Fraunhofer

ILT

FRAUNHOFER INSTITUTE FOR LASER TECHNOLOGY ILT

ANNUAL REPORT 2016

ANNUAL REPORT
2016

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, Dear Partners of Fraunhofer ILT,

For Fraunhofer ILT, the year 2016 was characterized entirely by Digital Photonic Production. On April 29, 2016, the Industry Building Digital Photonic Production was officially opened, marking the start of a new chapter of cooperation between industry and science in Aachen. In the building, financed by private investors, technology suppliers and buyers can develop and commercialize new technological concepts and business models side by side using an open innovation approach. Already 90 percent of the usable areas are occupied – R&D teams of large industrial players such as Siemens and MTU, business teams such as Philips Photonics' technology developers, as well as regional SMEs have settled in the attractive surroundings of the RWTH Aachen Campus, in close proximity to Fraunhofer ILT and the cooperating RWTH Aachen University chairs.

These players can now efficiently deal with fundamental issues relevant to opening up a new technology field or a business model in a technology-intensive industry for the long-term and with super-critical resources. Of course, large publicly funded initiatives such as the Digital Photonic Production DPP Research Campus, sponsored by the Federal Ministry of Education and Research, create ideal conditions.

Despite this new technology's industrial relevance, the players have not lost their view of doing supportive basic research on location. Already in 2018, scientists from 16 institutes and chairs of the RWTH Aachen University, all approaching their object with an interdisciplinary perspective, will move into the new Research Center Digital Photonic Production, which is currently under construction. There, engineers and scientists from different disciplines will research and develop new materials and processes in an integrated way. As a special feature, they will work in mixed research groups on a day-to-day basis; that way they can gain a common understanding of the technology and, thus, shorten innovation cycles. They will focus on new disruptive approaches to digital additive manufacturing, ultra-short pulse processing, »silicon photonics«, medical technology and beam source development.

The triad of business, applied sciences and the university is very popular in Aachen and we will keep you up to date on its further developments. You will find a selection of what we have accomplished this year in this report. On our Internet pages you will find other interesting topics that we are pushing forward with our R&D partners. If your company has tasks that you would like to address with us, please do not hesitate to contact us. We love short communication paths and direct dialog. I hope you find inspiring reading in the following pages.

Yours sincerely,

Prof. Dr. rer. nat. Reinhart Poprawe

CONTENTS

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 400 employees and around 19,500 m^2 of net floor area, the Fraunhofer Institute for Laser Technology ILT is among the most significant contracting research and development institutes in its sector worldwide.

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

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.

STRUCTURE OF THE INSTITUTE

BOARD OF DIRECTORS

Prof. Dr. Reinhart Poprawe M.A.
Director

Prof. Dr. 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

Dr. Konrad Wissenbach
(since November 2016: Prof. Johannes Henrich Schleifenbaum)
Additive Manufacturing and Functional Layers

Priv.-Doz. Dr. Reinhard Noll
Measurement Technology and EUV Sources

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:

- Dr. R. Achatz, ThyssenKrupp Stahl AG
- Dr. Norbert Arndt, Rolls-Royce plc
- C. Baasel (chairman), Carl Baasel Lasertechnik GmbH
- 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.
- Prof. R. Salathé, Ecole Polytechnique Fédéral de Lausanne
- Dr. Dieter Steegmüller, Daimler AG
- Dr. Ulrich Steegmüller, Osram Opto Semiconductors GmbH & Co. OHG
- Dr. Klaus Wallmeroth, TRUMPF Laser GmbH & Co. KG

The 31st Board of Trustees meeting was held on September 28, 2016 at Fraunhofer ILT in Aachen.

Institutsleitungsausschuss 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 (since February 2016), Dr. A. Gillner, Dipl.-Ing. H.-D. Hoffmann, Dr. I. Kelbassa (until January 2016), Prof. P. Loosen, V. Nazery Goneghany (since mid-May 2016), Priv.-Doz. Dr. R. Noll, Dr. D. Petring, Prof. R. Poprawe, Prof. J. H. Schleifenbaum (since December 2016), Prof. W. Schulz, B. Theisen (until mid-May 2016), Dr. B. Weikl, Dr. K. Wissenbach (until November 2016).

Health and Safety Committee

The Health & Safety Committee is responsible for all aspects of safety and laser safety at the Fraunhofer ILT. Members of this committee are: Dr. V. Alagic-Keller MBA, K. Bongard (until midyear 2016), M. Brankers, M.Sc. F. Eibl, R. Frömbgen, A. Hilgers, Dipl.-Ing. (FH) S. Jung, M.Eng. F. Käfer (since midyear 2016), A. Lekpek (since mid-May 2016), Prof. P. Loosen, V. Nazery Goneghany (since mid-May 2016), E. Neuroth, Prof. R. Poprawe, B. Theisen (until mid-May 2016), F. Voigt, Dipl.-Ing. N. Wolf, Dr. R. Keul (Berufsgenossenschaftlicher Arbeitsmedizinischer Dienst BAD), S. Schoenen (Berufs-genossenschaftlicher Arbeitsmedizinischer Dienst BAD), (since midyear 2016).

Science and Technology Council

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 the Fraunhofer ILT are: Prof. R. Poprawe, Dipl.-Phys. Dipl.-Volksw. D. Esser.

Workers' Council

Since March 2003, the employees of Fraunhofer ILT and the cooperating university chairs have elected a workers' council.

FACTS AND FIGURES

2016

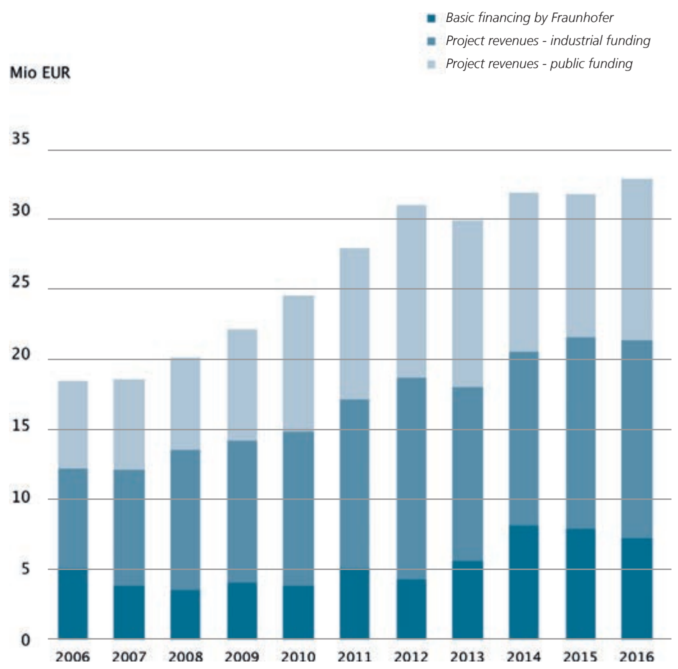
REVENUES AND EXPENSES

EXPENCES 2016	Mill €
- Staff costs	18,5
- Material costs	13,6
Expenses operating budget	**32,1**
Investments	**4,0**

REVENUES 2016	Mill €
- Industrial revenues	13,7
- Additional financing from Federal Government, States and the EU	11,3
- Basic financing from the Fraunhofer-Gesellschaft	7,1
Revenues operating budget	**32,1**
Investment revenues from industry	**0,3**
Fraunhofer industry ρ_{Ind}	**43,7 %**

BUDGET GROWTHS

The following graph illustrates the budget trend over the last 10 years.

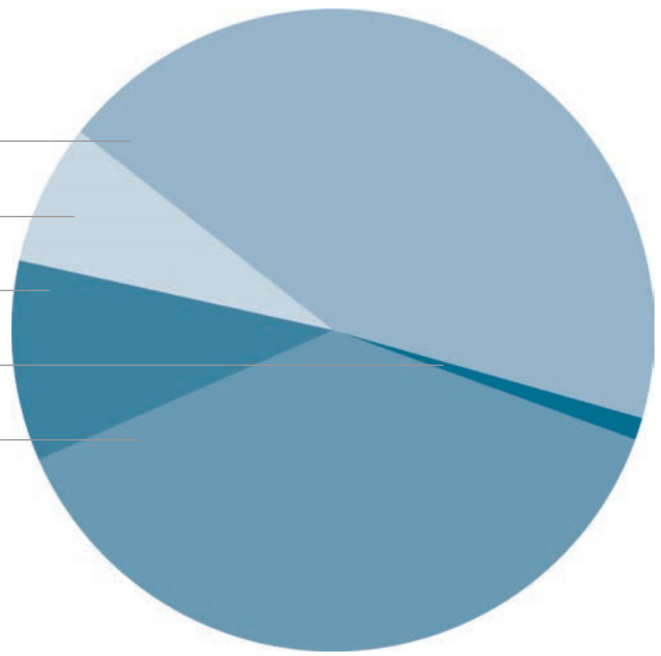


FACTS AND FIGURES

EMPLOYEES

Employees at the Fraunhofer ILT 2016 *(Status: 31.12.2016)*	number
Personnel	**240**
- Scientists and engineers	165
- Technical staff	44
- Administrative staff	31
Other employees	**196**
- Undergraduate assistants	191
- External employees	3
- Trainees	2
Total number of employees at the Fraunhofer ILT	**436**

- 9 members of staff completed their doctorates.
- 111 undergraduates carried out their bachelor or master theses at the Fraunhofer ILT.



44 % Undergraduate assistants

7 % Administrative staff

10 % Technical staff

1 % External employees, trainees

38 % Scientists / engineers

REFERENCES

As at December 2016. *Printed with the kind permission of our partners. The companies listed here represent a selection of the Fraunhofer ILT's many clients.*

COOPERATIONS

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
- development of X-ray, EUV and plasma systems

COOPERATIONS

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 cooperation with Fraunhofer ILT by the Research Campus »Digital Photonic Production«

By means of cooperation with other research organizations and specialized companies the Fraunhofer Institute for Laser Technology 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.

FRAUNHOFER ILT ABROAD

Since its foundation, Fraunhofer ILT has been involved in many international cooperations. The objective of these cooperations is to recognize new trends and current developments and to acquire further know-how. The customers of Fraunhofer ILT can directly benefit from this. Fraunhofer ILT carries out bilateral projects as well as international cooperative projects with foreign companies and subsidiaries of German companies abroad. These companies can also contact Fraunhofer ILT through:
- foreign cooperation partners of Fraunhofer ILT
- liaison offices of the Fraunhofer Society abroad

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
- lamps pumped solid state lasers up to 3 kW
- disc lasers from 1 to 10 kW
- mutimode fiber lasers up to 4 kW
- singlemode fiber lasers up to 5 kW
- diode laser systems from 1 to 12 kW
- ultra short pulse lasers up to 1 kW with pulse widths in the range of nano-, pico- and femtoseconds
- excimer lasers
- broadband tunable lasers

Plants and Processing Systems
- Selective Laser Melting (SLM) plants with laser power up to 2 kW
- five-axis gantry systems
- three-axis processing stations
- beam guiding systems
- robot systems
- direct-writing and laser-PVD stations

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

ALUMNI NETWORK

»AIX-LASER-PEOPLE«

The Fraunhofer Institute for Laser Technology ILT and its associate chairs – LLT, TOS, DAP, NLD and EUV – at the RWTH Aachen University substantially contribute to providing a qualified initial and advanced education of young scientists in the field of laser technology. For instance, in 2016, 111 students completed their bachelor's or master's thesis at Fraunhofer ILT; nine employees of Fraunhofer ILT completed their doctorate degree. Since they have gained practical experience and profound insights into innovative developments at Fraunhofer ILT, these employees have the best prerequisites to begin working in science and industry after working and studying at the institute. These alumni bring both specialist expertise in laser technology and methodical competence such as project management. Therefore, they are junior staff in high demand.

In order to promote the contact of the alumni with the current employees of the Fraunhofer ILT as well as with one another, the institute has systematically pursued an alumni network since 2000. It is called »Aix-Laser-People«. More than 450 alumni are in regular contact with the Fraunhofer ILT through this network. The vast majority of the alumni – about 80 percent – work in the manufacturing industry, meaning that many of the industries of interest to laser technology are represented. 20 percent of the alumni continue to work in science. About 10 percent of the alumni are company founders. The founding culture at Fraunhofer ILT is very pronounced, having generated over 30 spin-offs in 25 years. By transferring »innovative minds« into industry and science, the institute provides a direct social benefit.

In addition to the alumni network »Aix-Laser-People«, which creates the virtual and emotional bond, the association Arbeitskreis Lasertechnik AKL e.V. bundles the thematic interests of those who continue to work in the field of laser technology or at least have a great interest in the technology. About 150 alumni – well over a third – are members of the Arbeitskreis Lasertechnik e.V.

Contact

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

ARBEITSKREIS LASERTECHNIK E.V.

AKL
ARBEITSKREIS
LASERTECHNIK e.V.

Arbeitskreis Lasertechnik AKL 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 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 (managing director starting Jan. 1, 2017)
Dipl.-Phys. Axel Bauer (managing director until Dec. 31, 2016)
Telephone +49 241 8906-420
hartmut.frerichs@akl-ev.de
www.akl-ev.de

FRAUNHOFER ILT ABROAD

FRANCE – COOPÉRATION LASER FRANCO-ALLEMANDE CLFA

Short Profile

At the Coopération Laser Franco-Allemande (CLFA), the Fraunhofer ILT has been cooperating since 1997 with leading French research organizations such as CEA, CNRS, DGA and the university MINES ParisTech. At the moment the most important cooperation partners are the Institut de Recherche Technologique (IRT) Jules Verne and the University of Nantes, the École Nationale Supérieure de Mécanique et des Microtechniques (ENSMM) in Besançon as well as the engineer university ECAM in Rennes. Multidisciplinary teams of specialists from Germany and France work together on the transfer of laser assisted manufacturing processes to European industry.

Goals of the CLFA

The CLFA is actively participating in the realization of European research. The cooperation of the Fraunhofer ILT with the French partners also contributes to the improvement of the presence of the Fraunhofer Gesellschaft in Europe with the advantages for the French and German sides equally taken into consideration:

- Integration into scientific and industrial development in France
- Growth in know-how by faster recognition of trends in the field of European laser and production technology
- Strengthening the position in the European R&D market
- Increase of mobility and qualification level of employees
- Using the competence of the Fraunhofer ILT for French companies
- Using the experience of the Fraunhofer ILT in the introduction of new technologies
- Providing the connection between industry and university with practical training for students

Services

The CLFA offers services in the field of laser material processing. This covers the entire spectrum from application oriented fundamental research and training, feasibility studies and process development to pre-series development and system integration. Small and midsized companies have the opportunity here to get to know and test laser technology in an independent system.

Location and Equipment

Since July 2014 the CLFA has been located at the Technocampus Composites of the IRT Jules Verne in Nantes. In addition to the technical resources available at the Fraunhofer ILT in Germany, the CLFA possesses its own infrastructure at the IRT Jules Verne including access to the material science laboratories of the University of Nantes. The technical infrastructure of other French partners can also be shared on a project- or customer-specific basis.

Contact

Prof. Wolfgang Knapp (Director)
Telephone +33 2 2844 3711
wolfgang.knapp@ilt.fraunhofer.de

CLFA c/o IRT Jules Verne, Technocampus OCEAN
5 Rue de L'Halbrane
44340 Bouguenais, France

EUROPEAN LASER INSTITUTE

Short Profile

The European Laser Institute was founded in 2003 through an EU-funded initiative. The ELI mission is to strengthen and further enhance Europe's position in the field of laser technology. In addition, ELI aims to raise public awareness of the significance and prospects of the European laser technology industry. ELI is a network composed of almost 30 leading research facilities including the Fraunhofer ILT as well as small and medium-sized companies. This means that in addition to its participation in regional and national competence networks, as an ELI member the Fraunhofer ILT is also part of an influential, European-level laser technology network. Furthermore, the international cooperation of industry and research, especially in the field of EU research support, is forced by ELI. Amongst others, ELI creates adequate platforms by organizing conferences, workshops, summerschools etc. This is supported by the cooperation with the respective representations (e. g. EPIC, AILU, WLT). A strong cooperation with the Laser Institute of America (LIA) amongst others exists in the organization of international conferences (ICALEO, PICALO, ALAW) as well as the Journal of Laser Applications (JLA).

Executive Commitee

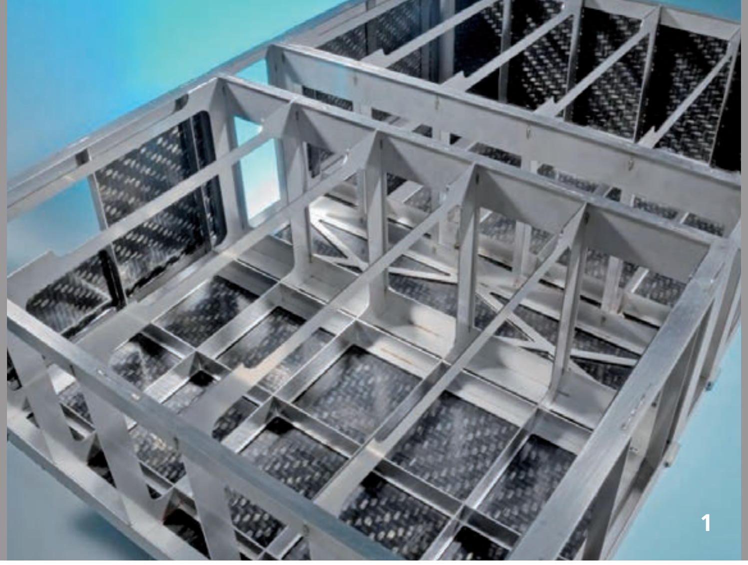
The members of the committee representing the ELI are:

- Dr. Paul Hilton – The Welding Institute TWI Ltd, Great Britain (Chairman)
- Prof. Dr. Wolfgang Knapp – CLFA / Université de Nantes, France
- Dr. Markus Kogel-Hollacher – Precitec GmbH + Co. KG, Germany
- Prof. Dr. Veli Kujanpää – VTT Technical Research Centre of Finland Ltd., Finland
- Prof. Dr. José Luis Ocaña – Centro Láser, Universidad Politécnica de Madrid, Spain
- Dr. Alexander Olowinsky – Fraunhofer ILT, Germany
- Prof. Dr. Andreas Ostendorf – Ruhr-Universität Bochum, Lehrstuhl für Laseranwendungstechnik, Germany
- Dr. Pablo Romero, AIMEN, Spain

Contact at Fraunhofer ILT

Dr. Alexander Olowinsky
Telephone +49 241 8906-491
Fax +49 241 8906-121
contact@europeanlaserinstitute.org
www.europeanlaserinstitute.org

FRAUNHOFER SYSTEM RESEARCH FOR ELECTROMOBILITY II



1

2

Short Profile

Since the beginning of 2013, 16 Fraunhofer Institutes have been working closely together in the »Fraunhofer System Research for Electromobility II - FSEM II« on innovative research topics dealing with electromobility. Thus, among others, the Fraunhofer Institutes shall expand upon the expertise and networks gained in the context of »FSEM I« in the field of electromobility.

With the »Fraunhofer System Research for Electromobility II«, the Fraunhofer-Gesellschaft is continuing to expand its successful work in the field of electromobility. Here, the institutes involved are not only focusing on solving the most important technological challenges for electromobility, but also participating in the industrialization of these technologies by directly incorporating industrially relevant issues into their research. In particular, they are taking this into account within the project by focusing increasingly on the production of components for electric vehicles.

One goal is to develop innovative technologies and components for hybrid and electric vehicles. These should then be transferred, together with research partners from the industry, to their practical application. At the same time, the Fraunhofer Institutes are making a contribution to continuing and refining system research by cooperating closely together.

Innovative Technologies

The complexity of vehicle and component development is represented by a division into three clusters:
- Powertrain / Chassis
- Battery / Range Extender
- Construction / Infrastructure

Battery systems in hybrid and electric vehicles pose several central challenges, such as high energy density, low production costs and high intrinsic safety in case a crash occurs.

It is, therefore, essential to develop battery systems and housing technologies and the necessary production technology for their safe and cost-effective use in electro-mobile applications.

The Cluster »Battery / Range Extender« is focused on constructing a battery system and implementing a range extender module. Eight Fraunhofer Institutes are working within this framework in nine subprojects. For the battery system, they have set their focus upon continuing to develop individual components and production technologies towards lightweight construction and efficiency. Examples include the development of a lightweight, yet crashworthy battery housing, battery cooling by means of PCM, or a contacting process for battery terminals with a laser-based process that is ready for series production.

Another module is the »Li-Booster«, a compact high-capacity battery that can cover the short-term high performance requirements in the wiring system in both the drive and in recuperation. This development makes it possible to build a two-part hybrid battery system that has greatly improved durability and consists of one power and energy storage part, each optimized for its specific operational purpose.

For the components in »Range Extender«, the institute is pursuing various approaches. A compact fuel cell module complements the »Lightweight Power Pack« with an optimized system to be used in electric vehicles to convert energy locally without generating emissions. Another Range Extender module is being designed and optimized for use in a light-duty truck or municipal vehicles. This is driven by a low-emission, reliable combustion engine in order to provide both electrical energy and also provide the necessary hydraulic energy needed in this particular application.

Simultaneously, the manufacturing and production technologies are also being developed in order to make cost-effective production possible.

Thanks to their collaboration, the various institutes are opening up new models of cooperation, especially in the innovative market environment of electric mobility of the Fraunhofer-Gesellschaft. This way, they can help the medium-sized automotive supplier industry in Germany to gain access to research benefits from the portfolio of the participating institutes.

Institutes Participating in FSEM II

- Fraunhofer ICT, Pfinztal
- Fraunhofer IDMT, Ilmenau
- Fraunhofer IFAM, Bremen
- Fraunhofer IIS, Erlangen / Nürnberg
- Fraunhofer IISB, Erlangen
- Fraunhofer ILT, Aachen
- Fraunhofer IPA, Stuttgart
- Fraunhofer IPT, Aachen
- Fraunhofer ISE, Freiburg
- Fraunhofer ISIT, Itzehoe
- Fraunhofer IVI, Dresden
- Fraunhofer IWES, Kassel
- Fraunhofer IWM, Freiburg
- Fraunhofer IWU, Chemnitz
- Fraunhofer LBF, Darmstadt
- Fraunhofer UMSICHT, Oberhausen

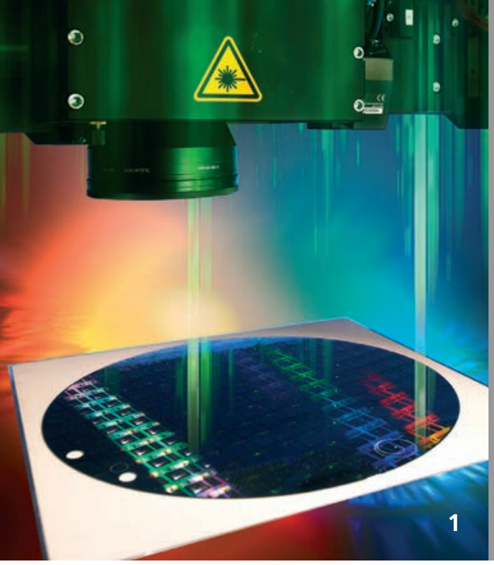
Contacts

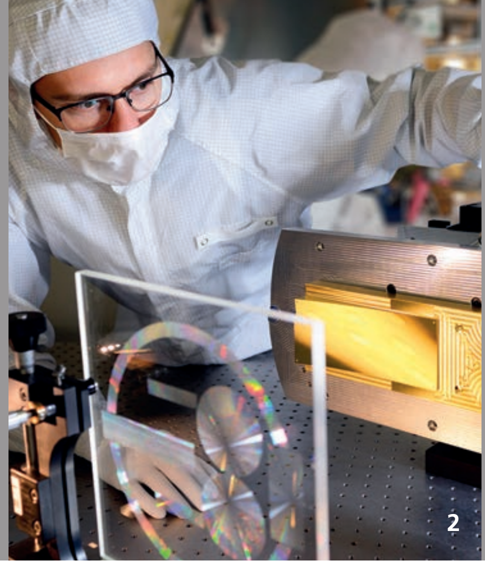
Dr. Alexander Olowinsky
Telephone +49 241 8906-491
Cluster Spokesman »Battery / Range Extender«
alexander.olowinsky@ilt.fraunhofer.de

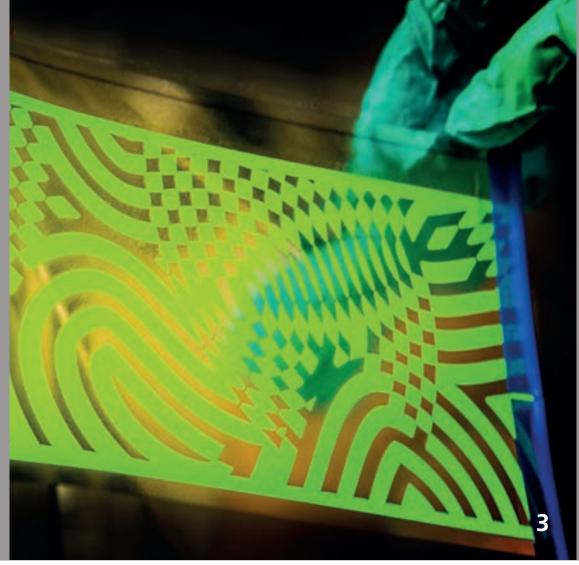
Dr. Arnold Gillner
Telephone +49 241 8906-148
arnold.gillner@ilt.fraunhofer.de

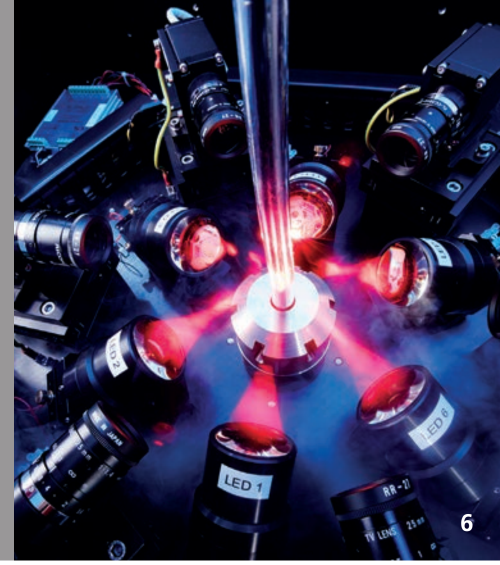
1 Lightweight power pack made out of a combination of high-strength steel and FRP.

2 Technology demonstrator »Lightweight Power Pack« with housing, battary modules and electronics.









FRAUNHOFER GROUP LIGHT & SURFACES

Competence by Networking

Six Fraunhofer institutes cooperate in the Fraunhofer Group Light & Surfaces. Co-ordinated competences allow quick and flexible alignment of research work in the field of optics, laser and thin film technology as well as material on the requirements of different fields of application. Coordinated activities are carried out to answer actual and future challenges, especially in the fields of energy, environment, production, information and security.

Core Competences of the Group

- Surface and coating functionalization
- Laser-based manufacturing processes
- Laser development and nonlinear optics
- Materials in optics and photonics
- Microassembly and system integration
- Micro and nano technology
- Carbon technology
- Measurement methods and characterization
- Ultra precision engineering
- Material technology
- Plasma and electron beam sources

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

Business Areas

- Ablation and cutting
- Imaging and illumination
- Additive manufacturing
- Light sources and laser systems
- Lithography
- Material testing and analytics
- Medical engineering and biophotonics
- Micro systems and sensors
- Opticals systems and instrumentation
- Tooling and mold making

Contact

Prof. Reinhart Poprawe (Group Chairman)
Telephone +49 241 8906-110

Dr. Arnold Gillner (Group Managing Director)
Telephone +49 241 8906-148
arnold.gillner@ilt.fraunhofer.de

www.light-and-surfaces.fraunhofer.de

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 optomechanical 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

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 competences 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

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

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

Fraunhofer Institute for Physical Measurement Techniques IPM

The Fraunhofer IPM develops tailor-made measuring techniques, systems and materials for industry. 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. Many years of experience with optical technologies and functional materials form the basis for high-tech solutions in the fields of production control, materials characterization and testing, object and shape detection, gas and process technology as well as functional materials and systems. www.ipm.fraunhofer.de

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

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 69 institutes and research units. The majority of the 24,500 staff are qualified scientists and engineers, who work with an annual research budget of 2.1 billion euros. Of this sum, 1.9 billion euros is generated through contract research. More than 70 percent of the Fraunhofer-Gesellschaft's contract research revenue is derived from contracts with industry and from publicly financed research projects. Almost 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

Target Groups

The Fraunhofer-Gesellschaft is committed to working for the economy as a whole, for individual businesses and for society. The targets and beneficiaries of our research activities are:

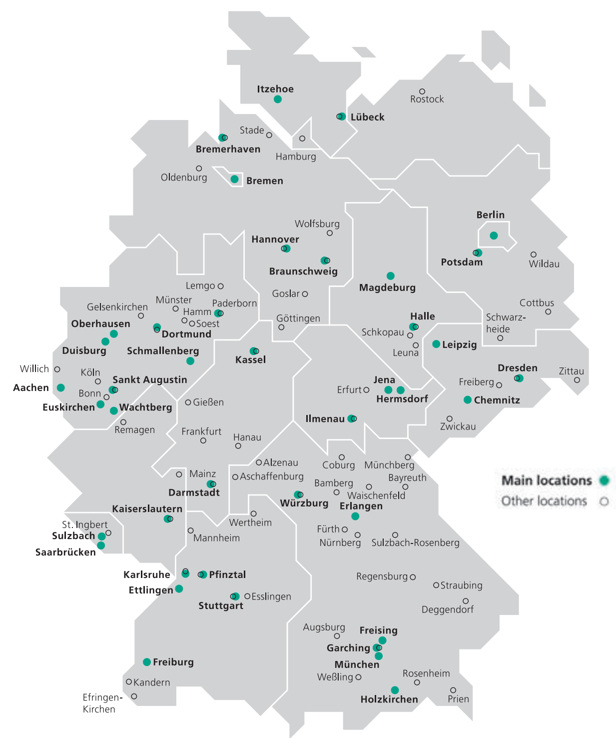
- The Economy: Small, medium-sized and large companies from industry and service sectors can all benefit from contract research. The Fraunhofer-Gesellschaft develops concrete, practical and innovative solutions and furthers the application of new technologies.The Fraunhofer-Gesellschaft is an important 'supplier' of innovative know-how to small and medium-sized companies (SMEs) not equipped with their own R&D department.
- Country and society: Strategic research projects are carried out at federal and state level, promoting key technologies or innovations in fields of particular public interest, e.g. environmental protection, energy technologies and preventative health care. The Fraunhofer-Gesellschaft also participates in technology programs initiated by the European Union.

Range of Services

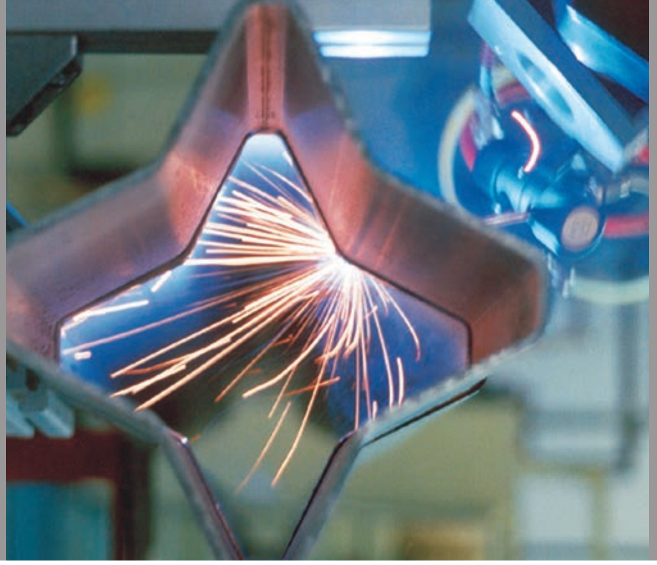
The Fraunhofer-Gesellschaft develops products and services to full maturity. We work closely with our clients to create individual solutions, combining the efforts of several Fraunhofer institutes if necessary, in order to develop more complex system solutions. The services provided by the Fraunhofer-Gesellschaft are:

- Product optimization and development through to prototype manufacture
- Optimization and development of technologies and production processes
- Support for the introduction of new technologies via:
  - Testing in demonstration centers using highly advanced equipment
  - In-house training for the staff involved
  - On-going support, also subsequent to the introduction of new processes and products
- Assistance in assessing new technologies via:
  - Feasibility studies
  - Market analyses
  - Trend analyses
  - Life cycle analyses
  - Evaluation of cost-effectiveness
- Supplementary services, e.g.:
  - Advice on funding, especially for SMEs
  - Testing services and quality validation

Research Facilities in Germany



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 the 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 the Fraunhofer ILT are building the future.

Chair for Laser Technology LLT

The RWTH Aachen University chair for Laser Technology has been engaged in application-oriented research and development in the fields of ultrashort pulse processing, in-volume structuring, drilling, additive manufacturing and integrated production since 1985.

The Cluster of Excellence »Integrative Production Technology for High-Wage Countries« in the field »Digital Photonic Production« is working largely on the integration of optical technologies into manufacturing processes and on the production of optical systems. Ultra-short pulsed lasers are being tested in basic experiments and used to process nano and micro components of practical relevance by ablation, modification or melting. Single-pulse, percussion and spiral drilling techniques as well as trepanning are being used to process metals and multi-layer systems mostly made up of metals and ceramics. This technology is useful for drilling holes in turbine blades for the aerospace industry, for example. Work in the field of generative processes focuses mainly on new materials, smaller structures, higher build-up rates, micro coating, process monitoring and control, and the development and enhancement of the university's own plants and systems. In the future the newly founded Chair for Digital Additive Production DAP will work on these topics.

Contact

Prof. Reinhart Poprawe (Director of the chair)
Telephone +49 241 8906-109
reinhart.poprawe@llt.rwth-aachen.de

Chair for the Technology of Optical Systems TOS

By establishing the Chair for the 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.

Contact

Prof. Peter Loosen (Director of the chair)
Telephone +49 241 8906-162
peter.loosen@tos.rwth-aachen.de

Chair for Digital Additive Production DAP

The Chair for Digital Additive Production DAP at the RWTH Aachen University, 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 in the field of additive manufacturing and the supporting processes, 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, while using digital technologies, 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 and deriving static and dynamic characteristic values.

Contact

Prof. Johannes Henrich Schleifenbaum (Director of the chair)
Telephone +49 241 8906-398
johannes.henrich.schleifenbaum@ilt.fraunhofer.de

CLUSTER OF EXCELLENCE

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. The diagnostic findings and the numerical calculations are then used to mathematically reduce the model equations. The solution characteristics of the reduced equations are fully contained in the solutions to the starting equations, and are not unnecessarily complex.

Contact

Prof. Wolfgang Schulz (Director of the chair)
Telephone +49 241 8906-204
wolfgang.schulz@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.

This work is carried out in collaboration with the Peter Grünberg Insitute (PGI) at Forschungszentrum Jülich – in particular with PGI-9 Semiconductor Nanoelectronics (Prof. Detlev Grützmacher) – with the Fraunhofer Institute for Laser Technology ILT in Aachen and with the Chair for the Technology of Optical Systems TOS (Prof. Peter Loosen) in RWTH Aachen University's Faculty of Mechanical Engineering. Their activities are embedded in the JARA-FIT section of the Jülich Aachen Research Alliance.

Contact

Prof. Larissa Juschkin
Experimental Physics of Extreme Ultraviolet EUV
Telephone +49 241 8906-313
larissa.juschkin@rwth-aachen.de

Cluster of Excellence »Integrative Production Technology for High-Wage Countries«

In the Cluster of Excellence »Integrative Production Technology for High-Wage Countries« process engineers and materials scientists based in Aachen are developing new concepts and technologies offering a sustainable approach to industrial manufacturing.

A total of 18 chairs and institutes of RWTH Aachen, together with the Fraunhofer Institutes for Laser Technology ILT and for Production Technology IPT, are working on this project, which will run until the end of 2017.

Funding of approx. 40 million euros has been granted to this Cluster of Excellence, an initiative that unites the largest number of research groups in Europe devoted to the objective of preserving manufacturing activities in high-wage countries.

Production in High-Wage Countries

The competition between manufacturers in high-wage and low-wage countries typically manifests itself as a two-dimensional problem, opposing production efficiency and planning efficiency.

In each case there are divergent approaches. With respect to production efficiency, low-wage countries tend to focus exclusively on economies of scale, whereas high-wage countries are obliged to seek a balanced equilibrium between scale and scope, in other words being able to satisfy customer requirements in respect of a particular product while at the same time attaining a minimum production volume.

A similar divergence is evident with respect to the second factor, that of planning efficiency. Manufacturers in high-wage countries aim to continuously optimize their processes, using correspondingly sophisticated, capital-intensive planning methods and instruments, and technologically superior production systems. In low-wage countries, by contrast, production needs are better served by simple, robust, supply-chain-oriented processes.

