Fraunhofer

ILT

FRAUNHOFER INSTITUTE FOR LASER TECHNOLOGY ILT

ANNUAL REPORT 2014

ANNUAL REPORT FRAUNHOFER INSTITUTE FOR LASER TECHNOLOGY 2014

Dear Reader, Dear Partners of Fraunhofer ILT,

You know those discussions in your company, when you are prioritizing which topics you want to focus your energy on? For example, which particular services, technologies or products have the greatest impact since there is great customer demand or wide press coverage? Which subjects count because they are socially relevant and provide associated benefits to your own brand? In which areas you can expand resources so as to strengthen existing focal points or to generate new ones? Which topics you want to highlight at a forthcoming meeting or trade fair? All of these issues spark passionate discussions among the decision-making committees in our company.

At Fraunhofer ILT, we are on the move in many different fields of applying laser technologies: this ranges from the development of laser beam sources for material processing or satellite communications, to cleaning and polishing tools, the design of miniaturized measuring systems for the analysis of sepsis pathogens all the way to the generation of individual implants or process optimization in micro- and nano-structuring. This annual report gives you an initial overview of the range of topics, applications and sectors that our technology serves. Here, however, we can only represent a small slice of our wide range of services. In 2014, we presented to a broad audience some of our priorities at trade fairs and conferences, such as the International Laser Technology Congress AKL. Among these include the prime topics such as Digital Photonic Production or precision machining by ultrashort pulse lasers of high power levels.

The main focal point – Digital Photonic Production – encompasses both the generation of three-dimensional tailored components and the precise manufacture of custom surface and bulk structures. A new research campus, strategically funded by the BMBF for over 15 years, will provide the ideal environment for basic research into DPP that has industrial relevance. In collaboration with our industry partners and other R&D institutes, we are developing innovative solutions for businesses and society, based on the intelligent networking of the »real production world« with the »virtual IT world«. This procedure is also flanked by new building construction. In the summer of 2014, the groundbreaking ceremony was held at our new Digital Photonic Production Innovation Center. We have already found interested parties for 70 percent of the approximately 7,000 square meters of floor space. Furthermore, we are continuing to use our spin-in concept for companies who want to put their R&D capabilities in our proximity. Thus, by setting technological priorities, we ensure we have a clear orientation – like a brand. And we will expand our priorities sustainably. Furthermore, what we explore and develop can be found in this annual report. I hope you find many inspiring ideas for cooperation with our company in the following pages.

Yours sincerely,

Prof. Dr. rer. nat. Reinhart Poprawe

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PROFILE OF THE INSTITUTE

SHORT PROFILE

ILT - this abbreviation stands for combined know-how in the sector of laser technology for almost 30 years. Innovative solutions for manufacturing and production, development of new technical components, competent consultation and education, highly specialized personnel, state-of-the-art technology as well as international references: these are guarantees for long-term partnerships. The numerous customers of the Fraunhofer Institute for Laser Technology ILT come from branches such as automobile and machine construction, the chemical industry and electrical engineering, the aircraft industry, precision engineering, medical technology and optics. With more than 400 employees and around 19,500 m^2 of net floor area, the Fraunhofer Institute for Laser Technology ILT is among the most significant contracting research and development institutes in its sector worldwide.

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

Under one roof, the Fraunhofer 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.

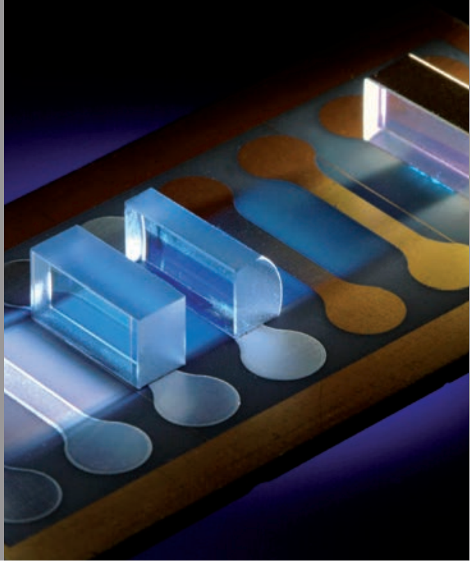
Furthermore, this technology field has a great deal of expertise in beam shaping and guiding, packaging of optical high power components and designing optical components. This field also specializes in dimensioning highly efficient free form optics. In general, the lasers and optics developed here can 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

	Contacts	E-Mail-Address	Phone Extension
LASERS AND OPTICS			
Optics Design	Dipl.-Ing. M. Traub	martin.traub@ilt.fraunhofer.de	Tel. -342
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Solid State Lasers	Dipl.-Phys. M. Höfer	marco.hoefer@ilt.fraunhofer.de	Tel. -128
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Plastics Cutting and Welding	Dr. A. Olowinsky Dr. A. Gillner	alexander.olowinsky@ilt.fraunhofer.de arnold.gillner@ilt.fraunhofer.de	Tel. -491 Tel. -148
Cleaning	Dr. J. Stollenwerk Dr. K. Wissenbach	jochen.stollenwerk@ilt.fraunhofer.de konrad.wissenbach@ilt.fraunhofer.de	Tel. -411 Tel. -147
Marking	Dr. J. Stollenwerk Dr. K. Wissenbach	jochen.stollenwerk@ilt.fraunhofer.de konrad.wissenbach@ilt.fraunhofer.de	Tel. -411 Tel. -147
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In-Volume Structuring	Dr. I. Kelbassa Dr. A. Gillner	ingomar.kelbassa@ilt.fraunhofer.de arnold.gillner@ilt.fraunhofer.de	Tel. -143 Tel. -148
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Thin Film Processing	Dr. J. Stollenwerk Dr. K. Wissenbach	jochen.stollenwerk@ilt.fraunhofer.de konrad.wissenbach@ilt.fraunhofer.de	Tel. -411 Tel. -147
Ultrashort Pulse Processing	Dipl.-Phys. M. Reininghaus Dipl.-Phys. S. Eifel	martin.reininghaus@ilt.fraunhofer.de stephan.eifel@ilt.fraunhofer.de	Tel. -627 Tel. -311
Micro Structuring	Dr. J. Holtkamp Dr. A. Gillner	jens.holtkamp@ilt.fraunhofer.de arnold.gillner@ilt.fraunhofer.de	Tel. -273 Tel. -148
Nano Structuring	Dipl.-Phys. S. Eifel Dr. A. Gillner	stephan.eifel@ilt.fraunhofer.de arnold.gillner@ilt.fraunhofer.de	Tel. -311 Tel. -148
Simulation	Dr. M. Niessen Prof. W. Schulz	markus.niessen@ilt.fraunhofer.de wolfgang.schulz@ilt.fraunhofer.de	Tel. -8059 Tel. -204

MEDICAL TECHNOLOGY AND BIOPHOTONICS

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Clinical Diagnostics	Dr. A. Lenenbach Priv.-Doz. Dr. R. Noll	achim.lenenbach@ilt.fraunhofer.de reinhard.noll@ilt.fraunhofer.de	Tel. -124 Tel. -138
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Microfluidic Systems	Dr. A. Olowinsky Dr. A. Gillner	alexander.olowinsky@ilt.fraunhofer.de arnold.gillner@ilt.fraunhofer.de	Tel. -491 Tel. -148

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EUV Technology	Dr. K. Bergmann Priv.-Doz. Dr. R. Noll	klaus.bergmann@ilt.fraunhofer.de reinhard.noll@ilt.fraunhofer.de	Tel. -302 Tel. -138

STRUCTURE OF THE INSTITUTE

BOARD OF DIRECTORS

Prof. Dr. Reinhart Poprawe M.A.
Director

Prof. Dr. Peter Loosen
Vice Director

Dr. Vasvija Alagic-Keller MBA
Head of Administration

ADMINISTRATION AND CENTRAL FUNCTIONS

Dr. Vasvija Alagic-Keller MBA
Administration and Infrastructure

Dipl.-Phys. Axel Bauer
Marketing and Communications

Dr. Alexander Drenker
QM Management

Dr. Bruno Weikl
IT Management

COMPETENCE AREAS

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

Dr. Arnold Gillner
Ablation and Joining

Dr. Konrad Wissenbach
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 (Vorsitzender), Carl Baasel Lasertechnik GmbH
- Dr. Hans Eggers, Bundesministerium für Bildung und Forschung BMBF
- Dr. Thomas Fehn, Jenoptik AG
- Dr. Ulrich Hefter, Rofin-Sinar Laser GmbH
- Dr. Franz-Josef Kirschfink, Hamburg Aviation Luftfahrtcluster Metropolregion Hamburg e.V.
- Dipl.-Ing. Volker Krause, Laserline GmbH
- Prof. G. Marowsky, Laserlaboratorium Göttingen e. V.
- MinRat Dipl.-Phys. T. Monsau, Ministerium für Wirtschaft, Energie, Industrie, Mittelstand und Handwerk des Landes Nordrhein-Westfalen
- Manfred Nettekoven, Kanzler der RWTH Aachen
- Dr. Joseph Pankert, Philips Lighting B.V.
- Prof. R. Salathé, Ecole Polytechnique Fédéral de Lausanne
- Dr. Dieter Steegmüller, Daimler AG
- Dr. Ulrich Steegmüller, Osram Opto Semiconductors GmbH & Co. OHG
- Dr. Klaus Wallmeroth, TRUMPF Laser GmbH & Co. KG

The 29th Board of Trustees meeting was held on September 10, 2014 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

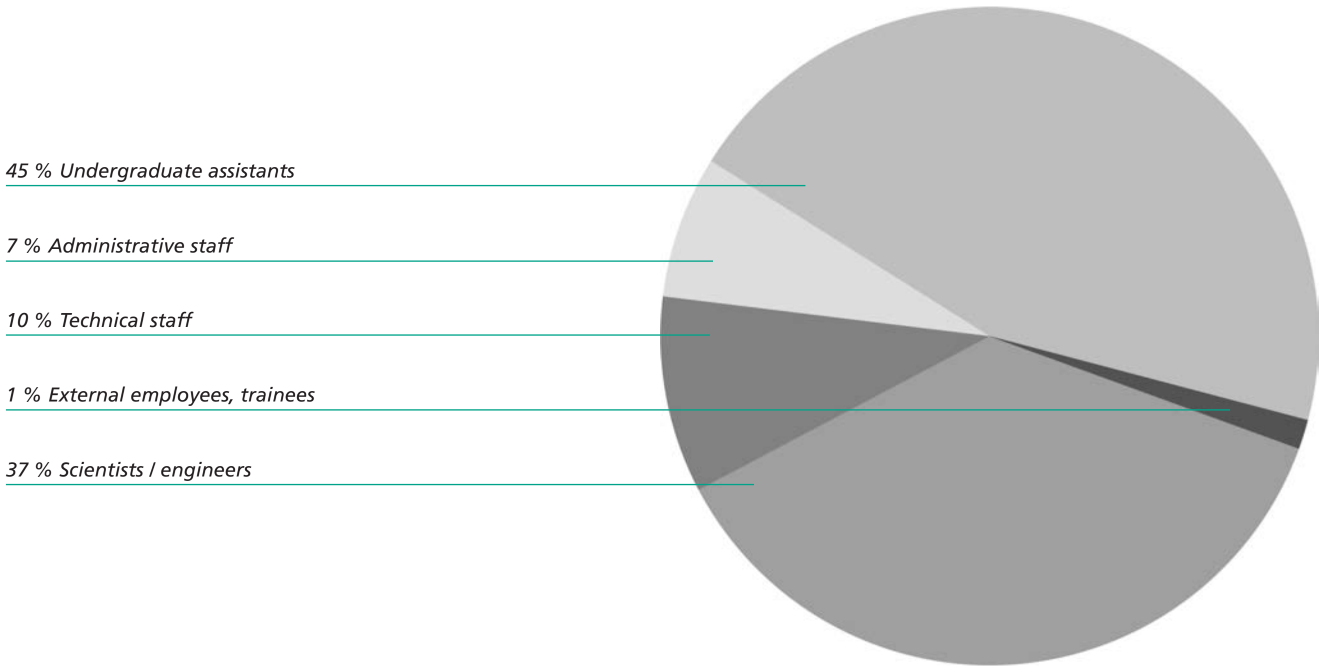
Since March 2003, the employees of Fraunhofer ILT and the cooperating university chairs have elected a workers' council.

FACTS AND FIGURES

EMPLOYEES

Employees at the Fraunhofer ILT 2014 *(Status: 31.12.2014)*	**number**
Personnel	**221**
- Scientists and engineers	152
- Technical staff	40
- Administrative staff	29
Other employees	**184**
- Undergraduate assistants	178
- External employees	3
- Trainees	3
Total number of employees at the Fraunhofer ILT	**405**

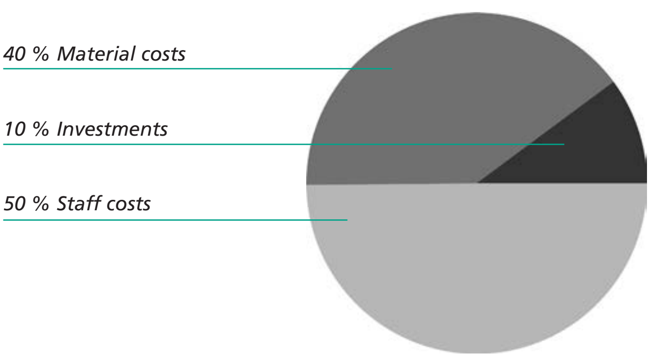
- 15 members of staff completed their doctorates.
- 77 undergraduates carried out their final year projects at the Fraunhofer ILT.



