or modification process, Fraunhofer ILT analyzed the absorption of the laser radiation from the transparent ceramics by means of fundamental pump-probe measurements on a time scale in the range of a few picoseconds. The process know-how obtained determines a pulse duration and shape for which the ceramic can be effectively processed with reduced damage in areas on the kerf. By adjusting the pulse duration, focusing conditions and the process strategy, the institute can specifically adapt both size and morphology of the structures produced.

Applications

The processed transparent ceramics can be used as scratch-resistant protective covers that increase the wear resistance of components for switching and display elements in the automotive industry. In addition, thin, flexible, transparent ceramics can be used for flexible electronics in the field of consumer electronics.

The »CeGlaFlex« project is being funded within the framework of the internal Fraunhofer program »MAVO«.

Contact

Christian Kalupka M.Sc.
Telephone +49 241 8906-276
christian.kalupka@ilt.fraunhofer.de

1 Cavities produced by ultrashort pulsed laser ablation.

2 Transparent ceramics.

HIGH-SPEED LASER MICROSTRUCTURING FOR PLASTIC METAL HYBRIDS

Task

The automotive and aviation industry are responding to the challenge of saving weight by using innovative lightweight construction concepts. In multi-material lightweight construction, materials are selected according to local loads and requirements. The cost of producing lighter components, however, should remain as constant as possible with comparable or even improved component properties. To achieve this, the industry needs fast, reliable and cost-effective joining methods for connecting dissimilar materials such as plastic and metal.

Method

Fraunhofer ILT has been researching the laser-based joining of plastics with metals for many years. For this purpose, undercut cavities are produced in the metal by means of laser microstructuring and are filled with plastic melt in the subsequent thermal joining process. To increase the productivity of this process chain, Fraunhofer ILT has developed a polygon-based laser microstructuring scanner system as part of the EU project »ComMUnion«, which enables continuous high-speed process control using high-performance fiber lasers. The generation of cavities with very high process speeds was investigated for various materials.

Results

Through the use of the high-speed scanner, feed rates of up to 0.5 m/min can be achieved during laser microstructuring. This corresponds to a 2.5 fold productivity increase. The feasibility was proven for various metallic materials, such as high-strength steels, titanium and aluminum.

Applications

The system was originally developed to pretreat surfaces in tape laying processes for the automotive industry. However, the undercut structures make it possible to generate high strength joints with a variety of thermal joining methods. Since the process is highly productive, it is particularly suitable to produce continuous joint connections, such as for window frame profiles.

The work was carried out as part of the EU project »ComMUnion« under grant number 680567.

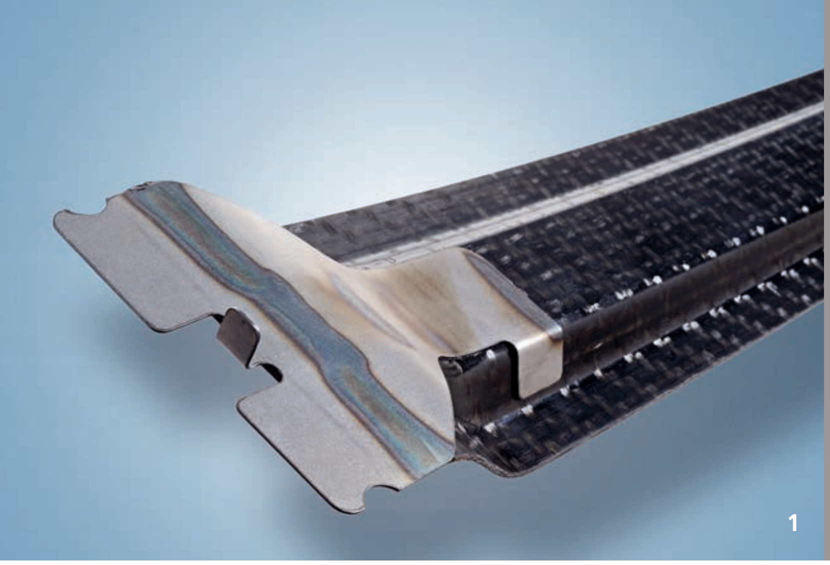
Contact

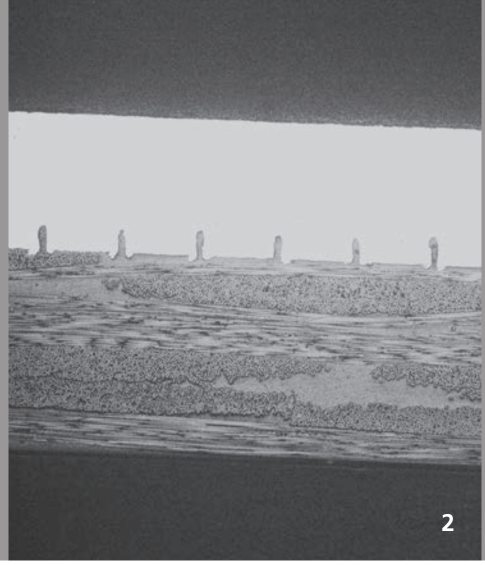
Kira van der Straeten M.Sc.
Telephone +49 241 8906-158
kira.van.der.straeten@ilt.fraunhofer.de

Dipl.-Ing. Oliver Nottrodt
Telephone +49 241 8906-625
oliver.nottrodt@ilt.fraunhofer.de

3 Polygon-based scanner system for laser microstructuring.

4 Continuous high-speed structuring process of a steel profile.





FULLY AUTOMATED PRODUCTION CELL TO MANUFACTURE HYBRID COMPONENTS

Task

Hybrid components play a crucial role in reducing vehicle weight as they allow the potential of all materials used to be fully exploited. Fiber-reinforced thermoplastics (TP-FRP) are particularly suitable for multi-material construction with metal as they provide excellent mechanical properties and good corrosion resistance. For this hybrid compound, however, no suitable joining method is currently available, one which en-sures a high quality connection without additional materials and, at the same time, is sufficiently automated for high volume production. To close this gap, Fraunhofer ILT has developed, among with nine other partners in the European »FlexHyJoin« project, a fully automated production cell for the production of hybrid components.

Method

By means of laser-based surface structuring, a positive connection and, thus, an optimized adhesion for hybrid components can be generated without any additional materials, such as adhesives. The combination of surface pre-treatment with induction and laser joining processes as well as the integration of all components in a fully automated production cell significantly reduce the cycle time.

1 Hybrid roof bow demonstrator.

2 Cross section of a hybrid joint, source: Institute for Composite Materials (IVW).

Results

Fraunhofer ILT has developed an efficient structuring process for the metal components of the roof bow demonstrator with a continuously emitting single-mode fiber laser for the production cell. For the production of the hybrid roof bow (material combination: Tepex® dynalite 102RG600 [PA6-GF] and DC04), all necessary components for the structuring process within the production cell have been constructed and integrated into the entire cell. Due to the curved shape of both of the side connection plates, a z-shifter was integrated into the scanning head. In the cell, the scanning head is positioned over the metal components with a robot, which are then structured linearly.

Applications

By developing a fully automated joining process for the rapid production of hybrid components based on metals and thermoplastic fiber-reinforced composites, the »FlexHyJoin« project has developed a process to manufacture lightweight and rigid hybrid components in short cycle times. Thanks to the project's results, the use of hybrid components in automotive mass production can thus be advanced.

The work was carried out as part of the EU project »FlexHyJoin« under grant number 677625.

Contact

Dipl.-Wirt.Ing. Christoph Engelmann
Telephone +49 241 8906-217
christoph.engelmann@ilt.fraunhofer.de

SEGMENTAL QUASI-SIMULTANEOUS WELDING OF ABSORBER-FREE TRANSPARENT PLASTICS

Task

In the development of high-tech products, such as lab-on-a-chip systems, the laser welding processes used are facing steadily increasing requirements. For example, a homogeneous welding contour has to be generated while having a simultaneously low thermal load of the component, even with complex seam geometries. Furthermore, possible defects in the component should be detected during the welding process and possibly sorted out.

Method

As a technological approach, quasi-simultaneous welding is used with laser radiation, which is characterized, in comparison to contour welding, by a defined energy input in the joining area. The integration of a pyrometer guarantees a spatially resolved recording of the heat distribution. With the pyrometric temperature measurement, the entire seam contour is segmented into individual segments, making it possible to adjust the irradiation order and welding parameters per segment during the welding process. As a result, a heat accumulation and, thus, a possible distortion of the component are prevented in tight-fitting seam contours.

Results

The automatic segmentation of the seam contour has been implemented in an operating software prototype. The advantages of quasi-simultaneous welding could be proven with selected materials, both experimentally and by means of simulative investigations.

Applications

The focus of this process development is, in particular, on components from the field of microfluidics, since a gentle and precise melting of the plastic is required due to the high seam densities. In addition, the general trend towards miniaturization to ever more complex components opens up new application areas in the automotive, electronics and medical technology sectors.

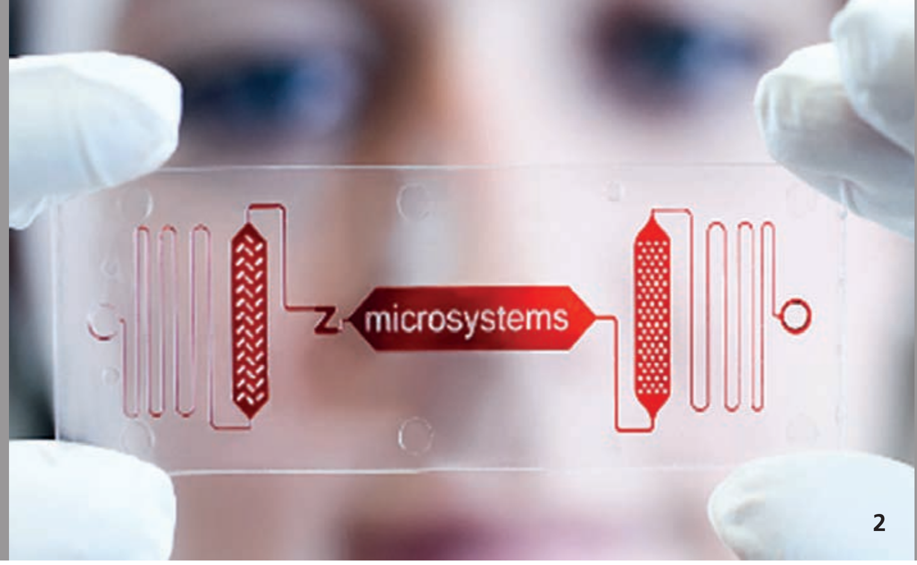
This project was funded by the European Regional Development Fund ERDF and the State of North Rhine-Westphalia.

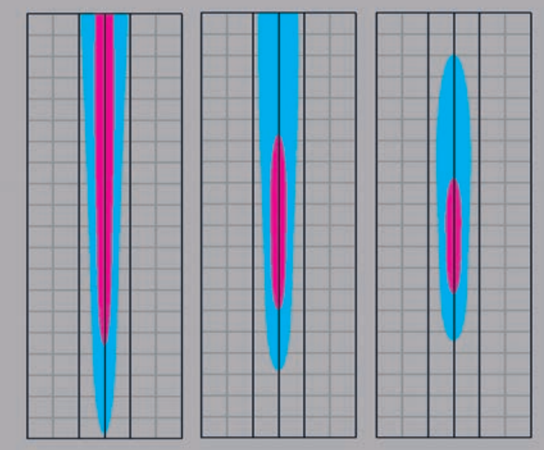
Contact

Phong Nguyen M.Sc. M.Sc.
Telephone +49 241 8906-222
phong.nguyen@ilt.fraunhofer.de

Dr. Alexander Olowinsky
Telephone +49 241 8906-491
alexander.olowinsky@ilt.fraunhofer.de

3 Individual components of a micropump (demonstrator component).





ABSORBER-FREE LASER WELDING OF MICROFLUIDIC COMPONENTS

Task

An essential element of most microfluidic components is the substrate. Special fluidic structures are embedded in it and ensure a defined transport of investigated fluids. After the preparation of the substrate, for example, by injection molding, the fluidic structures are initially open and must be closed with a cover layer (Figure 1). Since the substrates are small and often equipped with temperature- and vibration-sensitive components, only a few joining methods are able to securely connect the cover layer and the substrate without impairing the integrity of individual components. In principle, laser transmission welding is well suited for this joining task, but presupposes previously defined optical properties of the parts to be joined. These properties are adjusted by special absorbers, the use of which is often critical in analytical applications.

Method

A laser source is employed which exploits the intrinsic absorption capacity of the plastics so that laser transmission welding can be used generally or in analytical applications – those that place high demands on the hygiene and transparency of the parts to be joined. The selective deposition of the radiation energy is achieved by a sharp focusing of the radiation.

Results

Using a thulium fiber laser (λ = 1.94 µm), the institute was able to tightly seal the substrate and the cover layer, both made from a cyclic olefin copolymer (Topas®), without needing additives (Figure 2). Due to its high quality ($M^2 < 1.1$), the laser beam can be focused very small, so that parts can be welded – even in the interstices of close-fitting channels – without affecting the channel cross-section.

Applications

The method is particularly suitable for microfluidic applications in the field of analytics. There, the use of additives is critical insofar as they can interact when they contact the fluids tested in the component. In optical measuring methods such as fluorescence measurement, the actual measurement signal may be superimposed on the intrinsic fluorescence of the additives.

Contact

Dipl.-Ing. Viktor Mamuschkin
Telephone +49 241 8906-8198
viktor.mamuschkin@ilt.fraunhofer.de

Dipl.-Wirt.Ing. Christoph Engelmann
Telephone +49 241 8906-217
christoph.engelmann@ilt.fraunhofer.de

1 Components of a microfluidic component before joining.

2 Tightly welded component filled with test fluid, source: z-microsystems.

SIMULATION OF LASER RADIATION WELDING OF ABSORBER-FREE POLYCARBONATE

Task

Components made of transparent polycarbonate (PC) should be welded by laser radiation without the addition of absorber particles. In the process, the laser radiation penetrates both samples and is absorbed over the entire propagation length. The process should be conducted so that the material is melted in the area of the sample contact surface. By contrast, the laser entrance and exit surfaces should not be melted or thermally modified.

Method

For the investigation, laser radiation with a wavelength of 1650 nm was chosen since it lies in the spectral range of the first CH harmonic of the absorption spectrum of PC. Focusing optics adjust the energy density distribution in the workpiece. Fraunhofer ILT investigated the extent to which the divergence angle of the focused laser beam influences the temperature distribution, which occurs during bead on plate welding of a 2 mm thick PC sample. The temperature was determined by thermal simulation.

Results

The simulation was carried out for the following parameters: laser power = 1.1 W, focus diameter = 50 µm and welding speed = 240 mm/min. In Figure 3, the divergence angles 8° (left), 14° (center) and 20° (right) show the 150 and 220 °C isothermal surfaces perpendicular to the welding direction. They correspond to the glass transition or melting temperature of PC. In each case, the laser beam focus was in the middle of the component and the laser entry point in the upper edge. For 8°, the melt volume extends to the laser entrance surface. For 14° the surface temperature remains below 220 °C, and the glass transition temperature is exceeded. If the divergence angle is increased to 20°, the temperature at the laser entrance surface remains below the glass transition temperature. The maximum temperature is the same in all three cases. The simulation results can be used to design the focusing optics so that a beam distribution required for the welding task can be generated.

Applications

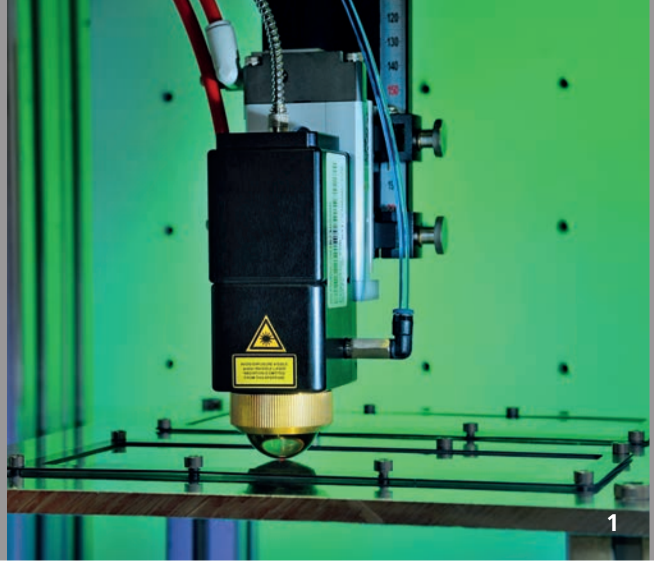
The welding of absorber-free plastics is of particular interest to medical technology since it eliminates the otherwise necessary additives and absorbers.

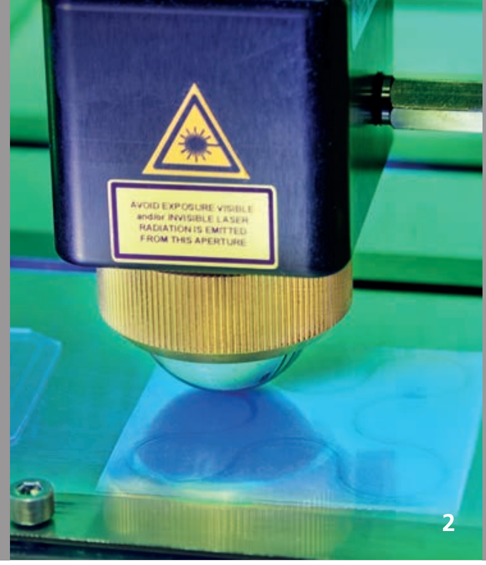
Contact

Dr. Mirko Aden
Telephone +49 241 8906-469
mirko.aden@ilt.fraunhofer.de

Dr. Alexander Olowinsky
Telephone +49 241 8906-491
alexander.olowinsky@ilt.fraunhofer.de

3 150 (cyan) and 220 °C isothermal surfaces (magenta).





GLOBO WELDING OF TRANSPARENT POLYMERS

Task

Transparent polymer films and components can be joined together directly in an overlap arrangement without the material needing to be modified. Required for this, on the one hand, are an adapted laser-beam source that addresses the specific absorption bands of the respective polymer and, on the other, suitable laser-beam shaping. Furthermore, a joining force is absolutely necessary in order to fix the two joining partners to each other and, thus, to achieve the technical zero gap relevant to the process. To apply the joining force, pneumatically operated clamping devices are commonly used; they dispose of a flat glass-based contact pressure that can be transmitted by the laser radiation employed, in the wavelength range of 1.5 to 2 µm, with low losses. Alternatively, instead of glass, metal clamping devices can be used, which press the component arrangement in the outer area, but not in the area of the interaction zone between the laser radiation and the material. Current trends in many industries are moving towards format flexibility and individualization. The pressure systems described above can only meet these challenges to a limited extent or not at all.

Method

In order to satisfy current trends, various alternative clamping concepts have been examined. Emerging from these investigations is a clamping design patented by Leister Technologies AG, in which the laser beam is guided through a rollable glass ball, similar to a ballpoint pen. In this case, the optical ball component is used to guide the beam and apply it. As a result, a high degree of format flexibility is possible because the arrangement via, for example, a robot system can be moved to any position desired. This so-called globo principle was previously applied exclusively in the field of conventional laser plastic welding with absorber modification.

Results

In cooperation with the company Leister Technologies AG, Fraunhofer ILT has adapted and thus transferred the globo welding principle to absorber-free polymer welding. Moreover, the design has been implemented in a prototype optic.

Applications

In particular, this technology has great promise in packaging technology, medical technology but also in OLED, OPV and display encapsulation.

