Fraunhofer

ILT

FRAUNHOFER INSTITUTE FOR LASER TECHNOLOGY ILT

ANNUAL REPORT 2015

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FRAUNHOFER INSTITUTE
FOR LASER TECHNOLOGY
2015

Dear Reader, Dear Partners of Fraunhofer ILT,

The year 2015 has been labeled the International Year of Light. The UNESCO campaign of this name aims at strengthening how we perceive optical technologies in the different areas they can be used: in mobility, medicine, communication and production. Furthermore, the campaign should stimulate a great interest for the extent to which this technology can benefit society. At the Fraunhofer Institute for Laser Technology, we deal with optical technologies daily. Indeed, our fascination with laser technology is not only limited to a professional's point of view, but rather, as creative scientists and engineers, we first and foremost have a basic curiosity and enthusiasm for this technology. For many years, this fundamental belief has been reflected in our principles: »We are fascinated by the unique characteristics of laser light and the resulting diversity of its uses. We are excited by the possibility of setting international standards through technological excellence and implementing this technology for the first-time in the industry«. This credo has driven our employees for 30 years. In this respect, we could celebrate every year as a »Year of Light«.

In the three decades of its existence, Fraunhofer ILT has developed numerous innovations in close cooperation with our industrial partners: from first diode-laser applications for joining plastic via the development of high-power ultrashort pulse lasers for material processing all the way to Selective Laser Melting for making individualized metallic components.

What is the key to these successful innovations? Certainly, when the inventive process begins, laser experts place their creativity and expertise firmly in the foreground, but they are also attracted to solving a challenging task effectively. This fosters their curiosity, enthusiasm and will to implement a solution. But when the product managers, production experts and developers of our industrial partners start to continuously discuss and cooperate with each other, they create a catalytic action for a specific product or process development. Crucial here are the single-mindedness, teamwork, motivation and ultimately the resilience of the parties toward solving problems. When it is given sufficient free space without restrictive structures and processes, research can take different approaches within a reasonable time and with limited resources. Then, as implementing the product pays for the industrial partner and the market accepts a new development positively, an innovation has been created. In this respect we still see ourselves at Fraunhofer ILT as partner of innovators.

This year, our teams were also active on many innovative paths. Whether we worked in the micro or the macro world, this annual report presents you with many developments we are advancing together with our customers and 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,

Reinhart Poprawe

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 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 semiconductors and biology.

Under one roof, the Fraunhofer Institute for Laser Technology 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 user center of the Fraunhofer ILT, guest companies 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 ten companies use the advantages of the user center. 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 occupy an international top position in transferring laser technology to industrial application. We continually expand the knowledge base and know-how in our sector and make significant contributions to the ongoing development of science and technology. Working with our partners in industry, science and government, we create innovations on the basis of new beam sources and new applications.

Customers
The customers needs are the focus of our work. Discretion, fairness and a spirit of partnership are top priorities in our customer relationships. Our customers can rely on us. We tailor solutions and their cost-effective implementation to the demands and expectations of our customers, with the objective of creating a competitive advantage. We support industry's needs for new specialists and managerial staff through project-based partnerships with our customers. We want our customers to be satisfied because we want them to return.

Chances
We strategically expand our knowledge base across the network.

Facination Laser
The unique characteristics of laser light and the resulting diversity of applications, are a constant source of inspiration and fascination.

Staff
Teamwork between the individual and the group is the foundation of our success.

Strengths
Our broad spectrum of resources enables us to offer one-stop solutions.

Management Style
Cooperative, demanding and supportive. Knowing the value of our staff as individuals and the value of their know-how and their commitment forms the basis of our management philosophy. We involve our staff in the formulation of goals and the decision-making process. We place a high value on effective communication, goal-oriented and efficient work and clear decisions.

Position
We work within vertical structures, from research to application. Our expertise extends from beam source, machining and measuring techniques, to application, through to integration of systems into the customer's production line.

TECHNOLOGY FOCUS

LASER AND OPTICS

This 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.

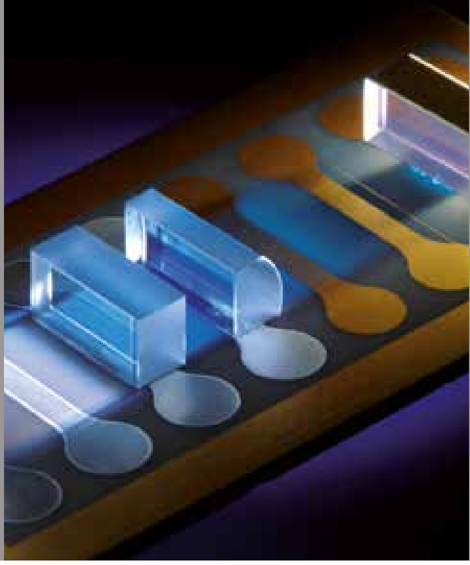
Furthermore, this technology field has a great deal of expertise in beam shaping and guiding, packaging of optical high power components and designing optical components. This field also specializes in dimensioning highly efficient free form optics. In general, the lasers and optics developed here can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

PRODUCTS AND SERVICES

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In-Volume Structuring	Dipl.-Phys. S. Nippgen Dr. A. Gillner	sebastian.nippgen@ilt.fraunhofer.de arnold.gillner@ilt.fraunhofer.de	Tel. -470 Tel. -148
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STRUCTURE OF THE INSTITUTE

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Prof. Dr. Peter Loosen

Vice Director

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Head of Administration

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Marketing and Communications

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QM Management

Dr. Bruno Weikl

IT Management

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Dr. Arnold Gillner

Ablation and Joining

Dr. Konrad Wissenbach

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. Hans Eggers, Bundesministerium für Bildung und Forschung BMBF
- Dr. Thomas Fehn, Jenoptik AG (until September 2015)
- Dr. Ulrich Hefter, Rofin-Sinar Laser GmbH
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- Dr. Ulrich Steegmüller, Osram Opto Semiconductors GmbH & Co. OHG
- Dr. Klaus Wallmeroth, TRUMPF Laser GmbH & Co. KG

The 30th Board of Trustees meeting was held on September 9, 2015 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. Vasvija Alagic MBA, Dipl.-Phys. A. Bauer, Dr. A. Gillner, Dipl.-Ing. H.-D. Hoffmann, Dr. I. Kelbassa, Prof. P. Loosen, Priv.-Doz. Dr. R. Noll, Dr. D. Petring, Prof. R. Poprawe, Prof. W. Schulz, B. Theisen, Dr. B. Weikl, Dr. K. Wissenbach.

Health & 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, M. Brankers, M.Sc. F. Eibl, R. Frömbgen, A. Hilgers, Dipl.-Ing. (FH) S. Jung, E. Neuroth, Prof. R. Poprawe, B. Theisen, F. Voigt, Dipl.-Ing. N. Wolf, Dr. R. Keul (Berufsgenossenschaftlicher Arbeitsmedizinischer Dienst BAD).

Science & 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, Dr. A. Olowinsky.

Workers' Council

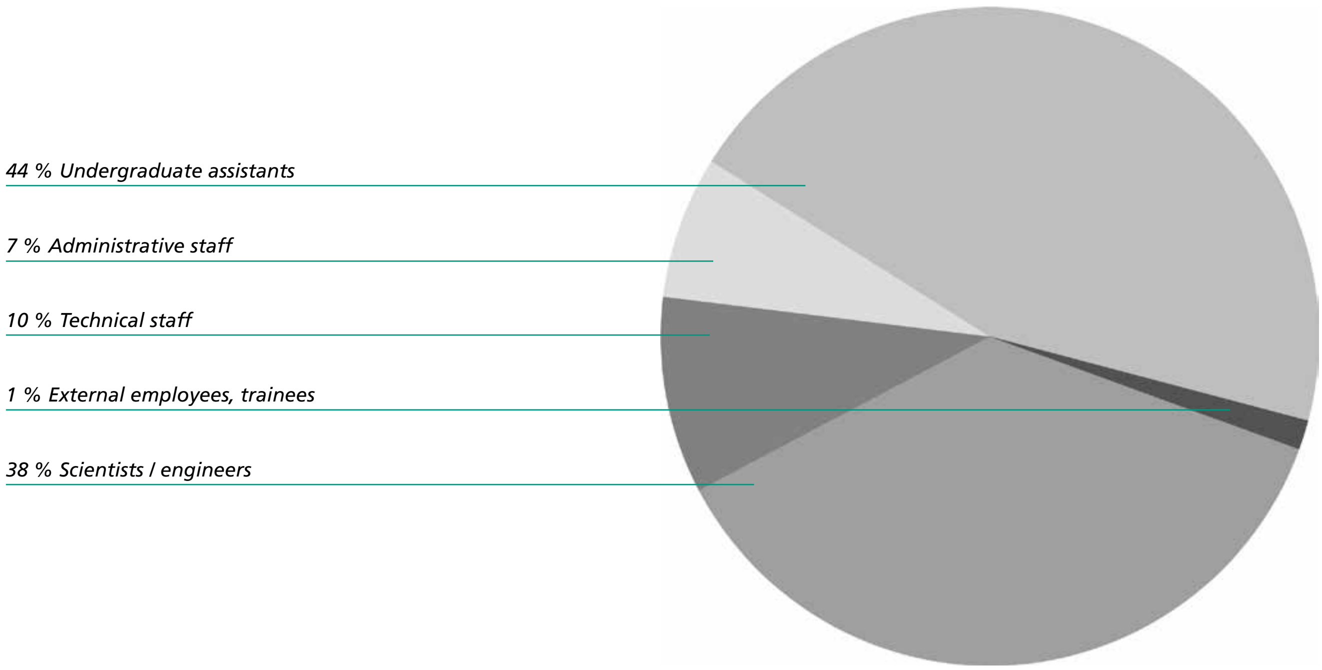
Since March 2003, the employees of Fraunhofer ILT and the cooperating university chairs have elected a workers' council.

FACTS AND FIGURES

EMPLOYEES

Employees at the Fraunhofer ILT 2015 *(Status: 31.12.2015)*	**number**
Personnel	**229**
- Scientists and engineers	158
- Technical staff	42
- Administrative staff	29
Other employees	**188**
- Undergraduate assistants	182
- External employees	3
- Trainees	3
Total number of employees at the Fraunhofer ILT	**417**

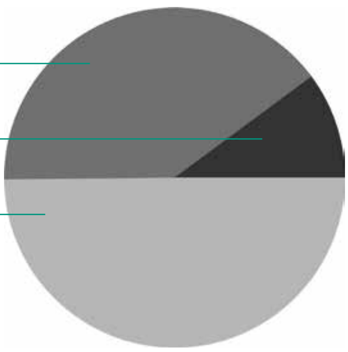
- 8 members of staff completed their doctorates.
- 86 undergraduates carried out their final year projects at the Fraunhofer ILT.



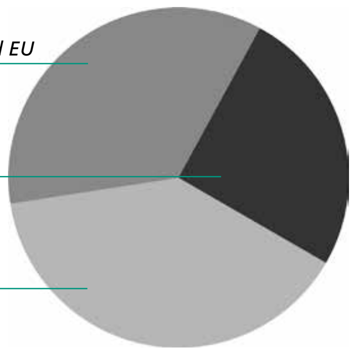
REVENUES AND EXPENSES

Expenses 2015	Mill €
- Staff costs	17,1
- Material costs	13,9
Expenses operating budget	**31,0**
Investments	**4,6**

Revenues 2015	Mill €
- Industrial revenues	13,3
- Additional financing from Federal Government, States and the EU	10,0
- Basic financing from the Fraunhofer-Gesellschaft	7,7
Revenues operating budget	**31,0**
Investment revenues from industry	**0,3**
Fraunhofer industry ρ_{Ind}	**43,9 %**



(100 % Operating budget und investments)

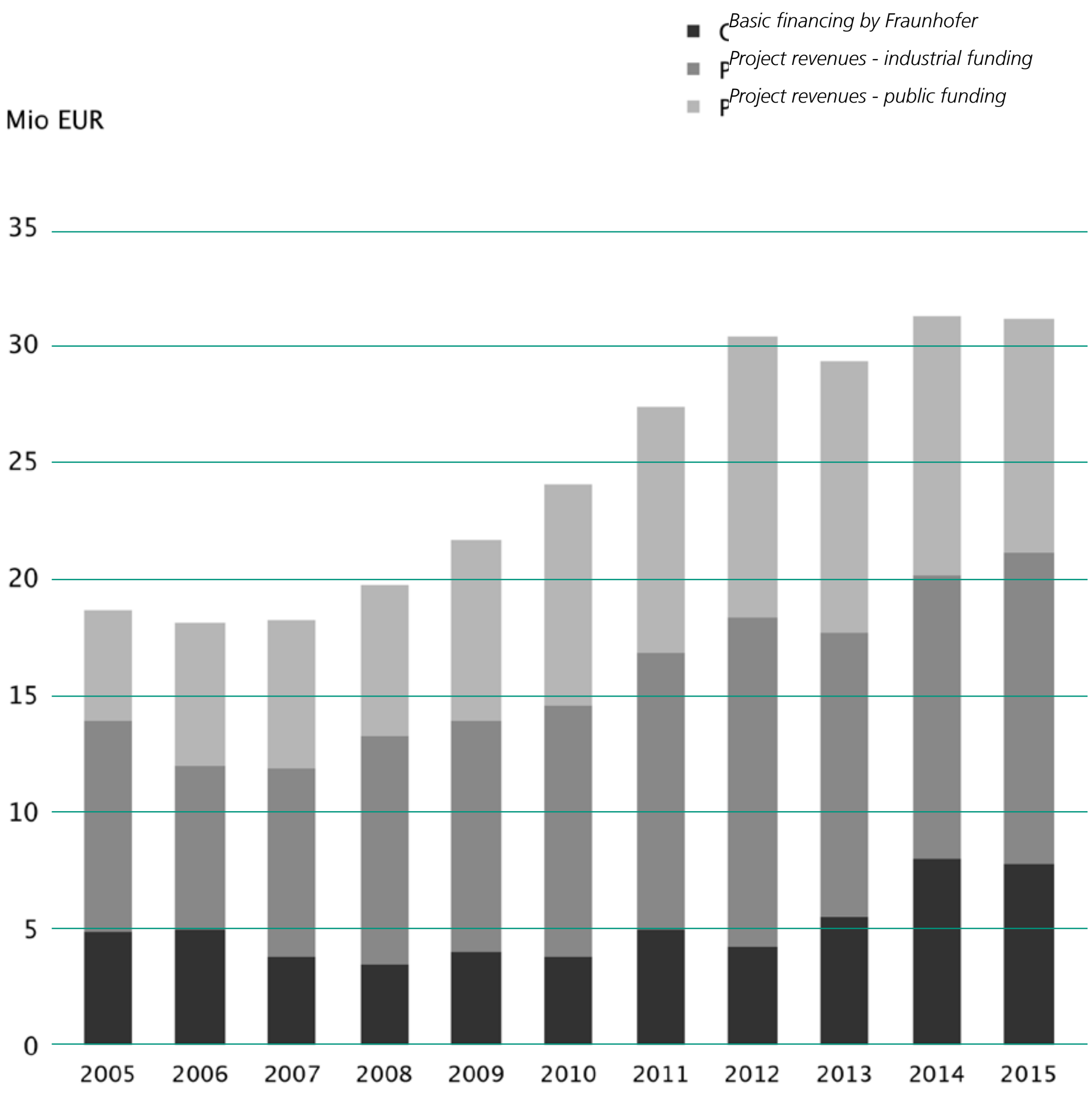


(100 % Operating budget)

FACTS AND FIGURES

BUDGET GROWTH

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



REFERENCES

As at December 2015. 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 guest status and with their own laboratries and offices at Fraunhofer ILT (special cooperation contracts)
- companies with subsidiaries at the RWTH Aachen Campus and cooperation with Fraunhofer ILT by the cluster »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.

During the implementation phase of new laser processes and products, companies can acquire ‘guest status’ at the Fraunhofer Institute for Laser Technology and use the equipment, infrastructure and know-how of the institute as well as install their own systems.

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:
- international subsidiaries of Fraunhofer ILT
- 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

FRAUNHOFER ILT ABROAD

USA – CENTER FOR LASER APPLICATIONS CLA

Up to the end of 2014, Fraunhofer's US laser activities have been realized by two separate centers, Fraunhofer Center for Laser Technology CLT and Fraunhofer Center for Coatings and Laser Applications (Laser Applications Division) CCL-L.

Due to the development of both businesses over the past years, a future complementary and joint approach in order to act as one Center for Laser Applications CLA under one roof as well as with just one single point of contact for the US market, center director Mr. Craig Bratt, has been launched on January 01, 2015. The activities of both former institutions has been consolidated under the flag of CLA, representing the accumulated expertise of Fraunhofer USA in lasers, beam guiding and shaping as well as primarily their applications such as additive manufacture, micro and macro material processing.

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FRANCE – COOPÉRATION LASER FRANCO-ALLEMANDE CLFA

Short Profile

At the Coopération Laser Franco-Allemande (CLFA) in Paris, the Fraunhofer Institute for Laser Technology 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. The CLFA is a member of the French association of laser manufacturers and users, the Club Laser & Procédés. In 2015 CLT participated in the joint Fraunhofer booth at the JEC Composite Show in Paris, organized the laser conference JNPLI in Bordeaux as well as the first German-French Lightweight Symposium in Nantes.

The goals of the CLFA are:
- 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
- Assembly of a European competence center for laser technology
- Increase of mobility and qualification level of employees

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.

The French partners' interests concentrate on:
- 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.

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FRAUNHOFER SYSTEM RESEARCH FOR ELECTROMOBILITY II

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

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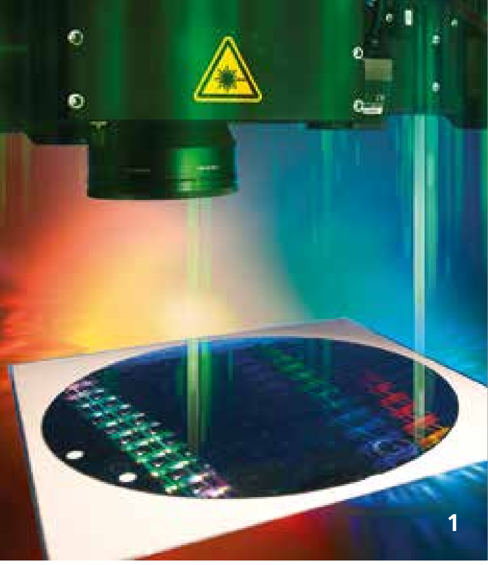
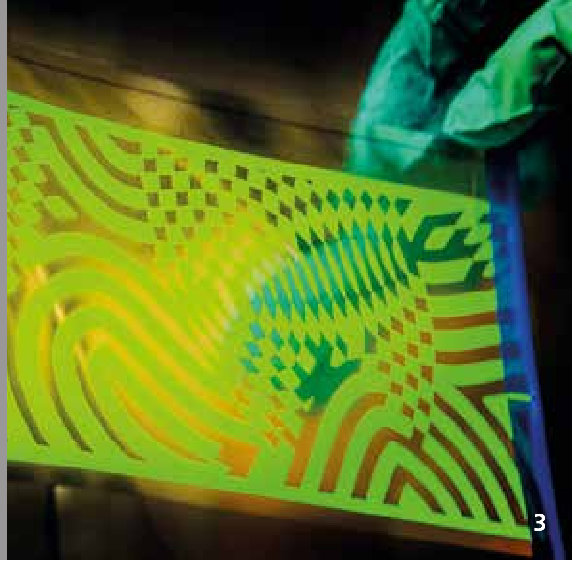
1 Lightweight power pack made out of a combination of high-strength steel and FRP.

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 on the requirements of different fields of application to answer actual and future challenges, especially in the fields of energy, environment, production, information and security. This market-oriented approach ensures an even wider range of services and creates synergetic effects for the benefit of our customers.

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

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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

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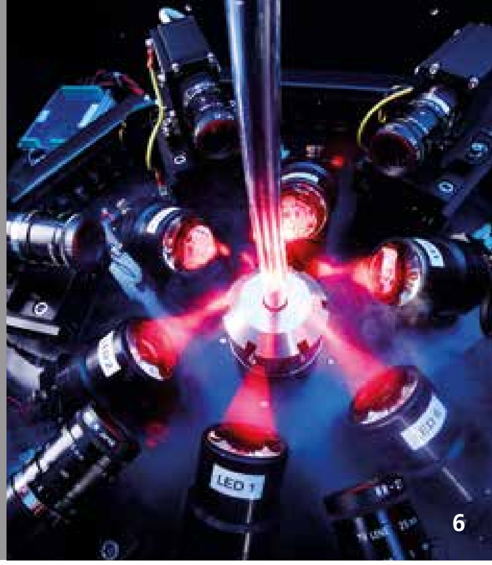

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Fraunhofer Institute for Organic Electronics, Electron Beam and Plasma Technology FEP
The Fraunhofer FEP works on innovative solutions in the fields of vacuum coating, surface treatment as well as organic semiconductors. The core competences electron 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 patents since 1985 the Fraunhofer Institute for Laser Technology 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 rapid 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 Institute for Material and Beam Technology 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 67 institutes and research units. The majority of the nearly 24,000 staff are qualified scientists and engineers, who work with an annual research budget of more than 2.1 billion euros. Of this sum, more than 1.8 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

JOINTLY SHAPING THE FUTURE

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

This structure particularly benefits up-and-coming young scientists and engineers. Knowledge of current industrial and scientific requirements in the optical technologies flows directly into the planning of the curriculum. Furthermore, undergraduates and postgraduate students can put their theoretical knowledge into practice through project work at the 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 three 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 in-volume structuring group is focused on developing production techniques for working transparent dielectrics using femtosecond laser light to manufacture micro-optical and micromechanical components. 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.

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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.

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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.

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LASER TECHNOLOGY AT RWTH AACHEN

Experimental Physics Study and Research Department Nano-Optics and Metamaterials

The »Nano-optics and metamaterials« junior professorship was created as part of the excellence initiative at the RWTH Aachen in 2008. With the addition of this thematic research area, Professor Thomas Taubner will expand the research activities in the field of physics to include new imaging techniques with nanometric spatial resolution.

This technology is based on so-called »field amplification« in metallic or dielectric nanostructures: locally amplified electric (light) fields enable innovative sensors to detect organic substances, but also support innovative imaging methods such as optical near-field microscopy, or super-lenses which far surpass the diffraction-limited resolution of conventional microscopes.

The research focuses on the mid-infrared spectral range: here infrared spectroscopy can provide chemical information on molecular compounds, the crystal structure of polar solids and the properties of charge-carriers.

This basic research at the RWTH supplements the ATTRACT junior-staff group at the Fraunhofer ILT. This group, which is also headed up by Professor Taubner, is evaluating potential applications of new nano-optic concepts using laser technology.

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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.

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CLUSTER OF EXCELLENCE

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.

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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 km^2, 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. 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 19 clusters in Melaten and the Westbahnhof as well as upgrading the infrastructure, including the construction of a congress hall, library and hotels.


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Photonics Cluster

The relevant industry frontline themes will be tackled jointly in up to 19 clusters – focusing on production technology, power technology, automotive technology, ICT technology as well as materials technology.

More than 100 companies, including 18 international key players, together with 30 chairs at the RWTH Aachen University signed up to long-term collaboration at the RWTH Campus in Melaten. These eight to ten building complexes covering a gross area of 60,000 m² will be home to the following six clusters in the first phase:

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

The Photonics Cluster researches and develops processes to generate, shape and use light, particularly as a tool for industrial production. The first building complex of the Photonics Cluster includes 7,000 square meters of office and laboratory space in the immediate vicinity of the Fraunhofer Institute for Laser Technology ILT. The opening of the building has been taken place on April 28, 2016.

Prof. Dr. Reinhart Poprawe from Fraunhofer ILT and from the Chair for Laser Technology LLT at RWTH Aachen University is director of the Photonics Cluster.

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1 3D view of the »Photonics Cluster«, source: KPF, New York.

2 RWTH Aachen Campus II – Melaten, sketch: rha reicher haase + associierte, Aachen.

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

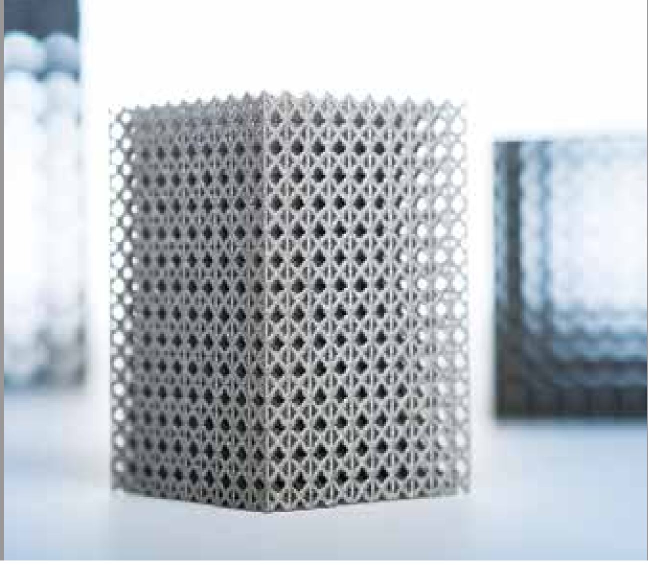
Digital photonic production goes far beyond laser-based additive manufacturing processes. New high-output ultrafast lasers, for example, can achieve very fast ablation almost regardless of material – allowing the finest of functional 3D structures to be produced down to the nanometer region. This new 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.

RESEARCH RESULTS 2015

Selected Research Results
of the Fraunhofer ILT

Note from Institute Director

We would like to point out that the publication of the following industry projects has been coordinated with our customers. In principle, industry projects are subject to the strictest obligation to maintain secrecy. We would like to take this time to thank our industrial partners for their willingness to have their reports listed published.

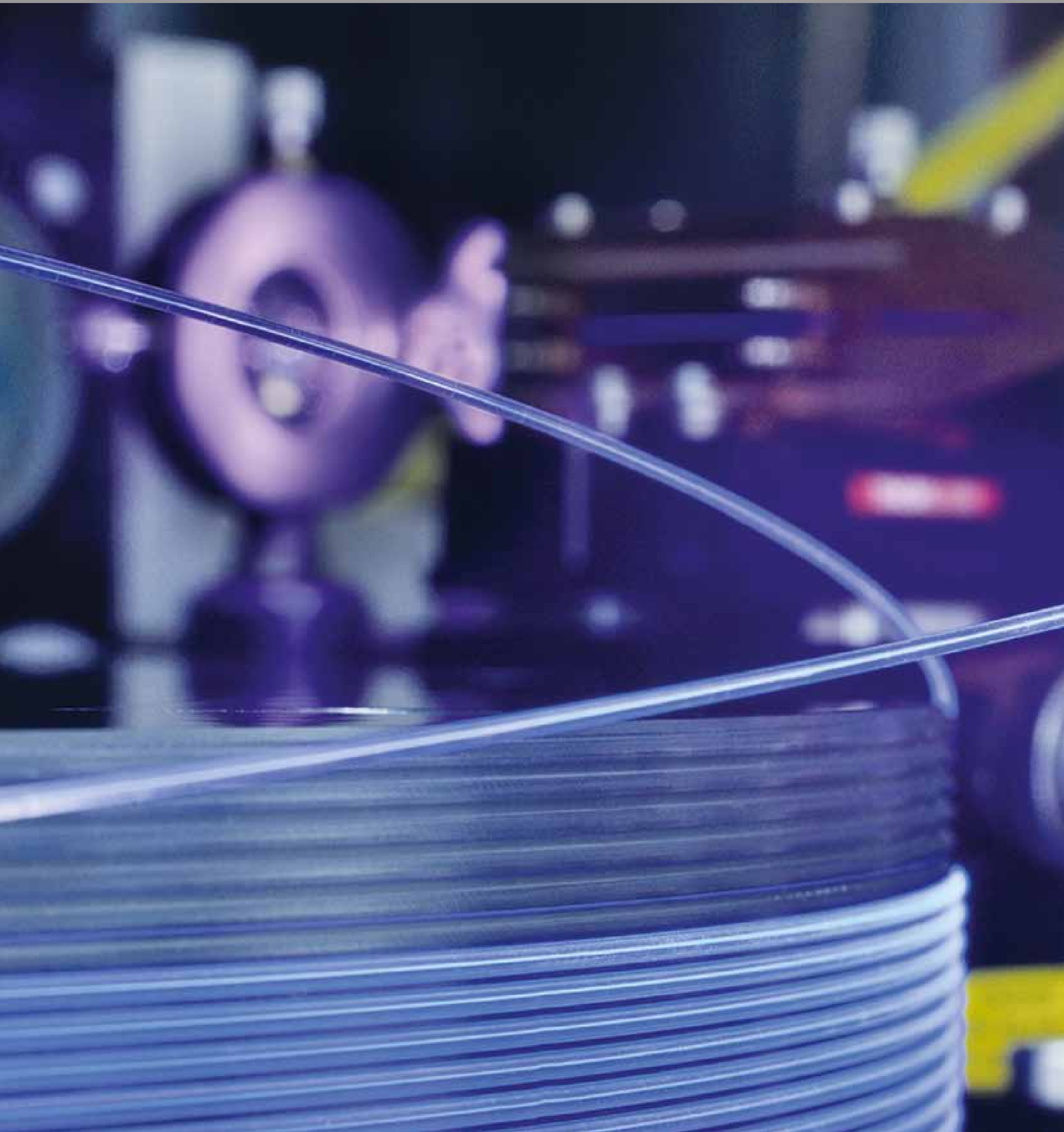
TECHNOLOGY FOCUS
LASERS AND OPTICS

This 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 pure research.

LASERS AND OPTICS



CONTENTS

Laser optical components in the optical parametric oscillator.

LASER OPTICS FOR HUMANITARIAN MINE CLEARING

Task

In many former war zones, mines, cluster munitions and unexploded bombs still lie in the ground long after conflicts ended. They constitute a high level of danger to the public and also severely restrict the agricultural use of these areas. Since many of these explosives are partially corroded and in an undefined state, defusing them manually poses a high risk.

Method

Laser radiation can be used to neutralize these explosive devices from a safe distance – without having to contact them. When the explosive sheathing is tapped, the housing can be opened and the charge ignited so that the explosives burn off and the combustion gases can escape without initiating a detonation.

To remotely focus a diffraction-limited laser beam, an optic was designed for the wavelength range around 1 µm, which can be focused on a spot diameter of less than 2 mm at a distance of 100 m. With this system, holes can be drilled having a few mm in diameter into the housing of anti-personnel mines and unexploded bombs.

1 Laboratory test on a steel plate with a thickness of 1.5 mm.

2 Prototype of the remote focusing optics on a tripod.

Result

In laboratory tests the effect of the laser radiation was examined on housing materials such as Bakelite and steel. Depending on the material and wall thickness, laser powers between about 200 W and 1000 W are required to produce openings having several millimeters in diameter within seconds (Figure 1).

The remote focusing optics was built as a laboratory prototype (Figure 2) and is now being characterized in terms of its optical imaging quality and the allowable laser power. Soon, thus, an optical system for testing of laser-based mine clearance will be ready.

Applications

The laser-based neutralization of mines and explosive devices justifies the effort whenever a manual evacuation is associated with a high risk. Moreover, the laser-assisted defragmenting of explosives can allow access to the ignition device or reduce the amount of detonatable material for the planned explosion.

The work was funded within the context of the EU project »Demining toolbox for humanitarian mine clearing (D-Box)« under the number »FP7-Security No. 284996«.

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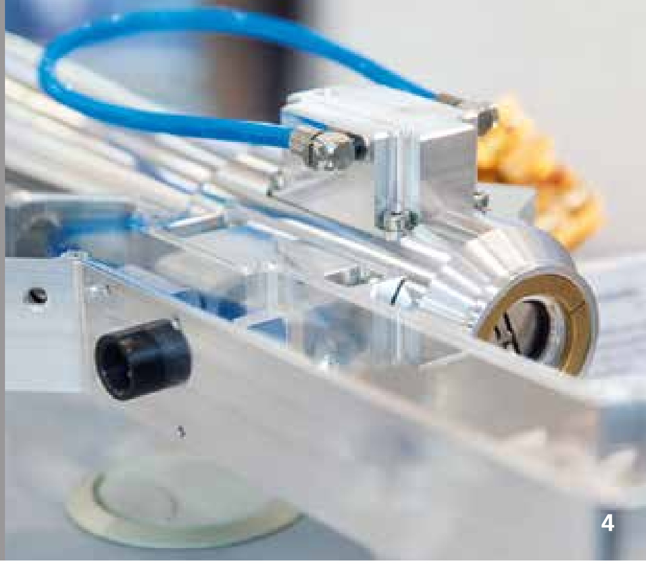

HIGH-POWER OPTICS MADE OF MONOCRYSTALLINE DIAMOND

Task

In laser processing, conventional optical materials are being pushed to their limits as power densities increase and as the demand for lightweight construction and material durability grows. The use of single-crystal synthetic CVD diamond as optics material provides unique potential for the future of high-power laser applications thanks to its extremely large refractive index, excellent thermal conductivity, high hardness and chemical resistance, including radiation resistance for short wavelengths. Poly-crystalline diamond has already become established for the long-wavelength range (i.e. for CO_2 lasers) as optical material, and while refractive spherical or aspherical optics from single-crystal diamond are suitable for the area around 1 µm, they are not yet commercially available.

Method and Results

As part of Fraunhofer's internal, market-oriented preliminary research – »Diamond4Optics« – Fraunhofer ILT, IAF and IPT are examining the potential of diamond as an optical material for high-power laser applications. To accomplish this, the institutes have generated single-crystal diamonds having dimensions up to 7 x 7 mm² with chemical vapor deposition (CVD) and processed them into spherical and aspherical optics for beam guiding and shaping. The synthetic diamonds exhibit optical quality, low birefringence and absorption and can be deposited in parallel with overall rates of up to 30 µm/h (60 substrates simultaneously). In operation at 2 kW laser power, first demonstrator optics show no focal position shift through a thermally induced refractive index gradient on account of the high thermal conductivity and low absorption. They also enable diffraction-limited focusing.

Applications

The project aims to develop a process chain from design through production, to operation and qualification of optical components made of single-crystal CVD diamond for high-power applications. By optimizing the diamond deposition process, Fraunhofer IAF has created fundamentally new opportunities for diamond-based applications. The single-crystal diamond lenses are aimed at the market of beam guidance systems for high-power lasers with short wavelengths (VIS to NIR). Due to their superior mechanical and optical material properties, the optics should find their way into applications for laser material processing, space technology, medical technology and metrology in the near future.

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3 Spherical lens made of monocrystalline diamond.

4 Measuring device for diamond substrates in high-performance tests.

FIBER-COUPLED DIODE-LASER MODULE WITH DENSE WAVELENGTH MULTIPLEXING

Task

Dense wavelength division multiplexing (DWDM) is an established technology for the simultaneous scaling of output power and radiance. Within the EU-funded research project »BRIDLE«, Fraunhofer ILT has developed concepts which can be used to implement and test compact modules in the medium power range, from 10 W to 100 W output power, from a fiber having a core diameter of 35 µm and a numerical aperture of 0.2.

Method

To be coupled into low-mode fibers, emitters are used whose stripe width and beam parameter product were reduced to 35 µm and 1.8 mm mrad compared to the current state of the art. Ultrasteep dielectric edge filters, which are characterized at Fraunhofer ILT, enable multiplexing at a wavelength spacing of 2.5 nm. The chirped wavelength stabilization of mini bars is carried out both internally and externally.

1 Diode laser module (without fiber coupling).

Result

The radiation of a diode laser bar, in which each single emitter is stabilized at chip level on its own wavelength, was superposed for the first time. The same optomechanical design was also used for simultaneous external stabilization and superposition. The loss mechanisms occurring were analyzed in detail. To date, an output power of 26 W has been achieved with two bars from a fiber with 35 µm core diameter. In this power range significantly more compact and robust systems can be constructed through the use of internally stabilized diode laser at lower costs than with the previously known concepts for DWDM. For further power scaling in the range of 50 W to 100 W, the losses incurred are reduced by optimizing the diode lasers, optical design and assembly, in addition, a polarization coupling is integrated into the setup.

Applications

High-brightness sources with medium output power can open up new fields of applications in the area of pumping broadband laser crystals and additive manufacturing (e.g. multi-spot SLM) in the future. In addition, by using fiber-integrated combiners, one can scale this concept for use in laser-beam welding.

The work was carried out as part of the EU project »BRIDLE« under the grant number 314719.

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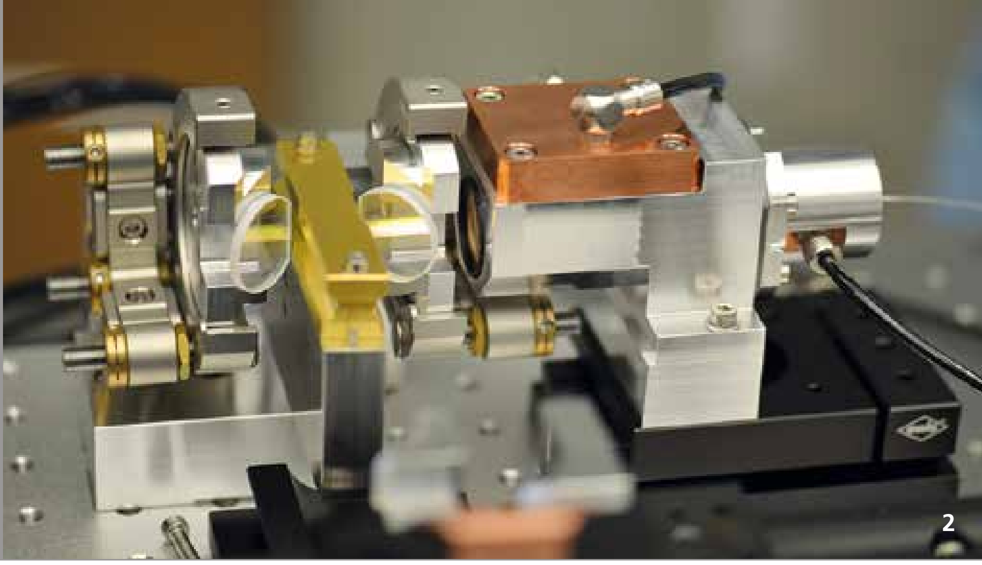

SCALABLE USP POWER AMPLIFIER BASED ON THE MULTIROD CONCEPT

Task

A linear laser amplifier should be developed for the output power range below 200 W and able to provide ultra-short pulses with pulse durations of about 700 fs with diffraction limited beam quality ($M^2 < 1.2$). So that inexpensive seed sources can be used, the amplification should be at least 100 or higher. Without CPA, pulse energies of several µJ should be achieved. Since Fraunhofer ILT's Yb:INNOSLAB platform reaches its maximum efficiency at laser powers above 200 W, an adapted amplifier concept needs to be developed.

Method

End-pumped rod lasers have become an established solution for ultrafast amplifiers. When Yb:YAG is used as an amplifier crystal, the average output power per rod is limited to about 20 - 40 W. The use of multiple sequential rod amplifiers is a proven concept that, however, becomes costly and complex in terms of component number and adjustment as the number of laser crystals increases. The MULTIROD concept solves this issue by using only one slab-shaped laser crystal comprising multiple rod-shaped pumped volumes and common pump optics for all pumped volumes. In this way, the number of optical components can be minimized and a substantial reduction in complexity can be achieved. In particular, for the amplifier beam path, Fraunhofer ILT offers different customized solutions.

Result

Up to seven fiber-coupled pump modules, each with 50 W output power at 940 nm, have been used in the demonstrator model. Amplification factors between 5 and 400 were reached. Depending on amplification, the optical-to-optical efficiency varies between 20 and 40 percent. At a pulse duration of one picosecond, a pulse energy of more than 10 µJ can be achieved at a B-integral of < 2 without CPA. The maximum demonstrated output power is 150 W. The laser beam is rotationally symmetric (ellipticity less than 5 percent). At an output power of 120 W, a beam quality of $M^2 < 1.12$ was measured. The setup is extremely compact and has no restrictions with respect to high repetition rates.

Applications

The MULTIROD amplifier makes it possible to scale the productivity of ultrafast processes for industrial applications.

The R&D projects underlying this report were commissioned by the Federal Ministry of Education and Research under grant numbers 13N11628 and 13N12715 as well as on behalf of Amplitude Systems and ROFIN-BAASEL Lasertech GmbH & Co. KG.

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2 Detailed view of the MULTIROD amplifier.

1 *Detailed view of the multi-pass arrangement of the disk amplifier.*

HYBRID 1.5 KW USP LASER: FIBER – INNOSLAB – THIN DISK

Task

Increasing the average output power of ultrashort pulse lasers (USP lasers) is one approach to meet the challenge of reaching economical process speeds in ultrashort pulse laser processing. In addition, fundamentally new possibilities are opened up by the combination of USP and high-speed machining.

Method

In an ytterbium-based USP laser, fiber oscillators and low power preamplifiers have been combined together with INNOSLAB amplifiers with high amplification and a thin disk amplifier with high average power.

A commercial USP fiber laser with 7 W output power and 400 fs pulse duration is amplified by two INNOSLAB amplifiers to 630 W output power and $M^2 = 1.2$. The subsequent disk amplifier makes it possible to increase the power into the multi-kW range. The amplification by the Yb:YAG thin disk – 5 percent per pass – requires a multiple folding of the seed beam to be amplified via the disk. The compact multi-pass arrangement developed allows 18 passages of the disk at a comparatively low overall beam path of 22 m. One rotation of the slightly elliptical (1:1.2) seed beam between each passage ensures that the inversion of the disk is spatially homogeneous.

Result

With the system described here, an average power of 1.5 kW was achieved in the initial tests; the pulse duration is 710 fs, the beam quality is $M^2 = 1.5 \times 2.0$ – this is the highest average power ever reached in an ultrashort pulse laser. At a pulse repetition rate of 40 MHz, this corresponds to a pulse energy of 37.5 µJ. The overall gain of the disk amplifier is currently 2.4 and is not limited by the pump power but only by the maximum gain per pass. With a double passage through the multi-pass arrangement, the power can theoretically be increased to > 3 kW. Fraunhofer ILT is currently preparing the necessary improvement of the optical insulation in the amplifier stages among each other.

Applications

Laser systems of the power class > 1 kW are suitable for composite materials without causing them great damage, removing dielectrics or blackening of metals and semiconductors by generating surface structures. The disk and the associated pump module were provided by the company TRUMPF Laser GmbH for the experiments.

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

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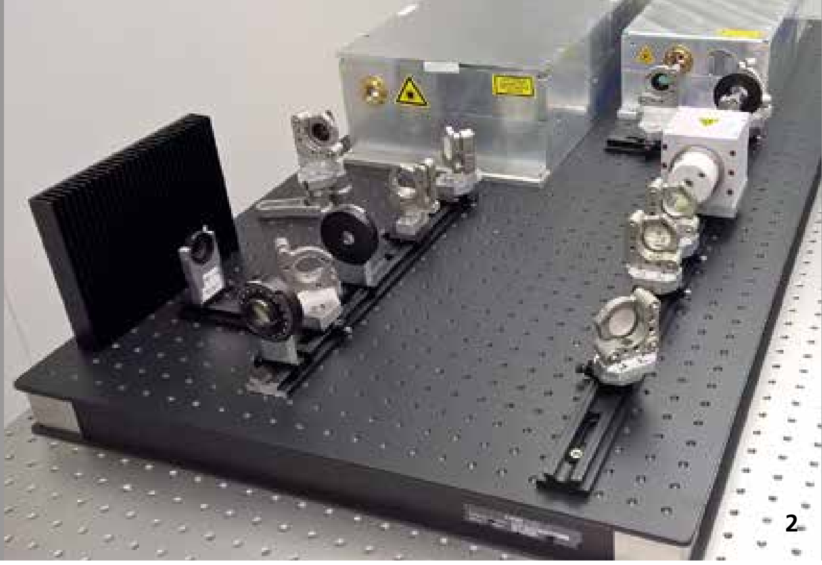

COMBINED PICO-/ NANOSECOND LASERS

Task

Metal surfaces structured with nanosecond and picosecond pulses are being examined as part of the European project »EMLACS«. This application aims to improve the adhesion of coatings applied by means of the »cold-spray method«, following the laser structuring, at economic area rates. In this process, solid particles of the applied material, about 10 - 50 µm in diameter, are accelerated at high speeds so that when they hit the surface they form a solid, positive connection. When the construction is completed, the flexible laser system should make it easier, above all, to compare structuring results and to find advantageous parameter ranges.

Method

One commercial ns und ps laser, each adapted to the task, is spatially superposed so that both beams rest coaxially and, subsequently, can use the same processing optics. The ps source has an output power of up to 80 W at a pulse repetition rate of 1 MHz and pulse energy of up to 80 µJ at a pulse duration of 12 ps. The ns source also has output power of up to 80 W, but a pulse repetition rate of 100 kHz and pulse energy of up to 0.8 mJ at an optional pulse duration of 1.5 ns or 8 ns. Before superposition, the optical radiation of the two sources is symmetrized by means of beam shaping and adapted to each other concerning propagation parameters.

Result

Fraunhofer ILT has made a flexible beam source available with superposed laser pulses of different pulse durations. In the basic configuration, both beams exhibit the same focus diameter. If necessary, the diameter may be selected differently for the two beams. The two radiation sources can both be operated simultaneously pulsed as well as with an adjustable temporal offset of the laser pulses.

Applications

This system is suitable for the systematic investigation of advantageous temporal and spatial parameter ranges in the structuring of surfaces. Since commercial laser platforms serve as a basis for further development, both the single-beam source as well as the entire system can be provided by the industrial partners directly or in cooperation with Fraunhofer ILT.

The R&D project underlying this report, »EMLACS«, was conducted on behalf of the European Union under grant number 606567.

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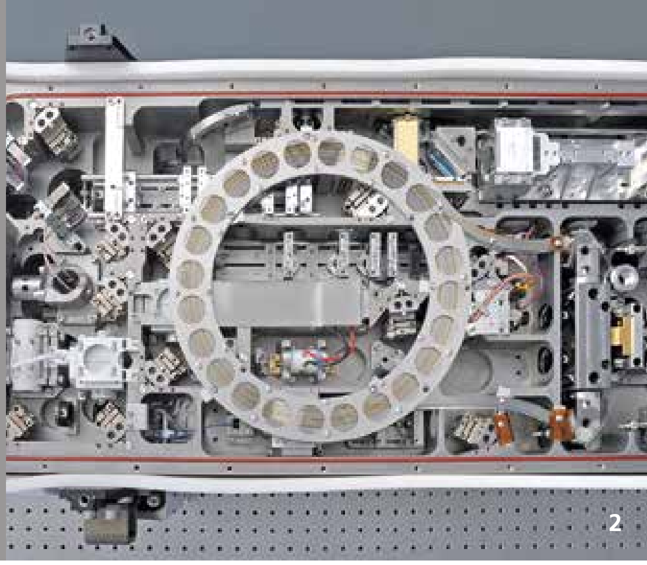
2 Ps-ns beam source.



QUALIFICATION OF A LIDAR BEAM SOURCE FOR OPERATION ON A HELICOPTER

Task

For several years, the company Open Grid Europe has been using the helicopter-based LIDAR system »CHARM®« to detect leaks in gas pipelines. Using the INNOSLAB concept, Fraunhofer ILT has designed and built a more powerful beam source with a ten-time higher pulse repetition rate and other advantageous properties – such as a double pulse mode adjustable over a wide range. The use of a helicopter requires not only a compact, weight-saving construction, but also high robustness, both in operation as well as during transport and storage. Several measurement campaigns served to prove that these properties are feasible.

Method

After the specified laser features were checked, a load-free continuous test was first carried out in the laboratory environment in which relevant temporal, spatial and energy parameters were monitored. Subsequently vibration and shock tests in all spatial axes were conducted with the beam source at a service provider. Operational and non-operational stress scenarios (e.g. excitation frequencies and bandwidths, shocks) were simulated and relevant laser parameters measured after or during the trial.

1 LIDAR beam source in test mode.

2 Detail of the LIDAR beam source.

Result

The beam source has successfully withstood all tests and shows no relevant changes in beam characteristics. Thus, the tests have demonstrated fundamental suitability for the intended use. After temperature tests have been conducted, the client will supplement the beam source with a frequency converter for methane detection and subsequently incorporate it into the CHARM-2 LIDAR system.

Applications

These kinds of beam sources and the construction technology used can be deployed for numerous LIDAR measurement tasks, for example, wind speed measurements, detection of water vapor, methane, CO_2 and emissions measurements from industrial plants and traffic. Generally, these applications require a mobile application, thereby causing the associated loads upon the beam source. The results are also relevant for the development of lasers for use in industry and medical technology.

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FLIGHT CAMPAIGN »CHARM-F«

Task

Within the »CHARM-F« project (CH_4 Airborne Remote Monitoring – Flugzeug), Fraunhofer ILT has developed two Nd:YAG pump lasers as well as their control and supply units for an airborne LIDAR system to measure the greenhouse gases CO_2 and CH_4. The pump lasers are used to drive the optical parametric converters from the Institute of Atmospheric Physics (DLR-IPA). The LIDAR system is designed specifically for use on the research aircraft HALO (High Altitude and Long Range Research Aircraft) to simultaneously measure both trace gases. The »CHARM-F« system can measure the amount of gas in a column between the aircraft and ground.