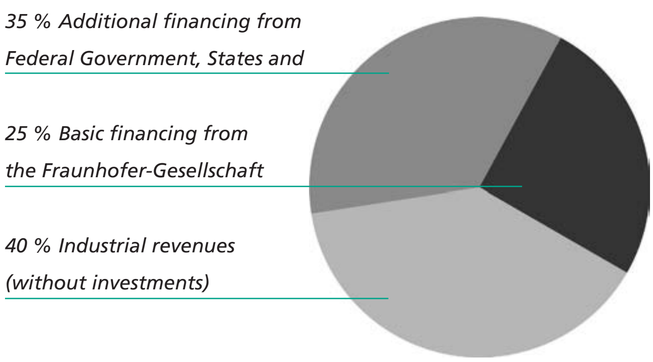
REVENUES AND EXPENSES

Expenses 2014	Mill €
- Staff costs	16,7
- Material costs	13,4
Expenses operating budget	**31,1**
Investments	**3,4**

Revenues 2014	Mill €
- Industrial revenues	12,2
- Additional financing from Federal Government, States and the EU	11,0
- Basic financing from the Fraunhofer-Gesellschaft	7,9
Revenues operating budget	**31,1**
Investment revenues from industry	**0,4**
Fraunhofer industry ρ_{Ind}	**40,6 %**



(100 % Operating budget und investments)

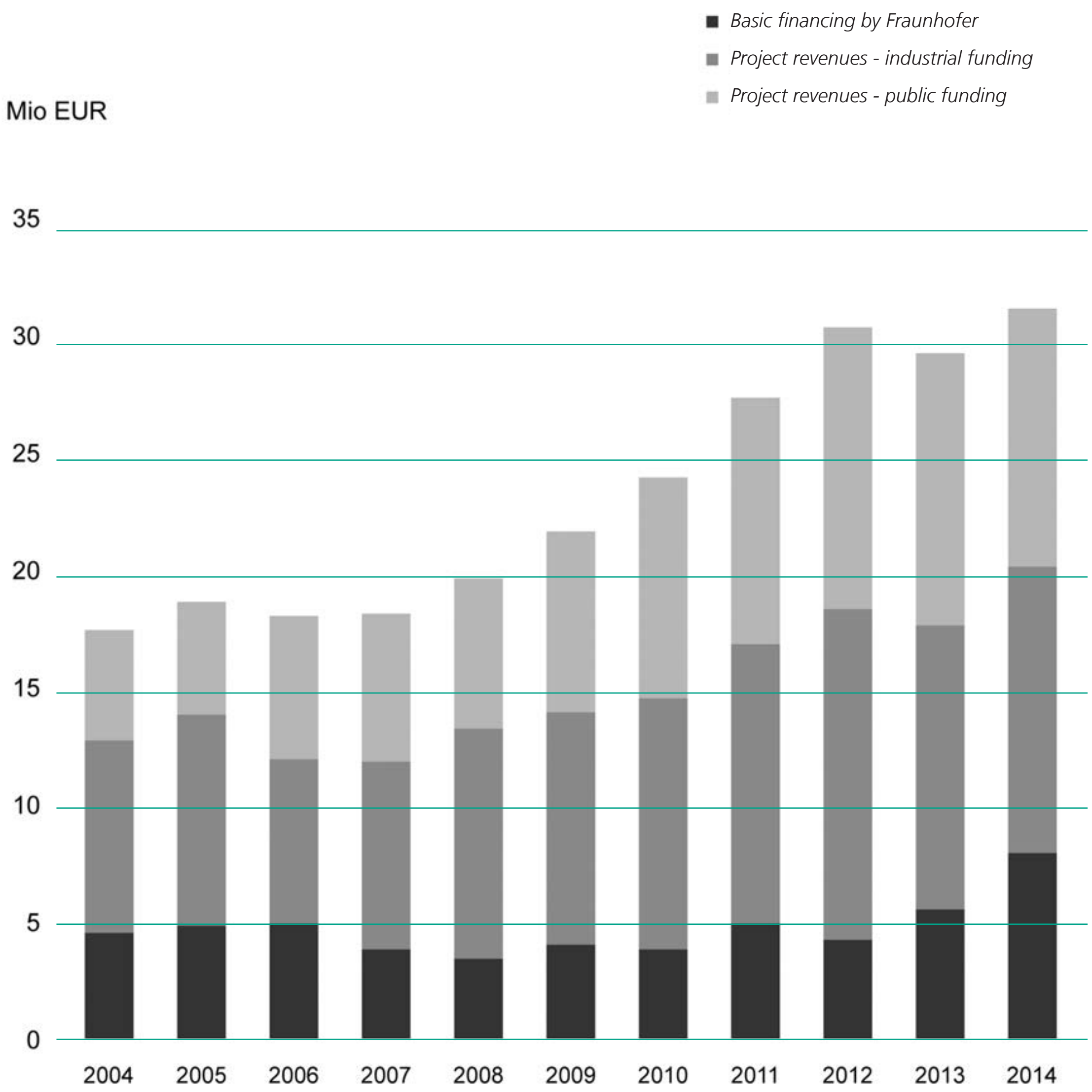


(100 % Operating budget)

FACTS AND FIGURES

BUDGET GROWTH

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



REFERENCES

As at December 2014. 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 m^2.

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 programmes 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:

- 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
- INNOSLAB lasers with pulse widths in the range of nano-, pico- and femtoseconds
- excimer lasers
- ultra short pulse lasers up to 1 kW
- broadband tunable lasers
- 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
- sensors for process control in laser material processing
- direct-writing and laser-PVD stations
- clean rooms for assembly of diode and solid state lasers as well as laser optics
- clean rooms for assembly of diode lasers, diode pumped solid state lasers and fiber lasers
- life science laboratory with S1 classification
- 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

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 2014 CLT participated in the joint Fraunhofer booth at the JEC Composite Show in Paris as well as in the national laser conference JNPLI in Bordeaux.

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 institute and 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

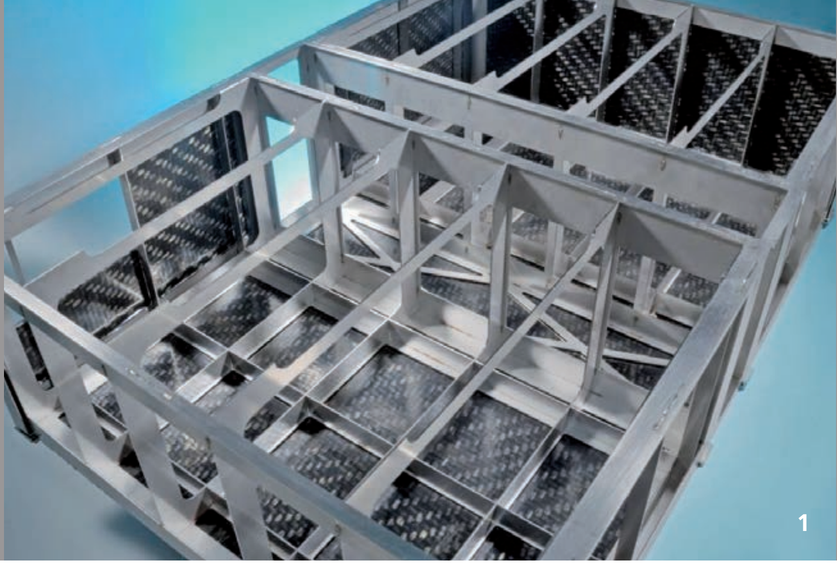
The complexity of vehicle and component development is represented by a division into three clusters:

- 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

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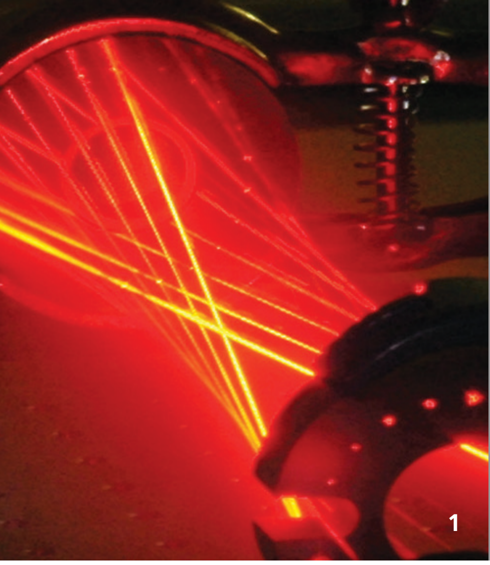
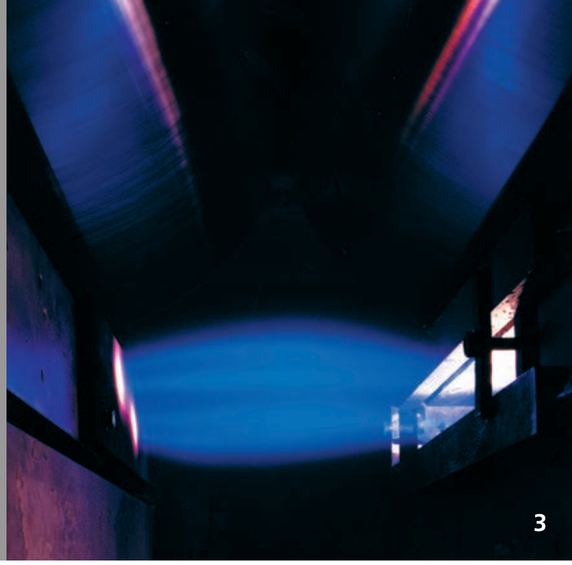
1 Lightweight power pack made out of a combination of high-strength steel and FRP.





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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susan.oxfart@iof.fraunhofer.de

www.light-and-surfaces.fraunhofer.de

Fraunhofer Institute for Applied Optics and Precision Engineering IOF
The Fraunhofer IOF develops solutions with light to cope foremost challenges for the future in the areas energy and environment, information and security, as well as health care and medical technology. The competences comprise the entire process chain starting with optics and mechanics design via the development of manufacturing processes for optical and mechanical components and processes of system integration up to the manufacturing of prototypes. Focus of research is put on multifunctional optical coatings, micro- and nano-optics, solid state light sources, optical measurement systems, and opto-mechanical precision systems.
www.iof.fraunhofer.de

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

Electron beam technology, sputtering technology, plasmaactivated high-rate deposition and high-rate PECVD are the core areas of expertise of Fraunhofer FEP. The business units include vacuum coating, surface modification and treatment with electrons and plasmas. Besides developing layer systems, products and technologies, another main area of work is the scale-up of technologies for coating and treatment of large areas at high productivity.
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 industry oriented R&D service center, the Fraunhofer IST is pooling competencies in the areas film deposition, coating application, film characterization, and surface analysis. Scientists, engineers, and technicians are busily working to provide various types of surfaces with new or improved functions and, as a result, help create innovative marketable products. The institute's business segments are: mechanical and automotive engineering, aerospace, tools, energy, glass and facade, optics, information and communication, life science and ecology.
www.ist.fraunhofer.de

Fraunhofer Institute for Physical Measurement Techniques IPM

Fraunhofer IPM develops and builds optical sensor and imaging systems. These mostly laser-based systems combine optical, mechanical, electronic and software components to create perfect solutions of robust design that are individually tailored to suit the conditions at the site of deployment. In the field of thermoelectrics, the institute has extensive know-how in materials research, simulation, and systems. Fraunhofer IPM also specializes in thin-film technologies for application in the production of materials, manufacturing processes 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 areas joining and cutting as well as in the surface and coating technology. 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 solution systems 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 66 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 billion euros. Of this sum, around 1.7 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:

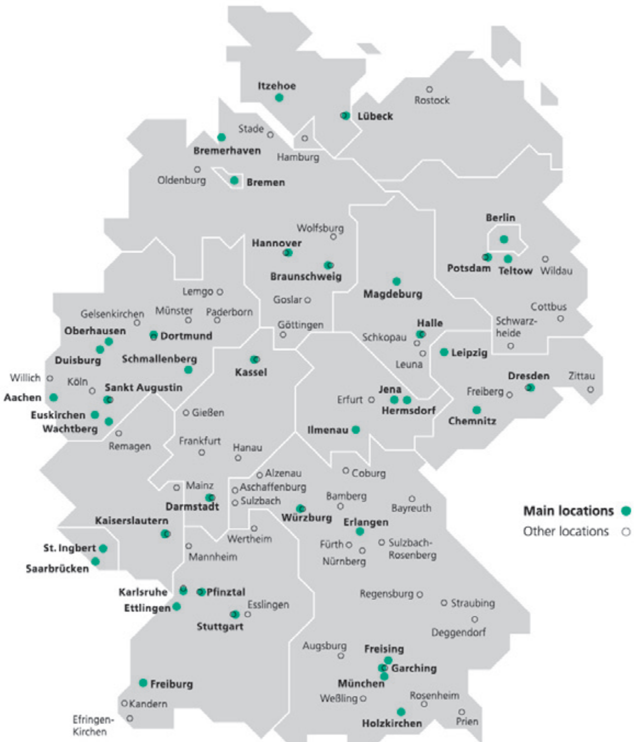
- The Economy: Small, medium-sized and large companies from industry and service sectors can all benefit from contract research. The Fraunhofer-Gesellschaft develops concrete, practical and innovative solutions and furthers the application of new technologies.The Fraunhofer-Gesellschaft is an important ‘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. The interdisciplinary collaboration between physicians and engineers, for instance, has resulted in a university seminar for advanced dental training being set up. 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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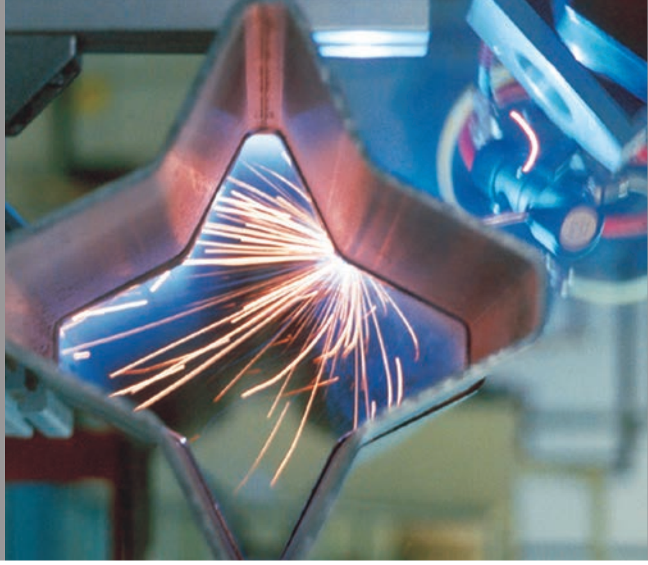

Chair for the Technology of Optical Systems TOS

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. It is being built in the immediate vicinity of the Fraunhofer Institute for Laser Technology ILT on Campus Boulevard.