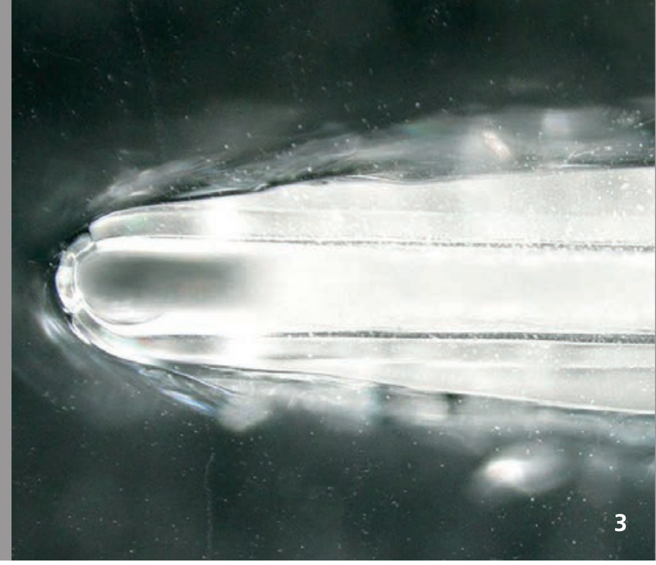
The project is being conducted as part of the »PhotonFlex« project with funding from the European Regional Development Fund ERDF under grant number EFRE-0800066.

Contact

Maximilian Brosda M.Eng.
Telephone +49 241 8906-208
maximilian.brosda@ilt.fraunhofer.de

1 Globo welding optics during the welding process.

2 Welding seam after the process.



CUTTING SODA-LIME GLASS WITH CO LASER RADIATION

Task

Since the eighties, CO_2 lasers emitting at 10.6 µm have been established industrially as high-performance components for material processing among laser beam sources with wavelengths in the mid-infrared range (3 to 50 µm). Above all they are used for cutting and welding aluminum and steel as well as for processing many non-metallic materials, which usually have a high absorption capacity in the infrared range. Apart from the specific gas mixture, CO lasers have a similar structure to CO_2 lasers, but emit at 5.5 µm in the mid-infrared range. Fraunhofer ILT is examining a CO-based laser process on various non-metallic materials, among others, soda-lime glass.

Method

The CO laser investigated here has been combined with a telescope for beam widening, a focusing lens with a focal length of 127 mm and two xy-linear axes to form a processing unit. The jet path is purged with dry air or nitrogen because the absorption of the water vapor contained in ordinary air distorts or expands the laser beam (thermal blooming). The cutting gas nozzle is fed with N_2 and has a diameter of 2 mm; the distance to the workpiece is 2 mm.

Results

Sections were produced from a 1 mm thick flat sample of soda-lime glass at a speed of 10 mm/s, an average CO laser power of 95 W and 0.8 bar N_2 cutting gas pressure. The cut edges are rough, but the glass sample does not show the shell-like cracks typical of CO_2 cutting.

Applications

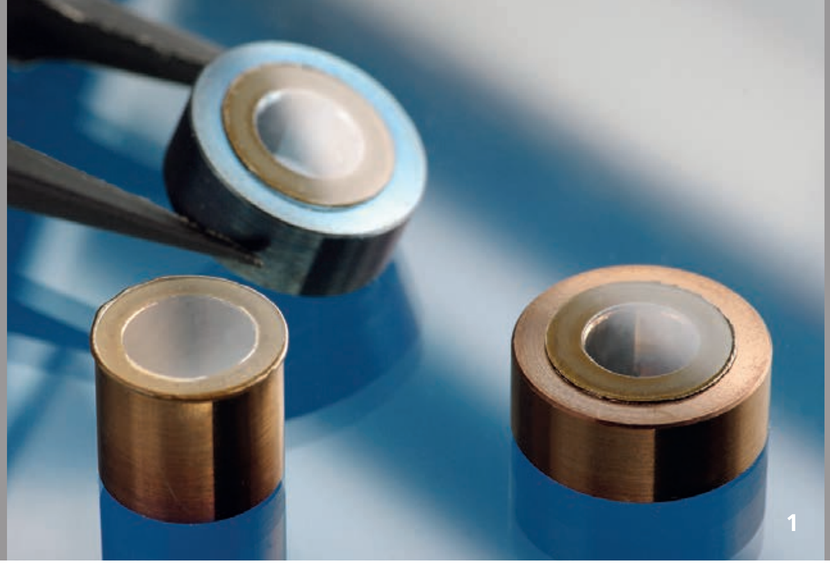
As an alternative to CO_2 laser radiation, CO lasers with a wavelength of 5.5 µm can be used to process many non-metallic materials with similar processing results. Conspicuous differences are found when cutting soda-lime glass: While glass absorbs the CO_2 laser radiation only in a very thin, near-surface layer and cracks as a result of the resulting stresses, the CO radiation is coupled over the entire sample thickness because of the greater optical penetration depth so that a largely crack-free kerf arises. Thus, CO lasers could be applied for the cutting of thin glass sheets.

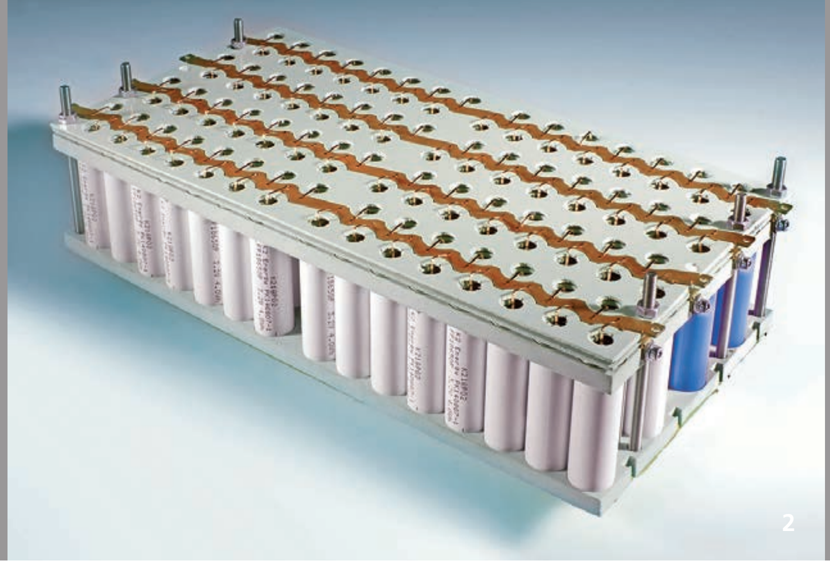
Contact

Dipl.-Phys. Gerhard Otto
Telephone +49 241 8906-165
gerhard.otto@ilt.fraunhofer.de

Dr. Alexander Olowinsky
Telephone +49 241 8906-491
alexander.olowinsky@ilt.fraunhofer.de

3 CO laser cut in 1 mm thick soda-lime glass (top view), v = 10 mm/s, P = 95 W, p = 0.8 bar, nitrogen.





LASER-BASED GLASS FRIT BONDING FOR THE PRODUCTION OF GLASS-METAL BONDS

Task

When bonded together, glass and metal constitute an indispensable combination of materials for different applications. The requirements placed on glass-metal connections range from a simple adhesive bond to a load-bearing, temperature-resistant, vacuum-tight bond between the dissimilar materials. Although adhesive joints can compensate for the stresses resulting from the different coefficients of thermal expansion (CTE), they are not suitable for applications with high service temperatures or tightness requirements. Glass frit-based glass-to-metal joints meet these requirements, provided that the CTEs of glass, metal and glass frit are carefully matched.

Method

So that a strong, hermetically sealed, glass-to-metal bond can be generated with a brittle-hard intermediate glass frit layer, the CTEs of the joining partners must be compatible over a wide temperature range. This boundary condition is fulfilled, among others, by the material combination of borosilicate glass (α = 3.3 ppm/K) and Kovar (α = 5.1 ppm/K). These are connected with glass frit.

The energy required to melt the glass frit is based on absorption of the laser radiation applied. In the quasi-simultaneous soldering process, the laser beam is scanned several times over the joint at a speed of 1000 mm/s and a power of 60 W. After about ten seconds, the frit melts and wets both joining partners. This method was used to produce a load-bearing connection between the glass cover (thickness: 400 µm) and the metal sleeve (diameter: approx. 10 mm).

Results

By means of laser-based glass frit bonding, borosilicate glass covers could be bonded to metal housings made of Kovar, with bonds that are both sealed and able to carry loads. The glass solder can also be used to bond silicon and Kovar with a positive-locking connection.

Applications

Applications for this method can be found, for example, in the optical assembly or the encapsulation of optical sensors.

Contact

Dipl.-Ing. Heidrun Kind
Telephone +49 241 8906-490
heidrun.kind@ilt.fraunhofer.de

Dr. Alexander Olowinsky
Telephone +49 241 8906-491
alexander.olowinsky@ilt.fraunhofer.de

1 Glass-metal connections consisting of a borosilicate glass cover and a Kovar sleeve.

AUTOMATED LASER BONDING OF BATTERY CELLS

Task

For electromobility, individual battery cells are often combined to form powerful energy storage systems. As the demand for corresponding battery modules increases, their production time needs to drop and, consequently, the degree of automation has to rise. Due to their high availability, round cells (type 18650) are frequently used in industry today. To achieve the necessary specifications of a battery module, a large number of cells are interconnected. This requires a joining process with a high level of automation and high process stability.

Method

Laser bonding can constitute a connection technique for the cohesive contacting of battery cells. As part of the research project »RoBE« (Robust Bonds in Electric Vehicles), a corresponding bonding machine was developed and set up. Instead of conventional ultrasonic bonding, metal strips (aluminum or copper) are joined using a laser-beam welding process. The laser bonder combines the high degree of automation of a conventional ribbon bonder with the ability of the laser beam welding process to join copper and aluminum materials. The use of larger sized ribbon geometries compared to ultrasonic bonding enables the provision of necessary conductive cross sections.

Results

The laser bonder with the laser-beam welding process is capable of automatically and reproducibly connecting 18650 type round cells with copper conductors. Only the accessibility from one side is required because the laser bonder is positioned on the negatively polarized bead of the cell.

Applications

In addition to contacting round cells, the developed process and machine technology can be used for other types of cells as well as in power electronics.

The work presented here has been partly funded by the Federal Ministry of Education and Research BMBF within the »RoBE« project. Furthermore, results come from the »evTrailer« project, which has been funded by the Federal Ministry for Economic Affairs and Energy BMWi, in cooperation with the Fraunhofer Institute for Structural Durability and System Reliability LBF.

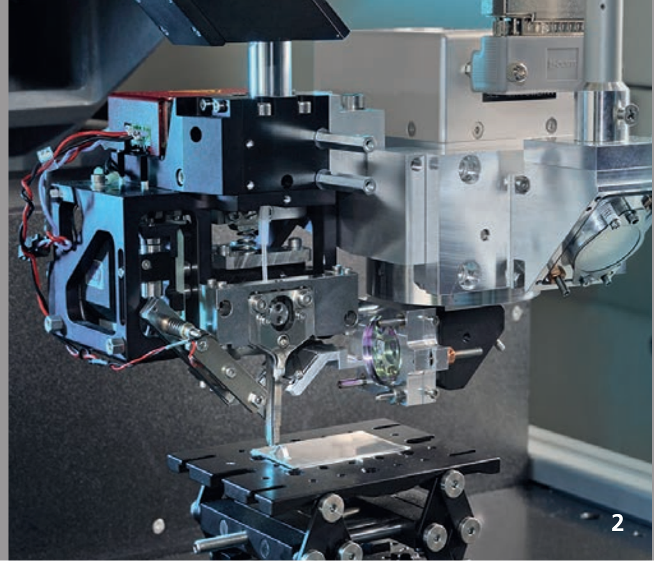
Contact

Sören Hollatz M.Sc.
Telephone +49 241 8906-613
soeren.hollatz@ilt.fraunhofer.de

Dr. Alexander Olowinsky
Telephone +49 241 8906-491
alexander.olowinsky@ilt.fraunhofer.de

2 Laser bonding of positive and negative pole at the top of round cells.

1



2

3

4

WELDING OF FLEXIBLE COPPER CONNECTORS FOR HIGH-CURRENT APPLICATIONS

Task

As automobiles become increasingly electrified, the demand for efficient energy storage systems is growing. So that maximum flexibility of form and performance for the modules and battery packs can be ensured and high currents transmitted safely, a flexible and low-loss interconnection of the energy storage devices is required. As part of the publicly funded project »FlexJoin« (Reliable system and joining technology for flexible production of battery modules), a laser-based bonding and joining process for aluminum and copper arresters with contact cross-sections of ≥ 500 µm in thickness and up to 10 mm in width shall be built and integrated into a machine system.

Method

For secure joining of thick and wide ribbons on battery cells and lead frames, a robust laser joining process was first developed and the required technology integrated into a conventional bonding machine. The wire bonder modified in this way is equipped with a fiber laser, a Z shifter for adjusting the focus position in the vertical direction, a galvanometric scanner for beam deflection in the X-Y plane and a beam guiding and specially developed focusing unit. The system technology allows automatic feeding, positioning and contacting of the flexible connector on the battery or the lead frame.

Results

The described optical elements and systems for process monitoring have been integrated into the system technology. Copper connectors up to 10 mm wide and 500 µm thick can be guided and safely and reproducibly joined to different materials.

Applications

The laser bonder can be used in broad areas of power electronics in high-current applications and battery technology. In particular, it can be used wherever fast and flexible contacting solutions are required.

The R&D project underlying this report was conducted on behalf of the Federal Ministry for Economic Affairs and Energy BMWi under grant number 01MX15010B.

Contact

Johanna Helm M.Sc.
Telephone +49 241 8906-8382
johanna.helm@ilt.fraunhofer.de

Dr. Alexander Olowinsky
Telephone +49 241 8906-491
alexander.olowinsky@ilt.fraunhofer.de

1 Welded copper connector (0.5 x 10 mm²) on 18650 battery cells.
2 Positioning unit of the prototype laser bonder.

PROCESS MONITORING FOR LASER WELDING OF HIGH-CURRENT CONTACTS

Task

Laser welding is increasingly being used to contact battery cells and thus create complete modules or packs, as well as to electrically interconnect components of power electronics, a situation accelerated by advances in electromobility. A critical problem in such applications, however, is when individual connections are faulty, thereby reducing the capacity or peak power of the battery packs. In addition, a continuous documentation of the production chain is required in the automotive sector.

Method

Fraunhofer ILT has developed a process monitoring module for scanner-based laser welding of electrical contacts. In this process, the connector is pressed with a pressing tool at a defined force on the lower joining partner. During the joining process, a galvanometer scanner guides the laser beam to produce the desired weld geometry while a pyrometer and a coaxially integrated camera monitor and record this process. This sensor module checks whether the temperature of the welding process is within the tolerance range and whether dangerous short-circuiting splashes occur during the process. After the process, the weld seam geometry can also be measured with the camera and its shape evaluated.

Results

To demonstrate the scanner-based laser welding process with process monitoring, Fraunhofer ILT has set up a system with relay optics already used industrially in this process for constricted production areas. With the aid of process monitoring, process deviations can be reliably detected and every weld documented. The system was evaluated as part of a demonstration on a robot for a flexible production line.

Applications

The processing head with process monitoring can be used, for example, for micro laser welding processes that connect the contacts of energy storage devices and components of power electronics. The process monitoring included can be used for documenting each weld, which meets the requirement set by the automotive industry of a fully documented processing chain. In principle, the process monitoring module can also be used for other scanner-based laser processes, such as structuring or fine blanking.

Contact

Dipl.-Ing. Oliver Nottrodt
Telephone +49 241 8906-625
oliver.nottrodt@ilt.fraunhofer.de

Dipl.-Ing. Peter Abels
Telephone +49 241 8906-428
peter.abels@ilt.fraunhofer.de

3 Camera image of coaxial process monitoring.
4 View of the processing optics with process monitoring.

LASER IMPULSE METAL BONDING

Task

Conventional integrated circuit packaging faces a particular challenge: raising the working temperature and the increasing conductor cross-section area in the field of power electronics. The novel joining process Laser Impulse Metal Bonding (LIMBO) was developed to connect large-area power connectors with thermally sensitive components (e.g. batteries, circuit boards, ceramic substrates).

Method

The LIMBO process thermally separates the joining partners by means of a gap, through which the high energy input required to melt the connector can be introduced without the lower component being exposed to the high temperatures. In order to produce a cohesive connection between the two joining partners, the molten bath is deflected and the lower joining partner wetted and bonded. Thanks to an evaporation process at the melt surface, temporal focus modulation is used for this deflection.

Results

The LIMBO process can generate a connection – stable at high temperature – within a total process time of less than 100 ms; the connection has an aspect ratio of welding depth to connection cross-section of up to 1:45. The thermal substrate load is kept low by an energy input time in the deflection and connection phase of less than 5 ms.

Applications

These properties make LIMBO a new contacting solution for, among others, circuit boards, ceramic substrates with metallization (e.g. DCBs, DABs) and hybrid components (e.g. MIDs). In addition to joining thermally sensitive substrates, the process can be applied to cohesively join metallic components with high gap tolerances.

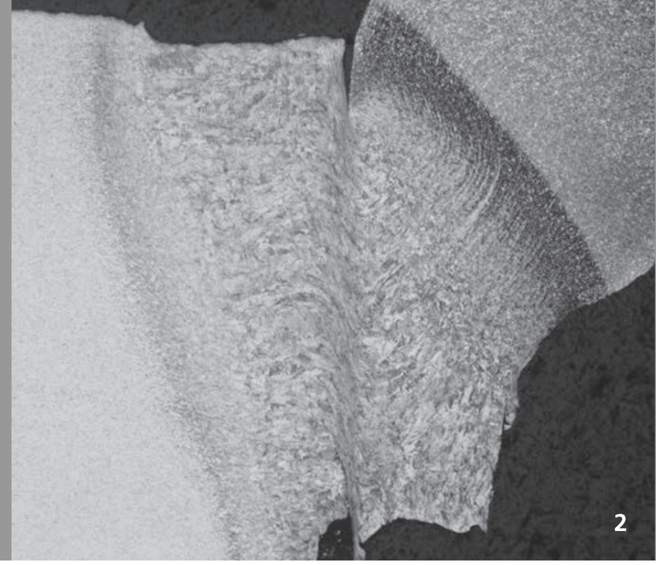
The »LIMBO« project has been financially supported by the Fraunhofer-Gesellschaft.

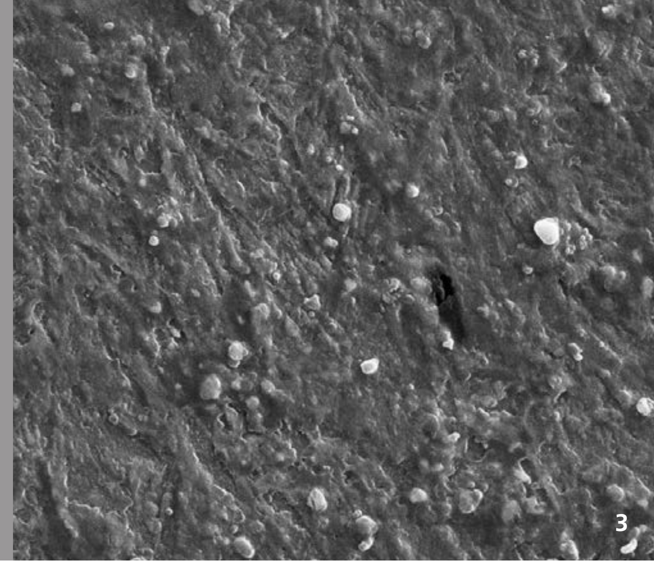
Contact

Dipl.-Ing. Simon Britten
Telephone +49 241 8906-322
simon.britten@ilt.fraunhofer.de

Dr. Alexander Olowinsky
Telephone +49 241 8906-143
alexander.olowinsky@ilt.fraunhofer.de

1 Cross-section of a weld of copper on PCB metallization.





ANALYSIS OF LASER BEAM WELDED ULTRA-HIGH-STRENGTH DUAL-PHASE STEELS

Task

When dual-phase steels with strengths of 980 and 1180 MPa are laser welded, subcritical failure and localized deformation in the heat affected zone restrict their usability. By analyzing the thermally influenced zones, research can help understand the causes as well as contribute to defining corrective measures.