In order to maintain a sustainable competitive advantage for production sites in high-wage countries, it is no longer sufficient to aim for a better position that maximizes economies of scale and scope or reconciles the opposing extremes of a planning-oriented and a value-oriented approach. Instead, the goal of research must be to cancel out these opposite poles as far as possible. Ways must be found to allow a greater variability of products while at the same time being able to manufacture them at cost levels equivalent to mass production. This calls for value-optimized supply chains suited to each product, without excessive planning overheads that would compromise their cost-effectiveness.

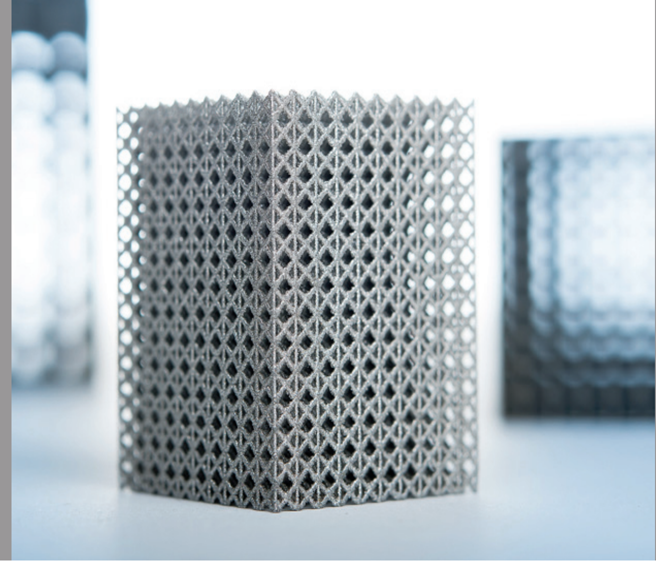
Tomorrow's production technology therefore requires a thoroughly new understanding of these elementary, interrelated factors which are acquired in the four research areas Individualized Production, Virtual Production, Hybrid Production and Self-Optimizing Production in the framework of the Cluster of Excellence.

In efforts to bring down production costs, Fraunhofer ILT has for example increased the efficiency of its selective laser melting (SLM) processes by a factor of 10, an improvement that goes a long way toward eliminating the scale-scope dilemma. With its research into methods of self-optimization for laser-cutting systems and the automated assembly of solid-state lasers, Fraunhofer ILT is helping to break down the distinction between a planning-oriented and a value-oriented approach.

Contact

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

DIGITAL PHOTONIC PRODUCTION



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.

Series Production of Customized Products

Just like the products they make, commercial enterprises' production requirements undergo constant change. The products customers are looking for are getting more complex all the time, all the way to customization. In some sectors, the volume of units ordered swings from several thousand down to just one. As they struggle to achieve commercial optimization of their business processes, designers and production managers are being called upon to design and manufacture components that are as tailored and yet as cost-effective as possible. This is the case in both the aviation and tool making industries, where it is becoming more important than ever to deliver weight savings that reduce fuel consumption on the one hand while on the other offering a sufficient number of variants to cover what many different customers want. To nevertheless achieve economies of scale these days often means that the dimensions of components used in such variants exceed actual load requirements. Correcting this is a design challenge that usually entails an increase in complexity. Digital photonic production offers the chance to create components that exactly match functional requirements without pushing up production costs.

For instance, there is a need in medical technology for implants that are tailored to individual patients. This not only increases the complexity of implants, it also requires them to be custom manufactured at a reasonable cost. What is more, new materials such as those that the body can resorb demand greater flexibility in manufacturing techniques. Whether in medical technology or in aircraft manufacturing, expensive parts are almost always still produced using conventional techniques. This can generate up to 90 percent waste. Both these avoidable costs and the call for sustainable use of available resources are leading to a rethink in manufacturing industry.

Individuality and Co-Creation

Today's consumers are also more demanding, seeking customized products that let them stand out from the crowd. Ideally, they would like to create the object themselves before they order it. For manufacturers, this necessarily raises product complexity and hence requires greater flexibility in production. This in turn pushes conventional, mostly mechanical processing techniques and standardized production processes to their limits, both technologically and economically. As the fourth industrial revolution approaches, we are seeing the merging of customization with series production and of the free and open virtual world with the real world of manufacturing. Light is the tool that is acting as a bridge between the two worlds. Digital photonic production allows customers to take an active part in design and production processes. With the help of lasers, products created and optimized on a computer can be series produced at a reasonable cost.

From Bits to Photons to Atoms

Experience in industry shows that a part's production costs rise in step with its complexity and uniqueness. The various digital photonic production processes get around this scale and scope issue by producing each part as a one-off at constant cost – regardless of complexity or batch size. Cost is determined purely by the part's weight and hence the material it consumes. With laser-based manufacturing techniques, parts are produced directly from the CAD data provided. Light as a tool is computer controlled in a flexible, non-contact and part-specific way. CAD data are transferred through the medium of light to the material: from bits to photons to atoms.

RWTH AACHEN CAMPUS

RWTH Aachen Campus

Taking its lead from the Stanford University and Silicon Valley model, the RWTH Aachen will create 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. The location will be the former university extension site in Aachen Melaten along with part of the Aachen Westbahnhof (Aachen West Train Station). This setup will connect for the first time the core areas of the RWTH Aachen 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 setup in Germany. This enables companies to actively participate in key fields addressed by the competence clusters, as well as in research, development and teaching, while incorporating their own areas of interest and resources. At the same time, it ensures access to qualified young staff and facilitates accelerated practically based PhD programs.

Interested companies can relocate to the RWTH Aachen Campus by leasing space or with their own building. This 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.

A holistic 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 center. The campus also offers superb quality of life, through hotel and living accomodation, 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 three stages. The first stage was started in 2010 with the development and construction of Campus Melaten with its 6 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

The second stage will see the development and construction of Campus Westbahnhof with 4 clusters. The third stage will focus on the growth and consolidation of 16 clusters in Melaten and the Westbahnhof as well as upgrading the infrastructure, including the construction of a congress hall, library and hotels. The relevant industry frontline themes will be tackled in all 16 clusters. More than 280 companies are already involved in the RWTH Aachen Campus.

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. At the end of 2016, 90 percent of 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

1

2

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 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 2016, 90 percent of the approximately 7,000 square meters of usable floor space at the Industry Building Digital Photonic Production was already occupied. 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 also located here. 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.

Contact

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

1 Topping-out Ceremony of the Research Center Digital Photonic Production in May 2016.

2 Industry Building Digital Photonic Production in the Photonics Cluster on the RWTH Aachen Campus.

BMBF RESEARCH CAMPUS DPP

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.

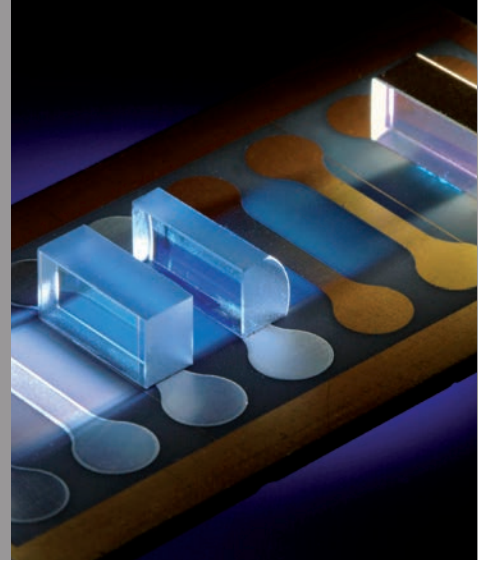
DPP Digital Photonic Process Chain

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 Ceremonial key handover for the opening of the Industry Building Digital Photonic Production in the Photonics Cluster.

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

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.

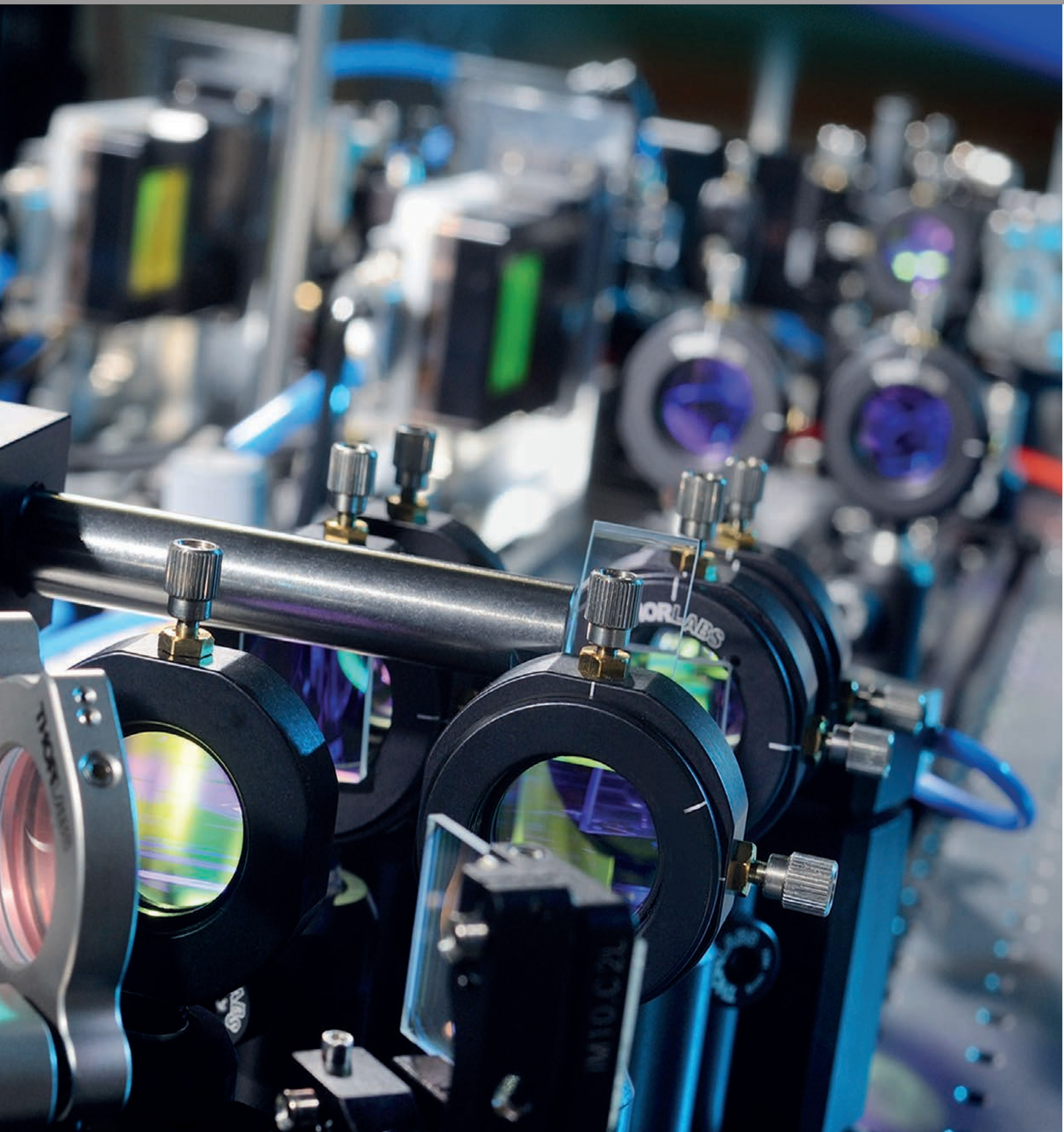
LASER MEASUREMENT AND EUV TECHNOLOGY

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.

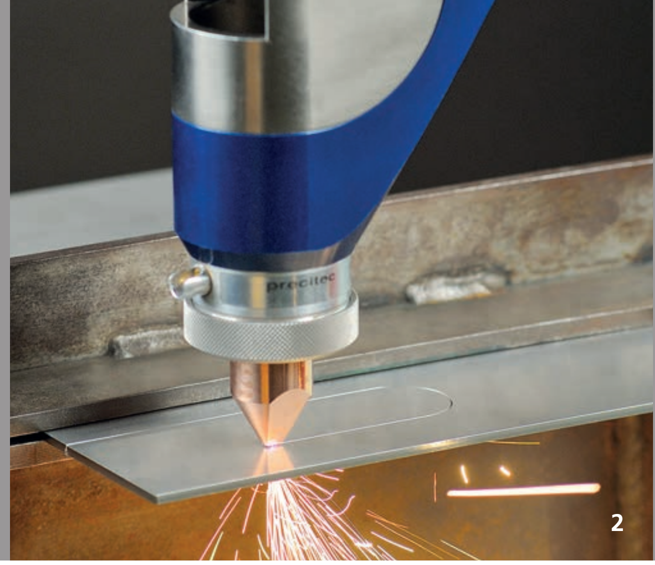
In EUV technology, Fraunhofer's experts develop beam sources for lithography, microscopy, nanostructuring or x-ray microscopy. Optical systems for applications in EUV engineering are calculated, constructed and manufactured as well.

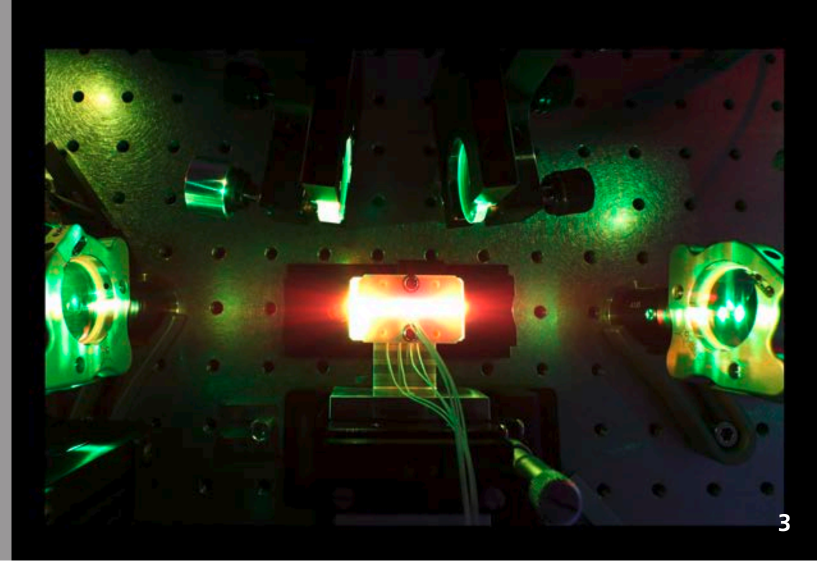
LASERS AND OPTICS



Direct diode laser
for cutting applications.

CONTENTS





DIRECT DIODE LASER FOR CUTTING APPLICATIONS

Task

Fiber-coupled diode lasers are among the most cost-effective and efficient beam sources for cw laser applications and are widely used for applications requiring medium brightness such as hardening, soldering and welding of metals. The EU-funded research project »BRIDLE« aims to develop novel, cost-effective diode laser beam sources to open up applications that place high requirements on brightness, such as the cutting of metals.

Method

Within the framework of »BRIDLE«, laser diodes optimized for maximum brightness were developed and integrated into commercial pump modules, which have been manufactured fully automated by the project partner DILAS. These modules were wavelength stabilized by means of volume Bragg gratings. The radiation was then combined with the aid of cost-efficient dielectric edge filters with a small distance of the central wavelength and coupled into an industrial fiber. The filters enable a comparable small spectral spacing of 4 nm.

Results

The diode laser system reaches an output power of 800 W with a beam parameter product of 8.5 mm mrad and achieves a combining efficiency of 95 percent for the partial beams. It is possible to scale the output power even further – up to 2 kW with a beam parameter product of 6 mm mrad. The system has successfully cut stainless steel plates with thickness of up to 4.2 mm. The cutting quality corresponds to results obtained with fiber lasers having comparable output power. The approach investigated here makes it possible to scale the brightness of existing sources cost-effectively by a factor of ten when standard components are used.

Applications

Direct diode lasers with an optical output power in the kW range and a beam parameter product smaller than 10 mm mrad represent a cost-effective alternative to fiber lasers in cutting applications. Alternatively, the stabilized emission spectrum and the high beam quality of the diode laser can be used to a great advantage in technically demanding pump applications, e. g. multi-kW fiber lasers or ultra-short pulse lasers.

The work has been funded within the framework of the EU project »BRIDLE« under the grant number 314719.

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 Pump diode laser module with dense wavelength combination.

2 Cutting stainless steel with a direct diode laser.

PULSED NANOSECOND LASER AT 3 µm WAVELENGTH

Task

Many materials absorb laser radiation in the mid-infrared (MIR) to a far greater degree than they do at a wavelength of 1 µm. In order to make use of this absorption and expand the range in which a commercial cleaning laser can be used, Fraunhofer ILT shall convert the wavelength of a laser from 1 µm to 3 µm. The converter shall be designed as a downstream module to the existing system. The solid-state laser used provides an average power of 115 W at a pulse duration of 120 ns and pulse frequency of 12 kHz at the fundamental wavelength of 1064 nm. The randomly polarized emission and limited beam quality ($M^2 = 18$) of the laser represent a challenge, however, for efficient conversion.

Method

So that the entire randomly polarized radiation can be used for the frequency conversion, the raw beam was separated into the two linear polarization components. One of the two beams was guided in an optical parameter oscillator (OPO) that generates radiation at 1645 nm and 3012 nm. The radiation generated at 3012 nm was mixed with the second portion of the raw beam at 1064 nm in an optical parameter amplifier (OPA) and thereby amplified. Periodically polarized lithium niobate (PPLN) was used as a non-linear medium in both the OPO and OPA.

Results

The output wavelengths of the frequency-converted laser can be tuned from 2.85 to 3.1 µm and from 1.62 to 1.71 µm. It provides a power of 16 W at 3 µm and 20 W at 1.6 µm. The system is equipped with processing optics consisting of a galvanometric scanner and an F-theta objective lens and is available for material processing tests with MIR radiation.

Applications

A relevant example for this application is the pre-treatment of CFRP component adhesive surfaces in the automotive and aerospace industry at a wavelength of > 3 µm.

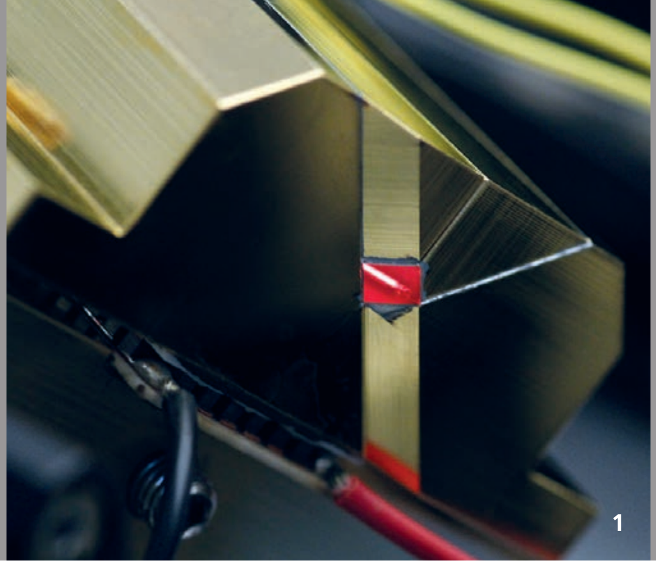
The R&D project underlying this report was carried out on behalf of the Federal Ministry of Education and Research (BMBF) under the grant number 13N12930.

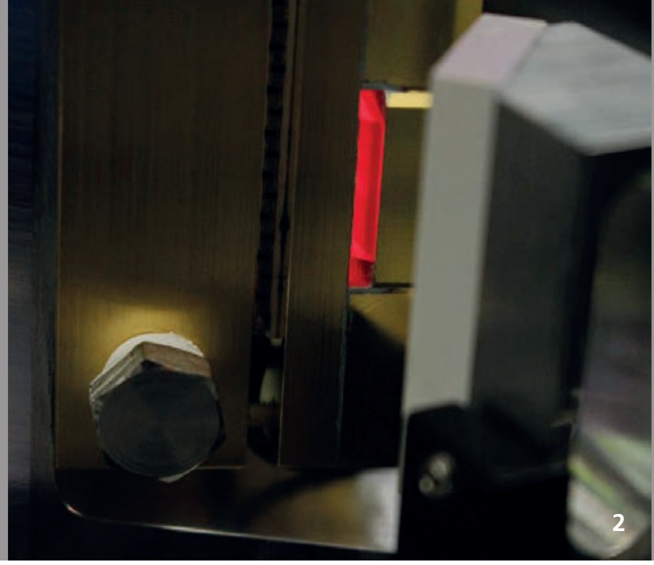
Contact

Dipl.-Phys. Sebastian Nyga
Telefphone +49 241 8906-123
sebastian.nyga@ilt.fraunhofer.de

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

3 Optical parametric oscillator.





HIGH-STABILITY HO:YLF OSCILLATOR

Task

Laser beam sources in the wavelength range around 2 µm and with pulse lengths in the nanosecond range can be applied in many different areas: materials processing, remote sensing, science and military can all make use of the special absorption properties of 2 µm radiation. As part of the DLR project »CHOCLID« and the ESA project »HOLAS«, a pulsed, spectrally narrow beam source with a particularly high wavelength stability at 2.051 µm is being developed to detect CO_2 in the atmosphere.

Method

A Ho:YLF-MOPA system based on INNOSLAB, which is pumped by diode-pumped Tm:YLF lasers, was designed by means of numerical simulations to generate the required double pulses with 45 mJ and 15 mJ pulse energy and a repetition rate of 50 Hz. Pulses with a constant energy of 2 mJ are generated in the oscillator. A high spectral stability has been achieved as a cavity with high finesse is used for the oscillator and an optically pumped semiconductor disc laser (OPSEL) for the seed source.

Results

As a pump source for the Ho:YLF oscillator, Fraunhofer ILT constructed a Tm:YLF rod laser with a cw power of 15 W and whose power is limited by the pump diodes used.

This pumped Ho:YLF oscillator produces longitudinal single-mode, diffraction-limited pulses at a 50 Hz repetition rate, a 2 mJ pulse energy with a pulse duration of 25 ns. The spectral bandwidth is 1 MHz (RMS) and the time-bandwidth product is bandwidth limited by approximately 0.44. With an Allan deviation of less than 40 kHz for 10 seconds, the spectral stability is significantly better than the required 200 kHz. For single pulses with a repetition rate of 100 Hz, 11 mJ have been generated. Testing at high pulse energies shows that there is a great distance from the destruction threshold at the working point of 2 mJ. In cw operation, an optical-optical efficiency of 53 percent has been achieved. An Ho:YLF INNOSLAB amplifier has also been built and is currently being tested.

Applications

As well as a master oscillator for the following amplifier, the oscillator can be used in materials processing. The output wavelength of 2 µm is also advantageous for use as a source to pump efficient optical-parametric frequency converters for the long-wave infrared spectral range.

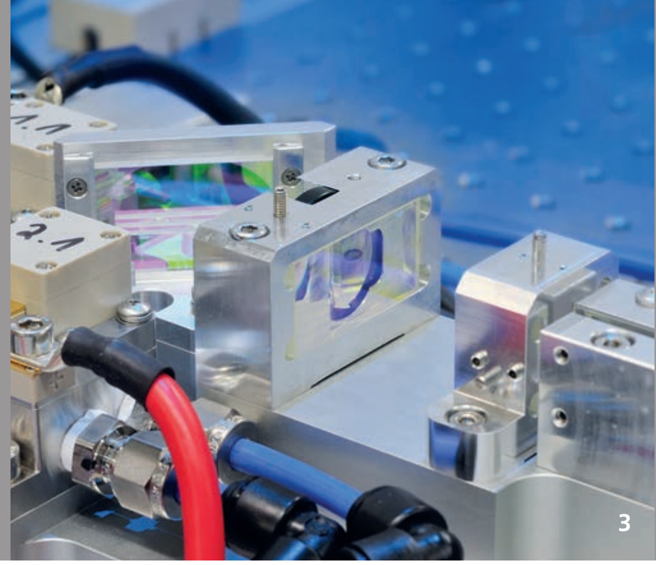
The R&D project underlying this report was carried out on behalf of the Federal Ministry of Education and Research under grant number 50EE1222.

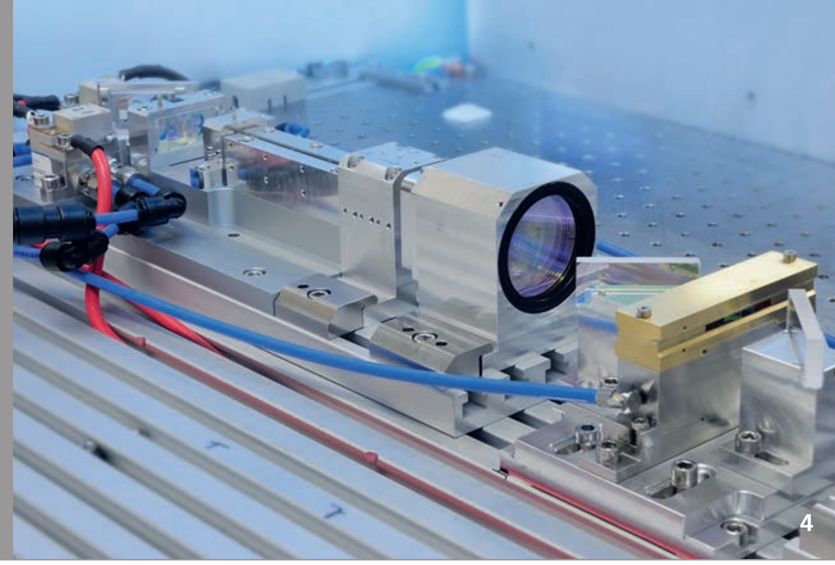
Contact

Philipp Kucirek M.Sc.
Telephone +49 241 8906-8108
philipp.kucirek@ilt.fraunhofer.de

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

1 Pumped Ho:YLF crystal of the oscillator.
2 Pumped laser crystal of the Ho:YLF INNOSLAB amplifier.





ER:YLUAG INNOSLAB AMPLIFIER AT 1645 NM

Task

To detect methane in the atmosphere, the Franco-German climate mission »MERLIN« requires single-frequency laser pulses at a wavelength of 1645 nm with a pulse energy of > 9 mJ with pulse durations between 10 ns and 100 ns. In addition to the approach pursued in »MERLIN« – to obtain this by frequency conversion of pulses at 1064 nm in optically parametric steps – erbium-doped garnet crystals as laser media can also be used to directly generate these pulses. The aim is to reduce the complexity of the beam source with comparable or higher efficiency. First, however, a feasibility study has to be conducted.

Method

Single-frequency laser pulses from a diode-pumped rod oscillator with a pulse energy of 4 mJ and a pulse duration of 80 ns are scaled in the pulse energy in an INNOSLAB amplifier. The amplifier crystal is an erbium-doped YAG/LuAG mixed crystal, in which the maximum of the emission cross-section is precisely matched to the measurement wavelength of 1645.2 nm (in air) through the mixing ratio (crystal field tuning). This crystal is pumped with four stacks, each consisting of four wavelength-stabilized diode laser bars, at a wavelength of 1532 nm. The two stacks are superposed geometrically through so-called interleaving by means of slotted coupling mirrors. The filling factor is thus doubled and the polarization retained. The pumping light transmitted in the first crystal passage can thus be reflected again into the crystal by polarization rotation.

Results

The laser pulses from the oscillator are amplified up to a pulse energy of 12 mJ in nine single passes through the amplifier crystal, which is currently limited by the absorbed pump power and the fluence attainable. In both beam axes, the measured diffraction index M^2 is < 1.1. The spectral properties attained experimentally also fulfill the requirements for the satellite-supported detection of methane.

Applications

The beam source constitutes a technology demonstrator for possible further future developments of LIDAR instruments for methane detection. Based on the work conducted to date, the erbium-based system has a scaling potential towards larger pulse energies up to about 30 mJ.

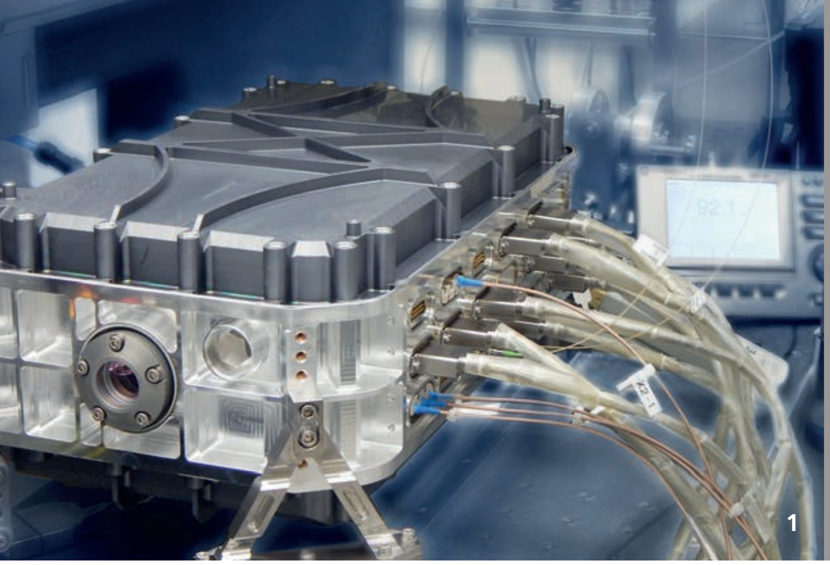
The R&D project underlying this report was supported by the Federal Ministry of Education and Research under the grant number 50EE1222.

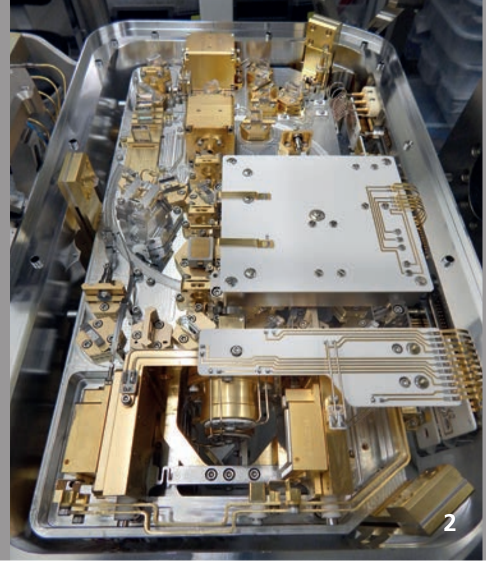
Contact

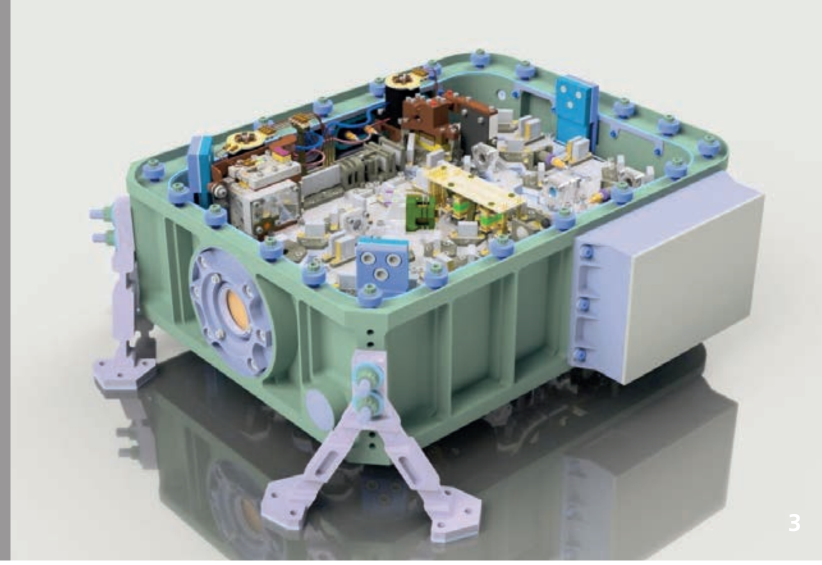
Dipl.-Phys. Ansgar Meissner
Telephone +49 241 8906-8232
ansgar.meissner@ilt.fraunhofer.de

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

3 Geometric superposition of the pump sources.
4 INNOSLAB amplifier with pump-beam shaping.







FULAS – LASER PLATFORM FOR FUTURE SATELLITE-BASED LIDAR SYSTEMS

Task

Satellite-based instruments for atmospheric research (LIDAR) enable scientists to measure the climatically relevant distribution of aerosols, wind or greenhouse gases such as carbon dioxide, methane and water globally. These instruments require a tailor-made laser beam of the highest beam quality which emits pulses with energies in the 10 mJ or 100 mJ range at a particular wavelength. The pulses have a bandwidth-limited duration of a few 10 ns and are typically repeated at 100 Hz, but anywhere from 10 Hz to a few kHz can also be necessary. Decisive is generally an energy demand as low as possible. Construction of these complex laser sources with the reliability and lifetime required for operation in space has proved extremely challenging in recent years.

Method

As part of the »FULAS« project and in cooperation with Airbus, Fraunhofer ILT has developed a laser that demonstrates novel technologies in this context. Soldering techniques for mounting and adjusting the laser optics enable the laser to withstand environmental influences easily. By dispensing with critical organic and outgassing materials, we prevent laser-induced contamination. The laser source consists of a cavity-controlled seeded actively Q-switched diode-pumped Nd:YAG oscillator and an INNOSLAB amplifier.

1 FULAS laser head in operation.

2 Inner view of the FULAS laser head.

Results

The laser was integrated into the system up to the expansion stage which has 90 mJ pulse energy at 1064 nm wavelength and meets all laser-optical requirements of the ATLID instrument on the ESA EarthCARE satellite. A multi-week operational and non-operational (-30 °C to 50 °C) test was successfully completed in a thermal vacuum chamber at Airbus Defence & Space.

Applications

The FULAS platform allows beam sources to be generated with currently up to 500 mJ at 1064 nm. Wavelengths from UV to MIR can be provided with high efficiency and beam quality by means of frequency converters. A preliminary design for the laser beam source of the MERLIN instrument has been developed based on the FULAS platform. According to current plans, this Franco-German satellite will be launched in 2021. It shall measure the global distribution of methane, a gas relevant to the climate change.

The work was carried out under the leadership of Airbus Defence & Space GmbH as part of the ESA project »FULAS« (COO-8/09/FF) and projects »Optomech II & III« (grant numbers 50EE0904, 50EE1235) for the Federal Ministry for Economic Affairs and Energy (BMWi).

Contact

Dipl.-Phys. Jörg Luttmann
Telephone +49 241 8906-675
joerg.luttmann@ilt.fraunhofer.de

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

LASER DESIGN FOR THE MERLIN MISSION

Task

The global distribution of greenhouse gas methane shall be monitored from 2021 onwards using the IPDA (Integrated Path Differential Absorption) method within the scope of the Franco-German climate mission »MERLIN« (Methane Remote Sensing LIDAR mission). In this active measurement method, a laser source emits light pulses with very specific characteristics, thus making it possible to draw conclusions on the methane quantity between the satellite and the earth’s surface by simply measuring the quantity of backscattered light. However, for use on a satellite, the system must be able to withstand a great range of temperatures and vibrations and have a service life of more than three years. This also means that all components must be designed to be extremely low outgassing.

Method

Over the past few years, a technology has been systematically developed which allows the construction of the appropriate laser source. Requirements for optomechanical fastening elements have been derived and corresponding key elements (such as holders for mirrors, lenses, different crystal types) as well as processes have been developed and tested. The core process in this case is the adjustment soldering, with which the mirrors can be precisely adjusted and then be joined with great robustness and without needing adhesives. In addition, the entire assembly technology was validated using the platform demonstrator »FULAS« as was the optical design of the MERLIN laser in breadboard studies.

Results

The laser source consists of an Nd:YAG-based setup arrangement consisting of a rod oscillator and an INNOSLAB amplifier with a subsequent parametric frequency converter for 1645 nm. A preliminary design was developed and the PDR (preliminary design review) status was achieved. Based on this, the detailed design of the final flight model is currently being developed.

Applications

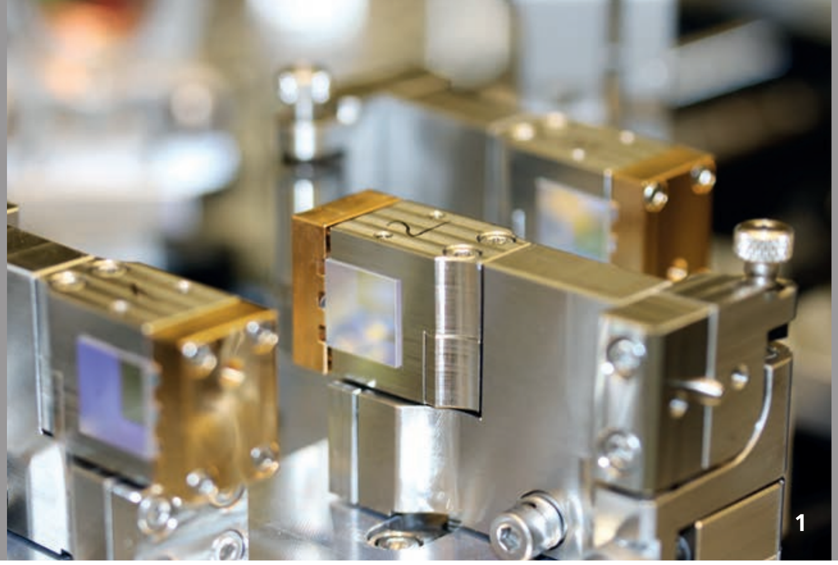
The structural concept of the laser as well as the model philosophy applied to the flight model can, in principle, be transferred to other requirements and systems. The development risks are greatly reduced by using previously tested key components. In addition to application fields in aerospace, the principle can be applied to all areas where reliability and long-term stability play a very important role.