Method

Both pump sources contain a single-frequency oscillator that supplies double pulse pairs at a repetition rate of 50 Hz, each having a pulse duration of approximately 30 ns and a pulse energy of 8 mJ, at nearly diffraction limited beam quality. In both systems, they are amplified in an INNOSLAB stage to 75 mJ. In the CO_2 system, the pulses are amplified to 150 mJ in a second INNOSLAB stage. A separate rack houses the supply of the pump laser. The project partner DLR-IPA is responsible for the conversion in the measurement wavelength of 1645 nm for the CH_4 and 1572 nm for the CO_2 system as well as for the entire measuring system. Both lasers and rack are designed so that they meet the requirements for equipment for flight operations in the DLR jet.

Result

Under the first test flight campaign in spring 2015, both systems were used successfully to measure both gases over Poland, Italy and Germany in five flights in a total of 22 flight hours.

Applications

The CHARM-F system will be used on different climate research missions in the future. Such measurements are an important step towards a deployment of satellite-based systems, as they are currently being developed in the MERLIN project at Fraunhofer ILT. The technology can also, in principle, be adapted to determine other atmospheric parameters such as wind speed or the distribution of other trace gases. Alongside climate research, such parameters play an important role, for example, in the evaluation of wind farm areas, in industrial gas monitoring or in the measurement of turbines.

This work was conducted within the »CHARM-F« project of the Federal Ministry of Education and Research under the grant number 01LK0905B well as within the »NIRLI« project of the Federal Ministry for Economic Affairs and Energy under the grant number 50EE1228.

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3 Laser and supply rack in the HALO airplane.

4 Measurement flight with a view of the Hambach and Düren strip mines.

LASERS FOR SATELLITE-BASED LIDAR SYSTEMS

Task

In order to monitor climate parameters globally, satellite-borne LIDAR systems should be used in the future. For these systems, however, tailor-made laser beam sources are needed which ensure maintenance-free operation over several years despite vibration loads and temperature fluctuations during transport and operation.

Method

To meet the requirements, an optomechanical assembly method has been developed in which the optical components are soldered onto sub-units, which are bolted to the central support plate. The adjustment is carried out using solder, which is selectively melted with electrical current. A mounting portal is used to carry out this operation. The connection technology ensures high stability, avoids organic substances and their outgassing, and allows comfortable multiple adjustment or exchange of components. In order to demonstrate the feasibility, Fraunhofer ILT is currently building a technology demonstrator model as part of the »FULAS« project (Future Laser System).

Result

Both the laser oscillator as well as the laser amplifier unit could be successfully integrated in the FULAS demonstrator. The characteristics of the laser pulses meet or exceed previous laboratory studies. Before being integrated, optomechanical subunits were qualified in a thermal cycle test.

Applications

The successful operation of the FULAS demonstrator is an important building block for the development logic of similar systems. The laser beam source for the MERLIN instrument is currently being developed and is based on the FULAS platform. Within the scope of the Franco-German MERLIN mission, it is planned to develop a satellite to measure global distributions of the greenhouse gas methane. The launch is scheduled for 2020.

The work described here was carried out within the project »Optomech II/III« of the Federal Ministry of Economic Affairs and Energy under grant number 50EE0904 and 50EE1235 and within the ESA project »FULAS« under grant number COO-8/09/FF.

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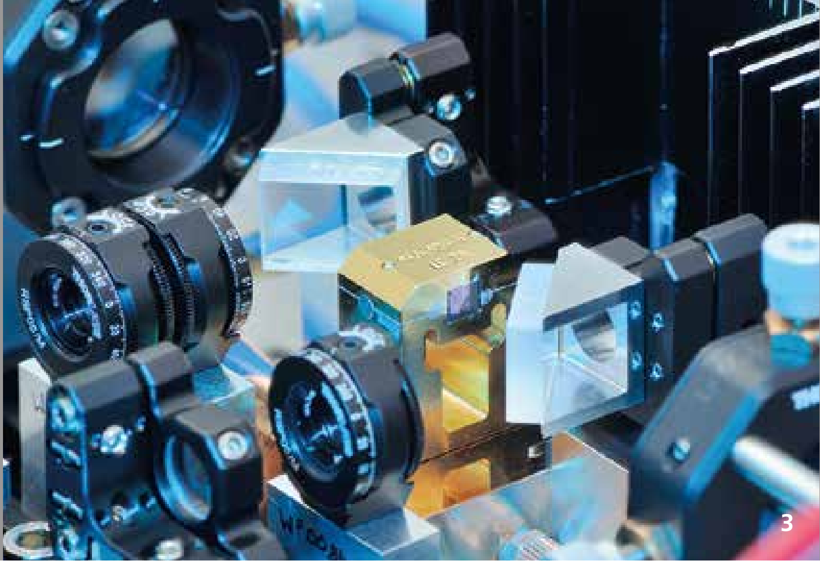
1 Preliminary design of MERLIN laser.

2 Assembly portal.



LAB DEMONSTRATOR OF A LIDAR BEAM SOURCE FOR »MERLIN«

Task

As part of the Franco-German climate mission »MERLIN«, a laser beam source is being designed to be used in a space-borne LIDAR system for the global mapping of atmospheric methane relevant for climatic processes in the atmosphere. In parallel with the development of the corresponding compact opto-mechanical setup, the optical concept should be validated by means of a laboratory demonstrator.

Method

The beam source consists of a diode-pumped laser oscillator and INNOSLAB amplifier based on Nd:YAG and a subsequent OPO for generating laser pulses with 9 mJ pulse energy at the measuring wavelength of 1645 nm. To generate pulses at longitudinal single-mode operation, both the OPO as well as the laser oscillator are »injection seeded« and actively length controlled. The setup was built with standard laboratory components and displays the current optical design of the later flight module in terms of all relevant design variables, such as resonator, pump spot size, etc.

Result

In the oscillator, laser pulses are generated with pulse energies of 5 mJ at a pulse duration of 16 ns, which are amplified in the INNOSLAB stage to 34 mJ. These are converted in the OPO into pulses with 11 mJ at 1645 nm. The required 9 mJ can already be produced from about 28 mJ of pump energy. The pulse duration is, then, 11 ns. The optical efficiency of the oscillator is 28 percent, the INNOSLAB amplifier 22 percent and the OPO 32 percent. To date, the overall setup has successfully completed an endurance test of 500 hours. Further tests shall soon follow.

Applications

Using flexible lab setups to verify optical parameters plays an important role in the risk management for developing complex prototypes. This is especially true for laser sources that are so tightly budgeted with respect to all optical parameters, such as pulse duration, pulse energy, efficiency, beam quality, spectral width as well as mass, volume and power consumption.
The laser platform used here is flexible and suitable for the generation of laser pulses in a broad parameter field.

The R&D project underlying this report, »MERLIN Phase B«, has been carried out on behalf of the Federal Ministry of Economic Affairs and Energy under grant number 50EP1301.

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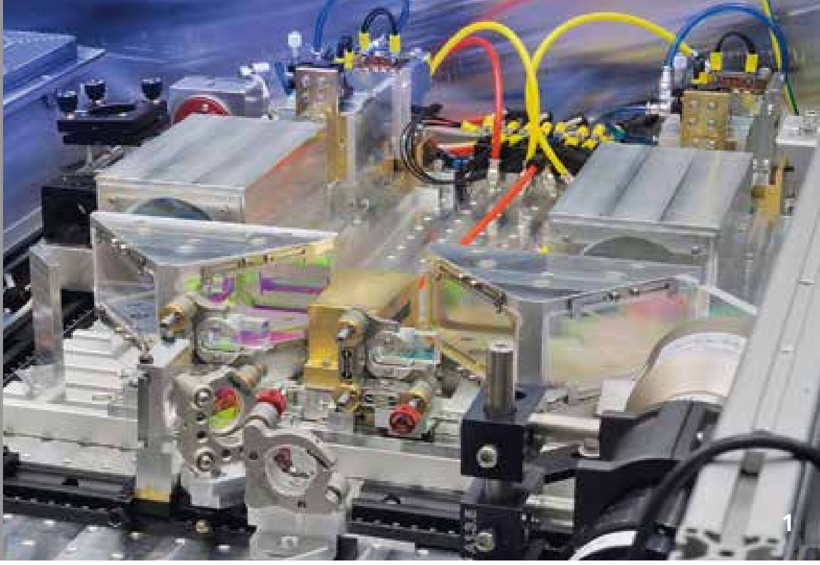
3 Detailed view of the MERLIN oscillator.



SCALING THE PULSE ENERGY OF INNOSLAB AMPLIFIERS

Task

When the LIDAR method is used to detect trace gases or measure wind speeds in the atmosphere, its signal-to-noise ratio is dependent on the available laser pulse energy. For satellite-borne measuring systems, pulse energies of several to more than 100 mJ are generally desirable, having repetition rates of 100 Hz and a wavelength adapted to the specific measuring task. To achieve spatially resolved measurements of the air column at an acceptable signal-to-noise ratio, a pulse energy of more than 400 mJ is required at a wavelength of 1 µm. So that such a beam source can be used on a satellite, it must be efficient and able to be built in a compact and robust design, while retaining high beam quality.

Method

Fraunhofer ILT has designed and constructed a demonstrator model of an oscillator-amplifier chain. Two INNOSLAB amplifier stages were used to achieve the desired total amplification and pulse energy. The institute built the demonstrator model based on its developments on highly stable optomechanical components for satellite use. The concept is compatible with the robust and compact »FULAS« platform (Future Laser System). ESA has funded its development as a platform for future satellite-borne lasers.

Result

Containing Nd:YAG as a laser crystal, the demonstrator model has generated longitudinal single-mode laser pulses with pulse energies of over 500 mJ and bandwidth-limited pulse durations of 30 ns at a 100 Hz pulse repetition rate and a wavelength of 1064 nm. The pulse energy is produced in only two INNOSLAB amplifier stages from 8 mJ pulse energy of the oscillator. The optical efficiency of the chain is over 22 percent. After passing the second amplifier, the beam is nearly diffraction limited in both directions at maximum pulse energy ($M^2 < 1.5$).

Applications

After the scalability of the platform FULAS has been successfully demonstrated, the beam source will be used as a pump source for an optical parametric oscillator with an output wavelength of 1.65 µm. The total system should be used as a testing laser on a measuring station to determine the laser-induced damage threshold of optical components at 1 µm and 1.65 µm.

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

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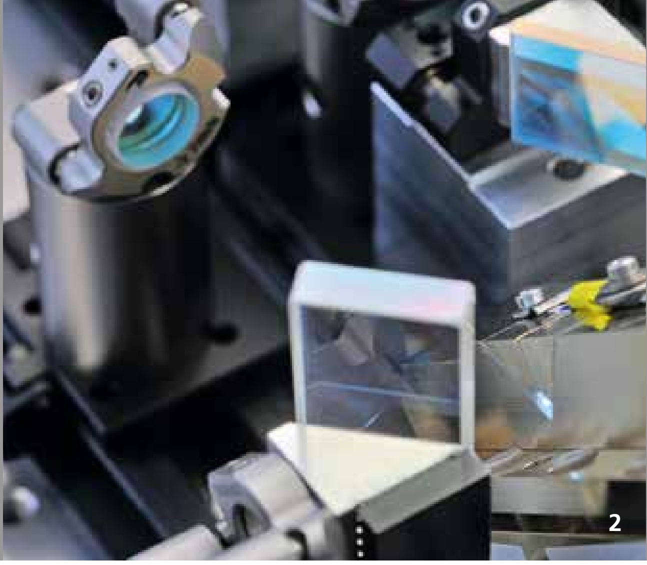
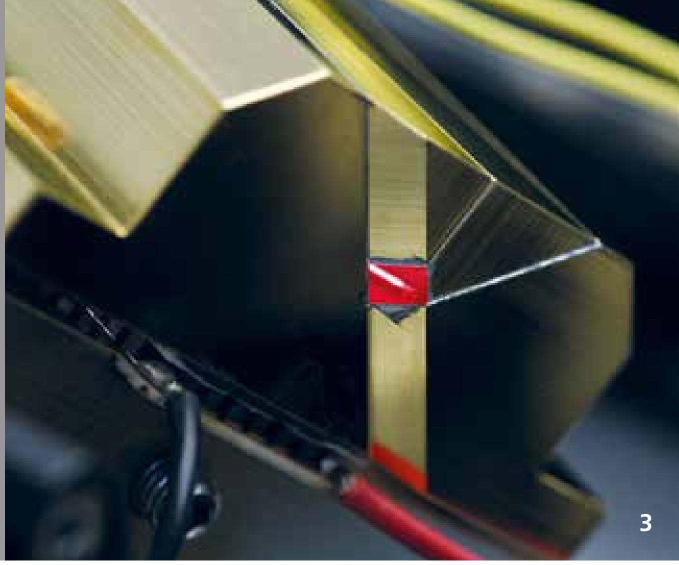
1 500 mJ INNOSLAB amplifier.





Q-SWITCHED SINGLE FREQUENCY DOUBLE PULSE OSCILLATOR AT 2 µm

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 medical technology 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 wavelength of 2.051 µm is being developed to detect CO_2 in the atmosphere by means of LIDAR methods.

Method

Based on INNOSLAB technology, an Ho:YLF MOPA system has been designed using numerical simulations to generate the required double pulses with 45 mJ and 15 mJ pulse energy and a repetition rate of 50 Hz. The system is pumped by a diode-pumped Tm:YLF laser. In the oscillator, pulses should be generated at a constant energy of 2 mJ. During design, particular attention was paid to the electro-optical efficiency and compliance of critical energy densities to prevent laser-induced damage of optics.

Result

As a pump source for the Ho:YLF oscillator, a Tm:YLF rod laser was installed, having a cw power of 15 W, which is tunable between 1870 nm and 1892 nm and whose power is limited by the pump diodes used. The Ho:YLF oscillator pumped in this way generates longitudinally single-mode, diffraction-limited double pulses with a spacing of 750 µs at a 50 Hz repetition rate, 2 mJ pulse energy and a pulse duration of 25 ns. The spectral bandwidth is 1 MHz (RMS) and the time-bandwidth product is bandwidth limited to about 0.44. For single pulses with a repetition rate of 100 Hz, 11 mJ can be achieved. Testing at high pulse energies shows that there is a great distance from the damage threshold at the operating point of 2 mJ.

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 region.

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

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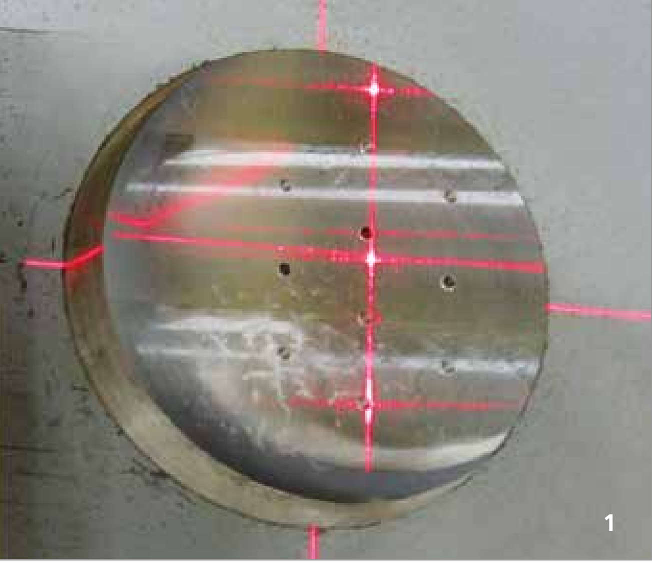
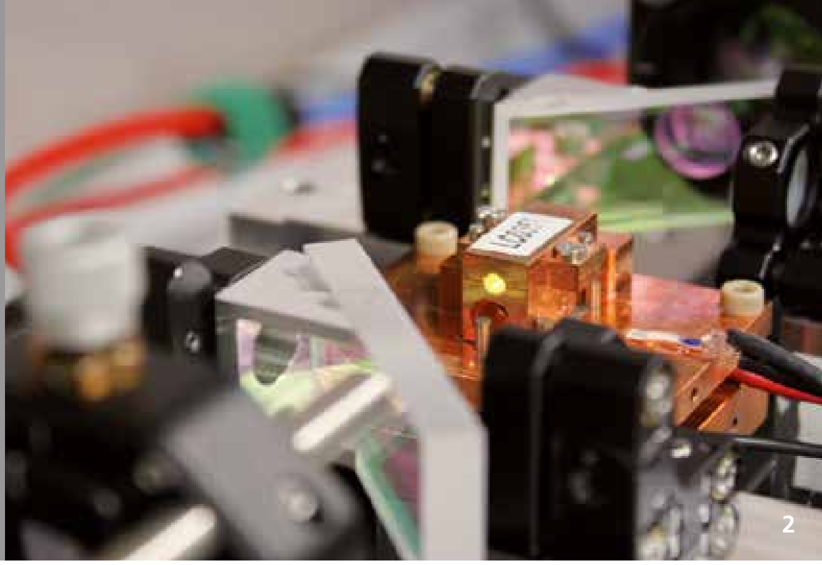
2 Tm:YLF rod laser.

3 Ho:YLF oscillator.





RADIATION TESTS ON TM^{3+}- AND HO^{3+}-DOPED FLUORIDE CRYSTALS

Task

Satellite-based LIDAR systems are suitable for the global and continuous measurement of CO_2 concentrations in the atmosphere. One possible design for the laser-beam source in such a system is a solid-state laser with an emission wavelength of 2051 nm based on Tm^{3+}- and Ho^{3+}-doped laser crystals of different stoichiometry. To date, however, there still have not been any published studies on these crystals regarding their radiation hardness against proton and gamma radiation.

Method

Different crystal samples from YLF and LLF with Tm^{3+}- and Ho^{3+}-doping and Ce^{3+}-codoping were irradiated with protons and gamma rays corresponding to a given mission scenario. The radiation-induced losses for the individual test items were determined in different ways: before and after radiation, transmission spectra of the specimens were measured. In addition, Fraunofer ILT built a test laser oscillator and all of the samples were used in this oscillator as a laser medium before and after irradiation. The laser thresholds and slope efficiencies before and after irradiation were measured for each specimen and radiation-induced losses calculated from them.

Result

Radiation-induced transmission losses in the magnitude of up to 7 percent/cm for Ho^{3+}-doped and 2 percent/cm for Tm^{3+}-doped specimens were measured in the spectral range < 1000 nm at ten times the mission dose. For the nominal mission dose and in the spectral region around 2 µm, no radiation-induced losses were measured within the measurement errors (detection limit about 0.6 percent/cm). The co-doping with Ce^{3+} also promotes the radiation hardness in Ho:LLF.

Applications

The results show that Tm^{3+}- and Ho^{3+}-doped YLF and LLF crystals can be used in radiation-intensive environments. In addition to aerospace, for example, they can also be considered for use in particle accelerators.

The project was funded by the European Space Agency (ESA).

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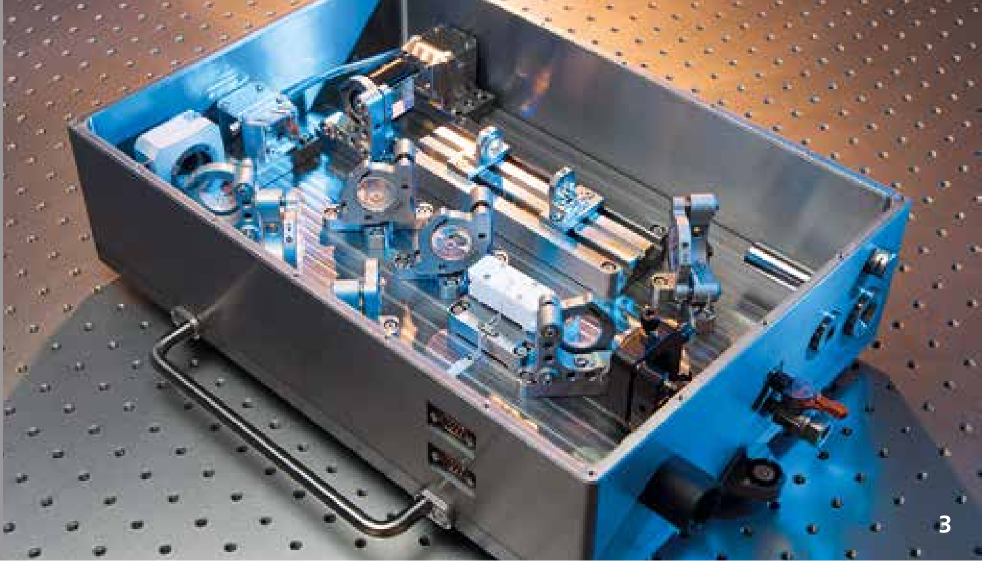
1 Specimen in test laser oscillator.

2 Setup for proton radiation.



HIGH-POWER SHORT PULSE LASER WITH ADDRESSABLE WAVELENGTHS IN THE IR

Task

Many technically and economically interesting classes of materials exhibit significantly increasing absorption in the SWIR range (λ = 1.5 to 3.5 µm). The number of innovative application ideas that would exploit this, however, faces a lack of sufficiently powerful short-pulse lasers in this wavelength range.

Method

Fraunhofer ILT has designed optical parametric generators (OPG) based on periodically poled nonlinear optical crystals for the generation of process-adapted laser wavelengths in the IRB. As pump lasers, established platforms have been used with an output wavelength of 1 µm. In the OPG the short-wave radiation of the laser driver is converted in a single pass through the nonlinear optical crystal in two long-wave radiation fields (signal and idler wave). By manipulating the so-called phase matching, e.g. by heating the nonlinear crystal, the wavelength pair of signal and idler wave can be tuned. The optical design of the converter can be adapted to pulse durations of femtoseconds to nanoseconds. The emission bandwidth of the converter, seeded with a continuous, low-power radiation field, can also be selectively tailored to specific application requirements.

Result

Fraunhofer ILT has achieved output power of up to over 20 W in the wavelength range between 1.6 µm and 3.0 µm with pulse durations between 900 fs and 1.5 ns based on OPG. Current projects address power scaling to more than 50 W. For use as a test system in various application tests, the experimental setup has been equipped with an independent, dustproof sealed box. Thanks to its variable lens sets, the converter can be adapted to the beam characteristics of different laser drivers, thus providing a wide range of different application parameters.

Applications

The solution presented here allows initial feasibility studies to be made for a wide range of applications of wavelength-flexible IRB lasers with short pulses. Moreover, it enables the commercial provision of innovative, process-optimized beam parameters in the IRB, based on established 1 µm laser platforms when adapted special sources are not yet available or their development is not economical due to a limited market volume.

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3 Converter box for application studies with IRB wavelengths.

PACKAGING OF LASER CRYSTALS

Task

Thanks to the steady development of solid-state lasers, the packaging of the individual components has to face ever new challenges. Laser crystals of different shapes and materials need to be fixed in a robust, tension-free and thermally stable manner.

Method

To connect laser crystals with specially adapted heat sinks, reflow soldering techniques established at Fraunhofer ILT are increasingly being used. Solder layers produced by PVD (physical vapor deposition) are used to bind the crystals with low thermal resistance and without tension. For particularly large dimensions, adapted soldering parameters – such as soaking times as well as heating and cooling rates – must initially be calculated.

Result

The reflow soldering technique is suitable for special bar-shaped or rectangular geometries, in addition to typical laser crystals (e.g. Nd:YAG, 5 mm x 5 mm x 10 mm). For example, Nd:YAG crystals having dimensions of 45 mm x 40 mm x 9 mm could be soldered. Measurements in the polarization meter showed negligible tensions in the interior of the crystal.

Applications

As part of the »Nirli« project (»NIR Laser Beam Source of High Pulse Energy as a Technology Demonstrator Model and LIDT Test Source«), a demonstrator model was built having two INNOSLAB amplifier stages. In the two-stage arrangement, the model generated slab pulse energies that have more than 500 mJ at a repetition rate of 100 Hz and at near-diffraction-limited beam quality.

The soldering process can be adapted to different crystal materials and geometries and applied especially in lasers of high average output power. The soldering process can be applied to other components such as mirrors, lenses or also nonlinear crystals.

The R&D project underlying this report was carried out on behalf of the Federal Ministry for Economic Affairs and Energy under grant number 50EE1228.

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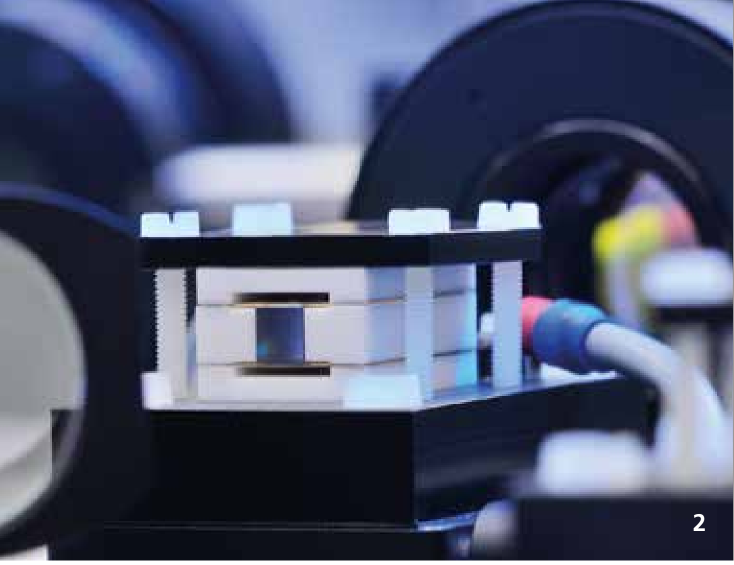
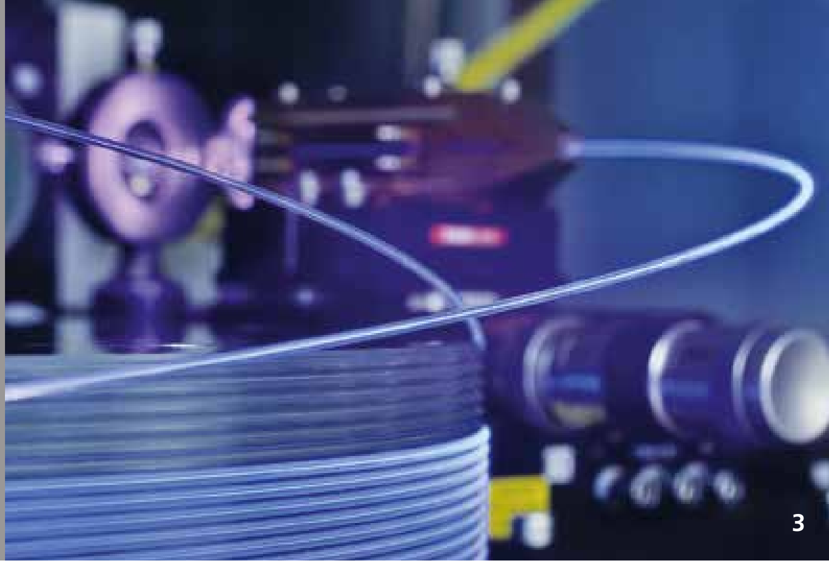
1 Soldered laser crystal.





POCKELS CELLS FOR USE IN HIGH-POWER PULSED FIBER LASERS

Task

Fraunhofer ILT has developed mechanically and thermally stable adhesive-free Pockels cells for use in satellite-based LIDAR systems for atmospheric research; in this system the crystals are soldered into its holder. In contrast to commercially available Pockels cells, this soldering technology does without the elastomeric contacts and adhesives, making this design suitable for high performance applications with average powers in the kilowatt range. Within a project conducted on behalf of Federal Ministry of Education and Research, Fraunhofer ILT is using these Pockels cells as Q-switches in a high-power pulsed fiber lasers.

Method

Due to the fiber resonator`s high amplification per pass, the Q-switches must exhibit a high contrast ratio in a repetition rate ranging from 10 to 100 kHz. Since the effective contrast ratio can be influenced by the piezoelectric oscillations of the Pockels cell crystal, an optical measuring station has been built which can test the static contrast ratio and the optical effect of the piezoelectric vibration of different Pockels cells.

Result

An extremely high contrast ratio of about 43 dB (1:20,000) could be measured in the voltage-free state. In the Pockels cells tested, a significant reduction in piezoelectric vibrations could be measured in the range of resonant frequencies as compared to commercially available Pockels cells, thanks to soldered connection of the crystals.

Applications

With the soldered Pockels cells, a Q-switched multimode fiber laser could be demonstrated with an average output power of 500 W and pulse durations of 100 ns.

This work was funded by the Federal Ministry of Education and Research under grant number 13N12930 and by the Federal Ministry for Economic Affairs and Energy under grant number 50EE1235.

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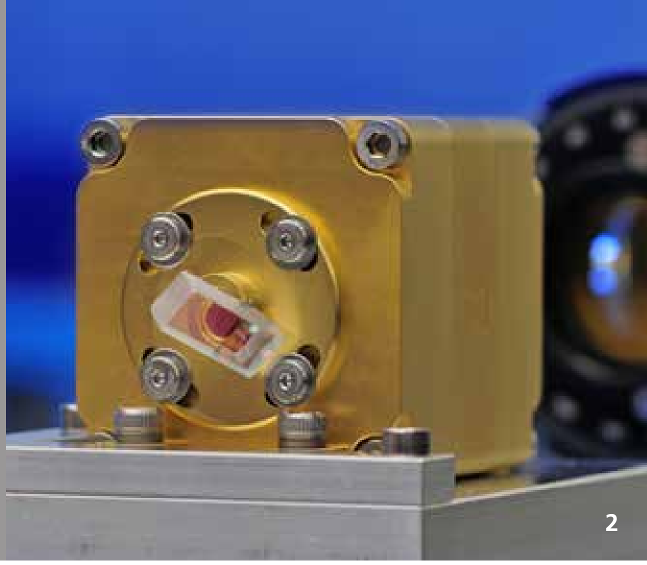
2 Soldered Pockels cell.
3 Active multimode fiber of the pulsed fiber laser.



FARADAY ISOLATOR FOR SPACE MISSIONS

Task

Laser systems deployed on satellites (e.g. in the field of atmospheric research) require optic components that are mechanically and thermally stable as well as free of emissions. The installation of TGG crystals in Faraday isolators is challenging due to mechanical stresses and resulting birefringence. Commercially available isolators are inappropriate due to low stability and poor outgassing behavior. For this reason, a soldering process is needed for the assembly of the TGG crystals. Before these crystals can be used in space, however, tests must prove that the components are suitable for use under the appropriate environmental conditions (vibrations of 4 g_{rms}, alternating thermal loads from -30 °C to +50 °C).

Method

A TGG crystal is soldered in a holder made of aluminum. In order to reduce the mechanical stresses in the crystal, a soft solder is used. Furthermore, the stresses are reduced by the geometry of the solder joint. In the same assembly step, a polarizer is soldered to the crystal holder. Subsequently, a second polarizer is mounted on the counterpart of the holder, also by means of solder. After that, the crystal holder and its counterpart can be placed in the adhesive-free magnetic field. The polarizers can be adjusted – to maximum isolation, or maximum transmission – via a screw connection.

1 Soldered optics of the Faraday isolator.

2 Faraday isolator in the measurement setup.

Result

The isolators achieve a degree of isolation of more than 34 dB and an insertion loss of less than 0.2 dB. Environmental tests on individual specimens do not show any changes. The soldered crystals have smaller mechanical stresses than do the bonded assemblies. To determine the potential of this soldering technology, however, long-term investigations will take place in a next step.

Applications

The Faraday isolators constructed using the method described here are suitable for, in addition to space applications, industrial solid-state laser systems in particular, where outgassing and laser-induced contamination play an important role. This is especially true for ultrashort pulsed and UV lasers.

Parts of the work were carried out within the R&D project »OPTOMECH III« on behalf of the Federal Ministry for Economic Affairs and Energy under grant number 50EE1235.

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TECHNOLOGY FOCUS
LASER MATERIAL PROCESSING

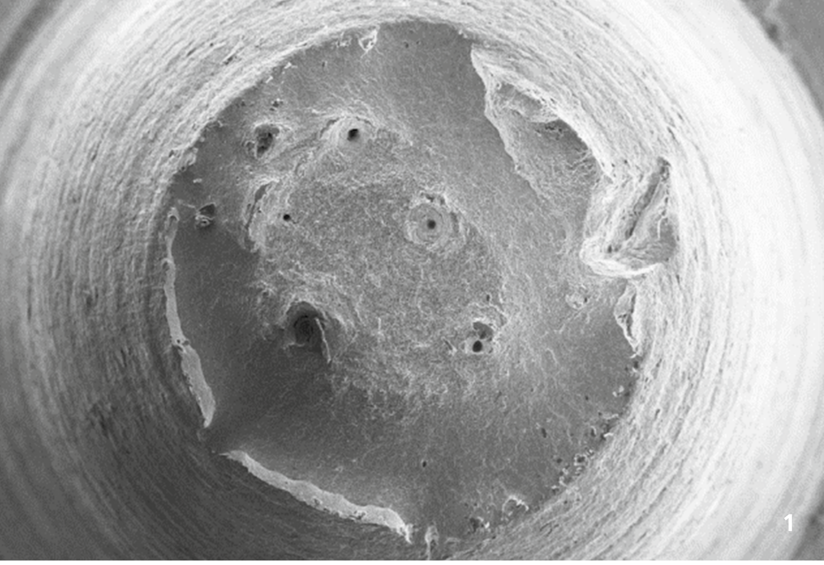
Among the many manufacturing processes in the technology field Laser Material Processing, cutting and joining in micro and macro technology as well as surface processes count among its most important. Whether it be laser cutting or laser welding, drilling or soldering, laser metal deposition or cleaning, 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.

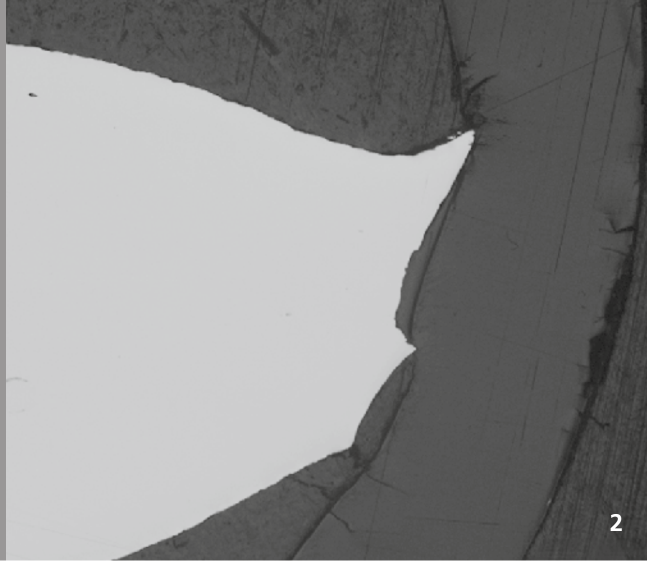
The strength of the technology field lies in its extensive know-how, which is tailored to customer requirements. In such a way hybrid and combination processes also result. Moreover, complete system solutions are offered in cooperation with a specialized network of partners. Special plants, plant modifications 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.

LASER MATERIAL PROCESSING

Laser cutting of CFRP.





PROCESSING OF CASE-HARDENED AND HEAT-TREATED STEEL BY MEANS OF SLM

Task

Selective Laser Melting (SLM) belongs to additive manufacturing technologies and has established itself in manufacturing technology thanks to its ability to produce highly complex geometries made of metallic materials. To expand the possible applications of SLM, researchers are focusing their priorities on, among others, increasing the efficiency and extending the range of materials that this method can process. Materials previously utilized with SLM include case-hardened steel 16MnCr5 and heat-treated steel 42CrMo4, both of which are used mainly in the automotive and mechanical engineering sectors. These are considered, however, susceptible to cracking and, thus, difficult to weld. The aim of the project described here is to identify stable process parameters so that these materials can be processed as free of cracks and defects as possible. This way, the advantages of this manufacturing process – such as geometrical freedom and topology optimization – can be exploited optimally.

Method

Fraunhofer ILT has examined the extent to which these two materials can be processed. To this end, it initially adapted the process-related parameters to a pre-heating strategy. The preheating system integrated in the plant engineering makes it possible to strongly reduce thermal gradients and stresses by preheating the materials to a temperature of about 500 °C. In a second step, the resulting structure will be investigated and the mechanical properties determined in a tensile test.

Result

Successful trials have demonstrated that the materials 16MnCr5 and 42CrMo4 can be processed free of defects on a laboratory scale. The adjustments to the process parameters allow a crack-free structure of specimens with a density of nearly 100 percent.

In further steps, suitable heat treatment will be determined and the preheating temperature reduced so as to transfer the parameters to conventional plants.

Applications

Thanks to the advantages of topology optimization and function integration, the process can be applied especially in the automotive and mechanical engineering sectors. Possible applications include the processing of transmission components, gears and camshafts.

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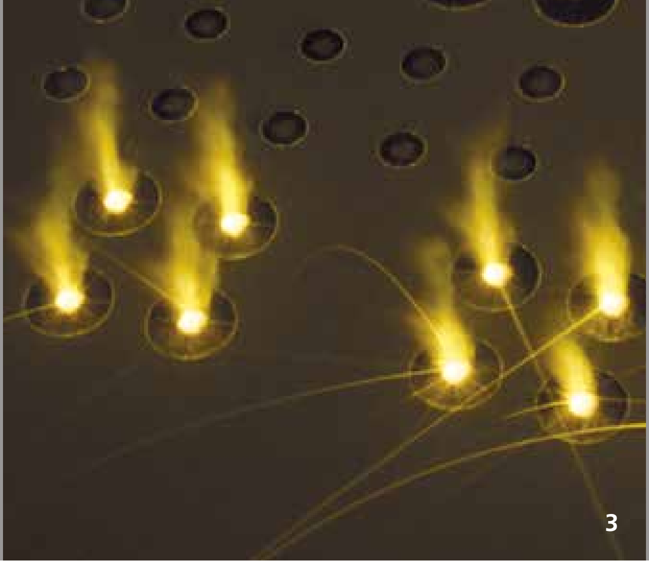
1 Fracture point of a tensile specimen out of 16MnCr5.

2 Micrograph of a tensile specimen out of 16MnCr5.



MANUFACTURE OF TOOLS FROM 1.2709 BY MEANS OF HIGH POWER SELECTIVE LASER MELTING – HP-SLM

Task

Thanks to its high mechanical strength and toughness, the maraging tool steel 1.2709 (X3NiCo-MoTi18-9-5) is commonly used in the plastics processing industry to produce molds with complex freeform surfaces and in small quantities. The additive manufacturing process Selective Laser Melting (SLM) makes it possible to produce such complex freeform surfaces of otherwise series-identical materials such as 1.2709 due to its virtually unlimited design freedom. However, there is a considerable need to increase the speed of SLM manufacturing.

Method

To accelerate the production of the tools made by SLM, Fraunhofer ILT has increased laser power ($P_L \leq 2$ kW) in combination with an adapted process management (skin-core strategy). For this purpose, the component is divided into a skin area and a core area; the core area is produced with an increased focus diameter (about 720 µm) in connection with laser powers of up to 2 kW. Thereby, the layer thickness (up to 180 µm) and the track pitch (to 600 µm) can both be increased, resulting in an increased build-up rate.

Result

In the manufacture of test specimens, it could be shown that the theoretical construction rate of V_{th} = 3 mm³/s with conventional process control at P_L = 300 W can be increased up to V_{th} = 18 mm³/s with the HP-SLM process control at P_L = 2 kW. In the next step, the process parameters thus identified were used to produce a mold for profile extrusion. The production times, which also contain delay times in comparison to the theoretical build-up rate, were compared between conventional SLM production (P_L = 300 W) and HP-SLM production. The HP-SLM process control at P_L = 1 kW enabled the production time to be reduced by 46 percent.

Applications

The work described here above took place within the scope of the Excellence Cluster »Integrative Production Technology for High-Wage Countries«. The results will be directly applied in the manufacture of functionally adapted extrusion tools for plastic injection molding or for profile extrusion.

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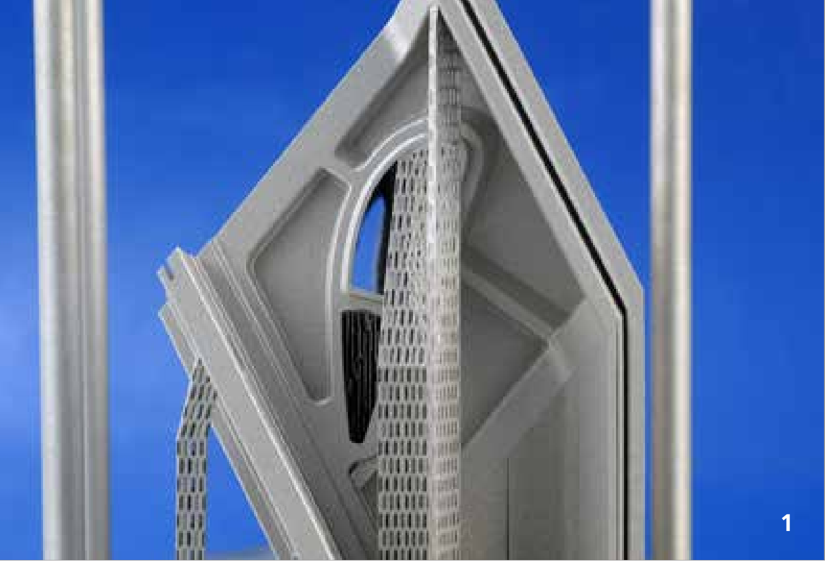
3 Photograph of the high power SLM process.

4 Profile extrusion tool manufactured by HP-SLM out of 1.2709.



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GUIDE VANE PROTOTYPES FOR PRODUCT DEVELOPMENT

Task

Turbomachinery manufacturers can profit greatly when true-to-form and near-net prototypes are made available quickly for the development of stationary gas turbine components. By promptly validating flow simulations under operating conditions or test runs of the production chain on the basis of such prototypes, development engineers can pursue different development approaches in parallel. This, in turn, can boost component performance and significantly shorten development time. As part of a bilateral project with Siemens AG, Fraunhofer ILT has investigated manufacturing guide vane prototypes with Selective Laser Melting (SLM). The project aims to create the most accurate image possible of the surfaces of blade and platforms conducting the hot gas and its internal cooling structure.

Method

The nickel-based superalloy Inconel® 718 is used to produce the guide vane prototypes with SLM because its thermo-physical properties are similar to the series material. For the production, two variants were considered: the monolithic production without (Figure 1) and the modular production in segments with a subsequent joining process (Figure 2). In both variants, the simplest possible procedure to derive defining surfaces for post-processing is considered when defining the build orientation of the components.

Guide vane out of Inconel® 718 ...

1 ... monolithically produced by SLM.

2 ... modularly prepared by high temperature brazing.

Result

The large residual stresses arising due to the component dimensions (> 200 mm) and wall thickness (> 10 mm) are accommodated both by suitable support concepts as well as an adapted component orientation. By means of the monolithic production, the hot gas conducting surfaces can be mapped, although non-removable support structures remain inside the blade. Since the blade and platforms are produced separately, the modular variant allows the most suitable orientation to be selected for the respective segments. This way, both the internal cooling structure of blades can be manufactured without supports and the hot gas conducting surfaces imaged as best possible. The segments may then be joined by means of high temperature brazing. Resulting deviations of hot gas conducting flow areas amount to approx. < 0.4 mm in both variants and, thus, meet the requirements.

Applications

The practices examined here and the results obtained can both be transferred to other components in turbomachinery as well as to other applications.

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INFLUENCE OF SHIELDING GAS GUIDANCE ON QUALITY OF COMPONENTS PRODUCED WITH SLM

Task

The shielding gas flow in SLM systems has to convey the smoke and splashes away from the zone where the laser and the material interact. If this does not occur, or only inadequately, the desired component density generally cannot be achieved. So far, however, it is not known which flow conditions are needed to optimize the SLM process. Hence, to better understand how the flow characteristics correlate with the resulting component quality, Fraunhofer ILT has visualized the flow in SLM systems. Based on the results, the flow of shielding gas can then be optimized.

Method

To visualize the flow in SLM systems, the institute has used two methods. Using Particle Image Velocimetry (PIV), it can make spatially resolved images of SLM process chambers, the protective gas flow amount and direction by using replicas. These results can be directly transferred to the plants and, thus, to the process due to the true-to-scale models. Furthermore, how the shielding gas flow influences the discharge of smoke during machining can be determined by the second method, high speed videography.

Result

It was shown that PIV can be used to map the shielding gas flow in SLM systems. In this way, it is now possible to obtain a spatially resolved image of the magnitude and direction of the flow of shielding gas in SLM systems. Moreover, it was demonstrated that high speed videography constitutes an appropriate tool for visualizing the impact of the inert gas flow on the smoke generated in the SLM process.

Applications

The results contribute to enhancing the process robustness and reproducibility in SLM. This can mainly be applied in the production of safety-related components in, for example, the aerospace industry.

The work has been carried out as part of the LuFo project »GenFly« under grant number 20W1305H.

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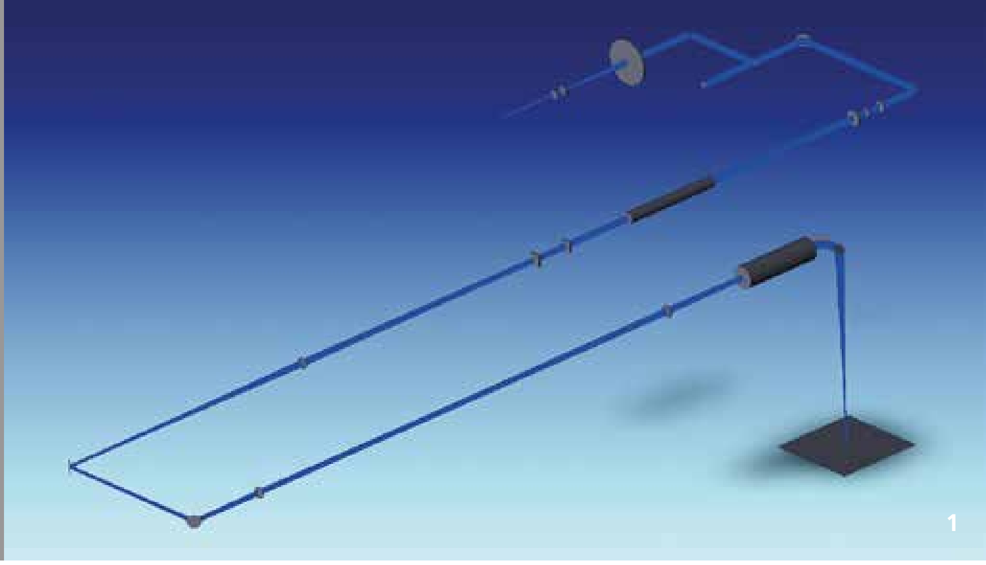
3 High speed recording of smoke removal from an SLM process chamber.



OPTICAL SYSTEM FOR HIGH-POWER LASER SINTERING

Task

The Selective Laser Sintering (SLS) of plastics has become established as an additive manufacturing process, in particular, for the production of complex prototypes and in small series. More and more, however, users are demanding both higher productivity through higher construction rates and a greater reproducibility of component properties. Therefore, a novel optical system for CO_2 laser radiation should be designed to improve both the productivity and consistency of SLS.

Method

By increasing the laser power as well as the laser beam diameter, Fraunhofer ILT aims to increase productivity. Thanks to the large laser beam diameter, large-volume core areas of the component can be exposed, thereby saving time (e.g. by increasing the layer thickness), which is analogous to the high-power Selective Laser Melting of metals. However, to maintain a high detail resolution and surface quality in the area of the component contour, the component contour should be exposed with a small beam diameter. To implement these different beam diameters, Fraunhofer ILT uses a 3D focusing system that allows for a dynamic and almost continuous variation of the beam diameter.

The reproducibility of the component properties shall be increased by homogenizing the temperature distribution in the exposure plane. This will be achieved both through the use of a homogenized intensity distribution and by the use of an acousto-optical modulator (AOM) so as to prevent power peaks when the laser is switched on.

Result

Fraunhofer ILT has completed the conceptual design of the optical system to adapt, both dynamically and variably, the beam diameter and the intensity distribution. Based on simulation results, the Gaussian beam diameter can be varied from 0.5 - 4 mm at laser powers of up to 600 W (instead of the usual 30 - 70 W). In addition, beam shaping optics can be integrated into the overall system to create homogenized intensity distributions (top hat or line distribution). In the next step, the system will be constructed and characterized in an experimental setup.

Applications

The optical system can be used in next generation high-power laser sintering systems.

The R&D project underlying this report has been carried out on behalf of the Federal Ministry of Education and Research under grant number 02PN2091.

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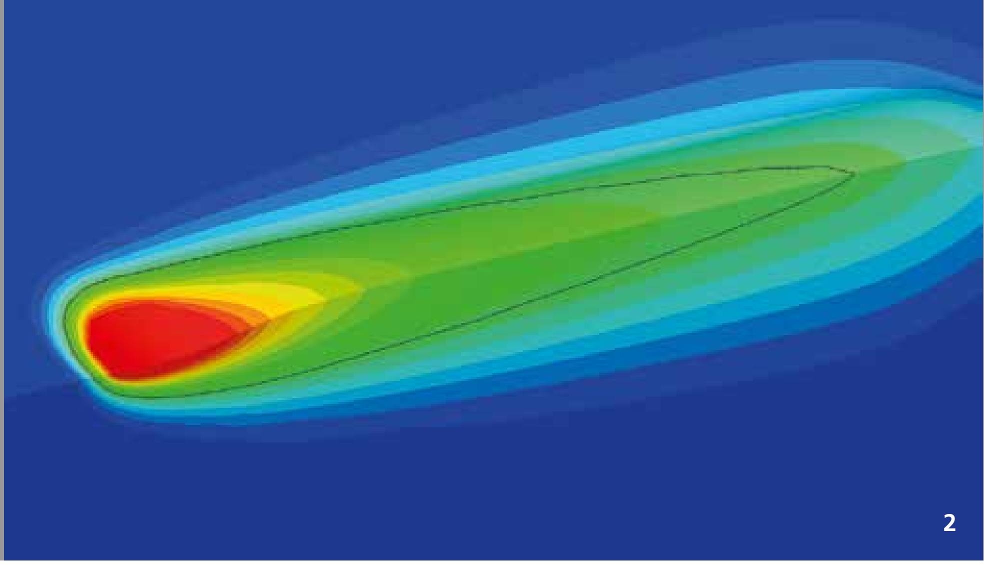
1 Schematics of the optical system beam path.