Method

As part of an error analysis, Fraunhofer ILT determined that annealing effects cause the material to weaken in the heat affected zone. At the same time, carbide precipitates strengthen the material in some areas. This development aimed to raise the minimum hardness in the heat affected zone and increase tempering resistance. In addition, an attempt was made to minimize the width of the annealing zone.

Results

When the process parameters as well as the alloy range are adjusted to increase the critical temperatures, the width of the weakened area can be minimized. The positive effects can be supported by design features in order to shift critical points to less loaded positions.

Applications

The extended findings on the causes of failure can be applied to all weldable martensite-phase steels. This makes the know-how available for welding production in a wide range of applications, from vehicle construction for road and rail to structural steel construction.

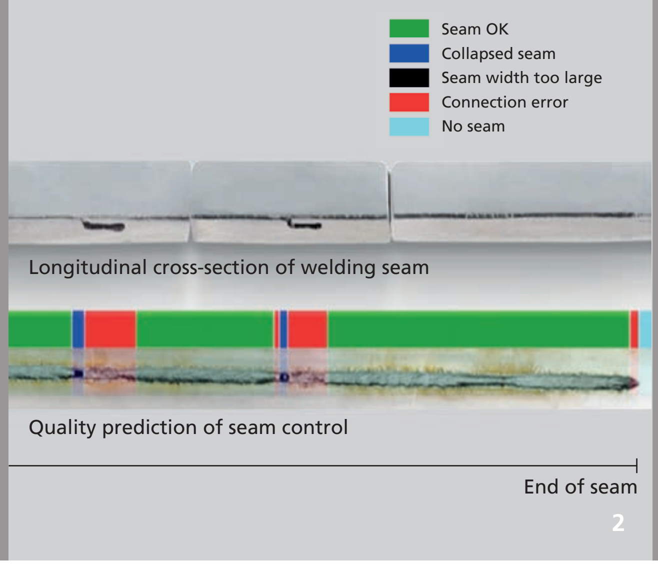
Contact

Dipl.-Ing. Martin Dahmen
Telephone +49 241 8906-307
martin.dahmen@ilt.fraunhofer.de

Dr. Dirk Petring
Telephone +49 241 8906-210
dirk.petring@ilt.fraunhofer.de

2 Weld seam in S500MC/DP980 after buckling-bending load in the forming tool.

3 Fracture edge of a tensile specimen of DP1180 with micro voids elongated in the direction of flow.



INTELLIGENT PROCESS SENSOR SYSTEM

Task

Process monitoring during welding and cladding places special demands on system technology due to high processing speeds. To satisfy these demands, Fraunhofer ILT has developed a multi-spectral, imaging sensor system for process monitoring which provides a clear quality fingerprint. A particular challenge here was the real-time data processing. For this, different sensor data streams had to be analyzed simultaneously during the process in order to be able to classify the current process status into a defined quality category.

Method

The process fingerprint is composed of several features, such as the cooling rate of the component surface or the melt pool surface geometry. These features are determined from multi-spectral process image data. Since determining and processing the features requires considerable processor power, a field programmable gate array (FPGA) had to be used to evaluate the cognitive data in real time. To generate the training data for the artificial intelligence generated in the FPGA, a binding error, the so-called »false friend«, was artificially provoked and recorded for laser-beam welding. Subsequently, the cognitive system was trained with these as well as with data from further process imperfections.

Results

The system is classified with different algorithms from the machine learning family and can distinguish between five categories of weld quality (Figure 2). The accuracy of the classification results reaches over 99 percent in the laboratory. During the development, 150 features were determined, based on image data of different spectral ranges. It has been shown that the uniqueness of the quality assessment also depends on the spectral range in which the process images were generated.

Applications

Within the scope of the project, the cognitive system has been applied for the industrial laser-beam welding of automotive components. In addition, artificial intelligence can be used in other processes, especially in the context of »Industry 4.0« in industrial applications for process monitoring.

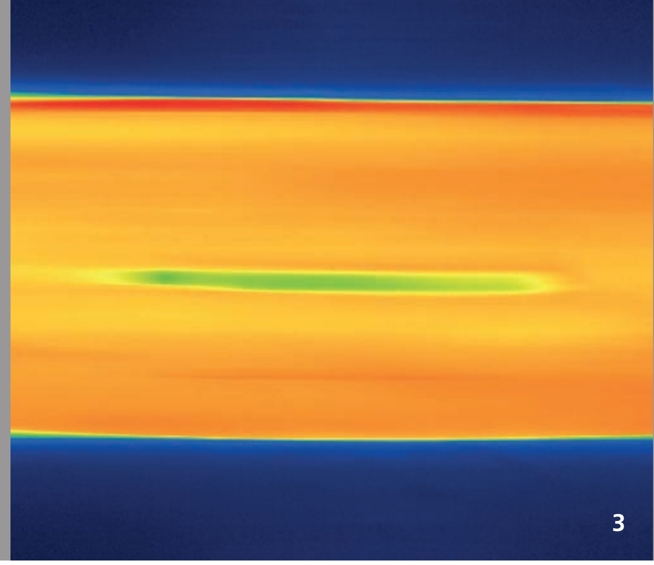
The work has been carried out as part of the EU project »MAShES« under grant number 637081.

Contact

Christian Knaak M.Sc.
Telephone +49 241 8906-281
christian.knaak@ilt.fraunhofer.de

1 Experimental setup with integrated sensors.

2 Prediction of weld quality and associated sample.



PROCESS MONITORING OF THE LASER-BASED TAPE-WINDING PROCESS FOR FIBER-REINFORCED THERMOPLASTIC COMPOSITES

Task

Currently, the demand for components made of fiber-reinforced plastics (FRP) is growing rapidly. However, manufacturing process for components has not yet been automated and, at the same time, is flexible, energy efficient and environmentally friendly. The »ambliFibre« project addresses this challenge: It has developed the first laser-based tape winding process with an easy-to-use software and online quality control. The system enables users to laser weld FRP tapes with integrated process control. The consolidation quality of the welded tapes is monitored online to detect defects in the component at an early stage. Moreover, the user does not need special expertise to use the operating software of the entire system.

Method

The task of the Fraunhofer ILT was to develop the online process control to detect insufficient consolidation of the tapes during winding. For this purpose, FRP tapes were embossed with rectangular structures. Thermal images taken during the winding process identify these embossments and then evaluate both their residual geometry after welding and the quality of the consolidation. The process control algorithm is based on a machine learning approach. In the first step, the existence of the embossments on the tape is detected and then the connection of the tape evaluated by means of a quality analysis on the basis of learned data sets. The measurement process functions in real-time and is easy to integrate into existing systems due to its interfaces.

Results

The implemented »Machine Learning Model« reliably detects embossments on the surface of FRP tapes. In the evaluation, with more than ten samples per set of parameters, the process achieved almost 100 percent certainty in identifying embossments and in the consolidation quality of the tapes during welding. The delay from image capture to completing the evaluation is less than ten seconds.

Applications

The »ambliFibre« monitoring system is suitable for all applications whose goal is to detect structures on surfaces with different tempered areas. The process can be easily adapted and flexibly expanded through machine learning. Thanks to dynamic object finding, not only can it recognize known imperfections, but also new ones that were created in the process.

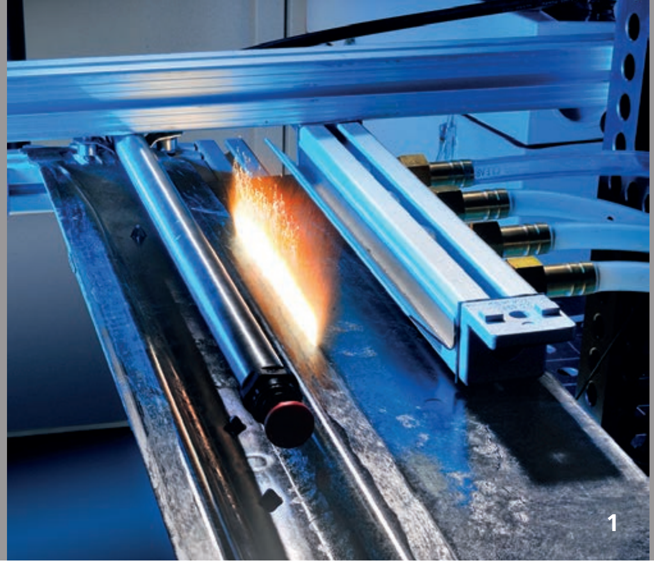
The work has been carried out as part of the EU-funded project »ambliFibre« under grant number 678875.

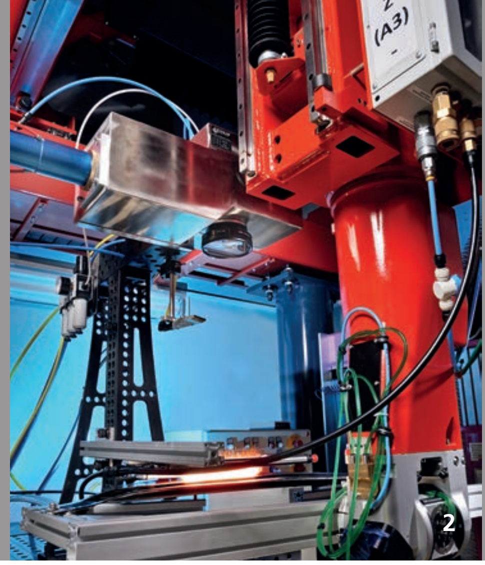
Contact

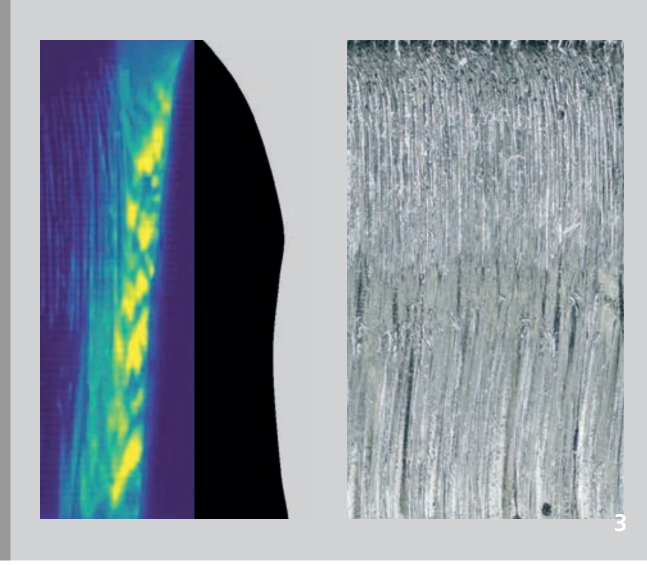
Andrea Lanfermann M.Sc.
Telephone +49 241 8906-366
andrea.lanfermann@ilt.fraunhofer.de

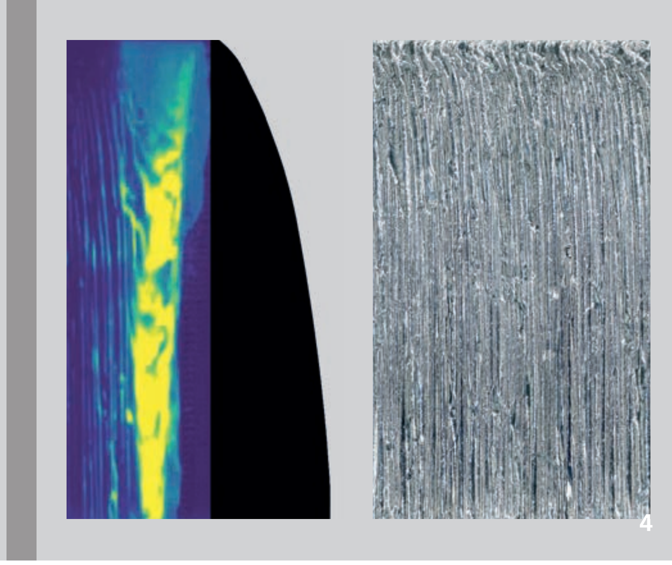
3 Infrared image of a FRP tape with imprinting applied.

4 Experimental setup for the simulated heating of FRP tapes.









CUTTING FIBER-COMPOSITE HYBRID MATERIALS

Task

By combining different materials in one component and manufacturing process, the industry can not only optimize the weight of lightweight components, but also make the process more cost-effective. For example, structural components made of glass-fiber reinforced plastic (GFRP) can be reinforced by unidirectional carbon fiber tapes and thus tailored to specific loads.

Cutting such mixed materials is challenging because the inhomogeneity of the materials makes conventional mechanical separation processes difficult. A laser can be employed, however, to adapt the cutting process to the locally existing material structure. In the present case, 2 mm thick components were trimmed, consisting of CFRP in the upper half and GFRP in the lower half at the separation line.

Method

So that the CFRP layer could be separated with a minimum heat-affected zone, the material was removed with a continuous-wave single-mode (SM) laser in a multi-pass process. Although long-fiber-reinforced GFRP can be efficiently separated with a cutting-gas-assisted CO_2 laser, a fiber laser and the multi-pass method ablating on the beam entry side are also used here for the GFRP layer. Since the filling material has an absorption-increasing effect in the matrix, the fiber laser can ablate the material efficiently even at a wavelength of 1 µm.

Results

The parts can be cut with the SM laser in one operation. With a laser power of 5 kW and a scanning speed of 4.2 m/s, the parts can be completely separated after 13 passes. The heat-affected zone or geometric edge deviation amounts to a maximum of 150 µm.

Applications

Trimming or cutting contours and holes on CFRP or GFRP components are process steps required in all areas of lightweight construction, especially in the aerospace and automotive industries. As multi-material components are increasingly being used to fulfill lightweight construction goals, there is a great need for cutting methods that can be simply adapted to the material combination by employing laser processing.

The R&D project underlying this report was conducted on behalf of the German Federal Ministry of Education and Research (BMBF) as part of the »HyBriLight« project under grant number 13N12718.

Contact

Dr. Frank Schneider
Telephone +49 241 8906-426
frank.schneider@ilt.fraunhofer.de

1 Remote laser-beam cutting of CFRP-GFRP hybrid material.

2 Continuous multi-pass cut with scanner and robot.

IN-SITU VISUALIZATION OF MULTIPLE REFLECTIONS DURING LASER BEAM CUTTING

Task

During laser beam cutting, instabilities of the laser cutting front cause an unwanted loss of quality, which appears in the form of ablation and solidification striations and can lead to dross formation. The effects of multiple reflections of the laser radiation in the kerf and their effects on the cutting result are still not fully understood.

Method

Thanks to a trim-cut procedure, the melting and solidification dynamics during laser beam fusion cutting can be diagnosed in-situ, which makes it possible to access and, thus, observe the kerf. In such trimming cuts, cutting is done along an existing rectilinear workpiece flank with defined laser beam overlap. So that a guided supersonic gas jet can be maintained along the melt film, the missing cut edge is simulated by a transparent replacement flank. The variations of laser-beam overlap and distance between the replacement edge and workpiece flank allow the amount of multiple reflections to be manipulated.

Results

For the first time, the trim-cut procedure has proven that there are multiple reflections in the cutting kerf. The existence of these reflections has been clearly demonstrated, thus having the following consequences:

- The molten area from the cutting to the solidification front on the cutting edge is significantly enlarged over the area that is illuminated directly by the laser radiation.
- Multiple reflections have a significant influence on the striation pattern and the horizontal structure of the forming cutting edge.
- The ablation rate is increased and thus multiple reflections increase the process efficiency.

Applications

The detection of multiple reflections is an important step in developing adapted process parameters to increase the cutting edge quality while avoiding dross formation.

The project has been funded by the German Research Foundation (DFG) as part of the Collaborative Research Center SFB 1120 (Precision manufacturing by controlling melt dynamics and solidification in production processes).

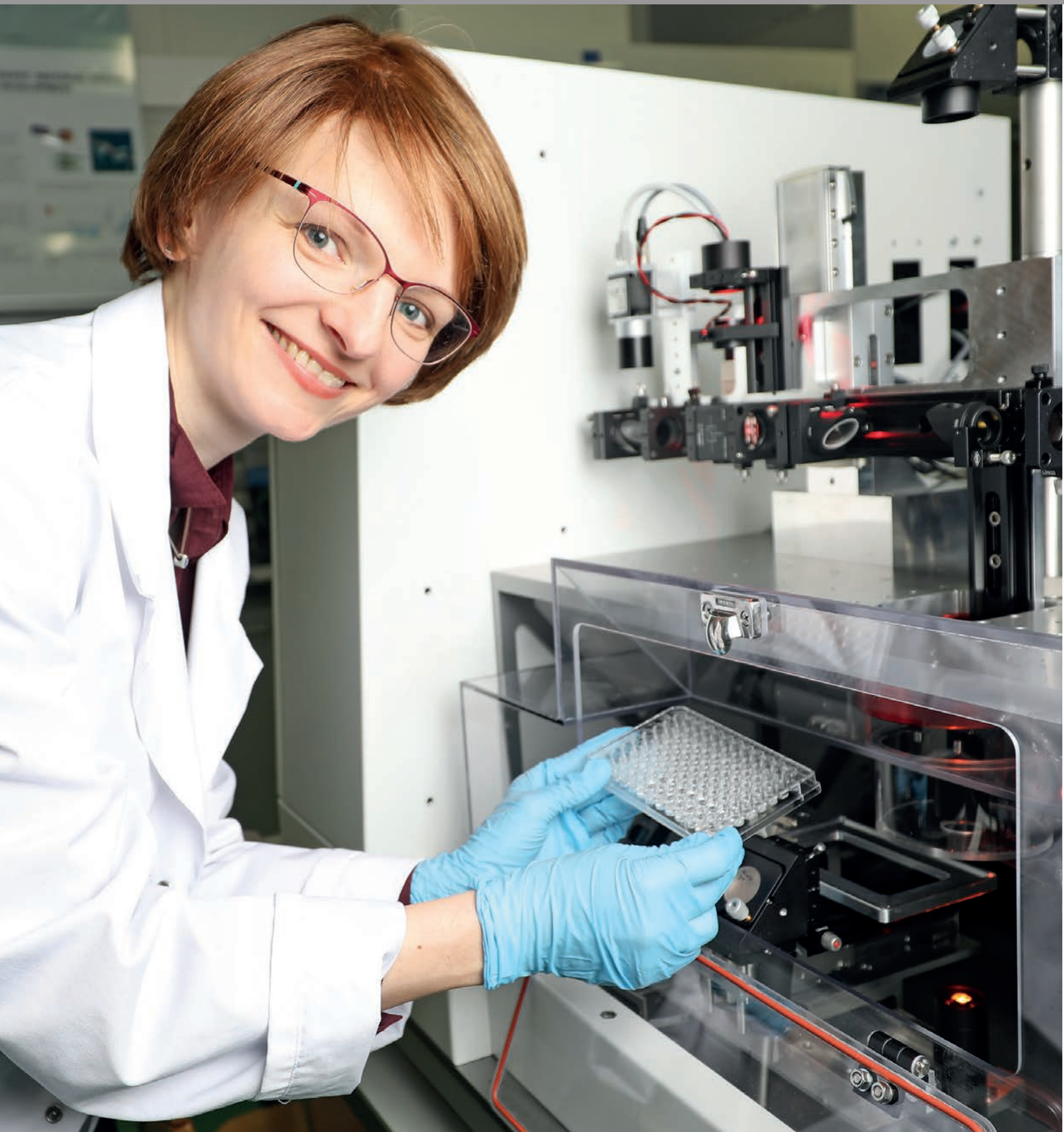
Contact

Dennis Arntz M.Sc.
Telephone +49 241 8906-8389
dennis.arntz@llt.rwth-aachen.de

3 Pruning incision, cutting flank profile and associated cutting flank (in each case from left to right) with multiple reflections.