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

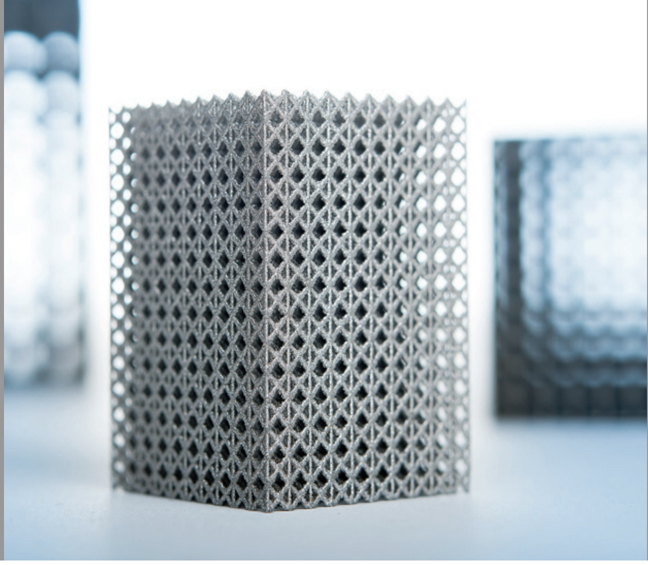
Digital photonic production goes far beyond laser-based additive manufacturing processes. New high-output ultrafast lasers, for example, can achieve very fast ablation almost regardless of material – allowing the finest of functional 3D structures to be produced down to the nanometer region. This new 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 2014

Selected Research Results
of the Fraunhofer ILT

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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

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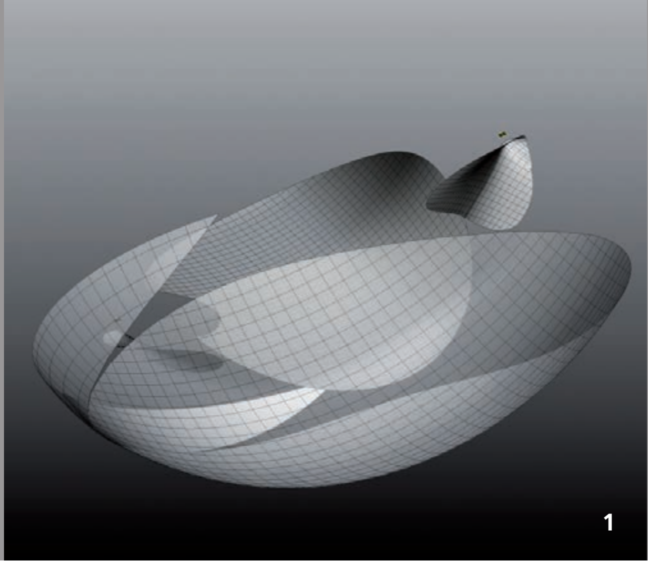
Laser optical components in the optical parametric oscillator.




DESIGN OF PLASTIC MULTIFUNCTIONAL FREEFORM OPTICS FOR AUTOMOBILE LIGHTING

Task

Compared to optics made of glass, plastic optics are an attractive platform for the development and implementation of new lighting concepts, as they can be mass produced cost-effectively by injection molding and offer a significantly greater freedom of shape.

This freedom can be used to design free-form lenses for automotive lighting that feature a single output surface but multiple input surfaces. As the lenses contain several LEDs, these multiple input surfaces enable the lens to perform two independent lighting functions: fog lights and daytime running lights.

Method

Different free-form surfaces designs are necessary so that the same lens can generate the luminous intensity distributions of both fog and daytime running lights. For the broad, smooth luminous intensity distribution of the daytime running lights, surfaces as small as the LEDs are required. However, as LEDs are extended sources, such surfaces are unable to produce the sharp cut-off expected from fog lights. For that purpose, a larger freeform input surface is essential.

Fraunhofer ILT developed the algorithms to dimension several optical freeform surfaces and is using these algorithms to design the common output surface of the optics in order to optimally generate the light intensity distribution of fog lights. The output surface thus obtained is used to optimize the two input surfaces for the daytime running lights.

Result

With this process, highly efficient optics can be designed which are able to perform two separate lighting functions by using three input surfaces. The use of elements reducing the optical efficiency such as diaphragms is no longer necessary.

Applications

The algorithms developed are suitable for use in all areas of lighting, especially if the output surface geometry has specific requirements.

The R&D project underlying this report was conducted on behalf of the Federal Ministry of Education and Research under the grant number 13N10832.

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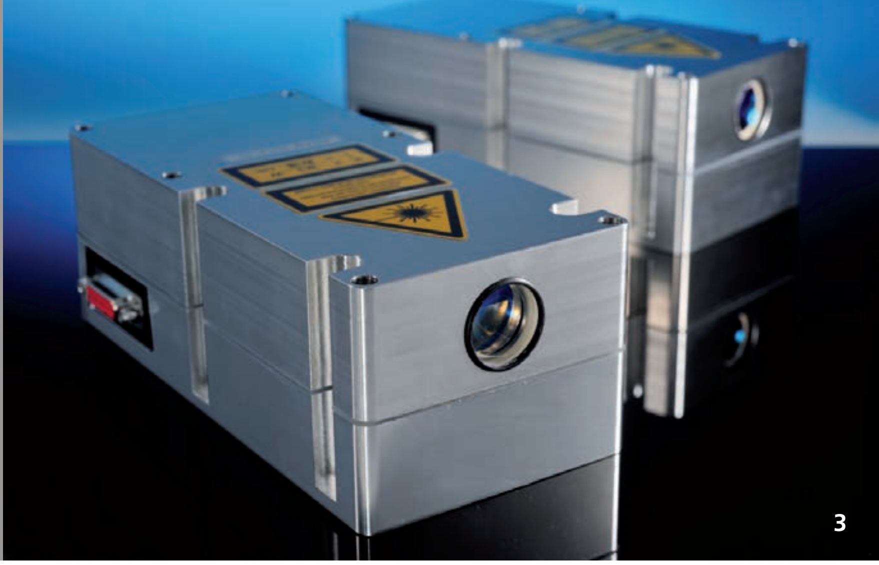
1 Optic design.

2 Fabricated prototype.



PULSED DIODE-LASER MODULE WITH LINE-SHAPED INTENSITY DISTRIBUTION

Task

Demanding applications within measurement and exposure technology require line-shaped intensity distributions in the range of 1 kW/cm² and a homogeneity of > 90 percent combined with adjustable pulse durations in the range of a few microseconds.

Method

Because of their fundamental-mode emission in the vertical direction and multi-mode emission in the lateral direction, diode-laser edge emitters are very suitable for generating linear intensity profiles. For easy integration into existing equipment, the beam source developed here is hermetically sealed and equipped with integrated drive electronics, trigger inputs, interlock interfaces and monitor outputs. The heat is dissipated by heat conduction so that the cost of a water cooler is omitted. If necessary, active cooling can be integrated.

Result

The pulse duration of the diode laser module implemented can be freely adjusted in the range between 1 µs and 1 ms. The demonstration model is operated at a repetition rate of 500 Hz and a pulse duration of 5 µs. The measured rise time to reach the maximum intensity is 300 ns. Peak power can be increased as needed from the current 10 W to approx. 50 W. In addition to the wavelength of 808 nm, the dimension of the line can be adapted to the application.

At a working distance of 45 mm, the demonstrated full width at half maximum (FWHM) of the intensity distribution is 65 µm in the vertical direction and 9 mm in the lateral direction. The standard deviation of the homogeneous intensity distribution in the lateral direction is only 4 per cent despite an inexpensive optical design.

Applications

In measurement and exposure technology, linear intensity profiles with defined geometry are commonly used to record shape and position in the range of a few micrometers up to the millimeter range. Radiation with power densities of up to 2 kW/cm² allows measurements to be made within a few microseconds. In addition, a high signal-to-noise ratio is achieved due to the short illumination duration and the spectrally narrow-band emission. When the pulse parameters are adjusted, the inexpensive modules are also suitable for the precise application of process heat.

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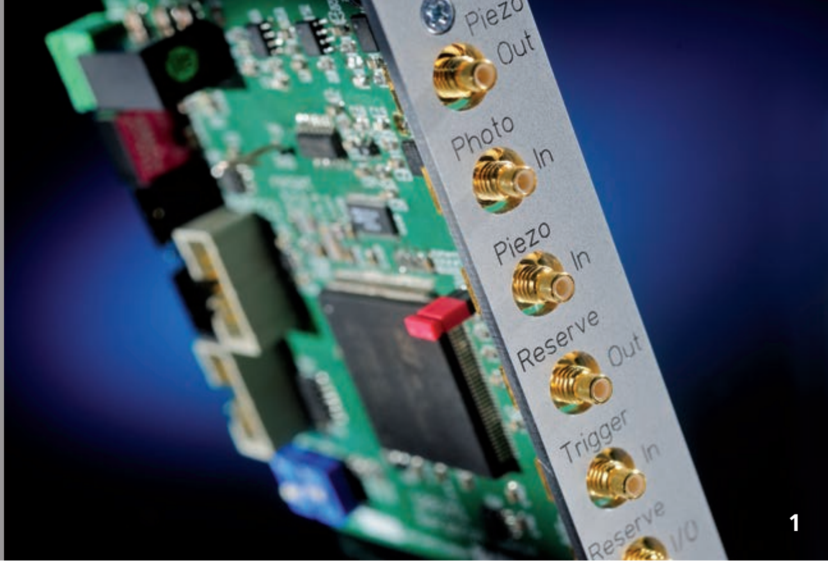
3 Compact, hermetically sealed diode laser module.



ADAPTED CAVITY CONTROL PROCESS FOR A SINGLE-FREQUENCY OSCILLATOR

Task

For the laser transmitter of the satellite-based CH_4 IPDA system MERLIN, laser pulse pairs at 1645 nm are required in the longitudinal single mode (single frequency). For this purpose, a nonlinear frequency converter will be used, which has to be pumped with single-frequency laser pulses at 1064 nm. For the MERLIN instrument, a repetition rate of 24 Hz has been designed for laser pulse pairs. Single-frequency pulses for such applications are usually generated in Q-switched and injection-seeded oscillators. Here, the optical length of the resonator has to be actively adjusted, resonant at a multiple of the irradiated half laser wavelength at an accuracy of one fraction of the wavelengths. As an actuator, a piezo is commonly used. The Ramp&Fire process, which has often been tested at Fraunhofer ILT, will be replaced by a cavity-dither process particularly due to the high mechanical stress and the typical process synchronization problem in the low vibration loads expected.

Method

The corresponding electronics were developed in collaboration with Beratron GmbH in order to implement this control task. To evaluate the resonance quality, the light of the seed source transmitted by the oscillator is detected with a photodiode. During dither phase, the piezo is controlled by the electronics such that it modulates the length of the resonator at 1 kHz.

1 Cavity-control card.

The regulator adjusts the center position of the piezo so that a symmetrical photodiode signal is detected. For the phase of the pulse generation, the piezo is statically driven in the optimum position.

Result

Single-frequency laser pulses could be reliably generated with the oscillator of the MERLIN laboratory demonstrator model in this process. The mechanical stroke of the piezo and, thus, the mechanical stress could be significantly reduced compared to the Ramp&Fire process. A final test under realistic vibration loads is still pending.

Applications

The control electronics is now available as a hardware solution in addition to the Ramp&Fire process and can be used as needed for the development of laser beam sources. Both control electronics are electrically and optically compatible and can be controlled via a controller system that has already been used in several lasers.

The R&D project underlying this report was conducted on behalf of the Federal Ministry for Economic Affairs and Energy under the grant number 50EP1301. The work is part of a joint project between DLR RfM and CNES within the scope of the German-French MERLIN satellite project. Fraunhofer ILT is conducting the work as a subcontractor of Airbus DS GmbH.

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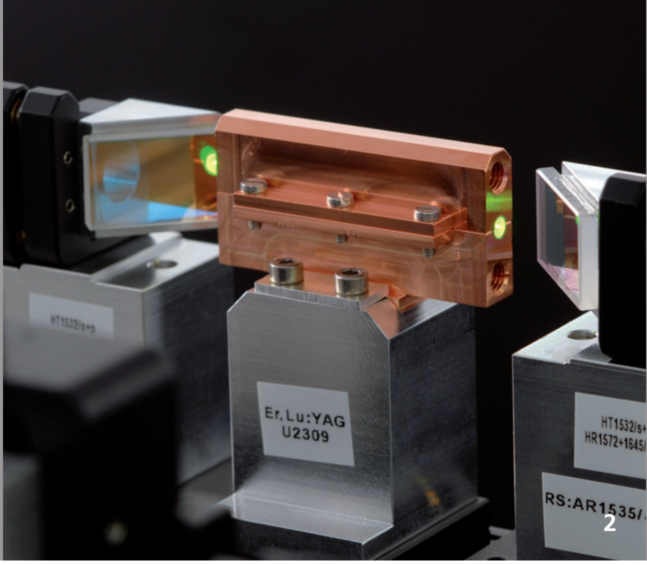

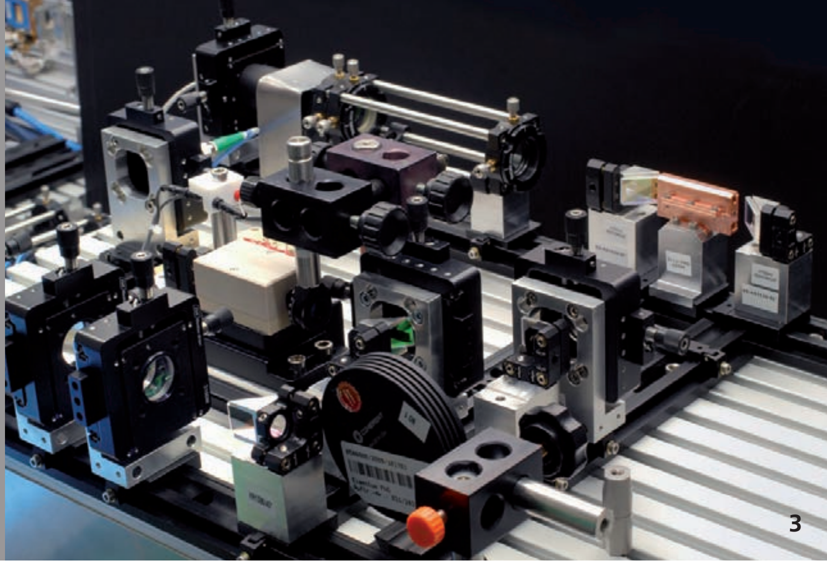

RESONANTLY DIODE-PUMPED ER:YLUAG LASER

Task

Satellite-based Lidar systems lend themselves to the global and stable measurement of methane concentrations in the atmosphere and have been, for example, developed for the joint German-French climate mission »Merlin«. A solid-state laser based on an erbium-doped garnet crystal can constitute the laser beam source of such a system. This application requires narrow-band Q-switched laser pulses at a repetition rate of 100 Hz with < 100 ns pulse duration, 1645 nm wavelength and a diffraction-limited beam profile.