PROCESS SIMULATION FOR SELECTIVE LASER MELTING

Task

When the cause-and-effect relationships during Selective Laser Melting (SLM) need to be systematically analyzed, a Design of Experiment (DOE) is normally used. The experimental costs for a full-factorial DOE in SLM are very high due to the many, partly dependent parameters. In practice, the number of test points shall be reduced by two factors. First, specialized knowledge is used to reduce the DOE and to select test points more skillfully. Second, the (further) developed micro model for SLM serves to simulate the process for various parameter settings and to restrict the possible test points mathematically. Furthermore, the physical phenomena relevant to the process shall be identified and understood from the comparison between model and experiment. A cause-effect relationship shall be derived between the solidification conditions calculated with the model and the structure generated and microstructure resulting in the experiment.

Method

Mathematically, SLM constitutes a free boundary problem. To solve this problem, the transient heat conduction equation and the pressure balance (Young-Laplace) equation need to be integrated, while the vapor pressure and the mass balance of the powder layer melted per time interval are taken into account. In a separate model, Fraunhofer ILT has simulated the interaction of the laser radiation with the powder layer as they depend upon the measured particle size distribution. For these models, the track geometry and the temperature distribution (Figure 2) have been calculated and resolved in time as a function of process parameters and the thermo-physical properties of the materials.

Result

The advanced simulation tool is currently in the validation phase; since melt pool depths were calculated as too small, other physical effects have to be implemented. Once experiment and model agree well with each other, then DOEs will be reduced in size due to the input of the simulation.

Applications

The results obtained by these simulations can be employed to adapt the process control specific to material or component and/or to generate improved process understanding.

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2 Simulated track geometry and temperature distribution.

MODULAR BENCHMARK SOFTWARE FOR SELECTIVE LASER MELTING (SLM)

Task

Not only is it very important to accurately predict the process time needed to build a component and to allocate this time among its individual components to optimize existing processes, but also it is particularly critical to modify or even develop new systems for SLM. Moreover, such a predictive model can also be used to compare different plants in terms of economical component manufacturing. This project aims to develop modular, database-driven benchmark software to compare the cost-effectiveness of SLM systems, concepts and processes.

Method

The software consists of the modules »Plant«, »Material«, »Component«,»Operation« and »Process«. By means of Fraunhofer ILT's processor for the commercial data processing software »Magics« from the company Materialise, the component data are provided in a separate file format of the benchmark software. They can be combined to form a so-called construction job analogous to daily production. On the basis of the data stored in the modules »Plant«, »Material«, »Component« and »Operation«, all system-side processing steps – melting process, media (powder, gas), hardware (scanners, build platform) – are displayed in the module »Process«. The metrics belonging to them are also identified.

1 Use of modular benchmark software in practice.

This includes, for example, production times, component unit costs and the downtime of the plant, from which result acquisition and running costs, among others, the productivity or the degree of added value.

Result

At its current state of development, the software can calculate the duration of the process for commercial systems with a max. error of 3.5 percent. Furthermore, the software can identify component unit costs incl. the underlying cost structure (prorated equipment, personnel, area, energy, protective gas and material costs).

Applications

The software is currently used, in particular, to evaluate new plant concepts developed at Fraunhofer ILT. It can also be deployed, moreover, in bilateral consultation and development projects, e.g. to compare the production times of different component designs, as well as to analyze the general operating efficiency of additive manufacturing. Part of the work was funded by the Federal Ministry of Education and Research within the »Digital Photonic Production« Research Campus under grant number 13N13710.

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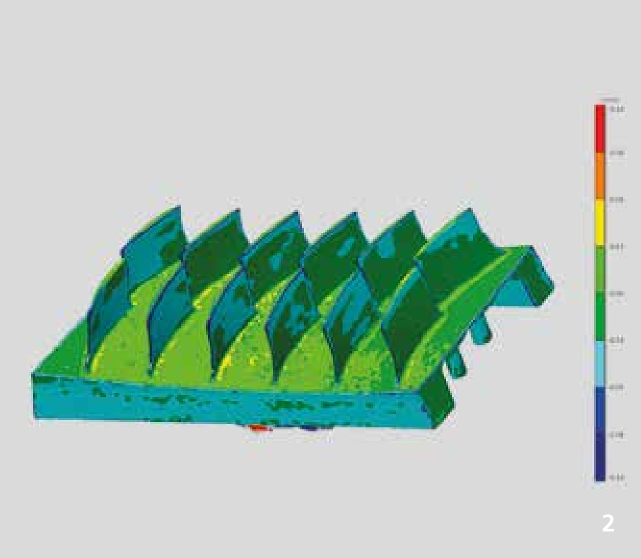

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3

POST-PROCESSING OF SLM-MANUFACTURED COMPONENTS

Task

Since it has a large amount of geometric freedom, the additive manufacturing process Selective Laser Melting (SLM) has great potential for use in the production of small to medium lot sizes for the turbomachinery sector. The characteristic high surface roughness ($R_a \geq 5$ µm) of SLM-manufactured components, however, is a limiting factor. So that the advantages of the process can be used in the turbomachinery industry, SLM must be combined with appropriate post-processing methods to meet the requirement of surface roughness ($\leq R_a$ 0.8 µm) and form accuracy. Therefore, the task is now to identify potential post-processing methods and to examine these in combination with SLM in terms of surface roughness and form accuracy.

Method

The first step consists in identifying potential processes for post-processing surfaces generated with SLM and hard to reach. In a second step, SLM shall be used to manufacture blade-shaped sample bodies. These were processed with the identified post-processing method. Before and after each post-processing, the sample body is measured and recorded. This way, by means of the company Alicona's »InfiniteFocus« device, based on focus-variation technology, both the input and the output roughness are determined; in addition, the ablation between the detected input and output geometry is compared by means of the company GOM's »ATOS Compact Scan 5M« device, based on light projection technology.

Result

The following post-processing methods – vibratory finishing, abrasive flow machining, plasma polishing and micro machining – were studied. All processes investigated reduce input roughness of about $R_a \approx 10$ µm to at least $R_a \leq 4$ µm. The smallest roughness, $R_a = 0.1$ ...0.3 µm, was achieved with the micro machining process. Here, a local ablation of 40 ± 20 µm was identified.

Applications

The current research on the subject of post-processing SLM-manufactured components addresses the turbomachinery sector, but can be extended to other sectors of mass production (e.g. the automotive industry).

The Fraunhofer Innovation Cluster »AdaM« was funded by the European Regional Development Fund (ERDF) »Investment in the Future«.

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2 False color image comparing measured input and output geometry during plasma polishing.

3 Post-processed guide vane cluster by means of micro machining.


1


2

LASER POLISHING SLM MANUFACTURED 3D COMPONENTS

Task

Due to its virtually unlimited design freedom, the additive manufacturing process Selective Laser Melting (SLM) can be used to produce complex and individual components of series-identical materials. However, since SLM generates components layer by layer in a powder bed, its components have, in comparison to those made with classic machining processes, high surface roughness (S_a about 10 - 30 µm). According to the current state of the art, therefore, it is often necessary, and expensive, to post-process the functional surfaces in order to improve the surface quality of the components.

Method

Within the scope of the European research project »AMAZE« (FP7-FoF.NMP.2012-4), Fraunhofer ILT has developed the laser polishing process for the finishing of components made of nickel-based alloy Inconel® 718 and manufactured with SLM. The roughness S_a of the surface after the SLM process was determined with »InfiniteFocus«, a device from the company Alicona and based on focus variation. The parameters needed for laser polishing were determined on cubic test specimens. To transfer the laser polishing results of the planar sides of the cubes to a 3D demonstrator, the institute developed strategies for working with non-perpendicular angles of incidence and for shaping edges. The roughness of the laser-polished surface was determined by the profile method.

Result

Initial laser polishing results on a component of an aircraft engine mount out of IN718 show that the surface roughness of the SLM surface can be reduced from S_a = 10 - 15 µm down to S_a = 0.25 µm. The area rate during laser polishing of the selected component geometry is 3.8 cm²/min. In the next step, the institute will conduct further research to reduce the surface roughness and increase the area rate as well as to adapt the strategy and parameters for small wall thicknesses.

Applications

In particular, the aerospace and turbomachinery sectors can profit from using SLM to produce components made out of IN718.

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1 Pylon brackets out of IN718 manufactured by means of SLM.

2 Laser-polished sub-segments of a pylon bracket out of IN718.

REDUCTION OF SURFACE ROUGHNESS OF SLM COMPONENTS BY MEANS OF MODULATED LASER RADIATION

Task

Before components made with SLM can be used in the industry, their surfaces usually require post-processing to reduce their roughness. The surface roughness depends not only on the SLM process itself, but also on the geometry of the component. The roughness of overhang areas is generally greater than of perpendicular constructed surfaces. For example, a surface roughness of Ra ≈ 15 µm is reached on components made of Inconel 718 built in layer thicknesses of 30 µm on vertical surfaces. In overhang areas, on the other hand, only a roughness of Ra ≥ 30 µm can be achieved despite adjusted parameters (downskin).

In order to efficiently finish complex SLM components, they need to have a minimal and homogeneously distributed surface roughness. By using modulated laser radiation, Fraunhofer ILT has been able to significantly reduce the surface roughness of small components (≤ 10 mm) in the Micro-SLM process. The project aims to identify parameters for the SLM process with scanning laser systems, with which the surface roughness in all areas of macroscopic components can be reduced and homogenized.

Method

The SLM process control to reduce the roughness is adjusted by means of scanning laser systems for areas near the surface of the component (contour and overhang areas). By discontinuous energy input, shape and size of the melt pool can be controlled and a significant reduction in surface roughness achieved. For the experiments, an SLM laboratory plant was used, which has a 400 W beam source, and the powder material Inconel® 718 in the particle fractions d_{100} = 15 - 45 µm.

Result

Initial samples produced by modulated laser radiation show a significant reduction in roughness on surfaces that are mounted directly on the powder bed (incidence angle = 90°). The Ra and Rz values are smaller by a factor of 2 when compared to the values of reference samples, which were made with cw laser radiation.

Applications

Turbomachinery construction and medical technology, for example, are two sectors that require SLM components with a low surface roughness. If post-processing costs can be reduced through the adapted SLM process control examined here, the SLM process could gain greater acceptance, thus opening up new fields for this application.

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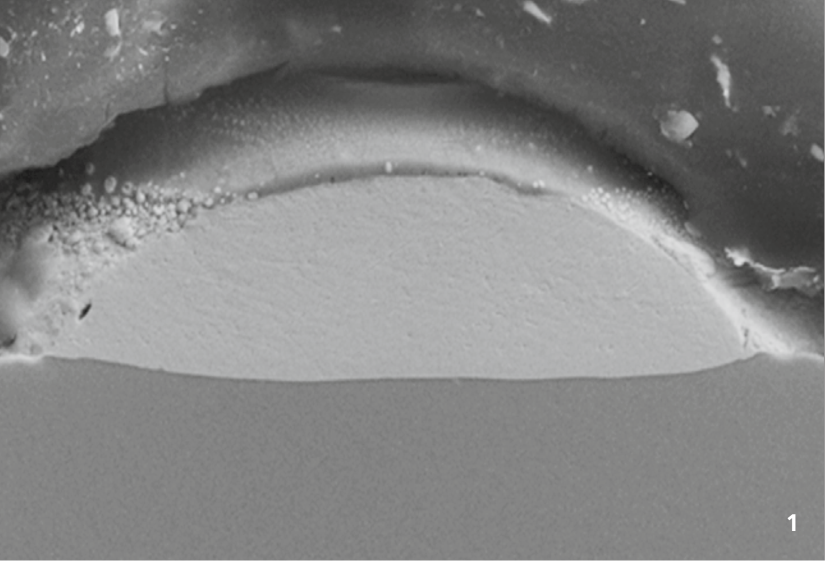
3 Demonstrator built out of Inconel® 718 using SLM and modulated laser radiation.



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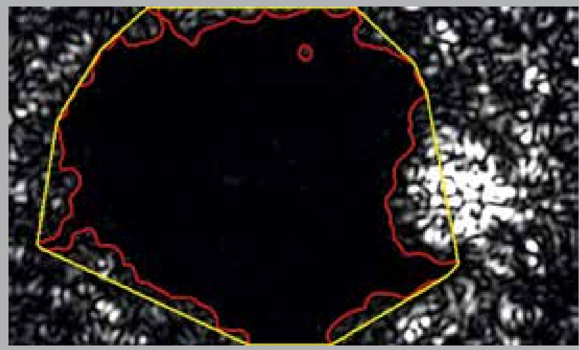

2

GOLD CONTACTING WITH INLINE QUALITY CONTROL

Task

Micro laser metal deposition (Micro-LMD) is a method that can generate site-selective contacts with precious metals such as gold. For the production of large quantities of the contacts, however, they need to undergo a quality control. To accomplish this, laser speckle photometry (LSP) shall be used. LSP is a method developed at Fraunhofer IKTS and based on the analysis of the temporal change of the optical speckle patterns (grained interference), which, among others, develop during thermal excitation of the test object. In a joint project of Fraunhofer Institutes ILT and IKTS, LSP shall be investigated as to its ability to indirectly determine the precious metal content and the geometry of the contacts.

Method

The gold contacts are applied by dispensing, then dried to drive off the binder and remelted by a laser. In LSP a CMOS camera is used for the necessary temporal and lateral resolution of the interference pattern. The excitation of the interference is carried out by reheating the contact with the processing laser.

1 SEM image: Cross-section of a gold contact point.

2 Graphical image analysis of laser speckle with automatic evaluation of the geometric dimensions and the gold content.

Result

Pulse processing can be used to remelt a gold contact with a diameter of about 200 µm and a thickness of several 10 µm within 100 ms. Through parallelization (e.g. by cascading beam splitting) dozens of contacts can be functionalized per second. The prerequisite is that the drying (e.g. by radiant heaters) is placed upstream in the process. The signals of LSP change with the gold content and the diameter of contacts; these signals can, therefore, be used as an indicator with appropriate calibration. The accuracy is currently around ± 7 percent. Up to 100 contacts per second can be recorded and evaluated externally, so that in principle a hundred-percent control is possible. Micro-LMD and LSP have been successfully tested in a laboratory setup.

Applications

The process can primarily be applied in electronics and electrical engineering, where electrical contacts are only required selectively (e.g. for sliding and plug contacts). Another field of application is the fuel cell industry.

The project was funded within the scope of the Fraunhofer program »MEF«.

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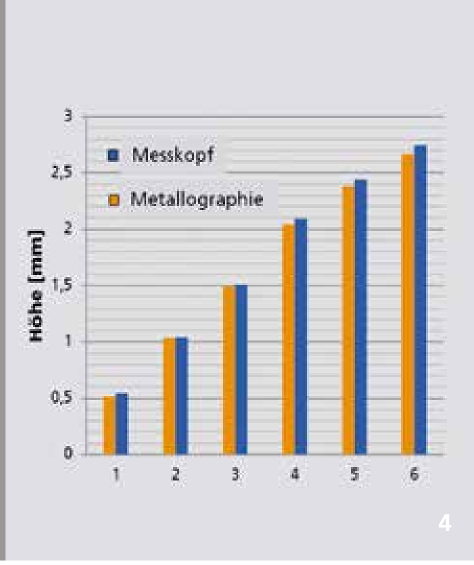

MEASUREMENT OF ONLINE THICKNESS USING AN INTEGRATED INTERFEROMETER

Task

Inner coatings are commonly used for reconditioning high-quality components such as bearings, housings or cylinders, which, for example, are commonly used in the oil and gas industry. In order to ensure the coating quality, and in particular to monitor the applied layer height during the process, Fraunhofer ILT has developed an online measuring method while also taking the restricted accessibility for the coating thickness measurement into consideration.

Method

As a solution, an absolute measuring interferometer has been integrated in the optical beam path of the internal coating optics. The interferometer emits a beam which is divided by a beam splitter into a reference beam and a measurement beam. Before the coating process, both partial beams are calibrated to one another so that their path lengths are equal. Measuring beam and processing beam are superimposed; they run coaxially to each other and meet at a point on the workpiece. During the coating process, the measuring beam reflected back from the workpiece is superimposed with the reference beam in the interferometer. The resulting difference between the optical paths of measurement beam and the reference beam is then used for determining layer thickness.

Result

The successful integration of an absolute measuring interferometer makes it possible to directly measure coating thickness during the coating process without destroying the sample. To verify the accuracy of measurement, Fraunhofer ILT evaluated six coated layers with different heights under a light microscope. The maximum deviation of the film thickness between the interferometry measurement and light microscopic evaluation is approximately 2.5 percent.

Applications

With this online measurement technology, the layer thickness of the coating process can be monitored, thus improving the coating quality substantially. In principle, the inner coating optics can be used for all applications in which internal surfaces need to be coated.

The project has been supported with funds from the »HORIZON 2020« program of the European Union.

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3 Experimental setup.

4 Measurement results.

THE INCLAD ONLINE MONITORING PROCESS

Task

Laser Metal Deposition (LMD) is being increasingly used to plate heavy-duty interior surface areas, for example, of bearings, housings or cylinder bores. Specially developed internal coating optics have made this hard cladding and repair technology available for high-quality components, whose inner surfaces could not previously be accessed with standard heads. The objective of the »LASHARE-INCLAD« project is to integrate sensors and systems for coaxial process monitoring so that the machine operator can observe the process online and, thus, better control it.

Method

The INCLAD optics were developed and designed in coordination and cooperation with the system supplier and industrial user. So that the process could be safely transferred, the system configuration was conceptualized and operated according to the industrial user's requirements. The technology readiness level (TRL) and the production acceptance test were conducted by the supplier as well as by the industrial user.

Result

The INCLAD 1500 optics allow internal coating in tubes or in tubular workpieces with a length of up to three meters. A 4 kW fiber laser as well as a 4 kW diode laser can be used as a beam source. To monitor the stability and quality of the INCLAD process online, the thermal radiation emitted by the weld pool is detected with a pyrometer coaxially through the INCLAD 1500 optics and is spatially resolved with a high-speed CMOS camera. If defined control limits are exceeded, the machine operator will either be alerted or the INCLAD process automatically stopped.

Applications

The INCLAD process can be used to repair high-quality workpieces whose inner surfaces have to meet strict requirements in terms of wear and corrosion. Examples can be found in the oil and gas industry, extruder barrels in plastic injection molding or sliding bearings in machine tools.

The work in the project »LASHARE-INCLAD« has been supported by the European Union with funds from the »HORIZON 2020« program.

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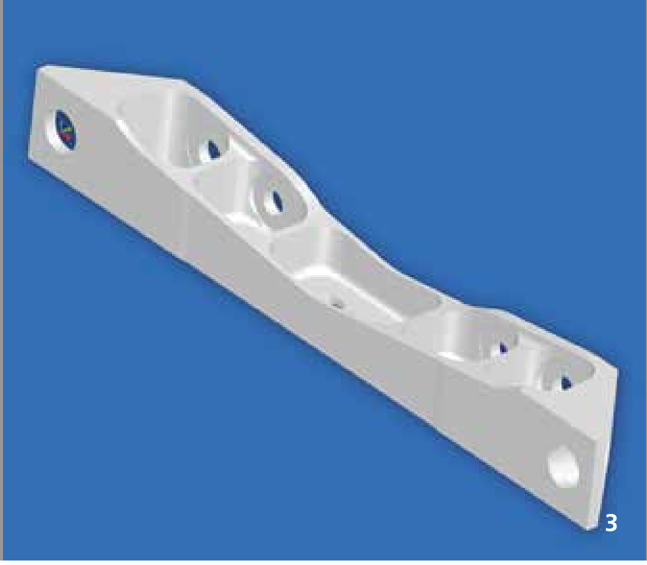
1 INCLAD 1500 optics.

2 Inner coating of an oil drill bit.



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ADDITIVE MANUFACTURING OF A JET ENGINE MOUNTING COMPONENT BY MEANS OF LMD

Task

So that the aerospace industry can more flexibly manufacture complex and expensive components, such as those made of nickel-base superalloys, additive processes such as laser cladding (LMD) are being investigated as alternatives to conventional production processes. A key consideration for the industrial prevalence of a process is, in addition to technological aspects, its economic efficiency. Two significant cost factors are the running time of the additive manufacturing process and subsequent post-processing. Within the scope of the EU project »AMAZE«, both aspects are being analyzed and tested on the engine mounting component out of IN718 as a demonstrator with increased build-up rate.

Method

From a process-technical point of view, the key factors are the targeted deposition rate, the quality achieved (e.g. pores) and the geometry quality (post-processing time). Among these, the increase in the deposition rate has the greatest potential, which was studied using different beam diameters and laser powers in the range of 500 to 3500 W and subject to a maximum surface temperature of 70 °C before the next layer was applied. Significant geometry elements (features) were extracted from the demonstrator and built with various strategies. These serve as the basis for manufacturing a demonstrator while aiming to minimize the production time.

Result

Parameters were developed using track widths of 1 - 4 mm, with which the feature geometries were generated (Figure 4). The deposition rates achieved of the individual layers varied from 0.15 kg/h at a 1 mm track width up to 2 kg/h at a 4 mm track width. The tests on the feature geometries were evaluated and showed that the deposition rates actually achieved were strongly reduced, especially at the 3 and 4 mm tracks due to the necessary cooling between the layers. By installing active water cooling, the deposition volume rate could be increased again, e.g. by a factor of 4 in the 3 mm track.

Applications

The know-how gained in this project with the material IN718 can be transferred to other materials and applications. Potential can be found in components that have a high volume of stock removal, e.g. integral and engine components from the aerospace industry or turbines made out of high-performance materials for energy generation. In the tool and mold industry, effective and flexible solutions lend themselves to, for example, the modification of components.

The work was funded within the EU project »AMAZE« under grant number 313781.

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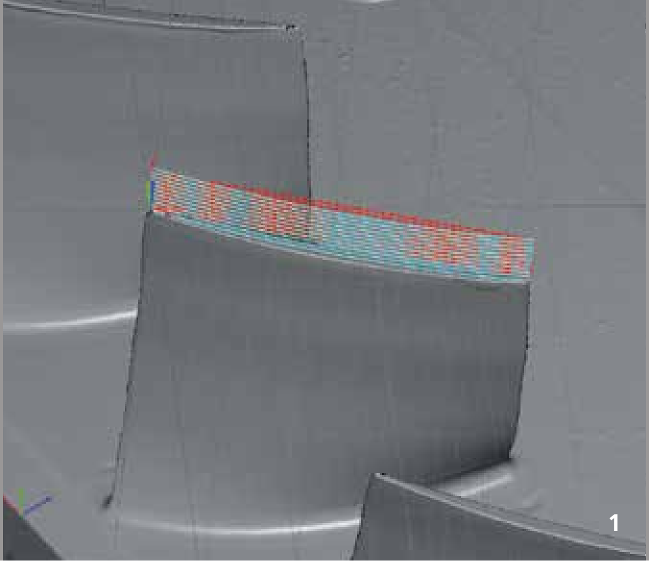
3 Demonstrator component APOD11 (Source: Airbus Group).

4 Demonstrator features with 1 - 4 mm track width (from left to right).



»MULTI-BLIR« REPAIR WITH LASER METAL DEPOSITION

Task

For Laser Metal Deposition (LMD) to be used to repair components with complex geometries, process development requires time and depends, in particular, on the geometry and material of the component. In order to reduce the time significantly and react flexibly to changes in geometry, the Innovation Cluster »AdaM« (Adaptive Production for Resource Efficiency in Energy Generation and Mobility) has, in part, focused on developing an LMD technology processor. It is based on experimental results from LMD, which are stored in a database, and a simulation tool. To illustrate the experimental results, process diagrams have been developed. With the example of a multistage, blade-integrated rotor segment (»Multi-BLIR« segment), a blade tip repair process shall be demonstrated.

Method

The CAM software »LMDCAM2« developed at Fraunhofer ILT can be used to compare the measured actual blade tip geometry to the target geometry. Then, the difference in volume to be built is determined and cut into several layers (Figure 1). Supporting points are created along the blade profile per layer. Here, at each supporting point, process parameters – which are determined from process diagrams – are adapted to the local blade geometry (laser beam diameter, laser power and scanning speed for a selected powder mass flow).

1 Tool paths created with »LMDCAM2« for blade tip repair.

2 Result of the blade tip repair of a »Multi-BLIR« segment.

Result

Using this approach and its CAM tool, Fraunhofer ILT has demonstrated that a blade tip of a »Multi-BLIR« segment could be successfully repaired when the parameters are adapted to the geometry (Figure 2). As a result, the time and effort needed for the LMD process development of blade repairs can be reduced significantly so that only small adjustments to the process parameters are required.

Applications

The concept behind the LMD technology processor and the process diagrams can, in principle, be used for all repair applications. Especially turbomachinery construction and mechanical engineering can profit from this development.

The Fraunhofer Innovation Cluster »AdaM« has been funded by the European Regional Development Fund (ERDF), »Investment in the Future«.

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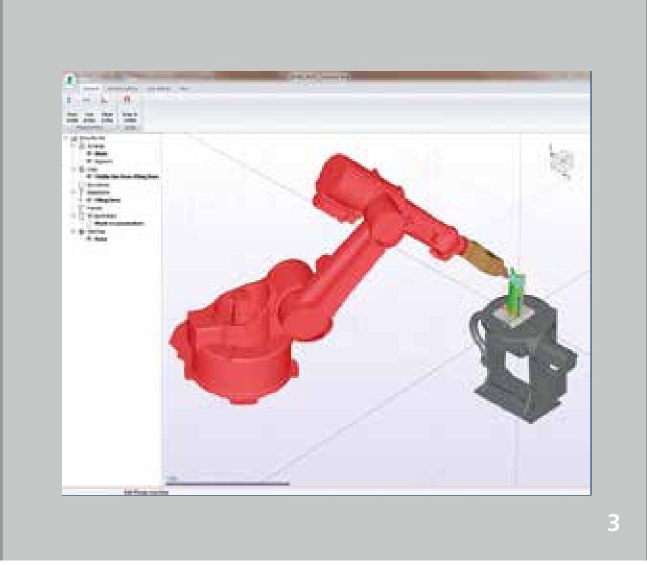

ROBOT BASED LASER METAL DEPOSITION WITH CAD/CAM COUPLING

Task

As part of the Fraunhofer Innovation Cluster »AdaM« (Adaptive Production for Resource Efficiency in Energy and Mobility), a robot-based plant consisting of a six-axis articulated robot with a tilt-and-turn module has been constructed and used to repair and manufacture turbomachinery components. With it, geometrically complex turbine blades, for example, should be repaired. Robot paths should be created on the basis of CAD data from the software developed at Fraunhofer ILT, »LMDCAM2«.

Method

The robot has been successfully commissioned. Simple movements can be programmed very quickly by a teach-in operation via the robot controller. However, if robot paths are generated based on CAD data, appropriate CAD/CAM software must be used. With »LMDCAM2«, both the 3D models of the components to be repaired or manufactured as well as the robot model including the definition of the kinematics can be read and animated graphically. This way, robot paths can be created according to the respective welding strategy. Preliminary robot movements can be simulated on the computer in order to avoid possible collisions of the robot.

Result

For the additive manufacturing of demonstrator components with Laser Metal Deposition, »LMDCAM2« has successfully been used to generate robot paths based on CAD data. The demonstrator components are geometrically complex shapes, which can be produced through different angles and orientations of the processing optics thanks to the robot's flexibility.

Applications

Due to its high flexibility, the robot is principally suitable for all types of repair and manufacturing applications in various industries (e.g. aviation, turbomachinery, tooling). Thanks to its greater freedom of movement as compared to Cartesian systems, it can be particularly interesting for applications where accessibility to the processing site is severely limited.

The Fraunhofer Innovation Cluster »AdaM« has been funded by the European Regional Development Fund (ERDF), »Investment in the Future«.

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3 Robot model in »LMDCAM2«.

4 Laser Metal Deposition process on a demonstrator component.

AUTOMATED MEASUREMENT OF POWDER JET NOZZLES

Task

In Laser Metal Deposition (LMD), the powder feed into the melt pool is of crucial importance. It has a decisive influence on powder efficiency, oxidation by the surrounding atmosphere and the geometry and roughness of the layer generated. For this reason, there is a need to characterize the powder gas jet to ensure process quality. Fraunhofer ILT has developed a measurement procedure that can be used to standardize powder nozzle characterization. For this process, a system has been built according to industrial standards and enables the measurements to be automated.

Method

The measurement process needs to be standardized and automated so that the characteristic properties of the powder feed can be compared. These include the particle density distribution and caustic of the powder gas jet as well as indicators derived from them such as location and size of the powder focus. To monitor the required sizes metrologically, the powder gas jet is illuminated by a laser line perpendicular to the powder gas stream and observed through the powder nozzle with a coaxially arranged camera. A high frame rate makes it possible to detect the individual powder particles in number and position. As the system progresses along the powder gas jet step-by-step, it records individual layers in order to calculate the particle density distribution with the appropriate algorithms.

Result

There is now a system for automated and standardized measurement of powder feed nozzles that can certify individual powder nozzles. For the first time, the measurement process opens up the ability to fully characterize a powder gas jet. The process has been qualified for different powder nozzles and powder grain fractions.

Applications

The areas where the system can be applied include all activities in cladding with laser radiation in which the exact knowledge of the powder gas jet is required. This know-how can be used in process development, nozzle development and production of components with high quality standards.

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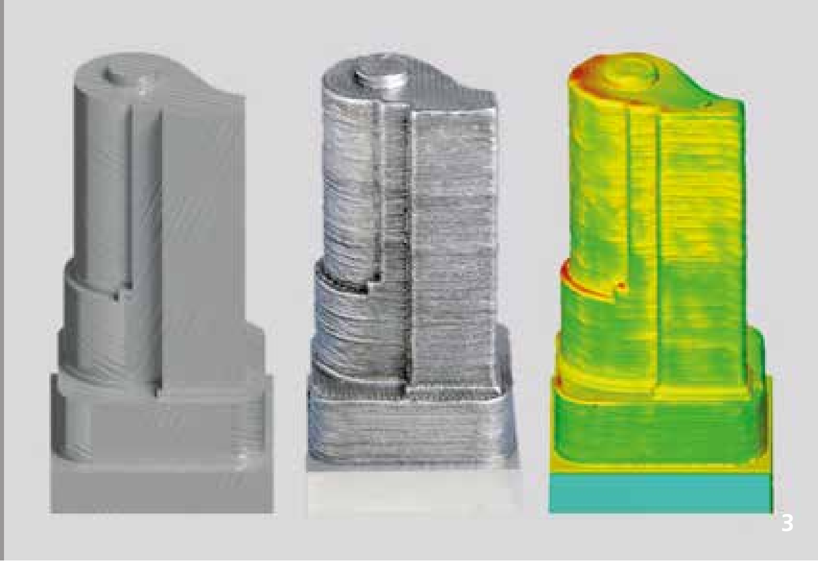
1 System for the automated measurement of powder nozzles.

2 Powder nozzle in the measuring system.



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ADDITIVE MANUFACTURING IN MOLD AND AUTOMOTIVE CONSTRUCTION WITH LMD AND SLM

Task

Within the scope of the Fraunhofer key project »E³ Production«, the resource efficiency of additive manufacturing chains is being investigated. To do this, two reference components (an injection mold and an automobile steering knuckle) are being used to implement the additive manufacturing chains and to determine the resource flows along these manufacturing chains (in particular energy, material and time). The additive manufacture of the reference components forms a basis to evaluate the resource efficiency of additive manufacturing chains and represents a central task of the project. The injection mold is manufactured with LMD, the car steering knuckle with SLM. Balancing resource flows begins with the powder preparation and ends with the finishing of the reference components.

Together, the project partners and Fraunhofer ILT are balancing the resources along the conventional production chains for the manufacture of components. With this, they are creating a foundation to assess the acquired resource data.

Method

The work to prepare the reference components starts with the selection of suitable materials. The injection mold is manufactured with LMD from the hot-working steel 1.2343, whereas the car steering knuckle is made with SLM from the aluminum alloy AlSi10Mg. The starting point for the production of the reference components are the CAD data provided by the partner company (BMW Group and WBA). An appropriate building strategy has been developed for the dimensioning of the LMD process. The CAD data are used with the software »LMDCAM2« to implement a final contour path planning for the construction of the injection mold. For the dimensioning of the SLM process, an adapted support strategy for positioning the steering knuckle in space will be developed and the guidance adapted to the protective gas flow.

Result

The components have been made by both methods and checked for their dimensional stability. The allowance of the side walls of the injection mold is not more than about 800 µm. The knuckle has an average allowance of about 400 µm.

Applications

The investigations presented here are focused on applications in the mold and automotive industry, but the findings can also be used in other industries.

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

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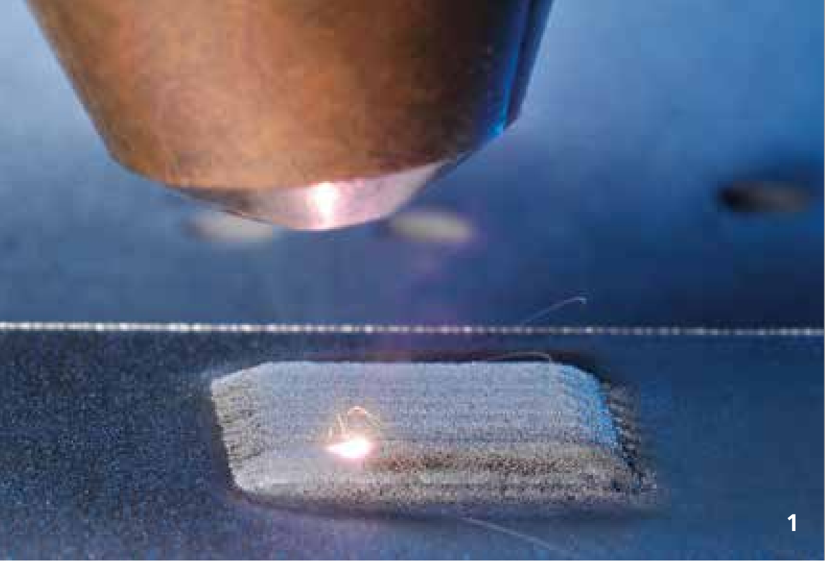
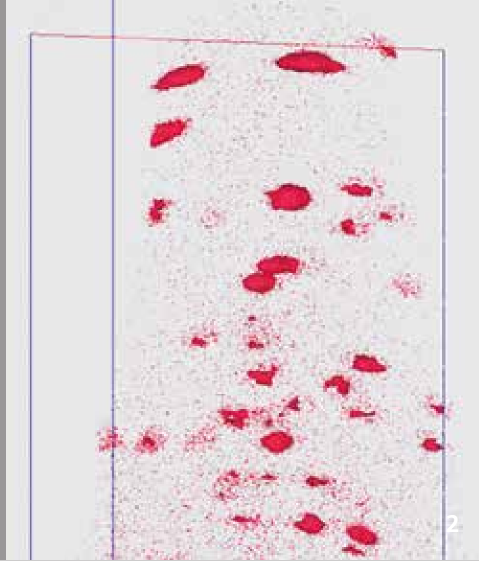
3 Injection mold produced with LMD.

4 Automobile steering knuckle produced with SLM.





INTRINSIC HEAT TREATMENT IN ADDITIVE PRODUCTION

Task

Selective Laser Melting (SLM) and Laser Metal Deposition (LMD) are important additive manufacturing processes. Additive manufactured components made of conventional alloys, however, frequently require subsequent heat treatment. As a rule, this is usually done by aging the alloy, which generates precipitates that increase the strength of the components. This additional process step is often, however, associated with a further distortion of the components. An alternative to this is using intrinsic heat treatment, which must be adapted to short temperature-time cycles of a few seconds occurring in SLM/LMD. Process technology and the alloy system must, however, be adjusted to this. Treatable aluminum-based alloys (aluminum-scandium), among others, have been investigated in cooperation with the Max-Planck-Institut für Eisenforschung (MPIE).

Method

When the process conditions, e.g. by preheating or a layered laser heat treatment, are varied, precipitates shall be generated from the supersaturated matrix after it rapidly solidifies. In parallel, the precipitation kinetics is adjusted to the short-term heat treatment by targeted modification of the alloying compositions.

Result

In the first step, process parameters were developed for the production of dense and nearly defect-free solids bodies. For the Al-Sc alloy Scalmalloy®, the formation of nanoscaled precipitates of the Al_3Sc has already been demonstrated in the process. The distribution and size of the precipitates, however, are still inhomogeneous.

Applications

This heat treatment can be applied, in particular, where the highest demands are placed on additive manufactured components, e.g. in turbomachinery, tool engineering, and in the medical and aerospace industries.

This project has been funded by the Fraunhofer Max-Planck Cooperation Program.

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1 LMD of Scalmalloy®.

2 Nanoscale precipitates of Al_3Sc (Source: MPIE).

ADDITIVE MANUFACTURING WITH IRON ALUMINIDE ALLOYS

Task

As a material for lightweight construction, iron aluminum alloys are gaining interest and may replace, for example, high-alloy chromium steels in the future. Laser-based additive manufacturing has been used successfully to process binary iron aluminide alloys. Laser Metal Deposition (LMD) and Selective Laser Melting (SLM), however, tend to generate a grain structure solidified in build-up direction, despite high cooling rates. Epitaxy leads to grains that grow over many layers. In addition, binary alloys are not suited for applications running at more than 550 °C due to the Fe_3Al-FeAl phase transformations. Measures specifically developed for alloys can lead to both a grain refinement and to stabilizing the Fe_3Al phase.

Method

Titanium and boron are analyzed as alloying additives. The addition of titanium is used for grain refinement and increase strength by generating a mixed crystal formation. At the grain boundaries, boron forms titanium borides that inhibit grain growth and increase creep resistance.

Result

Defect-free solids having a density greater than 99.5 percent have been made with both SLM and LMD. Due to the larger brittle-ductile transition temperature of Fe-Al-Ti and Al-Fe-Ti-B as compared to binary Fe-Al, a higher preheating temperature is required (400 - 600 °C compared to 100 °C). Thanks to the addition of titanium, a grain size greater than 1 mm could be reduced to about 20 - 50 µm. The addition of boron leads to titanium boride forming at the grain boundaries, thus resulting in a further grain refinement with an average grain size of 3 µm. Current work is identifying the mechanical properties of these alloys.

Applications

Ternary or quaternary Fe-Al alloys can be applied in heavy duty components that have to operate under mechanical, chemical, thermal and corrosive loads. Examples can be found in turbine engines, in aggregates for energy conversion or in the aerospace industry.

The R&D project underlying this report, »RADIKAL«, has been carried out on behalf of the Federal Ministry of Education and Research under grant number 03X3574F.

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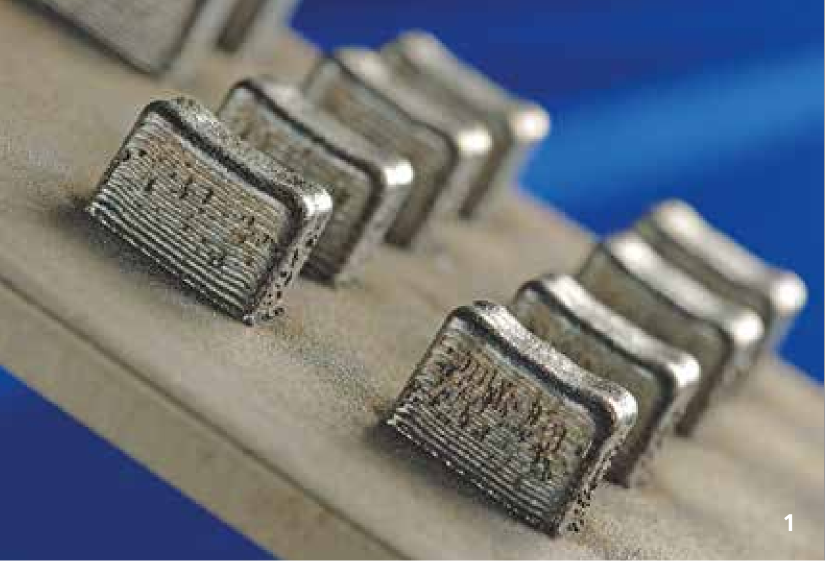
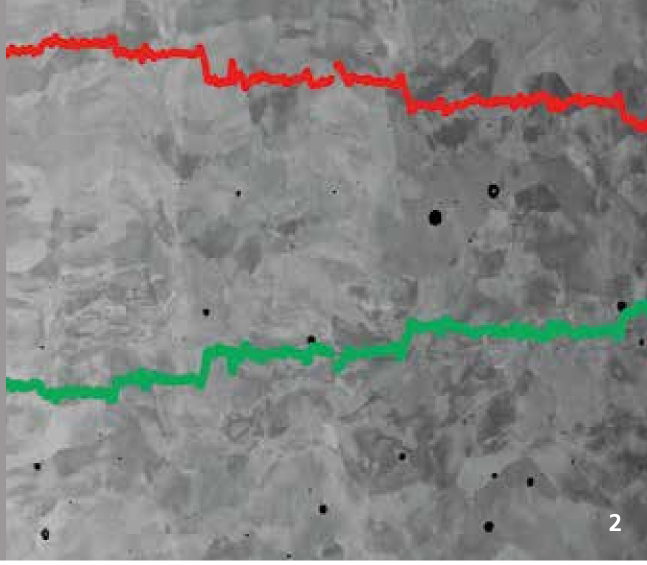
3 Impeller demonstrator out of Fe-Al-Ti-B.

4 EBSD recordings of Fe-Al, Fe-Al-Ti and Fe-Al-Ti-B (from left to right).





FUNCTION ADAPTED COMPONENTS THROUGH MATERIAL GRADING

Task

Thanks to material grading, a component can be optimally adapted to the loading profile. A potential application for this is in turbine blade manufacturing. As a rule, the stresses within a turbine blade vary locally. The foot must primarily have a high strength, while the blade must be protected against corrosion and abrasion. Furthermore, gradations for the hybrid construction are of interest. As an additive manufacturing process Laser Metal Deposition (LMD) can be used to produce graded materials thanks to its powder-nozzle technology. The investigations described here have been carried out using the example of iron aluminide alloys, which are gaining interest as a construction material for lightweight construction in hot or corrosive environments. The layered increase in the aluminum content (improved oxidation resistance) and a grading to stainless steel (hybrid design) are being investigated.

Method

The grading is achieved in-situ by simultaneous supply of two powder components. One component is the binary alloy Fe-28at.-%Al. The second component is pure Al or 1.4404. By varying the applied powder mass flows, the composition of each layer is set to a defined value.

1 Solids out of Fe-Al.

2 Process element concentration Fe (red) and Al (green, from 0 to 40 at.-%) over the cross section of a graded sample.

Result

In the first approach, a step-like increase in the alloy composition is adjusted by a continuous increase in the powder feed rate of Al. The Al content is thereby increased from 28 to more than 40at.-% via a construction height of 5 mm. In the second approach, 1.4404 is initially built on a stainless steel substrate. In each further layer, the portion of 1.4404 is reduced while the percentage of Fe-28at.-%Al is increased. The tenth and last layer is comprised of the binary Fe-Al alloy. In both cases, defect-free solids have been constructed.

Applications

This graded or hybrid construction process will find applications primarily in complex and heavy-duty environments such as in turbine engines or pumps.

The R&D project underlying this report, »RADIKAL«, has been carried out on behalf of the Federal Ministry of Education and Research under grant number 03X3574F.

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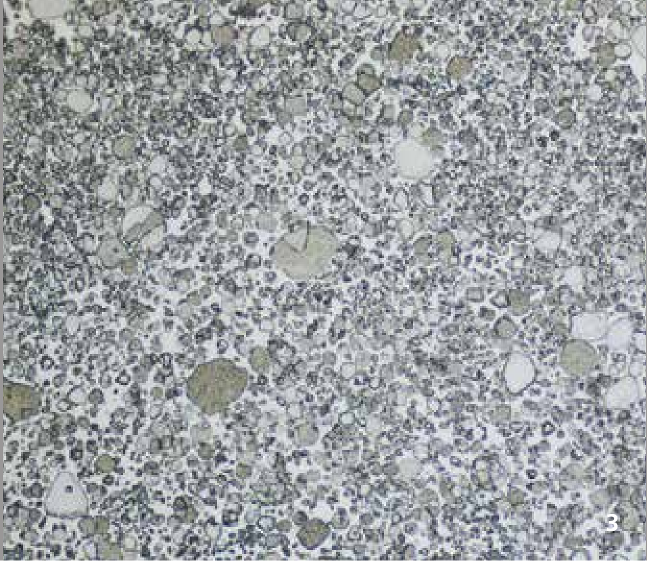

PROTECTION LAYERS OF TUNGSTEN FOR HIGH TEMPERATURE APPLICATIONS

Task

On account of its high melting temperature and high density, tungsten is an excellent material for protection against wear, corrosion and radiation at high temperatures. For reasons of cost and its poor machinability, however, tungsten is seldom used as a solid material; thus, coating with tungsten can serve as an alternative. In cooperation with the INR (Institute for Neutron Physics and Reactor Technology) of the Karlsruhe Institute of Technology, Fraunhofer ILT has set itself the goal of adapting Laser Metal Deposition (LMD) to produce pore- and crack-free layers of pure tungsten onto a steel material.

Method

A 3 kW diode laser is used as the beam source for LMD. Tungsten is fed into the process in powder form through a coaxial powder nozzle. To reduce the formation of cracks, the substrate is preheated to a temperature of about 330 °C.

Result

LMD can be used to generate pore- and crack-free tungsten layers with thicknesses of up to one millimeter. Due to the large melting point difference, a significant portion of the substrate material is melted. Through multi-layer coating, however, it is already possible to tune a tungsten content of up to 85 percent by weight in the layer with a constant parameter set. The layers are currently being tested at the INR. From further investigations, the research partners expect to be able to reduce the dilution of the substrate by adjusting the process parameters of the multilayer structure even further.

Applications

The process could be used in a fusion reactor; tungsten layers could increase the lifetime of the »first wall« during helium bombardment. Other potential fields where this technology can be applied are, for example, in the high-voltage current sector or plasma technology.

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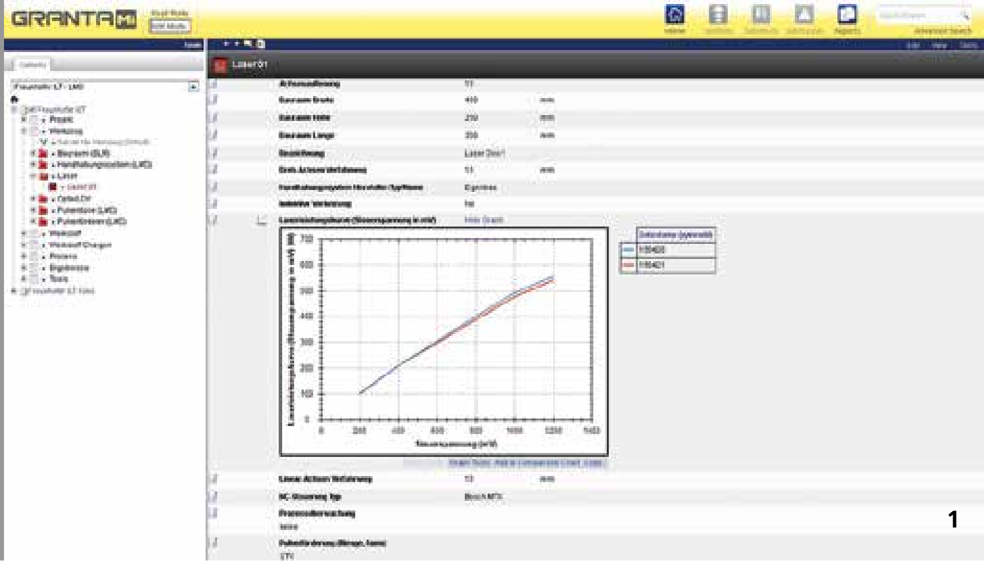
3 SEM micrograph of a tungsten layer with 200-fold magnification.



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DATABASE FOR LASER METAL DEPOSITION

Task

The database for Laser Metal Deposition (LMD) has two objectives. On the one hand, process knowledge on LMD that many individuals have will be documented systematically, centrally and uniformly (as knowledge management). On the other hand, by digitally filing engineering, materials, process and result data, Fraunhofer ILT has created a database that staff can access directly or via software tools (technology processor and CAx systems).

Method

First, the data structure has been developed through intensive discussions with end users of LMD and iteratively refined in several stages.

The resulting large data structure has revealed that a database can be implemented successfully only if an interactive and user-friendly interface is also available.

Fraunhofer ILT evaluated several alternatives for the database system in terms of time and money, ease of use, the availability of commercial systems, the feasibility of the project partners, the future care and maintenance of the system as well as the complexity of implementation of LMD data structure. Ultimately it selected the commercially available database system »Granta MI« by the company Granta Design. The data structure developed has been added to the database system.

Result

The database system is available to employees of Fraunhofer ILT; they continuously enter data in the system from completed and ongoing projects.

Applications

The results can be used for LMD in all sectors (energy, aerospace, tool and mold making, etc.) and on all kinds of tasks (coating, repair and additive structuring).