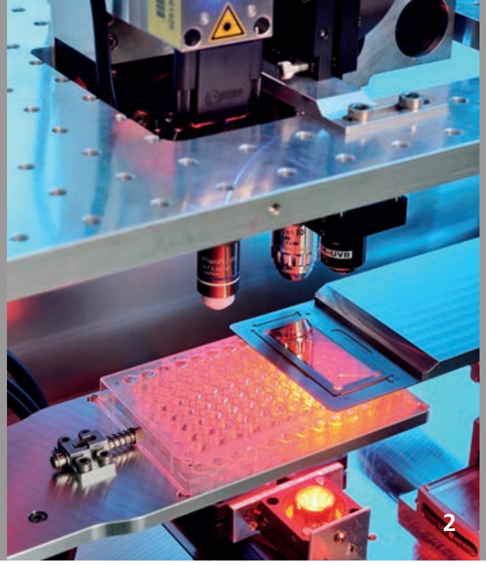
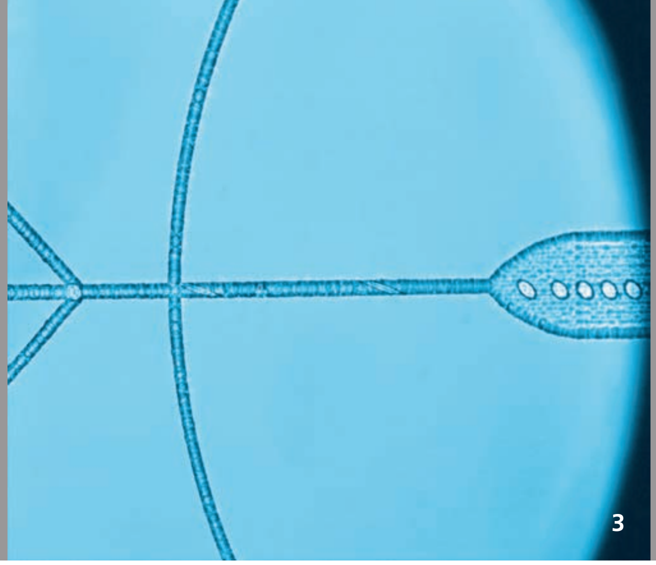
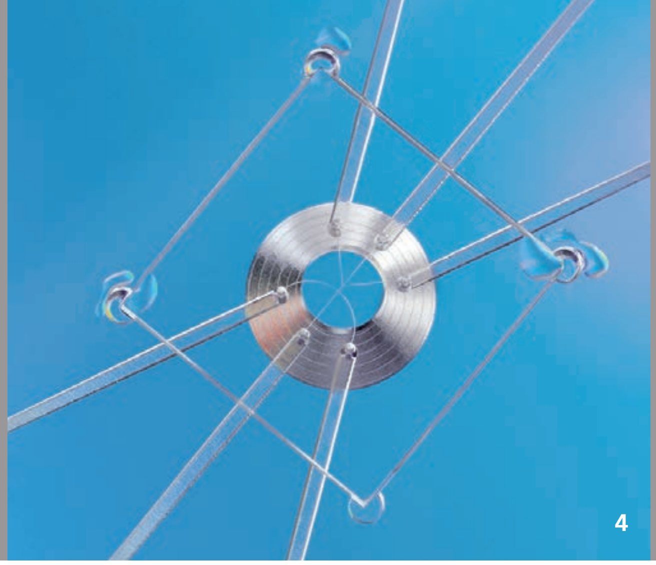
4 ... and without multiple reflections.

MEDICAL TECHNOLOGY AND BIOPHOTONICS



CONTENTS

Automated LIFT Process for the placement of individual cells.

LIFTSYS®+ – PROCESS CHAIN FOR THE ANALYSIS AND SEPARATION OF INDIVIDUAL CELLS

Task

The production of and research into new biotechnologically produced drugs requires the analysis and selection of powerful, living cell lines. Today, fluorescence-labeled antibodies are usually used for the selection of such cells. A marker-free analysis of them with subsequent selection and separation makes it possible to save a great deal of resources and time in the creation of efficient production cell lines.

Method

Established at Fraunhofer ILT, the LIFTSYS® system enables the precise placement of individual cells by means of Laser Induced Forward Transfer (LIFT). For the development of a process chain for analysis and subsequent separation, the institute built a new LIFTSYS® system (LIFTSYS®+) with an integrated Raman spectrometer. The protein-specific vibrational spectra of Raman analysis allow the cells to be studied without affecting cell viability. The LIFTSYS®+ has been adapted so that it can be installed on a biological workbench and, thus, work under sterile conditions. For integration into standard biotechnology processes and to increase productivity, microtiter plates are used as receivers.

Results

Fraunhofer ILT, in cooperation with the Fraunhofer IGB, has developed the LIFTSYS®+ system with integrated Raman analysis module and integrated it into an air-conditioned workbench. This process combination enables the label-free analysis, selection and separation of individual cells in optimal conditions for cell viability. The automated process of cell recognition, evaluation of cell productivity based on Raman spectra and transfer using LIFT is currently being investigated in cooperation with Fraunhofer FIT and Fraunhofer IGB.

Applications

The LIFTSYS®+ system can be broadly used in medical and pharmaceutical research as well as biotechnology. Especially for the production of pharmaceutical ingredients, this process promises a significantly shortened process chain for the production of biologics. In addition, the LIFTSYS®+ makes it possible to carry out fundamental investigations into the microscopic interaction of different cells with each other in a reproducible manner.

Contact

Richard Lensing M.Sc.
Telephone +49 241 8906-8336
richard.lensing@ilt.fraunhofer.de

Dr. Nadine Nottrodt
Telephone +49 241 8906-605
nadine.nottrodt@ilt.fraunhofer.de

1 Raman analysis module of the LIFTSYS®+ system.
2 Targeted cell transfer into the chambers using LIFT.

DROPLET-BASED SCREENING FOR THE ACCELERATED EVOLUTION OF OPTIMIZED ENZYMES

Task

Biotechnological processes based on enzymatic catalysis are increasingly replacing large-scale chemical processes since they are not only more ecological and economical, but they also make it possible to produce completely new types of substances, such as bioplastics. Before such biotechnological production is feasible, novel, optimized technical enzymes are needed. Making them available, however, is tedious and expensive.

Method

Based on an existing enzyme gene, therefore, one million different enzyme variants shall be generated by genetic engineering and subsequent cell-free enzyme expression. In this case, droplets with a diameter of less than 10 µm serve as micro-expression systems in which the genes are isolated and enzyme is produced from them using a cell extract. After addition of a substrate, which metabolizes the enzymes to a fluorescent product, the activity of the enzymes can be determined by the fluorescence intensity. Particularly active and thus promising production variants have a high fluorescence signal. In order to select the best enzymes for production, Fraunhofer ILT has developed a droplet-based screening method in which microdroplets with enzyme genes, cell extract and substrate are injected into an oily phase and examined in a sorting chip for their fluorescence. The best enzyme candidates are sorted out on a microfluidic branch with highly focused laser light and deposited on the chip. An iteration of the procedure described results in optimized technical enzymes.

Results

Selective Laser-Induced Etching (SLE) was used to develop fused-silica microfluidic systems that can generate 5 to 10 µm droplets at generation rates above 10 kHz. The developed screening and sorting platform screens droplets with rates of greater than 1 kHz and separates optical and non-contact droplets with fluorescence signals above the threshold.

Applications

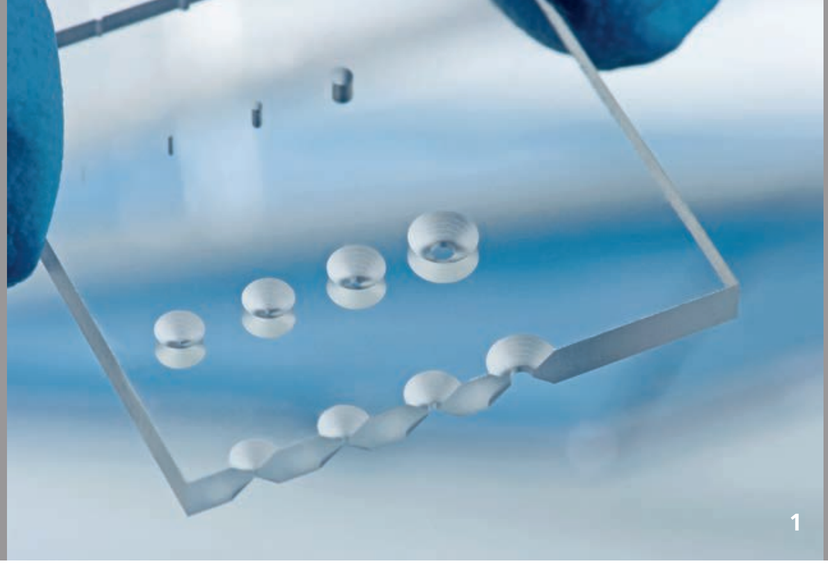
The screening and sorting platform can be used in biotechnology for the accelerated, directed evolution of enzymes. Moreover, it can also be used in personalized medicine for the detection and separation of circulating tumor cells in blood.

Contact

Dipl.-Phys. Georg Meineke
Telephone +49 241 8906-8084
georg.meineke@ilt.fraunhofer.de

Dr. Achim Lenenbach
Telephone +49 241 8906-124
achim.lenenbach@ilt.fraunhofer.de

3 Droplet generation with diameters of less than 10 µm.
4 Droplet generator on carrier chip.



WAVE GUIDE FOR ANGLE-RESOLVED LIGHT SCATTERING

Task

The angle-resolved measurement of the light scattered by particles makes it possible to determine particle sizes and particle shapes rudimentarily. This method – called static laser light scattering – is used in laboratory instruments for the analysis of particle diameters between a few 10 nm and hundreds of µm. For inline-capable, process-analytical immersion probes, however, the method is not yet suitable due to the complex optics with many detection channels, each with a small angle range. In a research project with partners from the industry, Fraunhofer ILT is developing a compact, inline-capable immersion probe that enables angle-resolved scattered light measurements for particle analysis.

Method

Fraunhofer ILT is pursuing a new approach for optical particle analysis that uses waveguides for angle-resolved detection of the particle-scattered light. In a glass chip, a short pulse laser is used to introduce both structural elements (e.g., an opening, which is flushed through by the sample liquid) and waveguides for guiding the scattered light. A CCD line on an outer surface of the glass chip detects the stray light guided by the waveguides.

Results

The waveguides have been optimized for use in a scattered-light probe. For this, the laser parameters for writing the waveguides had to be varied and the optical properties of the waveguides, such as transmission, angle of radiation and minimum radii of curvature, were analyzed. Fraunhofer ILT created a design concept for the construction of an analysis chip with elements for flow shaping.

Applications

The scattered light probe shall be used to measure the size of particles with a diameter between a few 10 nm and many µm. Application fields can be found, for example, in bioprocess analysis and chemical process analytics. Growth processes in biofermenters or particle formation in chemical crystallizations shall be recorded inline during an ongoing process.

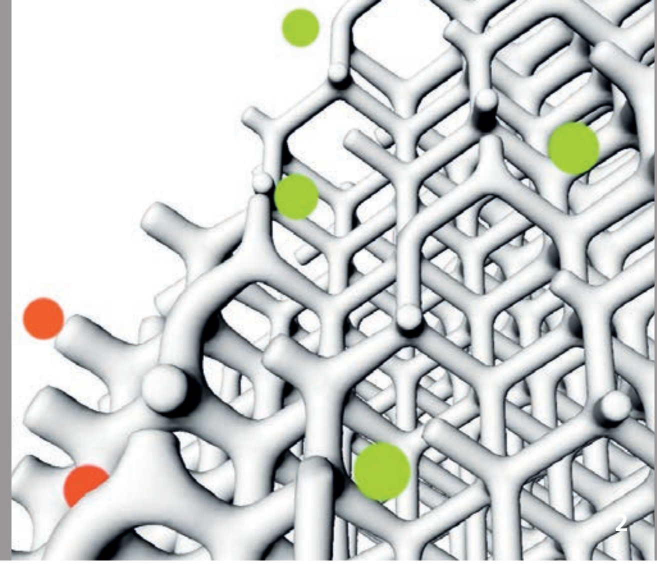
The R&D project »WAVESCATTER« underlying this report is being carried out in cooperation with companies on behalf of the Federal Ministry of Education and Research BMBF under grant number 13N14176.

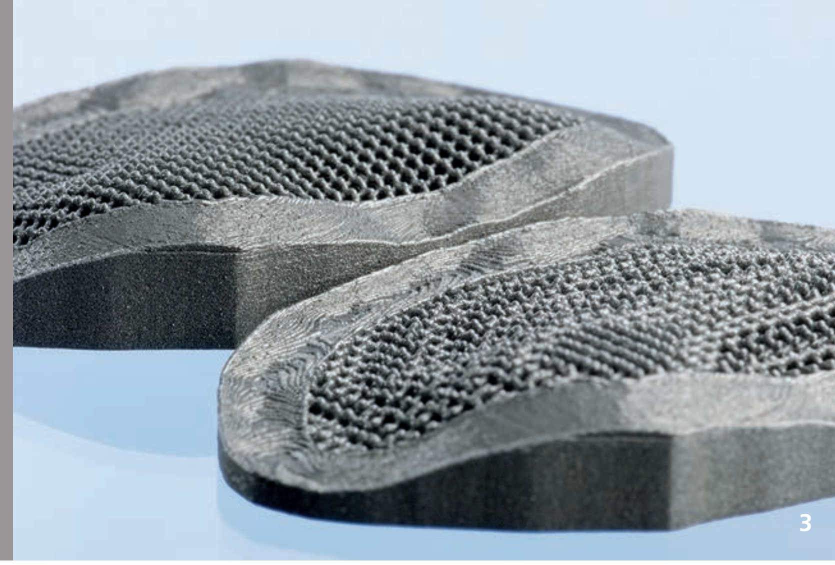
Contact

Dr. Christoph Janzen
Telephone +49 241 8906-8003
christoph.janzen@ilt.fraunhofer.de

Prof. Reinhard Noll
Telephone +49 241 8906-138
reinhard.noll@ilt.fraunhofer.de

1 Glass chip with laser-structured openings.





DESIGN AND ADDITIVE MANUFACTURE OF LOCALLY LOAD-ADAPTED VERTEBRAE IMPLANTS

Task

Degenerative instabilities in the spine can make it necessary to surgically remove spinal discs. So that the bones can fuse together, intervertebral cages are used in the resulting intervertebral space. The use of current cages may result in implant-related failure patterns such as non-union or migration due to a non-optimal press fit to the vertebral body. As part of the project »EITPSI«, a novel cage design is being pursued in order to determine geometry as well as rigidity and structure tailored to the patient – i.e. to individually adapt it to significantly reduce implant failure.

Method

In cooperation with the Chair for Digital Additive Production DAP of the RWTH Aachen University, Fraunhofer ILT has anatomically adapted the implant to the surface topography of the bone to produce a positive press-fit anchorage. The central fusion zone provides improved bony ingrowth. Moreover, by integrating a locally adapted lattice structure, the project partners have adapted the zone to the individual stiffness of the adjacent vertebrae and their individual bone density. At the same time, the ingrowth behavior of the bone tissue and, thus, the fusion can be significantly improved.

Results

An algorithm has been developed to locally adapt the lattice structure stiffness to the density of the adjacent bone. Based on a bone density point cloud determined by CT, local scaling factors (green = low, red = high stiffness) were derived (Fig. 2). These affect the initial and final diameters of each strut of the grid. A homogenous 3D mesh structure was generated by a subsequent smoothing process, and the general assembly ability was verified by means of selective laser melting (SLM), also known as laser beam melting or laser powder bed fusion (LPBF) (Fig. 2 and 3).

Applications

Due to the patient-specific adaptation, the production of locally load-adapted, additively produced vertebral body implants has great potential for improvement and can replace the implants that have become standardized in everyday clinical practice. The scope of applications can be extended to all implants to be fused with bone in the body.

Parts of the work have been carried out on behalf of the Federal Ministry of Education and Research BMBF within the framework of the »EITPSI« project under grant number 13GW0116.

Contact

Martin Kimm M.Sc.
Telephone +49 241 8906-618
martin.kimm@ilt.fraunhofer.de

Dipl.-Phys. Lucas Jauer
Telephone +49 241 8906-360
lucas.jauer@ilt.fraunhofer.de

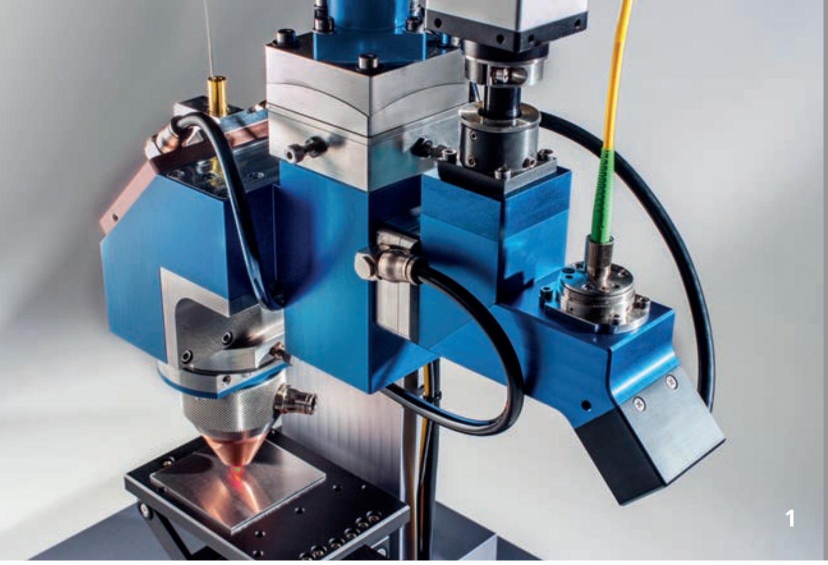
2 Scaling points with graded lattice structure.

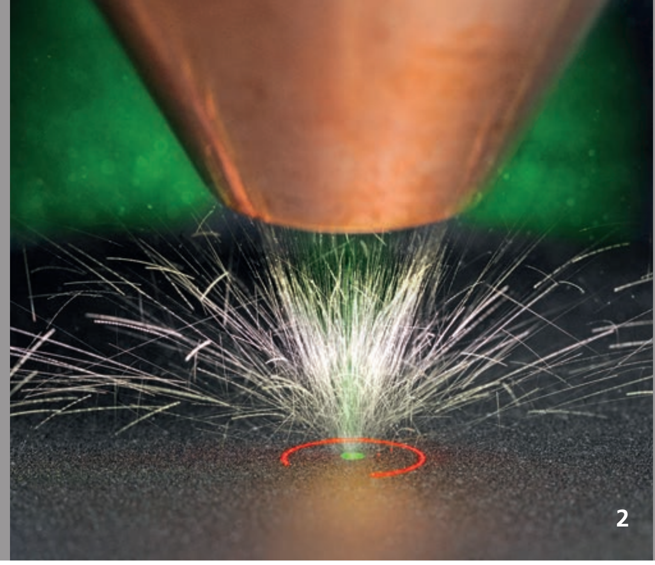
3 Additively made cage out of Ti6Al4V.

LASER MEASUREMENT TECHNOLOGY AND EUV TECHNOLOGY

Detection of materials for the recycling of refractory materials.

CONTENTS





»bd-1« SENSOR FOR INLINE MEASUREMENTS DURING LASER MATERIAL DEPOSITION

Task

In laser material deposition (LMD), the production result, such as the applied track height or layer thickness, depends on various factors. Despite constant process parameters, fluctuations in material feed (wire or powder) as well as non-constant speeds at reversal points can lead to fluctuations in the layer thicknesses, which reduce the dimensional accuracy of the job. A fast control of the material feed is not yet possible. The exact knowledge of the applied layer thickness is, therefore, essential to initiate corrective action for the next tracks and layers and to increase the accuracy of the applied layers. This is especially true when the LMD is used for the additive production of large 3D structures. In addition, an inline measurement of the layer thickness can be used for quality assurance.

Method

For the direct measurement of applied track heights during LMD, powder-based and coaxial-wire-based LMD optics were supplemented with ports to connect the absolute-measuring interferometric »bd-1« sensor developed at the Fraunhofer ILT.

The compact design of the »bd-1« measuring heads makes them easy to integrate into existing optics. So that the applied track heights can be measured independent of the direction, the measurement radiation is coupled coaxially to the processing radiation and deflected by mirrors around the point of application.