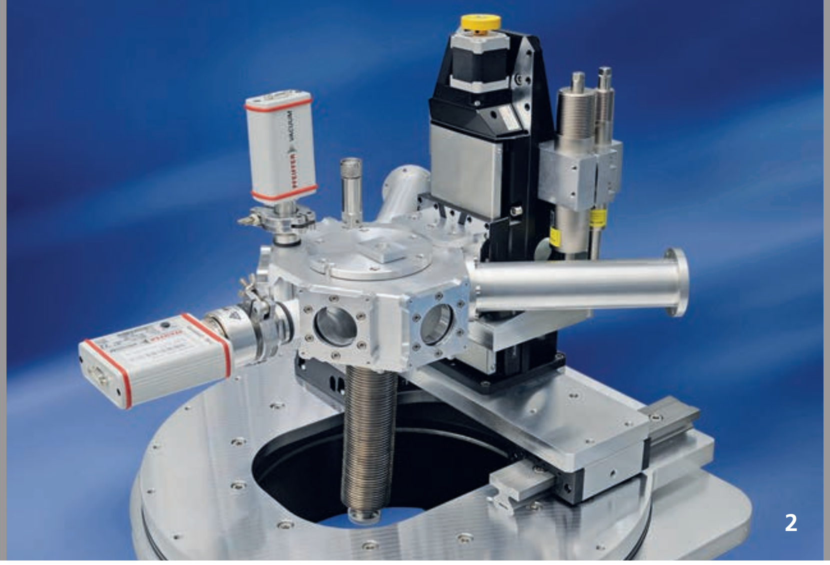
The R&D projects underlying this report were carried out under contract for the Federal Ministry for Economic Affairs and Energy under the grant numbers 50EE0904, 50EE1235, 50EP1001 and 50EP1301. The work for »MERLIN« is being conducted on behalf of DLR Space Administration, under subcontract for Airbus Defence and Space in the C/D phases under grant number 50EP1601.

Contact

Dr. Jens Löhring
Telephone +49 241 8906-673
jens.loehring@ilt.fraunhofer.de

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





POWER SCALING PARAMETRIC CONVERTERS FOR LIDT MEASUREMENTS AT 1645 NM

Task

Satellite-supported LIDAR systems shall be used to detect the concentration of trace gases in the earth's atmosphere globally. Required for this, however, are lasers with a pulse energy from a few to a few hundred millijoules at a pulse repetition rate of approximately 100 Hz and a wavelength adapted to the measurement task in order to achieve a good signal-to-noise ratio. For example, a laser with a parametric frequency converter is currently being developed at Fraunhofer ILT for the Franco-German climate control mission »MERLIN«. This laser generates a pulse energy of 9 mJ at a wavelength of 1645 nm for measuring atmospheric methane concentrations. In further LIDAR missions, the scalability of parametric frequency converters in the range > 100 mJ should be demonstrated. The newly developed beam source will continue to be used for the qualification of optics for the MERLIN mission in an LIDT (Laser-induced Damage Threshold) measuring station.

Method

To demonstrate the scalability, Fraunhofer ILT has developed a longitudinal single-mode MOPA system with 500 mJ at a repetition rate of 100 Hz and a pulse duration of 30 ns at 1064 nm. In order to reach pulse energies > 100 mJ, an optical parametric oscillator (OPO) is operated with part of the pump pulse energy, the output pulses of which are amplified at 1645 nm in an optical parametric amplifier (OPA).

Results

Fraunhofer ILT has demonstrated that the system described here, based on KTP crystals, can generate pulse energies > 110 mJ. The pulse duration is approximately 20 ns. The converter can be operated in a longitudinal single-mode via a cavity length control.

Applications

In the future, the entire system consisting of pumps and converters will be used in a measuring station for the qualification of optical components for the »MERLIN« mission. Furthermore, the output characteristics of the converter are suitable for future LIDAR missions to measure trace gases, such as methane. The optical design can also be used for frequency conversion in other wavelength ranges. Thereby, a great number of climatically relevant gases can be detected.

The R&D project underlying this report was sponsored by the Federal Ministry for Economic Affairs and Energy (BMWi) under grant number 50EE1228.

Contact

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

1 OPA converter stage.

MEASURING LIDT AT A WAVELENGTH OF 1645 NM

Task

Understanding the laser-induced damage threshold (LIDT) of optical components is essential for the design of efficient and reliable laser beam sources, especially when they are used in aerospace applications. A laser beam source emitting at 1645 nm is currently being developed for the Franco-German satellite mission »MERLIN« to detect methane in the earth's atmosphere. So far, however, there is still no LIDT measuring station worldwide to qualify the optical components at this wavelength.

Method

An existing structure, initially used at a test wavelength of 1064 nm to qualify the flight items of the laser altimeter for the ESA mission »BepiColombo«, is being upgraded for the new test wavelength. The new station uses a Q-switched single-frequency Nd:YAG-MOPA with two INNOSLAB amplifier stages and up to 500 mJ pulse energy at 1064 nm and 100 mJ at 1645 nm from a downstream OPO/OPA converter unit as a test laser source. The online damage detection system has been designed independent of the wavelength. The optics system has been adapted to use the additional wavelength of 1645 nm. The measurement sequence has been improved in terms of manageability and reproducibility of the results. The valid ISO regulation 21254 is used for LIDT measurements.

Results

The new measuring station allows ISO-compliant LIDT measurements at test wavelengths of 1064 nm and 1645 nm, each at a defined atmosphere. The test laser source provides pulses with 20 ns pulse duration and a repetition rate of 100 Hz with a Gaussian beam profile. The maximum test fluence at 1645 nm is 150 J/cm² at a beam diameter of 400 µm.

Applications

The measuring station is used for the qualification of optical components for the »MERLIN« mission. In addition, the test station is being upgraded to accommodate a test wavelength of 2051 nm.

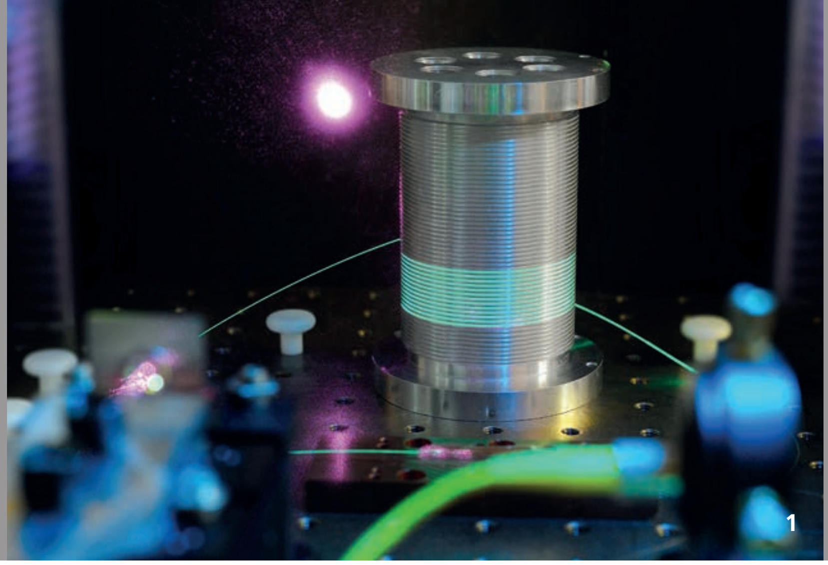
The R&D project underlying this report was carried out on behalf of the Federal Ministry of Education and Research (BMBF) under the grant number 50EE1228.

Contact

Dipl.-Phys. Ansgar Meissner
Telephone +49 241 8906-8232
ansgar.meissner@ilt.fraunhofer.de

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

2 LIDT test setup.



NARROW-LINEWIDTH FIBER AMPLIFIER FOR THE INVES-TIGATION OF STIMULATED BRILLOUIN SCATTERING

Task

As part of a study for the European Space Agency (ESA), Fraunhofer ILT has developed a power-stabilized narrow-linewidth single-mode fiber amplifier with an output power of > 500 mW. The amplifier shall be used to measure the earth's gravitational field. As stimulated Brillouin scattering can destroy fiber components as well as disturb power stabilization in the existing laser system and especially in further power scaling, it shall be investigated theoretically and experimentally.

Method

For the experimental investigation, Fraunhofer ILT built a narrow-linewidth fiber amplifier, which is used to measure both the threshold behavior as well as a temporal modulation of the signal by stimulated Brillouin scattering in active and passive test fibers. For the theoretical investigations, Fraunhofer ILT developed a numerical fiber-laser simulation tool that solves the time-, position- and wavelength-dependent rate equations. This simulation was extended to Brillouin source terms and also those of stimulated Brillouin scattering.

Results

The fiber-integrated amplifier for seed signals with a bandwidth below 10 kHz provides an output power of 5 W, limited by the pump power, with no evidence of stimulated Brillouin scattering. The fiber amplifier was successfully used to examine the effect of stimulated Brillouin scattering on backscattered power, temporal fluctuations of the output signal as well as of its frequency shift.

Thanks to this development, designing future fiber laser systems has been simplified – with regard to further power scaling and suppression of temporal performance fluctuations – when the stimulated Brillouin scattering in the numerical simulation is taken into account.

Applications

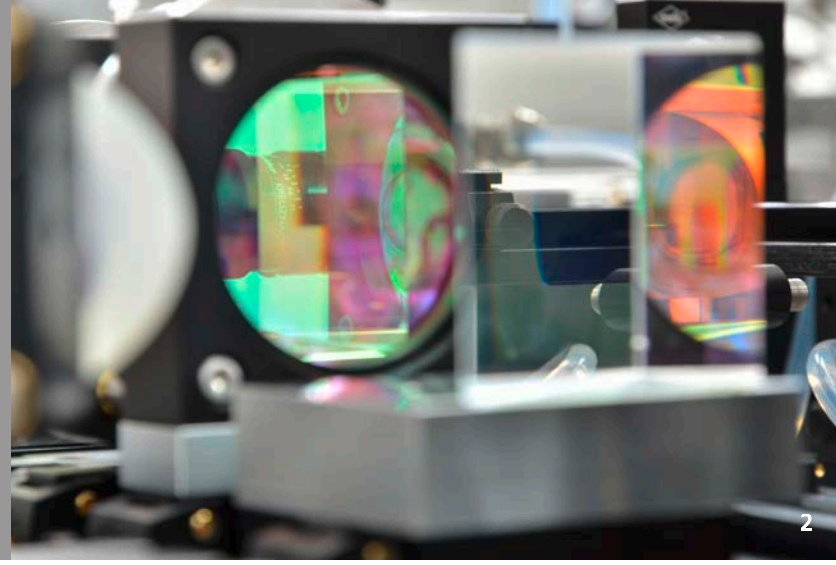
In addition to applications in optical measurement technology and communications, a narrow-linewidth fiber amplifier with an output power of approx. 5 W could also be used for satellite-based measurements of gravitational waves.

Contact

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

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

1 Narrow-linewidth fiber amplifier with active fiber.



NONLINEAR PULSE COMPRESSION IN A MULTI-PASS CELL

Task

The pulses of Yb-based high-power ultrafast lasers (pulse durations ~ 200 fs - 1 ps) shall be shortened with an additional passive compression stage. Existing high-power schemes for compressing sub-ps laser pulses are based on nonlinear spectral broadening in a waveguide. These schemes are, however, limited in average power scalability, efficiency (typically < 80 percent) and addressable pulse energy ranges (< 5 µJ for glass fibers, > 200 µJ for gas-filled capillaries). Fraunhofer ILT shall develop an efficient method that allows pulse compression in the pulse energy range of ~ 5 - 200 µJ, which currently cannot be addressed with existing schemes. The process should be suitable for average power up to the kW range.

Method

Instead of a classical waveguide, a multi-pass cell is used in which the pulses to be compressed pass through a thin nonlinear medium (e.g. fused silica) many times. In between these passages lies a long propagation without nonlinearity. This way, the limitations of existing waveguide-based methods are circumvented with respect to efficiency, power scalability and pulse energy range.

Results

With the method described here, the pulses of an Yb:YAG INNOSLAB laser system were compressed from an 880 fs pulse duration to < 170 fs. A compressed average output power of 375 W was achieved at a pulse energy of 37.5 µJ. The efficiency of the compression setup was 91 percent.

Applications

The demonstrated combination of pulse duration, pulse energy and output power is relevant both for applications in ultrafast material processing, which are based on nonlinear processes (multi-photon absorption, filamentation), as well as for the generation of coherent EUV radiation by cavity-enhanced high harmonic generation.

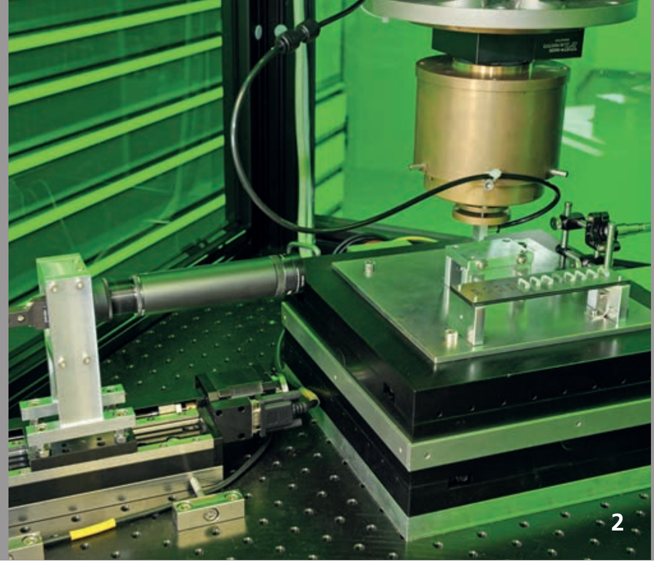
The R&D project underlying this report was carried out on behalf of the German Federal Ministry of Education and Research under the grant number 13N11628.

Contact

Jan Schulte M.Sc.
Telephone +49 241 8906-371
jan.schulte@ilt.fraunhofer.de

Dr. Peter Rußbüldt
Telephone +49 241 8906-303
peter.russbueldt@ilt.fraunhofer.de

2 Setup for nonlinear pulse compression in a multi-pass cell.



MODEL-BASED, SELF-OPTIMIZING MOUNTING OF OPTICAL SYSTEMS

Task

In many areas, manual production is still needed when optical systems are mounted and adjusted. In some special areas, however, individual lenses can be mounted and adjusted (e. g. FAC lenses) in large numbers fully automatically, but manual processes dominate in small series. The project presented here aims at developing a fully automatic, cost-effective adjustment and mounting of optical systems, even in small quantities.

Method

In a first step, based on the planar design of an optical system, the mounting sequence of the individual components is calculated using an optimization tool. The main goal in this step is to make the sequence insensitive to component and mounting tolerances. Then, the current actual state of the optical system is determined after each adjustment and mounting step with the aid of a measuring system. Thanks to an optical model, the positions of the remaining components, which are still to be mounted, can be optimized from this state in order to ensure the required optical functionality of the overall system.

Results

Fraunhofer ILT has developed and demonstrated a method to calculate an optimal mounting sequence for different optical systems. Furthermore, the measurement data in the optical model were mapped with an error of less than 1 percent. This was successfully tested using the example of an optical system consisting of three lenses.

Applications

The methods and algorithms developed here make it possible to determine the system state between adjustment and mounting steps and to use the optical model for optimization. Thus, Fraunhofer ILT has provided a system for self-optimizing and function-oriented adjustment and mounting of optical systems.

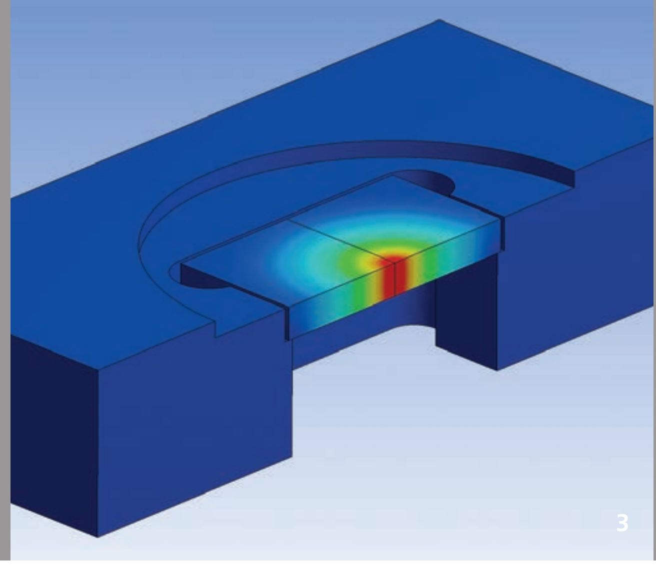
Contact

Martin Holters M.Sc.
Telephone +49 241 8906-351
martin.holters@ilt.fraunhofer.de

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

1 Assembly cell for the mounting of planar optics.

2 Kinematic system and measuring system of the assembly cell.



THERMO-OPTICAL EFFECTS IN PLASTIC OPTICS

Task

Thanks to injection molding, plastic optics can be manufactured with a high degree of design freedom and low costs per piece. Compared to optical glass, however, plastic has a high absorption coefficient in the range of 1%/cm. Moreover, the thermo-optic coefficient dn/dT and thermal deformation are about two orders of magnitude higher than that of glass. Consequently, significant thermo-optical effects are to be expected even at low thermal loads. Therefore, methods to model and compensate for these effects are required when plastic optics are used for laser applications in the power range of less than 10 W as well as for high-power LED applications.

Method

Finite element analysis is used to model the thermal load by absorption in the volume of the optics. The resulting temperature distribution and surface deformation are present in the form of discrete data. Thanks to specially developed software, the discrete data are transferred into continuously differentiable functions for the refractive index profile as well as the surface deformation and are made useable in the ray tracing program Zemax OpticStudio. In this way, thermo-optical effects can be taken into account when the optics are designed.

Results

Fraunhofer ILT has investigated the thermo-optical behavior of a polycarbonate planar plate with an IR laser beam source. Its simulation predicts a thermal refractive power of - 0.20 m^{-1} at 5 W laser power and a beam radius of 1.7 mm. Experimental measurements confirm the thermo-optical effects in the range of 1 to 20 W laser power.

Applications

The simulations allow a precise estimation of thermo-optical effects in plastic optics and, thus, form the basis for the development of compensation strategies. In a further step, practical plastic optics made out of different materials will be characterized.

Contact

Tobias Bonhoff M.Sc.
Telefon +49 241 8906-379
tobias.bonhoff@ilt.fraunhofer.de

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

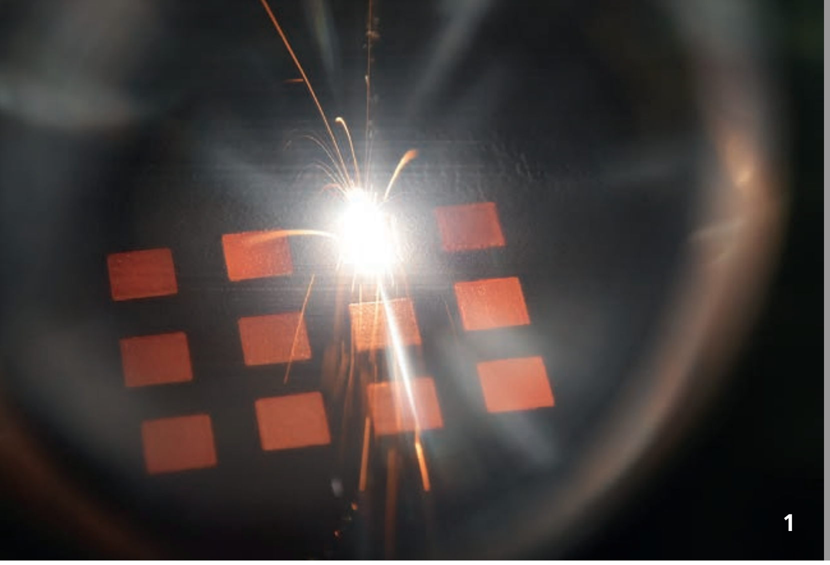
3 Finite element model of the polycarbonate sample.

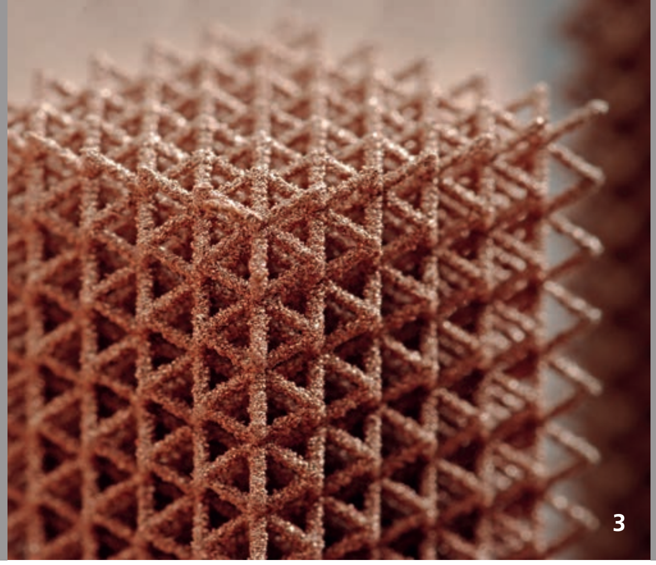
4 Freeform optics made of plastic.

LASER MATERIAL PROCESSING

CONTENTS

Coating a shaft for the offshore area.





PROCESSING OF TITANIUM ALUMINIDES (TIAL) WITH HIGH-TEMPERATURE SELECTIVE LASER MELTING (HT-SLM)

Task

Lightweight structures and materials are increasingly being used to reduce the emission of pollutants from mobile turbomachinery. The intermetallic lightweight material titanium aluminide (TiAl) has great potential for such purposes because it combines high material strength with low weight and high thermal resistance. However, since it is highly brittle and has mechanical characteristics significantly dependent on the oxygen concentration in the component, it is difficult to process TiAl with conventional production processes. As a powder-based additive manufacturing process, Selective Laser Melting (SLM) basically makes it possible to manufacture complex metallic structures without tools and with a near net shape. Therefore, this project aims to develop suitable process control for the processing of TiAl with SLM. Components are considered suitable when they are crack-free with a density > 99.5 % and with mechanical properties which are in the range of cast TiAl.

Method

Owing to the localized melting during SLM, large thermal gradients are created, which can lead to crack formation in the component structure, especially in the case of brittle intermetallic materials. For the crack-free processing of TiAl with SLM, the components are, therefore, preheated over the brittle-ductile temperature during the process. For this purpose, an SLM laboratory machine is used with an induction heating system which reaches preheating temperatures of > 1000 °C. So that the mechanical characteristic values »elongation« and »tensile strength« can be determined, tensile specimens are built and heat-treated by hot isostatic pressing (HIP) before they are subjected to tensile tests at room temperature. Finally, a guide vane ring is manufactured and its dimensional accuracy checked with the aid of a 3D scanner.

Results

Pre-heating over the brittle-ductile temperature makes it possible for SLM to process TiAl free of defects, with densities > 99.95 percent and a micro-duplex structure. The tensile strength of 917 ± 97 MPa at room temperature is comparable to the tensile strength of cast tensile specimens made of TiAl. However, the breaking elongation is smaller compared to cast samples. This can be caused by an increase in the oxygen concentration from the process chain. If a shrinkage that occurs during cooling is taken into account as an oversize in the CAD file, a dimensional accuracy of < 80 µm can be achieved.

Applications

Possible applications for TiAl components manufactured by SLM are in turbomachinery, as well as in the automotive and aerospace sectors.

The SME-innovative project underlying this report has been carried out on behalf of the Federal Ministry of Education and Research (BMBF) under grant number 033RKo35C.

Contact

Andreas Vogelpoth M.Sc.
Telephone +49 241 8906-365
andreas.vogelpoth@ilt.fraunhofer.de

1 Exposure of SLM specimens out of TiAl at a preheating temperature > 800 °C.

2 Guide vane ring made of TiAl with HT-SLM.

FURTHER DEVELOPMENT OF THE PROCESSING OF COPPER ALLOYS BY SLM

Task

In the last few years, Fraunhofer ILT has expanded the state of the art for the processing of copper alloys with SLM. Indeed, it has demonstrated that SLM can process the alloys CuCr1Zr and CuCrNi2Si. Moreover, the objective of achieving a density > 99.5 percent during processing has been achieved for these alloys. What has not yet been done, however, is to develop the process further in order to improve the surface quality and achieve higher resolution of the two alloys: these two factors pose an important challenge for the process so that it can be useful for the industry. Processing these materials faces two challenges: the alloy's high thermal conductivity and high degree of reflection for the laser radiation at a wavelength of λ = approx. 1 µm.

Method

To improve component quality, Fraunhofer ILT has systematically varied the process parameters while also taking the microstructure and surface quality into consideration. In addition, it has examined different processing strategies.

Results

The achievable surface quality for the processing of the alloys was reduced to S_A = ~ 10 µm from approx. S_A = 45 µm for vertically constructed walls. The minimum wall thickness was reduced from approx. 1 mm down to 0.3 mm. In addition, a shape tolerance in the range of ± 0.1 mm has been demonstrated by means of optical 3D measurements on various components.

Applications

Copper and its alloys are predominantly used in the field of toolmaking and electrical engineering. In addition, special copper alloys have special corrosion resistance. Examples of where this further development can be applied are the production of water-cooled induction coils, special cooling structures and heat exchangers as well as the prototype manufacture of electrically conductive components.

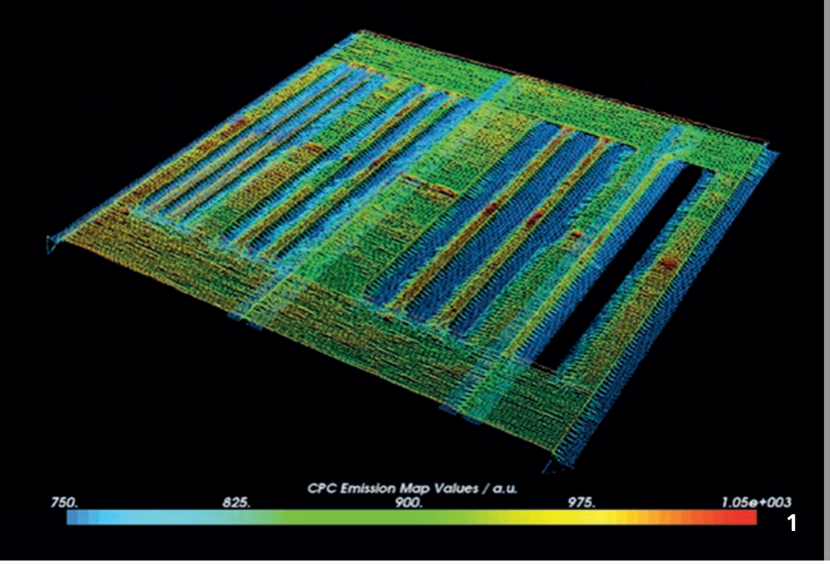
Contact

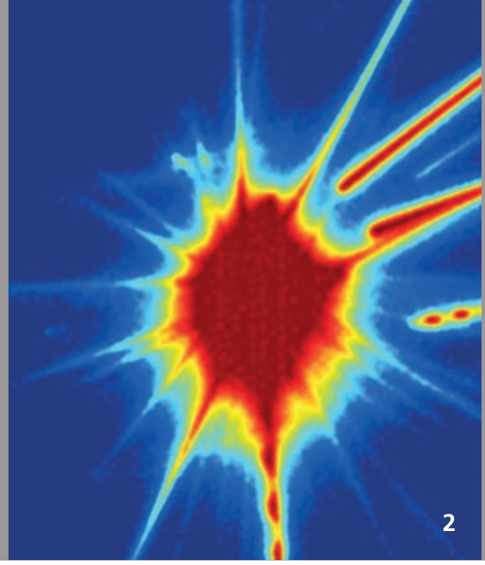
Daniel Heußen M.Sc.
Telephone +49 241 8906-8362
daniel.heussen@ilt.fraunhofer.de

Dr. Wilhelm Meiners
Telephone +49 241 8906-301
wilhelm.meiners@ilt.fraunhofer.de

3 Lattice structure, strut diameter: 0.3 mm.

4 Induction coils built with SLM.





MULTI-SENSOR PROCESS MONITORING FOR ADDITIVE MANUFACTURING

Task

When components with high geometric and technical complexity need to be manufactured, additive manufacturing processes offer new degrees of freedom in design and construction. Most importantly, they can be used to integrate a large number of functions in a single component. Selective laser melting (SLM) of metals from a powder bed can generate innovative components whose properties can be determined as needed. The product quality is ultimately determined during the course of the process by the interaction of the laser with the metal powder.

Method

Today, in a typical production system with a metallic powder bed process, the laser beam is positioned in the process chamber with a mirror deflection system and positioned according to the component geometry. The laser radiation melts the powder, creating a melt pool whose emitted heat radiation is detected in terms of magnitude and extent with pyrometers, photodiodes and fast cameras. The coaxial coupling of suitable sensors with the optical system permits the properties of the interaction to be determined in-situ. The radiation emitted by the melt pool is guided along the same optical path as the processing radiation and can thus be related to the exact location on the component. The analysis of the process results can thus be correlated with local events in the component.

Results

The multi-sensor process monitoring allows the recording of process sequence maps during processing. They represent the result of the interaction with the properties of the melt pool, while the information is located directly in the component. Typically different sampling rates are related by a robust temporal correlation in such a way that a consistent and usable result is available after the data have been condensed.

Applications

The system can be used for process control for the additive manufacturing of components generated by laser radiation from a powder bed. In the future the aim will be, in addition to monitoring, to control the process on this basis.

Contact

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

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

1 Emission map of the thermal emission from the melt pool.

2 Melt pool in the infrared range.

AUTOMATED SUPPORT REMOVAL FOR SLM COMPONENTS

Task

A major obstacle to today's use of the SLM process in industrial serial production is the great manual effort involved in finishing the component, in particular, the removal of its support structures. According to the present state of the art, the components are first separated from the construction platform by means of a sawing or wire cutting process. In the next step, the support structures are manually detached from the component with simple hand tools and the surfaces are post-treated as required. However, this results in a great time and expense and is, therefore, unsuitable for series production.

Within the scope of a current research project, Fraunhofer ILT examined various automated process approaches and assessed them in terms of their feasibility on SLM-machined geometrical structures made out of AlSi10Mg.

Method

A cost-benefit analysis according to the VDI 2221 standard was carried out to preselect potentially suitable process approaches. The designs with the greatest potential were then tested on the laboratory scale for their feasibility.

Results

In particular, the process approach »chemical removal« offers great potential for use in series production. The method can be used for the complete removal of various external and internal support structures, regardless of their geometry. In particular, however, a tree-like support structure is suitable for this method's operating mechanism. The method has other advantages: It operates independently of the pieces processed, several machining steps can be run in parallel and it smooths the surfaces once the supports have been removed. Currently, the process is being tested on AlSi10Mg.

Applications

Due to the simple plant technology, the process can be applied both in small scale and for industrial series production, for example in the automotive industry. When suitable etching agents are selected, the process can also be applied to other materials and, thus, made accessible for a wide range of industrial applications.

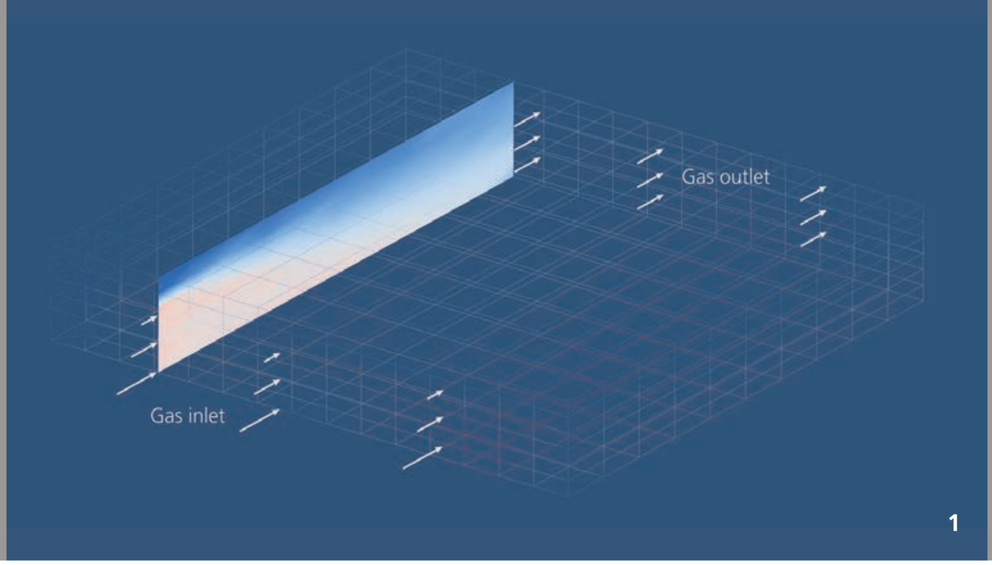
The R&D project underlying this report has been carried out on behalf of the Federal Ministry of Education and Research under the grant number 13N13641.

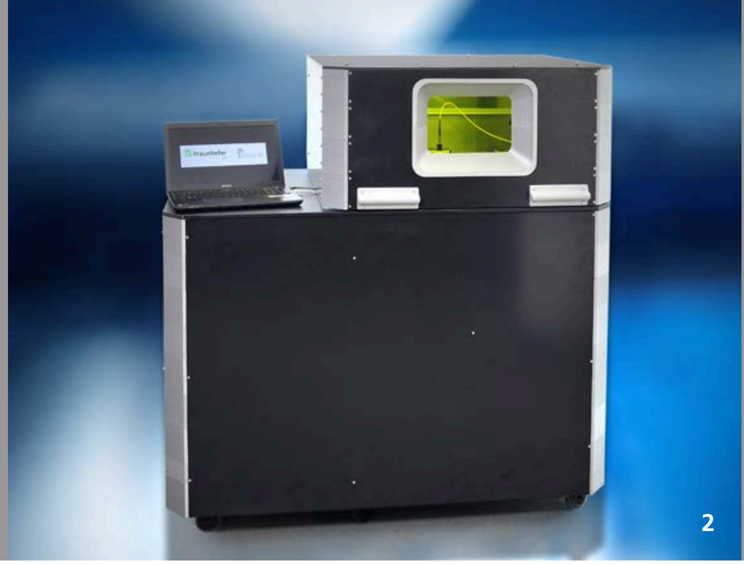
Task

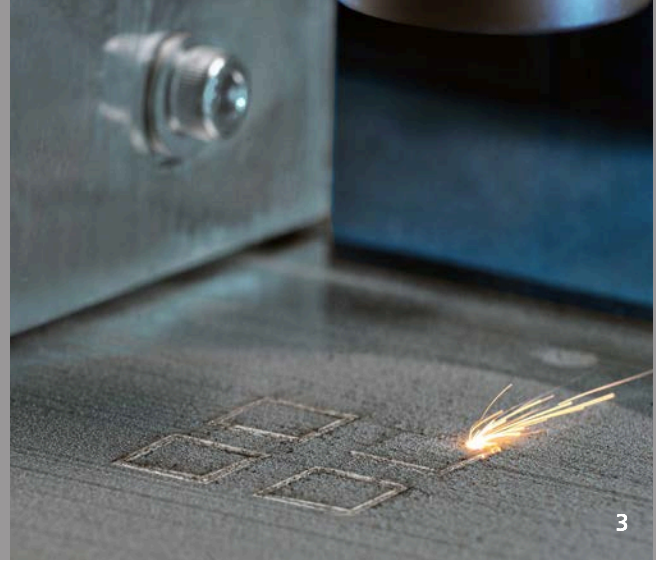
Tobias Schmithüsen M.Eng.
Telephone +49 241 8906-568
tobias.schmithuesen@ilt.fraunhofer.de

3 Internal and external SLM-machined geometrical structure.

4 Geometrical structure whose supports have been removed by the new process.







3D MEASUREMENT OF SHIELDING GAS FLOWS IN SLM SYSTEMS

Task

In addition to process parameters such as laser power, scanning speed and the build-up strategy, the shielding gas flow in SLM systems particularly influences the quality of the components it manufactures. Here, a general characterization of the flow via the volume flow is not sufficient; much more, the local flow profile above the construction platform is decisive. For a basic understanding of the correlation of the shielding gas flow with the resulting component quality, the flow in SLM systems shall, therefore, be visualized and quantified. On the basis of these results, an optimized design of the shielding gas flow can subsequently be developed.

Method

A thermal anemometry system is used for the measurement. This allows a time-resolved measurement with up to 50 kHz of flow velocity and direction at one point. By means of a flexibly adaptable portal system, the flow field in the SLM system can be measured sequentially point by point.