The Fraunhofer Innovation Cluster »AdaM« was funded by the European Regional Development Fund (ERDF), »Investment in the Future«.

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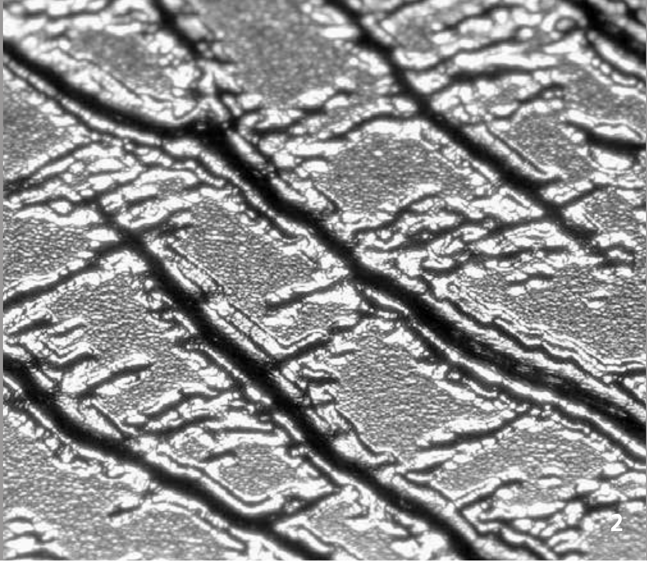
1 Screenshot of the database interface.



LASER REMELT STRUCTURING (LUST) ON CoCr28Mo

Task

In many industrial sectors, the structuring of surfaces has gained fundamental importance. The cobalt-chromium alloy CoCr28Mo can be found in a wide range of applications, especially in medical technology, where the focus is on implants, among others. However, structuring methods currently used (e.g., etching, laser ablation) are mostly time-consuming and/or expensive and based on structuring by removing material. In addition, both methods often produce rough surfaces, which can only be used to a limited extent for applications in the dental or implant sector. Furthermore, deficits are commonly found in the low ablation rates.

Method

For this reason, Fraunhofer ILT has developed a new process, Laser Remelt Structuring (LUST). In LUST, a laser beam melts the metal surface locally, while, at the same time, the laser power is modulated at frequencies between 10 Hz - 10 kHz. This results in a continuous change in the melt pool so that the material is redistributed, thereby generating mountains and valleys that are half above and half below the initial level. The surface layer solidifies directly from the melt, so that, in addition to structuring the surface, it is simultaneously polished. To increase the spectrum of materials that can be processed with LUST (e.g. 1.2343, Ti6Al4V, IN718, 100Cr6), Fraunhofer ILT has conducted systematic investigations on CoCr28Mo using single tracks within the project »Wave Shape« funded by the Volkswagen Stiftung.

Result and Applications

The investigations show that CoCr28Mo is basically suitable for use with LUST (Figure 2). It has also been shown, based on single tracks, that structures with a height of more than 4 µm can be generated by a single processing step. This is roughly the same structure height that can be produced with comparable process parameters on the tool steel 1.2343. Furthermore, the studies show that approx. 200 µm high wave structures (similar to 1.2343) can be generated in processing times of 2 - 3 min/cm². The method is suitable for producing a wide range of aperiodic and periodic structures (Figure 2, 3). The textured surfaces in this case have a small micro-roughness (Ra < 0.1 µm). Potential applications for such structures are, among others, in implant technology, for streamlined structures adapted to optimize biomechanical interactions between body and textured implant surface.

The work was conducted using devices and plants that were funded by the State of North-Rhine Westphalia and the European Union’s European Regional Development Fund ERDF (»Regional Competitiveness and Employment 2007-2013«) under the grant number 290047022.

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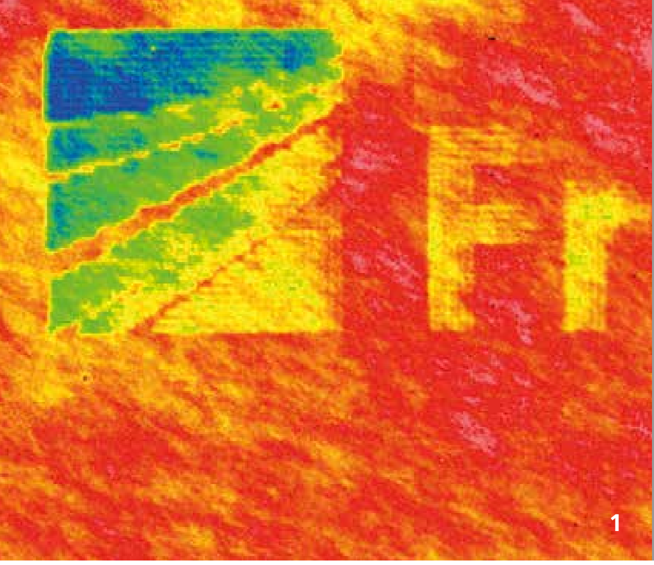
2 Aperiodic wood grain texture CoCr28Mo.

3 Demonstration structures generated with the LUST process on CoCr28Mo.



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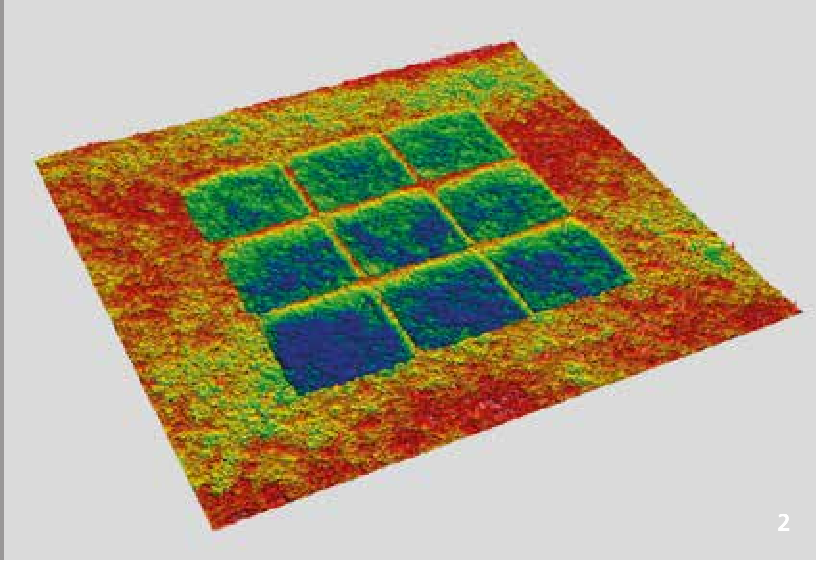

2

LASER FORM CORRECTING OF OPTICS

Task

Compared to spheres, glass aspheres have technical advantages in terms of imaging. They are, however, significantly more expensive to manufacture with currently established production methods. By means of laser polishing, optical systems of any surface shape, aspheres included, can already be processed in a short amount of time, and the roughness reduced to sufficient values for illumination optics. To reduce the waviness remaining after laser polishing and to approach the actual target form, Fraunhofer ILT has developed a laser-based shape correction process as a complement to laser polishing.

Method

The active principle of laser shape correction is based on the selective surface ablation of the glass material through evaporation. The local ablation volume can be adapted with high accuracy by using modulated CO_2 laser radiation and varying the pulse length. Thus, the smallest amounts of glass material may be selectively ablated, or evaporated, through laser-based shape correction.

1 White-light interferometry image to demonstrate the selective fine ablation.

2 Test fields for fine ablation on a conventionally polished glass surface.

Result

Laser shape correction can be used to selectively ablate fused silica glass with a vertical resolution of less than 5 nm and a lateral resolution of 100 µm. The initial roughness of the polished surface is not affected. By measuring laser-polished flat surfaces and detecting deviations from the desired form, Fraunhofer ILT can selectively process them by means of laser shape correction. Thus, the dimensional accuracy can be improved. As the method is adapted to curved surfaces, it will also be able to process aspheres in this same way in the future.

Applications

Thanks to its short processing time and great flexibility regarding the surface shape to be processed, the process presented here can be mainly used for the quick and inexpensive form correction of non-spherical optical components in small to medium quantities. Laser shape correction can be combined both with the laser polishing as well as with conventional processing methods for optics manufacturing. Furthermore, a complete laser-based optical manufacturing system will be developed, in which the shape will be generated by material ablation with laser radiation.

The work has been carried out within the framework of the BMBF project »Rapid-Optics« under grant number 13N13294.

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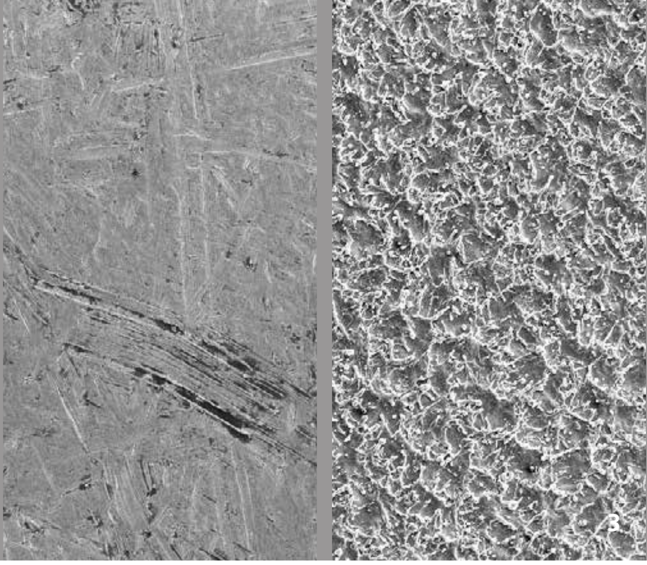

LASER-BASED TREATMENT OF METALLIC SURFACES FOR INCREASING ADHESION

Task

By using composites or multi-material coatings, the industry can meet the increasing demands placed upon workpieces and components in terms of corrosion and wear protection. The issue here – the adhesion between the respective layers – constitutes a central challenge, especially for adhesive bonds or metal-plastic bonds. The pre-treatment of a joining partner with pulsed laser radiation is a promising approach to improve adhesion without functionally deteriorating the base material.

Method

For the laser pre-treatment, pulsed laser radiation of wavelength $\lambda \approx 1$ µm is guided by means of a 2D or 3D scanner system in a meandering or unidirectional pattern across the workpiece. Typical pulse lengths are in the range of 5 - 100 ns at repetition rates of several kilohertz to one megahertz. To characterize the surfaces, Fraunhofer ILT uses scanning electron microscopy, white light or energy dispersive X-ray spectroscopy. The wetting behavior can be examined by means of contact angle measurements for temperatures up to 700 °C.

Result

Thanks to site-selective energy deposition and the short interaction times, the surface of the workpiece can be modified without a functionally relevant thermal effect, among others, on the base material. For metallic workpieces (e.g. aluminum or steel), the modifications include, in particular, chemical changes (e.g. oxidation) and changes in the surface topography. Typical lateral structure sizes are between 10 µm and several 100 µm.

Applications

This process can be applied where composites and multi-material layers are used. The polymer coatings generated with this process, under the project »RESKORR«, sponsored by the Federal Ministry of Education and Research (grant number 03X3564F), were made on bearing steel. Their adhesion could be improved thanks to laser pretreatment on substrate.

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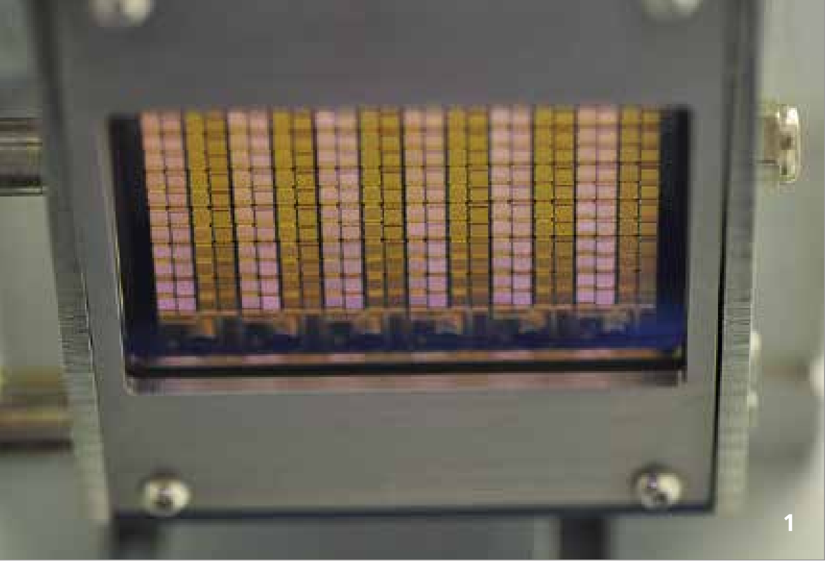
3 SEM image of untreated (l) and laser pre-treated (r) surface of a workpiece out of bearing steel.

4 Wetting on an untreated and laser-pretreated surface.



FUNCTIONALIZATION OF THERMOSETTING COATINGS WITH VCSEL

Task

Currently, the demands upon functional layers, such as high wear and corrosion resistance, low friction coefficient and high hardness, increasingly exceed the properties of base materials. Therefore, layers, either similar or dissimilar in type, are applied to the base material in order to achieve the required properties. Frequently, these layers must be thermally post-treated after being applied. Laser-based thermal post-treatment makes it possible to functionalize these layers in-line, that is to dry, to cure, to sinter or to crystallize them. In addition, with the so-called Vertical Cavity Surface Emitting Laser sources (VCSEL), it is possible to adjust the intensity distributions according to the application.

Method

In initial experiments, a VCSEL module was used to dry and cure thermosetting coatings on steel substrates. The module has a maximum output power of 2.2 kW, a beam exit area of 40 x 55 mm^2 and a total of 12 individually controllable rows of emitters. Both the coating and the laser processing were carried out under a flow box in order to prevent possible contamination of the sample surface with impurities.

1 VCSEL module with separately controllable emitter rows.

2 Surface irradiated, coated steel sample.

Result

The experiments show that VCSEL modules can be used for the drying and curing of thermosetting coatings. Moreover, the wear coefficient can be reduced by a factor of six as compared to furnace-based processes. The reasons for this are currently being investigated. The area rates achieved so far are in the range of some cm^2/s.

Applications

This VCSEL-based process can be used, in particular, to functionalize thin large-area, thermosetting coatings.

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

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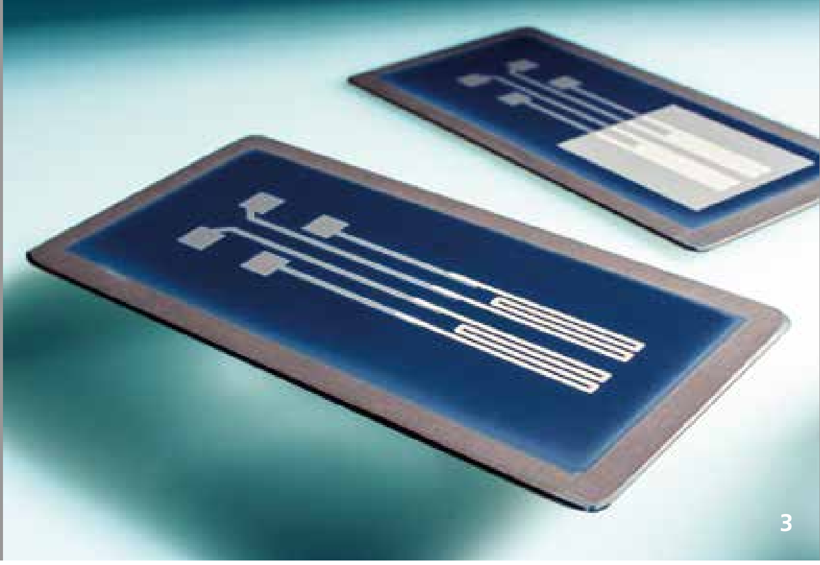

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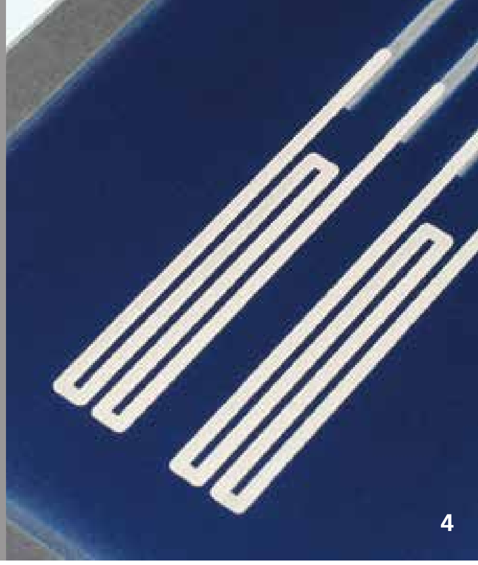

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ELECTRONIC MULTI-MATERIAL SYSTEMS FOR COMPONENT-INTEGRATED SENSORS

Task

The service life and function of mechanical components can be impaired, in particular, by excessive temperature increases or static and dynamic overloads. To prevent greater damage to massive structural components such as wind turbine bearings or turbine blades, Fraunhofer ILT, along with Fraunhofer IZM and IKTS, has developed printed and laser-functionalized sensor systems to monitor massive, metallic components in temperature ranges up to 500 °C within the research project »INFUROS«.

Method

In addition to developing adapted evaluation electronics, suitable materials and deposition techniques, Fraunhofer ILT focuses on developing a laser-based method for high-resolution, substrate-gentle and inline-capable post treatment of printed functional layers such as isolation and PZT piezoelectric layers and of resistor and conducting tracks. After a laser is used to pretreat the surface to increase its mechanical and chemical adhesion, thick layers are applied from µm-sized particles and sintered/melted by means of laser radiation. On the first layer for electrical insulation, other functional layers follow for the production of sensors for measuring temperature, expansion, or structure-borne sound.

Result

By means of pulsed laser radiation, oxidized surface roughness can be generated on 100Cr6 steels with a property that promotes wetting. The laser-melted electrical insulation layers are adherent and exhibit a dielectric strength of 50 kV/mm. Thanks to laser radiation, debinding and sintered PZT layers are adherent and exhibit better dielectric properties (ε_{33}, R_{ISO}) because of much lower diffusion times during heating (ms range) in contrast to oven-sintered layers. The structure can be generated both with printing as well as with a laser-based process. This way, any geometry of a temperature-sensor can be functionalized with lasers.

Applications

This process can be used in the sectors of temperature, expansion, or structure-borne sensor monitoring of temperature-sensitive as well as high-temperature structural components (e.g. wind turbine bearings, turbine blades, etc.). The project »INFUROS« is funded by the Fraunhofer in-house program »MAVO«.

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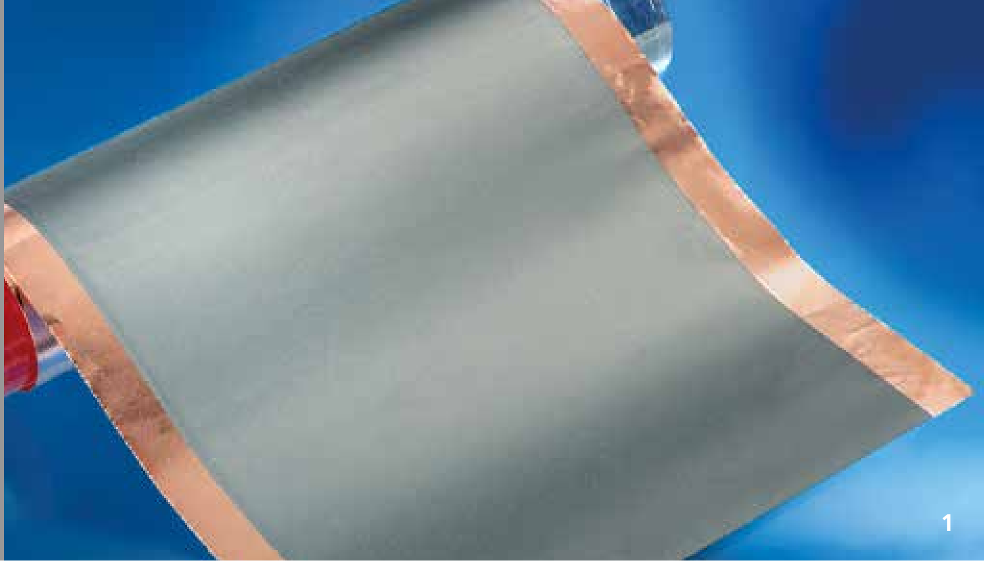
3 Printed and laser-functionalized temperature sensors before (rear) and after cleaning (front) on steel.

4 Detail of sensor structure.



LASER-BASED INLINE PROCESS FOR DRYING BATTERY ELECTRODE LAYERS

Task

In order for electromobility to become competitive on the mass market, production costs of battery cells must be reduced significantly. One promising approach to accomplish this is by substituting conventional furnace processes in battery manufacturing with innovative laser processes. When battery electrode layers deposited with knife-coating are dried, laser-based processes have a considerable potential for energy savings due to the efficient energy input in comparison to conventional drying in a continuous furnace. In addition, they can also enable a substantial reduction of the installation space for the corresponding roll-to-roll system.

Method

As part of the research project »DRYLAS«, Fraunhofer ILT, along with Fraunhofer IKTS, has developed a laser-based method for drying water-based battery electrode layers. The process requires the laser-induced temperature distributions to be adapted in such a way that the material is dried completely while peak temperatures do not exceed 300 °C. This way, the temperature sensitive components of the 50 - 100 µm thick layers are not damaged.

Result

Electrochemical testing of button cells on the basis of laser-dried electrodes shows that, with capacity of about 355 mAh/g, the performance of conventionally produced cells is achieved. By implementing a technology demonstrator in the form of a laser-drying module, Fraunhofer ILT has demonstrated the scalability of the process in an in-line coating unit. With 400 W laser power, a drying rate of about 60 cm²/s can be achieved while the energy consumption is reduced by about 50 percent.

Applications

In addition to drying conventional electrodes in the battery sector as described here, this laser-based temperature treatment can be applied for the sintering of solid electrodes for thin film batteries.

The project »DRYLAS« has been funded by the in-house Fraunhofer program »MEF«.

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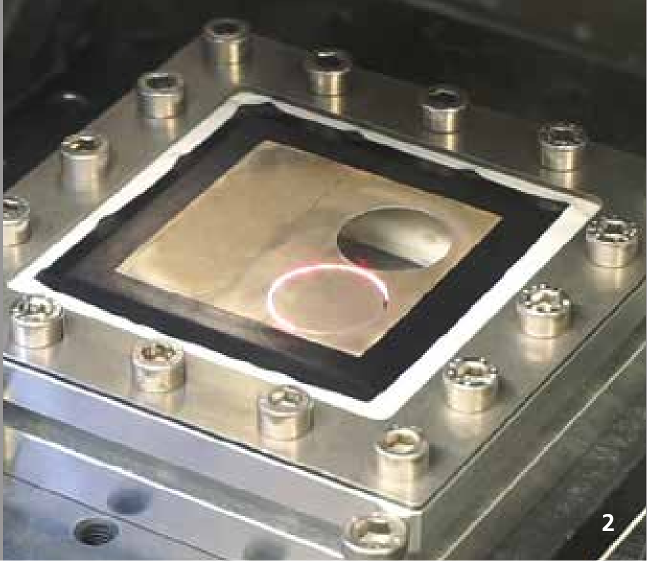
1 Laser-dried battery electrode layer on copper foil.



LASER STRUCTURING AND LASER CUTTING OF SOLID-STATE BATTERIES

Task

Solid-state lithium-ion batteries (SSLB) consist of different solid layers, only a few micrometers thick, thereby reducing the overall thickness of the battery to less than 1 millimeter. When individual cells are detached from large area battery substrates, no electrical connection may be formed between the layers. In conventional laser-based cutting, material is melted and expelled from the kerf. For sensitive layers, such as those within a thin-film battery, this is not allowed since a connection can be formed between the individual battery layers during the melting and re-solidification. The use of laser-based ultrafast processes under inert gas atmosphere makes this processing task possible.

Method

Laser beam sources with ultra-short pulses can be used to prevent melt from forming and, thus, a short-circuit from occurring. In addition, the battery layers can be removed by an upstream, selective structuring process around the kerf, which minimizes the risk of short circuits. Likewise, functional elements such as contact surfaces can be produced by selective laser ablation.

Result

For the selective structuring and fabrication of thin-film batteries, a processing system was set up, in which the laser processing is conducted by ultrashort pulsed lasers under an inert atmosphere. This makes it possible to process even highly reactive coating systems. When galvanometer and axle systems are used, the process is also geometrically flexible.

Applications

The know-how gained from the thin-film battery manufacturing can be applied to the manufacture of flexible OLED displays, electronic circuits and on organic and perovskite solar cells.

The research results are part of the R&D project »PROSOLITBAT«, which was conducted on behalf of the Federal Ministry of Education and Research under grant number 13N13241.

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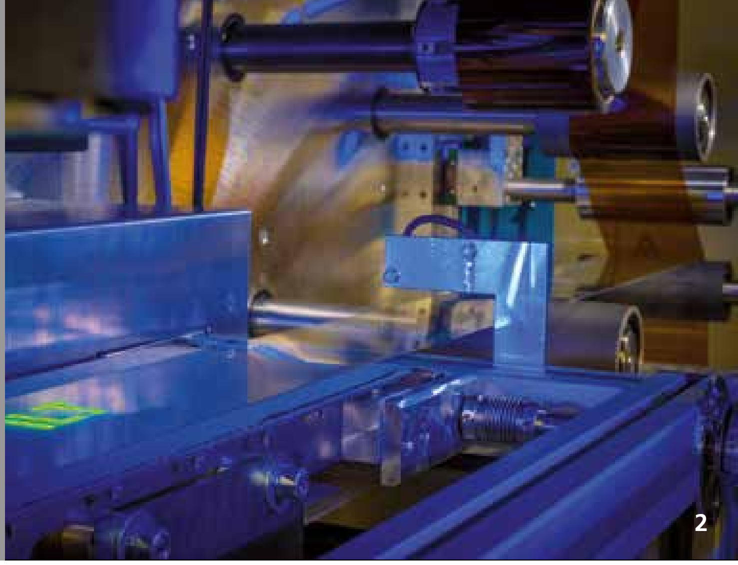
2 Laser patterning and cutting of an SSLB (solid state lithium battery).
3 SSLB fabricated with a laser.



STRUCTURING OF THIN LAYERS IN A ROLL-TO-ROLL PROCESS

Task

Roll-to-roll production lends itself well to the processing of thin and flexible materials. This process makes it possible to offer cost-effective products for a wide range of applications since both inexpensive substrate materials as well as a highly productive process are used. In polymer electronics, in particular, products are generally produced in this way. However, conventional patterning processes, such as lithography, can only partially be transferred to this type of component manufacturing. Laser-based processes can be used to work on both polymeric and inorganic functional layers as well as to significantly increase resolution.

Method

When high-repetition, ultrashort pulsed laser sources are used with optical systems for beam guidance and parallelization, powerful process components can be integrated in a roll-to-roll manufacturing system. Thanks to customized ablation strategies and temporal and spatial power modulation, high process speeds and a selective laser ablation of thin layers can be reached on polymers and metals.

Result

A demonstrator has been implemented in the roll-to-roll system to provide continuous laser-based structuring of semiconducting layers from the thin-film photovoltaic sector. By means of adapted optical systems, the production system is able to process material selectively at high continuous throughput rates. Geometrically flexible processing is also possible due to sensory monitoring of the machined strip material in connection with the use of galvanometer scanners.

Applications

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

The work presented here was funded as part of the ERDF program for North Rhine-Westphalia within the objective »Regional Competitiveness and Employment« 2007-2013 under grant number EN2061.

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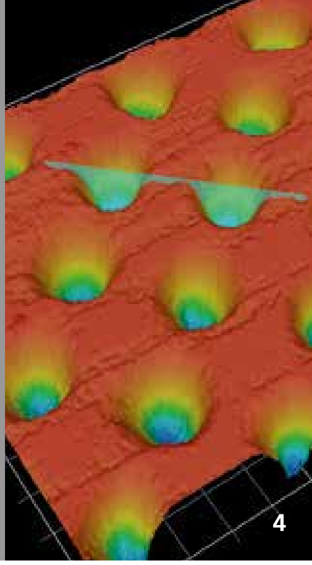
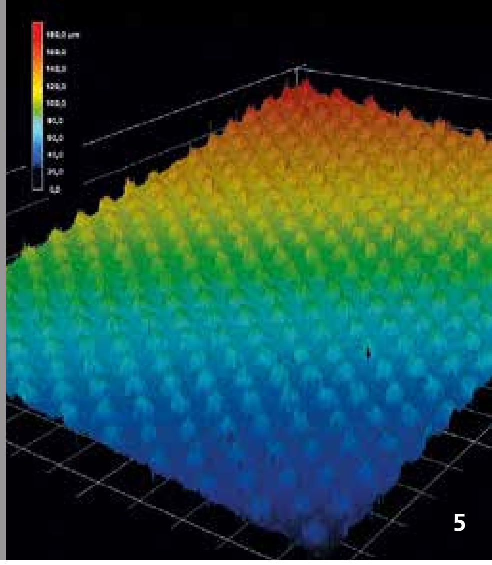
1 Inline structuring with fixed optics and scanning unit.

2 Roll-to-roll track process.





TOOL STRUCTURING FOR HYDROPHOBIC COMPONENTS

Task

Known from nature, self-cleaning and water-repellent surfaces are the object of many studies. Often, products for corresponding applications are provided with suitable coatings, which, however, mean an additional step and additional costs. As part of a project funded by the Federal Ministry of Economic Affairs and Energy (BMWi), an injection mold should be structured so that the molded surface has hydrophobic properties. The surface to be structured is the free-form surface of the inner side of a spoon.

Method

In order for a surface to have hydrophobic properties, its properties must behave according to the so-called Cassie-Baxter state – it needs to have elevations of sufficient height spaced close to each other. An ultra-short pulsed laser was used to produce a grid of conical holes, with each hole having a width and depth of 15 μm and located at a distance of 30 μm to each other. Since the ablation process exhibits a high share of evaporation – on account of the short period of interaction between ultrashort laser pulse and material – the surface does not need post-processing, nor does it show the annular melt protrusions typical for ablation with nanosecond laser pulses.

Result

So that the component surfaces produced by the injection molding process retain their hydrophobic properties as long as possible, a 2K injection molding is used to provide the spoon with a thin layer of elastomer along its inner side. The microstructure molded in the elastomer breaks less easily under mechanical contact than a thermoplastic, which was used for the rest of the body of the spoon.

To investigate the effect of different deformation directions on the form of the microstructures, Fraunhofer ILT has processed holes on the tool surface in five areas from different directions (+/- 30° in the x and y directions and vertically in the middle). Here, another advantage of the elastomer appears: demoldability without damage.

Applications

For users in the plastics and elastomer processing industry, the method makes it possible to produce complex but cost-effective bionic functionalized products.

The project was conducted in cooperation with the Institute for Plastics Processing IKV of RWTH Aachen University.

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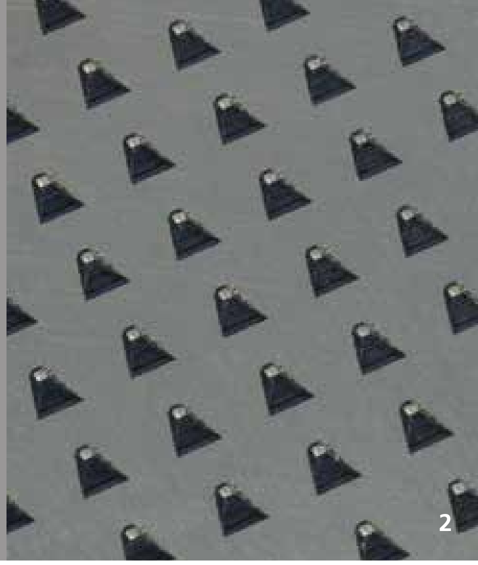
3 Spoon with a hydrophobic surface.

4 Photomicrograph of the tool.

5 Photomicrograph of spoon surface.



HIGH SPEED USP ABLATION BY TWO STEP PROCESSING

Task

Ultrashort pulsed (USP) laser radiation – with pulse durations of less than 10 ps – enables high-precision laser ablation with negligible thermal influence. The processing quality meets very high standards, but productivity, which is defined by the average applicable laser power, is too low for many applications. For potential applications in turbomachinery construction, the ablation rates and, thus, productivity during ablation should be improved with ultrashort pulsed laser radiation for nickel and titanium-based alloys.

Method

In addition to multi-beam approaches and the use of ultra-fast beam deflection systems, this project examined power scaling with the use of established, highly flexible galvanometer scanners. So that good surface quality could be attained with relatively high average laser power (>> 10 W), controlled heat was applied on the workpiece by using a large spatial pulse overlap (> 95 percent) and pulse repetition frequencies > 5 MHz. As a result, a thin melt film is generated during processing, preventing very rough microstructures from forming at the workpiece surface. The induced melt film can be removed in an optional second process step by using lower average laser power.

1 Mock-up blade made by laser ablation out of IN718.

2 Field of drill hole entrances on Ti 6246.

Result

For Inconel® 718, ablation rates of 9 mm³/min can be achieved with a surface roughness Ra < 1.5 µm. For Titanium 6246 the maximum ablation rate reached is 8 mm³/min with a surface roughness Ra < 1.6 µm. The induced melt film is < 5 µm thick and can be completely ablated in the optional second process step. Compared to what is achieved with conventional USP ablation, this corresponds to an increase of the ablation rate by a factor of 20.

Applications

One potential application is the finishing of turbomachinery components that have limited accessibility. Through the transfer of the process approach presented here to other materials, the productivity of USP processing for the mold and tool industry can be significantly increased with the use of highly flexible, well-established system technology.

The work was funded within the Fraunhofer Innovation Cluster »AdaM« by the European Regional Development Fund (ERDF) »Investment in the Future«.

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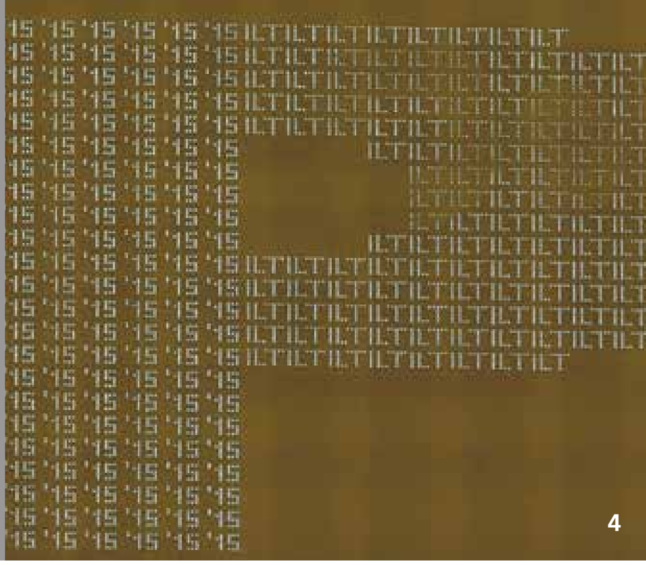

MULTI-BEAM PROCESSING

Task

The use of ultra-short pulsed (USP) lasers in materials processing makes a wide field of applications possible. Thanks to their high pulse intensities and the short interaction times, USP lasers can be used to process a variety of materials with the highest precision and almost damage-free. For economical use in direct production, however, ultra-short pulsed processes have previously been far too time-consuming, which is why they often were used only for indirect manufacturing (e.g. tool structuring).

Results

For the high-performance scaling of USP processes, Fraunhofer ILT has developed a technology with which surfaces can be processed in parallel and simultaneously with a large number of partial beams. These beams can be generated by diffractive elements. For static distributions, so-called DOEs can be used. For flexible beam shaping, a programmable diffractive optical system (PDO) has been developed, with which almost any intensity distribution can be produced with high efficiency and uniformity. The PDO is based on a spatial light modulator, which can be used to generate arbitrary beam patterns, in combination with a galvanomer scanner for fast laser deflection and, thus, fast processing speeds. These beams can also be changed dynamically, i.e. during processing, so that an extremely flexible working tool can be created. Thus, it is possible to retain the high level of machining quality (low thermal load, low surface roughness, high precision) of the USP process and to be able to increase the economical efficiency through increased productivity.

Applications

In all structures that exhibit symmetry or regularity, USP processes can be significantly accelerated by the use of multi-beam technology. In particular, in the processing of thin films and materials in which little energy for ablation is necessary, the process speed can be increased by up to two orders of magnitude.

Possible uses for this process range from structuring thin films in photovoltaics and for flexible electronics to the processing of masks and films with a high degree of periodicity.

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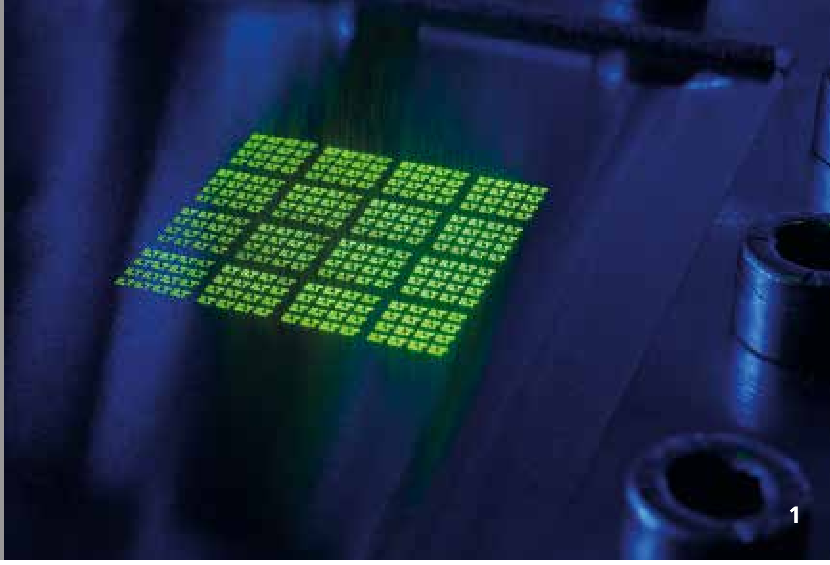
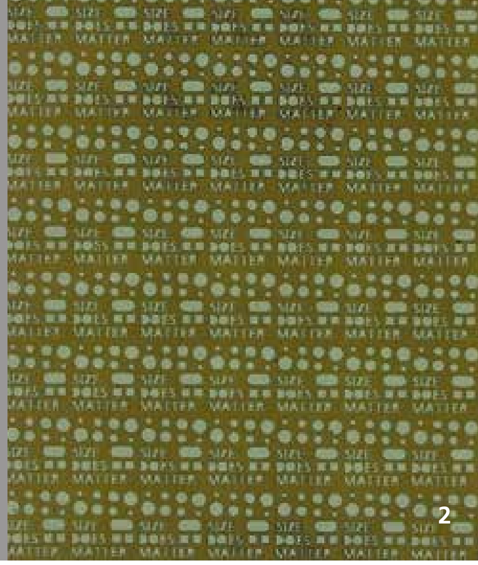
3 Parallelization with dynamic beam splitting into 950 partial beams.

4 Structuring of thin films with variable beam splitting.





HIGHLY PRODUCTIVE USP LASER PROCESSING WITH MULTI-BEAM OPTICS

Task

The productivity of industrial laser processes essentially depends on how well the average power can be transferred to the workpiece. This principle also applies to material ablation and cutting processes with ultrashort pulsed lasers, which provide the highest machining accuracies achievable in the nanometer range. In the meantime, in the ultrashort pulsed (USP) region, beam sources with outputs from 100 to 1000 W have become available. In order to meet the high standards of quality and accuracy even at very low beam diameters, intensities are needed near the ablation threshold to prevent undesired, thermally induced losses in quality. Thus, the power per single beam is generally limited to a few watts. Nevertheless, in order to implement the high available power, a new technological approach shall be used, in which the laser beam is split into several partial beams. Thus, a parallelization of the processing can be implemented and the ablation process accelerated. Through the use of diffractive optical elements, the beam can be split with high efficiency, uniformity and stability.

1 Ablation process with 16 partial beams.

2 Microstructured steel sheet produced with 196 partial beams.

Method

Fraunhofer ILT has developed industrially applicable multi-beam optical systems, which, based on diffractive optical elements, produce any number of arrays of partial beams. To ensure high process stability and reproducibility, the multi-beam module is monitored in real time by means of sensors and is adaptively stabilized. Thanks to a tailor-made design, the multi-beam optical systems can be used for many applications in the field of laser precision machining. In addition to classical surface structuring, this includes drilling and cutting applications.

Result

Figure 1 shows an ablation process with 16 partial beams, with each beam marking the lettering ILT 16 times. The variable deflection with a scanning system makes it possible to generate any ablation contour in multibeam operation. Figure 2 shows a microstructured 20 µm steel foil which has been processed by means of a multi-beam optical system. The smallest structure shown is 15 µm with an accuracy of 2 µm. The multi-beam optical system used generates 196 partial beams, allowing processing speeds of several hundred structures per second. Here, only an average power of 15 W was used at a wavelength of 515 nm, which illustrates that the productivity of the laser process is scalable with great potential.

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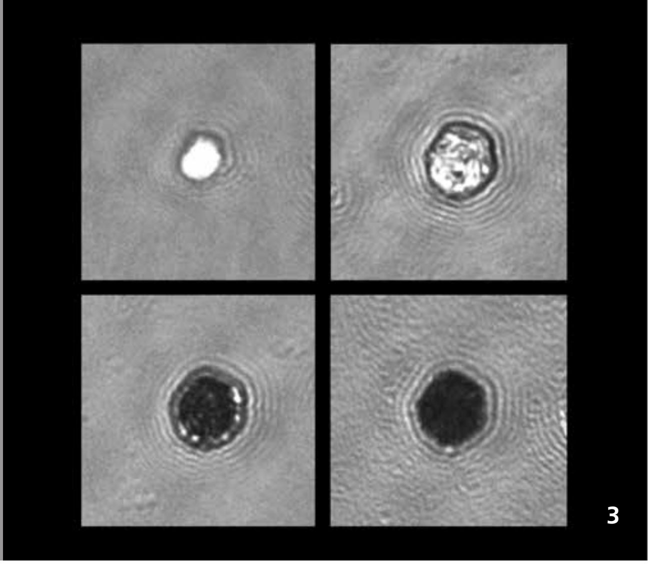

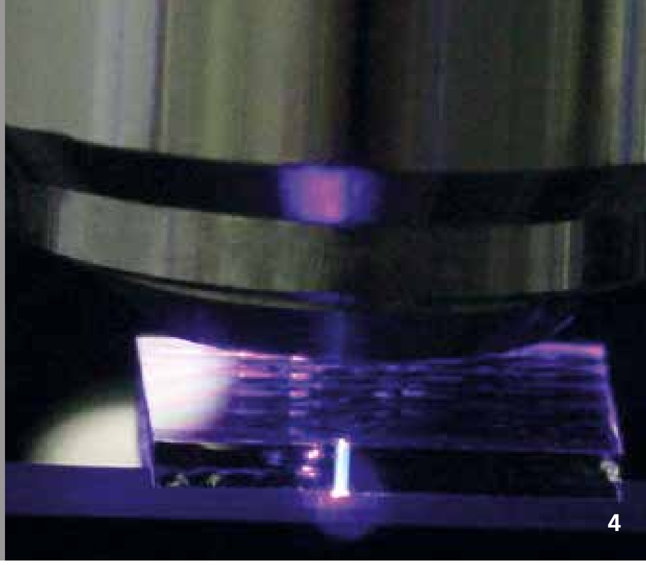

PUMP-PROBE MICROSCOPY OF PROCESSING GLASS WITH ULTRASHORT PULSED LASER RADIATION

Task

Due to the high intensity of ultrashort pulsed laser radiation, even transparent glass can be processed. When these materials are processed, however, non-linear interaction processes, such as the Kerr effect or plasma defocusing, play a central role. These effects eventually lead to material defects such as cracks, which are problematic for final applications. It is, therefore, a major challenge today to control the deposition of the laser pulse energy in the material and, consequently, to process with ultrashort pulsed laser radiation without generating defects. At the same time, controlled processing offers enormous potential for many applications, in particular for the production of displays. An understanding of process dynamics with high temporal resolution is required to guarantee that these interaction processes can be described and manipulated in a controlled manner.

Method

So that the absorption of laser radiation can be examined in the material with high temporal resolution, in-situ coaxial reflection measurements are performed using pump-probe measurement technology. Since it has a temporal resolution of about 100 fs, the interaction processes can be analyzed with high resolution.

Result

The reflection of the irradiated surface increases within the first 10 ps, which can be explained by the generation of a large number of free electrons and the resulting metal-like properties of the glass. From about 12 ps, the reflection is reduced or the absorption of the glass surface increases due to an onsetting ablation mechanism.

Applications

Understanding the fundamental process dynamics makes it possible to process glass defect-free with temporally tailored pulse shapes. The process can be used, in particular, for the production of glass in the electronics industry.

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

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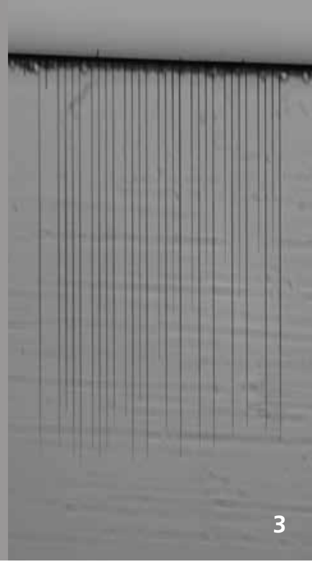
3 Time-resolved reflection of an irradiated glass surface.

4 Pump-probe setup.



TRANSFER OF SELECTIVE LASER-INDUCED ETCHING PROCESS TO NEW MATERIALS

Task

Selective Laser-induced Etching (SLE) is an innovative laser-based manufacturing process for the production of micro and macro components and complex micro components made of transparent materials. The current materials that can be structured or cut in 3D are quartz and sapphire. As part of a project funded by the Federal Ministry for Education and Research, the SLE method is being investigated for processing other materials, such as Borofloat 33 and Willow, in cooperation with the Chair for Laser Technology LLT at RWTH Aachen University and industrial partners. The project aims to open up applications for these materials in the chip industry or microsystems technology, medical and chemical industry.

Method

Selective laser-induced Etching is a two-step process. In a first step the material transparent to the laser radiation is modified internally. For this ultrashort pulsed laser radiation (500 fs - 5 ps) is focused into the volume of the workpiece (1 - 2 µm). In a second step, the modified material is selectively removed by wet-chemical etching. For the digital photonic production of complex components, the path data for the laser focus are created from digital CAD data and synchronously controlled by the microscanner system with CAM software.

1 Glass knot of quartz glass (Source: Fa LightFab).

2 Cutting edge top of a hole in Willow, d = 200 µm.

3 Etched microchannels in Borofloat 33.

Result

In Borofloat 33, etching selectivities have been achieved between laser structured and unstructured regions from about 1000:1, in Willow glass from about 100:1. Further steps will investigate the possibilities for precision cutting or for generating 3D structures in these materials.

Applications

The 3D structures created here can be employed, for example, in biology, the chemical or chip industry and used as micro-components or microfluidic components. Cuts in thin glass can be used to manufacture display glass or interposers for microchip contacting.

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

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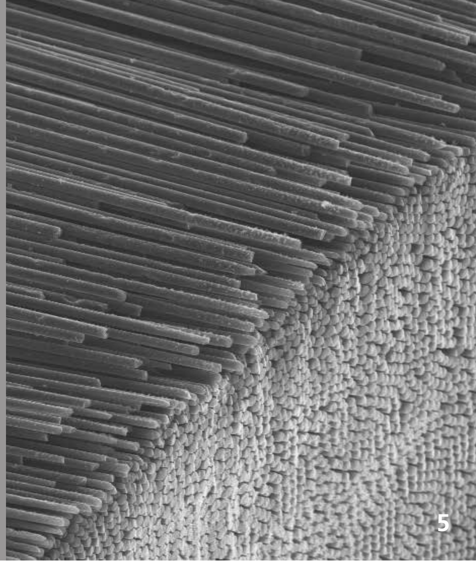

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LASER DRILLING OF CFRP PREFORMS

Task

So that heavy-duty and simultaneously releasable connections of CFRP structural components can be produced, metallic threaded sleeves (inserts) are commonly introduced into the components. Classically, these are glued either to the consolidated component or into the drill hole after a mechanical drilling process. The preparation and application of an adhesive body is complicated, wherein the mechanical processing, with a drill or milling tool, can cause irreparable damage, such as delamination. Therefore, it makes sense to introduce a hole in the textile (preform), which has not yet been impregnated and then consolidate it subsequently. For this purpose, laser-based drilling can be used for textiles with a thickness of several millimeters or which require small drill hole geometries.

Method

To drill 10-layer bi-axial carbon fiber preforms, Fraunhofer ILT used an ultrashort pulsed laser beam source from the company AMPHOS with a pulse duration of 7.6 ps and an average power of 400 W. By means of a scanner, both round and stellate holes can be introduced into the preform. This makes it possible to use custom inserts for component-specific load cases.

Result

Due to the very small tolerances of the drill hole shape, < 20 µm, the insert can be fixed to the preform in a non-displaceable manner. In the subsequent matrix infusion process, a firmly bonded material connection is made. Thanks to the direct connection of the insert with, for example, an epoxy matrix, the extract torque of the insert from the CFRP component can be increased by 15 percent (to 29 Nm) and the extract force increased by 75 percent (to 13.5 kN) compared to conventionally produced CFRP components. At the same time the corrosion protection layer of the insert is not damaged.

Applications

This process, for generating heavy-duty and simultaneously releasable connections, can be used in particular for high-maintenance automotive and aircraft components as well as in the leisure sector.