Results

With the developed arrangement, geometrical features – such as the layer thickness – can already be measured during production. LMD systems will, thus, be able to use the real-time measurement results in the future to immediately respond to deviations from the target geometry, preventing the accumulation of manufacturing errors. Also, fluctuating properties of precursors and materials to be processed can be detected and compensated for by autonomous parameter adjustments.

Applications

The »bd-1« sensors can initially be used in powder and coaxial wire-based LMD processes for quality assurance and later for controlling the production processes. Further fields of application for the interferometric sensor technology are, for example, in the monitoring and control of laser drilling and laser microstructuring.

Contact

Dr. Stefan Hölters
Telephone +49 241 8906-436
stefan.hoelters@ilt.fraunhofer.de

Prof. Reinhard Noll
Telephone +49 241 8906-138
reinhard.noll@ilt.fraunhofer.de

1 Laser material deposition with coaxial wire and »bd-1« for inline height measurement.
2 Orientation of powder focus, position of processing laser radiation (green) and measuring radiation of the »bd-1« (red).

INLINE POWDER GAS JET MEASURING SYSTEM

Task

When laser metal deposition (LMD) is used to additively manufacture components and coatings, their quality depends highly on reproducible process parameters. Demanding components, such as those used in the aerospace industry, can only be produced faultlessly in a defined process window; here, even small deviations change the process result. For this reason, there is a need to standardize and document both the process set-up and to monitor the process itself.

Method

Since the setting of the powder-feed nozzle determines the process result in LMD, measuring the powder gas jet is of crucial importance. Therefore, together with Trumpf Laser- und Systemtechnik GmbH, Fraunhofer ILT has developed a process for the certification of powder nozzles and implemented it in an integrated system. This system has also been expanded with functions for process setup and online process monitoring.

Results

The system has been adapted to the camera interfaces of industrial processing heads and can be integrated into any TRUMPF-LMD optics as an »in-line powder-gas stream measuring system«. The following function modules are available in modular form:

- Support and documentation of process setup by measuring and marking the positions of processing laser, nozzle orifice, powder focus, and workpiece features,
- Measurement of the powder jet stream and characterization of powder feed nozzles by calculating characteristic numbers
- Monitoring of process stability based on geometric characteristics of the melt pool.

Applications

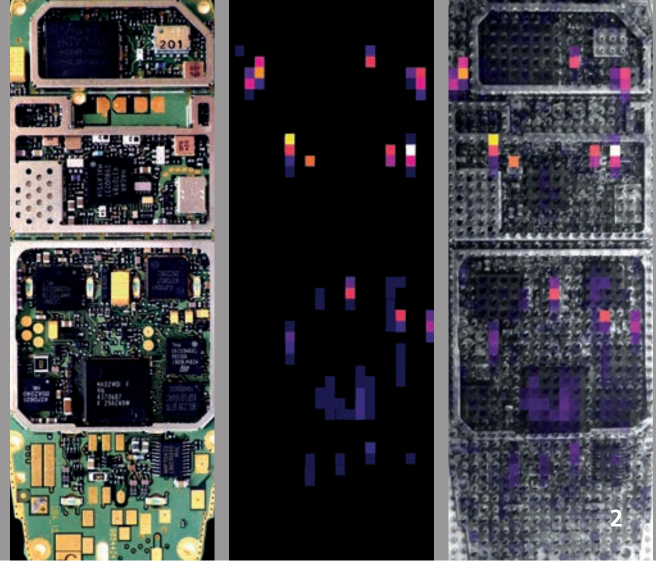
Applications include all activities in the LMD sector that require detailed knowledge of process equipment and process stability. This know-how can be used in the aerospace industry, which places the highest demands on machining and documentation, and in the manufacturing industry, which uses high-speed LMD to produce components or in any sector that requires extended machining times.

Contact

Dipl.-Ing. Stefan Mann
Telephone +49 241 8906-321
stefan.mann@ilt.fraunhofer.de

Dipl.-Ing. Peter Abels
Telephone +49 241 8906-428
peter.abels@ilt.fraunhofer.de

3 Module for quality assurance during LMD.
4 Powder nozzle for LMD.



LASER-BASED DETECTION OF ELECTRONIC COMPONENTS

Task

To recover valuable raw materials from electronic waste, the industry must be able to identify the components in which the materials are present in high concentrations. Since this information is not available in the large variety of today's electronic devices, the components cannot be selectively removed and processed in separate fractions.

Method

Fraunhofer ILT is coordinating the European joint innovation project »ADIR«, in which technological solutions are being worked out in order to automatically recover the individual recyclables. For this purpose, methods are being developed to identify physical and chemical properties of valuable assemblies and electronic components and to selectively remove them.

Results

A combined process is being used to detect the substances in a component without contacting it. In the process, a pulsed laser beam first penetrates the upper layers of the components locally. Then, the subsequent analysis is carried out by the process of Laser-Induced Breakdown Spectroscopy (LIBS). Here, the laser beam excites the internal material for optical emission, which is analyzed spectroscopically.

1 Separated, pre-disassembled mobile phones.

2 Circuit board of a mobile phone and positions of tantalum-containing components.

The beam paths for laser excitation and detection are aligned quickly and precisely to individual positions on a circuit board. As a result, both individual components can be specifically investigated and scanning measurements of larger areas carried out. Whole circuit boards with an edge length of up to 50 cm can be measured quickly and, for example, represented on a multi-element map.

Applications

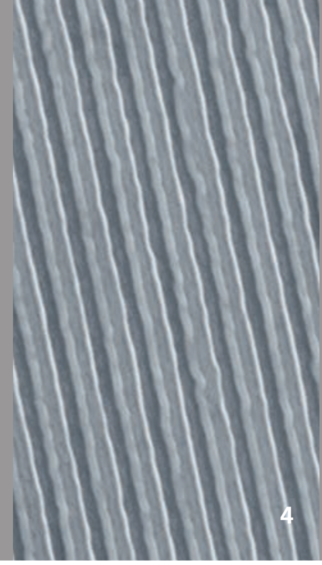
This fast and non-contact analysis can record spatial distributions and opens up a broad field of applications: from characterizing natural raw materials through the quality inspection of metallic components and semi-finished products all the way to locating recyclable materials for recycling applications.

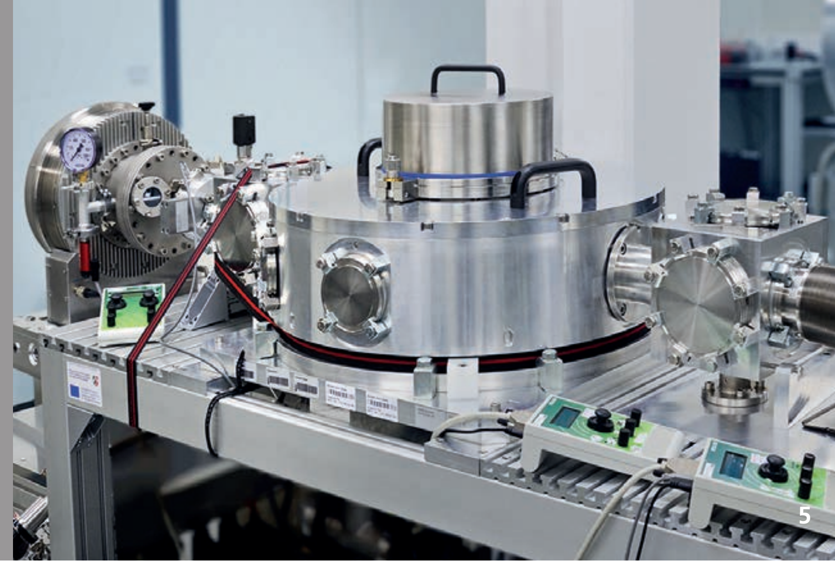
The work is being carried out as part of the EU project »ADIR« under grant number 680449.

Contact

Dr. Cord Fricke-Begemann
Telephone +49 241 8906-196
cord.fricke-begemann@ilt.fraunhofer.de

Prof. Reinhard Noll
Telephone +49 241 8906-138
reinhard.noll@ilt.fraunhofer.de





SPECTROSCOPIC EUV REFLECTOMETRY FOR THE CHARACTERIZATION OF NANOSTRUCTURES

Task

Extreme ultraviolet (EUV) radiation is a promising alternative to spectral ranges previously used for photon-based metrology applications. In contrast to the surrounding spectral ranges from infrared to the X-ray range, EUV radiation has a much stronger interaction with matter. In addition, the short wavelengths – of the same order of magnitude as current structure sizes (~ 10 nm) of semiconductor and nanotechnology – are advantageous.

Method

In a EUV spectroscopy system developed and built for the spectral range from 9 nm to 17 nm, nanostructures were measured for their spectroscopic reflectance at various angles in grazing incidence. With sufficiently thin samples (< 100 nm) the spectroscopic transmittance can be determined. This model-based procedure can be used to reconstruct the sample geometry – such as lateral distances and sizes of periodic structures as well as vertical thicknesses of complex multilayer systems – from the determined radiometric quantities. In addition, samples with unknown material properties can be characterized in terms of their stoichiometry and density.

Results

The system was able to characterize ultrathin membranes with thicknesses of about 20 nm, multilayer systems with single-layer thicknesses of less than 1 nm and periodic grating structures with respect to their geometry down to the subnanometer range. In addition, the stoichiometry of membrane samples and multilayer systems could be successfully determined.

Applications

The described metrology process can be applied in the field of semiconductor measurement technology since measurement methods with high sensitivity for small structural dimensions are in great demand there. In addition, the developed process can characterize nanostructures and materials from other technological areas.

Contact

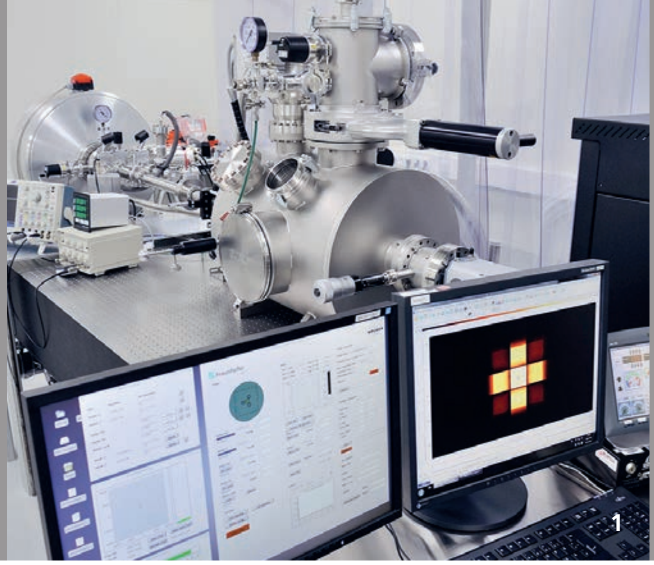
Lukas Bahrenberg M.Sc.
Telephone +49 241 8906-8326
lukas.bahrenberg@ilt.fraunhofer.de

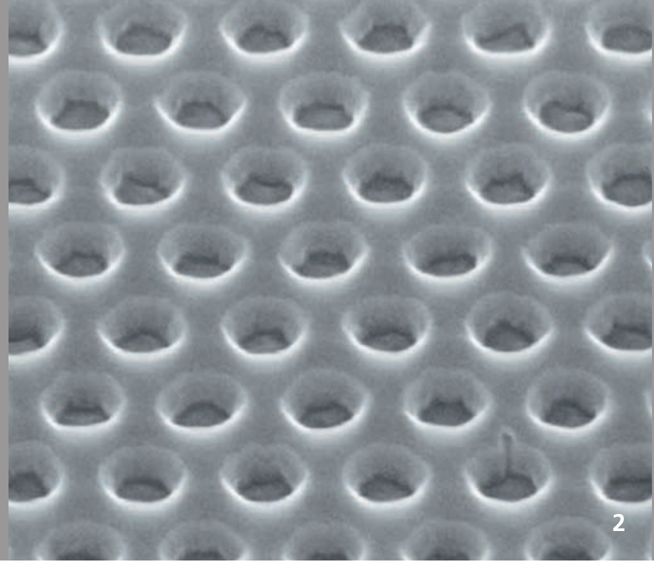
Dr. Serhiy Danylyuk
Telephone +49 241 8906-525
serhiy.danylyuk@ilt.fraunhofer.de

3 Ultrathin silicon nitride membrane in vacuum sample holder.

4 Line gratings (period = 150 nm, SEM image).

5 EUV spectroscopy system.





HIGHLY EFFICIENT TRANSMISSION GRATINGS FOR EUV APPLICATIONS

Task

Highly efficient transmission gratings are needed for spectroscopic and lithographic applications in the extreme ultraviolet radiation range (EUV wavelengths: 5 nm to 50 nm). The production of these special optical elements requires a suitable material selection and grating geometry. When the phase shift and absorption in the grating material are taken into account, intensities of the individual diffraction orders can be adjusted to the respective application. The periodicity of the lattice structures directly influences the achievable spectral resolution in spectroscopy and the minimum feature size in lithographic methods.

Method

The manufacturing process is based on the structuring of a polymer with electron-beam lithography. To achieve the required high aspect ratio for nanoscale structures, the processing is carried out on an ultrathin support membrane. Thus, it is possible to generate grating periods of 60 nm for line gratings and hole arrays over areas of several square millimeters. With an optimized grating design, diffraction efficiencies of over 50 percent have been achieved. The EUV Laboratory Exposure Tool (EUV-LET) can be used to characterize fabricated transmission masks. The intensities of the produced transmission masks can be measured down to the second diffraction order and the real grating efficiency and geometry calculated. Due to the high diffraction efficiencies, the transmission gratings produced are particularly suitable for interference lithography. With EUV-LET, these transmission gratings demonstrated a record resolution of 28 nm using achromatic Talbot lithography.

Results

The design, fabrication and characterization of customized, high-efficiency transmission gratings has been optimized for various EUV applications with a line density of up to 16,500 lines/mm.

Applications

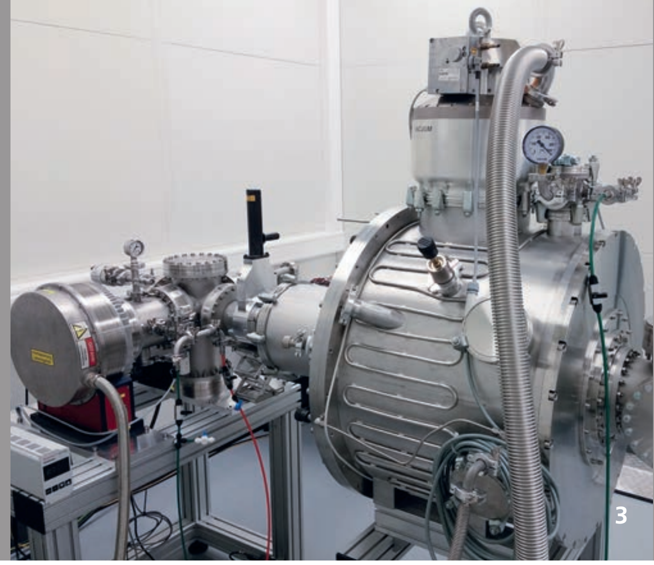
These transmission gratings can be used for high-resolution spectroscopy and nanoscale lithography in research and industry.

Contact

Dipl.-Ing. Sascha Brose
Telephone +49 241 8906-525
sascha.brose@ilt.fraunhofer.de

Dr. Serhiy Danylyuk
Telephone +49 241 8906-525
serhiy.danylyuk@ilt.fraunhofer.de

1 EUV Laboratory Exposure Tool (EUV-LET).
2 Hexagonal hole grating (period = 200 nm, SEM image).



TEST STAND FOR IRRADIATION EXPERIMENTS IN THE EUV SPECTRAL RANGE

Task

For a number of scientific issues on the interaction of short wavelength radiation with matter, the availability of high, medium as well as pulsed irradiation intensities in the extreme ultraviolet is of particular interest. The spectral range around 13.5 nm plays a special role since semiconductor production has demand for it and optical systems based on multilayer mirrors are generally available.

Method

In cooperation with the chairs »Technology of Optical Systems TOS« and »Experimental Physics of Extreme Ultraviolet EUV« of RWTH Aachen University, Fraunhofer ILT has set up a test stand with which high irradiation intensities in the extreme ultraviolet can be exposed to a sample. The test stand consists of a xenon-based gas discharge source as an emitter for 13 nm wavelength radiation, a 45° multilayer mirror for monochromatization, and a Wolter-type collector, with the source and sample placed in each of the focal points. The collector reduces the beam profile of the source to the sample, resulting in an illumination spot with a diameter of approximately 50 µm (FWHM).

Results

For a 50-Hertz discharge source with a 13.5 nm emission of 0.6 mJ/sr in a spectral bandwidth of two percent per pulse, average intensities of up to about 1 W/cm^2 on the sample were achieved at maximum focus. By defocusing, a tophead profile can be set in approximation, with a diameter of about 140 µm and an intensity of about 200 mW/cm^2. The peak intensity during the pulse is up to 4×10^7 W/cm^2 at maximum focus. When the bench is combined with the more powerful EUV radiation sources developed at Fraunhofer ILT, the average intensity can be increased by about two orders of magnitude and peak intensity by about one.

Applications

This test stand can be used for basic studies on the degradation of optical components under EUV irradiation and tests for scintillator materials. Moreover, it can be applied to process and structure materials (biomaterials) in EUV-induced ablation to selectively modify surfaces, which would not be possible by mechanical or laser material processing.

Contact

Dr. Klaus Bergmann
Telephone +49 241 8906-302
klaus.bergmann@ilt.fraunhofer.de

Dr. Serhiy Danylyuk
Telephone +49 241 8906-525
serhiy.danylyuk@ilt.fraunhofer.de

3 Test stand for high irradiation intensities in the EUV spectral range.
4 Wolter-type collector for focusing the EUV radiation.

NETWORKS AND CLUSTERS

THE FRAUNHOFER-GESELLSCHAFT AT A GLANCE

THE FRAUNHOFER-GESELLSCHAFT

Research of practical utility lies at the heart of all activities pursued by the Fraunhofer-Gesellschaft. Founded in 1949, the research organization undertakes applied research that drives economic development and serves the wider benefit of society. Its services are solicited by customers and contractual partners in industry, the service sector and public administration.

At present, the Fraunhofer-Gesellschaft maintains 72 institutes and research units. The majority of the more than 25 000 staff are qualified scientists and engineers, who work with an annual research budget of 2.3 billion euros. Of this sum, almost 2 billion euros is generated through contract research. Around 70 percent of the Fraunhofer-Gesellschaft’s contract research revenue is derived from contracts with industry and from publicly financed research projects. Around 30 percent is contributed by the German federal and Länder governments in the form of base funding, enabling the institutes to work ahead on solutions to problems that will not become acutely relevant to industry and society until five or ten years from now.

International collaborations with excellent research partners and innovative companies around the world ensure direct access to regions of the greatest importance to present and future scientific progress and economic development.

With its clearly defined mission of application-oriented research and its focus on key technologies of relevance to the future, the Fraunhofer-Gesellschaft plays a prominent role in the German and European innovation process. Applied research has a knock-on effect that extends beyond the direct benefits perceived by the customer: Through their research and development work, the Fraunhofer Institutes help to reinforce the competitive strength of the economy in their local region, and throughout Germany and Europe. They do so by promoting innovation, strengthening the technological base, improving the acceptance of new technologies, and helping to train the urgently needed future generation of scientists and engineers.