Results

For the first time, the design developed for the 3D visualization of the shielding gas flow makes it possible to directly measure the shielding gas flow in SLM systems without structural changes. The result is a position-resolved measurement of the velocity distribution in a grid of approximately 1 mm edge length. Since the thermal anemometer has a frequency response of around 50 kHz, the turbulence degree of the flow can also be inferred. With this information, a correlation between the flow profile and the component quality can be determined, which is necessary to better design the shielding gas flow of current and future machine generations.

Applications

The results contribute to improving process robustness and reproducibility during the SLM and are, therefore, relevant to manufacturers of SLM systems as well as to their users.

Contact

Dipl.-Ing. Maximilian Schniedenharn
Telephone +49 241 8906-8111
maximilian.schniedenharn@ilt.fraunhofer.de

Dr. Wilhelm Meiners
Telephone +49 241 8906-301
wilhelm.meiners@ilt.fraunhofer.de

1 Flow velocity in a measurement plane.

LOW-COST SLM SYSTEM

Task

As one of the additive manufacturing technologies, Selective Laser Melting (SLM) has established itself in the field of manufacturing technology since it can fabricate highly complex components made of metallic materials. Large companies are investing directly in the innovative technology to open up new sales markets or to improve existing products and processes. Small and medium-sized enterprises (SMEs) also increasingly see the economic and technological opportunities of additive manufacturing (AM), but they are often afraid of making the necessary investment. This is the issue the close-knit expert team of the Fraunhofer ILT and the FH Aachen University of Applied Sciences is addressing by setting up a low-cost SLM system. Since the partners have a practice-oriented approach and in-depth process and plant know-how, they can facilitate access to the additive manufacturing of metals, especially for SMEs.

Method

The idea behind the low-cost SLM system is to do without costly components, such as classical laser scanner systems. By using a Cartesian axis system in combination with a diode laser as a beam source, the partners have found the greatest potential for savings. The goal is to use the comparatively inexpensive plant design to help SMEs above all get started in the additive manufacturing of metals.

In a first step, a prototype plant was built with the following main components:
- 2-axis system
- Building space: Ø 80 mm x 90 mm
- Diode laser > 100 W with 250 µm focus diameter

Results

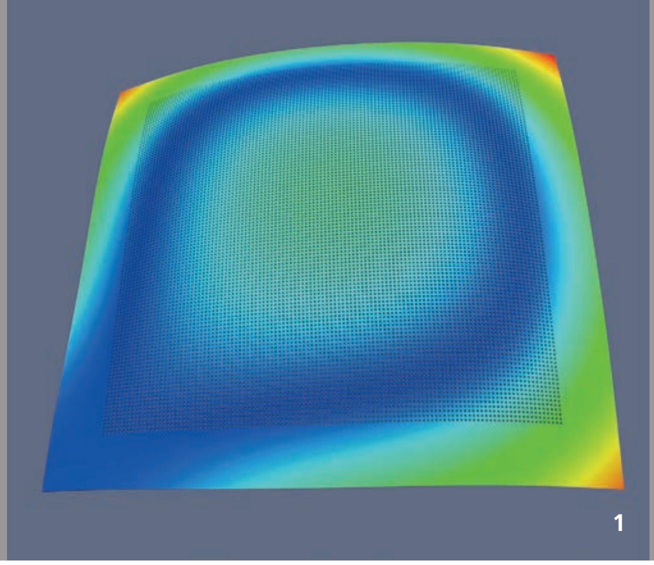
With this plant design, a diode laser was proven to be suitable for the selective laser melting of metal powder. In initial tests, parameters for material 1.4404 were validated, with which a density of over 99.7 percent was achieved. This results in a tensile strength corresponding to that of conventionally produced material. Demonstration models show how well the system functions and the geometrical component quality that can be achieved.

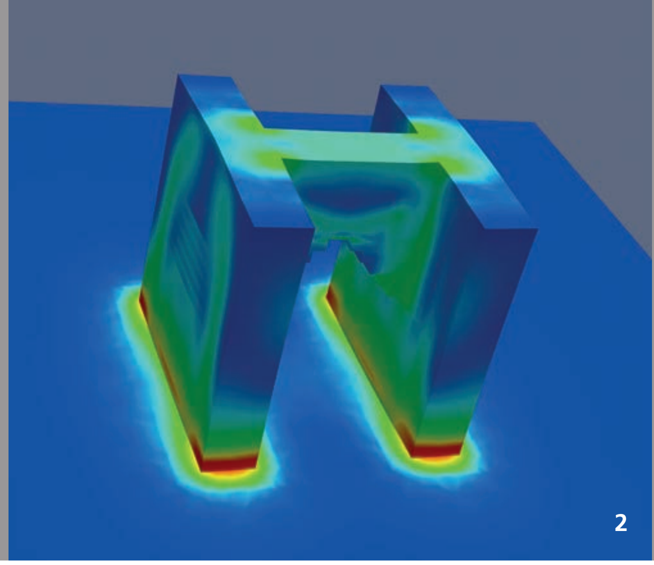
In a next step, the plant shall be adapted to industrial standards. This means continuing to develop the plant in the areas of control and software as well as integrating safety and protection functions. The parameterization of further materials, such as aluminum alloys and tool steels, will be at the forefront of process development. In addition, the building space will be enlarged in order to expand the fields in which the plant can be applied.

Contact

Dawid Ziebura M.Eng.
Telephone +49 241 8906-8172
dawid.ziebura@ilt.fraunhofer.de

2 Low-cost SLM system.
3 SLM process.





SIMULATION OF THE DISTORTION OF ADDITIVE AND ABLATIVE PROCESSES

Task

In additive manufacturing processes or in the structuring of thin films, thermally induced plastic strains lead to residual stress and distortion. A component shape modified by these plastic strains can require post-processing or simply become useless. To determine a component-specific and material-specific process control, a considerable experimental effort is needed, but can be simplified by numerical simulation of thermal distortion.

Method

In order to calculate the deformation of components as a function of process parameters, simulation tools are required with which temperatures, plastic strains and stresses on time-dependent component geometries can be calculated efficiently. For this purpose, a simulation tool (StrucSol) was developed that uses an iterative numerical method for the rapid solution of thermo-elastoplastic equations. This solver is massively parallelized and characterized by a low memory requirement and a high calculation speed in large systems of equations.

Results

StrucSol was used to calculate the temperature distribution and the distortion in the structuring of thin films (Fig. 1) with ultrafast laser pulses and Selective Laser Melting SLM (Fig. 2). In the structuring, the deposited laser power and the ablation geometries of the individual structures are calculated with a micro model and taken into account during the production of the metallic film in a macro model. In the SLM process, individual layers are grouped together into a compound and then activated and processed in a layer-by-layer manner as the component is built.

Applications

The developed simulation tool can be used to calculate the temperature distribution and distortion during structuring and during the SLM processes. In addition, the tool can be transferred to other machining processes such as Laser Metal Deposition, welding or drilling.

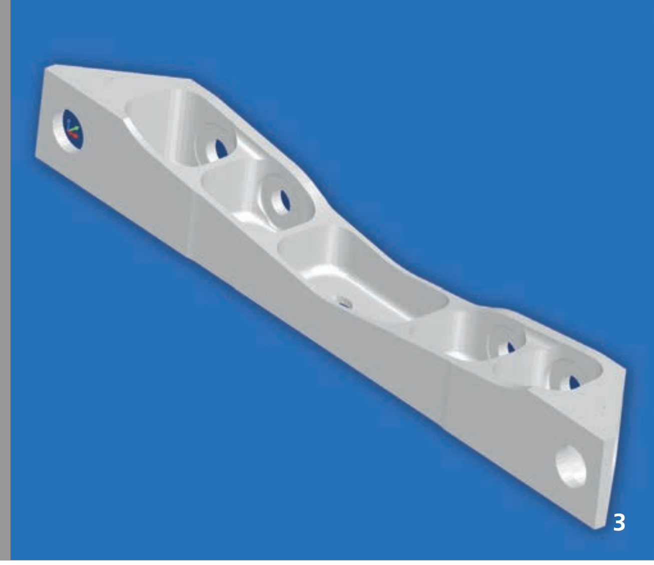
Contact

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

Dr. Rolf Wester
Telephone +49 241 8906-401
rolf.wester@ilt.fraunhofer.de

1 Distortion of a thin film after structuring.

2 Von Mises' yield criterion for an SLM component.



ADDITIVE MANUFACTURING OF A DEMONSTRATOR AVIATION COMPONENT WITH LMD

Task

To produce large, complex and cost-intensive components, e. g. out of nickel-based superalloys, for the aviation industry more efficiently, additional methods such as laser material deposition (LMD) have been under investigation as alternatives to conventional production. For this process to become widely used in the industry, however, the LMD process has to become more cost-effective, in addition to other technological aspects. Significant cost factors are production process time and the subsequent postprocessing. Both points are being investigated within the framework of the EU project »AMAZE« and are to be implemented on an engine suspension as a demonstrator component (Fig. 3) with an increased build-up rate. The demonstrator was produced with local shielding and without a process chamber.

Method

Due to the local inert gas shielding and the oxidation risk caused by this, the surface temperature before the beginning of the next layer was cooled to below 80 °C. The previously conducted parameter tests showed that the higher nominal deposition rates of larger track widths result in prolonged cooling times, which reduce the total build-up rates. Therefore, a track width of 2 mm was selected, providing an advanced build rate with reasonable cooling time and allowing a near net-shape build.

Results

With the established parameter set, half of the engine suspension was successfully built as a demonstrator in a construction time of approx. 11 hours (Fig. 4), the inert gas shielding occurred exclusively through the powder nozzle. Cooling times between the layers accounted for about 4 hours of construction time. The demonstrator component was generated in near-net shape with the aid of the CAM system »LMDCAM«, developed at Fraunhofer ILT for the offline planning of the NC programs. The construction of a support structure with LMD on the back of the substrate plate significantly reduced the deformation of the component.

Applications

The results obtained with the material IN718 can be transferred to other materials and applications. Potential can be found in components that have a high machining volume, for example, integral and engine components from the aviation industry or turbines of high-performance materials for energy production. In tool and mold making, effective and flexible solutions lend themselves to, e.g., the modification of components.

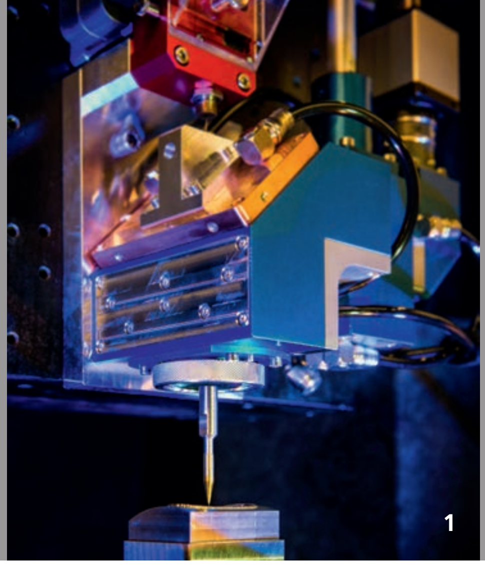
The work has been funded within the framework of the EU project »AMAZE« under the grant number 313781.

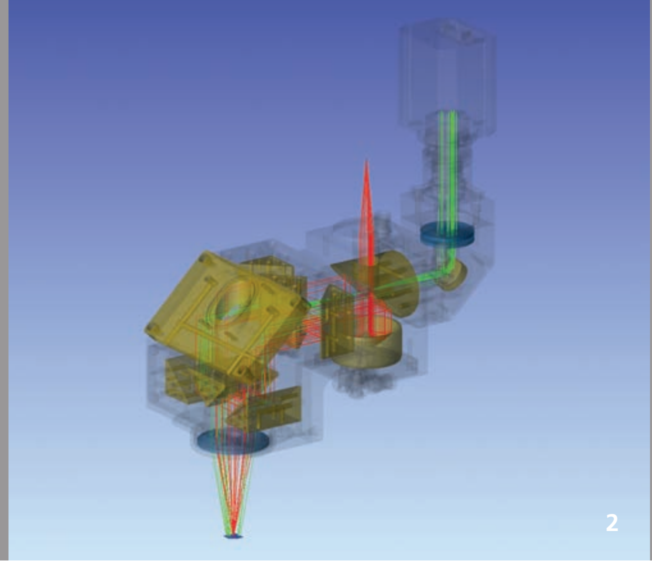
Contact

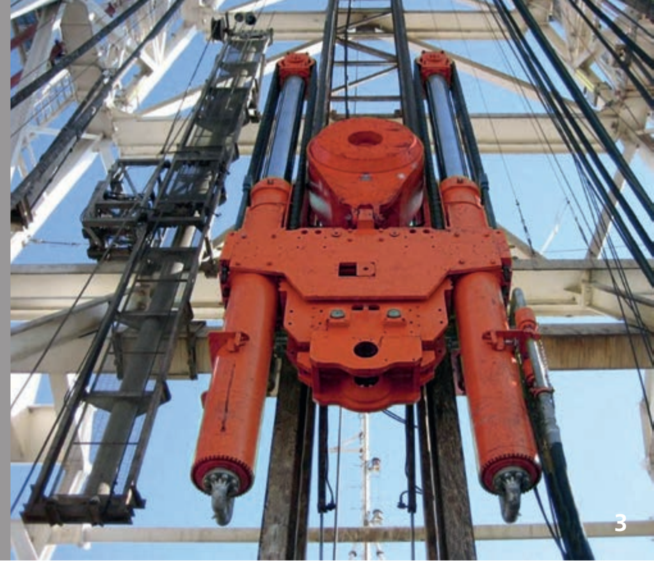
Dipl.-Ing. Jochen Kittel
Telephone +49 241 8906-136
jochen.kittel@ilt.fraunhofer.de

3 CAD model pylon bracket (source: Airbus Group).

4 LMD demonstrator pylon bracket segment (50 percent - 248 x 65 x 60 mm^3).







COAXIAL WIRE FEED FOR LASER METAL DEPOSITION

Task

Laser metal deposition (LMD) with wire-shaped filler material is an alternative to LMD with powdered filler materials. Indeed, the overspray, the catchment efficiency, the insufficient quality of the powder, or the contamination of the component and the system are factors that make powder-based LMD unfeasible for some applications. A disadvantage of the state-of-the-art wire processing heads, however, is the lateral feed, which makes direction-independent processing impossible. Exceptions are the coaxial designs developed at Fraunhofer IWS and ILT, which permit a direction-independent processing but are only of limited suitability for applications on robotic systems due to their size. The two institutes will continue to develop, therefore, a smaller and more compact machining head with a system weight of about 5 kg for LMD. Here, a coaxial wire feed shall enable direction-independent 3D processing.

Method

Before a compact processing head can be developed, the process for the generation of a ring beam, patented by Fraunhofer ILT, has to be revised. The use of reflective optics not only enables the plant size to be reduced, but also allows the processing head to operate independently of the wavelength. In addition to adding laser beam guiding and shaping, the institutes have integrated a coaxial process monitoring system into the machining head.

Results

A machining head has been developed for LMD with coaxial wire feed; it weighs approx. 5 kg and has a size of 200 x 100 x 200 mm^3 (W x D x H). During the testing of the processing head, a direction-independent LMD process could be verified, which was demonstrated by using the system to weld Ti6242. The integrated coaxial process monitoring was used to precisely position the machining head.

Applications

The processing head developed here can be used for LMD with wire-shaped filler materials for coating, repair and additive manufacture. The system weight and size allow use in 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. Oliver Pütsch
Telephone +49 241 8906-617
oliver.puetsch@ilt.fraunhofer.de

1 Machining head with coaxial wire feed.
2 Schematic representation of the beam paths.

CERTIFICATION FOR COATING OFFSHORE HYDRAULIC CYLINDERS WITH THE EHLA PROCESS

Task

The surface of hydraulic cylinder piston rods is exposed to extreme wear and corrosion stress. This applies in particular to offshore applications since they are in direct contact with salt water. So that the surface can be protected against the harsh environmental conditions, metallic coatings having layer thickness range of 100 to 300 µm are commonly used. If a coating fails, a company can suffer costly downtime and create immense environmental hazards. The replacement or repair of the piston rods is difficult, time-consuming and expensive because of their limited accessibility. For a long time, galvanic processes have been state-of-the-art for the coating of piston rods in the offshore industry. However, due to stricter requirements in environmental protection, CO_2 reduction and energy efficiency, there is now a growing need for alternative, resource-conserving and automated coating processes with a high layer quality.

Method

In cooperation with the Dutch system integrator Hornet Laser Cladding B.V., a machine that coats the hydraulic cylinder piston rods – up to ten meters long – was installed at one of the world's leading manufacturers of tailor-made hydraulic cylinders, IHC Vremac B.V. The system uses the extreme high-speed laser material deposition (EHLA) process developed by Fraunhofer ILT. The advantages of this new process are that high-quality, thin and metallurgically bonded metal protective coatings can be applied economically on large components.

Results

The entire coating process was reviewed by MME Group of Ridderkerk under the supervision of Lloyds' Register Nederland. The system was proved to have complied with all requirements of ISO 15614-7 (welding method test), EN 14732 (operator and installer test) as well as the salt spray test according to ISO 9227 and was certified by Lloyd's Register EMEA Marine.

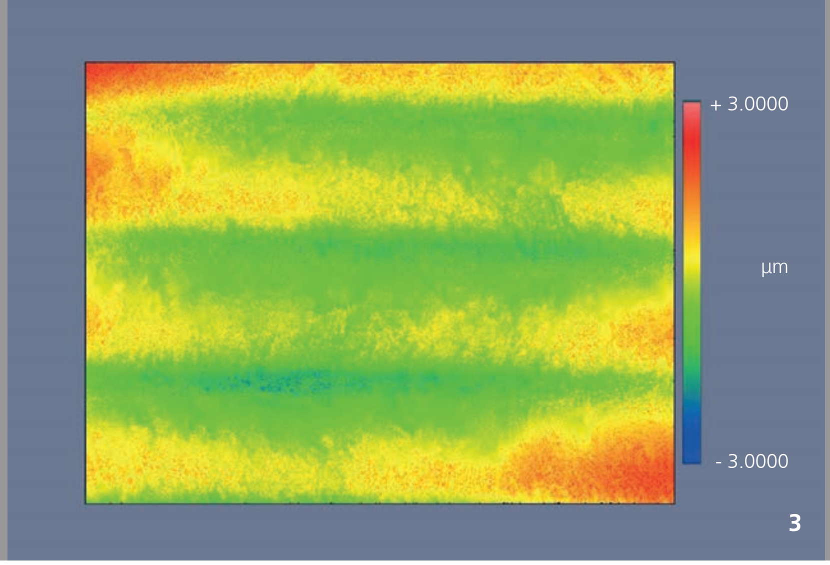
Applications

The EHLA process is basically suitable for coating all rotationally symmetrical components for protection against corrosion as well as for abrasive and adhesive wear.

Contact

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

3 Hydraulic cylinder in the offshore sector (source: IHC Vremac B.V.).
4 Hydraulic cylinder piston rod coated with the EHLA process.



POWDER FEED NOZZLE FOR THE EHLA PROCESS

Task

Conventionally, in Laser Metal Deposition (LMD), a powdered filler material is injected through a powder nozzle into the molten bath produced by the laser beam on the surface of a component and melted there. A layer is generated on the component by the laser beam as it moves relative to the component and overlap of individual tracks. The maximum process speeds are about 15 to 20 m/min. In the case of extreme high-speed laser metal deposition (German acronym EHLA), on the other hand, the powdered filler material is injected into the laser beam and melted there before the powder reaches the molten bath. This allows process speeds of several 100 m/min. Both the powder feed and powder nozzle, however, pose a particular challenge.

Method

So that the EHLA process can be used in the industry, the powder nozzle must meet the following requirements:

- Adjustable powder gas beam caustic for the optimized injection of the powder into the laser beam
- Generation of a dense powder gas jet to maximize powder efficiency
- Consistent powder gas jet quality for large flow rates > 500 kg
- Easily replaceable nozzle components after malfunctions caused by operating errors or wear

Based on the coaxial nozzle technology already existing at Fraunhofer ILT for laser metal deposition (LMD), further developments and modifications have been made for an EHLA nozzle.

Results

In order to meet the demands on the nozzle (see points 1 and 2 in Method), a freely adjustable powder gas-jet canal was developed. In combination with a protective gas stream, the powder gas stream was adapted to the laser beam caustic and, at the same time, the powder focus was optimized. By surface finishing the powder flow surfaces and by being able to quickly exchange damaged nozzle tips, Fraunhofer ILT was able to lengthen the service life of the process significantly.

Applications

The use of the EHLA process, and thus also the EHLA nozzle, is particularly suitable for applying thin, wear- and corrosion-resistant coatings on rotationally symmetrical components, for example shafts and washers for the heavy and offshore industry, e.g. as an alternative to chrome plating.

Contact

Dipl.-Ing. Gerhard Backes
Telephone +49 241 8906-410
gerhard.backes@ilt.fraunhofer.de

1 Coaxial powder nozzle with interchangeable tip.

2 Coating a shaft for the offshore area.

GENERATING THIN LAYERS WITH GOOD SURFACE QUALITY BY TWO-STAGE LASER COATING

Task

The project shall develop a two-stage coating process that makes it possible to select a high surface quality in a melt-metallurgical connection to the substrate in the layer thickness range of 20 to 300 µm. In addition, large area rates (A ≥ 0.5 cm²/s) are to be achieved with regard to industrial conversion.

Method

In the first stage, the coating is applied by means of an »air spraying process«. The powdery coating material (content about 70 percent) is, in this case, in an aqueous solution with proportions (< 3 percent) of chemical additives, including binders and antioxidants. Subsequently, the coating is dried at about 80 °C and melted by means of laser radiation.

Results

So far, a stainless steel (1.4404) and a Ni-based alloy (Deloro 22) have been tested. Crack-free and low-pore layers with thicknesses of 80 to 100 µm were produced and bonded to the base material metallurgically. The parameter studies show that surface area and surface quality cannot be improved in the same direction. The roughness value currently obtained for a surface rate of A = 0.5 cm²/s is limited to Ra ≈ 3 µm. For smaller surface rates, however, a roughness of Ra ≈ 0.5 µm can be achieved. The focus of further research will be the application of the layers to components.

Applications

Fields of application are, for example, the wear protection in tool and mold making and the production of functional layers in the electronics industry.

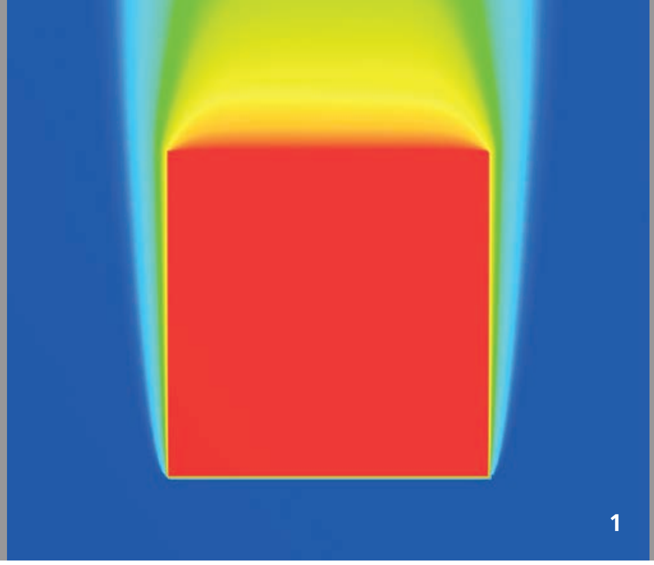
The work has been carried out in the context of a CORNET project (German project partner AiF) together with the Belgian institute CRIBC in Mons.

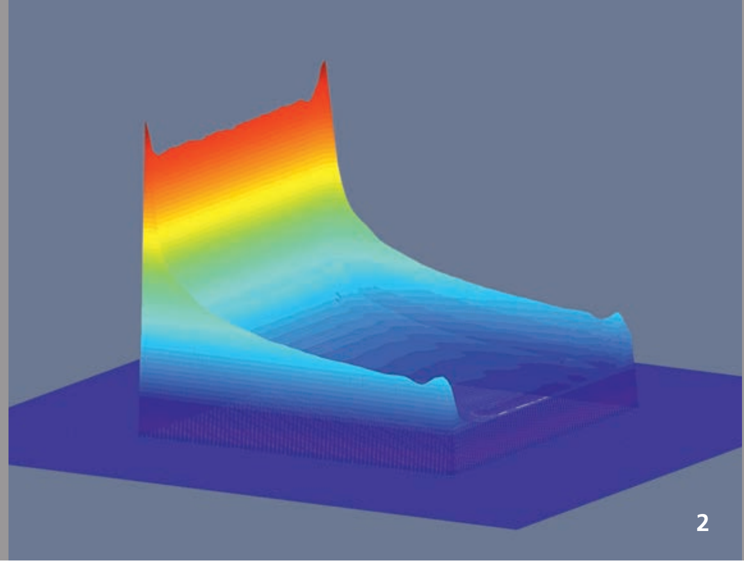
Contact

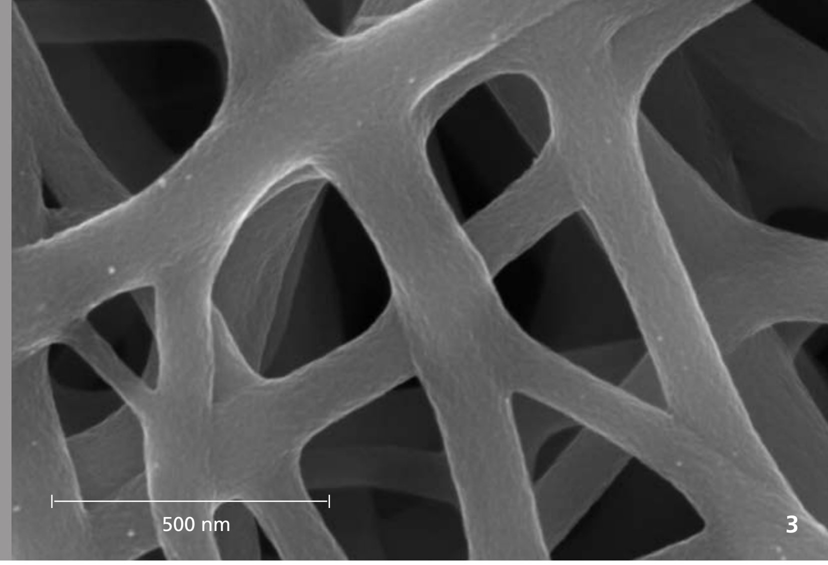
Dipl.-Ing. Dora Maischner
Telephone +49 241 8906-8017
dora.maischner@ilt.fraunhofer.de

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

3 Image of the surface of a layer out of Deloro 22 (Ra = 0.43 µm +/- 0.02 µm) with a white light interferometer for a measuring field size of 0.35 mm x 0.26 mm.







APPLICATION-SPECIFIC INTENSITY DISTRIBUTIONS FOR LASER HEAT TREATMENT

Task

Often, conventional intensity distributions cannot fulfil the ever-increasing requirements for laser heat-treatment processes in terms of workpiece geometry, material composition, processing quality and efficiency. When, however, intensity distributions are specifically adapted to the workpiece geometry and the material properties, these deficits can be counteracted. Here, beam shaping methods such as free-form optics or so-called »Vertical Cavity Surface Emitting Laser« beam sources (VCSEL) make it possible to adjust the temperature profile induced in the workpiece by shaping the intensity distributions.

Method

Firstly, for different laser heat treatment processes using conventional intensity distributions, Fraunhofer ILT has experimentally determined temperature-time curves that lead to an optimal processing result. When an algorithm is used to solve an inverse heat conduction problem, the optimal intensity distribution can then be deduced from the required temporal and spatial temperature profile. This is subsequently carried out – depending on the application – either by free-form optics or by VCSEL arrays.

Results

For laser softening as well as hardening, optimal temperature profiles have already been calculated. By implementing an efficient solution algorithm of the inverse heat conduction problem, the institute could determine the corresponding intensity distributions and then design suitable free-form optics to generate them.

Applications

The methods developed here can be applied in a wide range of laser heat treatment processes in various industries. These include, among others, laser hardening, laser softening and the functionalization of thin layers.

The R&D project underlying this report is being carried out under grant number 13N13476 within the scope of the research program »Digital Photonic Production«.

Contact

Annika Völl M.Sc.
Telephone +49 241 8906-8369
annika.voell@ilt.fraunhofer.de

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

1 Optimum temperature profile for many laser heat treatment processes.

2 Intensity distribution to produce a homogeneous temperature profile.

LASER-BASED PRODUCTION OF CARBON NANOFIBER NON-WOVEN FABRIC

Task

Carbon fiber non-woven fabrics provide an excellent starting point as membranes, as a conductive medium in energy applications, or as a deposition medium in filter applications. All three applications require high specific surfaces of the non-woven fabric for optimum material behavior. To produce the carbon nanofibers, an electrospinning process is used to form polyacrylonitrile (PAN) fibers, which are subsequently subjected to thermal treatment and stabilization in a furnace. In a final process step the carbonization of the stabilized non-woven fabric takes place.

Method

Within the framework of the AiF [the German Federation of Industrial Research Associations] project »ePolyVlies«, the last process step of the carbonization of the non-woven fabric is being investigated by means of laser-based thermal post-treatment. Due to the high heating rates achieved, 10 to 50 K/s, via the laser radiation, large amounts of process gases are released as byproducts during the carbonization process. The rapid evaporation leads to the formation of nanometer-sized pores, which induces the generation of large specific surfaces of the non-woven fabric.

Results

At the DWI – Leibniz Institute for Interactive Materials, BET measurements were carried out to determine the size of the surfaces by means of gas adsorption. The measurements show that non-woven fabric produced by the conventional furnace process has a specific surface area of 12 m^2/g. The specific surface area of the laser-based carbonized non-woven fabric has a value of 490 m^2/g, which is about 40 times as high as non-woven fabric carbonized in an oven-based process.

Applications

The process presented here has potential for use in membranes as well as energy and filter applications.

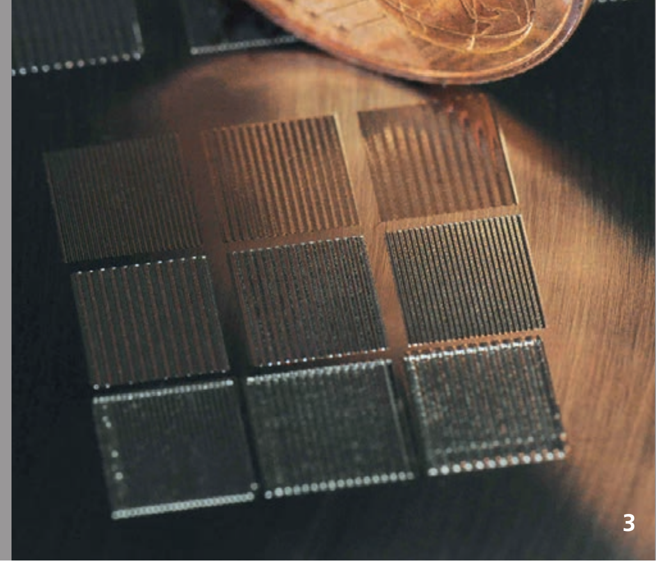
The R&D project underlying this report was carried out on behalf of the Federal Ministry for Economic Affairs and Energy under grant number 17973 BG/2.

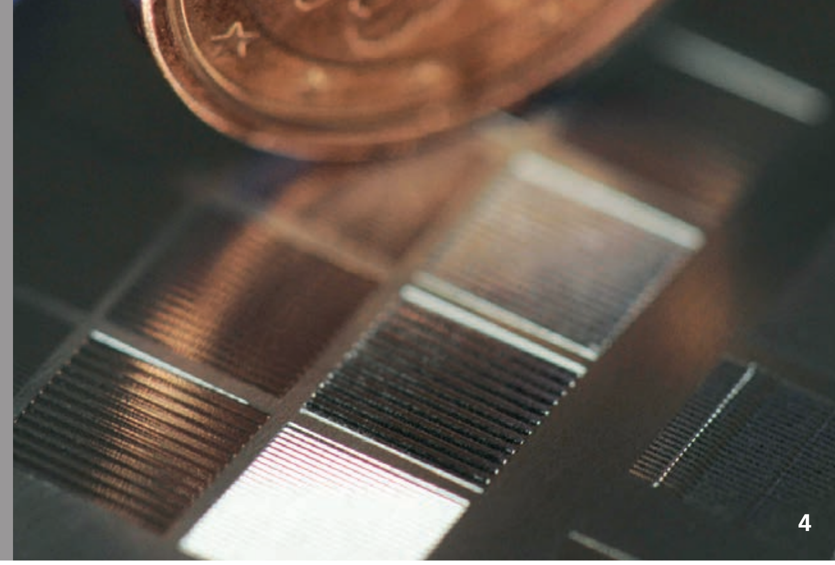
Contact

Dipl.-Ing. Philipp Lott
Telephone +49 241 8906-8036
philipp.lott@ilt.fraunhofer.de

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

3 Laser-based nanofiber non-woven fabric (source: DWI, Aachen).





LASER POLISHING OF GLASS COMPONENTS MANUFACTURED WITH SLE

Task

Thanks to its almost unlimited design freedom, the laser-based manufacturing process Selective Laser Etching (SLE) makes it possible to manufacture complex and individualized components made of fused silica. However, the surfaces produced with SLE have a micro-roughness of Sa = 400 nm (measuring field 100 × 100 µm2) due to the laser patterning in the bulk material and the subsequent etching process. Polishing the surfaces, in particular of complex geometries and internal surfaces of microfluidics, is very costly with the present state-of-the-art processing.

Method

The Fraunhofer ILT, in collaboration with LightFab GmbH, is developing a laser-polishing process for the post-machining of components made of fused silica manufactured with SLE. Here, the glass of the SLE surfaces is melted in a thin surface layer by means of laser radiation and smoothed by the surface tension with almost no material loss. If the heat penetration depth is sufficiently large, the laser-based polishing process can also be used to heat inner surfaces so that the micro-roughness is reduced. For the laser polishing of fused silica, both continuous and modulated CO_2 laser radiation (λ = 10.6 µm) is used. Since the process operates without contacting the component, complex surface geometries such as free-form lenses can also be polished.

Results

Initial results of the laser polishing of fused silica surfaces show that the micro-roughness of the SLE surface can be reduced from Sa = 400 nm to Sa = 0.5 nm (measuring field 100 × 100 µm²). In addition to the laser polishing of free-form lenses, the method has also been tested on complex 3D geometries that have been manufactured using SLE. In the case of the laser polishing of internal micro-channels, the roughness of the inner surface could be reduced to such an extent that flow processes inside the micro-channel could be observed with a microscope.

Applications

The SLE-based production of components made of quartz glass is commonly used, in particular, in microfluidics, micromechanics and micro-optics.

Contact

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

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

1 Microfluidics made of fused silica (height: 7 mm) manufactured by SLE (left) and laser-polished (right).

2 Chess piece made of quartz glass (left: after SLE, right: after laser polishing).

FAST LASER REMELT STRUCTURING (LUST) OF SMALL STRUCTURES OUT OF TI6AL4V

Task

Nowadays, one cannot imagine components without structured surfaces in many industrial sectors. The titanium alloy Ti6Al4V is widely used in many industries, starting with engine components for the aerospace industry, through implants in medical technology all the way to functional and design surfaces for the jewelry industry. However, the structuring methods currently used on this material (e.g. etching, laser ablation, etc.) are often time-consuming and/or cost-intensive and are based on a structuring by material ablation. Both methods produce rough surfaces which can only be used to a limited extent, for example, in the hygienic or design sectors. Moreover, the low ablation rate is another shortcoming.

Process Principle

Owing to these deficiencies in conventional processes, a novel process has been developed, laser remelt structuring (LUST). Here, a laser beam melts the metal surface locally by heat input. At the same time the laser power is modulated with frequencies between 10 Hz and 10 kHz, which results in a continuous change in the melt pool size so that the material is redistributed without ablation. In this way, the process generates mountains and valleys that lie half above and half below their initial level. The edge layer solidifies directly from the melt so that the surface is simultaneously polished as well as structured. As part of the »WaveShape« project sponsored by the VW Foundation, systematic experimental investigations have been conducted with laser beam diameters of less than 50 µm and scanning speeds of up to 500 mm/s for Ti6Al4V.

Results and Applications

The investigations confirm that a wide range of aperiodic and periodic structures can be generated on Ti6Al4V, which additionally have a small micro roughness (Ra < 0.1 µm). Using single track tests with a small laser beam diameter (50 µm) and a high processing speed (500 mm/s), Fraunhofer ILT has produced structures with a wavelength of 200 µm and a height of approximately +/- 90 µm for the first time (Fig. 3 and 4). This corresponds to a height-to-length ratio of almost one. Furthermore, the investigations show that the efficiency of the process, e.g. the achievable structure height per time, becomes even greater for larger scanning speeds if the laser power can be correspondingly adapted to the scanning speed. At present, an area rate of approx. 10 min/cm² has been achieved for these structures with a maximum laser power of 40 W and a scanning speed of 500 mm/s. Applications for such structures can be found, for example, in all areas in which novel functional (flow, light scattering) and design elements (optics, haptics) are desired.