The R&D project underlying this report has been carried out on behalf of the Federal Ministry of Economic Affairs and Energy under grant number KF2119107AB3.

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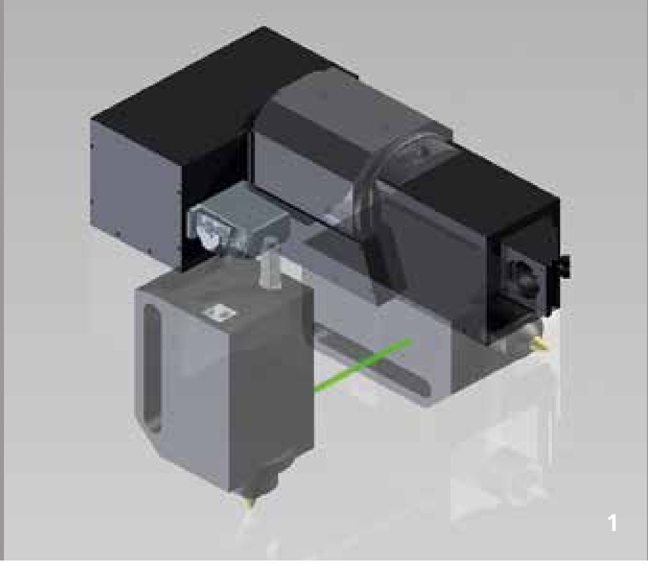
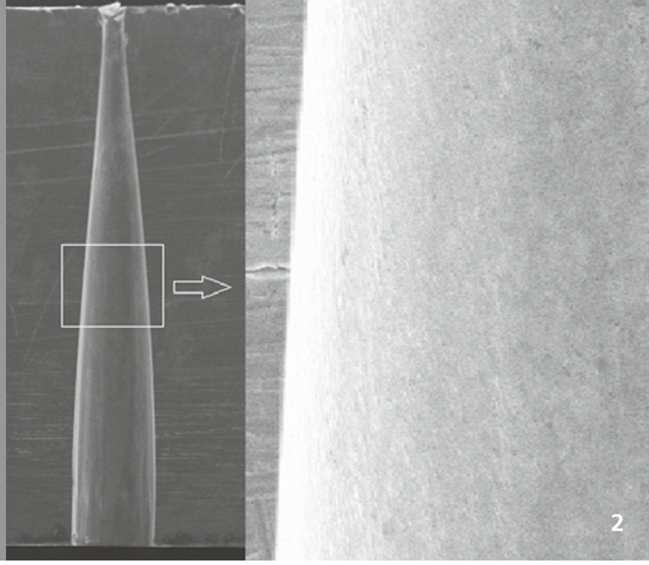
4 Laser-beam drilled CFRP preform.

5 SEM image of the drill hole wall.





MODULAR HELICAL-BEAM OPTICS

Task

To produce accurate holes and cuts, ultrashort pulsed laser radiation is generally used in combination with fast beam rotation. A helical-beam optical system, which moves the laser beam at high speed on a circular path, should be adapted to the requirements of the market with respect to its areas of application and functionality. The goal is a more compact system with enhanced process sensors and automated settings. Care must be taken to ensure system stability and achieve industrially useful process capability.

Method

So that the possible applications can be increased and the integration enhanced, the drilling optical system has been divided into three subsystems. The system consists of steel rotator, camera module and focusing system. In this way, the new camera module and the focusing module can be used separately from the main module. This modular concept is also reflected in the control soft- and hardware.

1 Modular helical optical system with freely adjustable process head.

2 Negative conical bore with an aspect ratio of 25 in 1.2 mm thick steel.

Result

To increase flexibility, Fraunhofer ILT has developed several focusing modules, which can be exchanged as a plug & play modular system without needing to be readjusted. Along with an encoder system of the hollow shaft motor, an integrated CMOS camera allows the adjustment states to be recorded automatically at defined positions of the hollow shaft. Since the DOVE prism is mounted with plastic cup springs and the ultrafine adjustment screws can be adjusted precisely, the system reaches an accuracy in the helical geometry of 1 µm.

Applications

The helical optical system is being used extensively in several industrial sectors. It dominates in several different areas: drilling precision holes with a defined drill channel in up to 3 mm thick metallic and nonmetallic materials, micro-crack-free precision cutting of sapphire and chemically tempered glass, and generating microscopic holes in the range of less than 50 µm with adjustable conicity for diverse applications, such as for microfilters. The combination of the helical design with an ultra-short pulsed laser beam source enables the system to be used virtually independent of the material to be processed.

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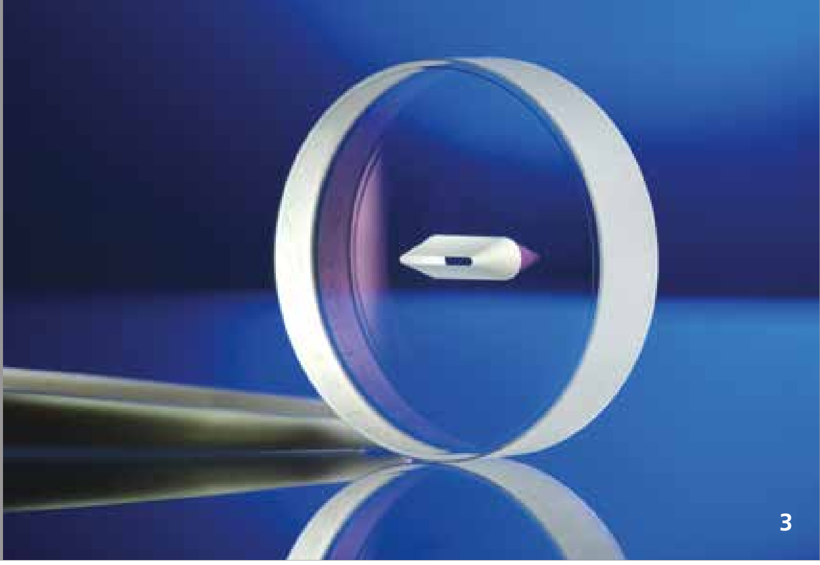

CHIPPING-FREE LASER PROCESSING OF MIRROR SUBSTRATES FOR GEOMETRIC SEPARATION OF RAY BUNDLES

Task

When High Harmonics are generated from ultra-short pulsed laser radiation in enhancement cavities in bow-tie arrangement, there is the problem of outcoupling the Harmonics from the cavity because dichroites do not exist for short wavelengths in the range of some 10 nm. One way of outcoupling is to drill a small hole on the order of 100 µm in one of the resonator mirrors on the optical axis. So that the losses for the Fundamentals are minimized, the mirror surface needs to be as undamaged as possible around the hole. In particular, chipping should be avoided. The hole must be undercut because the incident angle of the Fundamentals and Harmonics on the mirror amounts to a few degrees in the ring resonator.

Method

The undercut openings are structured into the uncoated mirror substrates with Inverse Laser Drilling. For this process, ultrashort pulsed lasers are only suitable to a limited extent due to non-linear effects in the propagation through the glass. Instead, a laser beam source is used with a pulse duration of several 100 ps. First, the process parameters are adjusted to minimize process-related induced tension, as these are partly responsible for chipping. In a further step, Fraunhofer ILT has examined whether the surface can be protected by contact bonding another mirror substrate onto the substrate before processing, and removing again after processing.

Result

Undercut openings of various geometries, adapted to the enhancement cavity's fundamental transverse mode structure, were structured into standard mirror substrates of various optical materials such as quartz glass, Corning ULE and sapphire. With the steps described above, chipping can be prevented completely. Thanks to this, it is possible to drill holes with large aspect ratios and an undercut in polished vitreous bodies without further impairing the polished surface. The method has been patented by the Fraunhofer-Gesellschaft.

Applications

In general, the process can be used to make optical systems with small openings for separating or coupling ray bundles. Examples of this, in addition to the above-described mirrors, include spatial filters and interleaving mirrors.

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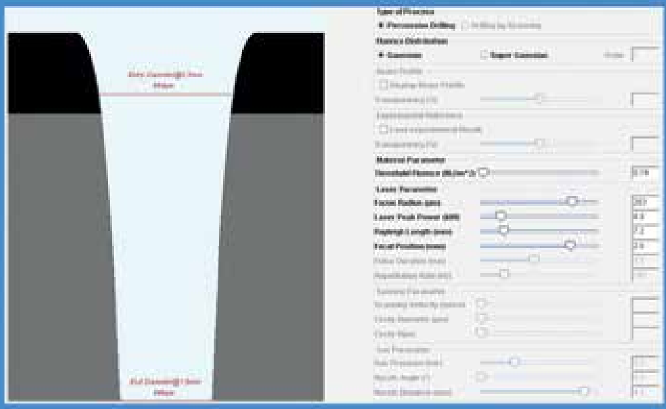
3 Undercut and chip-free slot in a ULE mirror substrate with a diameter of 25 mm and thickness of 6.35 mm.



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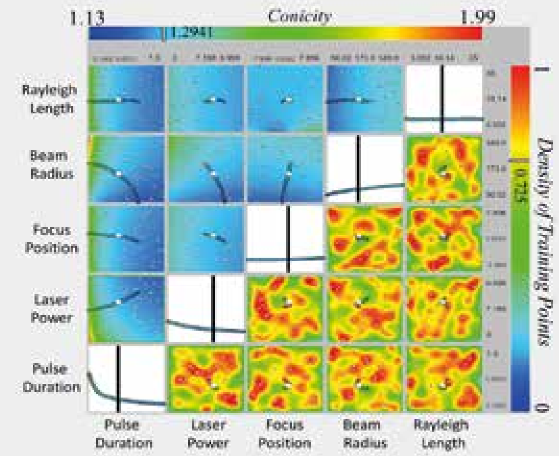

2

INTERACTIVE SIMULATION OF DRILLING WITH LASER RADIATION

Task

Given the ever increasing market requirements and thus complex processes caused by them, simulation is noticeably becoming an indispensable tool for process design and process optimization. This is especially true for laser manufacturing processes. However, usually only a small part of the parameter range can be investigated with current simulation tools because computing capabilities are still limited. In addition, process simulation has not yet been completely integrated into the everyday industrial environment. For example, an interactive and useful process simulation is still not available to assist the machine operator.

Method

Based on reduced models, Fraunhofer ILT has developed »fast« process simulations, which make it possible to study much larger areas of the parameter range. Using the thus generated »dense« simulation data (so-called training data), the institute has created »process maps« (so-called meta-models), which allow, on the one hand, intuitive visualization of parameter dependencies and, on the other, which support the development of process optimization. Both the meta-models and the »fast« simulations allow operators to use them interactively and are designed specifically for use on the customer PC/laptop or smart devices.

Result

As an application example, a reduced model has been developed for the final ablation contour during drilling with long pulsed laser radiation. This model has been implemented in a usable interactive simulation tool (AsymptoticDrill, see Figure 1). Moreover, on the basis of AsymptoticDrill, a meta-model has been developed (Figure 2). Fraunhofer ILT offers both simulation tools as licensed software.

Applications

Both the methodology of the reduced modeling (controlled reduction of model complexity) as well as the techniques of meta-modeling are applicable to all areas of modeling and thus to all processes (not only in the field of laser technology).

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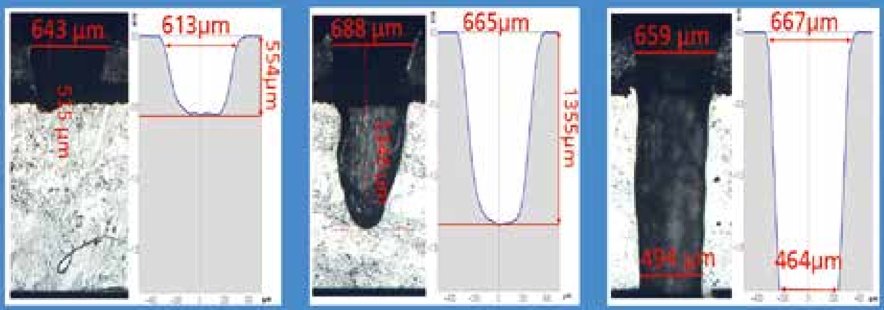
1 AsymptoticDrill: Interactive simulation tool for final ablation contour when drilling with long pulsed laser radiation.

2 Meta-model based on »AsymptoticDrill«.



3

SIMULATION OF THE TEMPORAL EVOLUTION OF DRILL HOLE CONTOUR WHEN DRILLING WITH LASER RADIATION

Task

The asymptotic ablation contour observed when long pulsed laser radiation is used to drill can be excellently described by »AsymptoticDrill«, a software developed at Fraunhofer ILT. However, this software only describes the final contour while assuming constant pulses. A variation of the pulse characteristics during the process can have a significant influence on the drilling and, thus, lead to a significant improvement in quality (for example, cylindrical drill holes). This state creates the need to develop a dynamic ablation model, one which can describe the pulse-resolved evolution of the drill hole.

Method

The aim of modeling and simulation is to describe and predict the pulse-resolved evolution of the drill hole on the basis of a reduced ablation model. According to the asymptotic ablation model, this new model should allow the customer to implement interactive simulation software for direct use.

Result

A reduced ablation model, which describes the pulse-resolved evolution of the drill hole, has been developed, numerically implemented and confirmed by comparison with experimental data (Figure 3). Fraunhofer ILT will offer an interactive simulation software (»DynamicDrill«) for use on a PC, laptop or smart devices in the spring of 2016.

Applications

In addition to the application described here, drilling metals with long pulsed laser radiation, the developed ablation model can also be applied in the field of USP ablation of dielectric and semiconducting materials.

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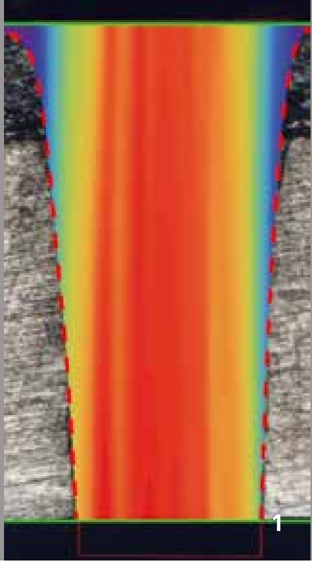
3 Comparison between the simulated drill hole contour and experimental results.



SIMULATION OF ASYMPTOTIC DRILL HOLE CONTOUR WHEN DRILLING WITH LASER RADIATION

Task

When long pulsed laser radiation is used for drilling, a so-called asymptotic ablation contour can be observed after a certain number of pulses. This contour is characterized by the fact that it changes only very little or not at all with irradiation by further pulses. Already well known from USP ablation of dielectric and semiconducting materials, this finding has been explained by Fraunhofer ILT when beam intensity falls below a threshold value.

Method

The aim of modeling and simulation is to describe and predict the final asymptotic drill hole contour, i.e., the hole shape, which no longer changes with further irradiation. In addition, the mechanism which leads to such asymptotics in the drill hole form should be identified and explained. This explanation cannot be extracted from the experimental results alone by mere observation.

Result

The explanation for why an asymptotic drill hole shape occurs has been developed, its underlying mechanism numerically implemented, tested and confirmed in comparison to experimental results (Figure 1). Fraunhofer ILT has implemented an interactive numerical tool that can illustrate – in real time – the impact on the resulting hole shape when process parameters are changed. This tool was especially designed for direct use by the customer and is offered by Fraunhofer ILT via a software license.

Applications

Originally, the basis for the observation of an asymptotic drill hole form comes from considerations on USP ablation, in which an asymptotic ablation contour occurs in the same way and was observed first. That this principle has proven to be valid also for ablation with long pulses seems to suggest that the same or similar principles can be applied to other laser manufacturing processes.

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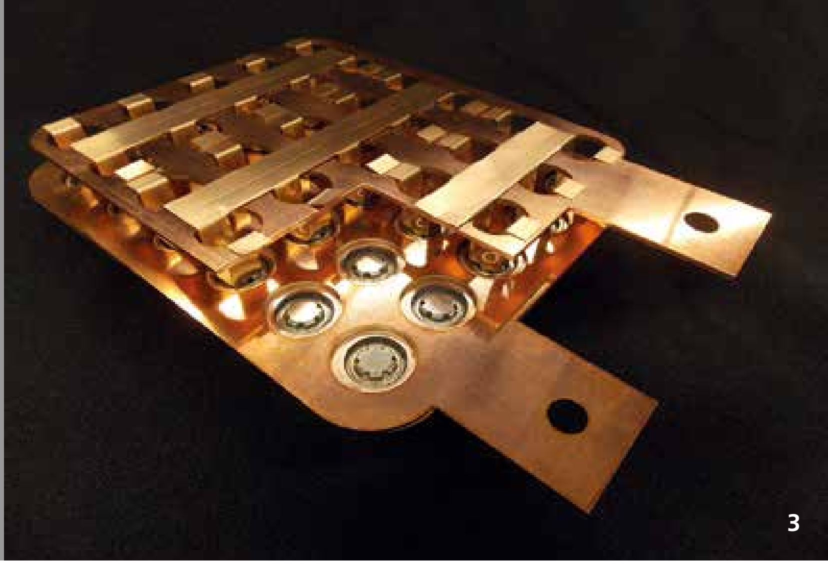
1 Comparison between simulated asymptotic drill hole contour and experimental results. The color scale describes the beam distribution.



LASER-BEAM MICRO-WELDING FOR THE CONTACTING OF LITHIUM-ION CELLS

Task

Since the demand for rechargeable batteries in electric vehicles and stationary energy storage systems is increasing, while individual cells still currently have low capacity, the connection technology of individual cells to powerful modules will become increasingly important in the near future. For this, joining processes capable of series production need to be developed.

Method

Due to its precise energy input, laser micro-welding has proven to be a suitable process for this application. So that the weld quality and process stabilization can be improved, local power modulation can be applied, wherein the global feed is superimposed with a circular oscillation. The connection technology was studied in different cell types (for example, an 18650 or a pouch cell). While safety factors are taken into account, the necessary connection cross-sections can be dimensioned and achieved by means of the welding parameters.

Result

The contacts can be produced reproducibly and reliably. Dissimilar materials can be joined by welding with local power modulation and the connection cross-section increased due to the additional lateral beam deflection. Thereby, a decrease in strength can be counteracted by the formation of intermetallic phases.

Applications

The welding strategy described here can be used to connect batteries in electric mobility and in stationary applications. Similarly, the findings can be applied to joints of electric cables and contacts in power components. An example of application was the welding of lithium-ion cells for the »Ecurie Aix Formula Student Team« of RWTH Aachen University.

The results achieved here stem partly from a project funded by the Fraunhofer-Gesellschaft (grant number 826 472, »Fraunhofer System Research for Electromobility II«).

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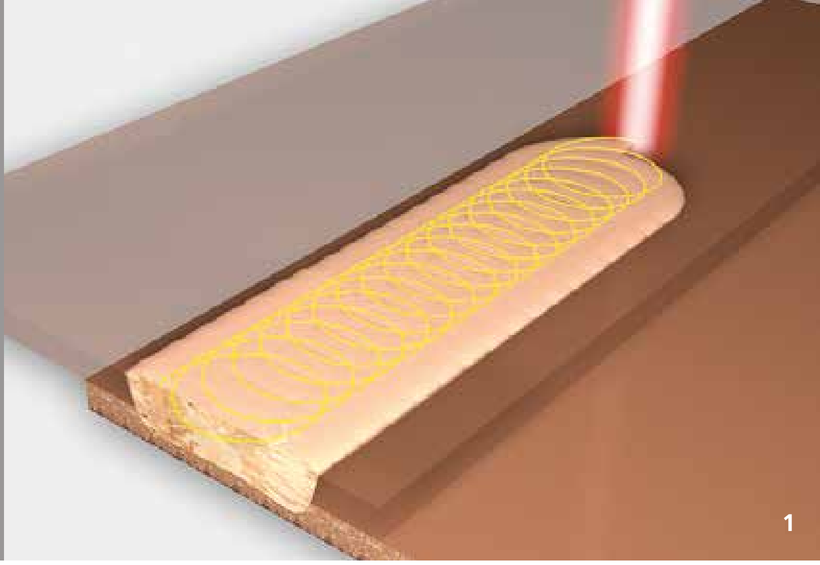
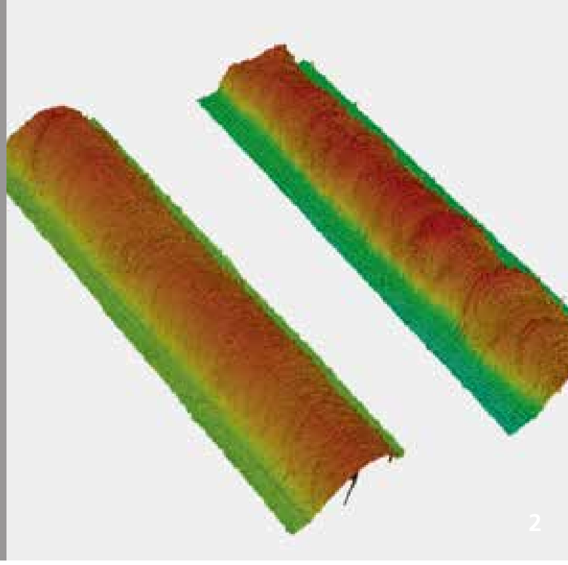
2 Welding on Li-ion pouch cells.
3 Joined macrocell consisting of 30 18650 cells.





TARGETED INFLUENCE OF SEAM GEOMETRY FOR LASER-BEAM MICRO-WELDING

Task

Metallic materials are being joined by means of laser radiation more and more often since the process can be automated and delivers consistent results. Depending upon the application, the quality of the weld is quantitatively evaluated with the help of seam surface roughness, welding depth consistency or the connection area. When the energy input is spatially resolved, these quality characteristics can be influenced selectively in order to satisfy application-specific requirements.

Method

For the local power modulation, the feed movement is superimposed by an additional oscillation, which greatly extends the frame in which laser beam welding can be deployed. In addition to the parameters laser power, beam diameter and feed speed, the local power modulation has opened up other parameters to control melt pool and to selectively form both seam and structure.

1 Path of the laser beam during local power modulation.

2 Comparison of seam surface roughness with and without use of the local power modulation.

Result

When local power modulation is used, the average roughness of a weld on a copper alloy can be reduced by up to 70 percent. The average roughness is a quantitative measure of the voids on the weld surface. Moreover, when the parameters are adjusted, a connection cross-section enlarged by a factor of three can be generated, in contrast to what conventional laser beam micro-welding can produce.

Applications

This laser welding technology in the fine and micro range can be found, for example, in power electronics or battery technology. The improved ways to increase the reproducibility and the targeted seam shaping can be applied to other applications such as in medical technology.

The works shown were promoted by the German Research Foundation (DFG) within the Collaborative Research Center 1120.

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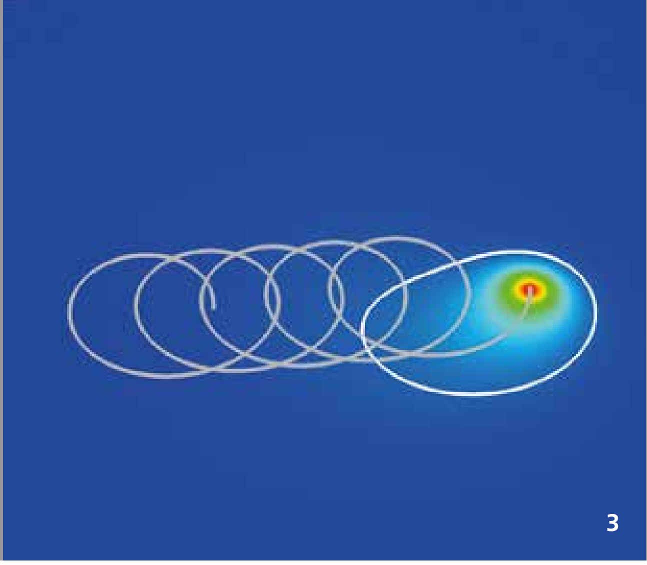

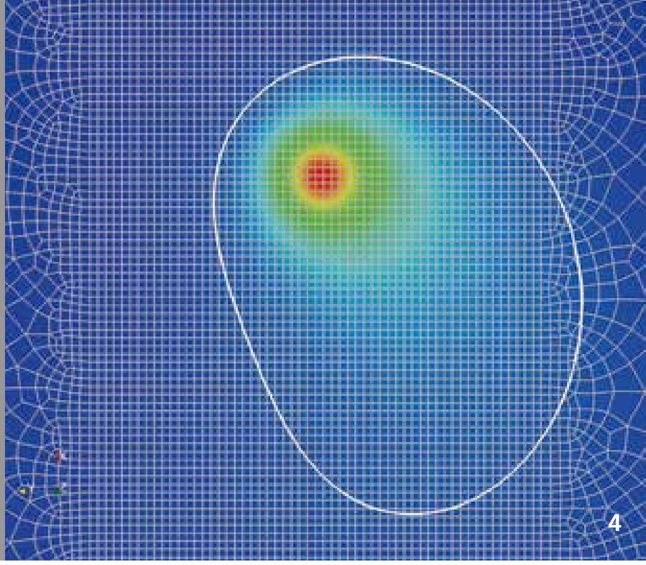

FAST TEMPERATURE FIELD CALCULATION IN MICRO WELDING

Task

Understanding the temperature distribution present during the welding process is a prerequisite for calculating distortion and residual stresses in the component. The thermal effect of the process on the component can be abstracted by using equivalent heat sources. So that the temperature distribution matches the experiment satisfactorily, it is necessary to calibrate the model parameters of the heat source. Refined mathematical and numerical methods are required to facilitate an automated and fast calibration of these heat source parameters.

Method

Selecting a suitable heat-source model depends to a great degree on the particular task. For the calibration of the heat source parameter, an objective function is formulated which makes it possible to automatically adjust the simulation results to experimental reference data of the micro-welding process. For this task, local optimization methods are used. A significant acceleration is achieved by applying the numerical model reduction method »Proper Orthogonal Decomposition (POD)«. To solve the heat conduction task, Fraunhofer ILT used its own fast parallelized FEM code. The methods applied are characterized by a high degree of flexibility because they do not place any restrictions on the material properties or the component geometry.

Result

A heat-source model was successfully used for the analysis of a melt pool surface on the upper side of a workpiece during laser-beam micro welding with local power modulation. The simulation is capable of imaging oscillations of melting pool surface, which are observable in the experiment and come about because of the changing process control.

Applications

The methods developed allow a fast and reliable calculation of the temperature distribution during laser welding process characteristics such as temperature, stress and distortion during welding.

The work presented here was funded by the German Research Foundation (DFG) within the Collaborative Research Centre 1120.

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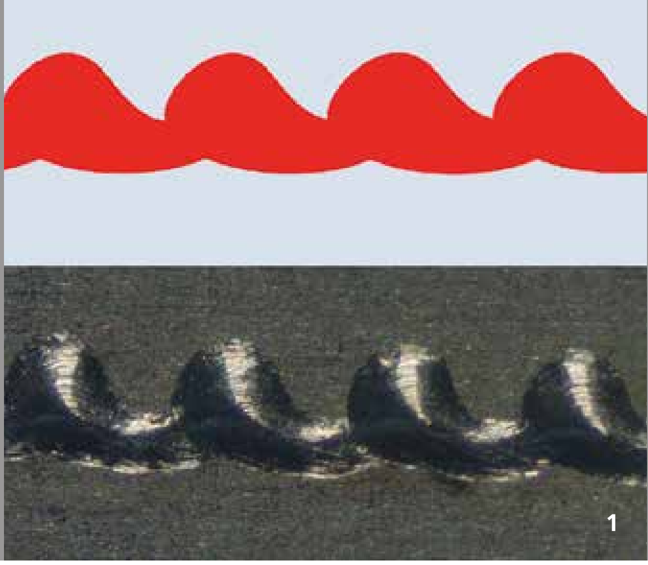
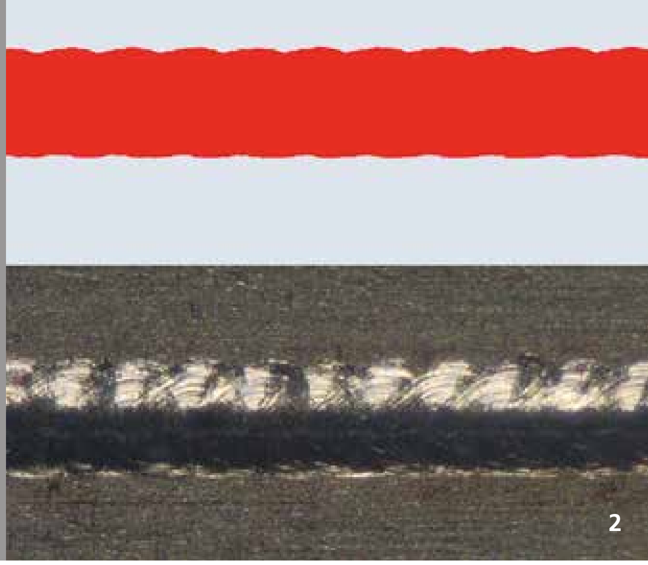
3 Calculated temperature field and presentation of melt pool isotherm during laser micro welding with local power modulation.

4 Top view of the welding process from image 3 with mesh.





SIMULATION OF WELD FORM FOR WELDING WITH LOCAL POWER MODULATION

Task

Fiber lasers with high beam quality and small focal diameters generally allow high process speeds. Their small interaction zone, however, leads to connection cross-sections that do not guarantee sufficient seam strength. In order to control the connection cross-section, a circular oscillation is superimposed on the linear feed movement. The shape of the weld seam is examined for different oscillation parameters, such as frequency and amplitude, using the example of the steel X5CrNi18-10.

Method

The weld bead is determined by calculating the temperature field with the software »Comsol Multiphysics®«. As a result, the area of the component surface is recorded whose temperature has exceeded the melting point at least once during the simulation. The results are compared with top-view photographs of seams from blind welding tests.

Simulated and experimental seam bead at:

1 ... 200 Hz.

2 ... 600 Hz.

Result

The welding tests have been carried out with the following parameters: laser power 100 W, focus diameter 30 μm, feed 100 mm/s, amplitude 100 μm, frequency 200 and 600 Hz. Figure 1 shows the simulated and experimental seam bead for 200 Hz, Figure 2 for 600 Hz. The feed direction is from left to right, the oscillation moves counterclockwise. Basically, the calculated bead shape corresponds to the measured shape. With a sufficiently large frequency, homogeneous seam widths, or a uniform connection cross-section, can be achieved. This way a tool has been made available for the dimensioning of electrical contacts and which can be used to observe connection cross-sections in dependence on the material characteristics and the laser parameters when the component is designed.

Applications

Micro welding with laser radiation is commonly used in the automotive industry. Here, in particular, this application is interesting for the current-carrying capacity for electric contacts in power electronics or batteries as is its mechanical strength for the production of micro-mechanical components such as filters or sensors.

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LASER BONDING IN BATTERY TECHNOLOGY

Task

When battery modules and packs are manufactured, the individual cells are always connected such that higher voltages or capacitances can be generated. Thus, the joining of the individual cells is a critical manufacturing step which requires reliable, low resistance connections, stable processes and a high degree of automation. In this case, production needs to be highly flexible.

Method

A machine built within the scope of the publicly funded project »RoBE« (Robustness for Bonds in Electric Vehicles) – the Laserbonder – should be used for the joining task described above. Since the welding process »oscillation welding« has been integrated into a conventional ribbon bonder, a new machine technology has been created, in which a new laser welding process is used instead of conventional ultrasonic bonding. The project focused on applications for the electrical contacting of electronics, particularly power electronics. When the project was concluded, first feasibility studies were conducted to investigate the wider use of the process. It was shown that, when the process was combined with the feed of a flexible connector (ribbon), an excellent opportunity was created of contacting battery cells.

Result

This method is applicable for all prismatic and cylindrical battery cells. In particular, the process is characterized by the possibility of generating the connections quickly, flexibly and effortlessly in terms of positioning, of contacting the individual cells and, therefore, of producing modules or packs. Here, too, both the use of aluminum and copper materials is possible.

Applications

The machine technology and the process can be used in wide areas of the power electronics and the battery industry. Laser bonding can be used to great advantage especially where fast and flexible contact solutions are required.

The R&D project »RoBE« underlying this report has been carried out on behalf of the Federal Ministry of Education and Research under grant number 13N11464.

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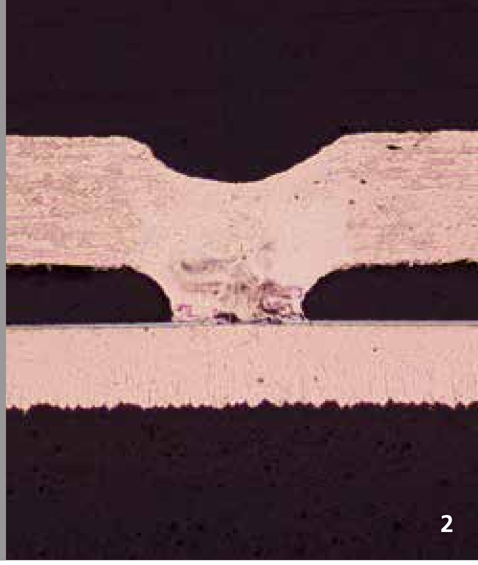
3 Top of a 18650 battery cell with welded copper strips.

4 Example of the construction of a four-cell 18650 module with contact on both poles of the upper side.



LASER IMPULSE METAL BONDING

Task

As the requirements in electric mobility and high-performance electronics become more demanding, the industry is looking more and more to power electronics components that have high strength and thermal stability. Conventional joining processes of electronic components, such as soldering or wire bonding, are of limited use in these applications due to the low melting points of the solders and small cross-section of the wire bonds. A method is required that can join thick copper connectors to thin metallization layers on sensitive substrates without causing any damage.

Method

In the innovative process approach »Laser Impulse Metal Bonding« (LIMBO), the two process stages – melting of the interconnector and joining on the metallization – are separated energetically. The process is driven by the acceleration of the melt over the gap, which is achieved by temporal modulation of the laser beam. As the energy of the melt is transferred to the metallization material, a weld joint is generated in the intersection between deflected melt and metallization. This leads to a minimal welding depth in the µm range in combination with a large joining diameter.

1 Copper connector contacted to metallization circuit board.

2 Cross-section of copper weld on circuit board metallization.

Result

The process makes it possible to weld 200 µm copper sheets on 10 µm metallization layers on FR4 circuit boards. Since the welding penetration depth is minimized to one wetting process, the critical temperature of the circuit board is not reached, and a reproducible joint is generated.

Applications

The process enables thick connectors to be joined to sensitive substrates in semiconductor technology (silicon-based components) or electronic engineering (FR4 circuit boards) without damaging the substrate. In addition to joining on sensitive substrates, process approach is applicable for joining of metal components with high gap tolerances.

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

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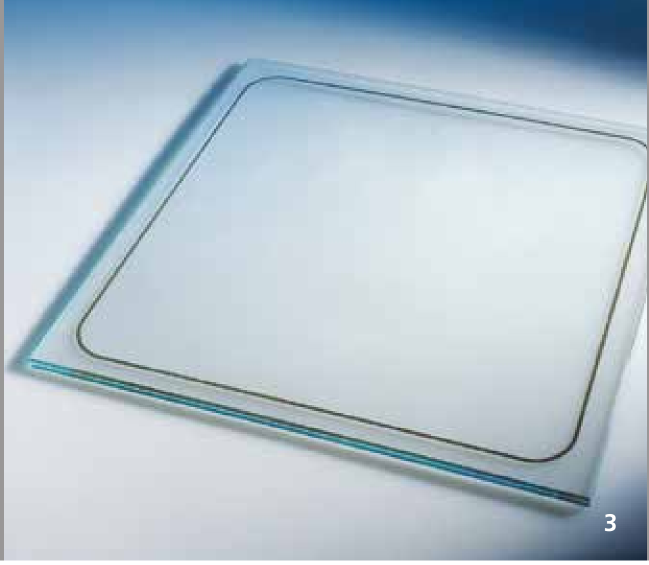

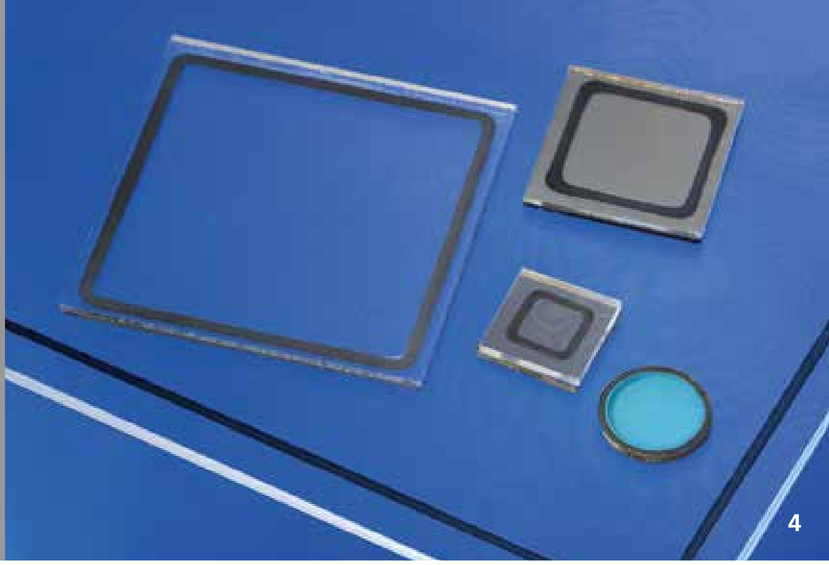

GLASS FRIT BONDING – A PROCESS FOR MICRO AND MACRO APPLICATIONS

Task

The laser-based glass frit bonding now represents a serious alternative to conventional joining techniques when temperature-sensitive electronic components need to be encapsulated. That it is suitable for industrial use has been demonstrated by hermetically sealed components in the field of microsensors. Their typical housing geometries range from a few square millimeters to several square centimeters. In this new process, the bond is formed within a few seconds as the energy is introduced into the joining zone to a spatially limited extent by a quasi-simultaneous irradiation strategy. The laser beam is guided repeatedly over the soldered contour at very high speeds with the aid of a scanner system (~ 1000 mm/s), which however limits component size. Since the process offers great benefits for large-area applications, further development of the process technology for macro applications is required.

Method

Applying this process to large components is possible by replacing the quasi-simultaneous strategy with a serial irradiation strategy. In the so-called contour soldering process, the laser beam is moved continuously over the joining zone. The bond forms continuously in series in the region of the glass solder contour, which the laser beam passes. The component size is not limited by this type of process strategy; depending on the material and application, feed speeds of 15 mm/s can currently be achieved.

Result

Different irradiation strategies enable laser-based glass frit bonding to be used both for micro and for macro applications. Matched to the joining task, the irradiation strategy generates a homogeneous, crack-free bond.

Applications

Possible applications include the closure of microsensors and microactuators as well as the encapsulation of OLEDs and displays. Also, this laser-based process could be used to generate the edge seal of vacuum-insulated glazing.

Work on the laser-based glass frit bonding of vacuum-insulated glazing was funded by the Federal Ministry of Education and Research within the scope of the »ILHVG-VIP« project under grant number 03V0714.

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3 Contour soldered soda-lime glass plate (dimensions: 340 x 340 mm²).

4 Examples of the quasi-simultaneous laser-based glass frit bonding of different materials (dimensions: 10 - 80 mm²).

LASER PROCESSES IN PLASTICS PROCESSING

Task

The requirements upon processing methods in plastics technology today are manifold. The Fraunhofer Institute for Laser Technology ILT has developed and qualified individual processes for the welding, cutting, drilling, structuring and marking of plastics.

The technology demonstrator model presented here was designed as part of a technology study and shows a wide range of laser-based methods that can be successfully applied in plastics processing.

Method

For the production of the demonstrator model, a process chain was set up during the technology study, which covered the following process steps:

- Cutting PMMA in various thicknesses (0.3, 1 and 2 mm) with CO_2 lasers
- Removing PMMA in the form of microfluidic structures with CO_2 lasers
- Absorber-free laser welding PMMA with diode laser radiation (λ = 1660 nm)
- Laser microstructuring stainless steel (1.4301) with fiber laser radiation (λ = 1064 nm)
- Joining a plastic-metal hybrid compound with diode laser radiation (λ = 940 nm)

1 Components of the technology demonstrator model.

2 Joined demonstrator model.

Result

Based on the demonstrator model, the institute can show the diverse applications of laser technology in the processing of plastics. All laser-based methods are characterized by a high flexibility, high automation and an energy deposition precisely adjustable to time and location.

Applications

Given the broad spectrum of the procedures, this laser technology is suitable for plastic machining in almost all industries, from the automotive industry via the electric industry to the food and health industries.

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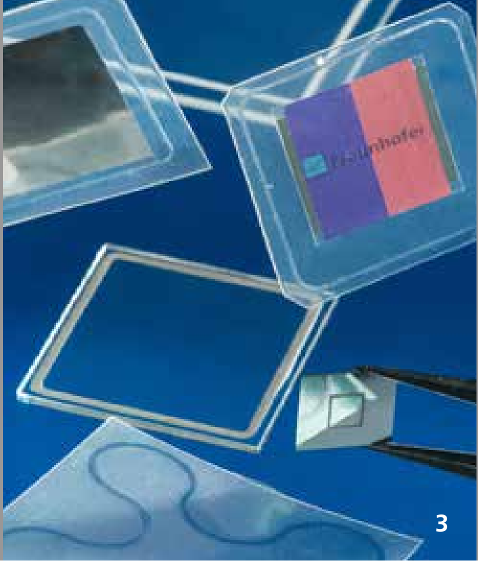

ENCAPSULATION BY LASER WELDING OF MULTILAYER PLASTIC FOILS

Task

Developments in the course of renewable energies as well as the trend towards mobile devices have led to ever more intricate, complex electronic components, which partially require the use of highly sensitive materials such as lithium or organic conductors and semiconductors. These materials often react very sensitively to water and oxygen. To prevent this interaction with the environment, high-barrier multilayer films have been developed. Thanks to special barrier layers, these films, often very thin, prevent water and oxygen from permeating, or reaching the sensitive components. The base substrate of the film is usually a polymer which provides the film with high flexibility. Conventionally, the protected components are bonded peripherally to the foil or welded so that a pocket results, which, for example, contains the flexible organic LED. This new joining technique, laser welding of multi-layer polymer films, promises higher throughput and format flexibility.

Method

Polymers have specific absorption bands in higher wavelength regions. The location and intensity of these absorption bands is dependent upon the polymer. A suitable laser beam source can be used to melt only one layer in a multilayer film consisting of various polymers. This makes it possible to locally melt the bottom layer in order to weld it to the opposite sheet during laser transmission welding, for example. No energy is deposited in the overlying layers.

Result

Welding tests and thin sections show spatially limited melting in the targeted layer and no melting in the overlying layers.

Applications

This technology can be used in a wide range of applications: from food packaging with lower requirements on the tightness to water and oxygen, via medical packaging with more stringent requirements, all the way to the encapsulation of organic LEDs and solid-state lithium batteries described above.

The R&D project underlying this report has been carried out on behalf of the Federal Ministry of Education and Research under grant number 13N13241.

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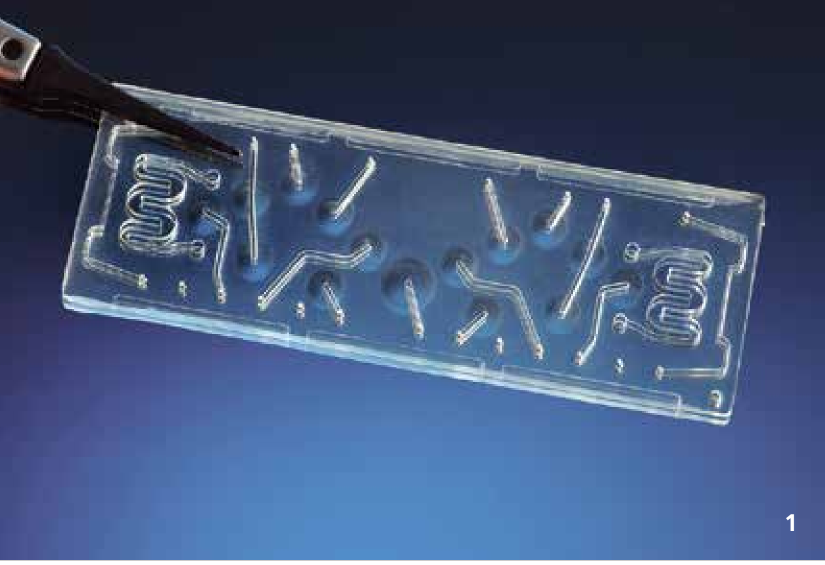
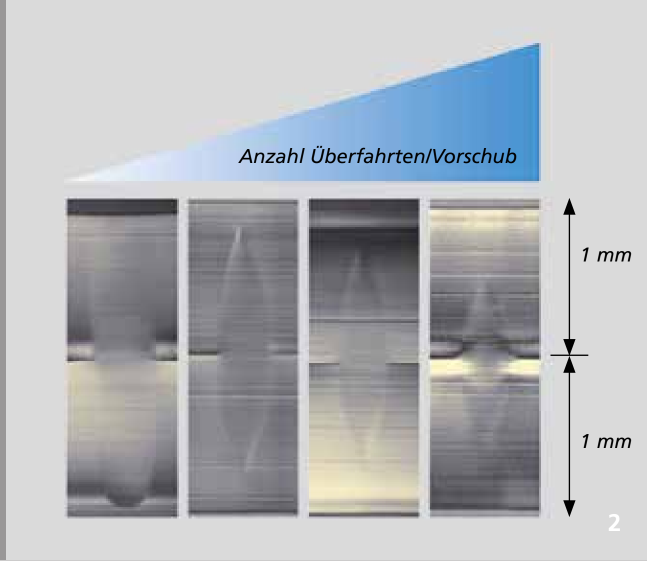
3 Encapsulated demonstrators.





QUASI SIMULTANEOUS WELDING OF ABSORBER-FREE THERMOPLASTS

Task

Since thermoplastics are transparent in the wavelength range of classical beam sources used in laser beam welding (800 - 1100 nm), a joining partner usually requires a modification: an absorbent layer is needed so that the laser radiation is absorbed. However, when appropriate beam sources are used, intrinsic absorption properties of thermoplastics can be exploited so that two plastic parts can be welded together without requiring additional absorbers. Here, the challenge is to fuse both joining partners in the contact area as selectively as possible.

Method

So far, a selective melting of the contact region has not been achieved despite adjusted wavelength and strongly focusing optics. The heat affected zone (HAZ), which extends far along the beam axis, can lead to distortion in flat components, such as lab-on-a-chip applications (Figure 1), and, moreover, promote melt discharge and burns on the irradiated surface. A more compact HAZ can be achieved by quasi-simultaneous welding in which the laser beam is repeatedly guided along the weld contour in succession at very high feed rates (> 1 m/s). Due to the poor thermal conductivity of plastic materials, the heat in the joining zone is accumulated while it is discharged at the upper and lower sides by the elements of the clamping device (glass, aluminum), which have a much higher thermal conductivity.

Result

Compared to the contour method, this absorber-free welding process generates a substantially more compact HAZ in the beam direction because of the quasi-simultaneous irradiation (Figure 2). The almost uniform heating of the entire welding contour generates a joining path with which remaining gaps can be leveled out between the joining parts. Despite the radiation passing over the joint repeatedly, the welding time is comparable with the contour welding processes due to significantly higher feed rates.

Applications

The method presented here is primarily targeted for applications in medical technology (Figure 1) in which the use of absorbers may present a risk to biocompatibility. However, the method can be used in other applications where optical absorbers are inadmissible due to economic or functional reasons.

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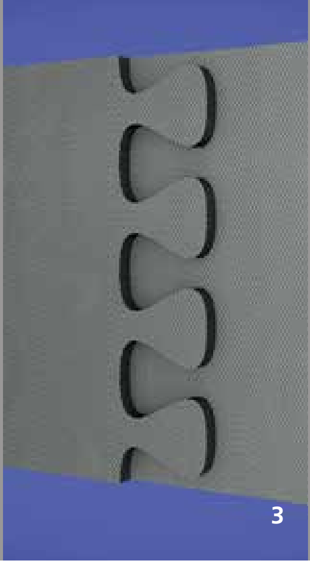
1 Example of a microfluidic component.

2 HAZ with increasing number of pass-overs.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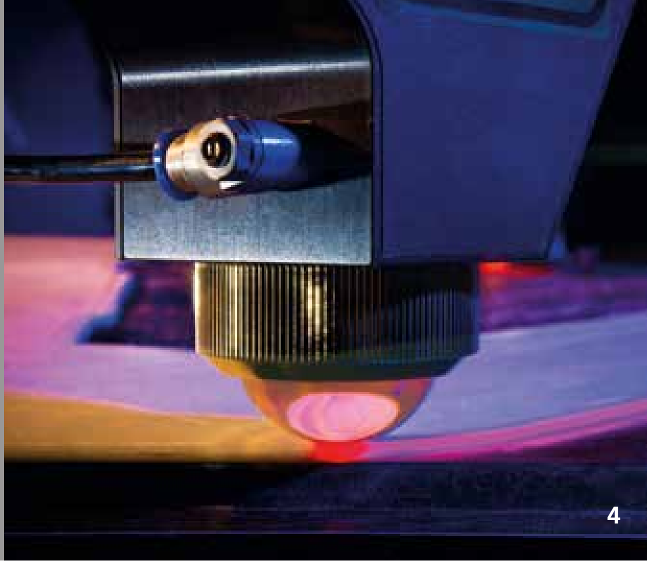
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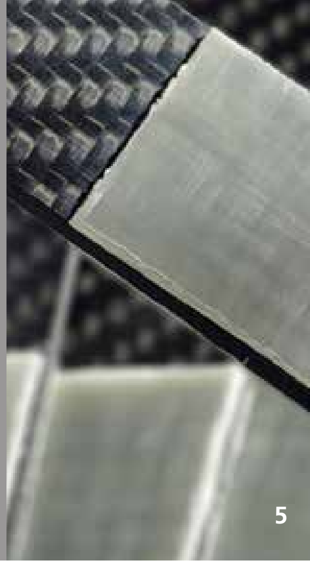
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POSITIVE AND DIRECT JOINING OF CFRP AND GFRP

Task

The industry faces an increasingly important challenge: to save raw materials and energy both in manufacturing and in the use of products. And yet the performance of the components needs to be preserved, if not even increased. This applies particularly to the automotive and aerospace industry, where innovative lightweight designs are increasingly being used to reduce dead weight, thereby contributing to a reduction in fuel consumption and environmental emissions. Here, components of thermoplastic fiber-reinforced plastics (TP-FRP) are increasingly being produced, which can have both carbon- and glass-fiber reinforcement.