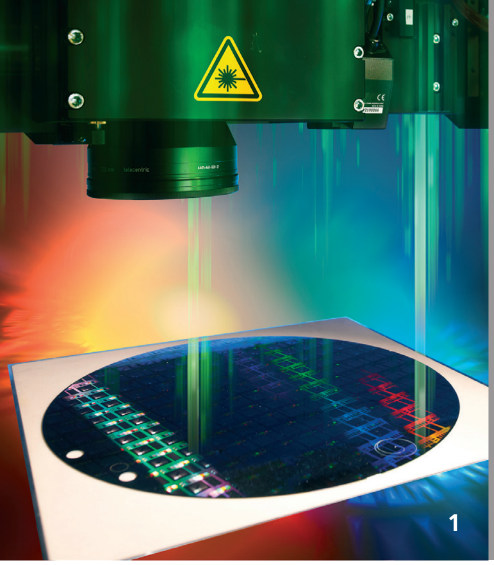
As an employer, the Fraunhofer-Gesellschaft offers its staff the opportunity to develop the professional and personal skills that will allow them to take up positions of responsibility within their institute, at universities, in industry and in society. Students who choose to work on projects at the Fraunhofer Institutes have excellent prospects of starting and developing a career in industry by virtue of the practical training and experience they have acquired.

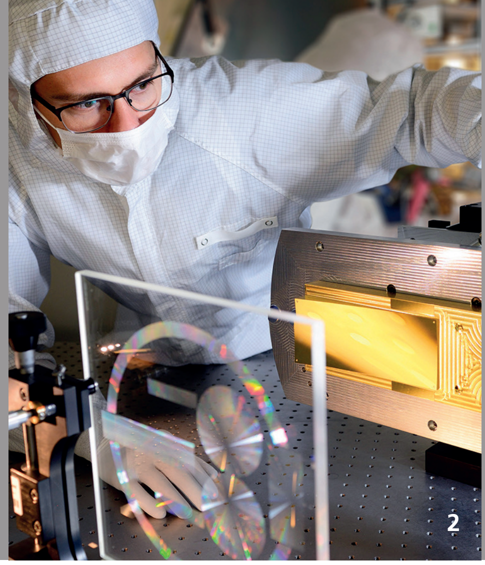
The Fraunhofer-Gesellschaft is a recognized non-profit organization that takes its name from Joseph von Fraunhofer (1787–1826), the illustrious Munich researcher, inventor and entrepreneur.

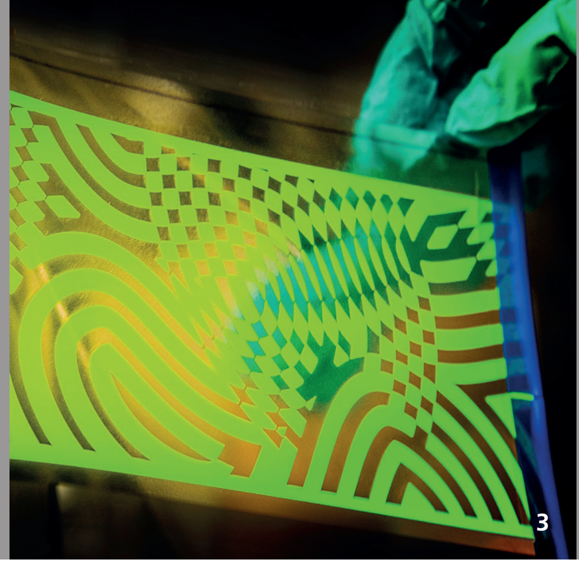
FIELDS OF RESEARCH

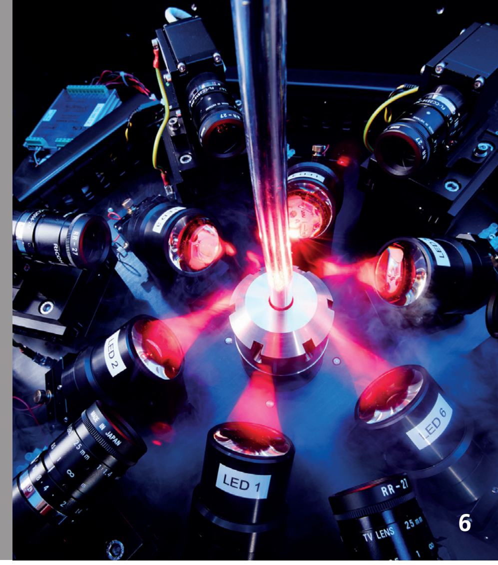
The Fraunhofer-Gesellschaft concentrates on research in the following fields:

- Materials technology, component behavior
- Production and manufacturing technology
- Information and communication technology
- Microelectronics, microsystems engineering
- Sensor systems, testing technology
- Process engineering
- Energy and construction engineering, environmental and health research
- Technical/economic studies, information transfer









FRAUNHOFER-GROUP LIGHT & SURFACES

Competency by networking

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

Core competencies of the group

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

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

1 Fraunhofer IWS
2 Fraunhofer IOF
3 Fraunhofer FEP
4 Fraunhofer ILT
5 Fraunhofer IST
6 Fraunhofer IPM

Contact

- Prof. Reinhart Poprawe (Chairman)
  reinhart.poprawe@ilt.fraunhofer.de
- Dr. Arnold Gillner (Managing Director)
  arnold.gillner@ilt.fraunhofer.de

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

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

The Fraunhofer FEP works on innovative solutions in the fields of vacuum coating, surface treatment as well as organic semiconductors. The core competencies electron beam technology, sputtering, plasma-activated deposition and high-rate PECVD as well as technologies for organic electronics and IC/system design provide a basis for these activities. Fraunhofer FEP continuously enhances them and makes them available to a wide range of industries: mechanical engineering, transport, biomedical engineering, architecture and preservation, packaging, environment and energy, optics, sensor technology and electronics as well as agriculture. www.fep.fraunhofer.de/en

Fraunhofer Institute for Laser Technology ILT

With more than 400 employees the Fraunhofer ILT develops innovative laser beam sources, laser technologies, and laser systems for its partners from the industry. Our technology areas cover the following topics: laser and optics, medical technology and biophotonics, laser measurement technology and laser material processing. This includes laser cutting, caving, drilling, welding and soldering as well as surface treatment, micro processing and additive manufacturing. Furthermore, the Fraunhofer ILT is engaged in laser plant technology, process control, modeling as well as in the entire system technology. www.ilt.fraunhofer.de/en

Fraunhofer Institute for Applied Optics and Precision Engineering IOF

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

Fraunhofer Institute for Physical Measurement Techniques IPM

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

Fraunhofer Institute for Surface Engineering and Thin Films IST

As an innovative R&D partner the Fraunhofer IST offers complete solutions in surface engineering which are developed in cooperation with customers from industry and research. The IST's »product« is the surface, optimized by modification, patterning, and/or coating for applications in the business units mechanical engineering, tools and automotive technology, aerospace, energy and electronics, optics, and also life science and ecology. The extensive experience of the Fraunhofer IST with thin-film deposition and film applications is complemented by excellent capabilities in surface analysis and in simulating vacuum-based processes. www.ist.fraunhofer.de/en

Fraunhofer Institute for Material and Beam Technology IWS

The Fraunhofer IWS is known for its innovations in the business units joining and cutting as well as in the surface and coating technology. Across all business units our interdisciplinary topics include energy storage systems, energy efficiency, additive manufacturing, lightweight construction and big data. Our special feature is the expertise of our scientists in combining the profound know-how in materials engineering with the extensive experience in developing system technologies. Every year, numerous solutions with regard to laser material processing and coating technology have been developed and have found their way into industrial applications. www.iws.fraunhofer.de/en

FRAUNHOFER PROJECTS

Kick-off of the Fraunhofer focus project »futureAM« on November 14, 2017 in Aachen.

FRAUNHOFER FOCUS PROJECT »futureAM«

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

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

Strategic goals of the project partnership

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

Fields of activity

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

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

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

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

Contact and overall coordinator

Prof. Johannes Henrich Schleifenbaum
Telephone +49 241 8906-398
johannes.henrich.schleifenbaum@ilt.fraunhofer.de

www.futuream.fraunhofer.de/en.html

START OF THE FRAUNHOFER LIGHTHOUSE PROJECT »QUILT«

The second quantum revolution

The discovery of quantum mechanics is one of the most momentous achievements of humanity. Not only does it provide access to the macro world of stars and galaxies, but also to the world of molecules, atoms and subatomic building blocks. As far as the latter is concerned, billions of electronic transistors penetrate living and working worlds, whether as computers, smartphones, but also as control systems of modern cars and inconspicuous kitchen appliances. Countless photons and optics network our world to the last corner of the globe. Quantum physics is the basis of many modern technologies. For example, the first generation of quantum technologies is the foundation of semiconductor and laser technology.

A radically new paradigm is increasingly moving into the focus of quantum physics: While previously properties of collective quantum systems were exploited, now individual quantum states can be prepared, controlled and used. To take advantage of this research, the Fraunhofer-Gesellschaft is excellently positioned in the field of quantum imaging along with its institutes and partners from science and industry.

Quantum optical application research

The Fraunhofer lighthouse project »QUILT« (Quantum Methods for Advanced Imaging Solutions) bundles outstanding scientific expertise, technology platforms and great market knowledge of six Fraunhofer institutes, including Fraunhofer ILT, with the scientific excellence of the world's leading quantum technology institutions such as the Institute of Quantum Optics and Quantum Information (IQOQI) of the Austrian Academy of Sciences, and the Max Planck Institute for the Physics of Light (MPG MPL). In close collaboration with the world's best research groups in the field of quantum imaging, QUILT consortium has set itself the following mission:

1. To provide original scientific contributions to three research domains of quantum imaging and to conduct five excellent lighthouse experiments.
2. To network and adapt the outstanding technology platforms of its partners to achieve technology leadership in four key quantum technologies.
3. To establish quantum technology as an interdisciplinary field of excellence in the Fraunhofer-Gesellschaft and to anchor it in an open and lively research school.
4. Make the Fraunhofer-Gesellschaft the most important player in quantum optical application research, secure a strong presence in all important funding initiatives, open up new fields of application and develop innovative solutions with quanta for global industries.

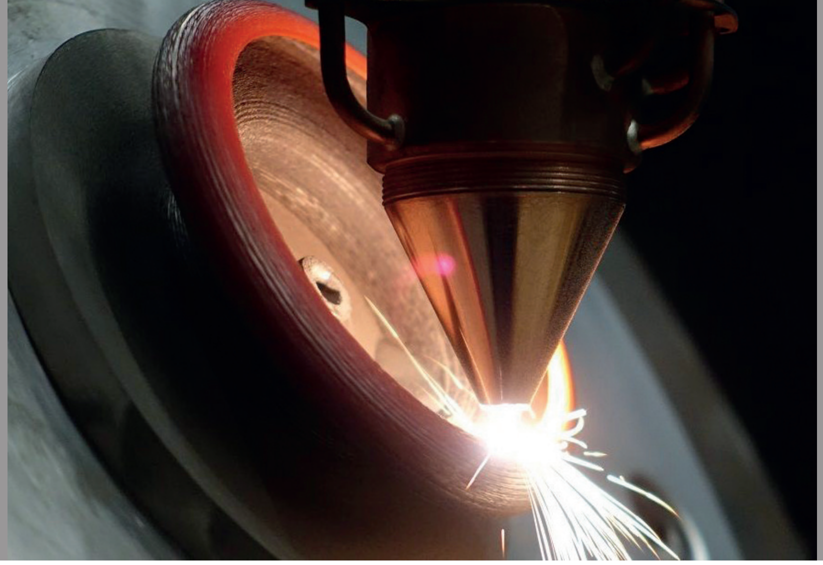
The project started in October 2017. The participating institutes are Fraunhofer IOF (Coordinator), Fraunhofer ILT, IMS, IOSB, IPM and Fraunhofer ITWM.

Contact at Fraunhofer ILT

Dipl.-Ing. Hans-Dieter Hoffmann
Telephone +49 241 8906-206
hansdieter.hoffmann@ilt.fraunhofer.de

Source and further information on the Internet at: www.fraunhofer.de/en.html

FRAUNHOFER ALLIANCES AND CENTERS OF EXCELLENCE



Robot-based Additive Manufacturing with Laser Material Deposition.

FRAUNHOFER ALLIANCES

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

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

CENTERS OF EXCELLENCE

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

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

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

Contact at Fraunhofer ILT

Dr. Alexander Olowinsky
Telephone +49 241 8906-491
alexander.olowinsky@ilt.fraunhofer.de

Further information at: www.fraunhofer.de/en.html

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 30 industrial partners are turbine manufacturers as well as groups and medium-sized companies, which together cover all areas of the process chain. The center focuses on the research around the repair and production of turbomachinery. The research center was founded without any state funding and is thus one of the few independent networks that emerged from the Fraunhofer innovation clusters »TurPro« and »ADAM«. The ten-member steering committee comprises representatives of the participating industrial companies and research institutes.

Contact at Fraunhofer ILT

Dr. Andres Gasser
Telephone +49 241 8906-209
andres.gasser@ilt.fraunhofer.de

Further information at: www.ictm-aachen.com

CLUSTER OF EXCELLENCE

In the Cluster of Excellence »Integrative Production Technology for High-Wage Countries«, Aachen-based production and material scientists developed concepts and technologies for sustainable economic production. A total of 18 chairs of RWTH Aachen University as well as the Fraunhofer Institutes for Laser Technology ILT and Production Technology IPT are involved in the project, which ran until the end of 2017. The cluster of excellence, worth around 40 million euros, was the most comprehensive research initiative in Europe that aimed to keep production in high-wage countries.

To do this, the partners had to find ways of simultaneously increasing the product variability and manufacturing at the cost of mass production. This required product-oriented, value-optimized process chains whose cost-effectiveness is not jeopardized by excessive planning costs. Tomorrow's production technology, therefore, needs a fundamentally new understanding of these elementary interrelations, each of which was developed as part of the Cluster of Excellence in the four fields of research: »Individualized Production«, »Virtual Production«, »Hybrid Production« and »Self-Optimizing Production«.

Contact at Fraunhofer ILT

Dipl.-Phys. Christian Hinke
Telephone +49 241 8906-352
christian.hinke@ilt.fraunhofer.de

Further information at: www.rwth-aachen.de

LASER TECHNOLOGY AT RWTH AACHEN UNIVERSITY

JOINTLY SHAPING THE FUTURE

The RWTH Aachen University Chairs for Laser Technology LLT, the Technology of Optical Systems TOS and Digital Additive Production DAP as well as Nonlinear Dynamics of Laser Processing NLD and Experimental Physics of Extreme Ultraviolett EUV 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 three chairs and at Fraunhofer ILT. University courses are drawn up jointly as well. Teaching, research and innovation – those are the bricks with which the five university departments and Fraunhofer ILT are building the future.

Chair for Laser Technology LLT

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

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

Present topics of research:

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

Prof. Reinhart Poprawe (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. The performance of fiber lasers and diode-pumped solid state lasers, for instance, is determined by optical coupling and pump light homogenizers. Free-form optics for innovative laser beam shaping are yet another topic of research. In the area of high-power diode lasers, micro- and macro-optical components are developed and combined to form complete systems. In addition, assembly techniques are optimized.

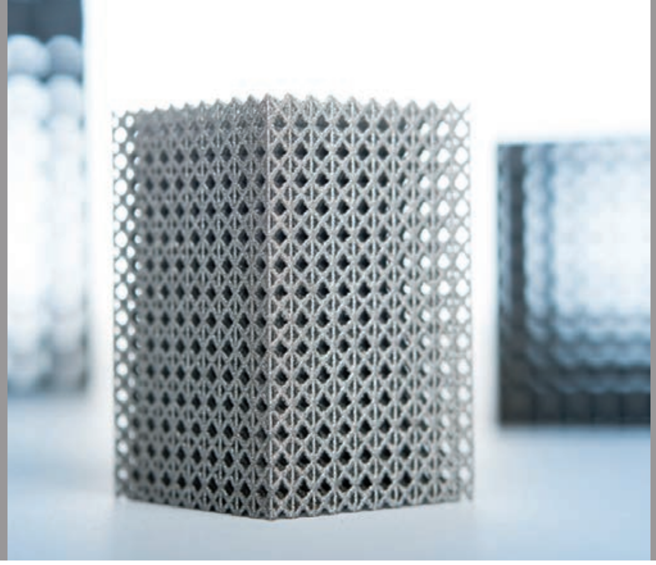
Prof. Peter Loosen (Director of the chair)
www.tos.rwth-aachen.de

Chair for Digital Additive Production DAP

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

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

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



Chair for Nonlinear Dynamics of Laser Processing NLD

Founded in 2005, the chair for Nonlinear Dynamics of Laser Processing NLD explores the basic principles of optical technology, with emphasis on modeling and simulation in the fields of application macro welding and cutting, 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 (Director of the chair)
www.nld.rwth-aachen.de

Chair for the Experimental Physics of Extreme Ultraviolet EUV

The spectral range of extreme ultraviolet radiation (extreme ultraviolet, EUV or XUV, 1 - 50 nm) offers the advantages of short wavelengths and strong interactions between light and material with atomic resonances. This allows both lateral and depth resolutions in the nanometer region with element-specific contrasts.

The Chair for the Experimental Physics of Extreme Ultraviolet EUV, founded in 2012 in RWTH Aachen University's Physics department, conducts research into various aspects of EUV radiation. These range from beam production and characterization, through wave propagation and interactions with materials, to specific applications and development of relevant methods. Two areas are of particular interest in all this: high-brilliance sources and interference lithography.

The research activities are embedded in the JARA-FIT section of the Jülich Aachen Research Alliance and are carried out in cooperation with the Peter Grünberg Insitute for Semiconductor Nanoelectronics at Forschungszentrum Jülich, with Fraunhofer ILT and the Chair for the Technology of Optical Systems TOS.

Prof. Larissa Juschkin (Director of the chair)
www.euv.rwth-aachen.de

DIGITAL PHOTONIC PRODUCTION DPP

Digital Photonic Production – the Future of Production

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

Mass Customization

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

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

Digital Photonic Production Research Campus

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

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

RWTH AACHEN CAMPUS

RWTH AACHEN CAMPUS

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

Research catalyst and innovation generator

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

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

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

Development and timetable

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

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

At the moment, the university is concentrating on the next thematic cluster, which will see the development of Campus Westbahnhof with four clusters and focus on the growth of 16 clusters in Melaten and the Westbahnhof. The infrastructure, for example, will be upgraded by the construction of a congress hall, library and hotels. The relevant future topics for industry and society will be tackled in all 16 clusters. More than 360 companies are already involved in the RWTH Aachen Campus.

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

PHOTONICS CLUSTER

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

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

2018 will see a further infrastructure project open: the Research Center Digital Photonic Production DPP, funded by the federal government and the state of NRW for interdisciplinary cooperation in the field of digital photonic production. The topping-out ceremony of the new building took place on May 24, 2016 in the presence of Thomas Rachel, congressman and state secretary of the Federal Ministry of Education and Research (BMBF) and Prof. Ernst Schmachtenberg, the rector of RWTH Aachen University. On an area of 4,300 square meters, 16 institutes of the RWTH Aachen University from 6 faculties will tackle the interdisciplinary and integrated research of digital photonic production chains.

The two buildings of the Photonics Cluster – Research Building DPP and Industry Building DPP – are the starting point for further investments on site and, in addition to initiatives such as the BMBF Research Campus DPP, include specialized centers such as the ACAM Aachen Center for Additive Manufacturing or individual companies that promote innovative photonic technologies on location. These include large corporations such as Philips, MTU or Siemens as well as medium-sized companies and spin-offs of Fraunhofer ILT. The Photonics Cluster is thus the ideal spring board for research and development, education and training, innovation and networking in the field of optical technologies.

Contact

Prof. Reinhart Poprawe (Head of the Photonics Cluster)
Telephone +49 241 8906-109
reinhart.poprawe@ilt.fraunhofer.de

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

PHOTONICS CLUSTER

RESEARCH CENTER DPP

Research Center Digital Photonic Production

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

In 2014, 15 institutes and chairs of the RWTH Aachen University, headed by the Chair for Laser Technology LLT, received funding for the construction of a »Research Center Digital Photonic Production DPP«. 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 building of the Research Center DPP is to be put into operation in 2018. Up to 96 people will be able to conduct basic research in the field of photonics on about 4,300 square meters of usable floor area, including 2,800 square meters of laboratory, clean room and hall areas.