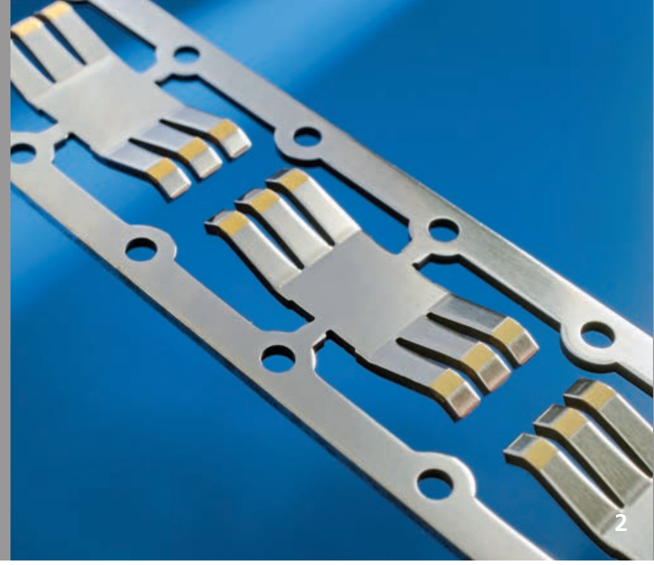
The work presented here was conducted using devices and plants that were funded within the scope of the ERDF program for the state of North-Rhine Westphalia (»Regional Competitiveness and Employment 2007-2013«) under grant number 290047022.

Contact

Dr. Dr. André Temmler
Telephone +49 241 8906-299
andre.temmler@ilt.fraunhofer.de

3 Demonstration sample with selected wave structures.

4 Sample for process development of wave structures.



LASER FUNCTIONALIZATION OF PRE-APPLIED TAPE COATINGS

Task

Flexible tapes with metallic and ceramic powder particles and a binder (< 7 percent) are commonly used with thicknesses of 0.5 to several mm to provide wear protection or to repair components. Laser melting can be used to functionalize the tapes selectively, thereby replacing the previous sintering process, which uses temperatures up to 1000 °C in a furnace. Compared to the furnace-based process, laser melting not only saves time, but can also be used for very large components and makes it possible to prevent unwanted structural changes and distortion. The challenges it faces, however, are a suitable material design (e.g. binder type and binder fraction, particle size of the hardening materials) as well as precise control of the melting process.

Method

Within the scope of »LasT«, a project to support innovation in SMEs, Fraunhofer ILT has been investigating the laser functionalization of tapes since autumn 2015 along with industrial partners (Euromat, IXUN, Extruder Experts, IRLE rollers). Fraunhofer ILT is developing the process with regard to suitable temperature-time cycles and the toolpath guidance in order to produce crack- and defect-free layers. Further criteria to be achieved are a small surface roughness and a homogeneous distribution of the hardening materials.

For this purpose, suitable process parameters have been determined in the first step. In the second step, these parameters will be adapted to the geometrical conditions of selected demonstrators. The latter are calender rolls (repair of casting defects), extruder screws and double-worm housings (wear protection).

Results

Re-melted layers made of a nickel-based carbide composite could be applied to the nitriding steel in a crack-free and defect-free manner with an admixture of < 5 percent and uniform distribution of the hardening component in the layer. Ongoing research is examining the adaptation of the coating material to the laser melting process and the characterization of the resulting surfaces and microstructures.

Applications

The method is basically suitable for the wear protection and the repair of small defects for high-quality components. The process has particular advantages for the on-site processing of large-volume components (e.g. rolls) since the complex powder or wire feed of the filler material can be dispensed with.

»LasT« has been funded by the Federal Ministry of Education and Research (BMBF) under the grant number 033RK025.

Contact

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

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

1 Carbide-containing tape during the remelting process.

LASER-BASED INLINE PROCESSING OF PRINTED GOLD LAYERS

Task

As the number of functions integrated into electronic components increases, the electronics industry requires cost-effective processes that enable functional layers to be produced flexibly and applied selectively in high volume production. Conductive thin contact layers are now applied by electroplating, PVD, or CVD. These processes are costly, time-consuming and partly harmful to the environment since they use a great amount of chemicals. Furthermore, these processes are not location-selective and, therefore, consume large quantities of precious metals. Within this context, the industry requires innovative and inline-capable contacting processes that enable a resource-efficient and energy-efficient production by selective coating.

Method

Fraunhofer ILT has developed a process consisting of three steps for the site-selective production of gold layers on metallic strip material. Step 1 involves the laser-based cleaning and roughening of the substrate surface in order to achieve a wetting of the gold paste applied with printing in step 2. In step 3, the solvents and additives contained in the paste are evaporated and the remaining gold particles are melted.

Results

The laser process strategy developed in this project makes it possible to functionalize selectively printed gold pastes on Ni-Cu substrates. The functionalized gold layers are metallurgically bonded to the substrate material and have a layer thickness of 2 to 5 µm.

Applications

This inline-capable process can be used for the selective plating of electrical contact surfaces of various components. At the present time of development, the process operates at a surface area rate of 7.3 mm²/s.

The R&D project underlying this report was carried out on behalf of the Federal Ministry of Education and Research (BMBF) under grant number 13N13333.

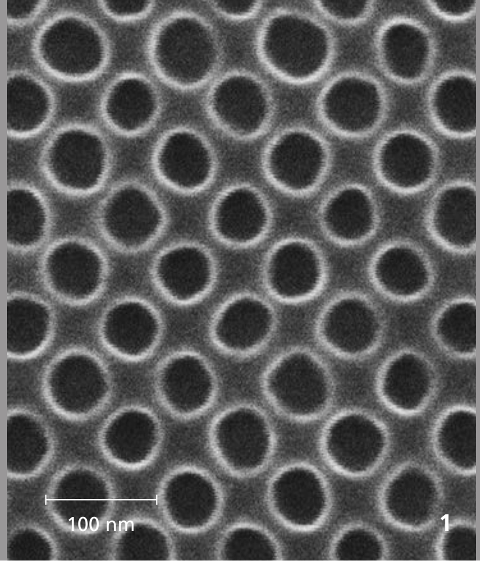
Contact

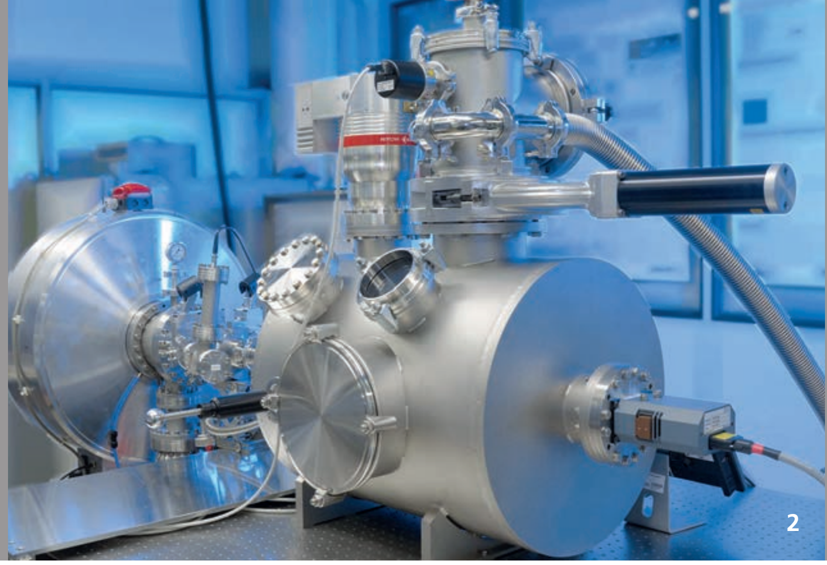
Nicole Ritschel M.Sc.
Telephone +49 241 8906-8203
nicole.ritschel@ilt.fraunhofer.de

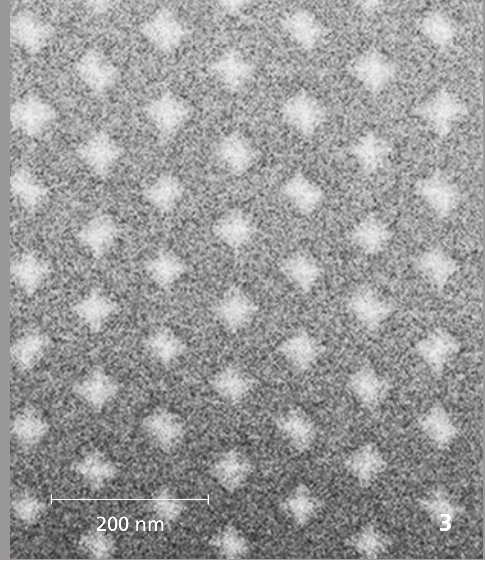
Dr. Christian Vedder
Telephone +49 241 8906-378
christian.vedder@ilt.fraunhofer.de

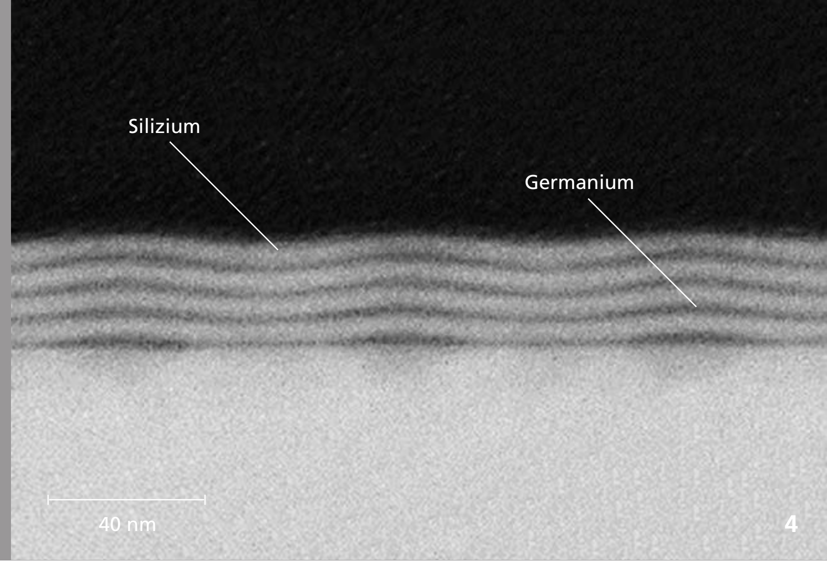
2 Contact tulips in the production process, selectively printed with gold paste.

3 Contact tulips: completely galvanically plated (left); contact surfaces selectively plated with gold paste and laser-functionalized (right).









PLANT FOR NANOSTRUCTURING USING ACHROMATIC TALBOT LITHOGRAPHY

Task

Various applications require nanoscale structures. In order to achieve a sufficiently high throughput, lithographic methods lend themselves to generating such structures. In this project a parallel, large-area exposure of highly efficient transmission masks is used to generate theoretically intensity modulations with a period of 20 nm. The use of the achromatic Talbot effect with short-wave, extreme ultraviolet radiation (EUV) offers further advantages such as mask defect compensation and structural reduction. Thus, when a contrast-rich photoresist is exposed, nanoscale structure arrangements such as line or hole arrays can be produced over a large area within a few minutes.

Method

The developed EUV-laboratory exposure tool consists of the EUV-gas-discharge source, the respective transmission mask and the photoresist to be exposed, which is applied to a wafer. Reproducible exposure conditions are ensured by a precise dose monitor and a sophisticated mask-wafer distance metrology system, which enables the highly accurate positioning of the wafer at a distance of a few micrometers behind the transmission mask. Stationary intensity modulation, which is used for the structuring, results in a distance range of 20 µm. The contrast of the intensity modulation was increased further by means of phase-shift masks to achieve the theoretical resolution limit.

Results

The structuring system developed here makes it possible to produce minimum structure sizes of 35 nm. At present, this is the world record for the interference principle of achromatic Talbot lithography.

Applications

The structuring plant can be used for the production of periodic, nanoscale structural arrangements extending over several square millimeters. In addition, photoresists can be characterized in terms of sensitivity, contrast and resolution.

Contact

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

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

1 Exposure result (35 nm, a world record).

2 Exposure station EUV-LET.

PRODUCTION OF ARTIFICIAL SIGE QUANTUM DOT CRYSTALS

Task

Quantum dots (QD) are highly interesting objects with unique electronic and optical properties. The production of densely packed and well-ordered quantum-dot crystals makes it possible to create a new type of a solid body with an energy structure that does not exist in nature.

Method

Various process steps are necessary for the production of quantum-dot crystals: the basis is a silicon wafer, which is coated with a photoresist and structured by means of EUV interference or electron beam lithography over a large area. Subsequently, the nanoscaled hole pattern is transferred from the photoresist into the underlying substrate by means of reactive ion etching. The resulting depressions in the silicon determine the horizontal position of the quantum dots. Then the Ge quantum dots and the Si intermediate layers are grown onto the pre-patterned wafer by means of molecular beam epitaxy. The difference in crystal lattice constants of Si and Ge produces strain at the interface, thus enabling the growth of quantum dots. The vertical order of the quantum dots is produced by repeated, alternating growth of Si and Ge layers and by a vertical strain in the Si intermediate layer, caused by the shape of the Ge quantum dots. Thus, an artificial crystal is formed from ordered quantum dots in three dimensions with a grating period determined by lithography.

Results

In collaboration with Forschungszentrum Jülich, Fraunhofer ILT has produced artificial SiGe quantum-dot crystals in a hexagonal arrangement with a lateral lattice period between 200 nm and 40 nm. They have also been characterized by µ-photoluminescence spectroscopy.

Applications

The artificial quantum dot crystals or the directed self-assembly of quantum dots, based on the SiGe investigated here or a related IIIV material system, makes a variety of applications possible, e. g. improving the efficiency of solar cells, producing lasers in the wavelength range of optical data communication or IR photodetectors.

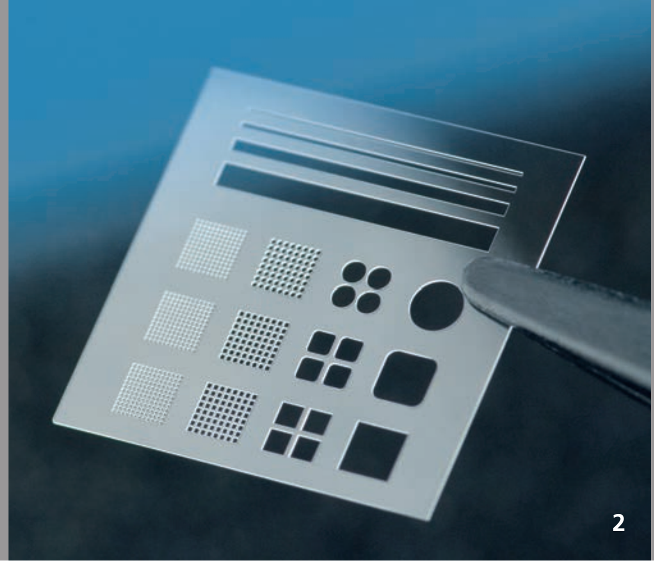
Contact

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

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

3 Hexagonally ordered Ge quantum dots.

4 Section of an artificial quantum dot crystal.



PRECISION MACHINING OF THIN GLASS WITH ULTRASHORT PULSED LASER RADIATION

Task

Ultrashort pulsed laser radiation with pulse durations less than 10 ps has made it possible to process transparent glass that has a thickness of less than 1 mm. Due to the high intensities of the laser radiation, complex non-linear interaction processes of material and laser radiation occur, which can lead to material modifications or defects such as microcracks. Processing such materials faces a major challenge: to control the deposition of the irradiated pulse energy in the material and, consequently, to achieve defect-free results. In particular, a comprehensive understanding of the underlying processes is required to produce geometrical forms with structure sizes in the range of 10 to 50 µm with minimal material damage.

Method

The choice of the process parameters leads to a direct ablation of the glass substrates either on the upper or lower side. In a second process step, the material can be modified selectively when the laser radiation is focused into the glass volume. The modified material is then removed in a second wet-chemical process step (selective laser-induced etching). By characterizing the structures with optical and temporal high-resolution pump-probe microscopy, Fraunhofer ILT can identify suitable process windows and contribute to an understanding of the relevant physical effects.

Results

Direct laser-induced ablation of glass substrates can be used to generate almost any structure desired on thin glass that has a large aspect ratio. Furthermore, the selective etching process can produce – on surfaces and in volumes – structures that are significantly smaller than 100 µm and have particularly smooth edges.

Applications

Both the direct laser-induced ablation and the selective etching of thin glass can be used, in particular, for the production of interposer structures for the electronics industry.

The R&D project underlying this report was carried out on behalf of the Federal Ministry of Education and Research (BMBF) within the framework of the funding initiative »Femto Digital Photonic Production« (Femto DPP) under grant number 13N13307.

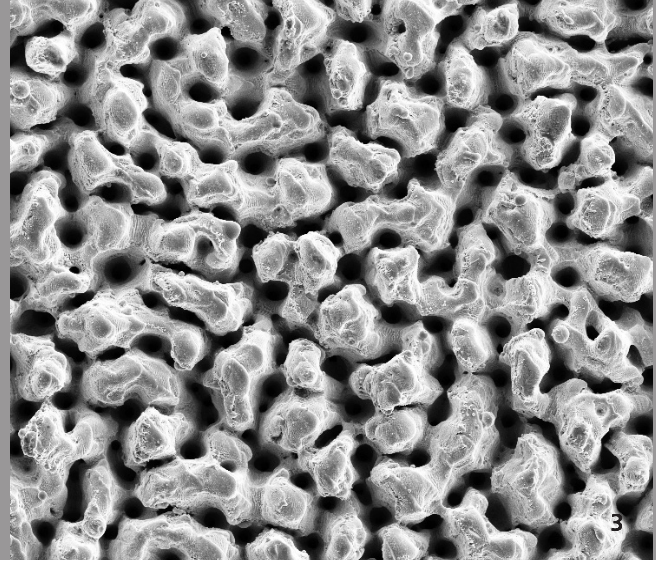
Contact

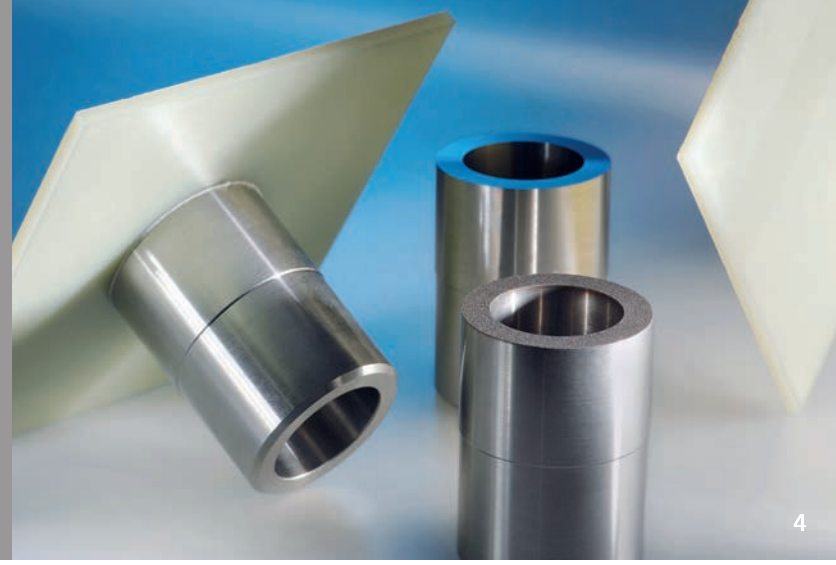
Christian Kalupka M.Sc.
Telephone +49 241 8906-276
christian.kalupka@ilt.fraunhofer.de

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

1 Thin glass surface structured by direct laser ablation.

2 Different geometrical structures produced by selective laser-induced etching.





USING ULTRAFAST LASERS TO GENERATE PLASTIC METAL HYBRIDS THROUGH MICRO AND NANO STRUCTURING

Task

The production of plastic-metal hybrid components is a central issue in lightweight automotive construction. To accomplish this, fiber-reinforced plastic components are the key technology, but often require metallic reinforcements and hybrid joints to transmit high loads. Today, these plastic-metal compounds are usually glued. In order to achieve short process cycles and low production costs, the industry needs fast and capable inline joining processes that can be integrated into the manufacturing process of the components and ensure high bond strengths.

Method

Today, metals and plastics can already be connected thanks to a positive-locking fit in the structured metal surface. Fraunhofer ILT has developed a new process chain that generates, in addition to the positive-locking bonded joint, specific adhesion between plastic and metal and creates a lasting and adhesive-free connection. To this end, ultrafast laser radiation is used to generate a combination of micro- and nanostructures in the metallic joining partner. These structures, in turn, make it possible to transfer force via the mechanical interlocking connection and create high adhesion over a nanostructured surface within the microstructure. In the following joining process, the heat from the metallic joining partner softens the plastic, which flows into the microstructures and results in a strong and durable connection.

Results

Powerful ultrafast lasers can be used to generate high static structures with an extremely high structural density. These structures make it possible to produce nearly isotropic joints between plastic and metal. The tensile shear strengths that can be achieved, depending on the plastic used, are approx. 25 MPa. The necessary micro- and nanostructures are generated through 2D scanning of the surface.

Applications

Due to the large potential for lightweight hybrid connections, the new process is especially suitable for the aerospace and automotive industry.

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

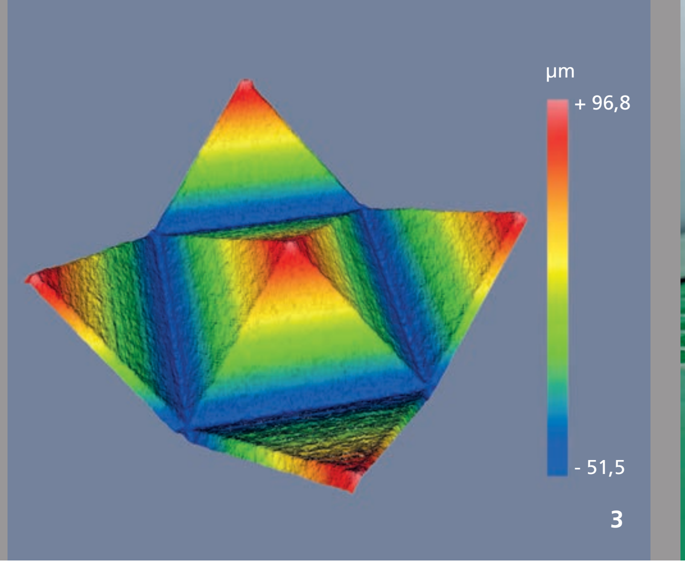
Contact

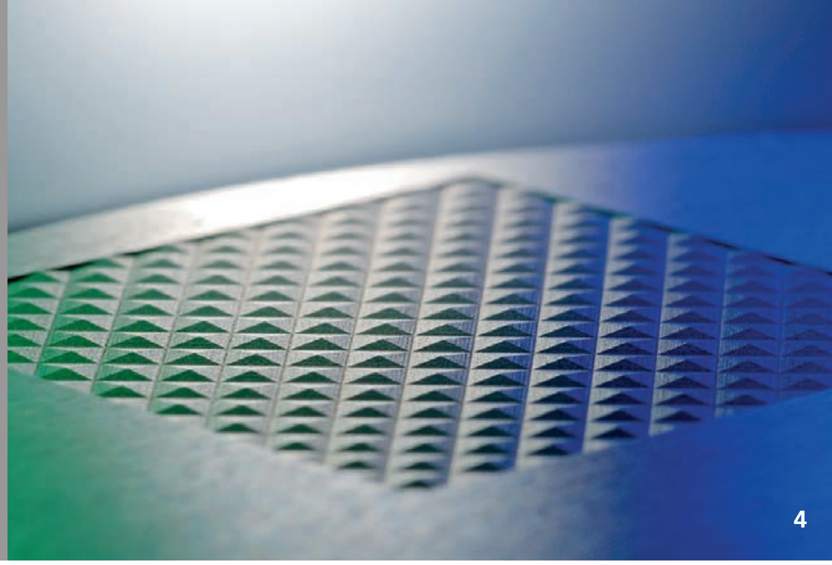
Kira van der Straeten M.Sc.
Telephone +49 241 8906-158
kira.van.der.straeten@ilt.fraunhofer.de

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

3 Microstructure on stainless steel (1.4301).

4 Test specimens made of steel and PA6.6/GF25.





PROCESS FOR THE INDIVIDUALIZATION OF PAINTED COMPONENTS

Task

Individualization of products is increasingly becoming an important argument for the market success of all types of goods. In classic printing processes such as pad and screen printing, masks and tools have to be produced, which means that these processes can only be used economically in large series. Direct methods, such as digital printing, allow a flexible design of individual parts, but they have limitations in terms of workpiece geometry. Along with partners from the industry, Fraunhofer ILT is developing a series-based process that can generate freeform surfaces with colored, high-resolution motifs. These can be designed individually and are competitive with conventional printing processes at identical production rates.

Method

Since the painting systems and subsequent selective laser ablation are applied over a large-area, colored images with a high resolution can be generated. A correspondingly high productivity is necessary for the process to become cost-efficient; a multi-beam optics has been developed to accomplish this. The laser beam is divided into approx. 100 to 200 partial beams that can process the workpiece simultaneously.

Results

The basic features needed to generate colored motifs with high resolution have already been developed in a prototype plant. The partners are currently working on paints that are specially adapted to the process, which allow thinner layers to be applied at the same opacity and can be structured better by means of a laser. The other goals are to transfer the process to arbitrary freeforms and to scale the process speed.

Applications

The method developed here can be used to address a variety of applications. They include individual design and personalized surface layouts in automotive engineering or user-friendly control elements in mechanical engineering. In the bulk goods and packaging sector, it is thus possible to create individualized special series.

This project has been funded by grants from the state of North-Rhine Westphalia using the funds from the European Regional Development Fund (ERDF) as part of the project »LAPIX 3D« under grant number ERDF-0800259.

Contact

Dipl.-Phys. Patrick Gretzki
Telephone +49 241 8906-8078
patrick.gretzki@ilt.fraunhofer.de

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

1 Laser-based generation of colored pictograms.
2 High-resolution grey-scale images.

EFFICIENT PROCESSING OF 3D TOOLS WITH THE COMBINED USE OF SHORT AND ULTRASHORT LASER PULSES

Task

Thanks to their functionality, structured surfaces can reduce friction in, for example, combustion engines. Such surface textures are also becoming more and more a sign of a product's quality due to their optical and haptic properties. Processes currently used to structure components, such as photochemical etching, are limited not only in their precision (manual process) but also in their flexibility to design the grain structures. For the production of optically and haptically functional structures with high productivity, the industry requires methods that enable the desired structures to be generated on a purely digital basis.

Method

Ultrashort pulsed laser radiation in the ps (10^{-12} s) to fs range (10^{-15} s) is characterized by high intensities (> 10^{12} W/cm²), which lead to a direct evaporation of the material and, therefore, to the highest precision. However, a long processing time may create disadvantages. For efficient processing, short ns pulses (10^{-9} s) will be used to insert a coarse structure into the workpiece in an upstream process step. In contrast to material ablation with ultrashort pulsed laser radiation, the ablation process with ns pulses is dominated by the melt, which results in higher ablation depths with, however, lower surface quality.

Results

Similar to the strategy of roughing and finishing in machining processes, an initial laser process with ns pulses ablates the largest volume before a second laser process with ps pulses enhances the surface. This combination joins the advantages of each individual process into one: a short processing time (ns pulses) with the highest accuracy (ps pulses).

Applications

In automotive interiors, a trend is moving from the classic leather grains to functional, technically appealing surfaces. For this purpose, tool inserts for the production of plastic molded parts (e.g. dashboards, airbag covers, trim strips) shall be provided with a technical structure (e.g. pyramids).

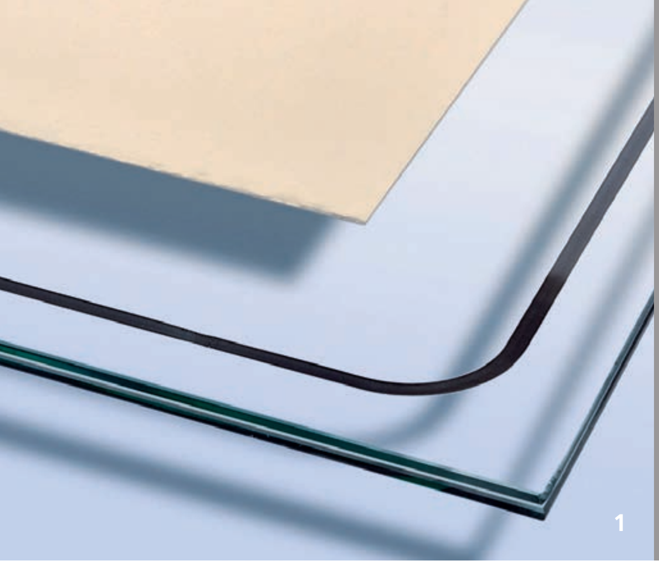
The R&D project underlying this report was carried out on behalf of the Federal Ministry of Education and Research (BMBF) under grant number 02P14A145.

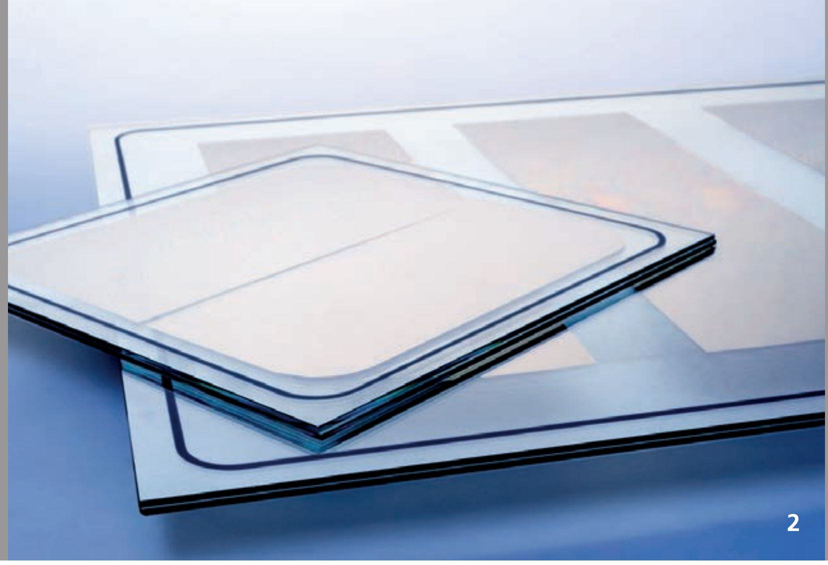
Contact

Andreas Brenner M.Sc.
Telephone +49 241 8906-8365
andreas.brenner@ilt.fraunhofer.de

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

3 Pyramid structure generated in tool steel with ps laser radiation.
4 Chromatically confocal 3D image of pyramid structure enhanced with ps-laser radiation.





LASER-BASED GLASS SOLDERING PROCESS FOR THE EDGE BONDING OF VACUUM INSULATION GLASS PANES

Task

Over the last few years, research on the thermal insulation of buildings has identified windows as a critical weak point for efficient insulation. One approach to counteract this is a double-pane construction with a vacuum gap. In addition to providing excellent thermal insulation, this approach is characterized by a slim design and a significantly reduced weight compared to conventional approaches. For the so-called vacuum-insulation glazing, a vacuum-tight edge joint is absolutely necessary to maintain this vacuum and the resulting good insulation values. Fraunhofer ILT has been developing and examining a laser-based glass soldering process to generate such a joint.

Method

The contour soldering process is used for large components such as vacuum-insulated glass panes. In this case, the laser beam is moved continuously over the joining zone. The connection is formed continuously in the region of the glass solder contour, over which the laser beam passes. The size of the glass panes is not restricted by this type of process. Float glass, which responds highly critically to thermal stresses, places very high demands upon process management. So that critical temperature gradients can be prevented, an adapted thermal management of the laser-based soldering process is imperative. In addition to a temperature control of the panes that accompanies the process, the irradiation strategy is decisive for the homogeneous energy input into the radiation-absorbing glass solder.

Results

A laser-based glass soldering process vacuum has sealed safety glass panes measuring 720 x 640 mm² (material thickness 3 mm) successfully. Due to the thermo-mechanical properties dependent on the glass material, a connection could be formed at a speed of 15 mm/min without cracks. Ten-fold higher feed rates could be achieved for applications that allow the use of significantly thinner glass (< 1 mm).

Applications

Further possible applications of the method are the edge sealing of OLEDs, displays or dye solar cells.

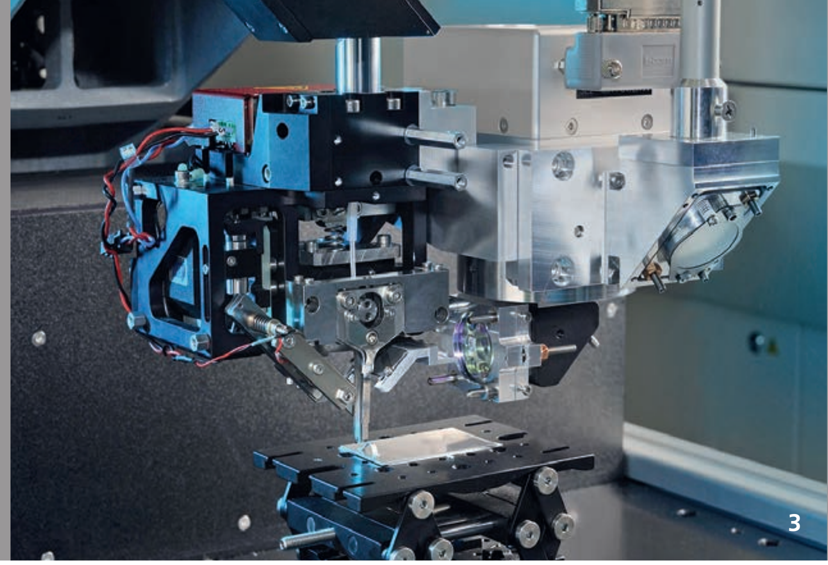
The R&D project underlying this report was carried out on behalf of the Federal Ministry of Education and Research (BMBF) under grant number 03V0714.

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 Homogeneous, crack-free solder joint.
2 Vacuum-sealed soldered glass panes (dimensions 720 x 640 mm² and 340 x 340 mm²).



LASER BONDING OF ALUMINUM CONTACTS FOR BATTERY TECHNOLOGY

Task

Contacting battery packs in the automotive industry faces a challenge – the high demands from structural loads. Vibrations occurring during operation, large temperature fluctuations and mechanical stresses can impair the performance and the service life of the battery pack. An electrically and mechanically robust connection process is required for meeting the requirements; for this purpose, Fraunhofer ILT has developed a laser welding method that can join aluminum ribbons to the battery poles of prismatic battery cells.

Method

For the connection technology, a Laserbonder developed at Fraunhofer ILT is used in which a modified wire bonder is equipped with a fiber laser, a galvanometric scanner and a beam guiding and focusing unit. The system technology allows an automatic feed of a flexible connector to the component surface. Using spatial power modulation, the system can weld an aluminum ribbon having a cross-section of 300 x 2,000 µm² to an aluminum alloy, representing the battery pole of the prismatic cell. The mechanical robustness of this compound has been tested by means of shear tests and metallographic analysis.

Results

The laser bonding allows adjustment of the bond width in the range of 300 to 450 µm and a mechanical shear strength of up to 40 N per bond. The method approach demonstrated here can be applied to all prismatic and cylindrical battery cells. In particular, the process is characterized by its ability to create the connections quickly, robustly and flexibly without needing specific component preparation, thereby contacting the individual cells to make modules or packs.

Applications

The Laserbonder can be used in wide ranges of power electronics and battery technology. Laser bonding can be applied especially where fast and flexible contacting solutions are required.

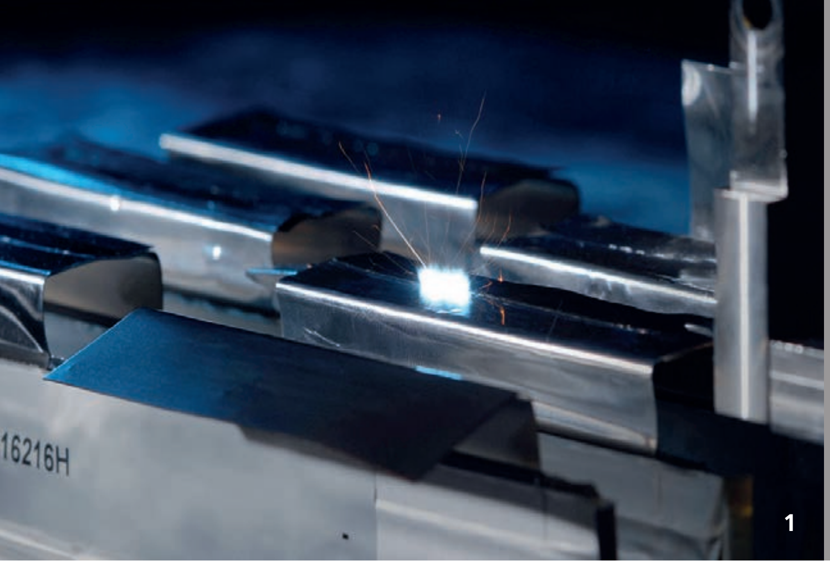
The work presented here was supported by the Federal Ministry for Economic Affairs and Energy (BMWi) as part of the »FlexJoin« project under grant number 01MX15010B.