Method

With a new laser-based approach, Fraunhofer is pursuing an innovative joining concept, which is based on a combined positive locking and direct bond. First, in a multi-pass laser cutting process, the interlocking components are manufactured out of CFRP. This process makes it possible to produce a high quality cut edge with the required high accuracy for the positive connection thanks to short interaction times between laser radiation and material. Subsequently, the cut components are inserted into each other and fixed together with a laser welding process. For this purpose, a laser-transparent glass-fiber reinforced material is used, which has the same matrix material of the CFRP components. The GFRP material is overlapped on the positive sector, connected cohesively in a laser transmission welding process and, hence, the positive fit is fixed transverse to the loading direction.

Result

Initial test samples were manufactured with the bonding concept described here. By scaling and arranging the form-locking elements, the institute can adapt the design of the connection to the loading conditions. Investigations on the size and shape of the elements and on the transmission joined surfaces will offer potential to further optimize the processes.

Applications

The processes demonstrated in this bonding approach for welding and cutting thermoplastic FRP components provide an alternative to mechanical processing and to joining by screw, riveting and adhesive bonding for the bonding technology of different components and material options. These processes may also be used to repair fiber-reinforced composite components.

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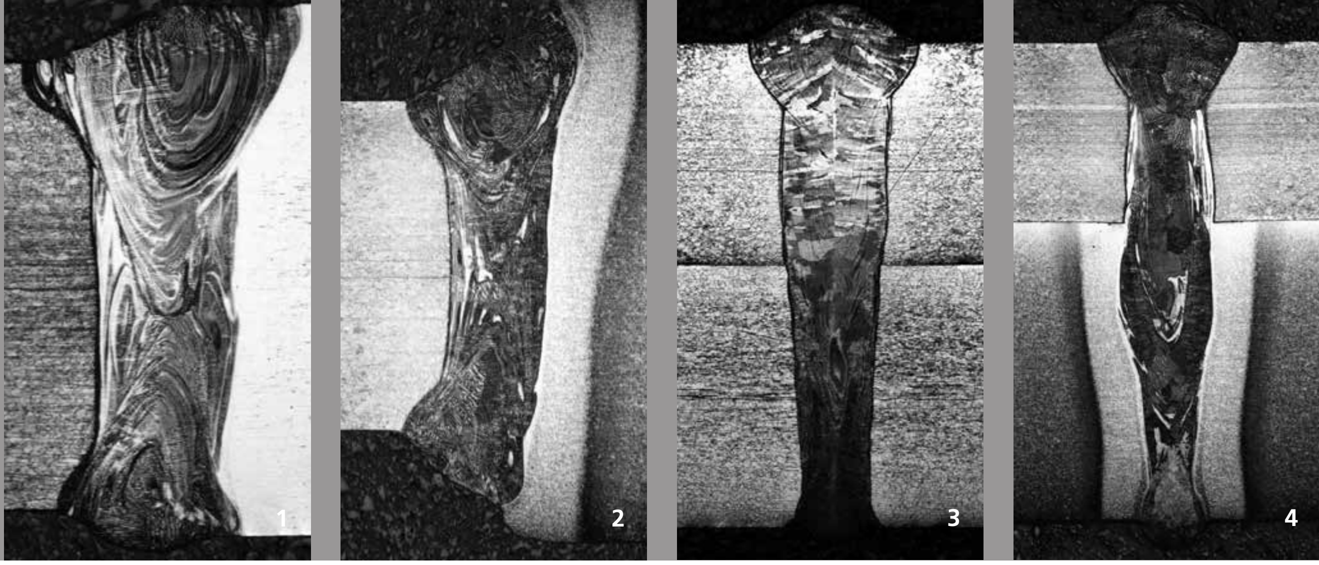
3 Workpiece edge with positive locking geometry.

4 Laser transmission joining of the cover layers.

5 Connection generated by form and material closure.



WELDING HIGH-MANGANESE STEELS IN DISSIMILAR COMPOUNDS

Task

High-manganese austenitic steels are characterized by a high plasticity and an increase in strength when they are cold formed. This makes them ideal candidates for lightweight construction. Despite their high carbon content, these steels prove suitable for welding, whereas the weld seams have a high degree of deformation. The combination with other standard materials and ultrahigh-strength grades of steels should be examined from a technical and welding-based perspective.

Method

The project shall examine the weldability of dissimilar compounds with 1.4678, cold worked to 1100 MPa (H1100), on the one hand, and 1.4301 (X6CrNi18-10) or hardened 1.4034 (X46Cr13), on the other. As a part of the investigation, the effect of autogenous laser welding shall be tested, without pre- and post-heating, on seam geometry, mixing behavior and hardness.

1 Butt joint 1.4678/1.4301.

2 Butt joint 1.4678/1.4034.

3 Lap joint 1.4678/1.4301.

4 Lap joint 1.4678/1.4034.

Result

The cold-formed manganese steel loses strength in the cast structure of the welding seam. In conjunction with the metastable 1.4301, a smooth transition of strength can be achieved in the butt joint. In the lap joint, the strength is maintained in the connection zone since martensite is partially formed as a result of mixing. In connection with the hardened 1.4034, a drastic loss of hardness occurs. This is due to the dilution with manganese, whereby the formation of soft austenite is promoted. The basic investigations show that a welding of the above combinations is possible in the thin-sheet range. Whether and how far the strength can be produced by heat treatment or stress again is being examined as the work continues.

Applications

The process can be used wherever an application can take advantage of the combination of high elongation and high strength with predominantly static loading. For example, web-core sandwich panels may be constructed of steel with improved damping properties. Due to the narrow welding seams, further constructive possibilities exist, but whose potential has yet to be explored.

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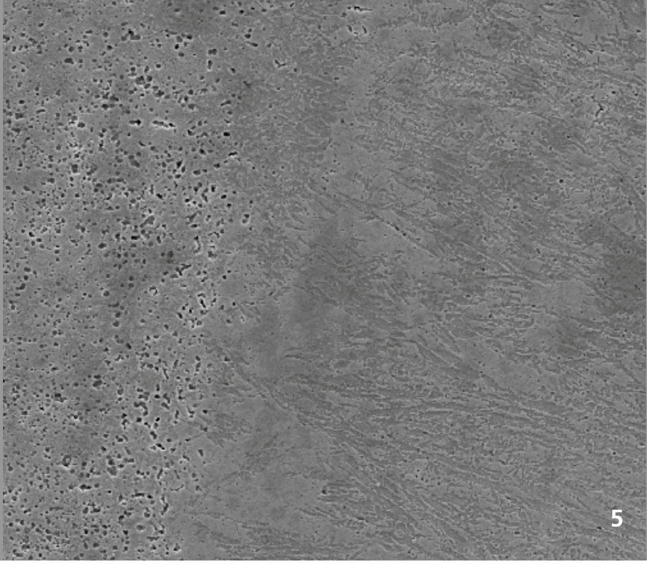

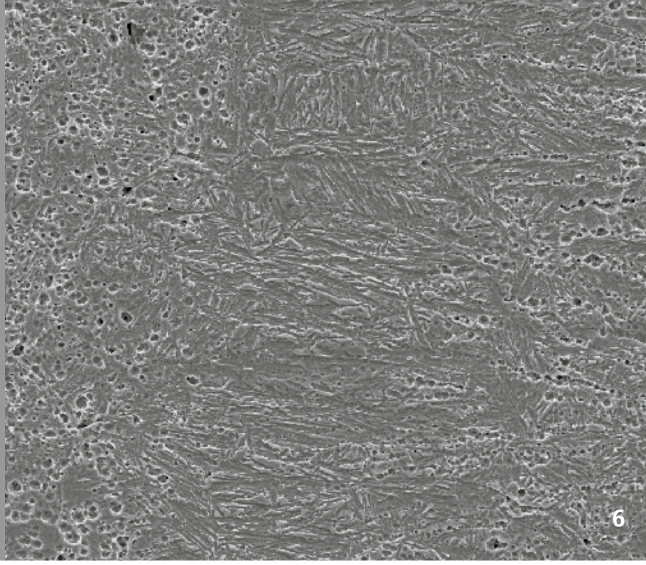

SENSITIZATION IN WELD ZONE OF PRESS HARDENED MARTENSITIC CHROMIUM STEEL

Task

Steel with more than 12 weight percent of chromium is intrinsically resistant to corrosion. For this reason, different grades are commonly used in the vehicle engineering and in vessel manufacturing. Their strength can be increased by press hardening; with increasing carbon content, greater strength is achieved, wherein laser beam welding is used for joining. This project shall examine how and in what way a corrosive attack occurs on welded joints.

Method

The investigation aims, on the one hand, to test if the oxalic acid test can be applied to martensitic steels. On the other hand, it shall investigate the susceptibility of the weld zone to corrode in press-hardened metal sheets and in welded plates after press hardening. The tests were conducted on grades with a carbon content from 0.03 to 0.46 percent by mass.

Result

Thanks to the comparative tests, it has been shown that the oxalic acid test is applicable to the examination of press-hardened stainless chrome steels according to ASTM 763-83. In welding seams in press hardened materials, corrosion sensitivity increases with the carbon content and application of welding heat treatment. If the steels are press-hardened after welding, dual etched structures occur only sporadically on steel with the highest carbon content.

Applications

The ASTM 763-83 makes available a method for the simplified testing of intergranular corrosion. The results show that stainless chromium steels with a martensitic structure do not exhibit any loss in their corrosion resistance on tailored blanks where press hardening is applied after welding. When press-hardened materials are welded, there is a sensitization. Nevertheless, the resistance to intergranular corrosion is significantly higher than that of unalloyed steels. For many applications there is now a statement on the weldability of the grades considered here.

The R&D project underlying this report has been carried out on behalf of the Federal Ministry of Economic Affairs and Energy under grant number IGF 17.433 N.

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5 1.4034 press-cured after welding.

6 1.4034 welded after press hardening.

REPAIR OF JET ENGINE COMPONENTS BY LASER-BASED CUTTING AND WELDING

Task

Depending on their function and operation, engine components are subjected to high thermal and mechanical wear. For aircraft that were put into operation in the 1960s, it is becoming more and more difficult to find spare parts. For these reasons, the repair of specific components is an important method to preserve the value and function of these engines. Laser Metal Deposition has become an important method for their repair and overhaul.

Method

The target of various studies is to find the operational capability of the laser cutting and welding as a repair method for aircraft engine components. Fraunhofer ILT has developed a process oriented to the variety of the machined components and materials and that is a reliable approach for the reprocessing of previously used components. The process begins at the first weldability testing and ranges from apparatus construction, via the definition of service regulations all the way to the acceptance of procedures and components.

1 Separated, purified and re-welded lubricant container.

2 Exchange of connecting protrusions on a compressor outlet housing.

Result

Initially, the suitability for welding has to be checked for materials aged during operation. Here, precipitates can form at the grain boundaries depending on operating temperature, which can result in liquation cracks during joining. It is possible to prevent them when a minimum supply of energy is set, which is one of the strengths of laser welding. The concentrated energy input also enables design changes to components that will be accepted due to the limited thermal influence by the licensing authorities. Prior to the application of laser cutting, internal structures may not be damaged or their damage must be minimized. In many cases this is possible by a suitable cutting control.

Applications

The methods developed here are primarily used for components of aircraft engines. Beyond reprocessing, they can also be used for the production of new components. A transfer to other components subjected to wear and high temperatures is also conceivable.

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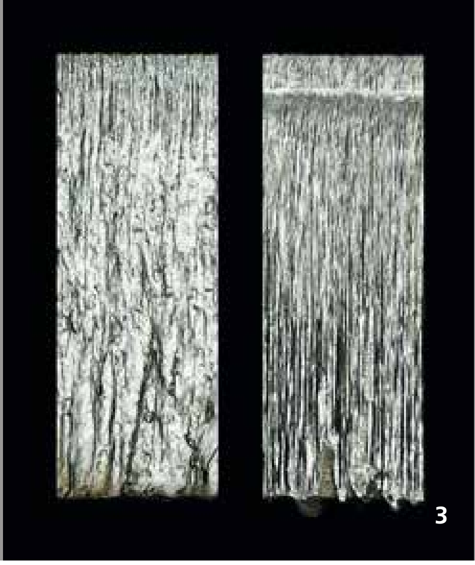

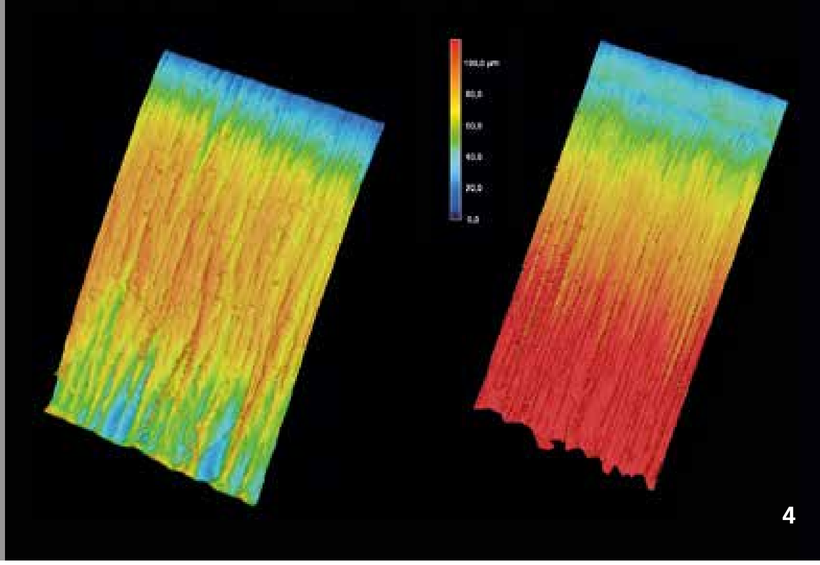

IN SITU PROCESS DIAGNOSTICS IN LASER-BEAM FUSION CUTTING

Task

In laser-beam cutting, instabilities of the laser cutting front cause unwanted losses in quality in the form of ablation and solidification striations and also lead to dross formation. The in-situ diagnosis of melting and solidification dynamics in laser fusion cutting makes it necessary to create a testing stand to enable optical accessibility of the cutting kerf during the process.

Method

In the trimming process, the workpiece flange is cut along its linear axis with a defined laser-beam overlap. So that a guided supersonic gas beam path along the melt film can be maintained, the missing cut edge is simulated by a transparent replacement edge (protective glass). The quality of the cut edge as it forms is usually indicated at several places in the form of average surface roughness. This quality criterion, however, does not reflect the edge quality in an ideal way, which is why the surface must be viewed integrally.

Result

The testing stand developed for the trimming cuts is equipped with two x/y tables, each with a feed and infeed axis, with which speeds from 0.05 to 120 m/min can be reached with positioning and repeatability of < 2 µm and a parallelism of < 15 µm in the feed direction. In conjunction with an independent camera mounted »off-axis« (opt. resolution < 5 µm), the conditions for the experimental procedure are reproducible.

The trimming cuts carried out by the process described here show promising results regarding its ability to analyze and influence the process. As the test method is gradually adapted, it will approximate the process more accurately.

Applications

The in-situ diagnosis forms the basis for developing process parameters matched to increase cut edge quality while avoiding dross formation.

The project has been funded by the German Research Foundation (DFG) within the Collaborative Research Centre 1120 »Precision Melt Engineering«.

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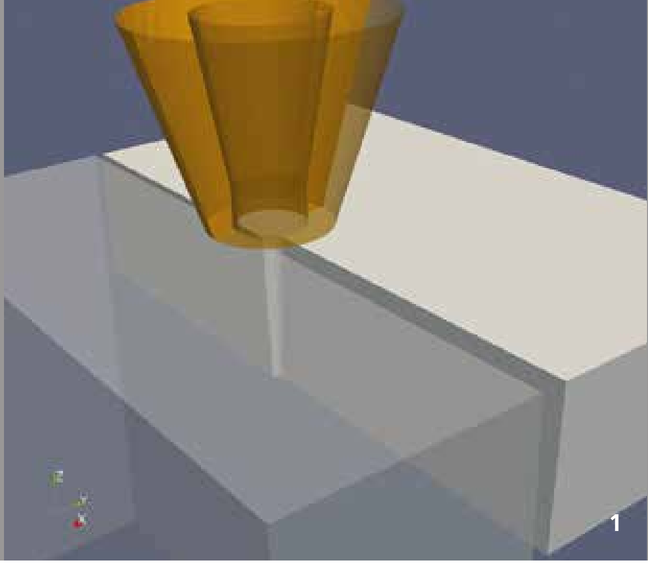
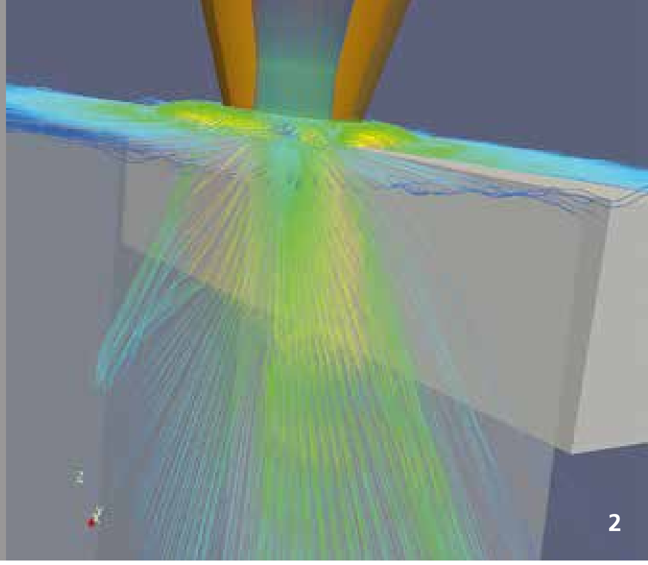
3 Photo of a real cut edge (l) and a cut edge created with the trimming process (r).

4 3D view of a real cut edge (l) and one created with the trimming process (r).





SIMULATION OF GAS FLOWS FOR IN-SITU DIAGNOSIS OF TRIMMING CUTS

Task

During in-situ diagnostics of laser fusion cutting, when trimming cuts are made, the process' melting and solidification dynamics can be observed by means of quartz glass. When this diagnostic process is used, however, kerf geometry changes, thus leading to deviations in the driving forces upon the melt caused by the cutting gas flow, in comparison to the real cut. The simulation allows the gas flow to be adjusted to the conditions of a real cut.

Method

An existing gas flow simulation code is extended so that the driving forces at the cutting front can be analyzed directly. Thereby, a discontinuous Galerkin method is used to calculate the dynamics of turbulent flow. So that the driving properties forces can be analyzed, the flow properties are averaged over a time scale typical for the present turbulent flow. To calculate the gas flow for various trimming geometries, a module is supplemented with a commercial mesh generation tool to load computational grids.

Result

The software »COMSOL« used for meshing provides a CAD import filter and enables parametric geometries to be created rapidly and efficiently. By calculating time-averaged, i.e. effective shearing forces, the software can assess computation results automatically. This simplifies the simulative adaption of gas flows and automates much of the work flow.

Applications

The newly developed work flow for the design of gas flows enables the gas flow solver to be used so effectively that gas flows for laser applications such as cutting, welding or drilling can be dimensioned with a greater deal of simplicity.

The work was funded by the German Research Foundation (DFG) within the Collaborative Research Centre SFB 1120.

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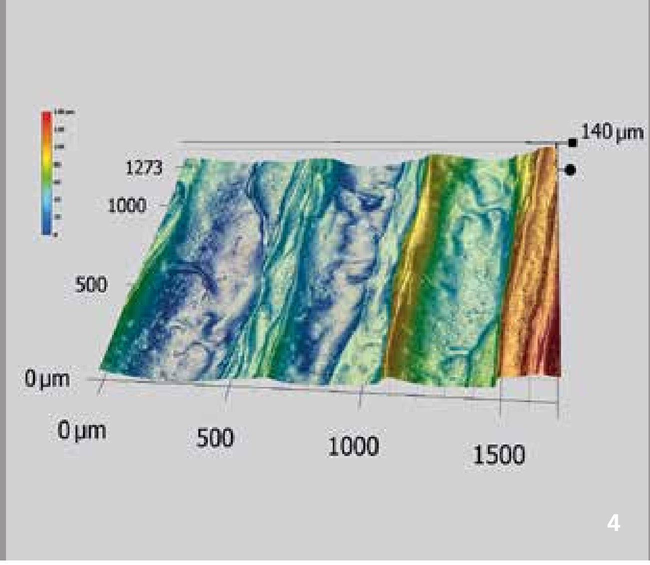
1 Geometry for trim cut diagnosis.

2 Flow lines of the gas flow simulation.



INFLUENCE OF BEAM SHAPING ON LASER-BEAM CUTTING

Task

Fiber and disk lasers offer numerous technological and economic benefits. Indeed, the number of fiber-coupled flatbed cutting plants sold annually will soon exceed that of CO_2 laser systems. In the thick plate industry, however, the average cutting quality CO_2 lasers generate is still unsurpassed. To increase the quality of fiber laser cuts, therefore, a basic study should analyze the extent to which elliptical beam shaping influences the process.

Method

The beam is shaped by means of several cylindrical lenses of different focal lengths. The optomechanical setup of the cutting head allows the beam ellipticity to be varied over a wide range. In parameter studies upon 8 mm thick stainless steel sheets, the effect of the beam shape on the cut edge quality and melt film dynamics has been analyzed. The melt flow is observed by means of a high-speed camera with more than 100,000 frames per second. The recordings are evaluated based on streak analyzes to identify key dynamic and statistical values of the melt flow.

Result

This investigation – on how elliptical beam shaping influences the melt film dynamics – has contributed significantly to understanding the way these physical sub-processes function in laser cutting. In the course of this work, a comprehensive cutting database has been created, which contains process parameters and measurements of the cutting quality of a few hundred cut samples. It also contains the respective high-speed shots of the melt flow and derived dynamic and statistical characteristics of the melt flow behavior.

Applications

The findings gained here have been included in the development of industry-standard beam forming concepts to increase the productivity and cutting quality of fiber-laser cutting systems. Furthermore, the measured experimental data can be used to calibrate numerical models and as meta-model data sets.

The work has been funded within the EU project »HALO« (High Power Adaptable Laser Beams for Materials Processing) under grant number FP7-314410.

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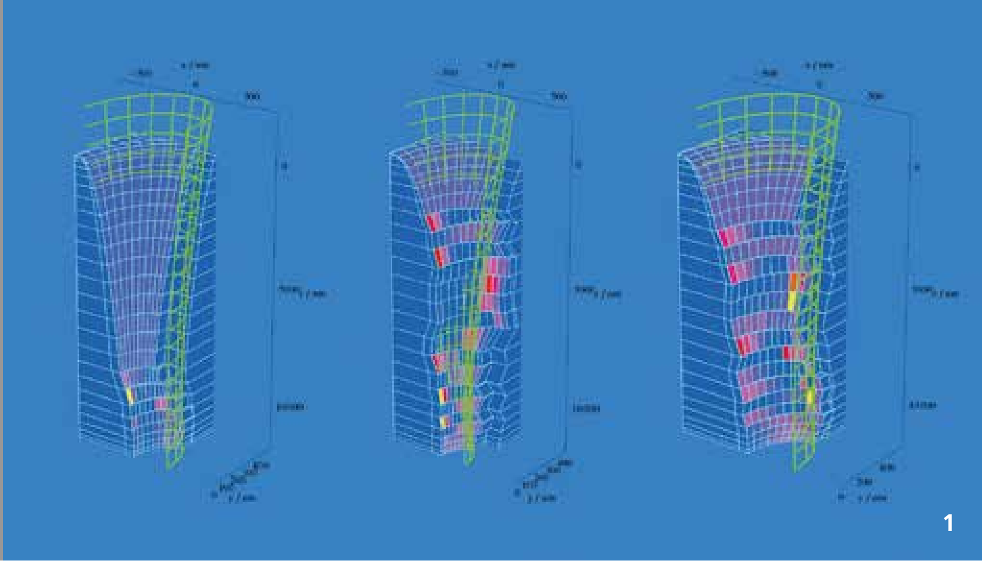
3 Cutting process and diagnostics setup.

4 Macro image of the topology of a cut edge.



PROCESS OPTIMIZATION OF LASER CUTTING WITH THE SIMULATION TOOL »CALCuT«

Task

The market for laser cutting systems has seen particularly dynamic development for nearly 10 years. Meanwhile, almost all of the cutting machine manufacturers provide systems with fiber-coupled laser sources. Their market share has already risen to over 50 percent of the total annual sales of flatbed cutting systems. While CO_2 lasers are the second choice for thin sheets, for the cutting of thick stainless steel sheets, they remain unbeatable in terms of the high cut edge quality they achieve. If, however, the development of fiber laser cutting is to advance further, more than just empirical parameter variations are required. To develop new process technologies and beam forming concepts and to successfully implement them with the customer, Fraunhofer ILT has been using the simulation software »CALCut« for a long time.

Method

Since »CALCut« can factor in a unique scope of physical sub-processes, it can be used to calculate the three-dimensional steady-state cutting front geometry and the resulting kerf geometry while also allowing for the following parameters: material, material thickness, laser wavelength, beam quality, beam power and distribution, polarization, raw beam diameter, focusing optics, focal length, focus position, type and pressure of cutting gas, as well as the cutting speed. »CALCut« identifies the spatial distribution of the absorbed laser power density, the temperature, the expansion and flow velocity of the melt film as well as the evaporation rates and pressures. The maximum cutting speed is determined by automatic iteration.

Result

The process model underlying the simulation software »CALCut« describes the stationary solution as a function of the selected process parameters. Recent studies now show that even the cut edge quality, for example, its degree of roughness and dross formation, can be predicted from »CALCut« calculations.

Applications

An issue currently much discussed concerns the influence of different laser beam distributions on the quality of the cut. Simulations with »CALCut« provide sound guidelines for developing optimized, beam distributions adapted to the cutting job and that can be used in future laser cutting systems.

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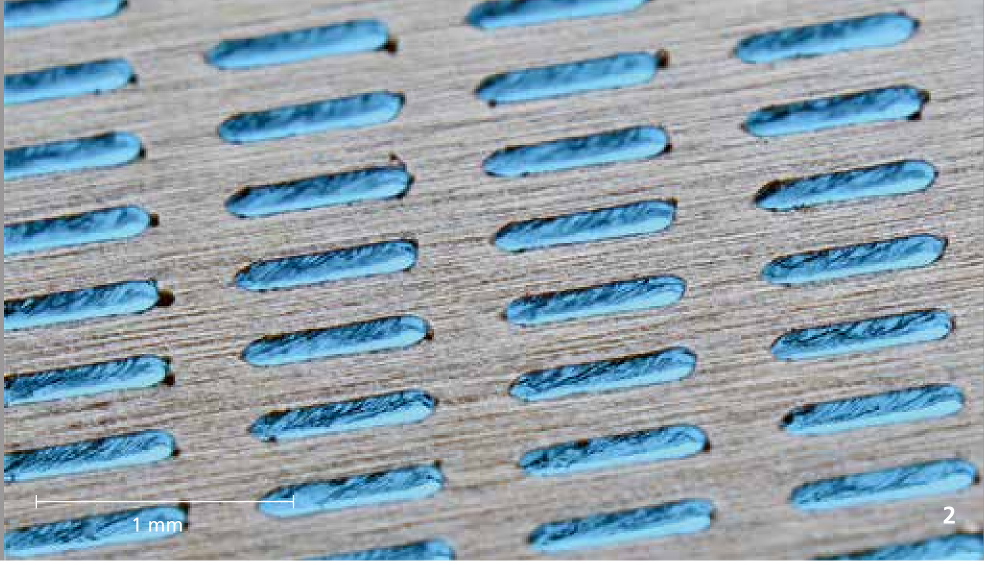
1 Simulated cutting fronts for different beam distributions.



HIGH SPEED CUTTING OF SLOT ARRAYS IN THE SUBMILLIMETER RANGE

Task

Laser radiation should be used to cut large arrays of slots into a 250 µm thick stainless steel foil with a prescribed kerf geometry and high surface rates. The process is intended to enable slot geometry and kerf widths to be adjustable in the sub-millimeter range. Also required are consistently high cutting quality and dimensional stability over the entire array surface. In addition to these high quality requirements, the process should also achieve high perforation rates of about 100,000 holes/min.

Method

A fiber laser having a high brilliance is used as a laser beam source. The high processing rate requires the kerf to be generated at cutting speeds of at least 40 m/min. The desired form of the kerf is immediately given by the selected process parameters in an on-the-fly process. The physical effects of the high-speed cutting process, in which melt flow has a significant influence upon kerf formation, as well as a modulation of the laser power were used to selectively form the kerf. To ensure a consistent cut quality and contour accuracy, parameter sets are selected that ensure the process is stable.

Result

Slot arrays with high cut quality have been created with cutting speeds of over 100 m/min. It could be shown that the dimensions of the holes can be adjusted within broad limits in the sub-millimeter range.

Applications

This technology can be applied in industrial segments that require micro and aerodynamically optimized structures with a high density and high quality of drilled holes.

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2 Slot array with a gap width of 110 microns.

FORM CUTTING OF BRITTLE CARBON MATERIALS

Task

When conventional manufacturing methods, such as mechanical cutting or grinding, are used to process hard and brittle materials, such as diamonds or other forms of carbon or ceramic materials, uncontrolled ruptures often result due to mechanical stresses introduced into the component. The resulting microcracks lead to unwanted ruptures and corresponding contour deviations. Depending on the processing method, contour cuts can only be done to a limited extent. The use of ultra-short pulsed lasers often provides the desired cutting results, but is very slow or cannot be used for materials having a thickness in the range of several millimeters. To reduce the process time, the suitability of fiber lasers in multi-kilowatt power range shall be investigated.

Method

So that the thermal influence is kept low, the laser beam of a fiber laser (up to 4 kW power laser) is guided at high speed (3 - 5 m/s) over the workpiece. Galvanometer scanners were used for a stationary workpiece and a 2D handling system with fixed optics for a moving workpiece. The process strategy used was to pass over the component multiple times while resetting the focal position and varying the trace offset.

1 Cylindrical sample cut out of a layered graphite body (thickness 4 mm).

2 Laser-cut »black diamond« (Ø ~ 6 mm).

Result

The process generates high-quality cut edges while only causing minimal damage to the material thanks to short interaction times. This way, 4 mm thick cylindrical specimens of graphite were cut out of a layered graphite body at an effective rate of 15 mm/s, while preserving the material and preventing flakes from forming. In addition, the sample surfaces were leveled with the same laser system. Similarly, good results were achieved in the processing of »black diamonds«.

Applications

In addition to working with pure carbon, this flexible laser process can also be used on other difficult, hard and brittle materials, such as ceramic matrix composites (CMC).

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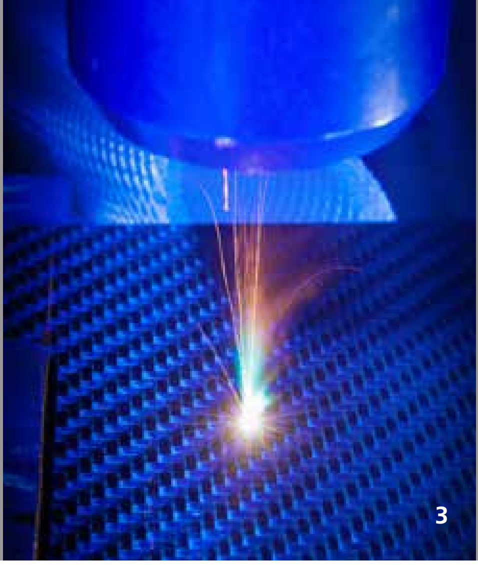

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4

LASER CUTTING OF CFRP

Task

Since it has great lightweight potential, carbon fiber reinforced plastic (CFRP) is being used more and more in many industrial sectors, yet it creates high tool wear when it is machined by milling or drilling. This drawback can be overcome by means of contactless laser cutting.

The cut kerf is formed with a scanning-based step-by-step ablation process to reduce the thermal influence. As material thickness increases, kerfs with high aspect ratios are formed, especially when single-mode lasers with their outstanding focusability are used. These ratios do not allow, among others, effective ablation at the kerf base due to the ablation behavior and shading. Furthermore, a greater proportion of the laser power only leads to heat impact, thus enlarging the heat-affected zone (HAZ). In addition, the removal of material from the kerf base by the cut edges is increasingly hampered as the aspect ratios increase.

Method

When staggered cutting tracks are used, the kerf width can be increased, thereby improving the accessibility for the laser radiation and the removal of the emission products. The offset, number and sequence of scans as well as the distribution of possible cooling phases are varied for processing with different beam caustics.

One option for applying these processing strategies is precut machining, which utilizes parameters to optimize efficiency, then a final trimming of the pre-cut edge, which utilizes parameters to minimize the HAZ.

Result

By means of the ablation variants under investigation, the HAZ can be substantially reduced, in some cases by up to 50 percent, or the processable cutting depth increased without enlarging the HAZ. The required number of scans for a cut is reduced for larger material thicknesses as compared to machining with single tracks because with greater cutting depth, the removal rate is maintained.

Applications

Trimming CFRP components or cutting holes are process steps required in all CFRP processing sectors, in particular in the aviation and automotive industries. The methods presented here expand the thickness range that can be processed, but also result improvements in cutting quality in CFRP components with material thicknesses from 2 - 3 mm.

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3 Cutting process of CFRP.

4 CFRP cut edge, 8 mm material thickness.

DISPERSION-FREE, CONTINUOUS EXPANSION OF HIGH-POWER LASER RADIATION

Task

Many laser material processing applications require the raw beam emitted from the laser source to be adjustable so that the focus can be adapted onto the workpiece surface. Due to the thermal lens effect of semiconductor materials (e.g. ZnSe) when CO_2 laser radiation is used, transmission-based optical concepts are not expedient for applications with high process sensitivity to thermo-optical effects. By contrast, mirror-based concepts enable a more effective dissipation of the heat loads produced and, moreover, wavelength-independent beam forming. Reconfiguring the folded optical path is, however, challenging for the optical design and for automation.

Method

For the use of high-power laser radiation (P > 6 kW), Fraunhofer ILT should develop a mirror-based zoom telescope that enables continuous, variable expansion of a collimated laser beam by a factor of 2.2. A major challenge is generating the common optical axis where the beam should enter into and exit from the optical system.

Result

A fully automated, mirror-based zoom telescope has been developed. The beam path has three aspherical and two flat mirrors that can be moved by means of three linear axes. The main specifications are:

- A diffraction limited design for 10.6 µm and for 1064 nm
- Permissible laser power: P_{cw} = 30 kW
- Variable expansion: 0.9 to 2.2

Applications

The mirror-based zoom telescope can be applied to a wide variety of fields. Besides being used for high-power CO_2 laser radiation, the concept is particularly relevant for applications which have a great sensitivity to the thermally induced focal shift.

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1 Fully automated high-power zoom telescope.

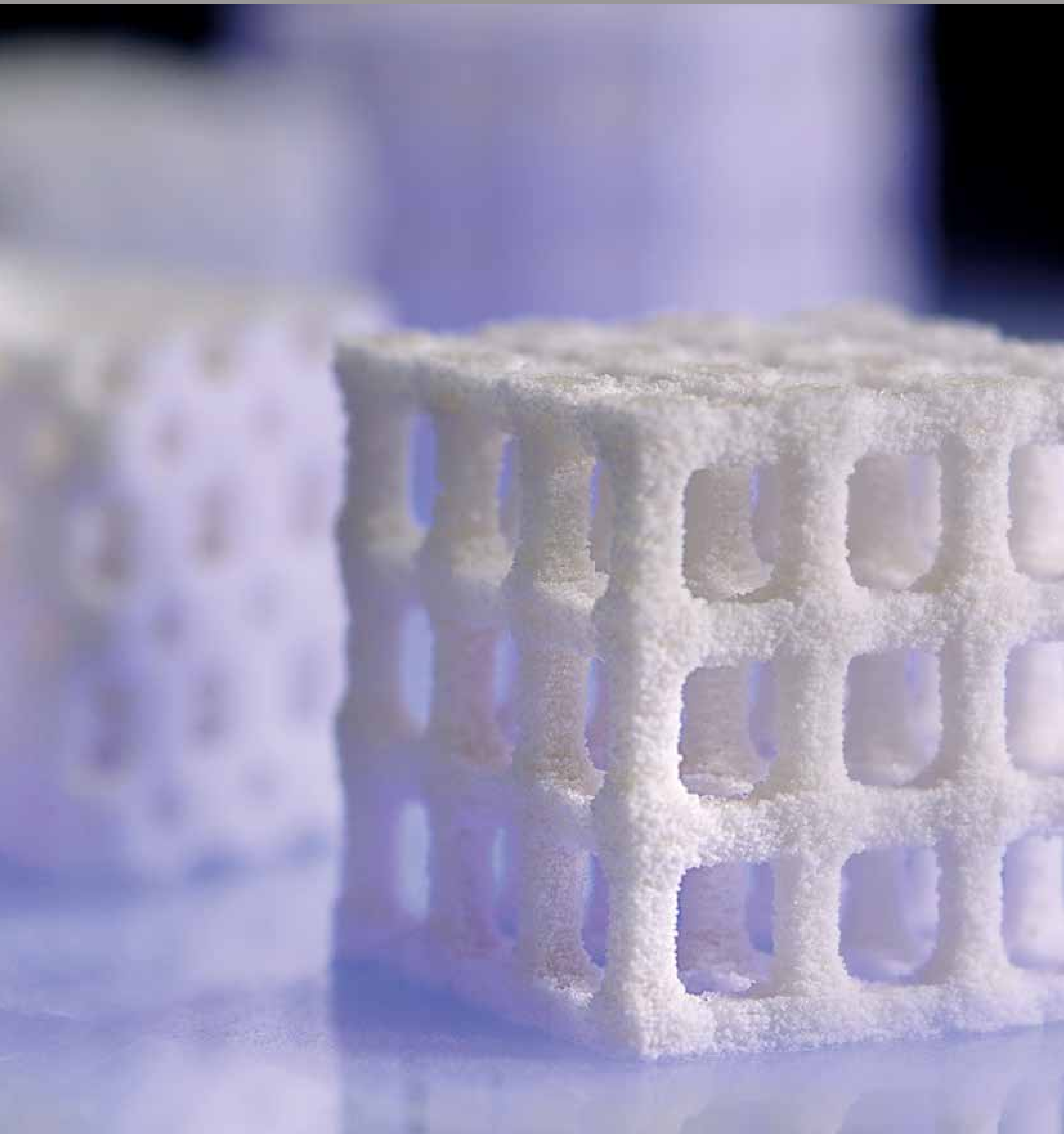
TECHNOLOGY FOCUS
MEDICAL TECHNOLOGY AND BIOPHOTONICS

Gemeinsam mit Partnern aus den Life Sciences erschließt das Technologiefeld Medizintechnik und Biophotonik neue Einsatzgebiete des Lasers in Therapie und Diagnostik sowie in Mikroskopie und Analytik. Mit dem Selective Laser Melting Verfahren werden generativ patientenindividuelle Implantate auf der Basis von Computertomografie-Daten gefertigt. Die Materialvielfalt reicht von Titan über Polylactid bis hin zu resorbierbarem Knochenersatz auf Kalzium-Phosphat Basis.

Für Chirurgie, Wundbehandlung und Gewebetherapie werden in enger Kooperation mit klinischen Partnern medizinische Laser mit angepassten Wellenlängen, mikrochirurgische Systeme und neue Lasertherapieverfahren entwickelt. So werden beispielsweise die Koagulation von Gewebe oder der Präzisionsabtrag von Weich- und Hartgewebe untersucht.

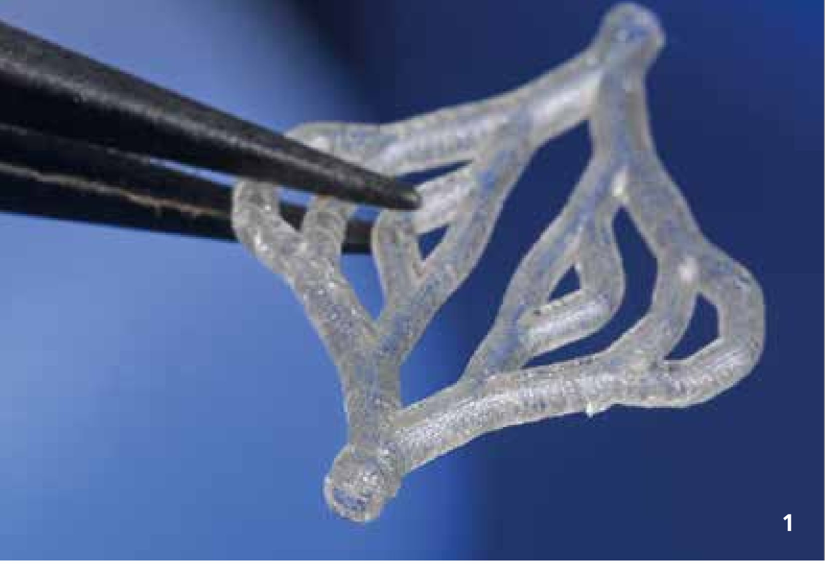
Die Nanoanalytik sowie die Point-of-care Diagnostik erfordern kostengünstige Einweg-Mikrofluidikbauteile. Diese werden mit Hilfe von Laserverfahren wie Fügen, Strukturieren und Funktionalisieren mit hoher Genauigkeit bis in den Nanometerbereich gefertigt. Die klinische Diagnostik, die Bioanalytik und die Lasermikroskopie stützen sich auf das profunde Know-how in der Messtechnik. Im Themenbereich Biofabrication werden Verfahren für in vitro Testsysteme oder Tissue Engineering vorangetrieben. Mit der Nanostrukturierung und der photo-chemischen Oberflächenmodifikation leistet das Technologiefeld einen Beitrag zur Generierung biofunktionaler Oberflächen.

MEDICAL TECHNOLOGY AND BIOPHOTONICS



CONTENTS

Selective Laser Melting of polymer based bioresorbable implantats.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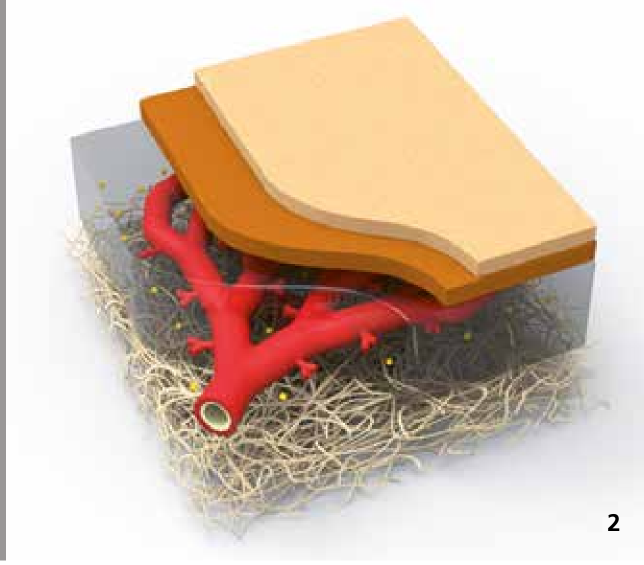
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ARTIVASC 3D – ARTIFICIAL BLOOD VESSELS IN 3D PRINTING

Task

Artificial organs from living cells are only functional in the long term if they are accompanied by blood vessels that provide nutrients and remove metabolic waste products. A fundamental aspect of the EU project »ArtiVasc 3D«, therefore, was to prepare such branched blood vessels from macroscopic vessels and capillaries for the generation of three-layered artificial skin.

Method

A consortium of 16 partners from research, industry and clinicians developed a concept that provided the three-layer structure of subcutaneous fat tissue, dermis and epidermis. The isolation of tissue-specific cells and their cultivation had to be established within the project. Then, artificial blood vessels within the fat layer from a 3D printer should supply the surrounding cells with nutrients.

1 Branched blood vessel made by a 3D printer.

2 Sketch of the three-layered skin model (© University of Loughborough, X. Han, R. J. Bibb).

Result

As a part of the four-year project, the researchers – in close cooperation – were able to develop materials that largely meet the requirements of biology and of processability in 3D printing. Thanks to this, Fraunhofer ILT has generated branched porous vessels that can provide fat cells with nutrients in a hydrogel matrix. The project has shown that the three-layer structure can be generated and that the cells behave specific to fatty tissue. Nevertheless, materials and processes have to be optimized in the future to establish a process chain as reproducible as possible so that artificial three-layered skin can be built.

Applications

There are two major areas of application that can benefit from this development in the future. The project's immediate objective addressed the structure of a skin model to replace animal tests in pharmacological testing. The ultimate goal, however, is a skin model that can be used as an implant for patient care.

The work was funded by the European Commission under the »ArtiVasc 3D« project under grant number 236416.

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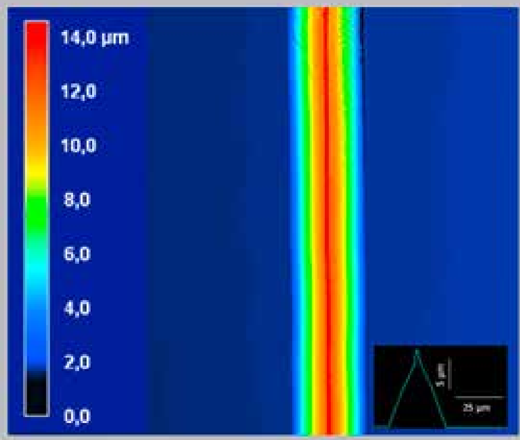

ADDITIVE FREE THIOL-ENE POLYMER RESINS FOR 3D PRINTING

Task

Stereolithography is a 3D printing process that has a wide range of uses: from fast prototyping to the production of functional end products. While the process largely determines product characteristics, the composition of the photo-resins does so even more decisively. The photochemical thiol-ene (poly) addition provides an alternative to the conventionally used acrylic and epoxy resins. Almost all conventional stereolithography systems use blue or near-UV light (340 - 405 nm) in combination with photoinitiators to cure the photopolymer resins; the curing depth is generated by the addition of absorbers. By contrast, the thiol-ene reaction allows for a homogeneous polymerization at a wavelength of 266 nm without additives such as photoinitiators or absorbers.

Method

The thiol-ene resins are cured by deep UV laser radiation in a spatially controlled manner so as to build up solid three-dimensional objects layer by layer. Since the intrinsic absorption and initiation from the monomers are themselves sufficient to generate layers on the order of 1 - 100 µm, additives can be dispensed with completely. This way, transparent products can be generated with high refractive indices and reduced toxicity.

Result

In the project »Thiolight« a highly transparent, elastic photopolymer was developed from trifunctional thiols and enes. This polymer can be successfully processed with a 266 nm laser (cw) into high-resolution 3D objects in stereolithography without needing photoinitiators and absorbers. The process speeds are comparable to conventional material systems. The low oxygen inhibition, lower tension and the delayed gel point are more process-related advantages of these resins.

Applications

These new photo resins can be applied in, for example, polymer optics, medical devices or implants and in other polymer components with special requirements for mechanical properties, transparency or toxicity.

The project »ThioLight« has been funded by the Fraunhofer-Gesellschaft within the scope of its SME-oriented research.

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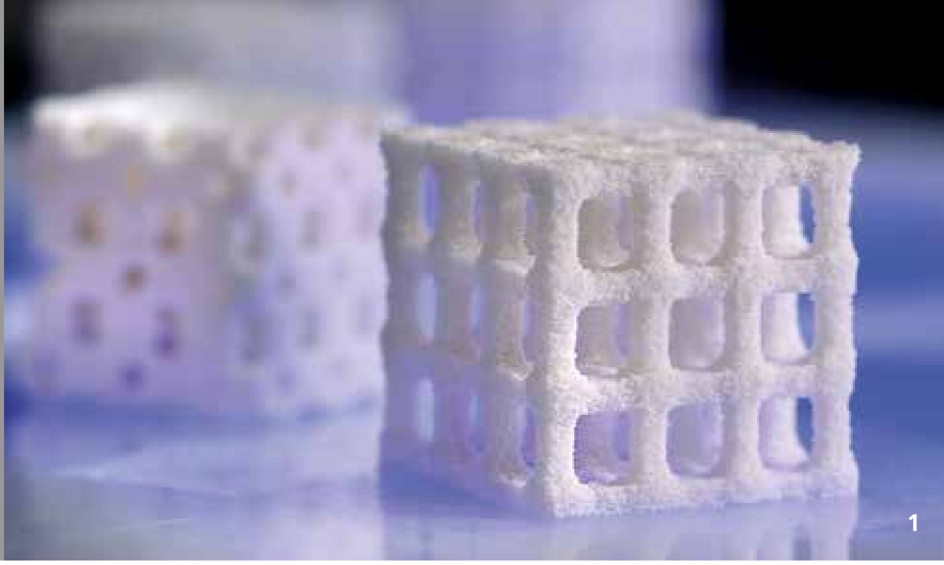
3 Stereolithography setup (266 nm) and printed 3D structure.