Method

A rod-shaped laser crystal of Er:YLuAG is resonantly pumped – i.e. pump light absorption takes place between the same electronic multiplets as laser light emission – on both ends with spectrally stabilized fiber-coupled diode laser modules continuously at 1532 nm. Laser pulses are generated with a Pockels cell and a thin-film polarizer.

Result

Fraunhofer ILT has measured laser pulses with pulse energy of 5.1 mJ and pulse durations of 80 ns at a wavelength of 1645 nm and a repetition rate of 100 Hz. With respect to the incident pump power, the slope efficiency is 15 percent, which is in the same range as a previously designed system with high brightness fiber lasers as a pump source. Currently an INNOSLAB amplifier is being built for the scaling of the pulse energy.

Applications

In addition to its use in metrology, laser radiation with wavelengths around 1.6 µm is suitable for medical applications. Furthermore, it could be used to process materials transparent in the visible wavelength range. This laser can be operated continuously or at higher repetition rates in the kHz range, whereby the optical efficiency is also significantly larger.

The R&D project underlying this report was conducted on behalf of the Federal Ministry for Economic Affairs and Energy under the grant number 50EE1222.

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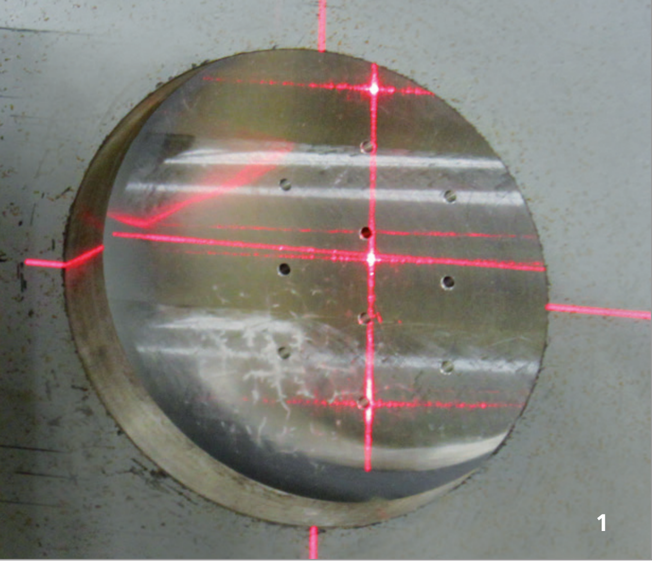
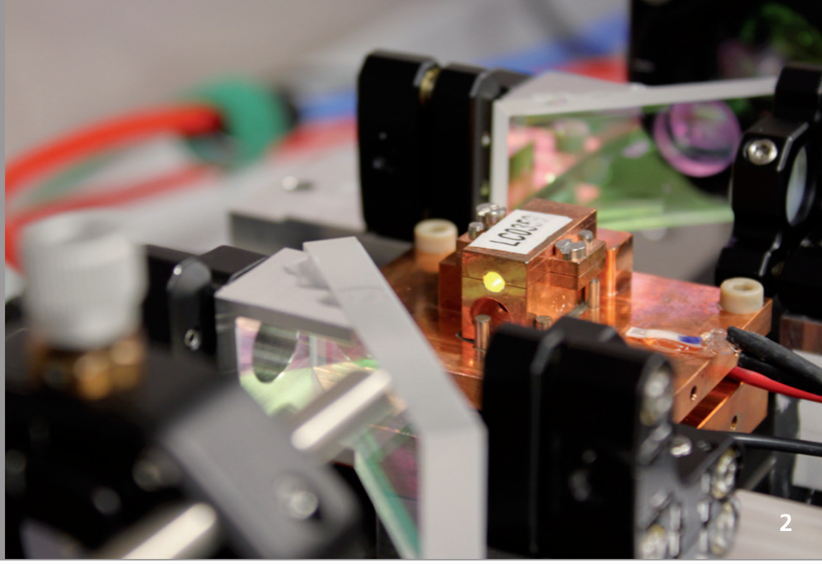
2 Pumped laser crystal.

3 Er:YLuAG laser oscillator.





RADIATION TESTING ON ER^{3+}-DOPED GARNET

Task

Satellite-based Lidar systems lend themselves to the global and stable measurement of methane concentrations in the atmosphere and have been, for example, developed for the joint German-French climate mission »MERLIN«. A solid-state laser based on an erbium-doped garnet crystal serves as the laser beam source of such a system. There have not been any published studies, however, on these crystals' radiation hardness against proton and gamma radiation.

Method

Different crystal samples of Er:YAG, Er:YLuAG and Er,Ce:YLuAG were irradiated with protons corresponding to a given mission scenario. The radiation-induced losses were determined for the individual specimens in three different ways:

- Before and after irradiation, transmission spectra of the specimens were measured.
- A test laser oscillator was built and all specimens were used before and after irradiation in this oscillator as a laser medium. The laser threshold and slope efficiency were measured before and after the irradiation for each individual specimen.
- By means of photo-thermal common path interferometry (PCI), the radiation-induced volume absorption was measured in the specimens.

Result

Proton radiation-induced losses are only measured for specimens irradiated with the ten-fold mission dosage. These amount to about 2 percent/cm for Er:YAG and Er:YLuAG and about 0.5 percent/cm for Er,Ce:YLuAG. All specimens are sufficiently radiation-hard for use in the given mission scenario. Furthermore, it was demonstrated that co-doping with cerium increases the proton radiation hardness. Currently, gamma radiation tests are being conducted.

Applications

The results show that erbium-doped garnet crystals can be used in radiation-intensive environments. In addition to the aerospace industry, for example, their usage in particle accelerators may also be suitable.

The R&D project underlying this report was conducted on behalf of the Federal Ministry for Economic Affairs and Energy under the grant number 50EE1222.

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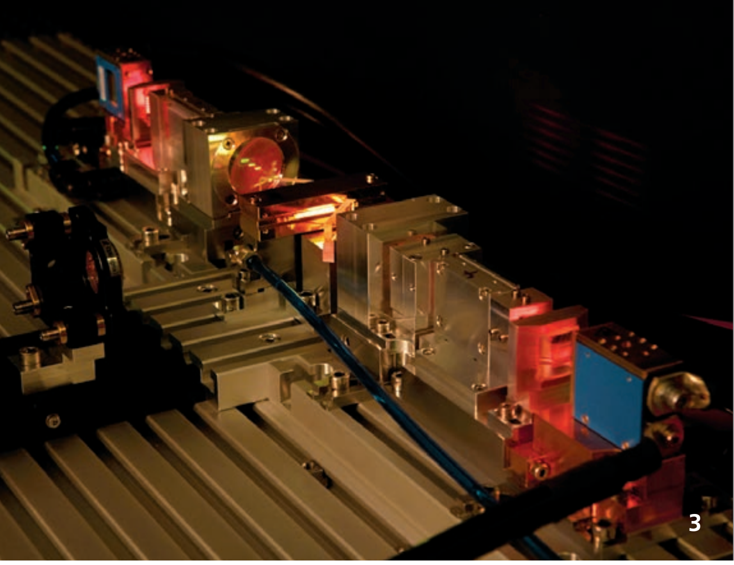
1 Setup for proton radiation.

2 Test specimen in the laser oscillator.



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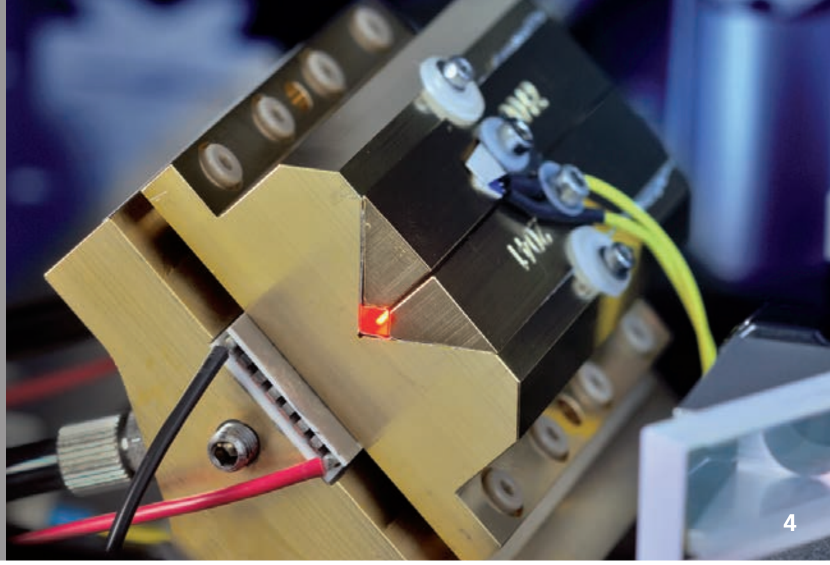

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PULSED HO:YLF LASER

Task

Laser sources in the wavelength range around 2 µm and with pulse durations in the nanosecond range have many fields of application: materials processing, remote sensing, science and the military all take advantage of the special absorption properties of 2 µm radiation, as compared to, e.g., 1 µm. As part of the DLR project »CHOCLID« and the ESA project »HOLAS«, a pulsed spectrally narrow-band 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

To generate the required double pulses with 45 mJ and 15 mJ pulse energy and a repetition rate of 50 Hz, a Ho:YLF MOPA system was designed using numerical simulations; it is pumped by diode-pumped Tm:YLF lasers. In the oscillator, pulses should be generated with a constant energy of 4 mJ, which are scaled in an INNOSLAB amplifier to the required pulse energy. Special attention in the design was paid to meeting critical energy densities so as to avoid a laser-induced damage to the optics.

Result

As a pump source for the Ho:YLF oscillator, a Tm:YLF rod laser was built with a cw power of 25 W; currently its power is limited by the pump diodes used. The Ho:YLF oscillator generates pulses of 3.5 mJ with a pulse duration of 35 ns at a frequency of 1 kHz, and 11 mJ with a pulse duration of 25 ns at 100 Hz. The testing at high pulse energies shows that damage thresholds are not exceeded at the operating point of 4 mJ.

A Tm:YLF INNOSLAB laser, having 200 W cw power and adapted beam distribution, was built as a pump source for the prospective Ho:YLF amplifier.

Applications

Except as master oscillator for the following amplifier, the oscillator can be used in the named parameter field in materials processing. The output wavelength of 2 µm is also advantageous for use as pump source of efficient, long-wavelength, optical-parametric oscillators.

The R&D project underlying this report was conducted on behalf of the Federal Ministry for Economic Affairs and Energy under the grant number 50EE1222.

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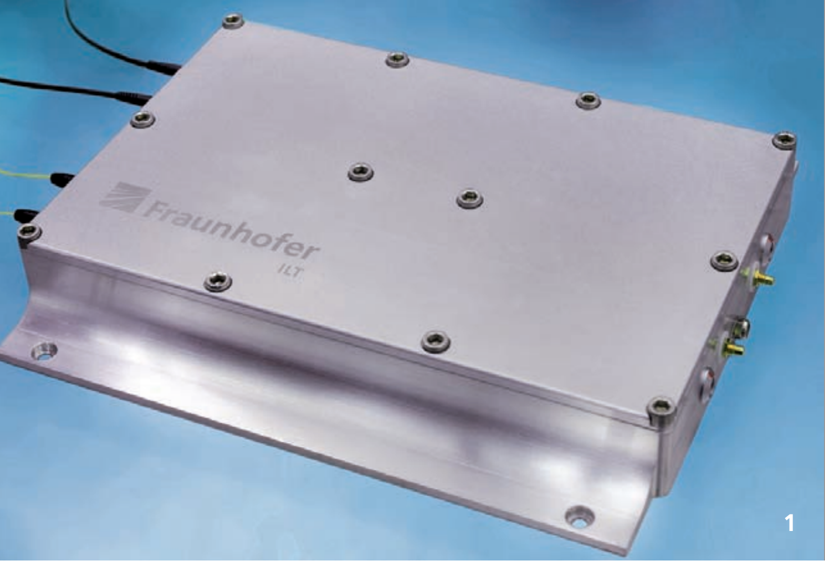
3 Tm:YLF INNOSLAB laser.
4 Ho:YLF oscillator.