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

3 Bonding head of the Laserbonder.
4 Laser-bonded aluminum strips on aluminum contact.



LASER-BEAM MICRO-WELDING IN BATTERY TECHNOLOGY

Task

As automobiles are increasingly being powered by electrical motors, demand is growing for high-performance energy storage systems. Various types of cells are used for the construction of battery modules or packs: 18650 round cells, prismatic cells or pouch cells. The joining processes required to interconnect the cells require high process stability and reliability irrespective of the type of battery, while at the same time providing low electrical transition resistances and high geometric flexibility.

Method

Laser-beam micro-welding with local power modulation is being used to firmly bond battery cells to one another. When the feed motion is overlapped with a circular oscillation movement, the attachment geometry and the mixing ratio can be adjusted. Thanks to the overlapping feed motion, the process can contact joining materials of different cell types, ranging from aluminum-copper up to copper-steel connections. The welding process has been designed to reduce the welding depth while the bonding width remains the same so that the active material in the battery cell is not damaged. In addition, the metallurgy of the joining compound can be specifically controlled by this approach.

Results

Laser welding processes have been developed to contact pouch and round cells as well as prismatic battery cells. The process is also able to generate reproducible joint connections with different material combinations (aluminum/copper/steel) and positioning on the cells (contact of positive and negative poles on one side of the round cell). The spatial laser power modulation improves the consistency of the welding depth of all the battery types and increases the connection width of the current-carrying joint connection.

Applications

The joining processes developed here are particularly suitable for contacting battery cells, e.g. for applications in electromobility. The results can also be transferred to the joining of other electrical connections.

The work presented here was funded partly by the German Federal Ministry of Education and Research (BMBF) as part of the »Robe« project, and, on the other hand, by the Fraunhofer-Gesellschaft as part of the project »Fraunhofer System Research for Electromobility II«.

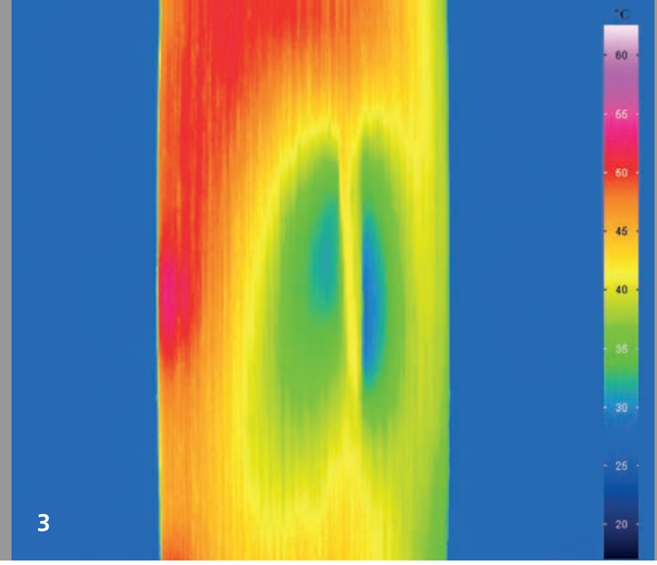
Contact

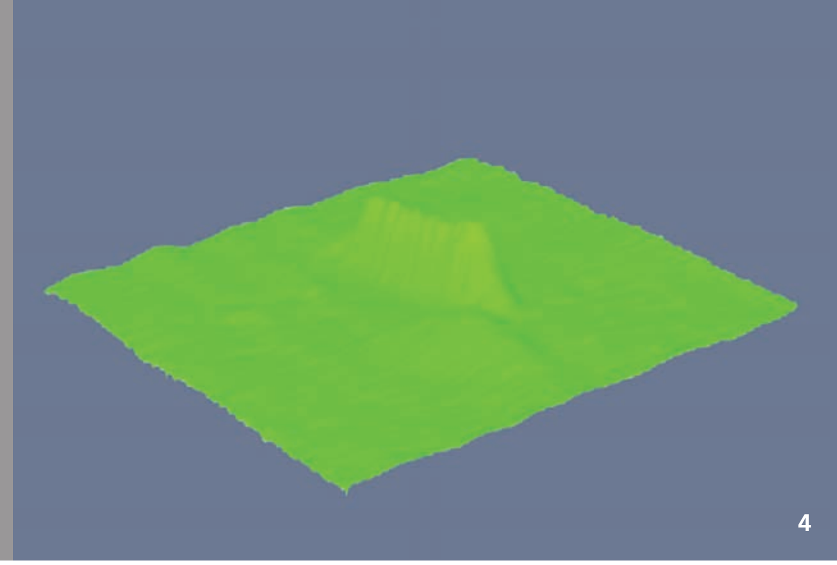
Sören Hollatz M.Sc.
Telephone +49 241 8906-613
soeren.hollatz@ilt.fraunhofer.de

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

1 Welding on Li-ion pouch cells.

2 Contacting both poles of round cells on the top, laser bonding on the positive pole.





PROCESS MONITORING FOR THE LASER-BASED PRODUCTION OF CFRP COMPONENTS

Task

The market for components made of fiber-reinforced plastics is growing steadily as are the requirements for automated, flexible, energy-efficient and environmentally friendly manufacturing processes to produce them. By developing a laser-based tape winding system with easy-to-use software for process planning and inline quality monitoring, Fraunhofer ILT has addressed this challenge. In this process, tapes made of fiber composite materials are automatically welded using a diode laser; the quality of the tapes welded in the multi-layer process is monitored inline directly after the welding process in order to immediately recognize an insufficient connection of the tapes. The aim is to enable the application of process monitoring without special expertise.

Method

In the project »ambliFibre«, Fraunhofer ILT has developed an inline monitoring system for tape winding and implemented the necessary interfaces for its integration into the tape winding system. For process monitoring, defined embossments in the output tape will be recognized after the welding process to decide between different consolidation qualities. The embossments are recorded with optical, non-contact measurement methods such as, for example, thermography and/or laser triangulation. A particular challenge is the robust recognition of the 300 µm high embossment at a process speed of 600 to 800 mm/s.

Results

In the first stationary tests, the measuring principles active thermography and laser triangulation have already been successfully applied and confirmed for the fiber composite material CFRP. The next step will be to examine which of the methods is more suitable for inline surveying and how the evaluation and storage of the measured data can be carried out.

Applications

It is expected that the application of the »ambliFibre« results can be successfully used in many areas for the processing of fiber-reinforced plastics. In particular, the process can be used in the production of heavy-duty gas and oil lines as well as high-pressure vessels for the energy industry and of ultralight CFRP components for the aerospace technology.

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

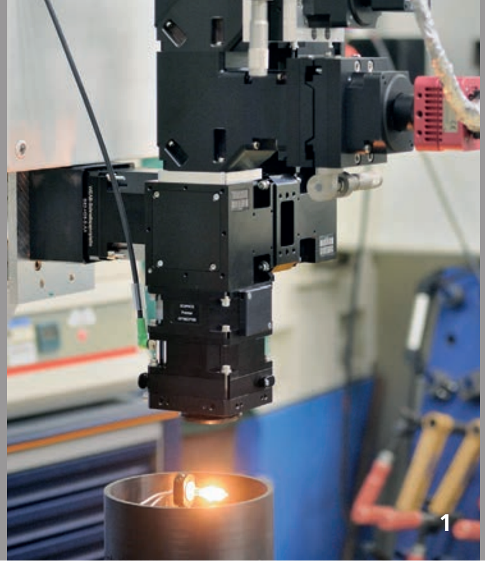
Contact

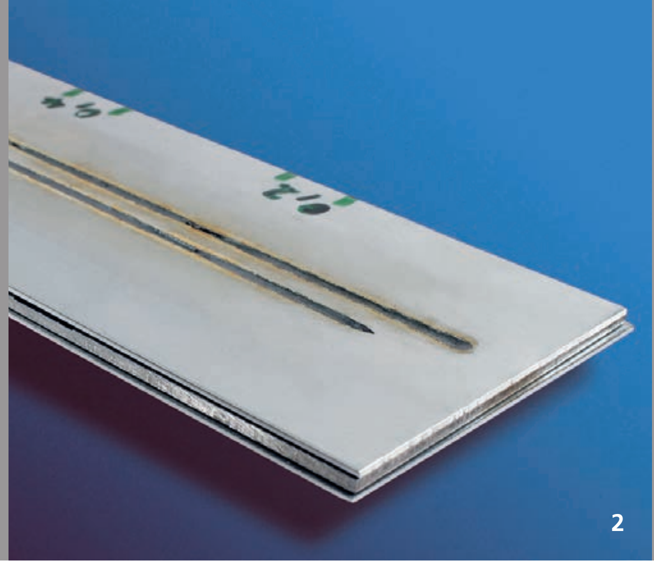
Andrea Lanfermann M.Sc.
Telephone +49 241 8906-366
andrea.lanfermann@ilt.fraunhofer.de

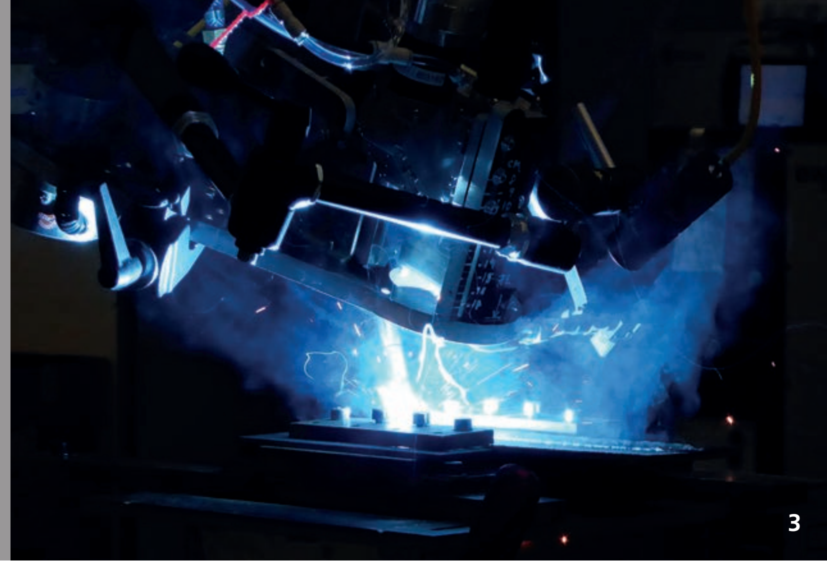
Dipl.-Ing. Peter Abels
Telephone +49 241 8906-428
peter.abels@ilt.fraunhofer.de

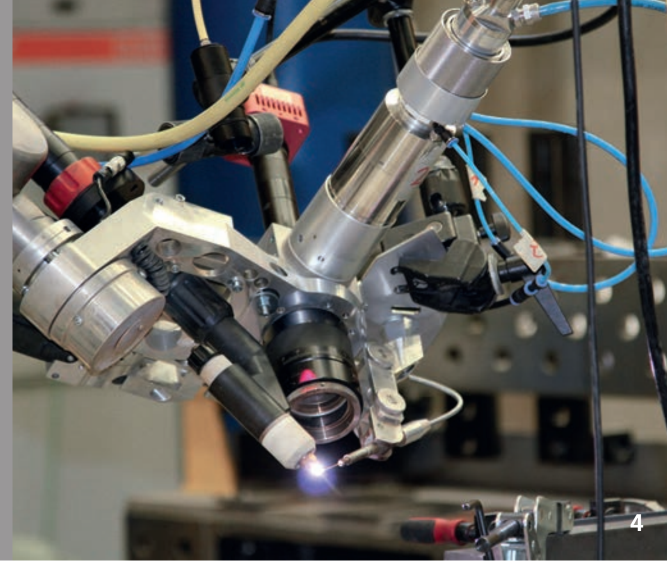
3 Thermographic image of an embossed CFRP tape.

4. Image of an embossed CFRP tape with a laser-triangulation sensor.









COGNITIVE PROCESS MONITORING

Task

The EU research project »MAShES« (Multimodal Spectral Control of Laser Processing) promotes the development of a multispectral, imaging and intelligent sensor system for process monitoring. This system has been integrated into processing optics and applied to a laser-beam welding and laser metal deposition process. The real-time data processing and the upstream sensor data fusion pose, however, a particular challenge. The relevant information of several different sensor data streams needs to be extracted during the process in order to be subsequently fed to a cognitive process monitoring algorithm for data processing.

Method

The development of the cognitive system includes the areas of »Computer Vision« and »Machine Learning«. These methods are used to determine relevant features from the image data, such as the cooling rate of the component surface or the surface geometry of the melt pool. The calculation and evaluation of the characteristics requires considerable processor power and is accomplished for the real-time application with a Field Programmable Gate Array (FPGA). The training phase provides the basis for evaluating the process monitoring features. By means of the calculated process characteristics and expertly assessed welding samples, the cognitive system learns to classify the characteristics and, thus, how to recognize different process imperfections clearly.

1 Test setup with integrated sensors.

2 Laser-beam welded sheet sample with induced binding errors.

Results

The classification is carried out with different algorithms from the family of machine learning and, at the moment, can make a rough distinction of the two classes into good and bad welds. The classification into different error classes is currently being implemented. In order to generate as robust a result as possible, Fraunhofer ILT is testing and comparing further classification methods within the scope of the evaluation.

Applications

Within the framework of the project, the cognitive system has been applied in the field of industrial laser beam welding of automotive components. Furthermore, the results can also be used in this industrial application to document and improve the process quality within the scope of the automation strategy »Industry 4.0«.

The work presented here is being funded within the scope of the EU project »MAShES« under grant number 637081.

Contact

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

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

TEXTURE-BASED SEAM TRACKING

Task

When the shipbuilding and vehicle construction sectors weld components from sheet metal, they must be able to reliably identify the seam geometry and position with an automatic image processing system. In contrast to classical approaches based on brightness gradients, an alternative approach has been pursued here: segmenting the image data based on textures, whereby changes in the texture of adjacent image details are used for their differentiation and delineation. In this texture-based analysis, the image information is classified by means of a filter bank and complex statistical algorithms. Because of the computing power required for this, real-time implementation has hitherto been uneconomical. The performance of field-programmable gate arrays (FPGA) as well as PC hardware, however, has been improving constantly, as used, for example, in graphic cards with a large number of graphic processor cores operating in parallel. Nowadays such advances make it possible to economically implement, in real time, the image processing algorithms needing such computational power required for the seam tracking control.

Method

The system has an image sensor arranged coaxially in the beam path of the focusing optics for the laser beam. By means of real-time image processing, it measures the distance between the butt joint and the interaction point (TCP) as well as the joint width for an adaptive control during joining with the laser-assisted GMAW welding process.

Results

Algorithms for the (pre) processing of the image data were implemented on programmable FPGA hardware as well as for texture-based joint tracking on GPUs. An arc-synchronous illumination and image acquisition has been implemented with a pulsed diode laser and will soon be optimized with cost-effective VCSEL devices. With this approach, Fraunhofer ILT has developed and implemented a real-time process monitoring and control system.

Applications

In the medium term, the developed system will provide an inline-capable seam tracking system for applications in shipbuilding, rail vehicle construction and steel building.

The »ShipLight« R&D project underlying this report was carried out on behalf of the Federal Ministry for Economic Affairs and Energy (BMWi) under grant number 03SX389M.

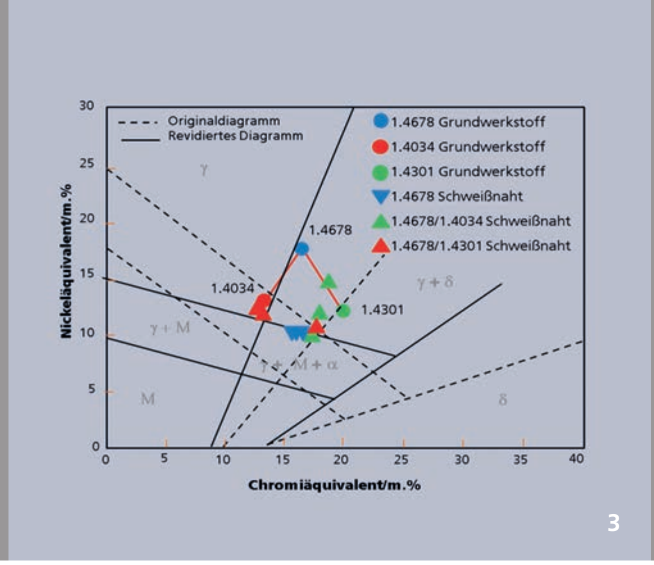
Contact

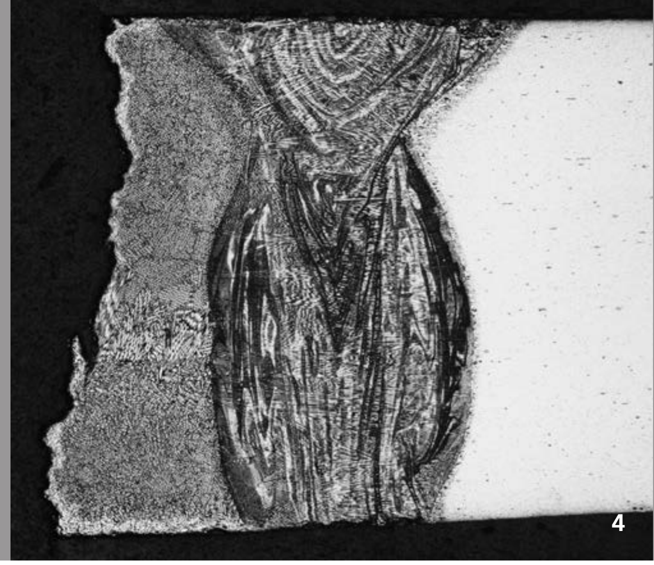
Wolfgang Fiedler M.Sc.
Telephone +49 241 8906-390
wolfgang.fiedler@ilt.fraunhofer.de

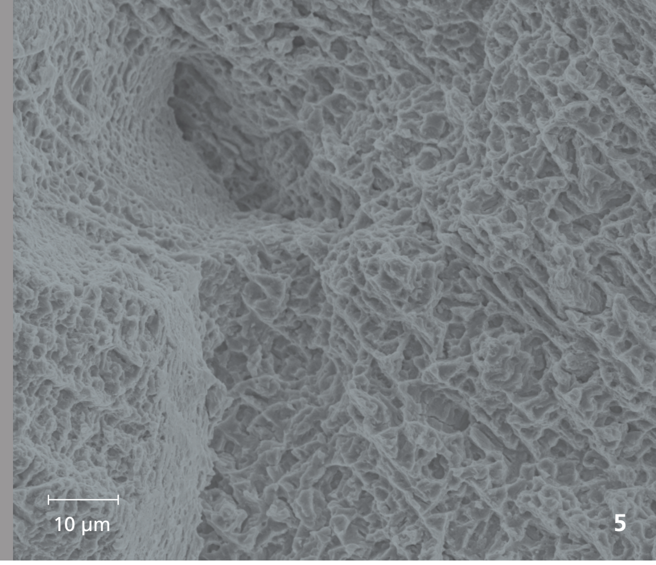
Dipl.-Ing. Peter Abels
Telephone +49 241 8906-428
peter.abels@ilt.fraunhofer.de

3 Laser-assisted welding process.

4 Integrated process monitoring system.







STRENGTH OF WELDED JOINTS OF DISSIMILAR ULTRAHIGH-STRENGTH MANGANESE STEELS

Task

With appropriate process parameters, laser beam welding can reliably join thin high-strength sheet metal. Not only does the industry have a demand for connections of similar materials, but it also requires, increasingly, connections between different steel material combinations. In this context, the properties of welded joints of 1.4678 (FORTA H100) with 1.4301 (X6CrNi 18 10) and press-hardened 1.4034 (X46Cr 13) shall be determined and appropriate process parameters and strategies presented.

Method

After systematic welding tests were conducted, EDX analyses were used to determine the local composition of the alloy in the fused metal. The composition was then recorded so that the microstructural components could be specified according to the Schaeffler diagram. Transverse tensile tests were carried out at room temperature to determine the strength of the joints. In addition, the fracture behavior was analyzed with a fractographic analysis.

1 Welding structure of 1.4678/1.4301.

2 Welding structures of 1.4678/1.4034.

3 Arrangement of the composition according to the Schaeffler diagram.

Results

According to the classical Schaeffler diagram, all welding materials solidify austenitically. In the revised diagram, which takes into account the influence of manganese, the welded metal of the compound with 1.4301 can have up to 40 percent ferrite. The high carbon content causes a shift to martensite. In the joint with 1.4301, the component fails in the chrome-nickel steel due to the lower strength of this material. The joint with the press hardened 1.4034 shows a reduced elongation which leads to fracturing in the weld area. With a yield strength of 900 MPa and a tensile strength of 1200 MPa, the strength of the press-hardened material is not achieved in the weld. The seams have a strong notch effect due to their hardness distribution. Future studies will show whether the properties can be improved by welding and heat treatment.

Applications

Applications can be found where the advantages of the combination of high elasticity and high strength need to be used with predominantly static loads. For example, hollow-chamber plates made of steel with improved damping can be constructed. Due to the narrow weld seams, there are further constructive possibilities which allow new designs in 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

JOINING OF SHAPE-WELDED STELLITE 31 WITH ROLLED NIMONIC 75

Task

Additive manufacturing processes make it possible to manufacture new geometrically and materially optimized components. Frequently, however, connections to sheets and profiles are necessary in which the welded connection has a decisive influence on the component properties. For the joining of Stellite 31 and Nimonic 75, the strength and the failure behavior of the weld seam were determined by means of suitable test specimens, in order to derive guidelines for the application; Laser Metal Deposition was used as an additive manufacturing technique. The aim was to determine the strength of the bond between dissimilar materials at normal load, as well as to investigate the welding metallurgy and fracture behavior.

Method

Laser Metal Deposition was used to produce ingots of Stellite 31. The process parameters were adjusted so that the size and frequency of cracks were minimized. After tension annealing, milling, wire-cut EDM and finishing, strips of Stellite 31 were welded onto a test piece out of Nimonic 75 with two seams in a butt joint. Mechanical testing was carried out by transverse tensile tests with and without a thermal cycle up to 750 °C at room temperature and at 750 °C (operating temperature).

Results

At room temperature, the welded connection reaches strengths which are higher than those of the rolled base materials. An influence of the layer direction on the strength could not be detected. The fracture was mainly found in the cobalt material, to a small extent on the fusion line. One reason for this is microcracking, which occurred during shape welding. At operating temperature, the fracture tests cause all samples to fail in the nickel material outside the welding zone.

Applications

The tested materials are commonly used in components subjected to high mechanical stress and high-temperature corrosion, such as guide vanes of gas turbines or parts of combustion chambers. Additional applications are possible in the field of power plant technology and chemical equipment construction. Moreover, the combination of Laser Metal Deposition and fusion welding allows a cost-effective production of large components whose production with additive methods alone would be uneconomical.

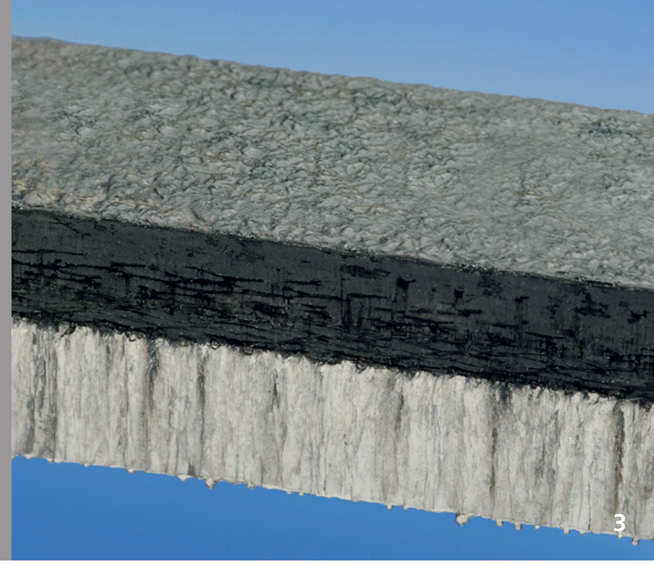
Contact

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

4 Macro cut of a broken tensile specimen.

5 Fracture surface in 1.4682.



HIGH-SPEED LASER BLANKING

Task

The industrial series production of car body parts can reap great economical benefits when the metal blank is cut directly from the coil by means of a flexible laser cutting process, in comparison to a tool-based cutting one. These benefits include, in particular, investment costs savings for tools and their storage, the simple optimization or modification of the cutting contour in product development or conversion phases, and the flexible distribution and nesting of the production program. For high-productivity large-scale production, there are clear specifications regarding the cutting speeds and cutting qualities required in various coated and high-strength car body grades. Fraunhofer ILT assumed responsibility for creating a laser-based blanking plant for an automotive OEM; it designed the laser system and developed the cutting process.

Method

Using the customer's specification sheets, Fraunhofer ILT designed the system as to its beam power, beam quality and cutting optics on the basis of simulation calculations. It conducted an experimental demonstration of the feasibility on an appropriately laboratory system. By optimizing the nozzle design, the cutting gas parameters and the laser modulation characteristics, the institute ensured that the process could be applied reliably.

Results

As a result, a robust process with high, burr-free cutting quality and cutting speeds of up to more than 100 m/min was qualified for the customer's entire body panel range. The system demonstrated impressively that punching processes can be replaced by laser cutting, something that has often been attempted in the automotive industry. 18,700 body parts are produced every day in this plant and, thus, the new system fulfills the user's expectations to the highest degree: tool-independent production, material savings, problem-free processing of even high-strength steels and the ability to change designs during ongoing production.

Applications

Thanks to this industrial development project, automobile manufacturers can cut blanks from coils with lasers with great flexibility and high productivity. Moreover, it has reached a status which enables manufacturers to economically produce mass products made of sheet metal materials in constantly changing variants. Since this system has higher laser power at a moderate cost, its technology is becoming increasingly interesting even for larger sheet thicknesses above 3 mm.

Contact

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

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

1 Laser blanking plant.
2 High-speed cutting of car body sheet metal.

LASER CUTTING FOR CFRP-METAL HYBRID COMPOUNDS

Task

For a multitude of assemblies, for example, in automotive engineering or aerospace, the best approach to optimize component weight is to combine fiber composite material and lightweight metals, such as high-strength steels, aluminum or titanium. The joint between CFRP and metal can be prepared with a laser in compliance with the specific process requirements for the very different material groups; furthermore, it is wear-free. Such processes can be used to drill holes in already overlapping layers of CFRP and metal for rivet joints, or to cut the contours for combined positive- and material-locking joints.

Method

The CFRP material is cut by sequentially ablating material with a high-performance fiber laser and a fast galvo-scanner. When the material is stacked, the scanning strategy is chosen in such a way that the resulting CFRP kerf width and kerf shape offer favorable conditions for the subsequent laser cut in the metal. This cut is then carried out with cutting gas in one overpass. For the cases considered here, the same laser beam source was successfully used for both steps, but there are also scenarios in which different lasers could be used for CFRP and metal from an economical and technical point of view.

Results

A very good connection of the cuts carried out in the two process steps has been achieved both in butt-joint arrangement and overlapping material composites. When the material is stacked, the cut in the metal below does not damage the contact area. Depending on the combination of thicknesses, the heat-affected zone can increase in size at the edge of the CFRP through the metal cut.

Applications

Connections of fiber composite material to metal parts are present in all areas of lightweight construction. In addition to the applications in vehicle construction, connection flanges for pipes in vessel construction are another example where this process can be used. It is also possible to transfer the processes to applications with other hybrid materials, for example in disassembly engineering when nuclear power plants are dismantled.

Parts of the R&D results underlying this report were achieved on behalf of the Federal Ministry of Education and Research (BMBF) under the grant number 13N12718.

Contact

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

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

3 Cut edge for a CFRP-titanium joint.
4 CFRP-metal contour cuts.

LASER CUTTING OF POLYESTER-KNITTED FABRICS FOR APPLICATIONS IN TISSUE ENGINEERING

Task

A plastic knitted fabric made of polyester and seeded with human cells shall be produced for the manufacture of textile implants in the field of tissue engineering. For the required preliminary tests for implantation in mouse hearts, small round discs with a diameter of approx. 10 mm and a thickness of 3 mm are required as test specimens in order to create different cell cultures. Mechanical separation processes are usually associated with damage to knitted fabric, so laser cutting should be tested as an alternative separation process.

Method

Since polyester, like many other thermoplastics and thermosetting plastics, has high absorption values in the infrared spectral range, a CO_2 laser source with an emission wavelength of 10.6 µm is well suited for cutting it. The required laser power is determined in order to completely cut the approximately 3 mm thick knit at a given cutting speed and using a standard cutting head with plano-convex lens of 63 mm focal length as well as xyz linear axes for beam movement. The cutting edges are analyzed by means of an incident light microscope.

Results

By adapting the focus diameter and feed speed, Fraunhofer ILT has achieved high-quality cutting results. The flat edge zone of a Gaussian single mode CO_2 laser beam causes melting zones to form at the cutting edges. These areas harden after solidification and reduce the resilience of the customized molded part. This is, however, quite advantageous for the intended application of the component – as a heart implant – since the mechanical stability of the disk, which is thick compared to its diameter, increases.

Applications

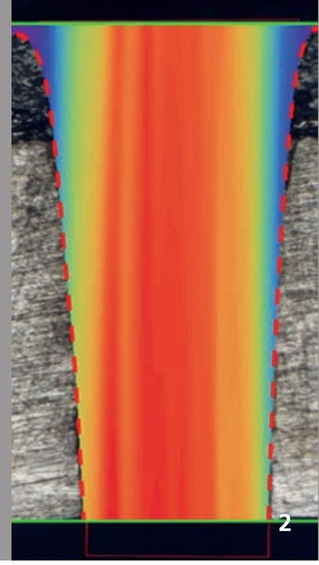
Laser-cut polyester knitted fabrics for medical applications can be produced with great flexibility of shape even for small components with dimensions down to 5 mm. The resultant melt edge hardening increases the mechanical stability, prevents fraying of the knitted fabric and can be reduced by multiple crossings in case excessively high formation occurs. In the next step, the polyester knitted fabric shall be replaced by a biocompatible polyvinylidene difluoride (PVDF) fabric.

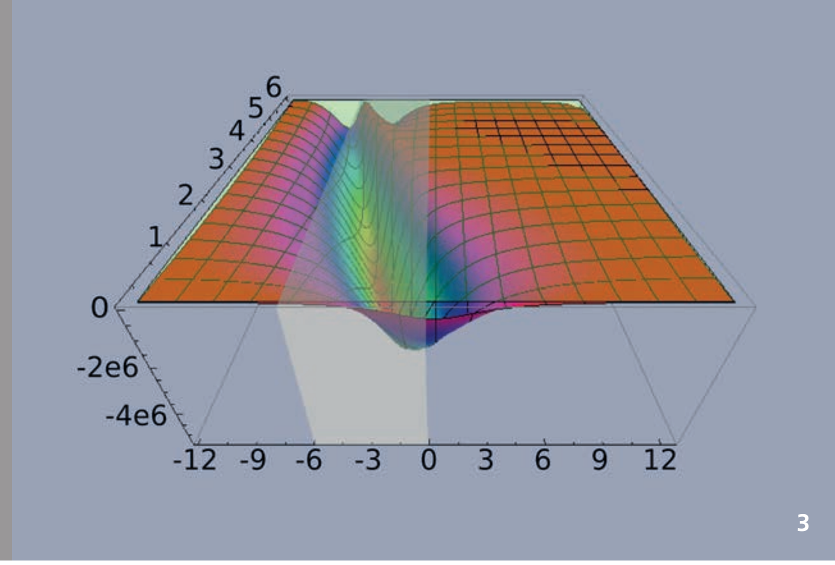
Contact

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

1 Laser cut 10 mm round disc of 3 mm thick polyester knitted fabric. CO_2 laser cutting at 110 W, 2 m/s, 5 crossings, 230 µm beam diameter.





INTERACTIVE SIMULATIONS FOR CUTTING AND DRILLING WITH LASER RADIATION

Task

Simulations are increasingly becoming an indispensable tool for process design and process optimization as the market requirements continue to grow and manufacturing processes become more complex. This applies in particular to laser manufacturing processes. However, today's simulations can be used to examine only a small part of the parameter space due to limited computing capacities. In addition, the integration of process simulations into everyday industrial life has not yet been completed. For example, interactively usable process simulation has not yet been made available to support the machine operator.

Method

On the basis of reduced models, rapid process simulations have been developed and enable operators to examine considerably larger areas of the parameter space. With the aid of the »dense« simulation data generated in this way, »process maps« (so-called meta-models) have been created, which, on the one hand, allow intuitive visualization of parameter dependencies and, on the other, support the development of process optimization. Both the meta-models as well as the fast simulations can be used interactively and have been especially developed for use by the customer on PCs/laptops or on smart devices.

Results

The first application examples were reduced models for the drilling of metallic materials with long-pulsed laser radiation (Fig. 2) as well as for describing the stability properties of the melt film (Fig. 3) and the associated scoring during fusion cutting. Both models were implemented in real-time simulations and are offered by Fraunhofer ILT as license software.

Applications

The methodology of reduced modeling (controlled reduction of model complexity) and the techniques of meta-modeling can be applied to all areas of modeling, and thus to all processes (not only in the field of laser technology).

Contact

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

Prof. Wofgang Schulz
Telephone +49 241 8906-204
wolfgang.schulz@ilt.fraunhofer.de

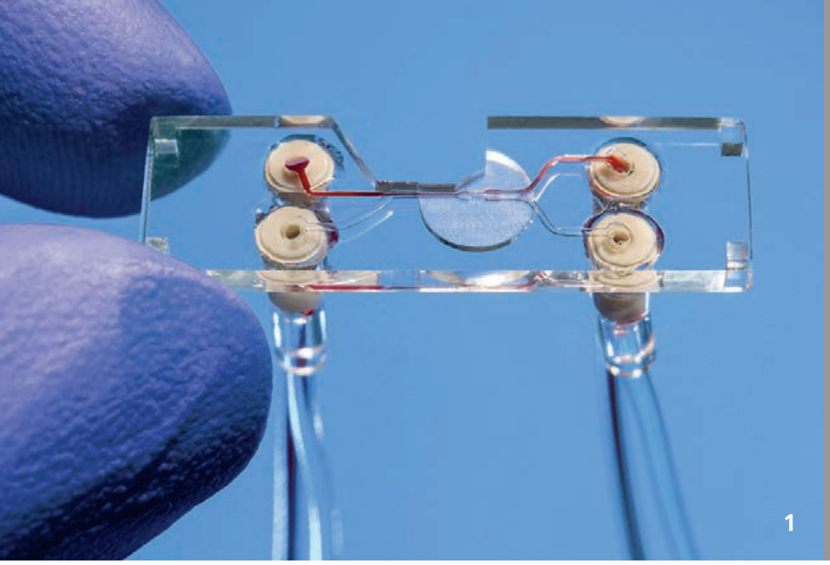
2 Comparison between simulated hole contour and experimental result. The color scale describes the beam distribution.

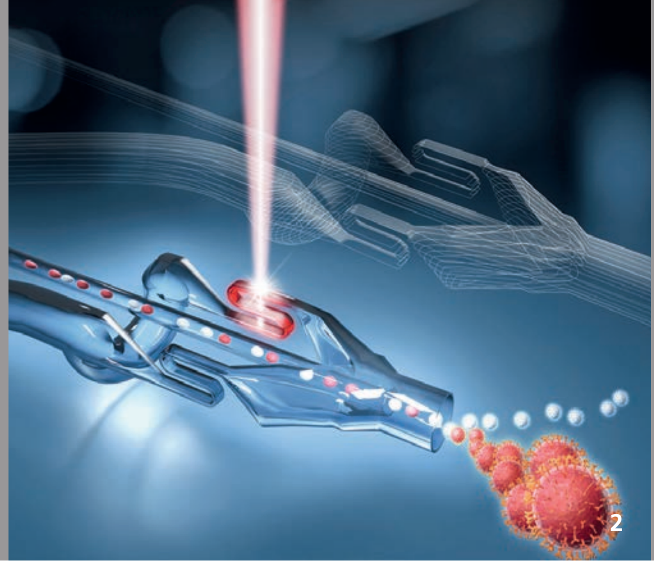
3 Stability function (> 0: stable, < 0: unstable) via focus (horizontal) and cutting depth (vertical). The gray stripe represents the workpiece.