4 Line profile of a thiol-ene structure to determine the curing depth.



SELECTIVE LASER MELTING OF POLYMER BASED BIORESORBABLE IMPLANTS

Task

Polylactide-based composite materials with β-tricalcium phosphate (β-TCP) or calcium carbonate as a filler make it possible to produce bioresorbable bone replacement implants that have controllable absorption kinetics and adjustable mechanical properties. So far, however, no one has developed a shaping production process which enables patient-specific implants to be produced with interconnecting pore structure so as to optimize bone ingrowth. In the future, Selective Laser Melting (SLM) could enable the production of such tailor-made implants. Fraunhofer ILT has developed the processing of a composite material made of polylactide and β-TCP with SLM on a laboratory scale. So that this process can be implemented in the industry, the following steps are necessary: a scale-up of material synthesis, use of commercially available equipment technology and an improvement of the material by using calcium carbonate with buffer capacity to neutralize the acidic degradation products of the polylactide.

1 Lattice structure manufactured with SLM (strut thickness about 1 mm) of a polylactide/calcium carbonate composite.

Method

The SLM process is currently being developed for a new composite material made of polylactide and calcium carbonate, which can be synthesized using a scalable and solvent-free dry grinding process in accordance with requirements of medical technology. The SLM process development is being carried out with an EOS Formiga P 110 system, whereby the process parameters (e.g. laser power and scanning speed) are adjusted to the new composite material.

Result

Complex geometries can be prepared from a polylactide/calcium carbonate composite material using commercially available equipment technology. In the next step, the geometries produced will be characterized both biologically and mechanically.

Applications

Selective Laser Melting can be used for the production of patient-specific bioresorbable bone replacement implants, of which the main area of application is in the maxillo-facial region.

The R&D project underlying this report has been carried out on behalf of EOS GmbH, the SCHAEFER KALK GmbH & Co KG and Karl Leibinger Medizintechnik GmbH & Co KG within the »ActiveBone« project funded by the Federal Ministry for Education and Research.

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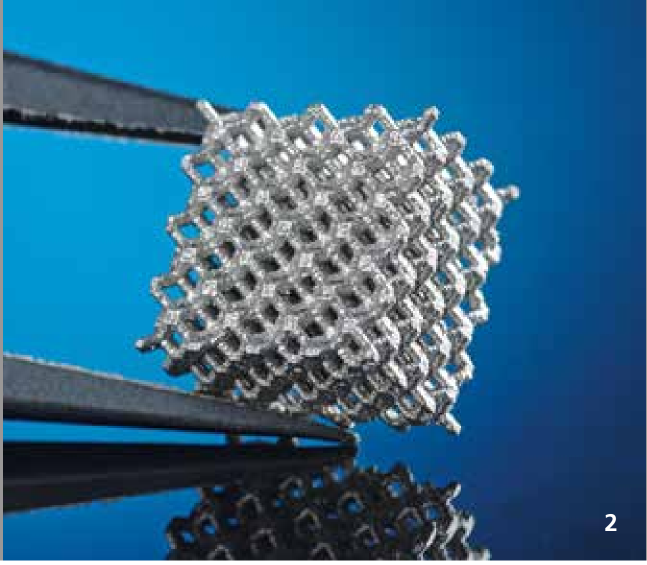

SELECTIVE LASER MELTING OF MAGNESIUM ALLOYS

Task

Thanks to their low density, magnesium alloys are commonly used today, especially in lightweight construction. These alloys are finding their way, however, into new, innovative applications in medical technology as well. For the latter, resorbable implants have been made of magnesium alloys and dissolve in the body, replaced by natural bone. Additive manufacturing processes such as Selective Laser Melting (SLM) can process such magnesium alloys with significant benefits for both applications. SLM can economically manufacture such components in small quantities (prototypes, patient-specific implants) or with unique functional properties (topology-optimized, defined porosity).

Method

When SLM is used to process magnesium alloys, a major challenge arises: Smoke is generated by the evaporation in the process because of the small temperature difference between the melting and evaporation temperature. In order to effectively remove smoke during the process, Fraunhofer ILT has developed a process chamber in cooperation with Aconity3D GmbH. The chamber allows the inert gas supply (e.g. flow profile and volume flow) to be adapted to process and material.

Result

Fraunhofer ILT has optimized the protective gas circulation for the processing of magnesium alloys and correspondingly adjusted the essential SLM process parameters such as scanning speed, laser power and exposure strategy to create a robust process. Thanks to this, components have been produced out of the magnesium alloys AZ91 and WE43 with component densities greater than 99.5 percent. The mechanical properties of the components fulfill the requirements of cast components in accordance with DIN EN 1753. The process can also be used to manufacture complex structures such as implants with interconnecting pore structures out of WE43 and structural resolutions smaller than 400 µm.

Applications

On the one hand, SLM can be used to manufacture lightweight components out of magnesium alloys. The process makes it possible to functionally optimize components with almost no restriction in design. On the other hand, it can be deployed to prepare resorbable implants in medical technology, which can be adjusted to a patient's individual needs and, at the same time, have an interconnective pore structure in which new bone tissue can grow better.

This project was supported by the Fraunhofer-Gesellschaft.

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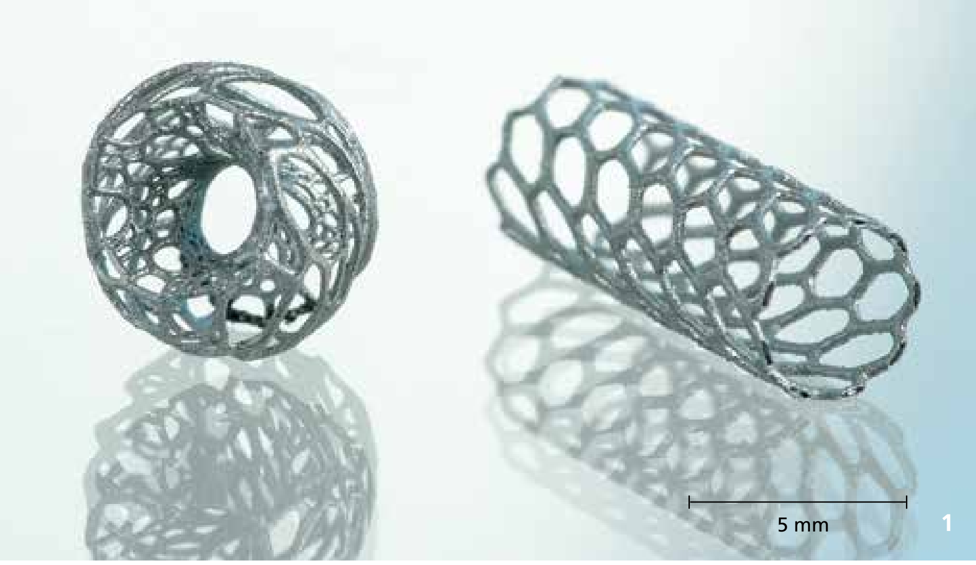
2 Biodegradable scaffold from WE43.

3 Demonstrator for a topology-optimized triple clamp AZ91 (scale 1:4).



CONSTRUCTION OF MICRO-STRUCTURES FROM AN NiTi MATERIAL WITH µSLM

Task

Thanks to the development of micro SLM (µSLM) out of Selective Laser Melting (SLM), the surface quality and detail resolution of small (≤ 10 mm) functional components have been enhanced significantly. To demonstrate the potential of the µSLM process with respect to the production of implants and microstructures, Fraunhofer ILT should qualify a binary alloy of nickel and titanium (NiTi) for the µSLM method. Due to its shape memory effect and proven biocompatibility, NiTi is suitable for various applications in the field of medical technology. The µSLM process has clear advantages over conventional milling processes as the expensive material has to be processed extensively and potential functional parts are quite complex.

Method

Process parameters and exposure strategies should be identified for NiTi with which complex structures and functional parts can be produced in the sub-centimeter size with a high detail resolution and enhanced surface quality.

1 Microstructures of NiTi (wall thickness: 32 µm, surface roughness: Ra = 1.3 µm).

Result

By adapting the conventional SLM systems engineering and using a laser modulation device, Fraunhofer ILT has been able to produce complex structures and functionally integrated micro devices made of an NiTi material. For this purpose, a set of parameters – scanning speed, laser power track pitch, pulse rate and pulse width – were identified, making it possible to produce thin-walled structures with a minimum width of 32 µm and a surface roughness of Ra = 1.3 µm.

Applications

In medical technology, NiTi is already being used as a material for endovascular stents and for osteosynthesis implants. The µSLM method has the potential to produce delicate implants individually and efficiently.

In addition to their applications in medical technology, many micro-components can only be produced with the µSLM process due to their complexity.

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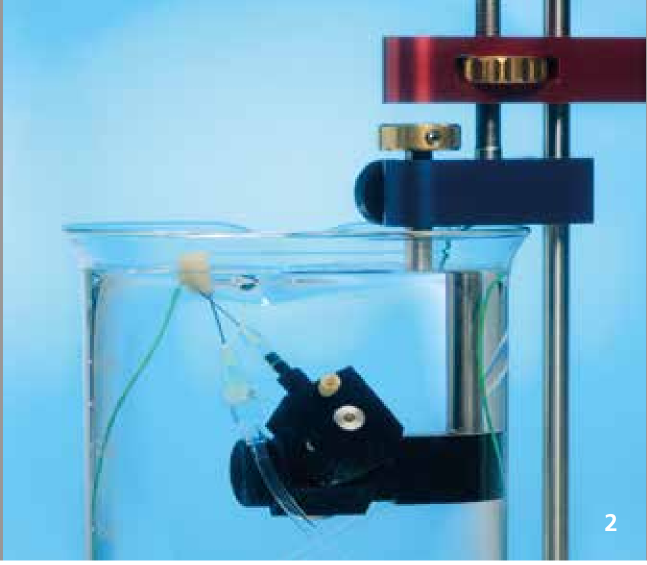

LASER-BASED PROCESS TO COAT DENTAL SURFACES FOR PREVENTION OF CARIES

Task

One of the main oral health problems today stems from decay or erosion caused by the consumption of acidic foods. And yet, current preventive measures, such as sealing the vulnerable areas with plastic-based composite materials, have limited durability. In order to provide a permanent preventive measure against this growing loss of hard dental substance, Fraunhofer ILT has functionalized, by means of laser radiation, a coating material applied to the tooth surface as a microparticulate dispersion. The particular challenge in doing this arises from the difference between the high firing temperatures, between 700 – 1,000 °C, of the glass-ceramic materials used in the coating and from the underlying tooth material, which can be damaged irreversibly when the temperature on the tissue changes by only 5.5 °C.

Method

Uncoated hard dental substances are first processed with modulated CO_2 laser radiation. To simulate the conditions existing in the mouth, a setup has been developed in collaboration with the Department of Restorative Dentistry at RWTH Aachen University; it heats the tooth during laser processing to body temperature and simulates blood flow through the tooth. At the same time, temperatures are measured both within the tooth by means of thermocouples as well as on the tooth surface by means of a thermal camera.

Result

The investigations show that the temperature needed to melt the glass ceramic at the tooth surface does not exceed the critical difference in temperature of 5.5 °C within the tooth when the process parameters are chosen suitably.

Applications

This process for the functionalization of glass ceramic layers can be utilized in preventive dentistry.

The R&D project underlying this report was funded by the German Research Foundation, grant number GZ PO 591/40-1.

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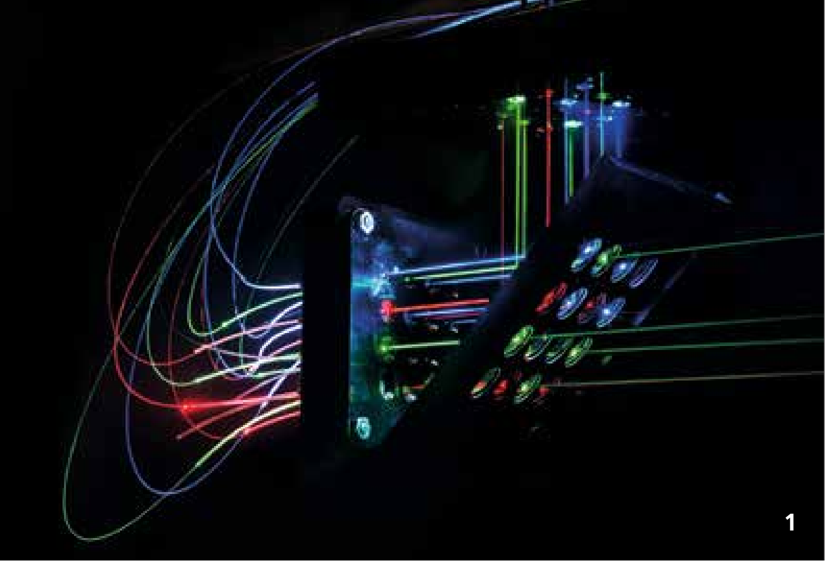
2 Tooth in a water bath heated to body temperature before laser treatment.



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IN VITRO DIAGNOSTIC DEVICE FOR PARTICLE BASED MULTIPLEX TESTS

Task

In particle-based multiplex testing, different types of particles are used simultaneously, with each type having immobilized a specific binding partner for a specific molecule species on the surface of its particles. In a solution, the analyte molecules to be detected are bound to their binding partners on the corresponding particle type. The bonds are then detected optically through the addition of a secondary marker that marks all particle-bound analyte molecules of the multiplex assay. In a flow cytometer, the binding of analyte fractions can be detected through the fluorescence of the secondary marker. In addition, the particles have an intrinsic fluorescence, which is spectrally distinct from the fluorescence of the secondary marker. Each type of particle is encoded via the intensity of its intrinsic fluorescence.

Method

To read out such particle-based multiplex assays, however, there is currently no standardized diagnostic equipment available which, in addition, can be integrated into an automated process. This absence strongly limits the expansion of particle-based multiplex assays, which are superior to conventional microtiter plate-based tests in terms of sensitivity and material usage. To fill this technological gap, Fraunhofer ILT has developed device technology that provides different excitation wavelengths in the visible and near-infrared spectral range and the corresponding detection channels.

Result

The technology has been implemented as a compact desktop unit for multiplex diagnostics and can be used in combination with a microfluidic system for the measurement of particle-based assays. The system can be used both as a stand-alone solution and as OEM module for fully automated sample analysis.

Applications

The device technology developed for reading out particle-based multiplex assays can be applied in clinical as well as in food and environmental diagnostics.

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1 Fiber-based multi-beam arrangement for the excitation of different fluorescent markers.

2 Demonstrator for an in-vitro diagnostic device to read out particle-based multiplex assays.

TECHNOLOGY FOCUS
LASER MEASUREMENT TECHNOLOGY AND EUV TECHNOLOGY

Die Schwerpunkte des Technologiefelds Lasermesstechnik und EUV-Technologie liegen in der Fertigungsmesstechnik, der Materialanalytik, der Identifikations- und Analysetechnik im Bereich Recycling und Rohstoffe, der Mess- und Prüftechnik für Umwelt und Sicherheit sowie dem Einsatz von EUV-Technik. In der Fertigungsmesstechnik werden Verfahren und Systeme für die Inline-Messung physikalischer und chemischer Größen in einer Prozesslinie entwickelt. Schnell und präzise werden Abstände, Dicken, Profile oder die chemische Zusammensetzung von Rohstoffen, Halbzeugen oder Produkten gemessen.

Im Bereich Materialanalytik wurde profundes Know-how mit spektroskopischen Messverfahren aufgebaut. Anwendungen sind die automatische Qualitätssicherung und Verwechslungsprüfung, die Überwachung von Prozessparametern oder die Online-Analyse von Abgasen, Stäuben und Abwässern. Je genauer die chemische Charakterisierung von Recyclingprodukten ist, umso höher ist der Wiederverwertungswert. Die Laser-Emissionsspektroskopie hat sich hier als besonders zuverlässige Messtechnik erwiesen. Neben der Verfahrensentwicklung werden komplette Prototypanlagen und mobile Systeme für den industriellen Einsatz gefertigt.

In der EUV-Technik entwickeln die Experten Strahlquellen für die Lithographie, die Mikroskopie, die Nanostrukturierung oder die Röntgenmikroskopie. Auch optische Systeme für Applikationen der EUV-Technik werden berechnet, konstruiert und gefertigt.

LASER MEASUREMENT TECHNOLOGY AND EUV TECHNOLOGY

CONTENTS

Inline-thickness and surface roughness of paper and cardboard sheet material with »bd-2«.

DOCKINGMONITOR – DRIFT MONITORING SYSTEM FOR LARGE SHIPS

Task

To monitor the berthing and cargo transfer process from large ships, particularly from oil and gas tankers, systems are needed that automatically monitor the position and velocity, e.g. the drift of the ship, relative to jetty structures and unloading systems. In contrast to existing products, a portable measurement system has been developed which eliminates the need for stationary distance sensors to be arranged at port facilities.

Method

The berthing and drift monitoring system, »DockingMonitor«, consists of two different measurement systems:

- Transversal Movement Monitor (TMM) and
- Longitudinal Movement Monitor (LMM).

The TMM is based on a laser scanning measurement system and is responsible for measuring the transversal movement of the ship as it approaches the jetty. The LMM uses an innovative machine vision system to detect and measure the longitudinal drift of the ship during the mooring phase. Control electronics have been developed to control and integrate the data from the two sensor systems. Ex-proof housings were chosen and dimensioned according to current regulations for oil and gas terminals.

Result

The DockingMonitor prototype is a portable system, mounted on a wheeled carriage for fast positioning parallel to the jetty. Corresponding switches allow the systems to be easily switched on and off on site. The compact system does not require distributed sensors and enables precise measurement of the longitudinal movement of ships through »feature tracking« algorithms, a function that is not available in current systems. When the project was completed, the developed system was tested and validated at a port facility under industrial conditions.

Applications

The portable system is suitable for a variety of different terminals. In addition to oil and gas terminals, it can also be used in container as well as in bulk solids ports.

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No. 77045 and has been subcontracted by the companies Marimatech AS, Cortem SPA and S&F Systemtechnik GmbH.

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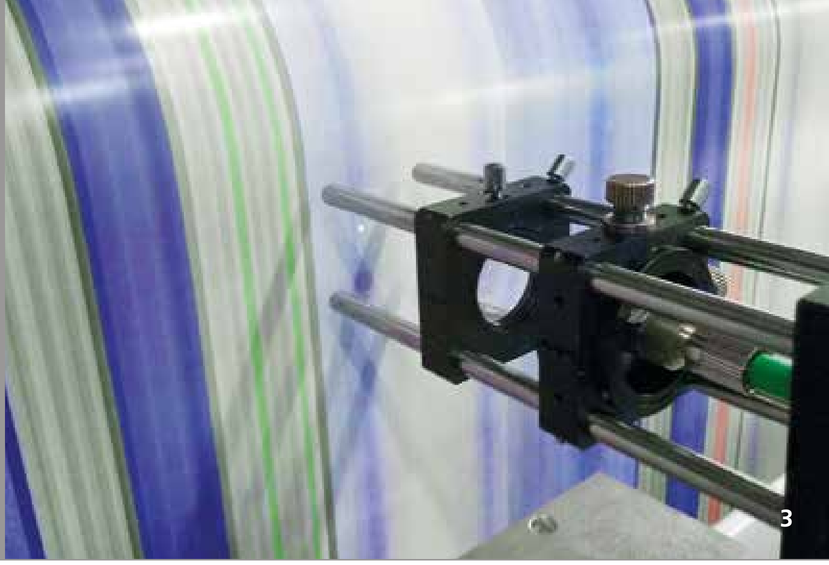
1 DockingMonitor prototype.



INLINE-THICKNESS AND SURFACE ROUGHNESS OF PAPER AND CARDBOARD SHEET MATERIAL WITH »bd-2«

Task

In the production of paper and cardboard, the weight per unit area constitutes the main product property. To determine this, manufacturers commonly use radiometric sensors. While these sensors operate without contacting the object, they make it necessary to observe a high degree of safety precautions to protect employees. An alternative are inductive and capacitive sensors, which are harmless to humans, but touch the sheet material to be measured or are separated from the surface only by a thin air gap. What these three measurement sensors have in common is that they measure the thickness of paper and cardboard webs only indirectly. Thereby, the measuring results are temperature and moisture dependent and do not provide information about the surface structure.

Method

In paper and cardboard production, laser sensors have already been successfully used for various purposes, e.g. to determine the track speed or the humidity of the paper. Thickness measuring methods, such as laser triangulation, are not sufficiently accurate because of the speckle effect. Within the scope of several studies, Fraunhofer ILT has conducted experiments for measuring the thickness of paper and board webs by absolute measurement interferometry for the first time. The sensors of the »bd-2« measuring device developed at Fraunhofer ILT have compact rotationally symmetrical measuring heads with bidirectional beam guidance, i.e. the beam moves back and forth along the same axis. This offers significant advantages for the integration of the measuring gauges in manufacturing machines or testing equipment.

Result

»bd-2« sensors use a spectrally wide radiation source so that they are unaffected by the speckle effect. This was confirmed in field trials on paper finishing machines at track speeds of up to 100 m/min. The thickness was measured with an accuracy in the micrometer range. Further experiments should show that the absolute measuring interferometric sensor also works reliably at track speeds of up to 2000 m/min.

Applications

In addition to the weight per unit area, the surface structure of paper and cardboard is of great importance for further processing steps and for the intended use. In addition to measuring thickness, »bd-2« sensors can also measure the roughness of untreated, painted, embossed, smooth or satin paper or cardboard.

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2 Measuring head with fiber optic cable, L x Ø = 55 mm x 18 mm, m = 40 g.

3 Measuring head for inline measurement of a board web interface.

RECOVERY OF VALUABLE MATERIALS FROM END-OF-LIFE ELECTRONICS

Task

Modern electronics contain a variety of materials, e.g. so-called technology metals, which are considered as valuable or critical raw materials in Europe. At the end of the useful life of equipment, these raw materials are, however, only partially recovered with current recycling methods.

Method

Fraunhofer ILT coordinates the European Collaborative Project »ADIR«, in which technological solutions are developed to recover individual materials in an automated process. To this end, the valuable electronic items should be identified and selectively removed to make them available for recycling in separated fractions. As an example, the methods are being tested for the processing of mobile phones and of commercial electronic boards from network technology.

Result

Laser technology plays a crucial role at several key points of this approach. On one hand, the laser equipment is needed for the identification of the valuable components because, in general, there are no data available from the manufacturers or their suppliers. For this purpose, methods are employed to conduct materials analysis, geometry measurement and object detection. On the other hand, the laser is also used as a tool to selectively remove valuable components or modules, for example, by laser unsoldering or laser cutting.

Applications

The project »ADIR« is initially aiming at processing electronics from the telecommunications industry. It strengthens an economically and ecologically attractive recovery of old electronics by providing a technology for improved recovery of raw materials. The introduction of networked and intelligent electronics in more and more private and economic goods will, in the future, lead to a broad application potential of laser-based recovery.

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

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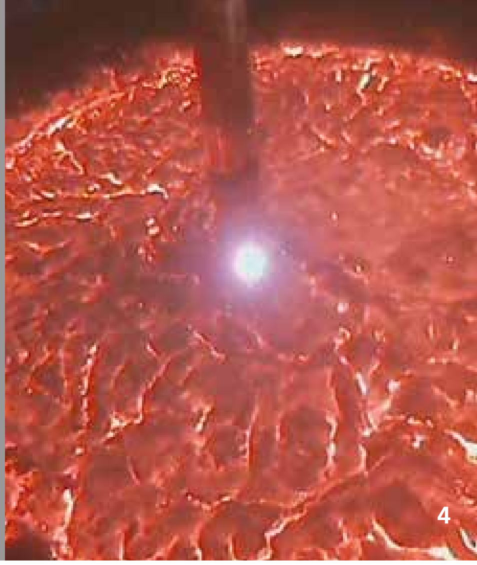
1+2 Electronics from end-of-life smartphones with valuable materials for recycling.



DETERMINATION OF THE LIME STANDARD OF LIQUID SLAG WITH LASER-INDUCED BREAKDOWN SPECTROSCOPY

Task

Laser-induced breakdown spectroscopy (LIBS) shall be used to analyze the LD slag generated in the production of crude steel by the company voestalpine Stahl GmbH in Linz, Austria. The analysis should be conducted in the ladle of slag transporters to determine the lime standard. The slag in the ladle is liquid or partially solidified at the surface at temperatures ranging from 600 °C to about 1300 °C. The measurements should serve to classify the slag so that it can be systematically recycled. The laser measuring device was designed, created and put into operation for automated 24/7 operation.

Method

Preliminary studies showed that the process is fundamentally suitable and that the analytical characteristics could be achieved at the given boundary conditions. In addition, the process parameters were determined. Great attention had to be placed on the requirements of continuous operation, on the large measuring distances and the heat and dust in process development and in the design and selection of components. The interfaces were selected in close cooperation with the client.

Result

The measurement runs automatically after the driver of the slag transporter has started it. Here, the LIBS measurement unit adapts to varying filling heights of the slag ladle. To average spatial variations in the composition, the measurement is performed along a line on the slag surface and takes height variations of the surface profile into account. The analysis from the release to the data transfer to the control system lasts less than two minutes. The measuring device runs in 24/7 operation and a total of more than 12,000 measurements have been made in the development and operation phase.

Applications

The methods and devices developed are suitable for automated analysis of mineral substances in the production process in the most difficult conditions. This way, substances generated in production processes can be classified at an early stage and conveyed to the targeted use.

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3 Transporter with slag ladle below the measurement site.

4 Slag surface during the LIBS analysis.

IDENTIFICATION TESTING OF SCALED ROLLING BILLETS

Task

Even in highly automated production processes, there is always a risk of mixing up different materials. For this reason, during the processing of steel ingots, several hundred different grades are handled and when they are fed into the beginning of the rolling mill, they are usually controlled manually. Hence, a mix-up cannot be completely ruled out. If this happens, significant economic losses can result, ranging from damage to the production line to subsequent losses at customers. In order to recognize such mix-ups before processing begins, all the ingots used need to be checked in terms of their chemical composition.

Method

Laser-induced breakdown spectroscopy (LIBS) has proven itself for the quantitative analysis of metals and identification testing of semi-finished products under industrial conditions. The challenges in this project are the variety of materials and primary scale layer of the rolling billets, the latter of which differs in the chemical composition from the bulk material. With a laser pulse sequence optimized to removal, the base material to be analyzed can be exposed locally and, in a further step – also with a laser – be directly analyzed chemically in the production line. A functional sample has been built for semi-automatic measurement of rolling billets on a roller conveyor.

1 Rolling billet on the conveyor during the laser measurement.

Result

In production environment, a testing period of less than 50 s has been reached with the functional sample. On several hundred low to high alloy rolling billets, the measured concentrations of more than 14 elements were compared with the nominal contents, and a good agreement was shown. The system can detect a change in the grades of the material, thus excluding particularly critical mix-ups with high certainty. Improvements for the detection of further elements are planned.

Applications

The primary area where this process can be applied is the analysis of scaled metal ingots and other scaled intermediate products in the metalworking industry. Another area of application where ablation and analysis are combined is the measurement of depth profiles down to a depth of several millimeters.

The work was funded by the ERDF program for North Rhine-Westphalia in the objective »Regional Competitiveness and Employment« 2007-2013 under grant number 300113002 and supported with funds from the Fraunhofer-Gesellschaft.

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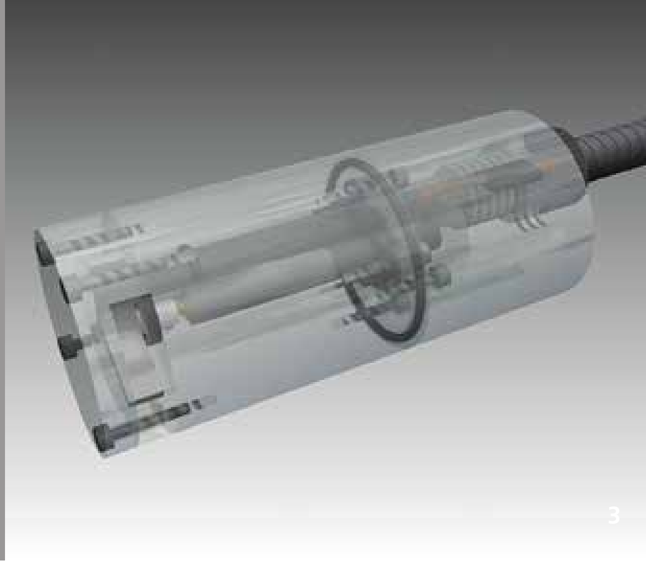

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INLINE PARTICLE ANALYSIS WITH DYNAMIC LIGHT SCATTERING

Task

Particle sizes ranging from a few nanometers up to several micrometers play a crucial role in many chemical processes and influence a product's properties decisively. Optical methods for particle analysis in this size range – such as dynamic light scattering (DLS) – are usually off-line processes so that it is not possible to directly monitor production processes such as polymerization reactions or grinding and dispersing processes.

Method

Dynamic light scattering is based on an optical measurement of the natural movement of particles in liquids (Brownian motion). The movements of the particles are superimposed by convection movements in an active mixed reactor so that DLS measurements cannot be used in such an environment. A fiber-optic backscatter probe was equipped with a new sensor head which enables »in-situ sampling«, and a small sample volume was separated from the surrounding fluid by means of a rotary impeller. This makes it possible to conduct in-line monitoring of particle size in actively intermixed fluids.

Result

The new probe was developed and built in cooperation with the RWTH Aachen University (SFB 985 – Functional Microgels and Microgel Systems). Comparative measurements between an offline measurement after sampling and an inline measurement in a vigorously stirred beaker show the functionality of the new measuring head.

Applications

Inline DLS measurement technology can be applied in all processes in which particle sizes between a few nanometers and a few micrometers have to be process monitored inline and measured without sampling. Examples are the monitoring of chemical polymerization reactions, the production of paints and varnishes, processes in the food industry (milk and dairy products) and various grinding and dispersion processes.

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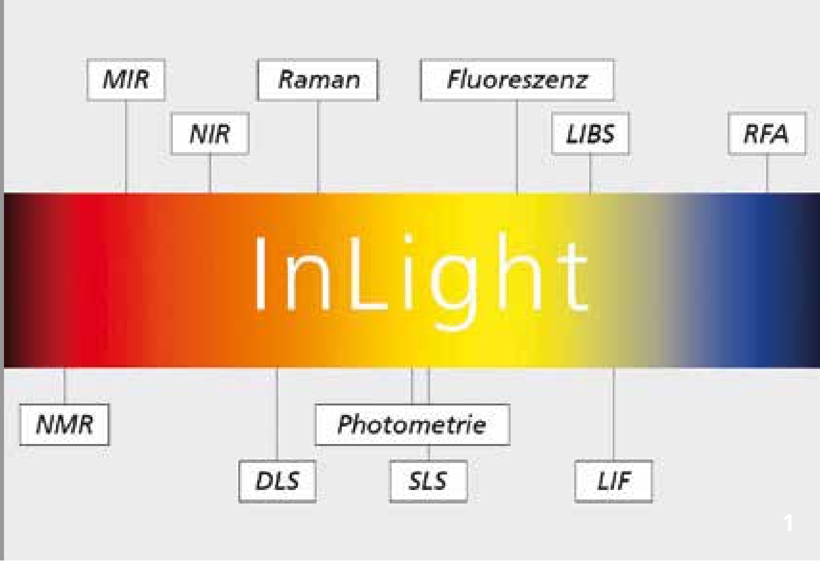
2 Measuring head for inline DLS measurements.

3 Construction drawing of the measuring head.



CONSORTIAL STUDY: INLINE PROCESS ANALYTICS WITH LIGHT – INLIGHT

Task

The domain of inline process analysis with light is to measure chemical and physical parameters in a process directly, without having to make a sample. Manufacturers and users of optical process analytics are faced with the challenge to meet the growing demands in this sector by developing innovative solutions and technological developments that strengthen their market position and take on a pioneering role. The Fraunhofer Institute for Laser Technology, together with the Federal Institute for Materials Research and Testing (BAM), RWTH Aachen University and industry partners, are conducting a consortial study in which a technology roadmap is being developed for the future development of optical process analytics. This study shall serve to guide the direction of future R&D projects as well as procedural, technological and product-oriented development tasks.

Method

In a series of meetings and workshops within a year, the research institutes and the participating companies will lay the foundations for the technology roadmap. The companies shall define the important topics of study, while research institutes will analyze the technological developments and future potential of the optical process analytics as well as create the technology roadmap.

1 Range of methods of optical process analytics.

Result

Based on four different intersecting issues (methods and processes, evaluation methods, components, and modeling and integration), different aspects of optical process analytics are being examined. In addition, future market developments will be included in the analysis of the topic area. Furthermore, a network of research institutes, suppliers and users of process analyzers has been formed, which should lead to concrete collaborative research projects.

Applications

The application fields of optical process analytics are varied, ranging from the monitoring of chemical processes, via quality assurance all the way to environmental analysis. The fields of application addressed in the study are defined by the participants of the study.

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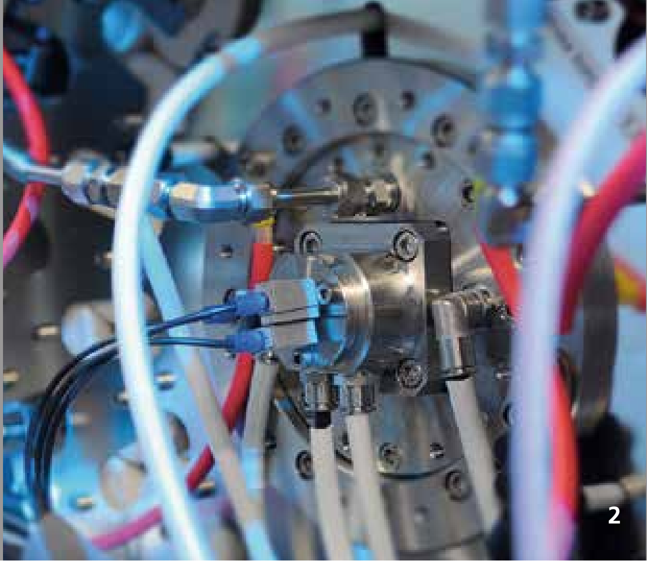

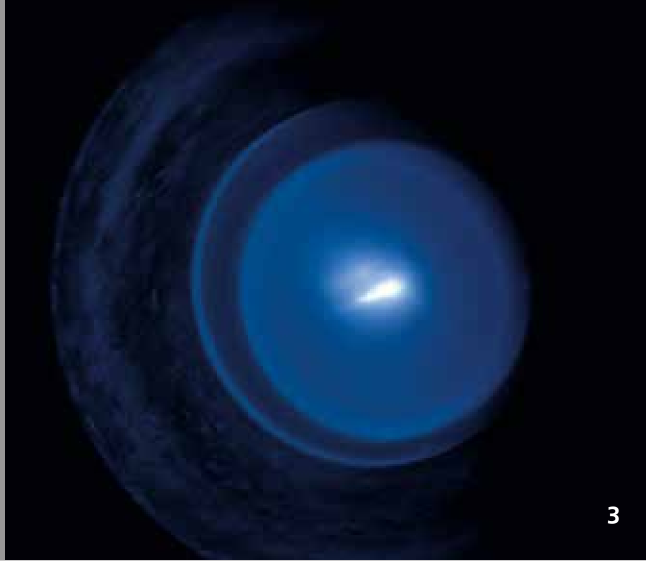

COMPACT RADIATION SOURCES IN EXTREME ULTRAVIOLET

Task

Discharge-based radiation sources in the extreme ultraviolet provide a cost effective and user friendly solution in the wavelength regime interesting for future chip production at 13.5 nm. In such sources, dense and hot plasma is generated by a pulsed discharge of electrically stored energy. Fraunhofer ILT has developed these sources and converted them for use in commercial applications. To make these programs more attractive to users and also to open up new areas of application, the institute has focused its development on increasing the intervals between maintenance work.

Method

By using other electrode materials, Fraunhofer ILT has aimed its work at reducing the inevitable erosion of the electrodes in contact to the plasma. But the institute is also developing parameters that make the operation of the source tolerant to the geometric changes of the electrodes. In particular, this was achieved by a new electric circuit used to ignite the plasma. Not only has the operation of the source been demonstrated with electrodes that would have otherwise already needed to be replaced, but the efficiency of the conversion of electrical energy into EUV radiation has also been increased through access to a larger field of operating parameters.

Result

With the solutions found, maintenance intervals can be increased by at least a factor of five, corresponding to a continuous operation of about one week (24/7).

Applications

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

Parts of the R&D project have been funded by the Federal Ministry for Economic Affairs and Energy under grant number KF2118109NT4.

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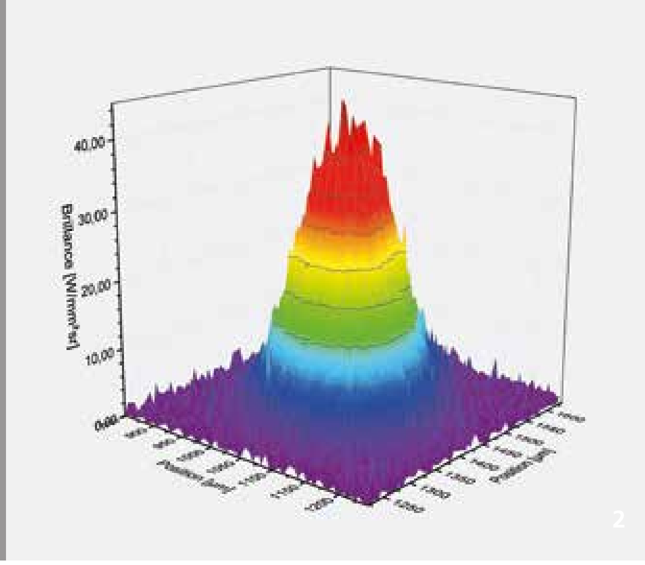
2 Back side of the electrode system of the EUV radiation source.

3 Off-axis image of the plasma in the coaxial electrode system.



LASER INDUCED RADIATION SOURCES IN EXTREME ULTRAVIOLET

Task

Laser-induced plasmas are considered to be highly brilliant radiation sources in the spectral range of extreme ultraviolet and soft X-ray range. Here, a major technological hurdle is to provide an efficient target. The target material, which is excited by a laser pulse to emit radiation characteristic for the material, should preferably be provided in a regenerative target concept. Today, the injection of tin droplets in a vacuum chamber is a common method for radiation sources at a wavelength interesting for semiconductor production, 13.5 nm. This approach is, however, associated with considerable technological effort, especially with regard to the service life of the injection nozzle and the stability of the droplet jet.

Method

A rotating wheel wetted with liquid tin constitutes an alternative target concept. In this case a laser is focused on the constantly regenerating surface to generate a tin plasma, which emits intensive 13.5 nm radiation. This concept has already been successfully demonstrated for a discharge-based electrode system – the laser-ignited vacuum spark – from the company Ushio. The thermal budget of the wheel allows it to provide electrical power input in the range of tens of kilowatts.

1 Wheel wetted with tin as a target for laser-induced plasmas.

2 Measured beam profile at a wavelength of 13.5 nm.

Result

In a first experiment, the feasibility of this concept was demonstrated using a pulsed multi-kilohertz laser. Without further optimization of the system, an efficiency for emission of more than two percent (2πsr 2% bandwidth) at 13.5 nm could be achieved for the in-coupled laser power. The demonstrated brilliance is about 40 W/mm²sr, which would be sufficient for commercial use in mask inspection.

Applications

These highly brilliant radiation sources in the extreme ultraviolet can be used in semiconductor lithography, preferably, for example, for inspection of masks.

This work was carried out in cooperation with the company Ushio/BLV Licht- und Vakuumtechnik.

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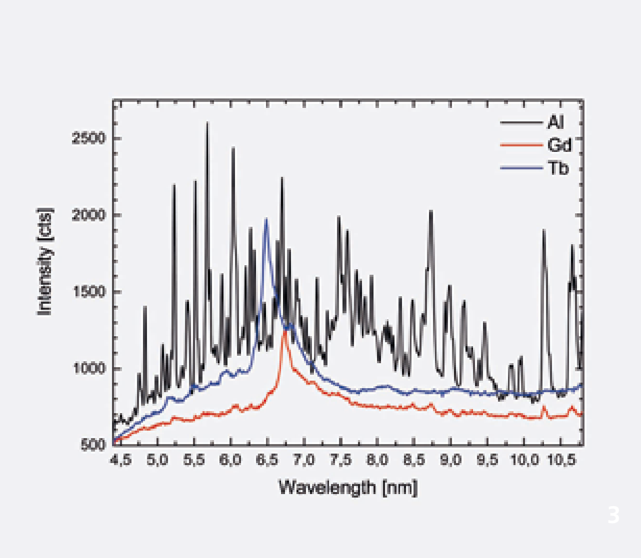

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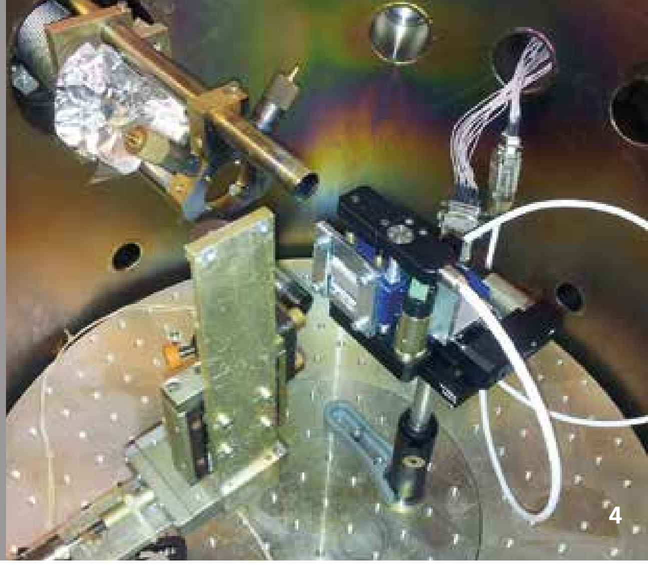

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ALTERNATIVE EMITTER FOR EFFICIENT RADIATION SOURCES AT 6.7 NM

Task

Dense, hot plasmas emitting at 6.7 nm are commonly discussed as radiation sources for the next generation of semiconductor lithography, both in metrology and as a production source. The favorite target materials are currently gadolinium (Gd) or terbium (Tb), which, as an isoelectronic continuation of tin – used for 13.5 nm lithography – have similar emission characteristics with a variety of emission lines. Both elements have to be used as regenerative targets in the liquid state in a commercially usable radiation source. Here, the high melting point and the associated problem of handling these elements in liquid form, however, may prove to be technologically and economically unsuitable.

As alternatives, the elements aluminum (Al) and magnesium (Mg) have been investigated in this project. These elements have intensive line transitions in the spectral region of interest and are attractive because of their lower melting point.

Method

In this project, the emission of laser-produced plasmas (LPP) of Al and Mg has been compared quantitatively with Gd and Tb. Furthermore, low melting Gd/Tb-containing alloys were considered in order to have an alternative regenerative target.

Result

In initial experiments, radiation at 6.7 nm with Al and Mg as emitters was detected, whereby the emission is in the same order of magnitude in direct comparison with Gd and Tb for the same experimental parameters. A study of low-melting alloys yielded promising systems having melting points below 500 °C and based on Al or Mg.

Applications

The radiation sources based on the low-melting Mg or Al alloys are of particular interest for future metrology sources emitting at 6.7 nm.

This project has been supported internally by the Fraunhofer-Gesellschaft. Work on the LPP emission is being performed in cooperation with the research group X-Optics of the University of Applied Sciences in Koblenz.

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3 Al, Gd and Tb-LPP spectra and reflection curve 6.x mirror.

4 Vacuum chamber with sample holder.

METROLOGY FOR CHARACTERIZATION OF RADIATION SOURCES AT A WAVELENGTH OF 6.7 NM

Task

For the production of future semiconductor devices, lithography is commonly discussed at an operating wavelength of 6 - 7 nm (6.x nm). Hot plasmas are suitable as radiation sources both for the production of the chips as well as for the accompanying metrology of this technology. To characterize these sources, however, a measurement technology is required for both the absolute photon flux as well as for the spatial extent of the sources. In particular, for laser-induced plasmas, it is a challenge to determine the source size with a resolution of a few microns at the central wavelength.

Method

In collaboration with the Fraunhofer Institute for Optics and Precision Engineering in Jena, Fraunhofer ILT designed and implemented different imaging systems on the basis of lanthanum-boron carbide-based multilayer mirrors. As detectors, both sensitive CCD cameras and fluorescent screens can be used. During construction, particular attention was placed on the system's suitability for daily use in the laboratory: i.e. an acceptable length of the setup with a large working distance to the plasma and sufficient magnification.

Result

Two systems have been built, each with a magnification of up to M = 3 and M = 9 and with which a spatial resolution in the range of a few microns can be achieved. The M = 3 system consists of a flat and a spherical mirror, and the M = 9 system consists of two spherical mirrors in a Schwarzschild lens arrangement. These setups guarantee a small total length of about 1.5 m at a distance from the plasma of about 40 cm, at the highest possible magnification.

Applications

The cameras can generally be used not only in the area of 6.x nm lithography, but also to spatial characterize radiation sources. When multilayer mirrors are exchanged with the correspondingly adjusted layer system, the setup can be adapted to other wavelengths.

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

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1 High-resolution camera for a center wavelength of 6.7 nm.

CHARACTERIZATION OF PHOTORESISTS IN EUV RADIATION RANGE

Task

When microchips are manufactured, one important process step is the patterning of photoresists with lithographic methods. Only after resist structures have been created they can be transferred into the actual (underlying, partially masked) target material by means of ion etching. The characterization of these photoresists is, therefore, particularly important since the resist needs to be able to resolve the intensity distribution provided by the optical system. For the photoresist to be successfully implemented into a process chain with given manufacturing tolerances (time, accuracy), their sensitivity and contrast must be sufficiently high at the required resolution.

Method

Resists are exposed to extreme ultraviolet radiation (EUV, in a wavelength range of 10 nm to 17 nm) over large areas with the EUV Laboratory Exposure Tool (EUV-LET). In this setup, a dose of 1 mJ/cm² can be introduced in the resist within one second. Thus, typical exposure times for the photoresists utilized are in the range of only a few minutes. So that so-called contrast curves can be determined, the exposure dose is increased stepwise. After the wet chemical development of the photoresist, its contrast can be extracted from the exposure result. The contrast curve also supplies information about the sensitivity of the photoresist including its development procedure. Furthermore, the EUV-LET is equipped with a quadrupole mass spectrometer that allows the outgassing behavior of the resist to be monitored before and during the exposure in order to prevent possible contamination of the nearby optics.

Result

With the measurement method developed here, various photoresists can be precisely characterized in the EUV range regarding their contrast, sensitivity and outgassing behavior.

Applications

Both companies in the field of resist development as well as research institutions now are able to characterize novel photoresists with a compact laboratory setup in-house. In addition, alternative developers and development procedures can be evaluated for their potential to increase the contrast.

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2 Exposure results.

3 Exposure station EUV-LET.

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DE 10 2014 002 298
Vorrichtung zur potentialgetrennten Übertragung von Steuersignalen für einen kaskadierten Hochspannungsschalter

DE 10 2014 000 330
Verfahren zur Überwachung und Regelung der Fokuslage eines Bearbeitungslaserstrahls beim Laserschneiden

DE 10 2014 200 633
Bearbeitungsvorrichtung und -verfahren zur Laserbearbeitung einer Oberfläche

DE 10 2010 026 107
Vorrichtung und Verfahren zum prozessgasbegleiteten Bearbeiten von Werkstücken mit energetischer Strahlung

DE 50 2011 007 944.3
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DE 10 2011 012 592
Verfahren und Vorrichtung zum automatisierten Indentifizieren, Abtrennen, Vereinzeln und Sortieren von Komponenten elektronischer Baugruppen und Geräte

DE 10 2011 100 456
EHLA Extremes Hochgeschwindigkeitslaserauftragsschweißen

DE 10 2013 015 429
Verfahren zum Schneiden von Materialien

Patents Europe

EP 2 621 713 B1
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EP 2 414 127
Verfahren zum Schweißen einer Vertiefung eines Bauteiles durch außerhalb oder um die Kontur angelegte Schweißbahnen; entsprechender Bauteil

EP 2 280 801
Verfahren und Vorrichtung zum Schweißen von Werkstücken aus hochwarmfesten Superlegierungen

Patents USA

US 8,988,766 B2
Optical resonator with direct geometric access to the optical axis

US 9,002,683 B2
Method for determining the cut quality of laser cutting process using a simulation program

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Method for machining material using laser radiation and apparatus for carrying out the method

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102006965
Bauteil mit Schweißnaht und Verfahren zur Herstellung einer Schweißnaht

ZL201080045589.7
Ceramic or glass-ceramic article and methods for producing such article

102039494B
Verfahren und Vorrichtung zum Schweißen von Werkstücken aus hochwarmfesten Superlegierungen

Patents Japan

5797887
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10 2015 201 140.2
Bearbeitungskopf für die Materialbearbeitung

10 2015 201 268.9
Verfahren zur Defektinspektion an Multilayer-Spiegelschichten für EUV- oder weiche Röntgenstrahlung

10 2015 202 470.9
Verfahren und Vorrichtung zur hochgenauen optischen Messung an Objekten mit anhaftenden fluidischen Schichten

10 2015 208 181.8
Anordnung und Verfahren für winkelaufgelöste Reflektometrie insbesondere im extremen ultravioletten Spektralbereich

10 2015 210 361.7
Flächendetektor für EUV- und/oder weiche Röntgenstrahlung

10 2015 213 898.4
Verfahren zum Fügen mikrooptischer Komponenten mit Laserstrahlung

10 2015 213 897.6
Anordnung und Verfahren zur verzeichnungsfreien zweidimensionalen Ablenkung von räumlich ausgedehnten Intensitätsverteilungen

10 2015 010 369.5
Schädigungsfreies Abtragen von sprödharten Werkstoffen (Bohrstop-elliptisch)

10 2015 215 559.5
Verfahren zur hochauflösenden Abbildung eines Oberflächenbereiches bei streifendem Einfall der Messstrahlung

10 2015 009 622.2
Schädigungsfreies Abtragen von sprödharten Werkstoffen (Bohrstop-taper)

10 2015 218 459.5
Verfahren und Anordnung zur Ansteuerung einer Laserdiode oder einer Anordnung von Laserdioden

10 2015 014 060.4
Verfahren zum Fügen von zwei Bauteilen im Bereich einer Fügezone mittels mindestens einem Laserstrahl sowie Verfahren zum Erzeugen einer durchgehenden Fügenaht (LIMBO)

10 2015 225 300.7
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PCT/EP2015/066047
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Anordnung und Abtastung einer Oberfläche mit mehreren Laserstrahlen und Verfahren zum Betrieb der Anordnung

PCT/EP2015/072697
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PCT/EP2015/076263
Verfahren und Vorrichtung zum Sortieren von Mikropartikeln in einem Fluidstrom

PCT/EP2015/050489
Bearbeitungsvorrichtung und -verfahren zur Laserbearbeitung einer Oberfläche

Patent Applications China

201480030334.1
Verfahren zum Abtragen von sprödhartem Material mittels Laserstrahlung, Brechung Eintrittskante

201480030330.3
Verfahren zum Abtragen von sprödhartem Material mittels Laserstrahlung, Weichzeichnung

Scientific Publications and Lectures

You will find a list of Fraunhofer ILT's scientific publications and lectures in 2015 on our Internet pages: www.ilt.fraunhofer.de/en.html.