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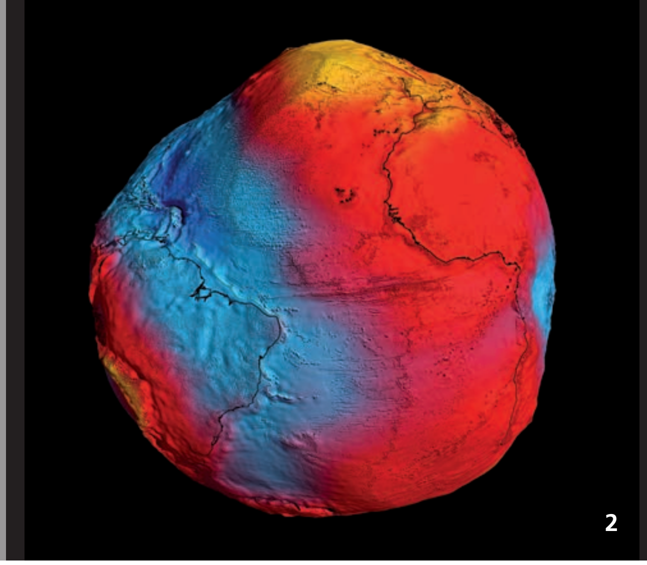
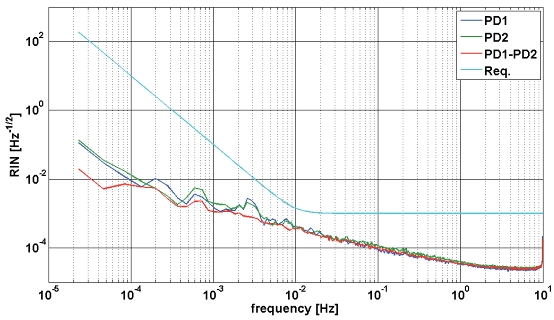


2

HIGHLY STABLE FIBER AMPLIFIER FOR NARROW-BAND SIGNALS



Output power stability.

Task

As part of its Earth Observation program, the European Space Agency is overseeing missions to measure the gravitational field of the earth. In order to improve the measurement resolution from previous missions (GRACE), it is developing a laser at 1064 nm, which exhibits a spectral bandwidth below 10 kHz and extremely high operating stability.

Method

The beam source consists of a fiber amplifier developed by Fraunhofer ILT, which scales the signal of a non-planar ring oscillator to the desired output power, and a reference cavity developed by the project partner, which stabilizes the laser in the frequency. The active medium of the amplifier is a polarization-maintaining fundamental-mode fiber with step index profile. This is pumped with a spectrally stabilized laser diode at a wavelength of 976 nm in order to counteract the occurrence of stimulated Brillouin scattering. By means of a photodiode and a customized, high-resolution electronics, the output power of the laser can be actively stabilized by modulating the pump power.

Result

The required output power of 500 mW could be successfully demonstrated while maintaining the stability criteria. At a central wavelength of 1063.9 nm, the amplifier was stabilized to a bandwidth below 3 kHz at full output power at a project partner. The degree of polarization is above 99 percent. Through the use of fundamental-mode fibers, the beam quality achieved amounts to $M^2 < 1.1$.

Applications

Due to the extremely narrow bandwidth and power stability as well as the high transverse beam quality, the amplifier is suitable for use as a beam source in various areas of industrial metrology, in addition to satellite-supported gravimetry and communication.

The R&D project underlying this report was supported by the European Space Agency (ESA).

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1 Fiber-amplifier module.

2 Local distribution of the gravitational field of the earth, source: © ESA/HPF/DLR, GOCE mission.

3

THERMO-MECHANICALLY RUGGED OPO DEMONSTRATOR MODEL FOR CLIMATE MISSION MERLIN

Task

As a greenhouse gas, methane has a significant share in in-fluencing climate change. By comparison, however, the global distribution as well as sources and sinks of the gas are poorly understood. Within the scope of the German-French Climate Mission »MERLIN«, a satellite-based LIDAR system shall be used to gather detailed and global density distributions of methane. The transmitter is a Q-switched Nd:YAG laser as a pump laser combined with an optical parametric oscillator (OPO) as a frequency converter. The OPO converts the laser output wavelength of 1064 nm into a characteristic methane absorption line at about 1645 nm. After the required output parameters of the OPO were demonstrated on a laboratory setup with classical mounting technology, the constructive feasibility of the conceptual design as a more robust demonstrator shall be shown. This particularly concerns the thermo-mechanical stability of the structure under non-operational thermal transport conditions: from -30° C to +50° C. For the resonator optics of the OPO, tilt stabilities have to be maintained within a 10 µrad range.

Method

The mechanical implementation of the demonstrator model is based on the optical design of the lab setup. The optical elements of the OPO, crystals and mirrors are soldered on metallic holders adapted to this purpose. These have been developed at Fraunhofer ILT to withstand the operating conditions of satellite-based lasers and are characterized by a large mechanical and thermo-mechanical stability. In order to ensure a high quality of solder joint, both the melting cycles and, thus, the number of adjustment steps were limited. Therefore, to construct the OPO, the strategy to adjust the optical components has been adapted to these characteristics of the assembly process.

Result

Two OPO modules have been successfully constructed and adjusted based on the soldering technology. They showed the same conversion efficiency as with OPOs constructed using conventional holders. Even after passing through an air cycle test, both modules exhibited the same efficiency as before.

Applications

The implementation of robust construction technique can also be used in OPOs in other wavelength ranges operating under demanding environmental conditions. In this way, a large number of relevant gases can be detected.

The R&D project underlying this report was conducted on behalf of the Federal Ministry for Economic Affairs and Energy under the grant number 50EP1301. The work is part of a joint project between DLR RfM and CNES within the scope of the German-French MERLIN satellite project. Fraunhofer ILT is conducting the work as a subcontractor of Airbus DS GmbH.

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3 Mechanically stable, optical parametric oscillator.

SOLDERING TECHNOLOGIES SUITABLE FOR NONLINEAR OPTICAL CRYSTALS IN THE AEROSPACE INDUSTRY

Task

In particular, satellite-based laser sources for LIDAR systems require mechanically and thermally robust opto-mechanical components and they should not contain organic materials such as adhesives. Adapted solder joints are particularly suitable here. The assembly of nonlinear optical crystals such as BBO, LBO, KTP or TGG is particularly critical because of the special crystal properties and the boundary conditions occurring in use (temperature load change, mechanical shock and vibration). In addition, the differences in thermal expansion coefficients between the crystals and metallic soldering partners can adversely affect the function of the crystals due to mechanical stresses. Specifically in non-operational phases, alternating thermal loads ranging from -30° C to +50° C can compromise the mechanical strength of the crystal interface in satellite use.

Method

The nonlinear optical crystals are soldered between adapted metallic holders depending on the application and type of crystal. The geometry and the choice of materials play a crucial role. In BBO crystals, the mount is designed in the form of sheets and is elastic; it is soldered into a ceramic housing. Since LBO and KTP crystals need to be tempered in most applications, these crystals are soldered planar onto substrates adapted to heat expansion. The geometry of the holder is optimized for heat conduction. The TGG crystal is soldered into a passively cooled holder, which dissipates the heat loss at high mean power.

Results

By means of the soldered technical assembly that the Fraunhofer ILT developed for nonlinear crystals, functional modules have been built and successfully tested. For the tests, labor demonstrator models of the laser beam sources were used, which have the characteristics of the planned flight laser.

Applications

In addition to the crystals described above, the assembly technology described here can be used for other nonlinear crystal types. As well as for space applications, this method can be used for solid-state lasers in medical technology or materials processing.

Parts of the research described here were carried out on behalf of the Federal Ministry for Economic Affairs and Energy within the framework of the R&D project underlying this report. They have grant numbers 50EE1235 and 50EP1301. The work is part of a joint project between DLR RfM and CNES within the scope of the German-French MERLIN satellite project. Fraunhofer ILT is conducting the work as a subcontractor of Airbus DS GmbH.

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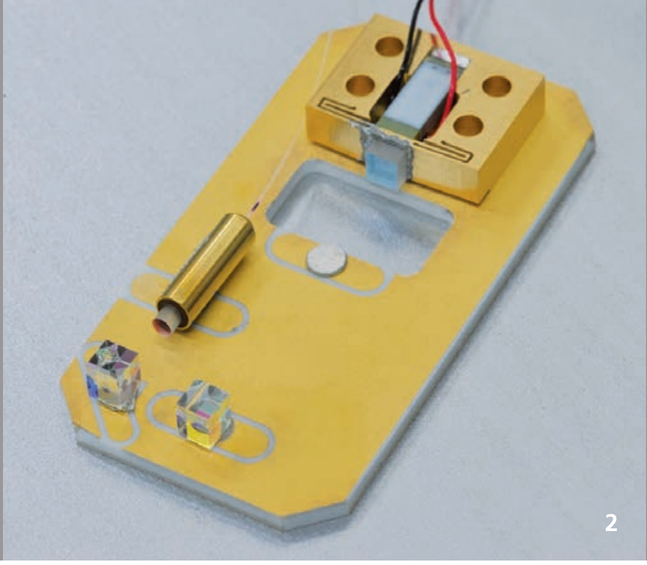
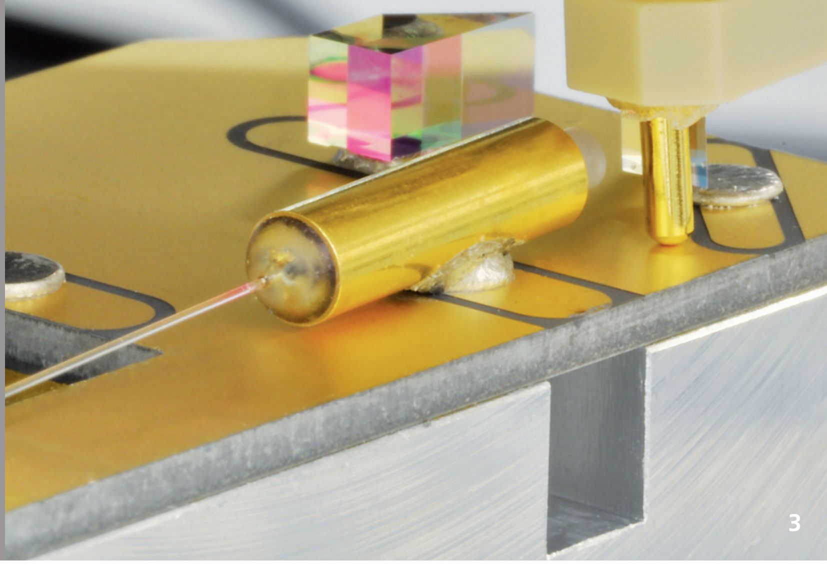
1 Fully functional prototypes of soldered nonlinear crystals (from left: BBO, TGG, KTP, LBO).





ASSEMBLY PROCESS FOR THE FREE-BEAM OPTICS OF A FREQUENCY COMB

Task

For the space-based analysis of greenhouse gases in the atmosphere, LIDAR systems based on laser diagnostics can be employed to a great advantage. An important component of a LIDAR system is a frequency comb generator, which assumes the function of an absolute frequency reference. Thereby, the wavelength of the LIDAR beam source can be set or switched with long-term stability for selected positions in the spectrum of the trace gas to be examined. In addition to fiber-based assemblies, a frequency comb includes a free-beam optics, which has to be set up mechanically and thermally stable. Moreover, the dimensions of the components and the available installation space pose special challenges.

Method

The free-beam optics consists of six components mounted on a ceramic plate with a surface area of 26 × 50 mm^2. First, the piezo holder and then the retro mirror are mounted on this by means of reflow soldering. Afterwards, the ceramic plate is aligned on a water-cooled vacuum support. In the next step, the beam splitter cube is actively aligned and soldered on the beam axis defined by the retro mirror. In the last step, the free-space optics is adjusted to maximum output using the collimator adjustment and the collimator is fixed by soldering.

Result

Thanks to the assembly method developed at the Fraunhofer ILT, free-space optics could be successfully constructed while the required tolerances were maintained (10 percent drop in performance after cooling). By increasing the mechanical stability of the ceramic plate, the institute can also improve the behavior of the assembly further.

Applications

The range of applications of the assembly process described extends far beyond aerospace usage. This concept can be used for all laser beam sources with similar requirements, for example, in the field of medical technology or for labeling devices.

The R&D project underlying this report was conducted on behalf of the Federal Ministry for Economic Affairs and Energy under the grant number 50EE1227.

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2 Completed free-beam optic setup.

3 Partially assembled free-beam group.

PRECISION ASSEMBLY SYSTEM FOR LASER COMPONENTS

Task

For the assembly of optical components in solid-state lasers intended for use in space, the Fraunhofer ILT has developed and built an assembly system, and put it into operation. This system makes it possible to assemble the optics necessary for the operation of a laser by soldering and to adjust them actively. The directional and positioning tolerances that must be maintained lie in the range of 10 µrad and 10 µm, respectively.

Method

The eight motion axes of the assembly system are arranged in such a way that two special vacuum grippers on two processing heads can work simultaneously to adjust two optical components simultaneously. Since, on the one hand, the axes must travel long paths and, on the other hand, maintain high positioning precision, the processing heads are equipped with an additional precision motion system. The pre-development to this assembly system has shown that the parallel kinetic system is suitable for soldering assembly. The actual soldering is done with a specially designed gripper. This gripper is used not only to supply and hold the optics, but also to apply the electrical current needed for the resistance soldering across two electrodes at the soldering point. The system is operated in a clean room with the clean room class ISO 5.

Results

Two air-bearing linear axes allow the system to travel paths of 950 mm x 350 mm. These axes are optimized for positional stability and rigidity so that high precision can be achieved with the two parallel kinematic systems even under mechanical load. Optical elements can be positioned with step sizes of 20 nm or 1 µrad. Two optical components can be adjusted simultaneously.

Applications

The Fraunhofer ILT has successfully applied the assembly system to the optical parametric oscillator (OPO) developed for the German-French Climate Mission MERLIN. The required specifications were met thanks to the high positional accuracy and stability of the assembly system. A complex MOPA arrangement based on a Nd:YAG laser will be assembled soon.

Since the assembly system is very flexible, it can be transferred to other applications where similar stabilities and accuracies are required. For example, this is true for laser systems used in industrial environments.