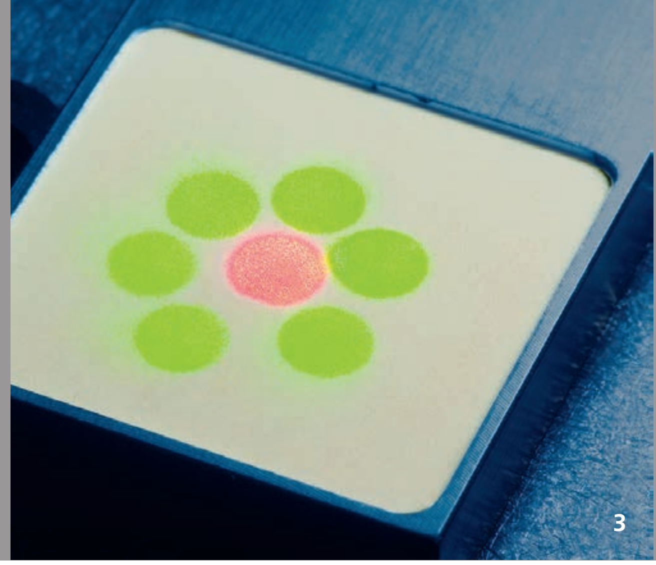
MEDICAL TECHNOLOGY AND BIOPHOTONICS

CONTENTS

Radiation characteristics of a fiber bundle for laser therapy with optical diagnostics.







AUTOMATED µFACS SYSTEMS FOR CLINICAL DIAGNOSTICS

Task

In laboratory diagnostics, FACS devices (Fluorescence Activated Cell Sorters) are used to detect pathogens, tumor cells and marker molecules. Commercial FACS devices, however, are high-priced stand-alone solutions and are not suitable for fully-automated high-throughput laboratory diagnostics.

Method

Fraunhofer ILT has developed an automated and easily integrated diagnostic system solution – based on glass chip technology – for the detection and sorting of specifically stained cells, pathogens and particles. Fluorescence sensors detect the hydrodynamically focused cells by stimulating them with laser light, thereby detecting and analyzing fluorescence. In contrast to conventional FACS devices, glass fibers guide the stimulating laser and fluorescence radiation, which considerably reduces the dimensions of the µFACS device. The devices are designed as OEM components and can be integrated into an automation platform for handling the samples and assays to be tested.

Results

A great number of fluidic channels for the parallelized sample guide can be arranged on the glass chip. Depending on the task, each of the fluidic channels is equipped with one or more fluorescence sensors, for which up to six different laser wavelengths are available.

The cell detection can be combined with an active sorting process, which selectively directs the cell to a fluidic branch through an optofluidic switch into one of the two channels behind the branch after the detection. During cell sorting, an IR laser beam heats the fluid locally and triggers the fluidic switch by changing the flow conditions at the branch point.

Applications

The µFACS technology can be used in clinical routine diagnostics as well as in bio- and environmental analytics.

This project was financially supported by the Fraunhofer-Gesellschaft.

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

1 Glass chip for clinical diagnostics.

2 Principle of operation of the optofluidic switch.

HAND PIECE FOR LASER-INDUCED COAGULATION

Task

To improve the healing process after operations in oral, jaw, and facial surgery, Fraunhofer ILT has developed a laser-assisted wound closure process and the necessary system technology. The main objective is to provide a temperature-controlled laser for medical applications and to develop a fiber-optic hand piece for applying the laser radiation while simultaneously detecting the tissue temperature.

Method

Up to now, oral wounds and defects have had to be covered with compresses after surgical interventions or supplied with the patient's own skin or mucous membrane graft with often complex seam technology. By contrast, a new approach has been developed by using the approach investigated in the »Biophotonic Technologies for Tissue Repair BI-TRE« project for wound dressing with collagen membranes, which are attached to the mucous membrane with lasers.

Results

In order to implement the objectives of »BI-TRE«, experts from Fraunhofer ILT have developed a process that enables them to adapt the optical penetration depth to the tissue optimally by using two different wavelengths. The coagulation state or the strength of tissue coagulation during the treatment can be determined by means of an optical return channel for the detection of process signals. So that the laser can be used especially in oral, maxillofacial and facial surgery, a hand piece has been developed in the research consortium; integrated in it are a laser fiber to transport the laser radiation as well as fibers to detect a temperature signal and other optical signals. This ensures that the treating physician can safely maintain the permissible temperature range and that the tissue is minimally affected. The wound closure takes place via a transparent collagen membrane, which is penetrated by the laser and fixed as a wound overlay onto the tissue.

Applications

In addition to oral surgery, a seamless wound closure in plastic and general surgery can be used whenever a cosmetically perfect result – without scarring and marks – is desired.

The work in the »BI-TRE« project has been funded by the Federal Ministry of Education and Research (BMBF) and the European Commission under grant number 13N13173. The VDI Technologiezentrum [Technology Center] is responsible for the project management.

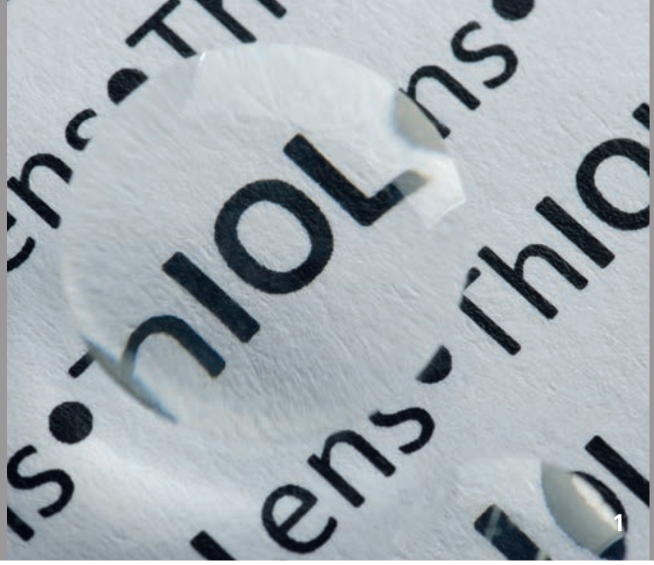
Contact

Dr. Martin Wehner
Telephone +49 241 8906-202
martin.wehner@ilt.fraunhofer.de

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

3 Laboratory pattern of a hand piece for oral surgery (source: LifePhotonic).

4 Radiation characteristics of a fiber bundle for laser therapy with optical diagnostics.



ADDITIVE MANUFACTURING OF INDIVIDUAL POLYMER OPTICS

Task

Transparent plastics are used in mass fabrication processes for optical components such as (micro) lenses, prisms and waveguides because they are light and easily moldable. In particular, parameters such as transparency, color, spectral transmittance and reflectance, refractive index and optical dispersion are essential for their use in optics. Within the framework of the BMBF project »ThIOLens«, Fraunhofer ILT is investigating the fundamentals of a laser-based additive process technology for the individualized production of optics with high refractive index and low optical dispersion.

Method

Individual polymer optics shall be manufactured with laser-based additive processes such as stereolithography and multi-photon polymerization. Along with the development of the associated process technology, extensive investigations on the material side are necessary in addition to those on optical properties and on aspects of process stability and handling. The aim of the development is a process control with an initiator-free photo resin for the production of individual optics with good optical and mechanical properties.

Results

For the laser polymerization of the optics, a stereolithography system was developed in which a continuous laser-beam source is used in the deep UV range for curing. The polymerization depth and the degree of crosslinking should be controlled locally by a rapid power and beam modulation in such a way that isotropic properties are achieved in the volume. For this purpose, Fraunhofer ILT developed a photo resin that can be crosslinked without initiator and has a high transparency (Fig. 1). Further investigations are planned to research the additive manufacturing of specific optics.

Applications

Especially in ophthalmology, there is an increasing need for individual artificial intraocular lenses for the aging population. This field of application is being researched together with the Institute for Experimental Ophthalmology at the University of Saarland.

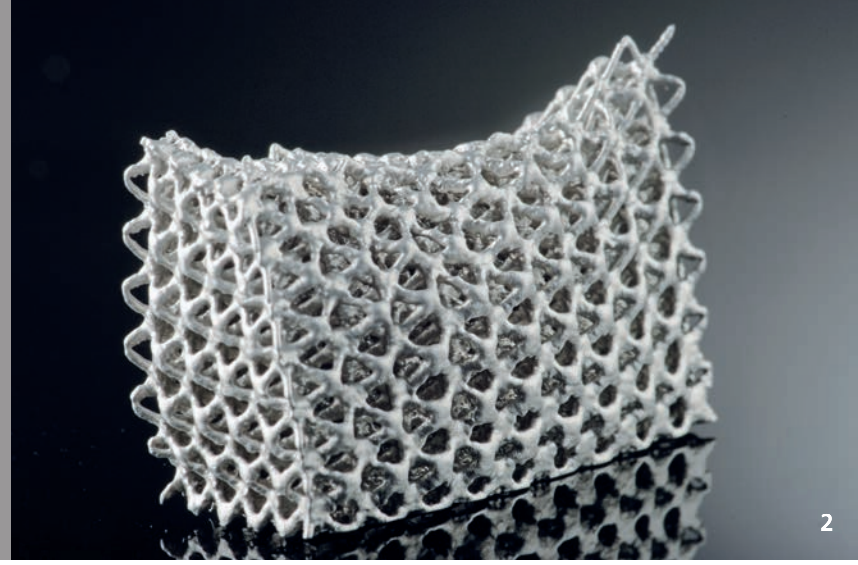
Parts of the work have been supported by the Federal Ministry of Education and Research (BMBF) within the framework of the »VIP +« funding measure under grant number 03VP00841.

Contact

Andreas Hoffmann M.Sc.
Telephone +49 241 8906-447
andreas.hoffmann@ilt.fraunhofer.de

Dr. Martin Wehner
Telephone +49 241 8906-202
martin.wehner@ilt.fraunhofer.de

1 Polymers optics based on polythioether.



ADDITIVE MANUFACTURING OF DEGRADABLE MAGNESIUM IMPLANTS

Task

Among the materials used for degradable implants, magnesium alloys show great promise. For bone replacement implants, not only is the material itself essential, but also the implant's geometric functionality. When interconnecting pore structures are introduced into the implant, new autologous bone can grow into the implant and degradation products can be efficiently removed. The additive production process laser-powder bed fusion (L-PBF) is predestined for the manufacture of such complex implants since it can build components economically due to its layer-by-layer method.

Method

To process magnesium alloys with L-PBF, research faces several challenges: the reactivity of the alloy, the small process window between the melting and evaporation temperature and the powder particles themselves, which are light due to their low density. Not only do these aspects need to be controlled, the process parameters also have to be specially adapted for the production of complex components with overhanging structures, as is the case with implants having interconnecting pore structures. Geometrically adapted exposure strategies are being used for this purpose.

Results

By appropriately adjusting the process control, process parameters and the exposure strategy, Fraunhofer ILT has been able to build implant demonstrators with complex pore structure from the magnesium alloy WE43. The demonstrators have a density of more than 99.5 percent in the solid material, are biocompatible, and can be smoothed by appropriate post-processing techniques such as blasting and etching to reduce the initial degradation.

Applications

In addition to producing degradable implants for various indications, L-PBF can also be used with magnesium alloys for lightweight construction applications since these alloys are about 30 percent lighter than aluminum alloys. Since the additive manufacturing process is highly flexible, thus allowing the construction of highly complex components, it has great potential for applications in the aerospace as well as automotive industry.

This project was funded by the European Regional Development Fund (ERDF).

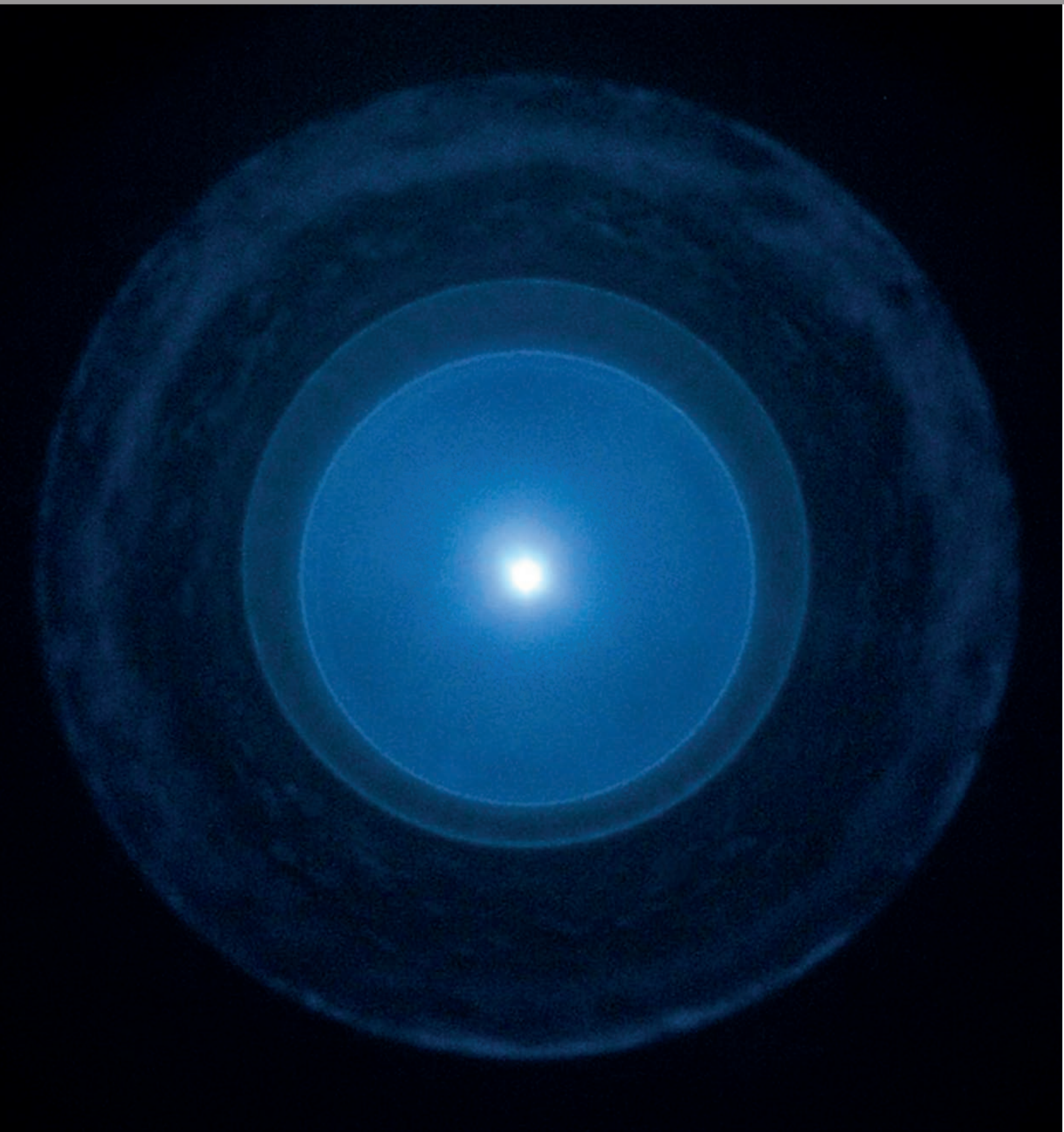
Contact

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

Dr. Wilhelm Meiners
Telephone +49 241 8906-301
wilhelm.meiners@ilt.fraunhofer.de

2 Demonstrator made out of magnesium alloy WE43 for a degradable bone replacement implant.

LASER MEASUREMENT TECHNOLOGY AND EUV TECHNOLOGY



CONTENTS

Brilliant radiation source for X-ray microscopy at 2.88 nm.

MINIATURIZED SAMPLE HEAD FOR INLINE PARTICLE ANALYSIS

Task

In many chemical processes, particle sizes in the range of a few nanometers to a few micrometers play a decisive role and influence product properties significantly. Using a novel sampling head for »in-situ sampling«, Fraunhofer ILT can now measure particle sizes in-line during running processes by using dynamic light scattering (DLS).

Method

Dynamic light scattering is based on an optical measurement of the diffusive motion of particles in liquids (Brownian molecular motion); for this reason, this measurement method cannot be used in actively mixed media. By means of a sample head with an impeller, a small sample volume is separated from the surrounding actively mixed liquid, and a DLS measurement is carried out with a fiber-optic back-scatter probe. So that the method can be used in applications with limited space requirements, the sample head has been miniaturized: the probe now has a diameter of only 10 mm. All electrical components (motor, laser, detector) are located outside the sample head, the rotary movement is transmitted via a flexible shaft.

1 Miniaturized measuring head for inline DLS measurements.

Results

The new measuring head was developed in cooperation with RWTH Aachen University (Collaborative Research Center 985 – Functional Microgels and Microgel Systems). The successful use of the sample head for in-line tracking of a polymerization reaction has been published (Measurement, 80 (2016), 92-98).

Applications

Applications of inline DLS measurement technology can be found in all processes in which particle sizes between a few nanometers and a few micrometers have to be monitored in-line in a single process and measured without taking a sample. Examples are the monitoring of chemical polymerization reactions, the production of paints and lacquer, processes in the food industry, as well as various grinding and dispersing processes.

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

IN-LINE MEASUREMENT TECHNOLOGY FOR LASER MICROSTRUCTURING

Task

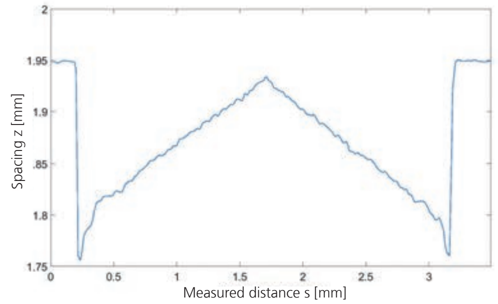
For the laser microstructuring of metallic surfaces, the processing and the evaluation of the production results are typically carried out on two different machines. After processing on a laser microstructuring system, the workpieces are examined for quality assurance, for example, using a white light interferometer or a laser scanning microscope. However, investigations with such laboratory measurement methods are time-consuming and not suitable for a 100 percent level of control.

Method

For such a 100 percent level of control, there are measurement methods that can be integrated into laser microstructuring systems. Absolute-measuring interferometers are particularly suitable for this task since their measuring radiation can be guided coaxially through the existing processing optics. The »bd-2« sensor developed at Fraunhofer ILT has a very high measuring accuracy at a measuring frequency in the range of several 10 kHz so that microstructures of the order of 10 µm up to several 100 µm can be measured reliably and quickly.

Results

In test series, the compact, robust measuring heads of »bd-2« sensors have successfully measured various surfaces structured with laser radiation. The measuring distances were between 100 mm and 300 mm. Due to the large spectral width of the



radiation source used, the method is insensitive to disturbance from the speckle effect. Ambient light and even process lights do not impair the measurements so that quality control can even take place in-line, i.e. during the laser microstructuring process.

Applications

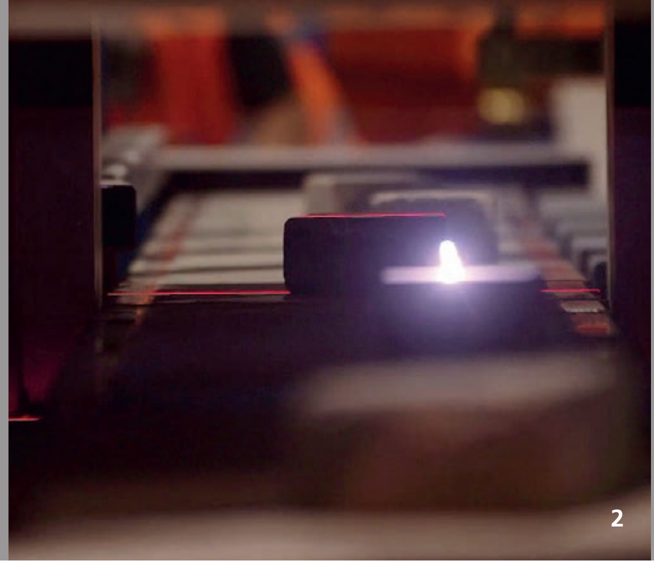
The in-line measurements will be used not only for 100 percent quality control, but also for increasing product quality. Thus, machining operations can be stopped in a targeted manner when the predetermined ablation depth has been reached, or corrective actions can be carried out before the workpiece is removed from the laser microstructuring plant.

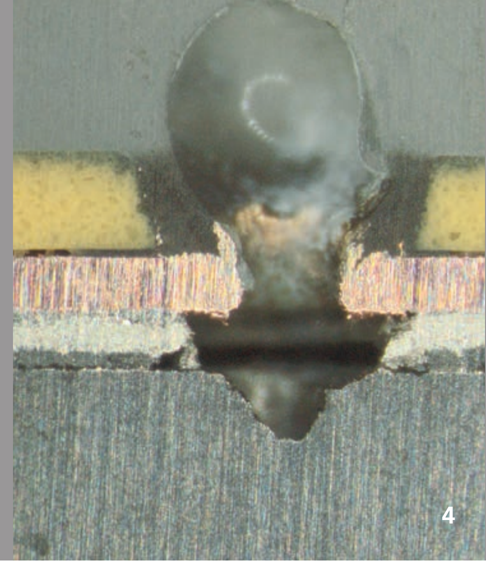
Contact

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

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

2 »bd-2« -sensor with connected measuring head; measuring head size: L x Ø = 55 mm x 18 mm, m = 40 g.





LASER-BASED DIRECT ANALYSIS OF REFRACTORY MINERALS

Task

Among mineral raw materials, refractory materials are of great importance as they are indispensable for all high temperature processes and must meet high quality requirements in order to ensure safe process control. Since, on the one hand, it is very hard to obtain primary raw materials in Europe and, on the other, considerable quantities of used material accumulate, natural resources can be protected and the generation of waste avoided with a closed material cycle.

The refractory materials used in the industry are largely based on magnesium, calcium and aluminum oxides. The exact composition determines the thermal, mechanical and chemical properties. Impurities and mixtures can quickly lead to a loss, for example of thermal stability.

Method

So that refractory materials can be reused, the recycled materials must be provided in pure fractions. This is made more difficult, however, because the material is mixed and contaminated after excavation and cannot be reliably recognized and sorted with conventional methods. To make this task feasible, project partners have developed a method for automatic sorting, which uses a laser-based direct analysis of the material. In a process combining laser ablation and laser-induced breakdown spectroscopy (LIBS), contaminants near the surface are locally removed and the underlying refractory material is identified on the basis of its chemical composition.

Results

Together with European partners, Fraunhofer ILT has set up a demonstrator to validate the function of the entire sorting process, including identification. The system was presented to a specialist public audience; it has already been used to recover 30 tons of purely fractionated material. The recycled material replaced a portion of new material in production, and partners could demonstrate in industrial tests that this mixture has the same quality as refractories produced from pure primary raw materials.

Applications

The automatic sorting with LIBS is able to separate raw materials into pure fractions in the primary and recycling sectors, where substances have to be identified by means of a fast multi-element analysis. Also in the metal industry, for example in aluminum recycling, laser-based direct analysis can distinguish between individual alloys, thus making closed raw material cycles possible.

The work has been funded within the framework of the EU project »REFRASORT« under grant number 603809.

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

1 Development of an automated material handling for refractory bricks.

2 Laser-based material recognition.

RECYCLING OF VALUABLE MATERIALS FROM MOBILE PHONES

Task

Mobile phones, like other modern electronics, contain a variety of chemical components that are considered to be valuable or vital raw materials in Europe. At the end of the equipment's life cycle, however, these raw materials are only partly recovered by current recycling processes.

Method

Fraunhofer ILT is coordinating the European network project »ADIR«, in which technological solutions are developed in order to recover the individual substances in an automated process chain. For this purpose, the valuable electronic elements shall be identified and removed selectively so that they can be recycled into separated fractions. The project is testing methods for the processing of mobile phones and of commercially used electronic circuit boards from network technology.

Results

There are two decisive factors needed to selectively recover the raw materials: first, exact knowledge of where and in which components the individual substances are located, and, second, a process for their targeted removal. Laser-based processes can be used for both points. The material identification by means of laser-induced breakdown spectroscopy (LIBS) allows a very precise elemental analysis of the contents of electronic components. Subsequently, processing lasers are used as a non-contacting tool in order to selectively separate the high-quality components and feed them in pure fractions into the metallurgical processes.

Applications

The »ADIR« project is initially targeted at electronics from the telecommunications sector. By providing a technology for the improved recovery of raw materials, »ADIR« aims to strengthen economically and ecologically attractive recycling of old electronic devices.

The Fraunhofer-Gesellschaft has launched »i-Recycle« as a model project. It will feed all of its discarded business mobile phones from all Fraunhofer institutes into the new recycling processes.

The work has been funded within the framework of the EU project »ADIR« under grant number 680449.

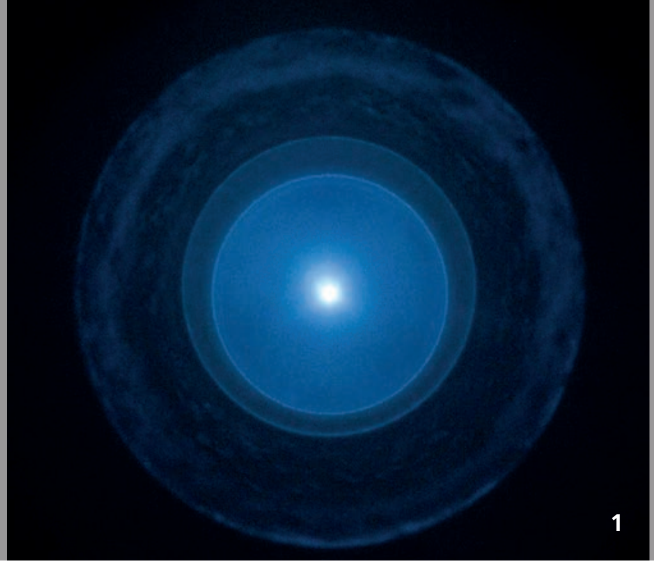
Contact

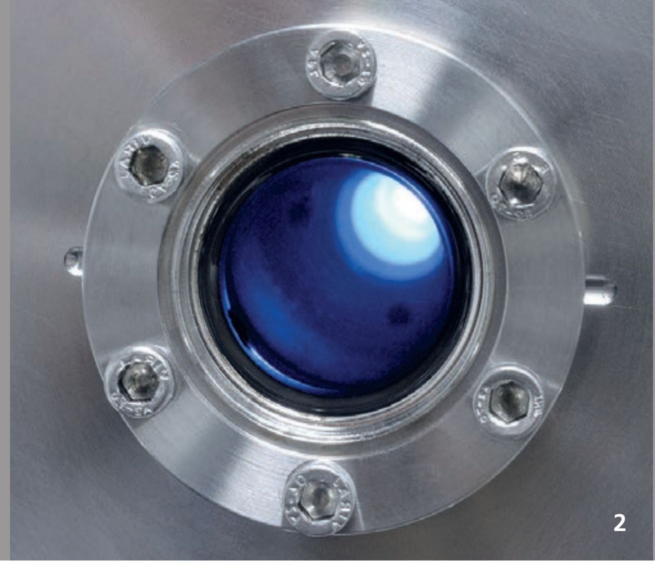
Dr. Cord Fricke-Begemann
Telefon +49 241 8906-196
cord.fricke-begemann@ilt.fraunhofer.de

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

3 Discarded, disassembled mobile phones.

4 Laser-based material analysis of electronic components.





BRILLIANT RADIATION SOURCE FOR X-RAY MICROSCOPY AT 2.88 NM

Task

Microscopy with soft X-ray radiation (XUV) in the spectral range of the water window (wavelengths between 2 and 5 nm) is suitable as a high-resolution, imaging method for the investigation of aqueous biological samples or of the self-organization of nanoparticles in the field of medicine and colloid chemistry. Unlike light microscopes, X-ray microscopes provide the required resolution in the sub-nm range.

Furthermore, in contrast to electron microscopy, the sample preparation is less complex in X-ray microscopy, which makes a significantly higher throughput possible. The most important characteristic of the light source for an X-ray microscope is the brilliance, which essentially determines the exposure time.

Method

In the past, an X-ray microscope with a discharge source was already demonstrated. For this source, nitrogen is used as the emitter gas, which exhibits the intense, monochromatic $1s^2$ - 1s2p transition of helium-like nitrogen ions at 2.88 nm. By extending the operating parameter range, researchers at ILT have been able to increase the brilliancy at 2.88 nm substantially when operated at significantly higher neutral gas pressures.

Results

In the new operating mode, the source can generate an average brilliance of $L = 2.5 \times 10^{10}$ Ph µm^{-2} sr^{-1}. This is approximately a factor of six higher compared to the prior state-of-the-art, and, thus, ranks among the peak values for plasma-based radiation sources for X-ray microscopy.

Applications

The X-ray microscopes can be used, for example, to investigate:

- aqueous biological samples
- nanoparticles in the field of colloid chemistry for the observation of the growth of nanoparticles
- nanoelectronics as organic semiconductor materials at a resolution in the range of 50 nm
- processes for 2D and 3D (tomography) imaging at high local resolution

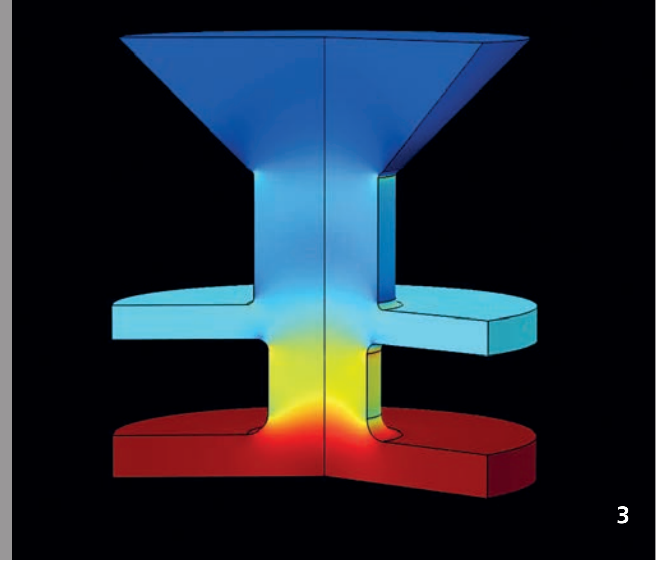
This project has been financially supported by the Fraunhofer-Gesellschaft.

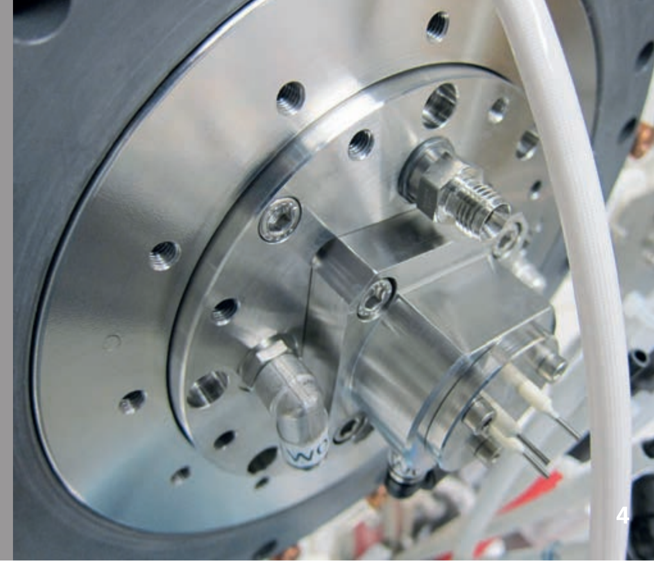
Contact

Alexander von Wezyk M.Sc.
Telephone +49 241 8906-376
alexander.von.wezyk@ilt.fraunhofer.de

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

1 Picture of the radiation source in the visible spectral range.
2 View of the radiation source through a window.





COMPACT RADIATION SOURCE IN THE EXTREME ULTRAVIOLET

Task

Discharge-based sources of radiation in the extreme ultraviolet are a cost-effective and user-friendly solution, in particular at a wavelength of 13.5 nm, which is of great interest for future chip production. In such sources, dense and hot plasma is generated by a pulsed discharge of electrically stored energy. At Fraunhofer ILT, these sources are being developed and converted into commercial applications. In order to make these sources more attractive to the user and also to open up further fields of application, the institute has focused its development on increasing the source's maintenance interval.

Method

The work presented here is aimed both at reducing the unavoidable erosion of the electrodes by the use of other materials as well as developing an extended range of operating parameters. In particular, a new electrical circuit for igniting the plasma was used to increase the efficiency for the conversion of the electrical energy into EUV radiation. Based on long-term tests and simulations of the flow dynamics of the working gas as well as cooling of the electrode system, an EUV source has been developed which achieves the increased output power at a longer maintenance interval.

Results

The solutions found to improve the performance and the maintenance interval have been developed to market maturity and integrated into the product portfolio. The units at international customers are being retrofitted with the upgrades.

Applications

The radiation source is suitable for various applications in the field of semiconductor lithography, such as the characterization of optics, contamination studies or the development of new photoresists.

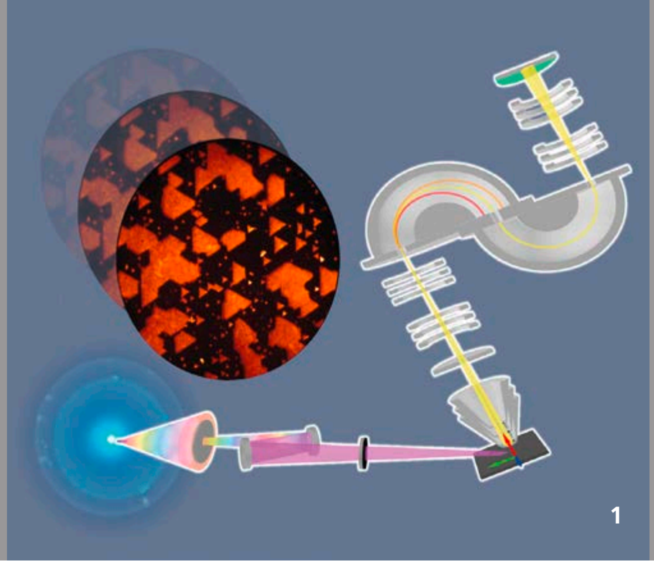
Parts of the R&D project underlying this report were carried out on behalf of the German Federal Ministry for Economic Affairs and Energy (BMWi) under grant number KF2118109NT4.

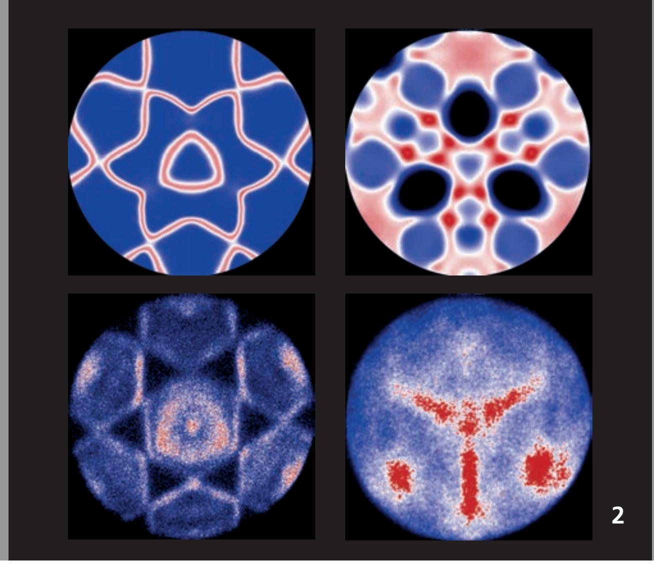
Contact

Dipl.-Phys. Jochen Vieker
Telephone +49 241 8906-397
jochen.vieker@ilt.fraunhofer.de

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

3 FEM simulation of the pressure distribution in the electrode system.
4 Rear side of the EUV radiation source.





EUV PLASMA SOURCES FOR PHOTOELECTRON SPECTRO-SCOPY AND MICROSCOPY IN THE LABORATORY

Task

Since various academic and industrial disciplines have a growing interest in functional microstructures, there is an increasing demand for spatially resolved methods to characterize chemical and electronic properties in the micrometer range. So that the potential of the so-called spectro-microscopy can be fully exploited, radiation is used in the ultra-ultraviolet, up to the soft X-ray range. This type of sample characterization is normally carried out on electron storage rings (synchrotrons), but these large devices can only be used for a limited time on request. In the laboratory, there is an extreme spectral gap between helium I/II lamps (21 eV or 40 eV photon energy) and X-ray tubes (e.g. Al-kα ~ 1400 eV). The idea is, therefore, to use an EUV source covering the range of 40 to 600 eV by identifying all elements and by having the radiation per se exhibit a high cross-section of activity given by nature and a high surface sensitivity.

1 Experimental setup and recordings of Ge-Sb-Te (GST) islands with photoelectrons.

2 Comparison between simulated (above) and measured (below) ribbon structure of gold at two different electron energies.

Method

In the first tests, the light from an EUV gas discharge source was spectrally filtered using multi-layer mirrors and focused on a sample within a FOCUS NanoESCA photoelectron microscope. The electrons released by the photoelectric effect are imaged and at the same time energetically filtered. The result is an image of the sample containing information on its chemical composition.

Results

In this project, Ge-Sb-Te (GST) islands were investigated. GST is a prototype material for processes based on a phase change of the material, widely known from rewritable optical media such as CD-RW or DVD-RW. It was possible to distinguish between oxidized and non-oxidized states of the material. Furthermore, it has been verified that images in the pulse space providing information on electronic properties can also be made with pinch plasma sources.