DISSERTATIONS

BACHELOR THESES

Dissertations

16.1.2015 – Sebastian Engler
Laserstrahlschweißen von Kupferwerkstoffen mit brillanten Strahlquellen im infraroten und grünen Wellenlängenbereich

15.4.2015 – Stephan Eifel
Effizienz- und Qualitätssteigerung bei der Lasermikrobearbeitung mit UKP-Lasern durch neue optische Systemtechnik

13.5.2015 – Joachim Ryll
Technologieentwicklung zum Wendelschneiden von Edelstahl mit ultrakurz gepulster Laserstrahlung

22.5.2015 – Sörn Ocylok
Herstellung und Eigenschaften nanopartikulär verstärkter Beschichtungen durch Laserauftragsschweißen zum Verschleißschutz von Schmiedegesenken

7.9.2015 – Melanie Meixner
Laserfunktionalisierung von nasschemisch applizierten piezoelektrischen Blei-Zirkonat-Titanat-Schichten

9.10.2015 – Simon Merkt
Qualifizierung von generativ gefertigten Gitterstrukturen für maßgeschneiderte Bauteilfunktionen

30.10.2015 – Markus Brunk
Charakterisierung und Kompensation geometrischer Einflüsse auf die Laser-Emissionsspektroskopie bei der Inline-Werkstoffanalyse

8.12.2015 – Wolfgang Thiele
Laserauftragschweißen mit der Aluminiumlegierung AlSi10Mg

22.12.2015 – Toufik Al Khawli
A metamodeling approach towards virtual production intelligence

Bachelor Theses

Balli, Reha Andre
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Barthels, Thilo
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Bertholdt, Daniel
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Burgfeld, Robert
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Dunker, Thomas
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Flaig, Roman
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Geus, Jan Fabian
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Gropp, Benedikt
Untersuchung des Einkoppelgrades beim Laserstrahlmikroschweißen von Aluminium unter Verwendung von örtlicher Leistungsmodulation

Ibach, Alexander
Modellbasierte Untersuchung der Korrelation zwischen Charakteristiken laserbasierter Kurzzeittemperaturbehandlungen und der Rissentstehung in Floatglas

Kaden, Nicolaj
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Kappner, Kai Tobias
Theoretische und konstruktive Auslegung einer rotierenden Dove-Hülse unter Verwendung von Tellerfedern

Keusgen, Alexander
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Kosugi, Takeshi
Aufbau, Inbetriebnahme und Charakterisierung eines aktiven optischen Systems für die 3D-Laserumschmelzstrukturierung

Mayer, Marimel
Aufbau und Charakterisierung miniaturisierter elektromechanischer Scannerspiegel

Mengel, Alexander
Selective Laser Melting vorgesinterter metallischer Werkstoffe

Meyer, Alexander Albert
Planung und Auswertung von statistischen Versuchsplänen zur Erstellung von Prozesslandkarten bezüglich Geometrietreue und Oberflächenrauheit bei der Kurzpuls-Laserablation

Miaskowski, Clemens
Fertigung eines Brennerelementes einer stationären Gasturbine aus Inconel 625 mittels SLM

Mösbauer, Pascal
Verfahrenstechnische Grundlagen für das Bohren von CFK-Preforms mit ultrakurz gepulster Laserstrahlung

Pascher, Benjamin
Machbarkeitsuntersuchung zur Verarbeitung einer spröden Eisenbasislegierung mittels Selective Laser Melting

Pastors, Felix Johannes
Untersuchung des Einflusses von Anlagenparametern auf die Bauteilqualität beim SLM von Inconel 718

Poppe, Marcus-Thomas
Einfluss der Finite Elemente Netzstruktur auf thermo-optische Simulationen

Schmitz, Peter
Reduktion von Wasserstoffporosität in AlSi10Mg

Schneider, Tobias
Untersuchungen zur Reproduzierbarkeit beim Feinstabtrag zur Formkorrektur von Quarzglas mittels CO_2-Laserstrahlung

Schürmann, Alexander
Einfluss der örtlichen Leistungsmodulation auf Nahtoberflächenrauheit und Einschweißtiefe beim Laserstrahlmikroschweißen

Schulz, Martin
Schweißen mittels Laser Impact Welding

Scholz, Patrick
Auswahl und Erprobung eines Abstandsmesssystems für das Hochgeschwindigkeits-Laserauftragschweißen

Streit, Felix
SLM von FeAl und Fe-Al-Ti-B

Thümler, Malte
Untersuchung des Einflusses von Selective Laser Erosionen auf die Oberfläschenrauheit von SLM-Bauteilen

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Ambrosius, Manuel
Einfluss des Laserstrahldurchmessers und der Leistungsdichteverteilung auf die mechanischen Eigenschaften beim Werkstoff Inconel 718

Bahrenberg, Lukas
Dark-field reflection microscopy at short wavelengths

Bindel, Kai Fabian
Laserbasierte Herstellung piezoelektrischer Schichten aus partikulären Materialien

Brenner, Andreas
Optimierung laserstrukturierter Elektroden resistiver Partikelsensoren auf keramischer Basis

Burkhardt, Irmela
Laserbasierte Kunststoff-Metall-Hybridverbindungen durch Metall-Mikrostrukturierung mittels UKP-Laserstrahlung

Deelmann, Martin
Aufbau und Inbetriebnahme einer Ringstrahloptik für das Laserschweißen absorberfreier Thermoplaste

Deuter, Valerie
Untersuchungen des Einflusses von verschiedenen Temperatur-Zeit-Verläufen auf das Benetzungs- und Adhäsionsverhalten von partikulären Polymerschichten auf Metalloberflächen

Dietz, Thomas
Untersuchung von INNOSLAB-Pulsverstärkern mit resonant-gepumpten Erbium-dotierten Granatkristallen

Doshi, Hemang
AlSi10-Mg-interlayers for processing laser metal deposition of AlSi10Mg on die cast aluminium and steel

Drosner, Peter-Andrej
Kombinationsprozess aus Laserstrahlschneiden und Laserwärmebehandlung von Bauteilen pressgehärteter Stähle

Duffner, Felix
Lokales Schutzgasführungssystem für ein neuartiges SLM-Belichtungskonzept

Eiselt, Patrick
Untersuchung von Ho:YLF als Lasermedium in Laseroszillatoren im Energiespeicherbetrieb

Ermakova, Galina
Ermittlung eines geeigneten Prozessfensters zur Herstellung von dichten und oberflächenoptimierten Bauteilen aus CuCr1Zr mittels SLM

Feicks, Simon
Einfluss der Bauteilgeometrie auf die SLM Gefügestruktur am Beispiel von TiAl6V4

Fernandes, Jason
Development of a new Material Model for Simulation of Laser Cutting of CFRP

Haasler, Dennis
Darstellung der Schutzgasströmung in einer SLM Maschine mittels PIV

Haschke, Felix
Untersuchung verschiedener Strukturierungsstrategien bei der laserbasierten Herstellung von Kunststoff-Metall-Hybriden

Helm, Johanna
Untersuchung des Anbindungsvorganges beim Lasermikroschweißen von Metallisierungen mittels örtlicher Leistungsmodulation

Herzig, Tobias
Design und Charakterisierung eines mehrkanaligen faserbasierten Fluoreszenzsensors zur Detektion von Pathogenen in mikrofluidischen Systemen

Heußen, Daniel
Generative Serienfertigung mittels SLM – Potentiale und Voraussetzungen einer frühzeitigen Integration in den Produktentstehungsprozess

Hermsen, Leonhard
Untersuchung der Verarbeitbarkeit des Einsatzstahls 16MnCr5 und des Vergütungsstahls 42CrMo4 mittels Selective Laser Melting (SLM)

Hilmes, Tobias
Trennen und Strukturieren von Optohalbleitern mit ultrakurz gepulster Laserstrahlung

Holub, Hans-Lukas
Grundlagenuntersuchungen zu neuartiger SLM-Prozessführung mittels Multi-Diodenlaser-Array

Ibrom, Markus
Thermographie zur Prozessüberwachung beim SLM

Inacker, Patrick
Investigation of the effects of system noise on the performance of the first OPA stage of the HERACLES laser system

Ingenhag, Christian
Untersuchung zur Vergrößerung der Auflösung beim SLE von Glas

Jaberi, Parisa
Experimental and theoretical investigations of thermally induced optical effects in Selective Laser Melting

Jeitner, Carolin
Interferometrische Untersuchung der Dampfkapillardynamik beim Laserstrahlschweißen mit zeitlicher Leistungsmodulation

Khavkin, Evgeniy
Untersuchungen zur generativen Fertigung unter Nutzung der Verfahren SLM und LMD mit der Nickelbasislegierung IN718

Klein, Sarah
Laser-Multiplexer mit integrierter Frequenzstabilisierung

Klerks, Tobias Peter Johannes
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Krebs, Vitali
Laserschweißen absorberfreier Thermoplaste mithilfe dynamischer Strahlüberlagerung

Kroll, Philipp
Generative Fertigung eines pylon bracket aus IN 718 mittels High Power SLM

Li, Yue
Untersuchung zum Laserdurchstrahlschweißen absorberfreier Kunststoffe mithilfe von Ultrakurzpulslasern

Lumberg, Dirk
Justagevorrichtung für Hochleistungsdiodenlaser

Maurath, Manuel
Untersuchungen zur generativen Fertigung von IN718 auf einkristallinen Substraten

Mersch, Jonas
Untersuchung des Ressourcenverbrauchs für verschiedene SLM-Prozessführungen bei der Fertigung eines Leitschaufelcluster

Pelzer, Martin
Parameteroptimierung und Untersuchung verschiedener Bestrahlungsstrategien für das laserbasierte Fügen von Aluminiumprofilen mit FVK

Pichler, Tobias
Generative Serienfertigung mittels Selective laser melting SLM

Schmadtke, Johannes
Technische und wirtschaftliche Analysen von Prozessketten zur generativen Fertigung eines Brennerelementes mittels SLM

Schmitt, Christoph
Untersuchungen zur Schutzgasführung beim SLM der Magnesiumlegierung AZ91

Staasmeyer, Jan-Helge
Minimierung von Muschelausbrüchen bei der Bearbeitung von Glaswerkstoffen mittels Inversem Laserstrahlbohren

Tenner, Vadim
Technologiescouting alternativer Fügeverfahren zum Kleben, zur Produktion mikrooptischer Systeme

Tetz, Thomas
Reduction of substrate thickness for LED chips and consequential efficiency increase by the use of ultrashort pulsed laser radiation during the separation process

Uzun, Ergün
Identifikation von Verfahrensparametern zur Verarbeitung von CoCr mittels SLM unter Verwendung eines Softwaremoduls zur Bauteilgeometrie angepassten Laserleistungsvorgabe

Walochnik, Martin
Untersuchungen zur Machbarkeit und Funktion eines Laser-basierten Kraftsensors

Walter, Simon
Analyse der Kostentreiber von SLM-Produktionsanlagen

Wedemeyer Markus
Introduction of 3D Scan Technology to the Aeronautical Fuselage Assembly

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Welschof, Lukas
Oberflächenbehandlung SLM gefertigter Turbinenschaufeln

Wolfring, David
Untersuchung zur Ressourceneffizienz von Prozessketten in der laserbasierten generativen Fertigung

Wu, Yingchao
Experimentelle Ermittlung von Bearbeitungsparametern zum Feinstabtrag von Quarzglas mit gepulster CO_2-Laserstrahlung

Zhang, Xiang
Untersuchungen zur Reduktion der Porosität beim additiven Aufbau einer γ-Titanaluminiumlegierung mittels Laserstrahlauftragschweißen

Yalcin, Safak
Realization of a control system for automated adjustment of a laser resonator mirror

Zhao, Tong
Integration of monitoring components in an inside laser cladding head for real-time process control

EVENTS

SINO – Chinese-German Symposium
January 21 - 23, 2015, Aachen
Around 35 senior researchers of institutes and universities from China and Germany met for this two-day Chinese-German Symposium. The symposium aims to deepen the bilateral cooperation of the leading experts from China and Germany in the field of laser additive manufacturing (LAM) and the processing of high-performance materials.

Opening Ceremony of the BMBF Research Campus »Digital Photonic Production (DPP)«
January 23, 2015, Aachen
On time for the start of the »International Year of Light and Light-based Technologies« of the United Nations, the Parliamentary State Secretary Thomas Rachel from the Federal Ministry of Education and Research opened the new BMBF Research Campus »Digital Photonic Production (DPP)« in Aachen. The research campus at the RWTH Aachen Campus sends out a clear signal because a new form of cooperation starts here – between science and industry, under one roof. The work done in the Research Campus »DPP« aims to promote the research and development of light as a tool for the production of the future.

1 *Prof. Dr. E. Schmachtenberg (Rector of RWTH Aachen University), R. Henke (Member of the German Parliament), T. Rachel (Parliamentary State Secretary at the BMBF) and Prof. Dr. R. Poprawe (from left to right) at the DPP opening ceremony in Aachen.*

Well attended: 3rd International Conference on Turbomachinery Manufacturing – ICTM, 2015.

3rd International Conference on Turbomachinery Manufacturing ICTM
February 25 - 26, 2015, Aachen

Higher efficiency and lower emissions were the main objectives in the latest technological and manufacturing developments presented to some 240 participants of the International Conference on Turbomachinery Manufacturing ICTM. At the conference, talks were held by experts mainly from the fields of aerospace and energy generation (Alstom, Pratt & Whitney, MTU Aero Engines, MAN Diesel & Turbo, Rolls-Royce Deutschland, Siemens and others). Other contributions were given by representatives of system suppliers, which implement new developments directly in practical applications, as well as R&D organizations, which work at the interface between the development and use of turbomachinery (GE Global Research, Fraunhofer IPT and ILT).

3rd Ultrashort Pulse Lasers (UKP) Workshop
April 22 - 23, 2015, Aachen

About 20 speakers from eight countries provided the approximately 160 participants with an overview, not only of the basics of UKP technology, but also of recent beam-source developments and new system technology, such as multi-beam optics and new scanner designs. In the field of process technology, speakers discussed the latest applications and process approaches, which could be used to exceed today's limits – in terms of materials, processing speed and quality.

Battery Conference
April 27 - 29, 2015, Aachen

Conference for the Energy Storage Sector
Ever since electromobility became a topic of great interest around six years ago, Fraunhofer ILT has been working on laser-based battery joining process, thus, on connecting individual cells to form a battery pack. During the Battery Conference in 2015, Fraunhofer ILT and F&K Delvotec Bondtechnik GmbH presented their collaboration, created as part of a publicly funded project on this topic, at their booth at the symposium »Battery Power Station« in the Eurogress center in Aachen. The researchers were able to integrate laser welding into a conventional ribbon bonder.

Management Circle Trend Forum »3D Printing«
May 4 - 5, 2015, Düsseldorf

In cooperation with Fraunhofer ILT, the Management Circle organized the third Trend Forum on »3D Printing« under the technical direction of Prof. Reinhart Poprawe. It was aimed at experts and executives from the fields of production, R&D, design, innovation and technology management, logistics, spare parts management, business development management, strategic business planning, law, marketing and sales. Key aspects included the question of the current technological and economic limits and the economic prospects of 3D printing as well as its differentiation from conventional manufacturing methods. Experts showed how companies already use the technology in their work successfully.

NRW Minister President Hannelore Kraft visited Fraunhofer ILT during her summer tour »NRW 4.0«.

Topping ceremony for the »Photonics« Cluster building on August 26, 2015 in Aachen.

Summer Tour »NRW 4.0«
July 13, 2015, Aachen

As part of her summer tour »NRW 4.0«, NRW Minister President Hannelore Kraft visited the RWTH Aachen Campus to catch up on the research on Industry 4.0 and its impact on the world of work. She was accompanied, among others, by Karl Schultheis, spokesman of the SPD state parliamentary group in the Committee on Innovation, Science and Research of the State Parliament. At the final exchange, the Prime Minister summed up her lasting impression with the following statement: »We are proud of what you are doing here. Keep it up!«

Topping Ceremony for the »Photonics« Cluster
August 26, 2015, Aachen

Along with numerous guests, Fraunhofer ILT, the RWTH Aachen Campus GmbH and ante4c GmbH, partner of Landmarken AG as a project developer, celebrated the topping ceremony of the first phase of the »Photonics« Cluster building at the RWTH Aachen Campus. The ceremony took place in the atrium of the building, flooded with light, which serves as a space of encounter, communication and exchange of knowledge between industry and academia.

ACAM Kick-off Meeting
September 23, 2015, Aachen

The kick-off event of the ACAM Aachen Center for Additive Manufacturing GmbH was well attended, with over 100 interested parties. Together with partners from science, the Fraunhofer Institute for Production Technology IPT and for Laser Technology ILT helped to found the ACAM Aachen Center for Additive Manufacturing with the aim of making additive manufacturing useful for production companies and profitable in their production processes.

High Power Diode Laser and Systems Conference
October 14 - 15, 2015, Coventry, Great Britain

The HPD conference took place during the Photonex fair in Coventry and was organized by the Scottish Chapter of the IEEE Photonics Society. In addition to a keynote speech given by Christian Hinke on »Selective Laser Melting for Additive Manufacturing: Perspectives for Diode Lasers«, Fraunhofer ILT presented research results attained in the context of the EU-funded project Bridle (www.bridle.eu) in the field of high-power diode lasers.

ArtiVasc 3D Final Event:
Biofabrication of Artificial Vascularized Tissue
October 28 - 29, 2015, Aachen

At the closing session at Fraunhofer ILT, the ArtiVasc 3D researchers presented their results in detail. The EU research project »ArtiVasc 3D« has advanced into a new dimension as it has developed a three-layered skin model with artificial blood supply and a 3D printing process for producing artificially branched blood vessels made from innovative materials.

Workshop »Laser Diodes for Space Applications«
November 23 - 24, 2015, Palaiseau, France

Together with ESA, the consortium partners of the EU-funded project Britespace (www.britespace.eu) organized a two-day workshop in which the participants discussed current issues and future trends resulting from the use of diode lasers in space. Martin Traub presented research results on the topic »Beam Shaping of High-Power Laser Diodes for Space Applications«.

INTERNATIONAL YEAR OF LIGHT

»LIGHT« EXHIBIT OF FRAUNHOFER ILT

The United Nations declared 2015 as the »International Year of Light«. Under the coordination of UNESCO, companies and public institutions in many countries organized activities that have emphasized the importance of light as a basic requirement for human, animal and plant life and as a central component of science and culture.

Thanks to its many institutions – especially from the group »Light and Surfaces« – the Fraunhofer-Gesellschaft has made a significant contribution to the continued development of optical technologies. For over 30 years, Fraunhofer ILT has been acting as a recognized partner for innovative laser manufacturers and users.

The core competencies of Fraunhofer ILT in high demand include, among others, laser-based additive manufacturing processes, in particular for the production of metallic components for the industry. Moreover, Fraunhofer ILT has won several awards for its innovation, Selective Laser Melting SLM. Additive processes are used in areas where complex component geometries, short reaction times, high individuality and a resource-friendly handling of the material are required.

1 At the exhibition »MakeLightLab« in mid-October 2015 at the BMBF, the exhibit »LIGHT« did not only attract the attention of Professor Johanna Wanka, Federal Minister for Education and Research.

To make a high-profile contribution to the Year of Light, Fraunhofer ILT developed a key exhibit, which establishes a connection to the optical technologies in the field of production technology and, simultaneously, reflects upon a core competency of Fraunhofer, one of national and international relevance. Here, additive laser manufacturing or 3D printing lent itself well as a key theme.

Man-sized Exhibit made with Additive Manufacturing

Designed by the Fraunhofer ILT, this key exhibit consists of the letters »LIGHT«. The visible hollow structure of each letter was produced with 3D printing and is unique in this style and size (h: 1.9 m x w: 5.9 m x d: 0.6 m). Thanks to the multiple meanings of the word light, in terms of weight and illuminance, the exhibit embodies a nice play on words, in addition to providing an optical effect. Light and lightness – a self-evident connection reflected in Digital Photonic Production.

The company Materialise, a cooperation partner of Fraunhofer ILT, produced the hollow internal structure of the letters by means of stereolithography at its plant, Europe's largest, in Leuven, Belgium. Following the generative process, the structures were provided with a metal coating in order to make a clear reference to metallic components produced with SLM at Fraunhofer ILT. In the metal sector, components can currently be produced with dimensions of approximately 65 cm.

The individual letters were then completely embedded in a transparent acrylic glass casing so that the honeycomb hollow inner structure remained visible. The back of the letters was equipped with flat LED lights that illuminate the exhibit in bright colors.

The Tour Stops of the »LIGHT« Exhibit

Annual Meeting of the Fraunhofer-Gesellschaft
June 9 - 10, 2015, Wiesbaden

During the annual meeting of the Fraunhofer-Gesellschaft, around 700 people from industry, science and politics were able to see the radiant energy of the key exhibit in the foyer of the Kurhaus of Wiesbaden, Germany. Guests of honor were German President Joachim Gauck and the prime minister of Hesse Volker Bouffier. In a special tour, Prof. Poprawe explained the special features of the key exhibit as well as the opportunities and prospects additive manufacturing offers industry and society to the two guests of honor and the President of the Fraunhofer-Gesellschaft.

LASER World of PHOTONICS
June, 22 - 25, 2015, Munich

The main topic of Fraunhofer ILT at the trade fair was lightweight construction. The key exhibit underscored this thematic focus with the appealing play on the word and form of the name »Light«. Around 12,000 of the total 27,000 trade visitors were recorded as having visited Hall A3, where the exhibit was located, during the fair. Furthermore, Dr. Flavia Schlegel, Deputy Director-General for Natural Sciences of UNESCO, visited the Fraunhofer booth.

Headquarters of the Fraunhofer-Gesellschaft
June 29 - September 18, 2015, Munich

For two and a half months the »LIGHT« exhibit lit the foyer of the Fraunhofer headquarters in Munich. In addition to over 500 employees, numerous visitors were able to view the exhibit.

Exhibition »MakeLightLab« at the BMBF
October 10 - 18, 2015, Berlin

As part of the »Festival of Light« of the German capital Berlin, the Federal Ministry of Education and Research (BMBF) hosted a theme week about light and its many applications in its new offices on the Kapelle-Ufer street from October 10 to 18, 2015. In these surroundings, the BMBF displayed the exhibit »LIGHT« via the project sponsor VDI TZ. Minister Prof. Wanka opened the event and was briefed, among others, about the technological and creative potential of 3D printing. The connection to maker culture, which is also intensely involved with 3D printing, was obvious. In addition to the visitors of the exhibition, 400 makers and students were registered in the courses and workshops of the VDI TZ.

Exhibition at the »Centre Charlemagne«
November 30, 2015 - January 10, 2016, Aachen

In the window of the »Centre Charlemagne«, the Fraunhofer key exhibit beamed over the Katschhof – the central square in the historic center of Aachen, between the cathedral and town hall – from November 30, 2015 until January 10, 2016. For the approximately 1 million visitors to the Aachen Christmas market, the exhibit made a brilliant reference to the »Centre Charlemagne«, in which the story of Charlemagne is explained. At the same time, the exhibit by the City of Aachen served as a herald for the upcoming »Future Lab 2016 Aachen« – the city's year of science – and had a broad impact.

2 The lightweight exhibit of metal, about 10 cm high, generated with SLM.

3 The exhibit »LIGHT« at the Fraunhofer Annual Meeting, from left to right: Hessian Prime Minister V. Bouffier, Federal President J. Gauck, Fraunhofer President Prof. R. Neugebauer.

Well attended: The 50th Aix-Laser-People meeting on June 24, 2015 at the Seehaus restaurant in Munich during LASER Word of PHOTONICS.

AIX-LASER-PEOPLE

June 24, 2015, Munich
The 50th Seminar of the Alumni Club »Aix-Laser-People« with Business Speed Dating and the 25th Anniversary Celebration of the Arbeitskreis Lasertechnik e.V.
The Arbeitskreis Lasertechnik e.V. celebrated its 25th anniversary on the fringes of the LASER World of Photonics 2015 in Munich. This association was established to promote industrial laser technology in Germany. Today, it connects 154 scientists and managers, practitioners and faculty members, who together develop and share new ideas on the use of laser technology in various industries. When the Arbeitskreis Lasertechnik, or AKL e.V. for short, was founded 1990 as a charitable organization by Prof. Dr. Gerd Herziger – the founder of the Fraunhofer ILT – Prof. Dr. Reinhart Poprawe and Dr. Ernst Wolfgang Kreutz in Aachen, laser technology in Germany was at a decisive turning point: After two decades of intensive development and research, researchers and laser system providers had developed robust solutions for the industrial use of laser technology. At that point of time, it was necessary to promote the introduction of this highly innovative technology among users across the board. To do this, the parties involved not only had to initiate public and private research and development projects, but also selectively promote the younger generation of engineers.

The association has systematically pursued its purpose, of »supporting the scientific exchange of views on the field of laser technology« in numerous publications of the members, award ceremonies and events. In addition to regular in-house seminars, AKL e.V., as ideal supporter, assists the International Laser Technology Congress AKL. The 10,000-Euro Innovation Award Laser Technology is conferred in these surroundings, which the AKL e.V. awards together with the European Laser Institute ELI to individuals and project teams for outstanding performance every two years.

At its core, the AKL e.V. is still a network of people, of laser professionals and laser enthusiasts, composed largely of former academic staff of Fraunhofer ILT and the Chair for Laser Technology at RWTH Aachen University. Many members are still active in the laser industry or are interested in the latest developments of this technology – regardless of the industry in which they are currently active. AKL e.V. systematically promotes these personal networks; indeed, they offer an open, creative atmosphere in which new projects can be conceived. Many college graduates have found a new professional challenge in this association.

The alumni club »Aix-Laser People« (Aachen is called Aix-la-Chapelle in French) was founded, in particular, to maintain contact with the former colleagues from the Fraunhofer Institute for Laser Technology ILT and the four related departments of the RWTH Aachen University. The list of club members now counts more than 450 names. Many of the Aix-Laser People have joined AKL e.V. to get involved in laser technology for the long term and to maintain and expand their personal networks. They also want to hand down professional experience to dedicated junior staff.

The association will continue to stress the importance of networking and exchanging experience in the future. There is a great opportunity to do exactly this since AKL e.V. organizes not only congresses but also joint visits to corporations and institutes several times a year. Even business speed dating between scientists and industrial partners – as in Munich during the anniversary celebration on June 24, 2015 – will be carried out in the future and contribute actively to the expansion of the association's network.

Female MINT students of the FemTec aid program at a demonstration in Fraunhofer ILT.

September 30 – October 1, 2015, Stuttgart
51st Seminar of the Arbeitskreis Lasertechnik e.V. and the Alumni Club »Aix-Laser-People«
at TRUMPF and Porsche in Stuttgart. At the beginning of the first day, Dr. Peter Leibinger, Vice-Chairman of TRUMPF GmbH & Co KG, welcomed the approximately 35 Aix-Laser attendees. Then, Dr. Hartmut Zefferer, Director International Sales, and Dr. Alexander Knitsch, sales area manager at TRUMPF, held presentations and made informative factory tours that showed, among others, 3D laser machines, combined punching and laser machines as well as equipment for sheet metal processing. In the laser-technology application laboratory, the participants had an opportunity to talk with the TRUMPF laser experts in detail on various laser processes and current developments. The second day led the group to Porsche in Stuttgart-Zuffenhausen. After an interesting tour of the modern production facilities, Alexander Georgoudakis from the department Brand Strategy of Dr. Ing. H. C. F. Porsche AG held an informative lecture and mediated a subsequent discussion. At the end of the seminar, there was a comprehensive guided tour of the impressive Porsche Museum in Zuffenhausen.

December 17, 2015, Aachen
52nd Seminar of the Arbeitskreis Lasertechnik e.V. and the Alumni Club »Aix-Laser-People«
at Clean Laser Systems GmbH in Herzogenrath. After briefly welcoming about 25 guests, Dipl.-Ing., Dipl.-Kfm. Edwin Büchter, CEO of Clean Laser Systems GmbH, held a presentation entitled »Integrated Laser Cleaning – from Portable »Backpack Lasers« to Fully Automated Systems for Series Production«. Subsequently, Dr. Arnold Gillner, the manager of competence area Ablation and Joining at Fraunhofer ILT, reported on the status and prospects of material processing with ultrashort pulse lasers. After a final discussion, the participants were able to visit the production halls of Clean Laser Systems GmbH.

EVENTS F0R PUPILS AND STUDENTS

January 27, 2015, Aachen
Student Tour
An orientation event organized by the Chair for Laser Technology LLT and Fraunhofer ILT for students of RWTH Aachen University.

April 23, 2015, Aachen
Girls' Day – Girls' Future
On this day, female pupils from the fifth grade upwards could experience the working world in art, crafts, engineering and science or they could get to know female role models in leadership positions in business, science and politics. Fraunhofer ILT participated in this nationwide vocational orientation day for girls between 10 and 15 years, together with Fraunhofer IPT and Fraunhofer IME.

May 27, 2015, Aachen
Fraunhofer BfC Regional Meeting
A guided tour of the labs for about 14 West German commissioners for equal opportunity (BfC) of the Fraunhofer-Gesellschaft.

May 29, 2015, Aachen
Student Tour
An orientation event organized by the Chair for Laser Technology LLT and Fraunhofer ILT for students of the South Westphalia University of Applied Sciences.

June 21, 2015, Munich
Excursion to the LASER 2015 in Munich
A visit with a group of students to the LASER World of Photonics 2015 trade fair within the framework of the RWTH Aachen University's excursion week.

Fraunhofer ILT at the »Companies' Night« in Aachen.

July 7 - 10, 2015, Aachen
Pupil University, Mechanical Engineering
During the summer school holidays, the RWTH Aachen University offers pupil universities on the MINT subjects (Mathematics, Information Technology, Natural Sciences and Technology) for students starting at the ninth grade. Here, pupils can get to know university life for one week. Jointly with other institutes from the Department of Mechanical Engineering A and the student body of Mechanical Engineering, Fraunhofer ILT participated by holding lectures and laboratory exercises on laser technology.

October 6, 2015, Aachen
FemTec Excursion Day
FemTec Initiative – Promoting Talents
During an excursion week, about 50 female MINT students were able to catch up on personal, professional and career opportunities in the field of research and development.
The Fraunhofer-Gesellschaft invited FemTec as a partner to a dialogue. When visiting Aachen, the students took advantage of the opportunity to get informed about the research content of both Fraunhofer ILT and IPT as well as career and development opportunities in the Fraunhofer-Gesellschaft.

October 15, 2015, Aachen
Student Tour
An orientation event for freshmen at the RWTH Aachen University and organized by the Chair for Laser Technology LLT and Fraunhofer ILT.

November 3, 2015, Aachen
Companies' Night
Career and Job Fair
Fraunhofer ILT presented itself with the slogan »DOCH« at the 8th »Companies' Night«. Over 2,000 graduates, students, and professionals gathered information from the approximately 100 exhibiting companies and institutions on how to organize their careers. Previously, as part of the broad-based and cross-media marketing campaign DOCH, Fraunhofer ILT informed visitors about job and career opportunities in Aachen.
Highlights of the campaign included the slogan's »four huge« letters before the Academica cafeteria and the promotional campaign on October 28, 2015.

December 2, 2015, Aachen
Bonding
Career Networking Fair
Fraunhofer ILT presented itself at the 28th bonding fair in Aachen on December 2, 2015, in addition to 300 other exhibitors, in order to provide information on job and career opportunities.

December 17, 2015, Aachen
Student Tour
Orientation event for a group of students of the Gerollten High School organized by the Chair for Laser Technology LLT and Fraunhofer ILT.

Joint Fraunhofer booth at the LASER World of PHOTONICS with the »LIGHT« exhibit of Fraunhofer ILT.

TRADE FAIRS & CONGRESSES

Fraunhofer ILT at LASER World of PHOTONICS

By using the heading »LIGHT«, the Fraunhofer Institute for Laser Technology ILT attended the LASER World of PHOTONICS in more than one sense: It was able to address a focus both on light(weight) construction and new ideas for industrial laser (light) technology at the world's largest photonics exhibition – with more than 30,000 visitors.

Eye-catcher from the 3D printer

One of the most striking eye-catchers of the exhibition welcomed the guests at the Fraunhofer booth: This year's motto – »LIGHT« – was announced with letters as tall as a human. The real surprise was in the lattice structure of the letters; they were produced with Europe's largest commercial stereolithography system, at the company Materialise in Leuven, Belgium. The process is one of the major 3D printing methods for the production of plastic components.

The industry has a great interest in such additive processes for manufacturing tailor-made components because some of these methods have now become a part of everyday life in the industrial environment. At its booth, Fraunhofer ILT showed various metal components for the automotive industry, the aerospace industry, medical technology and tool construction produced by Selective Laser Melting SLM, a process patented by Fraunhofer ILT. Especially in lightweight construction, SLM-produced components are increasingly being used because their weight can be reduced through a hollow interior structure. Depending on component requirements, a fill factor between 10 and 100 percent can be generated.

Ultrashort pulse lasers for industrial use

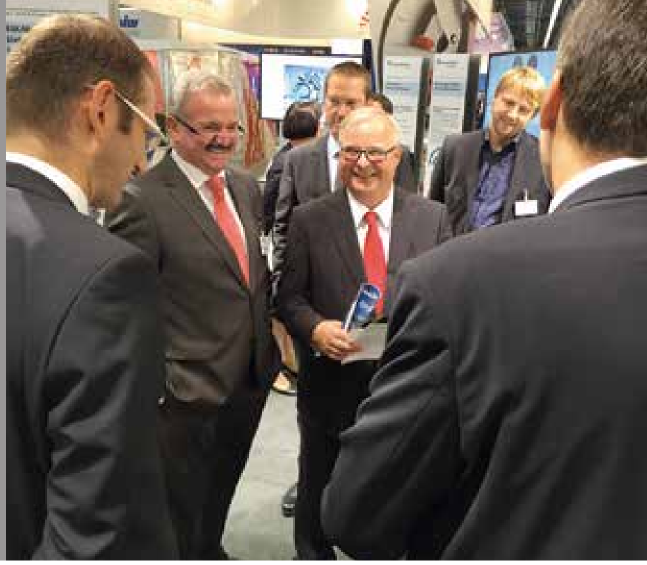
Another highlight was ultrashort pulse (UKP) lasers from Fraunhofer ILT. In addition to laser sources and amplifiers at up to 1.5 kW output power, various modules were offered, for example, for pulse shortening or for tunable wavelength conversion. All systems are specifically designed for industrial use. They provide distinct advantages over the existing technology in both the service life and productivity.

Joining of material combinations for lightweight construction

Whether in aircraft construction or the automotive industry, lightweight materials are in fashion. However, most of these sectors make special demands on processing, especially when different materials need to be joined. Laser technologies provide efficient solutions for this, which Fraunhofer ILT showed with several exhibits.

One example was the adhesive-free joining of fiber-reinforced plastics (FRP) and metal. For this, the laser can be used to structure the surface of the metal component, and the molten plastic flows into these 100-micron deep structures. During curing, the plastic then literally digs into the metal surface. At the Fraunhofer stand, the institute showed a car door with plastic reinforcement produced with this process.

Joint Fraunhofer booth at the JEC Europe, 2015.



Prof. R. Neugebauer (President of the Fraunhofer-Gesellschaft) and Prof. H. Waltl (Audi Board Member for Production) at the IAA in Frankfurt.

SPIE Photonics West
February 7 - 12, 2015, San Francisco, USA
International Trade Fair for Optics and Photonics
At the international trade conference Photonics West, scientists from Fraunhofer ILT held ten lectures: »Two-wavelength approach for control of coagulation depth during laser tissue soldering«, »Radiation tests on erbium-doped garnet crystals for spaceborne CH4-Lidar applications«, »High stability single-frequency Yb fiber amplifier for next generation gravity missions«, »Brightness and average power as driver for advancements in diode lasers and their applications« (an invited paper), »Advantages and drawbacks of Thiol-ene based resins for 3D printing«, »Laser transmission welding of absorber-free thermoplastics using dynamic beam superposition«, »Application of laser beam welding for joining ultra-high strength and supra-ductile steels«, »Laser transmission welding of long glass fiber reinforced thermoplastics«, »Process observation in selective laser melting (SLM)« and »Active optical system for advanced 3D surface structuring by laser remelting«. In addition, Fraunhofer ILT exhibited innovative developments in laser beam sources and optics at the joint stand of the Federal Republic of Germany.

JEC Europe
March 10 - 12, 2015, Paris, France
Composite Show & Conferences
At the joint Fraunhofer stand, Fraunhofer ILT presented economical manufacturing processes for fiber-reinforced composites. For this, the institute displayed FRP components and plastic-metal hybrid components from the process chain developed in the project »InProLight«, funded by the BMBF, as well as sections of front-end components. In addition, Fraunhofer ILT held, together with the Institute of Plastics Processing (IKV) at RWTH Aachen University, a presentation entitled »Process chain for next generations of TP-FRP components: 3-d fiber spraying, variothermal consolidation and laser processing«.

LASER World of PHOTONICS China
March 17 - 19, 2015, Shanghai, China
International Trade Fair for Optics and Photonics
At its stand, Fraunhofer ILT showed current trends and innovations in the field of laser material processing. These included, among others, results from the field of UKP radiation, such as multi-beam processing, helical drilling, thin film ablation for OLEDs and laser material processing with cw radiation (joining/cutting).

Rapid Tech
June 10 - 11, 2015, Erfurt
At a joint stand with the Aachen University of Applied Sciences, Fraunhofer ILT presented exhibits on 3D printing in Erfurt, Germany. Here, the »Aachen Center for 3D Printing«, a cooperation initiative of Fraunhofer ILT and the Aachen University of Applied Sciences, was the focus of attention.
In addition, visitors could view the process chain in the FabBus of the Aachen University of Applied Sciences.

Paris Air Show
June 15 - 21, 2015, Paris, France
International Aerospace Exhibition
At the »International Paris Air Show«, Fraunhofer ILT presented a multi-stage blisk that was produced with a new adaptive process chain. This leads to more creativity in component design and allows better production and repair processes.
The research is a subproject of the innovation cluster »AdaM – Adaptive production for resource efficiency in energy and mobility«.

Fraunhofer ILT at LASER World of PHOTONICS China in Shanghai.

Many interested visitors at the joint Fraunhofer stand of the Paris Air Show.

LASER – World of PHOTONICS
June 22 - 25, 2015, Munich

LASER 2015 World of Photonics and World of Photonics Congress 2015

Fraunhofer ILT presented itself at the LASER World of Photonics under the heading »LIGHT«. It addressed both the focus on lightweight structures and on the new systems for generating laser light. Furthermore, the institute showed a large number of new developments for industrial laser technology at the world's largest photonics exhibition with more than 30,000 visitors.

66th IAA International Motor Show
September 15 - 18, 2015, Frankfurt

International Trade Fair for Mobility, Transport and Logistics

Along with 16 other Fraunhofer institutes, Fraunhofer ILT presented the joint project »Fraunhofer System Research for Electromobility II«. Using the example of the lightweight battery pack, they demonstrated to the visitors how the energy for vehicle propulsion can be provided with lightweight technology. Three different and partially complementary process technologies were shown.

IAC - 66th International Astronautical Congress
October 12 - 16, 2015, Jerusalem, Israel

Together with the Fraunhofer Alliance, Fraunhofer ILT presented exhibits on laser optics, laser sources and Selective Laser Melting. The exhibited laser components and modules have been optimized for use in space and qualified, for instance, for telecommunications and LIDAR applications.

FAKUMA
October 13 - 17, 2015, Friedrichshafen

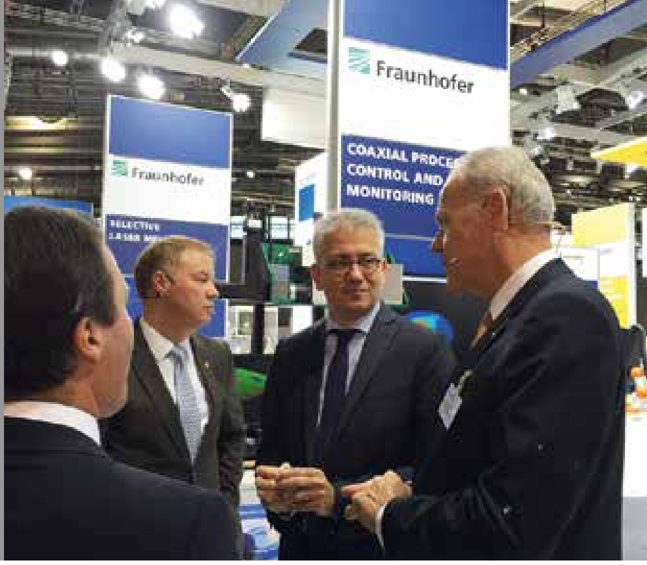
IInternational Trade Fair for Plastics Processing

Highlight of this year's joint stand of the IKV, Fraunhofer IPT and ILT was an injection molding machine from Babyplast, which produced the small freeform optics that projected the logo of the conference, »Aachen Plastic Optics Days 2016«. In addition, Fraunhofer ILT presented multifunctional freeform optics made out of plastic for highly efficient lighting applications and in-house freeform optical design software »freeformOPT«. During the live demonstration of the software, a freeform mirror was designed, which formed an image of the Aachen Cathedral.

ICALEO
October 18 - 22, 2015, Atlanta, USA

34th International Congress on Applications of Lasers & Electro-Optics

Fraunhofer ILT participated in the ICALEO 2015 with four lectures on laser material processing. In addition, Fraunhofer ILT was present as an exhibitor at the vendor session. Before the 350 participants of the ICALEO congress, LIA President Yongfeng Lu and LIA CEO Peter Baker awarded Dr. Keming Du, the founder of the Fraunhofer spin-off »Edge Wave GmbH« and former Fraunhofer ILT employee, with the Arthur L. Schawlow Award 2015.



At the formnext 2015, from left to right: O. Edelmann (Concept Laser), T. Al-Wazir (Hessian Minister of Economy, Energy, Transport and Regional Development) and Prof. Poprawe (Fraunhofer ILT).

Dr. F. Farassat (F&K Delvotec, right) and Dr. A. Olowinsky (Fraunhofer ILT, left) win the »Productronica Innovation Award 2015« for the »Laser Bonder« they developed together.

Productronica
November 10 - 13, 2015, Munich
21st International Trade Fair for Development and Manufacture of Electronics
The highlight of this year's Productronica was the presentation of the »Productronica Innovation Award«. The Laser Bonder, developed by Fraunhofer ILT together with R&K Delvotec GmbH, convinced the jury and was awarded the first place. The Laser Bonder was developed within the joint project »Robustness for Bonds in Electric Vehicles«, funded by the BMBF. In addition, Fraunhofer ILT presented the completely new laser-based joining technology »LIMBO: Laser Impulse Metal Bonding« for temperature-sensitive components, a technology which should provide impetus to electronics production. LIMBO makes it possible to thermally join thick ribbons – with a thickness of 200 microns and more – on thin metallization layers.

COMPAMED
November 16 - 19, 2015, Düsseldorf
World Forum for Medicine and International Trade Fair
At the joint IVAM pavilion, the experts of Fraunhofer ILT discussed opportunities and challenges from the project »Biophotonic Technologies for Tissue Repair BI-TRE«. This project aims to make a laser-based method available for maxillo-facial and oral surgery to ensure reliable wound closure after surgery.

formnext
November 17 - 20, 2015, Frankfurt
International Fair for Additive Technologies, as well as Tool and Mold Construction
Fraunhofer ILT presented its coaxial SLM process monitoring system, which will be offered with the option of adding coaxial coupling of pyrometers and high-speed cameras. Furthermore, Fraunhofer ILT presented further results from the areas of laser polishing, laser cladding and SLM in medical technology. In addition, Fraunhofer ILT made a contribution to the conference by holding the lecture »Update for Metal Processing with Additive Technologies«. This year's keynote speech at the opening ceremony was held by Prof. Poprawe.

Dr. Stefan Hengesbach wins the Hugo Geiger Prize for his doctoral thesis.

AWARDS AND PRIZES

WLT Award

Dr. Stefan Hengesbach was honored with the WLT award on June 22, 2015 from the Scientific Society for Laser Technology (WLT). The award was presented at the conference »Lasers in Manufacturing - LiM 2015« as part of the LASER 2015 in Munich.

Springorium Commemorative Coin

The Springorium coin is awarded by proRWTH – the development association of the RWTH Aachen University – to students who have passed their Diploma or Master's examination with distinction. In 2015, Carlo Holly, Daniel Brück, Patrick Eiselt and Lutz Lübbert were among the award winners from the associated departments of Fraunhofer ILT. 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 Universitiy in 1918 and led it as head of the board until 1925.

Borchers Plaque

The Borchers plaque is awarded to honor outstanding dissertations. This plaque was awarded to Dr. Stefan Hengesbach, employee of Fraunhofer ILT, for his doctorate exam, which he passed with distinction. Furthermore, an alumnus of the Fraunhofer ILT, Dr. Alexander Gatej, was also honored with this plaque. The privy counselor Professor Wilhelm Borchers lent his name to this award; he was a full professor of metallurgy at the university from 1897 to 1925.

Hugo Geiger Prize

At the Munich Science Days in November 2015, the Fraunhofer-Gesellschaft honored Dr. Stefan Hengesbach for his doctoral thesis on »Spectral Stabilization and Incoherent Superposition of Diode Laser Radiation with Volume Diffraction Gratings« with the Hugo Geiger Prize.

Productronica Innovation Award

The highlight of this year's Productronica was the »Productronica Innovation Award« ceremony. The Laser Bonder, which Fraunhofer ILT and R&K Delvotec GmbH developed within »Robust Bonds in Electric Vehicles«, a project funded by BMBF, convinced the jury and was honored with first place.

ARBEITSKREIS LASERTECHNIK AKL E.V.

ARBEITSKREIS LASERTECHNIK e.V.

Arbeitskreis Lasertechnik AKL e.V.
The Forum for Industrial Laser Applications

AKL e.V. was founded in 1990 to ensure that the fascinating opportunities opened up by the laser as a tool in terms of precision, speed and cost-effectiveness could be leveraged for industrial applications by improving the exchange of information and training.

A host of potential applications are now known, and the processes involved have been tried and tested. The use of lasers has become commonplace in many areas. Yet new laser sources and laser processes are constantly being developed that open up innovative, new opportunities in industrial production. A network like AKL e.V. effectively helps support innovation processes in this rapidly changing discipline.

The AKL e.V.'s activities focus on scientific work in the field of laser technology and the uptake of laser technology to improve the quality and cost-effectiveness of production processes. AKL e.V. sees itself as the mediator between suppliers and users as well as between the relevant economic, scientific and political institutions.

A continual exchange of information and development of a shared knowledge base, as well as the sustained improvement in training available, are key to achieving the association's aims. AKL e.V. has 154 members at the moment.

AKL e.V.'s Mission

- Providing information on innovative laser-technology products and processes
- Nurturing personal networks between laser experts
- Organizing conferences and seminars
- Producing teaching material on laser technology
- Promoting junior scientific staff
- Advising industry and the scientific community on laser-technology issues
- Presenting the Innovation Award Laser Technology

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Prof. Dr. Reinhart Poprawe M.A. (Deputy chairman)
Dr. Bernd Schmidt (Treasurer since 1.1.2012)
Dipl.-Phys. Axel Bauer (General secretary)

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EUROPEAN LASER INSTITUTE ELI

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

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AKL'18 – INTERNATIONAL LASER TECHNOLOGY CONGRESS

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