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

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

Contacts

Roman Flaig M.Sc.
Telephone +49 241 8906-646
roman.flaig@ilt.fraunhofer.de

Dipl.-Phys. Christian Hinke
Telephone +49 241 8906-352
christian.hinke@ilt.fraunhofer.de

INDUSTRY BUILDING DPP

Industry Building Digital Photonic Production

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

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

Partners from Industry

- 4JET Technologies GmbH
- Access e.V.
- AixPath GmbH
- Aixtooling GmbH
- AMPHOS GmbH
- BMW AG
- EdgeWave GmbH
- Exapt Systemtechnik GmbH
- EOS GmbH
- Fionec GmbH
- Innolite GmbH
- LighFab GmbH
- ModuleWorks GmbH
- MTU Aero Engines AG
- PHILIPS
- Pulsar Photonic GmbH
- Siemens AG
- SLM Solutions GmbH
- TRUMPF Laser- und Systemtechnik GmbH

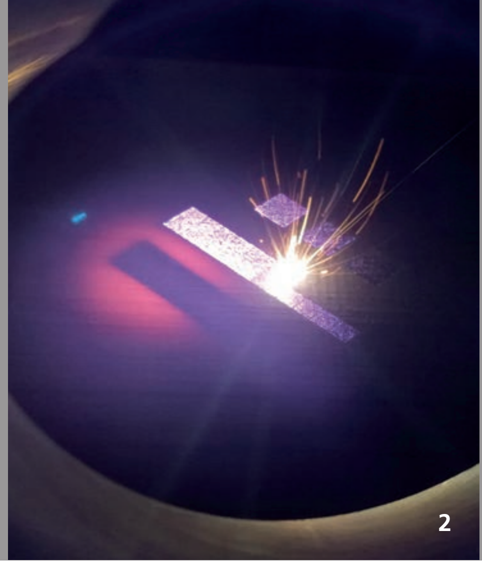
Contact

Dipl.-Phys. Christian Hinke
Telephone +49 241 8906-352
christian.hinke@ilt.fraunhofer.de

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

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

BMBF RESEARCH CAMPUS



BMBF RESEARCH CAMPUS »DIGITAL PHOTONIC PRODUCTION DPP«

Goals and tasks

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

Contact

Dipl.-Phys. Christian Hinke
Telephone +49 241 8906-352
christian.hinke@ilt.fraunhofer.de

Road mapping process

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

Joint working groups

The cooperation at the Research Campus DPP is organized along the technology roadmaps in joint working groups with scientists from the scientific community and the industry. The following five working groups have been established:
- DPP Direct
- DPP Femto
- DPP Nano
- DPP MaGeoOptics
- DPP Digital Photonic Process Chain

DPP Direct

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

DPP Femto

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

DPP Nano

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

DPP MaGeoOptics

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

DPP Digital Photonic Process Chain

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

1 Meeting space in the light-flooded atrium of the Industry Building DPP.

2 DPP Nano: Selective preheating by means of VCSEL in Laser Powder Bed Fusion (LPBF).

SPIN-OFFS

Networks and infrastructure

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

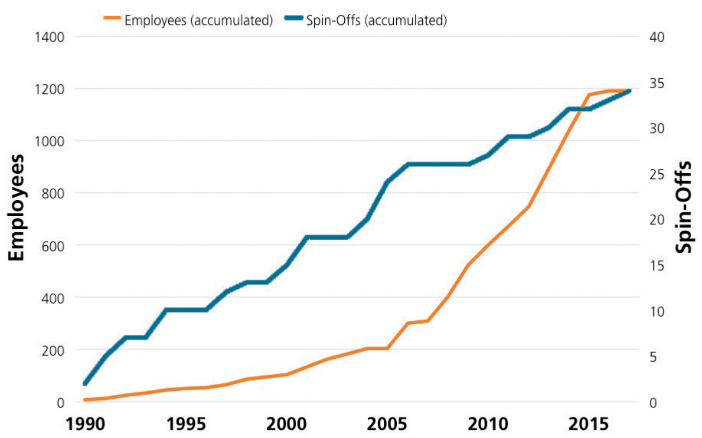
The DPP Research Campus forms the platform for intensive exchange with companies, institutes and consultants involved in the field of photonic production. Co-creation areas and open innovation concepts are also used at the research campus when required. In the DPP Industry Building on the RWTH Aachen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

Supporting services

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

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

Spin-offs since 1990



SPIN-OFFs OF FRAUNHOFER ILT

Intensive spin-off culture at Fraunhofer ILT

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

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

Spin-offs generate added value for the laser industry

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

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

Also in 2017 a company was founded, which, among others, deals with the development of cost-effective 3D printing equipment for metallic components: the Laser Melting Innovations GmbH & Co. KG. The company grew out of a research project between three regional institutions: RWTH Aachen University, Fraunhofer ILT and the Aachen University of Applied Sciences.

1 Clean-Lasersysteme GmbH in Herzogenrath.

2 Laser Melting Innovations GmbH – simple production of individualized metal components.

INITIATIVES

ACAM

ACAM Aachen Center for Additive Manufacturing

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

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

ACAM community meeting on March 21, 2018 at GKN Sinter Metals in Radevormwald.

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

Strategic partners of ACAM

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

RWTH Aachen University:

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

Contact

Prof. Johannes Henrich Schleifenbaum
Telephone +49 241 8906-398
johannes.henrich.schleifenbaum@ilt.fraunhofer.de

Further information at: www.acam.rwth-campus.com

AACHENER CENTER FOR 3D PRINTING

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

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

Contact

Dr. Sebastian Bremen (Fraunhofer ILT)
Telephone +49 241 8906-537
sebastian.bremen@ilt.fraunhofer.de

Prof. Andreas Gebhardt (FH Aachen)
Telephone +49 241 6009 52500
gebhardt@fh-aachen.de

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

MEDLIFE E.V.

MedLife is the network of life sciences in the Technology Region Aachen. Currently, more than 80 members are involved in this regional industry association. MedLife offers events and services for the medical technology, biotechnology, pharmaceutical and healthcare industries. The network is the contact for entrepreneurs and scientists who are looking for an exchange with other life science actors and competent advice and support for innovative projects and business ideas.

In addition to the MedLife e.V., the affiliated limited liability company (GmbH) deals with the management of clusters and funding projects and offers services such as business and innovation consulting. Fraunhofer ILT is actively involved in MedLife e.V. Since the general meeting on March 7, 2016, Dr. Arnold Gillner, the competence area manager of Ablation and Joining at Fraunhofer ILT, is the spokesman of the advisory board of the MedLife e.V.

Contact

Dr. Arnold Gillner
Telephone +49 241 8906-148
arnold.gillner@ilt.fraunhofer.de

Further information at: www.medlife-ev.de/en

Inauguration of the XLine 2000R on June 1, 2017 at the Aachen Center for 3D Printing. From left to right: Prof. Doris Samm and Prof. Andreas Gebhardt (FH Aachen), Prof. Reinhart Poprawe (ILT)

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, for example, can receive support in all aspects of additive manufacturing. In the life sciences too, Fraunhofer ILT is well networked via the MedLife e.V. The trade association IVAM e.V. allows ILT access to numerous experts in microtechnology. In the NanoMicroMaterialsPhotonic.NRW state cluster, Fraunhofer ILT is involved in the fields of nanotechnology, photonics and microsystem technology.

NATIONAL COOPERATIONS

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

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

NETWORKED INTERNATIONALLY

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

Contact

Dipl.-Phys. Axel Bauer
Telephone +49 241 8906-194
axel.bauer@ilt.fraunhofer.de

ARBEITSKREIS LASERTECHNIK E.V.

AKL
ARBEITSKREIS LASERTECHNIK e.V.

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

Tasks of the AKL e.V.

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

Currently, AKL e.V. has about 170 members. The personal communication between the members forms the backbone of the association. On 1 January 2017, Axel Bauer, who headed the association for 15 years as CEO, handed over the baton to his successor, Dr. Hartmut Frerichs. The board of AKL e.V. consists of Ulrich Berners (chairman), Prof. Reinhart Poprawe (deputy chairman) and Dr. Bernd Schmidt (treasurer).

Innovation Award Laser Technology

Every two years, the Arbeitskreis Lasertechnik e.V. and the European Laser Institute ELI e.V. bestow the Innovation Award Laser Technology, worth €10,000. This European prize for applied science is aimed at both individuals and project teams whose skills and commitment have led to an outstanding innovation in the field of laser technology. The ten-man international jury nominated three outstanding finalists in 2016:

- 1st place: Dr. Ir. Armand Pruijmboom, Philips GmbH Photonics. Topic: VCSEL arrays: A new high-performance laser technology for »digital heat treatment«
- 2nd place: Dr.-Ing. Jan-Philipp Weberpals, AUDI AG. Topic: Laser-beam remote welding of aluminum for lightweight automotive construction
- 3rd place: Dr. rer. nat. Ralph Delmdahl, Coherent Laser Systems. Topic: UVblade – serial production of flexible displays

Contact

Dr. Hartmut Frerichs
Telephone +49 241 8906-420
hartmut.frerichs@akl-ev.de

Further information at: www.akl-ev.de

EVENTS AND PUBLICATIONS

PATENTS

PATENTS GERMANY

DE 10 2013 008 085 B4 Verfahren und Vorrichtung zum Fügen von Werkstücken mit einem Bearbeitungsstrahl

DE 10 2009 038 590 B4 Verfahren zur Bearbeitung von Material/Werkstücken mit Laserstrahlung

DE 10 2010 008 781 B4 Verfahren zur schichtweisen Fertigung von Bauteilen, sowie Verfahren zur schichtweisen Fertigung von Bauteilen

DE 10 2015 224 534 B4 Verfahren zur Erzeugung von extremer Ultraviolett- und/oder weicher Röntgenstrahlung

DE 10 2014 007 159 B4 Verfahren und Anordnung zur spektralen Verbreiterung von Laserpulsen für die nichtlineare Pulskompression

DE 10 2013 011 676 A1 Verfahren und Vorrichtung zur generativen Bauteilfertigung

DE 10 2009 059 894 B4 Optische Anordnung zum optischen Pumpen eines aktiven Mediums

DE 10 2013 014 069 B3 Verfahren zur Laserbearbeitung eines Werkstücks mit polierter Oberfläche und Verwendung dieses Verfahrens

PATENTS EUROPE

EP 2 909 007 B1 Verfahren und Vorrichtung zur generativen Bauteilfertigung

EP 3 036 061 B1 Verfahren zur Laserbearbeitung eines Werkstücks mit polierter Oberfläche und Verwendung dieses Verfahrens

EP 2 683 521 B1 Verfahren zur Herstellung optischer Komponenten durch Bearbeitung mit energetischer Strahlung

39
Bachelor theses in 2017

PATENTS
20 patents, 23 patent applications in 2017

98
Scientific lectures in 2017

46
Master theses in 2017

118 Publications

PATENTS

PATENTS USA

9 827 632 Verfahren und Vorrichtung zur generativen Bauteilfertigung

9 847 615 Verfahren und Anordnung zur spektralen Verbreiterung von Laserpulsen für die nichtlineare Pulskompression

9 592 570 Laser processing apparatus

9 589 783 Verfahren zur Verbesserung der Benetzbarkeit einer rotierenden Elektrode in einer Gasentladungslampe

PATENTS CHINA

CN102112266 B Verfahren und Vorrichtung zum Schweißen von Werkstücken aus hochwarmfesten Superlegierungen

CN105228790 B Verfahren zum Abtragen von sprödhartem Material mittels Laserstrahlung

CN106163733 B Laserauftragschweißen von hochwarmfesten Superlegierungen mittels oszillierender Strahlführung

CN103658978 B Laser processing apparatus

PATENTS TAIWAN

I584696 Method and device for generating optical radiation by means of electrically operated pulsed discharges

PATENT APPLICATIONS GERMANY

10 2017 201 679.5 Verfahren zum Fügen von Bauteilen auf eine Trägerstruktur unter Einsatz von elektromagnetischer Strahlung

15/487,563 Ferroelectric element and method of manufacturing ferroelectric element

10 2017 206 843.4 Veränderung der Leistung beim Wobbeln

10 2017 119 697.8 Monitoring of tissue coagulation by optical reflectance signals

10 2017 130 241.7 Laserbasiertes Verfahren zur Herstellung funktionaler Beschichtungen aus partikulären Hochleistungspolymeren

10 2017 210 241.1 Optische Anordnung zur Umformung des Intensitätsprofils eines optischen Strahls

10 2017 116 140.6 Synchronisation von Werkzeug und Werkstück bei der Laserbearbeitung

10 2017 208 616.5 Verfahren zur Verringerung der Reibung aneinander gleitender und/oder rollender Flächen

10 2017 210 703.0 Vorrichtung zum Laserauftragsschweißen

10 2017 007 219.1 Verfahren zur Herstellung einer transmittiven oder reflektiven Optik

10 2017 207 262.8 Verfahren und Vorrichtung zur Bereitstellung einer eine gewünschte Zielprotein-Expression aufweisenden Zelllinie

10 2017 219 435.9 Verfahren zur Beschichtung einer metallischen Oberfläche mit einem metallischen Material

17 198 712.6 Verbesserung der Oberflächenqualität von SLM-Bauteilen durch Pulverentfernung im Prozess

17 001 479.9 Vorrichtung und Verfahren zur Materialbearbeitung

PATENT APPLICATIONS EUROPE

PCT/EP2017/063360 Verfahren und Vorrichtung zur generativen Fertigung von Bauteilen

PCT/EP2017/062360 Verfahren und Vorrichtung zur Prozessüberwachung bei der generativen Fertigung von Bauteilen

PCT/EP2017/076492 Verfahren zur werkzeuglosen Entfernung von Stützstrukturen bei der generativen Fertigung von Bauteilen

PCT/EP2017/078739 Vorrichtung und Verfahren zur generativen Bauteilfertigung mit mehreren räumlich getrennten Strahlführungen

PCT/EP2017/070916 Verfahren zur Bearbeitung einer Werkstoffschicht mit energetischer Strahlung variabler Energieverteilung

PCT/EP2017/070931 Hybrider Werkstoffverbund zwischen einer Metalloberfläche und einer polymeren Materialoberfläche sowie Verfahren zur Herstellung des hybriden Werkstoffverbundes

PCT/EP2017/078738 Verfahren und Vorrichtung zur Bearbeitung einer Werkstoffschicht mit energetischer Strahlung

PCT/EP2017/054185 A method of sintering, crystallizing and/or crosslinking of a coating material on a substrate

PCT/EP2017/064973 Optischer Scanner

DISSERTATIONS

DISSERTATIONS

26.1.2017 – Girum Beyene (Dr. rer. nat.)
Studies on laser-triggered discharge plasmas as extreme ultraviolet light sources

16.2.2017 – Michal Odstrcil (Dr. rer. nat.)
Coherent diffractive imaging using table-top sources

10.3.2017 – Sebastian Bremen (Dr.-Ing.)
Korrelation der High Power SLM-Prozessführung mit der Produktivität, Effizienz und den Materialeigenschaften für den Werkstoff Inconel 718

26.4.2017 – Johannes Weitenberg (Dr. rer. nat.)
Transversale Moden in optischen Resonatoren für Anwendungen hoher Laserintensität

19.6.2017 – Simon Britten (Dr.-Ing.)
Bauteilschonende Verbindungstechnik auf Metallisierungen durch moduliertes Laserstrahlschweißen

21.6.2017 – Ralf Freiberger (Dr. rer. nat.)
Realisierung eines hochauflösenden EUV-Mikroskops mit einer optimierten Gasentladungsquelle zum Betrieb mit Wellenlängen um 17 nm zur Mikroskopie an M-Kanten von Elementen

14.7.2017 – Johannes-Thomas Finger (Dr.-Ing.)
Puls-zu-Puls-Wechselwirkungen beim Ultrakurzpuls-Laserabtrag mit hohen Repetitionsraten

21.8.2017 – Oliver Nottrodt (Dr.-Ing.)
Polygonscannerbasierte Hochleistungs-Ultrakurzpuls-Laserstrukturierung

8.9.2017 – Ulrich Witte (Dr. rer. nat.)
Erhöhung der Strahldichte von Hochleistungs-Diodenlaserbarren mittels dielektrischer Kantenfilter

13.11.2017 – Christoph Meinhardt (Dr. rer. nat.)
Elementspezifische Analyse primärverzunderter Stranggussstähle mit Laser-Emissionsspektroskopie

18.12.2017 – Christian Weingarten (Dr.-Ing.)
Laserbasierte Formkorrektur von optischen Gläsern

19.12.2017 – Florian Eibl (Dr.-Ing.)
Laser Powder Bed Fusion of Stainless Steel with Power Multi-Diode-Laser-Array

20.12.2017 – Christian Nüsser (Dr.-Ing.)
Lasermikropolieren von Metallen

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

EVENTS

Well attended: the Fraunhofer ILT booth at the LASER World of PHOTONICS with a model of the Ariane 5 rocket as an eye-catcher.

LASER WORLD OF PHOTONICS 2017

Fraunhofer ILT shows laser technology for increased productivity as well as environmental and health protection

From June 26 to 29, 2017, the laser community met for the LASER World of PHOTONICS in Munich. Fraunhofer ILT was again represented with more than 50 exhibits from the different areas of applied laser technology and beam source development: from diode and fiber lasers, to new measuring technology, to complete machines for additive processes or even laser systems for space. With over 32,000 visitors and almost 1,300 exhibitors, LASER World of PHOTONICS set new records. The mood in Munich was correspondingly positive, and the fair was also a great success for Fraunhofer ILT.

Space-qualified lasers for climate protection

High-precision laser-based measurement technology was also one of the highlights at the Fraunhofer ILT booth. A six-meter model of the Ariane 5 rocket made a clear reference to the Franco-German climate mission »MERLIN«. The small satellite MERLIN (Methane Remote Sensing LIDAR mission) will be launched in 2023 from Kourou, French Guiana, into space to map methane in the earth's atmosphere. The greenhouse gas is 25 times more harmful to the climate than carbon dioxide, and in the past ten years its concentration has increased at a surprisingly fast pace. Among other things, it is stored in the ocean floor in the form of methane hydrate as ice. If the water warms up and thus the seabed, the hydrates could disintegrate and release the methane – with fatal consequences for the climate. Therefore, it is of great importance to measure where and in what amount methane is released into the earth's atmosphere. Researchers at Fraunhofer ILT are developing a new robust »LIDAR system« (light detection and ranging), which sends light pulses into the atmosphere and determines the methane concentration from the light scattered back from the ground and will do so with unprecedented measuring accuracy.

For several years now, the experts at Fraunhofer ILT have been working on new laser systems for the aerospace industry, with partners such as DLR, Airbus Defence and Space, TESAT Spacecom and ESA. With the new Future Laser System »FULAS«, Fraunhofer ILT is thinking beyond individual projects and has set up an entire technology platform. Here, not only can space-suitable components be developed and validated, but also a very own assembly technology: All essential adjustment steps are carried out with manually guided robots in the Pick & Align process.

Award-winning coating process protects the environment and health

For adequate wear protection, components such as paper rolls, brake discs on the car and hydraulic cylinders must be provided with a coating, to date done mostly by hard chrome plating or thermal spraying. A team from Fraunhofer ILT and RWTH Aachen University has developed an alternative coating process using Extreme High-Speed Laser Material Deposition (EHLA), which goes easy both on the environment and health since it does not require chromium (VI). Shortly before the LASER fair, the EHLA process was honored with the Joseph von Fraunhofer Prize. Now it will soon be put in praxis: A first large-scale plant with this technology is located at IHC Vremac Cylinders B.V. in Apeldoorn, Netherlands.

Additive Manufacturing for SMEs

Additive processes such as laser material deposition or 3D printing with metal powders are already industrially viable. However, not every potential user has orders justifying a high six-digit investment in this technology even though small companies have many ideas for using it. A research team from Fraunhofer ILT, RWTH Aachen University and the FH Aachen University of Applied Sciences are working together on a practical solution for small and medium-sized enterprises.

At the LASER World of PHOTONICS, the »Aachen Center for 3D Printing« presented a low-cost system with significantly lower production costs than is the case with conventional systems. In addition to a diode laser with 140 W power, the four-axis system includes a protective gas device and open-source control software. There was a great deal of interest at the fair: Both small machine and toolmakers enquired about the system as did experienced users who want to qualify new materials with the low-cost system.