Applications

Photoelectron spectroscopy and microscopy are used in countless fields of application, e.g. in quality control.
This project was financially supported by the »JARA-FIT Seed Fund« project in the course of the German Excellence Initiative.

Contact

Prof. Larissa Juschkin
Telephone +49 241 8906-313
larissa.juschkin@ilt.fraunhofer.de

PATENTS

PATENTS

PATENTS GERMANY

DE 10 2014 016 993 B3 Vorrichtung und Verfahren zur Durchführung faseroptischer Messungen in bewegten Flüssigkeiten

DE 10 2011 118 540 B4 Verfahren und Vorrichtung zum Schneiden oder Trennen von Feststoffen durch Materialabtrag mittels energetischer Strahlung

DE 10 2015 200 795 C2 Anordnung zur Bestrahlung einer Objektfläche mit mehreren Teilstrahlen ultrakurz gepulster Laserstrahlung

DE 10 2013 003 640 B4 Verfahren und Vorrichtung zur optischen Messung von Innengeometrien

DE 10 2013 017 289 B4 Verfahren und Vorrichtung zur Steigerung der Genauigkeit berührungsfreier Abstands- und Dickenmessungen

DE 10 2014 208 371 B4 Verfahren zur Laserbearbeitung einer Oberfläche

DE 10 2005 001 158 B4 Barriereentladungselektrode mit Kühlung

PATENTS EUROPE

EP 2 292 357 Ceramic or glass-ceramic article and methods for producing such article

EP 2 755 793 Verfahren und Vorrichtung zum Strukturieren von Oberflächen durch Bearbeitung mit energetischer Strahlung

EP 2 886 239 Verfahren und Vorrichtung zur Überwachung und Regelung der Bearbeitungsbahn bei einem Laser-fügeprozess

EP 2 387 803 B1 Verfahren zur Herstellung von Leiterbahnen auf Substraten

53
Bachelor theses in 2016

PATENTS
19 Patents,
25 Patent applications
in 2016

104
Scientific lectures

58
Master theses in 2016

95 Publications

PATENTS

PATENTS USA

9 414 476 Method and device for generating optical radiation by means of electrically operated pulsed discharges

9 484 705 Optically end-pumped slab amplifier comprising pump modules arranged in a distributed manner

PATENTS JAPAN

P 5862 286 Thin film manufacturing device, thin film manufacturing method, droplet discharge head and ink jet recording apparatus

P 588 0031 Thin film manufacturing apparatus, thin film manufacturing method, liquid droplet ejecting head, and ink jet recording apparatus

P 589 1782 Thin film manufacturing device, thin film manufacturing method, droplet discharge head and ink jet recording device

5 919 814 Electromechanical conversion element, manufacturing method of electromechanical conversion element, droplet discharge head, and ink jet recording device

5 982 486
Method and device for generating optical radiation by means of electrically operated pulsed discharges

PATENTS CHINA

102 448 650 B Welding method and component

PATENT APPLICATIONS GERMANY

10 2016 204 407.9 Verfahren zur Erzeugung von extremer Ultraviolett und/oder weicher Röntgenstrahlung

10 2016 208 309.0 Verfahren zur Überwachung der Qualität einer Schweißnaht

10 2016 209 065.8 Verfahren und Vorrichtung zur Prozessüberwachung bei der generativen Fertigung von Bauteilen

10 2016 110 266.0 Verfahren und Vorrichtung zur generativen Fertigung von Bauteilen

10 2016 111 531.2 Optischer Scanner

10 2016 211 471.9 Anordnung und Verfahren zur winkelaufgelösten Streulichtmessung mittels einer Wellenleiter-Sonde

10 2016 212 571.0 Vorrichtung und Verfahren zur Herstellung von dreidimensionalen Bauteilen mit einem pulverbettbasierten Strahlschmelzverfahren

10 2016 212 572.9 Verfahren zur Herstellung von dreidimensionalen Bauteilen mit einem pulverbettbasierten Strahlschmelzverfahren

10 2016 212 573.7 Verfahren zur Herstellung von dreidimensionalen Bauteilen mit einem pulverbettbasierten Strahlschmelzverfahren

10 2016 215 493.1 Hybrider Werkstoffverbund zwischen einer Metalloberfläche und einer polymeren Materialoberfläche sowie Verfahren zur Herstellung des hybriden Werkstoffverbundes

10 2016 218 951.4 Verfahren und Vorrichtung zur generativen Fertigung von Bauteilen auf einer Grundplatte mit Oberflächentopologie

10 2016 220 623.0 Verfahren zur werkzeuglosen Entfernung von Stützstrukturen bei der generativen Fertigung von Bauteilen

10 2016 121 594.5 Verfahren zur Verbesserung der Oberflächenqualität generativ hergestellter Bauteile

10 2016 222 067.5 Verfahren und Vorrichtung zur Bearbeitung einer Werkstoffschicht mit energetischer Strahlung

10 2016 222 068.3 Vorrichtung und Verfahren zur generativen Bauteilfertigung mit mehreren räumlich getrennten Strahlführungen

PATENT APPLICATIONS EUROPE

PCT/EP2016/000112 Bearbeitungskopf für die Materialbearbeitung

PCT/EP2016/052138 Verfahren und Vorrichtung zur hochgenauen optischen Messung an Objekten mit anhaftenden fluidischen Schichten

16 156 867.0 A method of sintering, crystallizing and/or crosslinking of a coating material on a substrate

16 001 137.5 Highly porous carbon fibers obtained by fast carbonization of carbon precursors fibers

PCT/EP2016/064297 Auftragschweißen von übereinander aufgetragenen Auftragslagen mit unterschiedlichen Dicken

PCT/EP2016/067123 Anordnung und Verfahren zur verzeichnungsfreien zweidimensionalen Ablenkung von räumlich ausgedehnten Intensitätsverteilungen

PCT/EP2016/074287 Vorrichtung zum Laserstrahlauftragschweißen mit Pendelbewegung

PCT/EP2016/074482 Parameter beim Auftragschweißen bei oszillierender Erstarrungsfront

PCT/EP2016/001810 Verfahren zum Fügen von zwei Bauteilen im Bereich einer Fügezone mittels mindestens einem Laserstrahl sowie Verfahren zum Erzeugen einer durchgehenden Fügenaht

PCT/EP2016/0800751 Verfahren und Anordnung zur Verringerung der Grenzflächenadhäsion bei der Photopolymerisation

DISSERTATIONS

DISSERTATIONS

4.3.2016 – Pütsch, Oliver (Dr.-Ing.)
Aktive und adaptive Strahlformungssysteme für die Werkstoffbearbeitung mit Laserstrahlung

22.3.2016 – Büsing, Lasse (Dr.-Ing.)
Optische Systeme für die hochpräzise, scannerbasierte Multistrahlbearbeitung mit ultrakurzen Laserpulsen

13.4.2016 – Bensmann, Stefanie (Dr.-Ing.)
Breitband-Nahfeldmikroskopie an phonon-resonanten Kristallen

15.4.2016 – Uchtmann, Hermann (Dr.-Ing.)
Modulares hybrides Laserstrahlbohren

5.7.2016 – Fornaroli, Christian (Dr.-Ing.)
Sublimationsschneiden von Silizium mit ultrakurz gepulster Laserstrahlung

15.7.2016 – Rolink, Gesa (Dr.-Ing.)
Entwicklung der laserbasierten additiven Fertigung für intermetallische Fe-Al-Legierungen

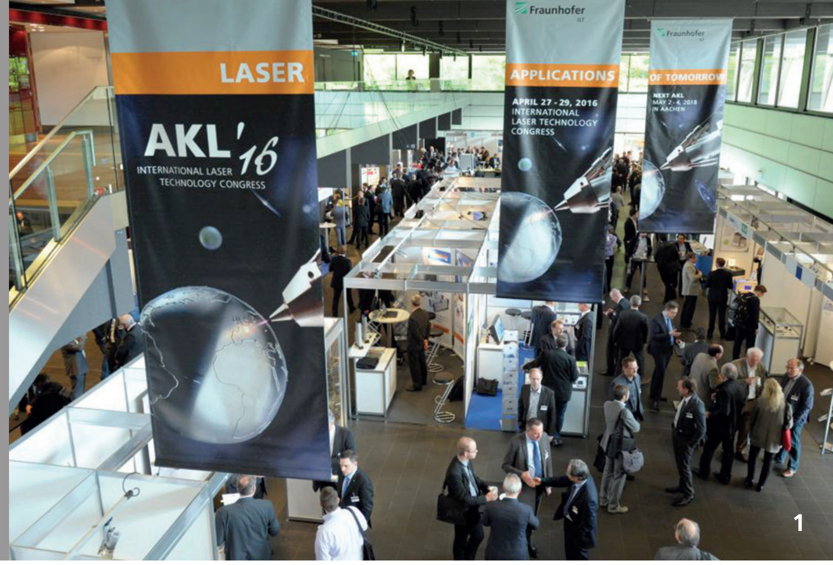
18.7.2016 – Steger, Michael (Dr.-Ing.)
Mehrstrahlinterferenz zur direkten, großflächigen Nanostrukturierung durch Laserablation

9.11.2016 – Hoerstmann-Jungemann, Maren-Christine (Dr.-Ing.)
Digital Photonic Production of Corundum Components by SLE

15.12.2016 – Christian-Alexander Tulea (Dr. rer. nat.)
Laserinduzierte Ablation von biologischem Hartgewebe unter Wasser mit Pikosekundenpulsen im sichtbaren Spektralbereich

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: www.ilt.fraunhofer.de/de/mediathek.html

EVENTS



AKL'16

AKL'16 – International Laser Technology Congress April 27 - 29, 2016 in Aachen

The International Laser Technology Congress AKL'16 took place in Aachen from April 27 to 29, 2016. In addition to micro- and macro-processing, the congress placed a special focus on process control and additive manufacturing. With more than 690 visitors, AKL'16 saw an increase of 10 percent compared to that of 2014. The congress has also continued to grow internationally: 196 visitors came from a total of 27 different countries. Far in advance, 52 companies had already fully booked the sponsoring exhibition.

In addition to its conference with three separate sessions, the program of the AKL'16 offered a variety of additional events such as the Seminar »Laser Technology ABC's«, the Forums »Process Control« and »Laser Additive Manufcturing« as well as several evening events. The event »Laser Technology Live« was also very well attended with a total of 91 live demonstrations of current projects at Fraunhofer ILT.

1 Well attended: the accompanying exhibition of the AKL'16 with 52 sponsors.

AKL Conference on April 28 and 29, 2016

At the Laser Technology Conference of the AKL'16, the participants discussed all the stages of lasers, from beam-source development to the most diverse laser applications, and several trends became apparent: for example, the development of beam sources is less dependent on disruptive technologies but more on higher efficiency and higher performance. Fiber lasers are now available up to 100 kW; direct diode systems reach the 50 kW mark. Initial experiments at Fraunhofer ILT further confirm that diode lasers are now also suitable for laser cutting. At the same time, the systems have become increasingly comparable and commodification leads to price competition and a progressive consolidation of the industry.

Ultra-short pulse (UKP) lasers are still relatively new, and the market for systems up to 150 W is growing at a slower pace. At AKL'16, applications in the electronics, semiconductor and consumer goods industry were presented. What is still missing, however, is higher productivity, but multi-beam systems, for example from the Aachen startup Pulsar Photonics offer a solution. In addition, various groups at Fraunhofer ILT are working on the development of UKP lasers in the kW range.

Forum »Laser Additive Manufacturing«

Productivity is also the central question in the broader application of additive processes, as the participants of the all-day forum »Laser Additive Manufacturing« agreed. Additively manufactured components have become established in turbine construction, while new applications in aircraft construction and the automotive sector are steadily increasing. For even broader applications, multi-beam processes could be provided, and a corresponding project at Fraunhofer ILT aims at a 30-fold increase in productivity.

Winning team Philips GmbH Photonics of the Innovation Award Laser Technology 2016 with moderator Annett Möller, Ulrich Berners (2nd.f.left) and Dr. Paul Hilton (1st.f.right).

2nd Conference on Laser Polishing LaP from April 26 to 27, 2016 in Aachen.

Klaus Löffler, managing director of Sales & Services, TRUMPF Lasertechnik GmbH, at the Technology Business Day of the AKL’16.

Forum »Process Control«

The new forum »Process Control« was also very well attended, with the participation well above original expectations. The lectures presented various sensor systems and experience in implementing process monitoring in the industry; as a part of this, inline measurements are increasingly gaining ground. The various sensors have now made great progress, but the problem is more likely to be the analysis of individual images: the rate of pseudo errors is still too high. Due to the strong interest in this topic, Fraunhofer ILT and IPT have founded the »Industrial Working Group on Process Control in Laser Material Processing«.

**»Laser Technology Live«
on April 28, 2016 at Fraunhofer ILT**

At the »Laser Technology Live« event on April 28, 2016, the participants were able to exchange information about new technological developments with the Aachen researchers at 91 live presentations in the Fraunhofer ILT Application Center. However, »Laser Technology Live« also gave valuable impulses not only from a purely scientific perspective. Among other things, companies also learned from managing directors of the ACAM Aachen Center for Additive Manufacturing how to use additive manufacturing technologies for their production processes. Christian Hinke, Managing Director of the »Research Campus Digital Photonic Production DPP«, presented interested parties with opportunities for medium- to long-term cooperation in the »Industry Building Digital Photonic Production DPP«.

**Inauguration of the »Industry Building
Digital Photonic Production DPP«**

On the evening of April 28, 2016, the participants of AKL’16 were able to participate in the inauguration of the »Industry Building DPP«. As the first building in the Photonics Cluster near Fraunhofer ILT, it is part of the newly emerging campus of RWTH Aachen University and one of the largest technologically oriented research landscapes in Europe. Here, scientists can work on projects of the »Research Campus DPP«, funded by the Federal Ministry of Education and Research, and explore new methods and fundamental physical effects for using light as a tool in the industrial production of the future.

**April 27, 2016, Aachen
Bestowal of the Innovation Award Laser Technology 2016**

A special highlight of the AKL’16 was the bestowal of the Innovation Award Laser Technology 2016 in the coronation hall of the Aachen city hall. The award is bestowed by the Arbeitskreis Lasertechnik e.V. and the European Laser Institute ELI for outstanding achievements in the field of industrial laser technology. In 2016, the first prize of €10,000 was awarded to Dr. Ir. Armand Pruijmboom and his team at Philips Photonics GmbH Aachen for their development of VCSEL arrays – a new high-performance laser technology for the »digital heat treatment« of workpieces.

Further information: www.innovation-award-laser.org

EVENTS

**January 20, 2016, Aachen
3rd Chamber of Commerce Economic Consultation Day with the Aachen Center for 3D Printing**

- Organized by the Aachen Chamber of Commerce in cooperation with the Aachen Center for 3D Printing, a collaboration between Fraunhofer ILT and Aachen University of Applied Sciences
- Small- and medium-sized enterprises were able to find out about the opportunities that additive manufacturing processes provide from technology experts at the Aachen Center for 3D Printing

**February 15, 2016, Munich
4th Trend Forum on 3D Printing**

- Organized by Management Circle in cooperation with Fraunhofer ILT
- Directed at professional and managerial staff from production, R&D, innovation and technology management, business development management, law, marketing and sales
- Main topics: technological and economic limits as well as prospects of 3D printing

**April 5, 2016, Brussels, Belgium
H2020 Workshop 2016: Photonics Research in Europe for Advanced Solutions in Laser-Based Manufacturing**

- Within the scope of the EU project »LASHARE«, innovations were presented around laser-based production

**April 12 - 13, 2016, Aachen
Aachen Polymer Optics Days International Conference**

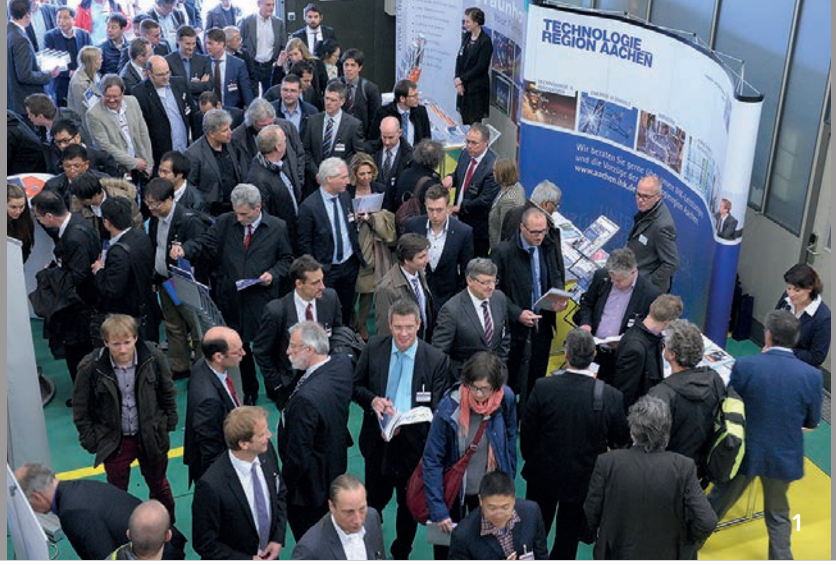
- Organized by Fraunhofer ILT and IPT as well as the Institute of Plastics Processing (IKV) of RWTH Aachen University
- Networking platform for industry and research participants in the field of optical plastic products
- 19 lectures on the topics of injection-molded optics, continuous production of flat optics and foils, new materials and applications for plastic optics, light sources and optical systems

**April 26 - 27, 2016, Aachen
2nd Conference on Laser Polishing LaP 2016**

- Almost 60 participants from 12 countries were informed about topics related to the laser-based surface treatment of metals and glass

**April 27 - 29, 2016, Aachen
11th International Laser Technology Congress AKL’16**

- More than 600 attendees, 79 speakers and 52 sponsors visited Europe’s leading forum for applied laser technology in production
- Supporting organizations: the European Commission, the European Photonics Industry Consortium EPIC, Arbeitskreis Lasertechnik e.V., the European Laser Institute ELI, the OptecNet and the industrial associations SPECTARIS, VDA, VDMA and VDI



September 14 - 15, 2016, Aachen
Conference »3D Valley Conference 2016«

- Organized by the ACAM Aachen Center for Additive Manufacturing of the Photonics Cluster
- Topic: What future possibilities do 3D printing and other additive production methods offer and what is already possible today?
- The event was aimed at small- and medium-sized enterprises in the region

November 3, 2016, Hannover
LaserForum 2016 – Laser applications in medicine

- Organized by the IVAM Microtechnology Network together with Fraunhofer ILT, the Laser Zentrum Hannover and the Chair for Laser Application Technology (LAT) at the Ruhr-Universität Bochum
- Focus on the production of medical products, applications of lasers in medicine and laser diagnostics

1 During the AKL'16 the conference participants experienced »Laser Technology Live« at Fraunhofer ILT.

2 Participants of the Aix-Laser-People meeting at the Center for Applied Aeronautical Research (ZAL) in Hamburg.

COLLOQUIUM LASER TECHNOLOGY AT RWTH AACHEN

February 11, 2016, Aachen – Colloquium Laser Technology
Chair for Laser Technology LLT at RWTH Aachen University
Nadine Bey M.Sc., Invensity GmbH, Wiesbaden: »New Technologies – Only One of Seven Sources for Innovations«

March 17, 2016, Aachen – Colloquium Laser Technology
Chair for Laser Technology LLT at RWTH Aachen University
Dr. Günther Derra, Philips GmbH Photonics Aachen: »High-performance VCSEL Systems – Properties, Applications and Perspectives«

June 30, 2016, Aachen – Colloquium Laser Technology
Chair for Laser Technology LLT at RWTH Aachen University
Prof. Dr. Jo van den Brand, National Institute for Subatomic Physics (Nikhef) and VU University of Amsterdam: »Observation of Gravitational Waves«

AIX-LASER-PEOPLE

April 28, 2016, Aachen
53rd Seminar of the Arbeitskreis Lasertechnik e.V. and the Alumni Network »Aix-Laser-People«
Within the scope of the International Laser Technology Congress AKL'16 from April 27 to 29, 2016, about 40 alumni from Fraunhofer ILT and members of the AKL e.V. caught up on the latest developments of Fraunhofer ILT and associate chairs of RWTH Aachen University in more than 90 live laser technology demonstrations. After the Arbeitskreis Lasertechnik e.V. had its annual meeting, the opening ceremony of the Photonics Cluster on the RWTH Aachen Campus gave the participants another opportunity to exchange ideas in a high-tech atmosphere.

October 6 - 7, 2016, Hamburg
54th Seminar of the Arbeitskreis Lasertechnik e.V. and the Alumni Network »Aix-Laser-People«
The 54th meeting in Hamburg was held entirely under the topic »Industry 4.0 in the Aviation Industry and Laser Applications in Aircraft Construction«. The 45 participants visited prestigious members of the Hamburg Aviation Cluster, such as Airbus, Lufthansa Technik, the Center for Applied Aeronautical Research ZAL and the Laserzentrum Nord LZN in Hamburg.

December 22, 2016, Aachen
55th Seminar of the Arbeitskreis Lasertechnik e.V. and the Alumni Network »Aix-Laser-People«
The 55th seminar was held by the Fraunhofer ILT spin-off EdgeWave GmbH in Würselen, Germany. After Dr. Keming Du, managing director of EdgeWave GmbH welcomed the 25 guests, Dipl.-Ing. Dieter Hoffmann, director of the competence area Laser and Laser Optics at Fraunhofer ILT, gave a lecture entitled »Laser Beam Sources for Use in Outer Space«. Subsequently, Dr. Du held his talk, »Innoslab Technology for Short-Pulse and Ultra-short Pulse Lasers – Beam Sources and Applications«. After a final discussion, the participants had the opportunity to visit the production of EdgeWave GmbH.

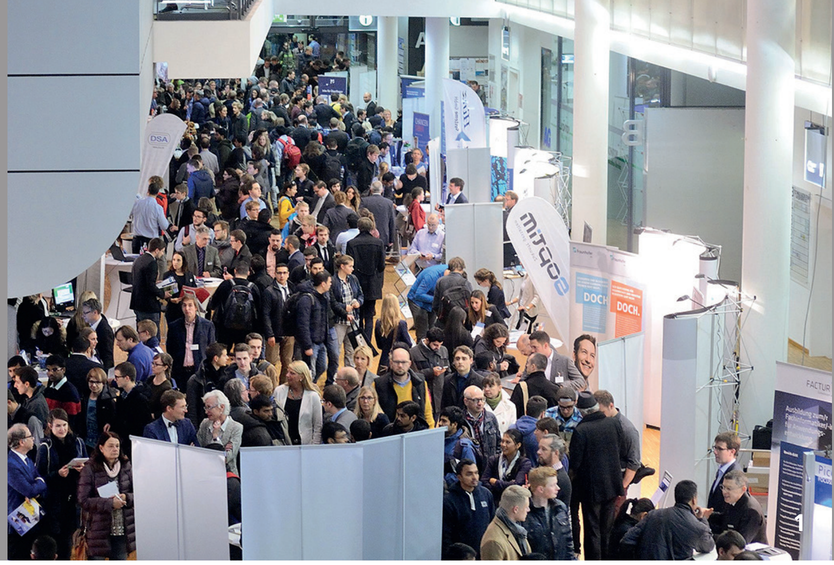
EVENTS FOR STUDENTS

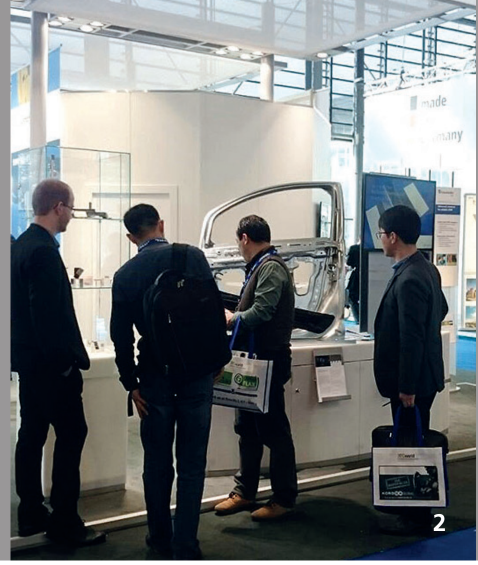
January 26, 2016, Aachen – Student Tour
Orientation event for high school graduates of the Anne-Frank-Gymnasium in Herzogenrath. Fraunhofer ILT gave a lecture introducing itself and the basics of laser technology and then gave the students a laboratory tour including experiments for them to conduct.

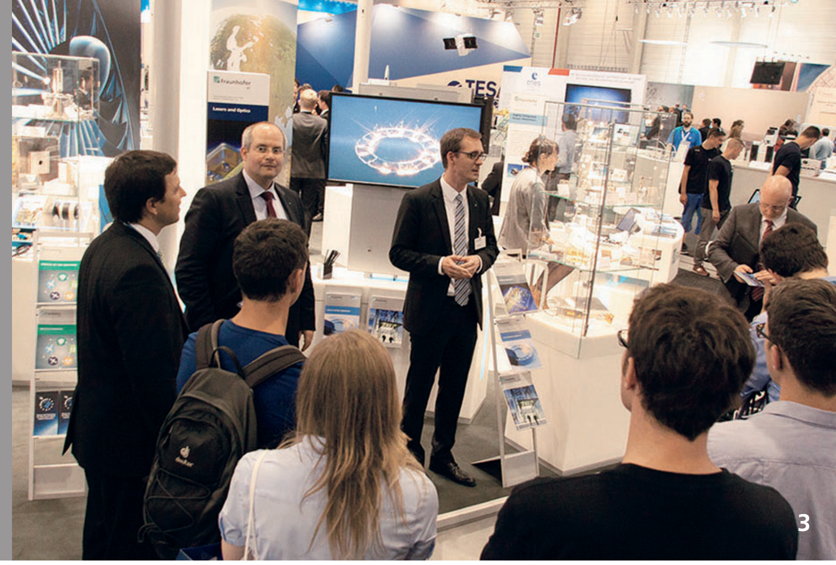
April 14, 2016, Aachen – Student Tour
Orientation event held by the university chairs for Laser Technology LLT and Technology of Optical Systems TOS for students attending courses of both chairs in winter semester 2015/2016 with a subsequent institute tour.

April 28, 2016, Aachen
Girls' Day – Girls' Future
On this day, female students from the fifth grade onwards were able to experience the working world in technology, crafts, engineering and natural sciences or learn about female role models in management positions in business, science and politics. Fraunhofer ILT, together with the Fraunhofer institutes IPT and IME, participated in this nationwide vocational orientation day for girls between 10 and 15 years of age.

August 1 - 5, 2016, Aachen
Students' University, Mechanical Engineering
The RWTH Aachen University offers students' universities in the summer holidays on STEM subjects (science, technology, engineering and mathematics) for students from the ninth grade onwards. The students learn about university life for a week. Fraunhofer ILT participated by giving lectures and laboratory exercises on laser technology.







October 13, 2016 Aachen – First Semester Tour
Orientation event by the Chair for Laser Technology LLT and Fraunhofer ILT for freshman students at the RWTH Aachen University. The chair and institute held a lecture introducing themselves and the basics of laser technology, and then gave the students a laboratory tour.

November 8, 2016, Aachen – 9th Companies' Night Career and Job Fair
Under the motto »DOCH«, Fraunhofer ILT presented itself at the 9th »Companies' Night«. More than 2000 university graduates, students and specialists were able to find out about the possibilities for their professional careers in the approximately 100 companies and institutes exhibiting at the fair. Previously, Fraunhofer ILT provided information on career entry and career opportunities at its location in Aachen as part of its broad-based and cross-media personnel marketing campaign, »DOCH«. One highlight of the campaign was the information event from November 16 to 17, 2016 at the Mensa Academica in Aachen.

November 16 - 17, 2016, Aachen – DOCH. Orientation event with improvisational theater in the foyer of the Mensa Academica in Aachen
From November 16 to 17, 2016, employees of Fraunhofer ILT and other Fraunhofer Institutes talked with students of natural and engineering sciences in personal discussions on the various entry and career opportunities in Aachen. In a creative and spontaneous manner, the actors of an improvisational theater conveyed the values of the Fraunhofer-Gesellschaft as an employer.

December 6, 2016, Aachen – 29th bonding Career Networking Fair
Also in 2016, Fraunhofer ILT presented itself at the largest student-organized job fair in Germany – the 29th bonding, a company networking fair. In addition to 300 other exhibitors, Fraunhofer ILT informed graduates from engineering, business and natural sciences in personal talks about entry and career opportunities at the institute on December 6, 2016.

TRADE FAIRS

SPIE Photonics West
February 13 - 18, 2016, San Francisco, USA
International Trade Fair for Optics and Photonics
Represented at the joint stand of the Federal Republic of Germany, Fraunhofer ILT presented exhibits on the topics of new laser beam sources and optical systems.

- 12 lectures by Fraunhofer ILT scientists

Battery Japan
March 3 - 4, 2016, Tokyo, Japan
9th International Rechargeable Battery Expo
Together with the Fraunhofer Battery Alliance, Fraunhofer ILT presented new technologies for laser-assisted battery manufacture.

- Highlights: laser welding of battery packs and ribbon bonding with laser radiation

JEC World Composites 2016
March 8 - 10, 2016, Paris, France
Composites Show & Conferences
Represented at Fraunhofer's joint stand, Fraunhofer ILT presented laser-based technologies for processing composite materials.

- Presentation of research results from the »HyBriLight« funded project, the EU-project »PMJoin« and »LaserInsert«, funded by the Federal Ministry for Economic Affairs and Energy

LASER World of PHOTONICS China
March 15 - 17, 2016, Shanghai, China
International Trade Fair for Optics and Photonics
Together with Laserfact GmbH, Fraunhofer ILT presented laser tools and applications for joining, separating, cladding and ablating with ultra-short pulse lasers.

- Highlight: four laser processing heads.

LOPEC 2016
April 6 - 7, 2016, Munich
Trade Fair and Conference for Printed Electronics
At the NRW booth, Fraunhofer ILT, together with the COPT NRW, presented laser innovations for printed and organic electronics as well as procedures for the laser structuring of flexible solar cells.

Medtec Europe
April 12 - 14, 2016, Stuttgart
Fraunhofer ILT presented new solutions from the laser-based medical technology at the joint Fraunhofer stand.

- Highlight: »AnaLighter«, a microchip-based fluorescence activated cell sorter »µFACS«

Control
April 26 - 29, 2016, Stuttgart
30th International Trade Fair for Quality Assurance
Fraunhofer ILT presented the interferometric sensor »bd-2« for thickness measurements on paper and cardboard sheets.

ILA Berlin Air Show 2016
June 1 - 4, 2016, Berlin
Fraunhofer ILT was represented on the joint stand of the Fraunhofer Space Alliance.

- Topics: diode-laser pumping modules for satellite-based open-area telecommunication, research results from the EU project »AMAZE«

Optatec
June 7 - 9, 2016, Frankfurt
13th International Trade Fair for Optical Technologies, Components and Systems
Fraunhofer ILT presented project results and demonstrator models from the fields of laser processing of glass optics and packaging at the joint Fraunhofer stand.

- Highlight: software »freeformOPT«, with which individual free-form optics can be calculated

Rapid.Tech
June 14 - 16, 2016, Erfurt
The Aachen Center for 3D Printing, a joint project of the FH Aachen University of Applied Sciences and Fraunhofer ILT, presented the »FabBus« of FH Aachen, a double-decker bus with fully equipped design and training facilities at various 3D printers for polymers.

1 Big crowds at the 9th »Companies' Night« in Aachen.
2 Laser-based solutions on lightweight construction at the JEC Composite in Paris.

3 Keen interest in the presentation of Martin Traub (left) and Oliver Fitzau (right) at the Fraunhofer Space Alliance at the ILA Berlin Air Show.

ICALEO
October 16 - 20, 2016, San Diego, USA
35th International Congress on Applications of Lasers & Electro-Optics

Fraunhofer ILT participated in the ICALEO 2016 with 12 lectures and was also represented at the vendor session as an exhibitor.

ICSO 2016
October 18 - 21, 2016, Biarritz, France
International Conference on Space Optics

Fraunhofer ILT participated in the ICSO 2016 with four contributions and was represented at the joint stand of the Fraunhofer Space Alliance.

K – Trade Fair for Plastics and Rubber
October 19 - 26, 2016, Düsseldorf

Visitors were able to get information about innovative laser-based technologies from Fraunhofer ILT at the joint Fraunhofer booth.

- Highlight: presentation of the research results of the »HyBriLight« project, funded by the Federal Ministry of Education and Research

EuroBLECH
October 25 - 29, 2016, Hannover
24th International Sheet Metal Working Technology Exhibition

Fraunhofer ILT was represented at the joint Fraunhofer stand.

- Highlights: hot-formed B-pillar with local softening zones, separation of CFRP-metal composite materials, cutting, welding and cladding

COMPAMED
November 14 - 17, 2016, Düsseldorf
World Forum of Medicine and International Trade Fair

Fraunhofer ILT was represented at the joint IVAM stand, presenting the topics of laser welding, micro-machining, microtechnology, optical engineering, prototyping, rapid prototyping and laser-assisted wound healing. In addition, Fraunhofer ILT participated in the COMPAMED High-Tech Forum by IVAM.

formnext
November 15 - 18, 2016, Frankfurt
International Exhibition and Conference on Additive Technologies and Toolmaking

The highlight of the Fraunhofer ILT exhibition at the joint Fraunhofer stand was the first-time presentation of the low-cost SLM system of the GoetheLab of the FH Aachen University of Applied Sciences and Fraunhofer ILT.

- Further topics: laser polishing and laser welding

1 Dr. Dirk Petring with Dr. Yoshiharu Inaba, president and CEO of FANUC Corporation, and his delegation to EuroBLECH.

AWARDS AND PRIZES

Teaching Award for Prof. Reinhart Poprawe

Prof. Poprawe and his team of the Chair for Laser Technology LLT once again received the faculty's internal »Teaching Award of the Faculty of Mechanical Engineering«. The ceremony at RWTH Aachen University was held on November 8, 2016 in the Kármán Auditorium in Aachen.

Springorium Commemorative Coin

The Springorium Commemorative Coin is awarded by proRWTH – the development association of the RWTH Aachen University – to students who have passed their Diploma, Magister or Master's degree with distinction. Of the associate chairs of Fraunhofer ILT in 2016, Sarah Klein, Lukas Bahrenberg and Dennis Haasler were among the most distinguished. The commemorative coins are named after the councilor of commerce, Dr. Ing. E.h. Friedrich Springorium, who founded the Association of Friends of Aachen's University in 1918 and led it as head of the board until 1925.

Best Speaker Award for Ulrich Thombansen

The technical committee of the Metromeet Conference in Spain annually nominates speakers for their extraordinary abilities. In February 2016, ILT employee Ulrich Thombansen received the Best Speaker Award for his lecture »Laser-Based Equipment Assessment for Advanced Manufacturing in Europe«. The committee praised both the quality of the presentation as well as the applicability of the treated subject.

Poster Presentation Award

At the ICALEO 2016 in San Diego, Christoph Engelmann and Dennis Arntz were awarded 3rd Prize in the Poster Presentation Award Contest for their poster on the topic »Novel Process for Butt-Joined Plastic-Metal Hybrid Compounds«.

Prism Award for spin-off LightFab

In April 2013, Martin Hermans, Dr. Jens Gottmann and Jürgen Ortmann founded the spin-off LightFab from the Chair for Laser Technology LLT. At the SPIE Photonics West 2016 in San Francisco, LightFab was given the Prism Award. In the »Industrial Lasers« category, the conference awarded the prize for the »LightFab 3D Printer«, which uses the Selective Laser Etching process for the subtractive 3D printing of precision parts made of glass.

2 Hessian minister Tarek Al-Wazir (left) in conversation with Prof. Johannes Henrich Schleifenbaum (right) at the formnext in Frankfurt.

3 Dennis Arntz (right) at the presentation of the »Poster Presentation Award« at ICALEO.

FUNDING BODIES

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

GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

Bundesministerium für Wirtschaft und Energie

Die Landesregierung Nordrhein-Westfalen

EUROPÄISCHE UNION

EUROPÄISCHE UNION
Investition in unsere Zukunft
Europäischer Fonds für regionale Entwicklung

esa
European Space Agency

DFG Deutsche Forschungsgemeinschaft

IMPRINT

Editorial Staff
Dipl.-Phys. Axel Bauer (responsible)
Stefanie Flock
M.A. Petra Nolis

Design and Production
Dipl.-Des. Andrea Croll
www.andrea-croll.de

Picture Credits
Front page: RWTH Aachen University / Maximilian Vosshage

Print
Druckspektrum
Hirche-Kurth GbR, Aachen
www.druck-spektrum.de

Paper
This Annual Report was printed on environment-friendly, unchlorinated and acid-free bleached paper.

Contact
Dipl.-Phys. Axel Bauer
Telephone +49 241 8906-194
Fax +49 241 8906-121
axel.bauer@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
www.ilt.fraunhofer.de