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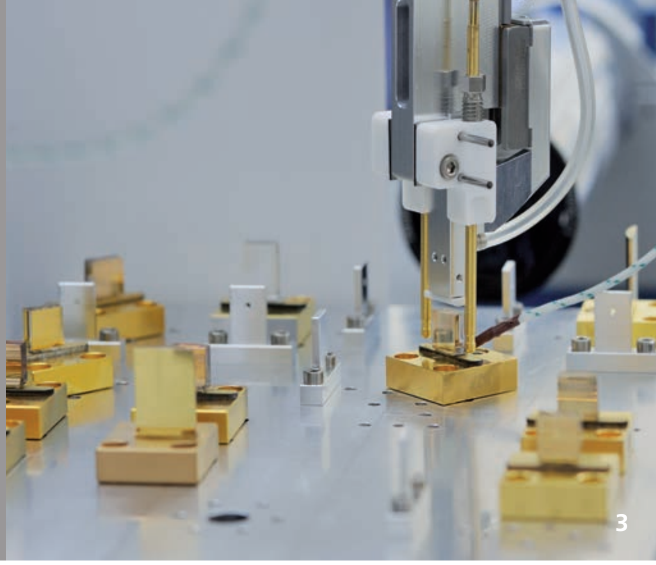
1 Assembly system.



CONSTRUCTION TECHNO-LOGY FOR LASER-OPTICAL COMPONENTS

Task

Optical components in satellite-based LIDAR laser systems are exposed to extreme environmental conditions such as mechanical shocks, vibrations and temperature changes between -30 °C to +50 °C. In addition, they have to exhibit a permanent tilt stability of < 10 µrad in most cases. These components also have to be adjustable, small, light and free of organic substances such as adhesives. Furthermore, the soldered components have to be screwed onto an aluminum base with high positional accuracy, which allows them to be exchanged in case of failure.

Method

To meet these requirements, various construction technologies have been developed and combined. The soldering techniques already established at the Fraunhofer ILT, such as »Heavy-Duty Reflow Soldering for Compact Optic Modules«, on the one hand, and »Pick & Align - Joining of Optical Components with Active Alignment«, on the other, form the foundation for a non-adhesive construction technology. In addition, a sub-mount structure that compensates for thermal expansion was used. On this basis, opto-mechanical holders have been developed and their stability and reproducibility in climatic cycle and vibration testing demonstrated many times.

Result

Using the example of the optical parametric oscillator (OPO) developed for the German-French Climate Mission MERLIN, the Fraunhofer ILT could examine the process on a representative laser assembly. Here, the institute was able to demonstrate aspects such as a sufficient number of melting cycles as well as sufficient holding time above the melting temperature of the solder in order to optimize the OPO parameters. Two identical OPO modules have been constructed. With the same conversion efficiency, the good adjustability and high positional accuracy could be shown as compared to arrangements with conventional holder systems. The temperature stability of the arrangement was proven in the climate test.

Applications

In addition to applications in the field of aerospace industry, this construction technology is also particularly suitable for building robust laser sources for industrial use. The holder designs tested here can be expanded to new geometries as well as new materials.

The R&D project underlying this report was conducted on behalf of the Federal Ministry for Economic Affairs and Energy under the grant number 50EE1235.

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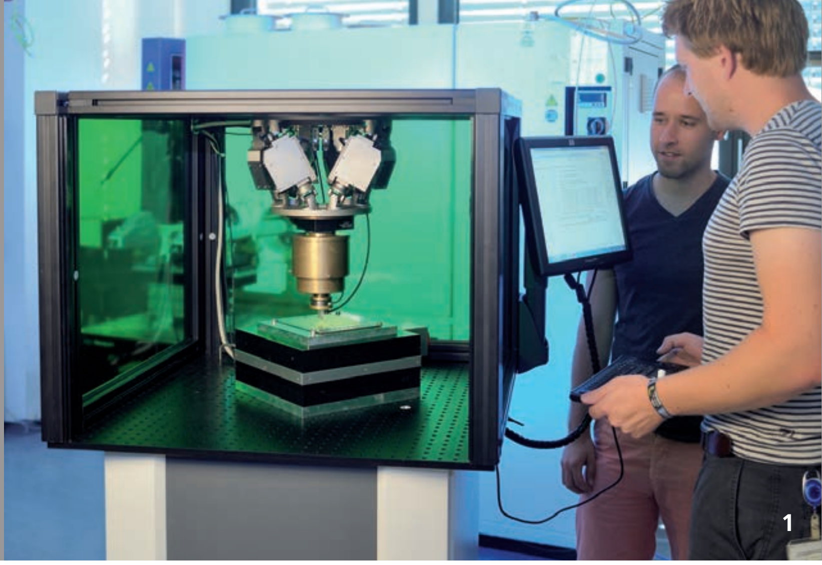
2 Laser optical components in the optical parametric oscillator.

3 Pick & Align: Post adjustment with assembly plant.



FUNCTIONAL ASSEMBLY OF OPTICAL SYSTEMS

Task

Optical systems in laser technology are mainly adjusted and assembled manually, which causes up to 80 percent of the costs in the value-added chain. In this context, therefore, many are searching for a semi- or fully automated solution. In particular, the tolerances of the optical elements and the joining process have prevented a time and cost-effective, fully automated assembly of optical elements so far.

Method

By means of a tolerance analysis and model-based calculations, Fraunhofer ILT has developed an optimized assembly sequence for the optical components so that the error in the assembly is minimized throughout the entire process. During the adjustment and assembly of the individual optical elements, misalignments are identified thanks to the integration of ray-tracing models in the control of the assembly cell; this can correct such misalignments in the process. For this purpose, appropriate measurement techniques and algorithms are used to detect the direct influence of the optical elements on the desired optical functionality (e.g. beam parameter product). In order to ensure that the system remains flexible, the individual components of the mounting system are interconnected via a multi-agent system. The definition of standard interfaces within this system allows fast and easy changes to the assembly system.

Result

In the early development stages of the mounting system, robotics were successfully coupled to the optical model of a beam shaping system via standardized interfaces so that changes to the optical model directly were implemented in the assembly system. Also, a measurement strategy was developed to record the functionality and influence of optical elements in the system.

Applications

The results can be used in the assembly of laser systems for small quantities with the aim achieving full automation. The developed algorithms can be modified and adapted to other alignment applications.

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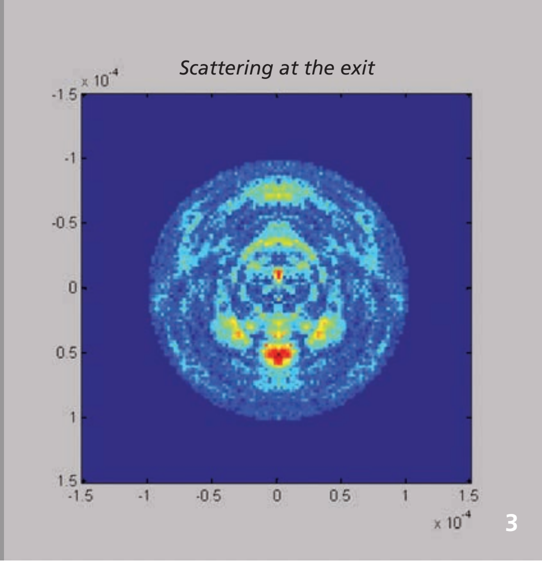
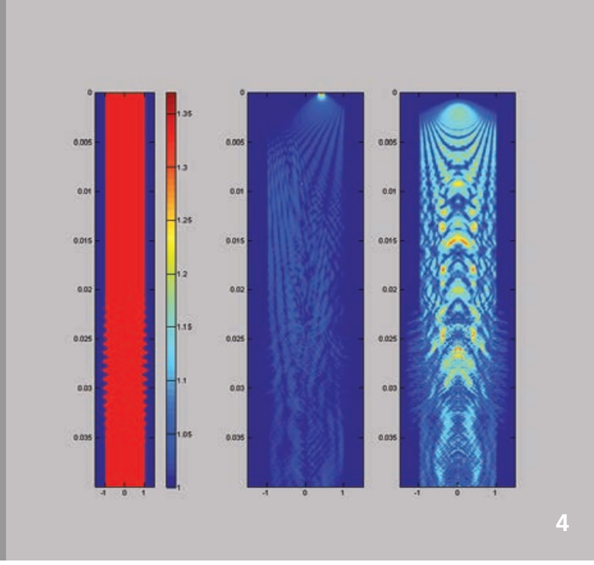
1 Assembly cell for laser systems.





MODELING AND SIMULATION OF WATER JET-GUIDED LASER RADIATION

Task

In addition to passing through glass fibers, laser radiation can also be guided by a water jet. When materials are micro-machined with short pulsed radiation, this type of beam guidance has special advantages. Connected with this technology, however, are relevant issues of water jet stability and diffraction or scattering of guided radiation, all of which need to be examined or described numerically since the apparatus itself is inaccessible for direct measurement of these phenomena.

Method

Having successfully described the free surface of the water jet with full spatial resolution in order to identify hydrodynamic instabilities, Fraunhofer ILT is now examining the beam propagation inside the water jet by using the proven techniques of modeling and simulation. For this purpose, various equations of beam propagation are solved for the media of air and water, namely a model formulation on the scattering of the radiation by the particles contaminating the nozzle chamber and a formulation for the diffraction of the radiation within the propagation along the resulting water jet.

Result

The institute has successfully conducted both the beam propagation in the water jet as well as in the water chamber and adjacent jet.

Applications

Both of the developed simulation techniques can be applied to beam propagation issues in fibers as to scattering problems.

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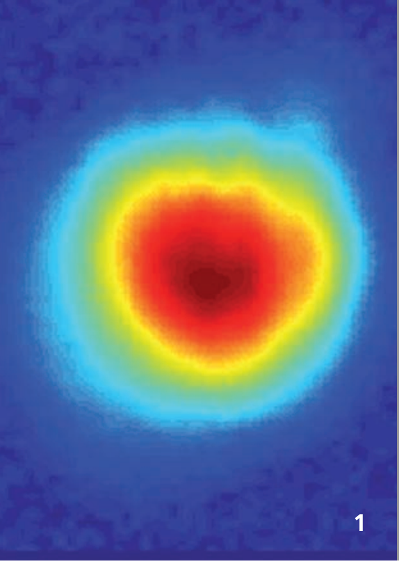
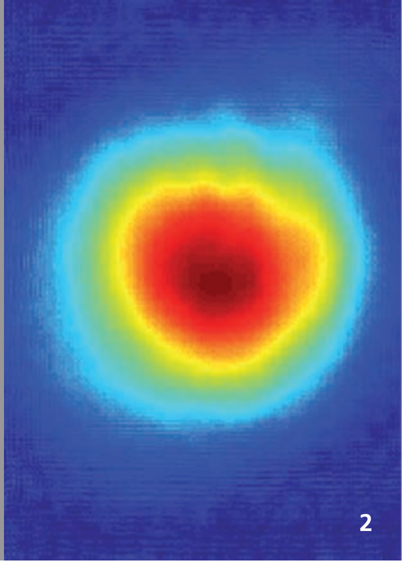
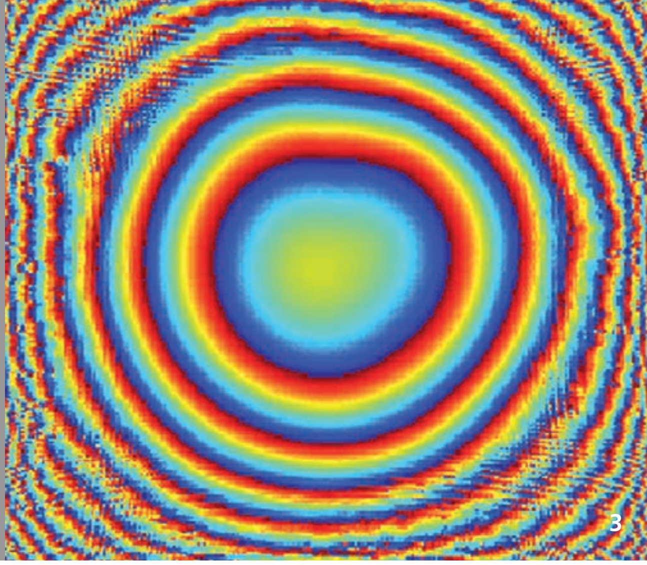
2 Scattering simulation in the area of the nozzle body.

3 Intensity profile at the exit of the water fiber.

4 Simulation of the beam propagation along the water fiber.







RECONSTRUCTION OF PHASE DISTRIBUTION BASED ON INTENSITY PROFILE MEASUREMENTS

Task

When a laser beam is designed specifically for a particular laser application, the distribution of intensity laterally to the beam axis is a design factor used to satisfy the quality criteria required by the application. To form a given laser beam in such a way that it has a desired intensity distribution during its propagation, one needs to understand the intensity and phase distribution of the beam. In contrast to measuring the intensity distribution, measuring the phase cannot be done so simply. Therefore, the measurement of the phases is replaced by their reconstruction, which is based on measurements of the intensity distribution at several positions in the beam.

Method

Fraunhofer ILT has implemented and applied a numerical algorithm that reads the intensity measurements from commercially available beam-measuring instruments to determine the beam profile and reconstructs the phase fronts of the measured laser beam. For this purpose, according to Gerchberg and Saxton, one of the measured intensity distributions and a suitably chosen phase front are used as starting distributions. The free propagation of the radiation is then calculated with this information and the phase front then is reconstructed in an iterative process through the forward and backward propagation between the measurement planes.

Result

The iterative process shall be continued until the calculated and measured intensity distributions agree with each other. The phase distribution, with which that agreement is obtained, then corresponds to the phase distribution actually present in the beam, thus completing the reconstruction.

Applications

The method can be applied to tasks in which shaping the intensity profile is used to dimension a laser beam for a specific application. Common examples of such applications are – as in the EU-funded project »HALO« – laser cutting of, for example, glass or metal and laser-based medical applications.

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1 Measured distribution of intensity.

2 Reconstructed distribution of intensity.

3 Reconstructed phase surfaces.

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 with elliptical beam shaping.

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SLM EXPOSURE DESIGN FOR EASY SCALING OF PRODUCTIVITY AND BUILDING SPACE

Task

For several years, the additive manufacturing method Selective Laser Melting (SLM) has been successfully used to produce prototypes and parts in small-lot sizes, mainly for small-volume components. However, users are beginning to demand greater productivity with higher build rates and increased flexibility in terms of the available building space. Furthermore, a robust process with reproducible component quality and process monitoring are of vital importance for series production. The optical system currently used in SLM systems (single beam, scanner and focusing optics), however, creates significant restrictions.