In addition to the affordable machine, the experts also offer two- to five-day training seminars for participants to acquire the necessary know-how. Then, the users will be able to fully exploit the potential of the low-cost system with various metal powders.

Great interest in the Fraunhofer ILT stand at the LASER World of PHOTONICS in Munich.

Process technology is becoming more important

Thanks to the wide range of topics – from laser processing in lightweight construction via ultrashort pulse processing to 3D bioprinting – Fraunhofer ILT has been able to gain numerous new contacts and deepen existing ones. Discussions with the trade fair visitors have also confirmed the trend towards Industry 4.0. For the laser user, the full utilization of all process data, thus digitally networked, laser-assisted production, is becoming increasingly important. In the future, the laser industry will increasingly focus its attention on process technology. The Aachen scientists are taking this trend into account by focusing more on process control, among other things.

Miniature edition of the Aachen Cathedral, produced with the low-cost SLM system of the »GoetheLab for Additive Manufacturing« of the FH Aachen University of Applied Sciences in cooperation with Fraunhofer ILT.

Prof. Johannes Henrich Schleifenbaum at the ICTM 2017.

Dr. Arnold Gillner, Fraunhofer ILT, (left) and Prof. Thomas Graf, IFSW University Stuttgart, (right) at the 4th UKP Workshop at the Tivoli Center in Aachen.

EVENTS

February 2, 2017, Aachen
7th IHK Business Day with the Aachen Center for 3D printing
Additive manufacturing as an opportunity for the economy – design, manufacturing, post-treatment, costs

- Organized by the Chamber of Commerce and Trade (IHK) Aachen in cooperation with the Aachen Center for 3D Printing, a cooperation of Fraunhofer ILT and the FH Aachen University for Applied Sciences
- Small and medium-sized companies were able to find out about the opportunities offered by additive manufacturing processes from technology experts of the Aachen Center for 3D Printing in individual appointments

February 15–16, 2017, Aachen
4th Conference of the ICTM – International Center for Turbomachinery Manufacturing

- Organized by Fraunhofer ILT and IPT
- Networking platform for experts from central turbomachinery companies
- More than 250 experts from 19 countries participated in the conference
- Speakers from leading companies in the industry reported on current developments and future technologies for the manufacture and application of turbomachinery and its components in aviation and energy generation in 20 lectures
- 44 live demonstrations at Fraunhofer ILT, Fraunhofer IPT and WZL of RWTH Aachen University

April 26–27, 2017, Aachen
4th UKP Workshop: Ultrafast Laser Technology

- Organized by Fraunhofer ILT
- The basics of UKP technology were presented as was an overview of current developments in the field of beam sources as well as the necessary system technology
- Recent laser-based applications and processing methods were introduced, extending the boundaries of previous technologies in terms of processing speed, quality, and material bandwidth
- 22 international speakers and 17 exhibitors at the accompanying tabletop exhibition
- 150 experts from research and industry participated

May 15–16, 2017, Aachen
Industrial Working Group »Process Control in Laser Material Processing – ICPC«

- First informative meeting of the industrial working group
- Initiative of Fraunhofer ILT and IPT
- The participating companies and research institutions aimed to develop best-practice solutions for more process reliability and faster dissemination and use of research results and intensive networking between users and developers

June 1, 2017, Aachen
Inauguration of the SLM facility XLine 2000R of the FH Aachen University of Applied Sciences on the RWTH Aachen Campus

- The »SLM XL« project brings together forces from science and industry to optimize the production of functional proto types and previously unattainable geometrical tool shapes
- Components with dimensions of up to 800 x 400 x 500 mm³ can be manufactured with the world's largest SLM system »XLINE 2000R« (manufacturer: Concept Laser GmbH)
- Thanks to this commissioning, Fraunhofer ILT and FH Aachen are strengthening their successful cooperation in the field of Additive Manufacturing at the Aachen Center for 3D Printing

September 19, 2017, Aachen
Workshop – New coating techniques:
Laser-based gilding
- Organized by Fraunhofer ILT
- Workshop presenting the laser-based process, the coating materials used, the prototype equipment and the components produced with it first-hand
- Discussion about the potential the process has for the respective industries as well as the necessary requirements and developments for its enhancement
- Applications: Electrical contact refinement (e.g. audio, video, data, etc.), anti-corrosive contact and component refinement, decoration of premium consumer products (e.g. lettering on metal hangers, dials, etc.), surface technology, medical technology

September 27–28, 2017, Aachen
Fachtagung »3D Valley Conference 2017«
- Organized by TEMA Technology Marketing AG and the ACAM Aachen Center for Additive Manufacturing in cooperation with Fraunhofer ILT and the FH Aachen University of Applied Sciences
- Topic: Industrial applications, new process development, integrated process chains and innovative business models in the use of additive manufacturing
- Fraunhofer ILT participated in conference-accompanying exhibition
- Seminar and lecture by Dr. Sebastian Bremen and Moritz Alkhayat, Fraunhofer ILT

COLLOQUIUM LASER TECHNOLOGY AT RWTH AACHEN

July 13, 2017 – Chair for Laser Technology LLT
Dr. Eric Jägle, Max-Planck-Institut Institut für Eisenforschung
»Alloys for AM, alloys by AM«

August 14, 2017 – Chair for Laser Technology LLT
Dr. Oleg Pronin, Max Planck Institute of Quantum Optics
»Femtosecond Ho: YAG thin-disk oscillator enabling two-octave 5-20 µm frequency comb generation«

November 2, 2017 – Chair for Laser Technology LLT
Prof. Matthias Wuttig, Institute of Physics (IA) at RWTH Aachen University
»Phase change materials: ultrafast switchable optical and electronic properties«

November 30, 2017 – Chair for Laser Technology LLT
Prof. Olexander Byelyayev, Institute of Semiconductor Physics NAS of Ukraine
»Optical sensor and nanomaterials at the Institute of Semiconductor Physics, Kiev Ukraine«

December 14, 2017 – Chair for Laser Technology LLT
Prof. Jeremy Witzens, Chair for Integrated Photonics at RWTH Aachen University
»Silicon Photonics in Optical Communications and Life Sciences«

Lively exchange during Business Speed Dating at the 56th Aix-Laser-People meeting in Munich.

56th Aix-Laser-People Meeting in the Seehaus in Munich on the occasion of the LASER World of PHOTONICS.

AIX-LASER-PEOPLE

June 28, 2017, Munich
56th Aix-Laser-People meeting at LASER World of PHOTONICS
For the ninth time, this alumni meeting took place during the LASER World of Photonics in Munich. Around 200 participants, including almost 100 AKL e.V. members and alumni of Fraunhofer ILT and its university chairs, came together in the Seehaus in the city's English Garden. There, they were welcomed by Prof. Poprawe, Deputy Chairman of the AKL e.V., together with the new Managing Director Dr. Hartmut Frerichs, who took the opportunity to introduce himself.

At this year's »Business Speed Dating«, 20 laser experts from various industries and scientists from the Fraunhofer ILT surroundings exchanged information and news in the groups »Industry meets Industry« and »Industry meets Science«. This time, the so-called »Make-a-Match Initiative« was new for the alumni. In addition to a total of 46 posted job advertisements in the field of laser technology, interested doctoral students or masters were given initial contacts with well-known companies in the laser industry looking for qualified employees. The initiative was very well received and will be continued at the next opportunity.

At the concluding get-together in a relaxed atmosphere, Ulrich Berners, chairman of the AKL e.V., bid farewell to Stefanie Flock and thanked her for her many years of work in the committee's office.

December 21, 2017, Herzogenrath
57th Aix-Laser-People meeting at the Fraunhofer spin-offs Lunovu and AMPHOS
At the end of the year, the Arbeitskreis Lasertechnik e.V. invited participants to an alumni meeting in the Herzogenrath Technology Park. There, Dr. Frerichs, managing director of AKL e.V., greeted the host companies Lunovu and AMPHOS as well as the numerous participants. Afterwards, Dr. Claus Schnitzler (AMPHOS GmbH) and Dr. Rainer Beccard (LUNOVU GmbH) presented their companies. Both are spin-offs of Fraunhofer ILT and have successfully established themselves on the market in recent years. In two groups, the participants were then able to visit the laboratories and several live demonstrations. In the evening, the event came to a close at Fraunhofer ILT, where networking was the main focus apart from the professional exchange.

Contact

Dr. Hartmut Frerichs
Telephone +49 241 8906-420
hartmut.frerichs@akl-ev.de

Further information at: www.akl-ev.de

Prof. Reinhart Poprawe at the SPIE Photonics West in San Francisco.

Fraunhofer ILT at the JEC World Composites 2017 in Paris.

productronica 2017: large crowds at the Fraunhofer joint stand.

TRADE FAIRS

January 28 - February 2, 2017, San Francisco, USA
SPIE Photonics West
International Trade Fair for Optics and Photonics
Presented at the joint booth of the Federal Republic of Germany, Fraunhofer ILT displayed lasers for satellite-based »LIDAR systems« (»FULAS«), a thermo-mechanically robust »OPO demonstrator« for the »MERLIN« climate mission and a fiber-coupled diode laser module with dense wavelength superposition (EU project »BRIDLE«). In addition, eight lectures were given by Fraunhofer ILT scientists.

March 14–16, 2017, Paris, France
JEC World Composites 2017
International Composites Event
At the joint stand of the Aachen Center for Integrative Lightweight Construction (AZL), Fraunhofer ILT presented laser-based technologies for the processing of composite materials made of plastic and metal:

- Technology for cutting CFRP components up to 10 mm thick (development as part of the »HyBriLight« funded project)
- Industrial solution for non-positive joining of plastic and metal parts
- Presentation of results of the joint project »LaserInsert on laser-based processes for metallic inserts in textile preforms«

March 14–16, 2017, Shanghai, China
LASER World of PHOTONICS China
International Trade Fair for Optics and Photonics
Fraunhofer ILT presented new ideas for the industrial application of lasers at the LASER World of PHOTONICS China. This included self-adjusting spiral optics for ultra-precise drilling and cutting. The Aachen scientists also presented solutions for laser-based micro- and macro-machining of various materials. Also on display was the Laserfact combi-head, which allows high-precision cutting and welding without any retooling required. Co-exhibitors were Laserfact GmbH and ACunity GmbH. In addition, Prof. Reinhart Poprawe and Franz Zibner gave lectures at the 12th International Laser Processing and Systems Conference LPC 2017 in Shanghai.

March 29–30, 2017, Munich
LOPEC 2017
Fair for Printed Electronics
In laser material processing, Fraunhofer ILT offers, for example, innovative solutions for the flexible and high-resolution structuring of thin layers, which are ablated by a laser at high speeds. With adapted wavelengths and pulse durations, special optical properties of organic and inorganic materials can be exploited and utilized for micromachining. This was demonstrated by the Aachen scientists at the »COPT.NRW« booth.

June 20–22, 2017, Erfurt
Rapid.Tech 2017
International Trade Show & Conference for Additive Manufacturing
The Aachen Center for 3D Printing presented itself at the FH Aachen booth. The Aachen Center for 3D Printing is a joint project between Fraunhofer ILT and the FH Aachen University of Applied Sciences with the aim of giving small and medium-sized companies access to the integrated process chain in the field of additive manufacturing.

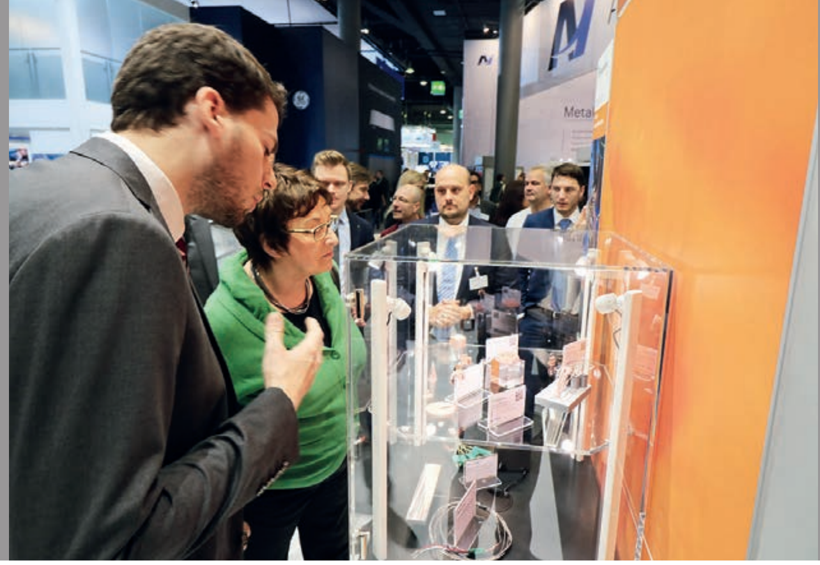
June 26–29, 2017, Munich
LASER World of PHOTONICS
At the LASER 2017 in Munich, Fraunhofer ILT showed how companies can use the right process technology to make efficient laser applications possible in many areas, thereby driving forward their entry into the digital photonic production market in the 21st century. A variety of new developments were shown, among others a laser system for the satellite-based measurement of methane concentrations in the atmosphere as part of the »MERLIN« project. In addition, the institute presented a new cost-effective 3D printer for metal components with a comprehensive consulting package, which is primarily intended to appeal to SMEs who simply want to build up know-how in the field of additive manufacturing (in this case SLM: Selective Laser Melting). In addition, the Fraunhofer ILT scientists gave numerous lectures.

September 12–14, 2017, Novi, USA
The Battery Show North America 2017
Fraunhofer ILT was represented with various informative materials on the stand of the Fraunhofer Battery Alliance. This alliance bundles the expertise of researchers and developers from 19 Fraunhofer Institutes, one of which is Fraunhofer ILT.

October 10–12, 2017, Karlsruhe
Deburring EXPO
Trade Fair for Deburring Technologies and Precision Surfaces
Fraunhofer ILT presented laser polishing for the machining of precision components at the joint Fraunhofer booth. Furthermore, it displayed laser-polished free-form surfaces, complex 3D components and the deburring of sheet metal edges.

October 17–21, 2017, Friedrichshafen
Fakuma 2017
International Trade Fair for Plastics Processing
Fraunhofer ILT, in cooperation with Fraunhofer IPT and the Institute for Plastics Processing IKV of RWTH Aachen University, presented the latest developments in the injection molding of optical components at the joint stand kunststoffland NRW. Highlights included free-form optical elements and nanostructured plastic optics, which were produced with multi-beam interference and ultra-short pulse laser ablation.

October 22–26, 2017, Atlanta, USA
ICALEO
36th International Congress on Applications of Lasers & Electro-Optics
Fraunhofer ILT's scientists gave seven lectures at ICALEO 2017 and the institute was also represented with one poster at the Poster Presentation Gallery as well as an exhibitor at the Vendor Session.



Federal Minister for Economic Affairs and Energy Brigitte Zypries visits the Fraunhofer joint stand at formnext 2017 in Frankfurt am Main.

November 13–16, 2017, Düsseldorf
COMPAMED
World Forum of Medicine and International Trade Fair
Fraunhofer ILT presented the following topics at the joint IVAM Microtechnology Network booth:

- Laser polishing
- Laser cutting, laser welding and hybrid joining of metal and plastics
- Personalized production of intraocular lenses by laser polymerization
- Microfluidic sensors and sorters

In addition, Maximilian Brosda gave a presentation at the COMPAMED HIGH-TECH Forum.

November 14–17, 2017, Munich
productronica
World's Leading Trade Fair for the Development and Production of Electronics
Fraunhofer ILT presented the following topics at the joint Fraunhofer booth:

- Efficient and precise laser micro welding thanks to Laser-Based Tape Automated Bonding (LaserTAB)
- Process monitoring and quality control for scanner-based laser material processing
- Electrical functional layers for component-integrated monitoring
- Encapsulation of electronic components
- Laser microstructuring for tools and in production

November 14–17, 2017, Frankfurt am Main
formnext
International Exhibition and Conference on the Next Generation of Manufacturing Technologies
The Fraunhofer ILT showed the following topics at the joint Fraunhofer booth:

- Selective Laser Melting (SLM), also known as Laser Melting or Laser Powder Bed Fusion (LPBF), with green laser radiation for additive manufacturing of pure copper components
- SLM: post-processing for support removal, sensor integration, industrial process chains for turbomachinery components, SLM/LMD combination process
- Low Cost SLM: revised machine design of the 3D printer for SLM
- Resin-based 3D printing: »T(w)oCURE process«
- Blueprints: reliable and fast production of metal components

November 20–22, 2017, Munich
expoAIR
International Aerospace Supply Chain and Technology
In cooperation with the Chair for Digital Additive Production DAP of RWTH Aachen University, Fraunhofer ILT participated in the lecture forum of expoAIR with lectures by Dr. Jens Löhring, Fraunhofer ILT and Tobias Stittgen, Chair for DAP.

You will find further information on our trade fairs and events on the internet at:
www.ilt.fraunhofer.de/en/fairs-and-events.html

REFERENCES

ABB
arnold RAVENSBURG
Aurubis
Bartels mikrotechnik
BASF
BEGO
Berlin Heart
BMW
BOMBARDIER
BOSCH
BRAUN
COHERENT
CONCEPTLASER
DILAS
DILLINGER HÜTTE
DOM
eos
EVONIK
FEV
HEIDELBERG INSTRUMENTS
Heraeus
Huf Tools
igm
IMA
INOVAN
JENOPTIK
Kargoma armaturen
KISTLER
laserline
LEYER & KIWUS
MAN ROLAND
MARQUARDT
Mubea
MULTEK
PHILIPS
POSSEHL ELECTRONICS
PRECITEC
PROMETEC
Radium
Raufoss
Reis Robotics
rofin
Rolls-Royce
Sempell
SIEMENS
STORK Technical Services
Techspace Aero
TESAT Spacecom
TRUMPF
Valeo
voestalpine
VYCON
ZWIESEL KRISTALLGLAS

As at December 2017. *Printed with the kind permission of our partners. The companies listed here represent a selection of the Fraunhofer ILT's many clients.*

FUNDING BODIES

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

Bundesministerium für Bildung und Forschung

EUROPÄISCHE UNION

EUROPÄISCHE UNION
Investition in unsere Zukunft
Europäischer Fonds für regionale Entwicklung

Bundesministerium für Wirtschaft und Energie

esa
European Space Agency

Die Landesregierung Nordrhein-Westfalen

DFG Deutsche Forschungsgemeinschaft

INFORMATION

For more information about Fraunhofer ILT please visit our website or follow the social media channels mentioned below.

→→ www.ilt.fraunhofer.de

Fraunhofer-Institut für Lasertechnik ILT
Steinbachstraße 15
52074 Aachen, Germany
Telephone +49 241 8906-0
Fax +49 241 8906-121
info@ilt.fraunhofer.de

Annual report 2017 online

Further columns online

- Project results
- Technology focus
- Branches
- Fairs and events
- Scientific lectures and publications
- Dissertations, master- und bachelor theses
- Technical papers and books
- Patents
- Press
- Media center

IMPRINT

Editorial Staff
Dipl.-Phys. Axel Bauer (responsible)
M.A. Petra Nolis
Stefanie Flock

Contact
Dipl.-Phys. Axel Bauer
Telephone +49 241 8906-194
axel.bauer@ilt.fraunhofer.de

Design and Production
Dipl.-Des. Andrea Croll
www.andrea-croll.de

Picture Credits
- Page 18 + 19 (Picture 3), VDI-TZ / Stephan Rauh
- Page 27, CNES / Illustration David Ducros
- Page 117, RWTH Aachen University
- Page 127 (Picture 1), Clean-Lasersysteme GmbH
- Page 127 (Picture 2), LMI GmbH & Co. KG
- Page 128, GKN Sinter Metals
- Page 129, FH Aachen / Arndt Gottschalk

Print
Druckspektrum Hirche-Kurth GbR, Aachen
www.druck-spektrum.de

Subject to alterations in specifications and other technical information.