Method

In this context, Fraunhofer ILT is developing a new exposure and plant design that does entirely without scanner systems and instead uses a machining head having several individually controllable diode lasers. This makes it possible to increase the build rate of the system by increasing the number of beam sources to a nearly unlimited extent, without having to adapt the system design and the process parameters. In addition, this new machine concept enables an increase of building space simply through greater travel paths of the axis system and without having to modify the optical system.

Result

Using funds from the Cluster of Excellence »Integrative Production Technology for High-Wage Countries«, Fraunhofer ILT has developed, designed and built a laboratory unit in order to investigate the new exposure concept. Its machining head consists of five diode lasers that can focus the beams in different configurations (e.g. as a line) into the machining plane. Moreover, it also has a local shielding gas guiding system to ensure a constant shielding gas stream at the machining point on any large construction space. Currently, the institute is investigating the component quality that this system is able to achieve.

Applications

This new exposure and plant design can be used to flexibly scale SLM systems for manufacturing metal components; its applications range from manufacturing prototypes in the pre-development phase to industrial series production.

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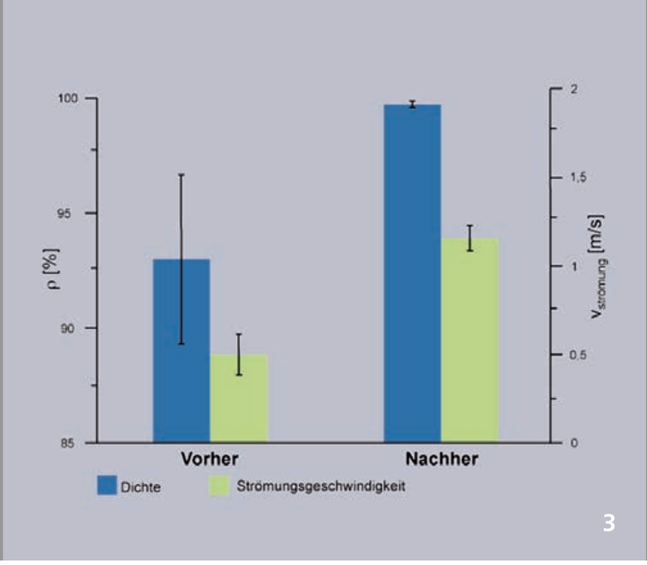
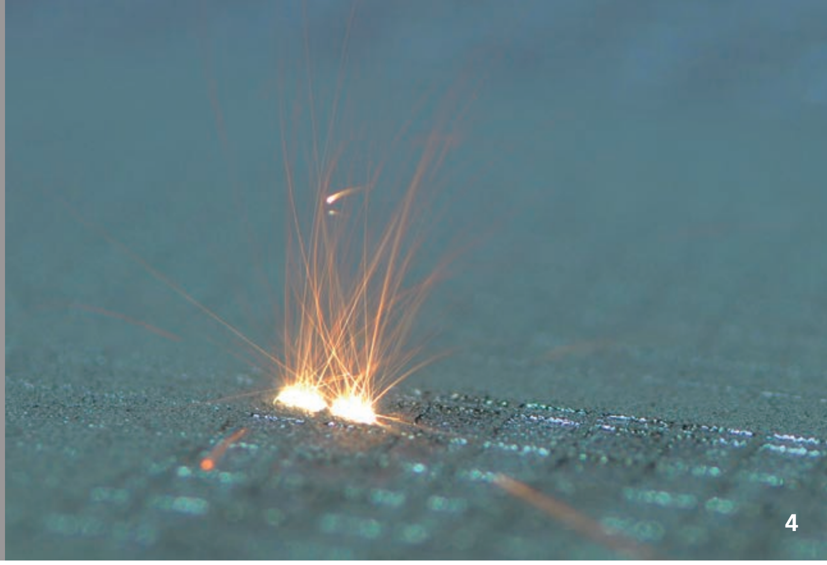
1 Processing head of the SLM laboratory plant.

2 Overall view of the plant.





STUDY OF PROTECTIVE GAS CONTROL IN THE SLM PROCESS

Task

When components are additively manufactured with SLM, their resultant density is an important criterion of their quality. Indeed, not only do the process parameters have a significant impact on component density, but so does the constructive configuration of the machine, such as the shielding gas flow through the building chamber. A central task of shielding gas flow is to remove smoke and splashes from the laser-material interaction zone. If this does not occur sufficiently, the desired component density might not be achieved. Therefore, Fraunhofer ILT is investigating to which extent shielding gas flow correlates with component density.

Method

As a first step, the inert gas flow was characterized by the local flow speed of the gas. This was done using a thermal anemometer, which measures the flow's speed through the construction area at different measuring points before the sample is set up. Then, test specimens were built at these measurement points and the correlation was generated between component density and the flow velocity. To vary the flow field generated through the construction area, various nozzle geometries of protective gas outlet were produced additively and the flow rate was varied.

Result

It has been shown that, with otherwise identical parameters, the local component density correlates with the flow speed of the inert gas. Here, a higher flow rate leads to an increase in component density and to a reduction in local density fluctuations. This is accomplished by adapting the nozzle geometry, which enables an increase in gas flow speed without disturbing the powder bed.

Applications

The results are aimed at equipment manufacturers and users who want to optimize their SLM processes.

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3 Correlation between density and flow rate.

4 Splashes in the SLM process.

ANALYSIS OF SLM MANUFACTURING COSTS

Task

Machine costs make up the largest share of expenses when components are manufactured with Selective Laser Melting (SLM). However, there still is no basic understanding of which machine components cause this largest share of the costs and how different machine designs influence the cost of manufacturing a component. Today's SLM machine designs, for example, differ in the number and power of the laser beam sources used and in their dimensions. The extent to which the SLM machine technology influences the component costs should be systematically investigated and combined in a model to predict the cost drivers of SLM-manufactured components.

Method

To take into account all cost elements and elements during the equipment acquisition (machine price) and while the machine is operated (power, shielding gas, powder, maintenance), Fraunhofer ILT has chosen the method of life cycle costing. For this purpose, a machine structural model was initially developed in which the SLM machine technology is broken down into individual cost-creating assemblies. Using a reference process, the institute shall map typical scenarios of SLM use (e.g. as production of small or large components).

Result

The result is a foundational cost model that can be used to identify the life cycle costs of existing SLM machines and to compare them with each other. The different types of costs can be directly assigned to the assemblies. Thus, the life cycle costs can already be reviewed while SLM machines are in the early stages of development and, where appropriate, optimization measures can be taken. The model allows users to depict the cost development for additively manufactured components, while increasing the total laser power, and to place them next to each other through parallelization of the SLM process by using multiple laser sources.

Applications

This cost method can be used both by users as well as by producers of SLM machines to analyze the machines in terms of the life cycle costs incurred.

The work was supported by the German Research Foundation (DFG) within the framework of the Cluster of Excellence »Integrative Production Technology for High-Wage Countries«.

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1 CAD model of an SLM machine.

TOPOLOGY-OPTIMIZED KINEMATIC LEVER FOR A BUSINESS CLASS SEAT

Task

The potential for symbiosis between additive manufacturing and topology optimization shall be depicted on the basis of a kinematic lever of a business class seat by Recaro. In contrast to subtractive manufacturing, the manufacturing time and process costs of Additive Manufacturing are affected, in large part, by the volume to be built. Topology optimization is a process to design components oriented to the loads they must carry; unnecessary volume will be removed until the optimization results in a perfectly adapted part. The outstanding geometric possibilities of Additive Manufacturing can be used to contribute to the production of complex optimization results, which are difficult or impossible to produce conventionally. Thus, Additive Manufacturing and the topology optimization form an ideal symbiosis so as to design functional components for Additive Manufacturing at comparatively low component costs.

Method

Conventionally, the kinematic lever is milled out of the aluminum material 7075. As a central component of the business class seat, the kinematic lever makes a complex movement to place the chair in a reclining position. The dynamic load of the component occurring in this movement is divided into five load cases used in topology optimization; these cases, in turn, take into account the peaks in tension at different times during the movement. A so-called optimization dummy was constructed which defines the maximum available space so that its required collision-free movement can be guaranteed. The optimization software Abaqus ATOM was used to determine material data, structural supports and fixed regions of the component (e.g. joints to other components). The target for optimization aimed to reach the maximum possible stiffness of the component at a predefined volume reduction. The optimization result was then slightly smoothed by Meshlab and validated anew in a final FEM. The final optimization result was prepared for Additive Manufacturing by means of SLM, produced on an EOS M270 and then reworked.

Result

The final optimization result exhibits peaks in tension of approx. 300 MPa, which are below the yield stress of 410 MPa of aluminum alloy 7075. In comparison to the component optimized with a milling process, the SLM component is about 15 percent lighter. Since the kinematic lever is a component for the aerospace industry, its lower weight can lower fuel consumption, thus reducing operating costs.

Applications

Major fields of application include the aerospace and automotive industries.

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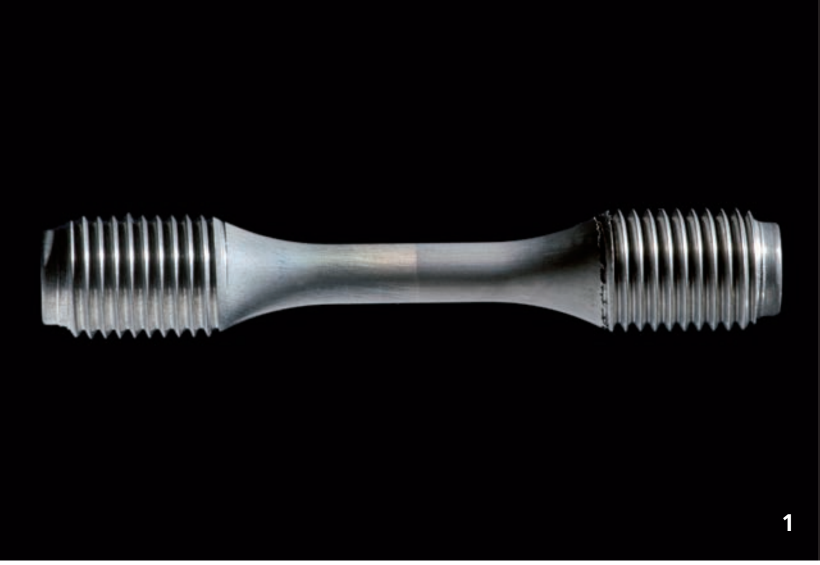
2 Topology-optimized kinematic lever a of business class seat by Recaro.



PROCESS DEVELOPMENT FOR REPAIR OF MONO-CRYSTALLINE TURBINE BLADES WITH SLM

Task

Quite often, high-pressure turbine blades (HP blades) are produced nowadays as single crystals with a special investment casting process in the aviation industry. Damage in the area of the blade tip by burning, abrasive wear or cracking is disastrous if it extends into the inner cavity of the blade and the cooling structure. Such damage cannot be repaired with currently available methods. Since it can manufacture complex geometries in a final near-net shape, the additive manufacturing process Selective Laser Melting (SLM) should be considered as a repair process.

Method

The nickel-based superalloys used for HP blades were developed especially for directional (DS) or single-crystal (SX) solidification and are highly susceptible to cracking when they are processed with SLM. For this purpose, in cooperation with the MTU Aero Engines, Fraunhofer ILT examined SLM-based processing of the DS alloy René 142® on an SX substrate of René N5® at very high preheat temperatures on a modified laboratory facility. SEM and EBSD were used to examine the manufactured samples for the formation of defects and grain structure.

1 Creep sample (left: René N5 SX, right: René 142 SLM).

2 Cross section of René 142® on René N5® with visible grain structure.

Result

With preheat temperatures considerably greater than 1000 °C in the working plane, crack-free samples can be manufactured with low porosity (< 0.2 percent). The structure exhibits homogenously arranged grains solidified in the direction of construction. The orientation of the <001> crystal layer is parallel to the building direction and only has a small scattering of approx. ± 7° maximum. The creep strength of heat-treated samples – consisting of René 142® and René N5® in equal parts – is greater than that of the widely used nickel-based superalloy MAR-M-247LC® (DS) at 980 °C and identical tensile testing.

Applications

The repair of components with DS or SX microstructure is particularly important for turbomachinery construction in the aviation industry and energy management.

The results presented were achieved using funds from the European Union 7th Framework Program (grant agreement 266271).

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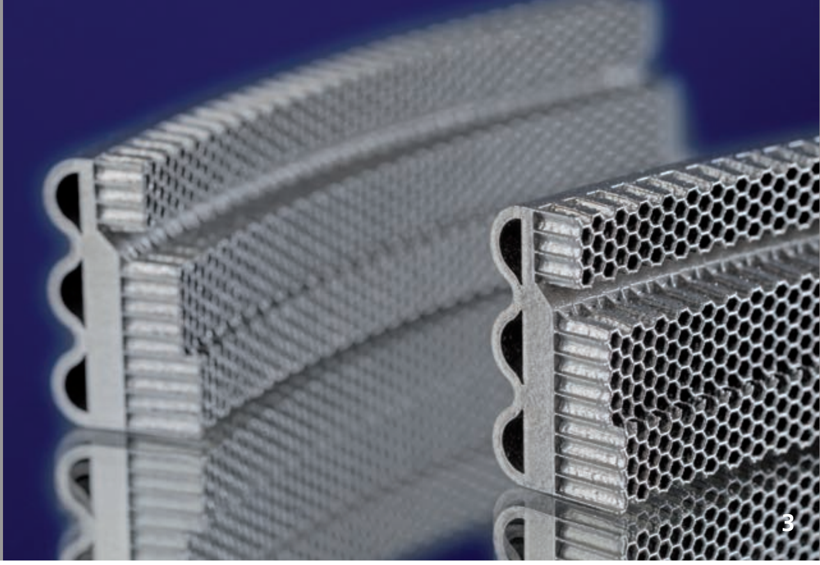

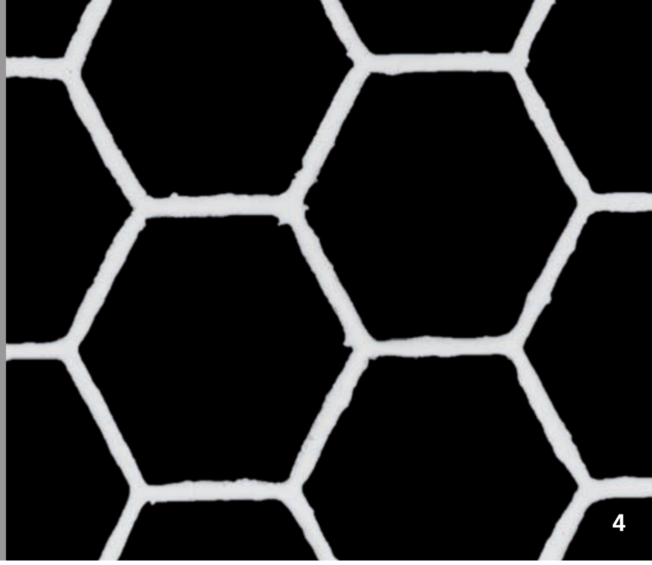

PRODUCTION OF TURBINE COMPONENTS OUT OF MAR-M-509®

Task

Components in the hot gas zones of turbomachinery must exhibit great high-temperature strength and corrosion resistance. The cobalt-based superalloy MAR-M-509® meets these requirements and is primarily used for static components such as vanes in aircraft engines and stationary gas turbines. This alloy, which currently can only be produced by casting, should be processed with Selective Laser Melting (SLM) in the future. The project aims to monolithically produce, for example, blade seals with a honeycomb structure or components with internal cooling structures, each of which are difficult or impossible to manufacture with conventional methods.

Method

Within the BMBF-funded project »EFCOPOST«, the SLM process is being developed for the manufacture of complex structures having walls as thin as possible out of MAR-M-509® on a commercial SLM system. Based on this, both the microstructure will be analyzed (pores, cracks, grain structure) and mechanical properties determined in the heat-treated state (hardness, tensile strength at room temperature and up to 900 °C).

Result

While specific tolerances of the chemical composition of the powder are maintained, a crack-free structure has been achieved having a density > 99.8 percent with the developed process parameters. The minimum wall thickness achievable depends on the geometry and its orientation in relation to the building direction. In the best case, an average wall thickness of < 100 µm could be achieved with construction angles < 20°. Due to the layered manufacturing, the microstructure has elongated grains and a crystallographic preferred orientation in the building direction, which leads to anisotropic mechanical properties. Independent of this, the tensile strength is – both parallel and perpendicular to the building direction at room temperature and temperatures up to 900 °C – clearly greater than that of the cast material. In contrast, the modulus of elasticity is less than that of cast material in the entire temperature range.

Applications

The additive manufacturing of components from MAR-M-509® is primarily of interest for applications in turbomachinery construction. Furthermore, the alloy may be also used for high temperature applications in, for example, kiln technology and glass processing.

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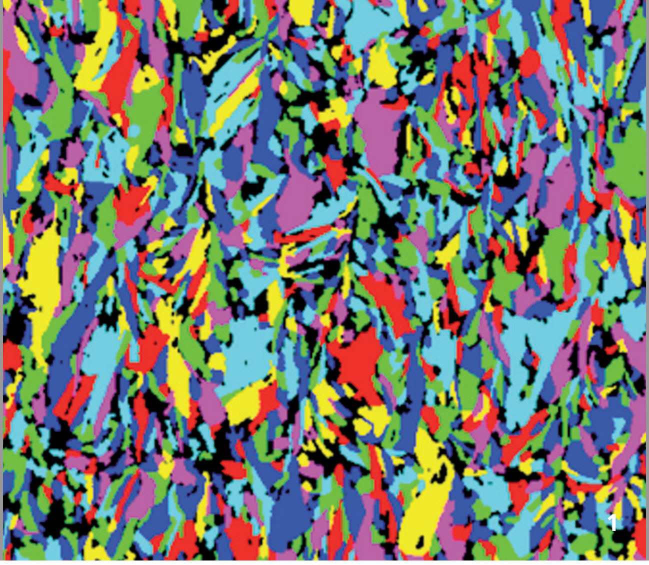
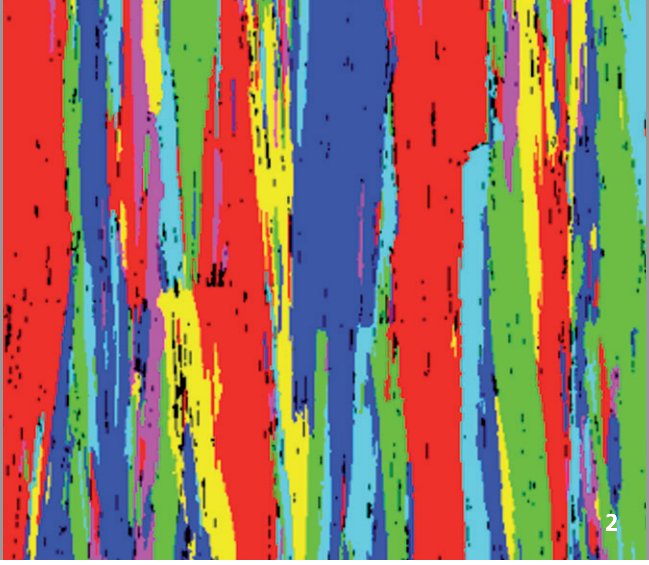
3 Mockup of a blade seal with honeycomb structure.

4 Honeycomb in cross-section.





MICROSTRUCTURAL PROPERTIES OF IN718 PROCESSED WITH HIGH POWER SLM

Task

Recently, end users are becoming more and more interested in using the additive manufacturing process Selective Laser Melting (SLM) for mass production with increased lot sizes. For this reason, in recent years higher laser powers (PL ≤ 1 kW) have been increasingly used in commercial SLM plants to improve the productivity of SLM. To use this laser power, the process parameters (e.g. laser-beam diameter, scanning speed and layer thickness) have to be adjusted according to the processed material. This adjustment, however, changes the cooling and solidification conditions in the melt pool bath and, thereby, the resulting microstructure and material properties of the finished part.

Method

For this reason, as part of the EU project »AMAZE«, basic studies were conducted on the extent to which high-power SLM process control influences the resulting microstructural and material properties of the material IN718. In these investigations, Fraunhofer ILT analyzed the resulting microstructure (e.g. grain size or orientation) and determined the mechanical properties (e.g. tensile strength, elongation at break). Additionally, it examined the influence of adapted thermal post-treatments on the material properties.

1 EBSD analysis conventional SLM (P_L = 300 W | d_s ≈ 70 µm).

2 EBSD analysis HP-SLM (P_L ≤ 1,5 kW | d_s ≈ 720 µm).

Result

In the first step a process control was developed for different laser beam diameters with laser powers of P_L ≤ 1.5 kW for densities ≥ 99.5 percent. Subsequent characterization of the microstructure (SEM, EBSD) shows that, when a laser beam diameter of d_s ≈ 70 µm is used, a fine structure (dendrite arm spacing DAS ≈ 1.6 µm) is formed in which the grain growth is re-initiated layer to layer (Figure 1). In comparison, grains form at a laser power of P_L = 1.5 kW and adapted process parameters and are oriented epitaxially in the building direction (DAS ≈ 2.3 µm, Figure 2). The significantly different solidification rates (conventional SLM: solidification rate ≈ 580 mm/s | HP-SLM: solidification rate ≈ 60 mm/s) cause the microstructure to develop differently. In the next step, Fraunhofer ILT will identify the extent to which these structural properties influence the mechanical properties.

Applications

Components additively manufactured out of IN 718 can be used mostly in the fields of aerospace and power engineering.

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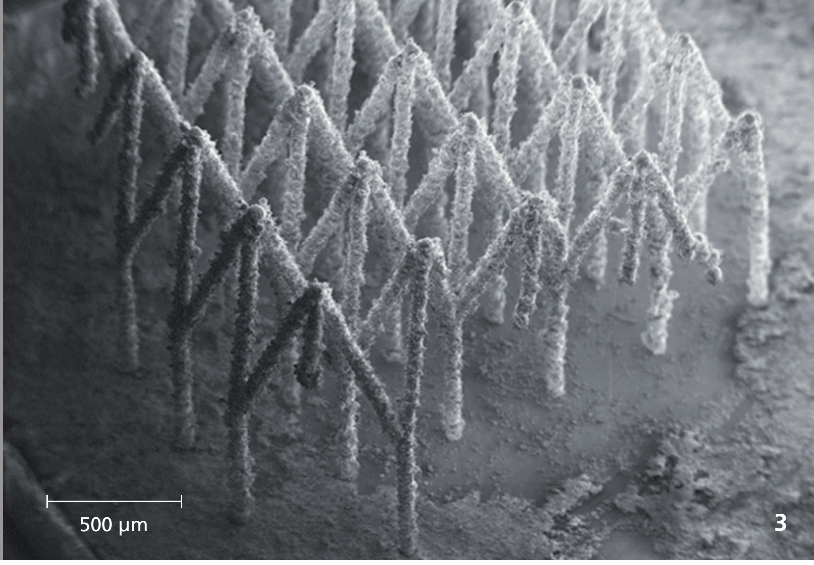

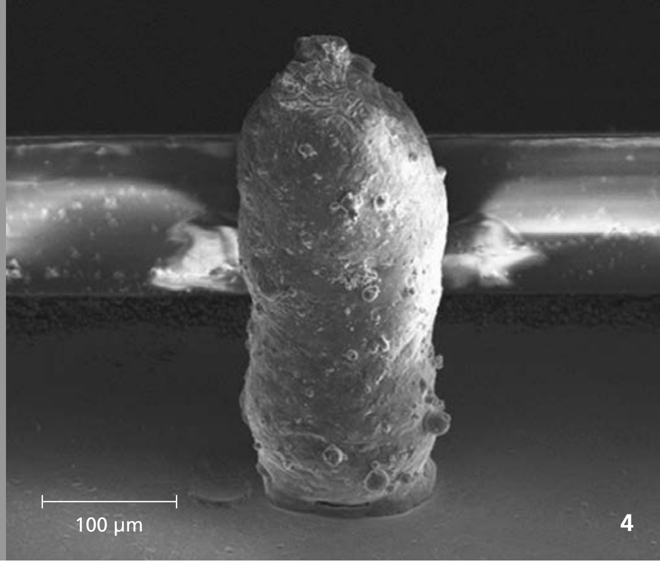

DEVELOPMENT OF A NEW ASSEMBLY AND PACKAGING TECHNOLOGY FOR POWER CONDUCTORS BY MEANS OF SLM

Task

Modern metallized power semiconductors allow, even at high voltages (voltage class in the range of 3 kV), high switching frequencies (up to 100 kHz). Three factors, however, cause significant parasitic switching currents: the reduced size of the passive components and, thus, the overall size of the power electronic system as well as the fast response times of modern equipment regardless of the semiconductor material, e.g. Si, SiC or GaN. These currents arise due to the coupling capacitances and stray inductances of the connection materials between the vapor-deposited metallization layer and the contact wires. These currents need to be reduced so as to enable an increase in the switching frequencies of the power semiconductors. Moreover, the lifetime of the switching elements is significantly reduced on account of the thermal resistance of the compound materials to the connections and the resulting power losses and temperature gradients at the contact surfaces. Thanks to SLM, contact structures from materials identical to the metallization layer can be built directly on the surface of the power semiconductors. This way, compound materials do not need to be used and the parasitic switching currents can be reduced. The contact structures (approx. 100 µm in diameter and 3 - 5 mm in height) are built on an aluminum metallization layer having a thickness of about 15 µm. The underlying Si substrate may, however, not be damaged in the process.

Method

To create damage-free contacts, Fraunhofer ILT conducted fundamental studies on the production of structures using point exposure of AlSi10Mg with a particle size < 25 µm on an aluminum metallization layer. A new method was developed to apply the powder so as to improve the quality of the first layer of powder, since the quality of the powder application on the metallization layer has proven crucial for the integration of contact structures built without damaging the semiconductor. There, the powder is applied as a suspension on the metallization layer; a high quality powder coating remains after the liquid portion evaporates. The institute also examined different building strategies of various contact structures.

Result

Contact structures with a diameter from 100 - 200 µm, a height of 3 - 5 mm and a gap of approx. 100 µm could be built. A functioning bipolar transistor with an insulated gate electrode could successfully be contacted with the structures thus generated.

Applications

Improving the switching times of semiconductor diodes is an important research area in modern electronics.

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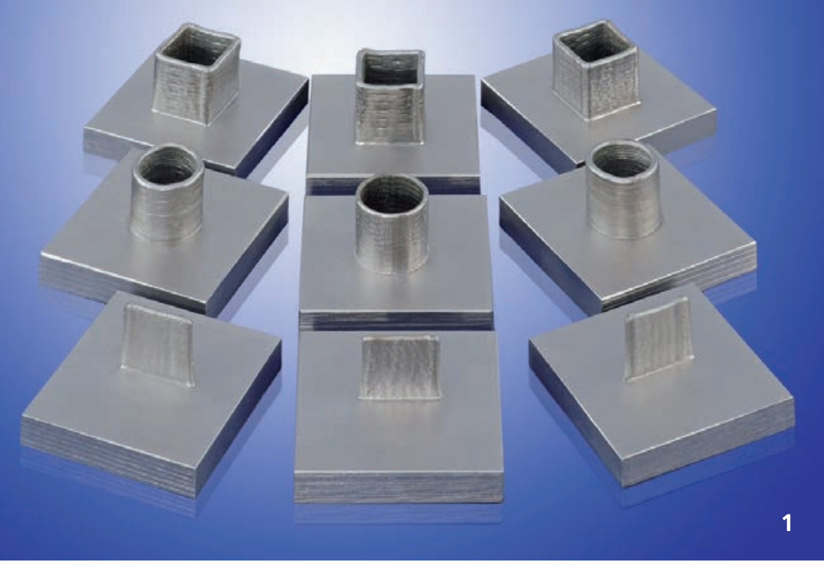
3 Contact structure generated with SLM on an AL metallization layer.

4 Enlarged detail of a contact structure.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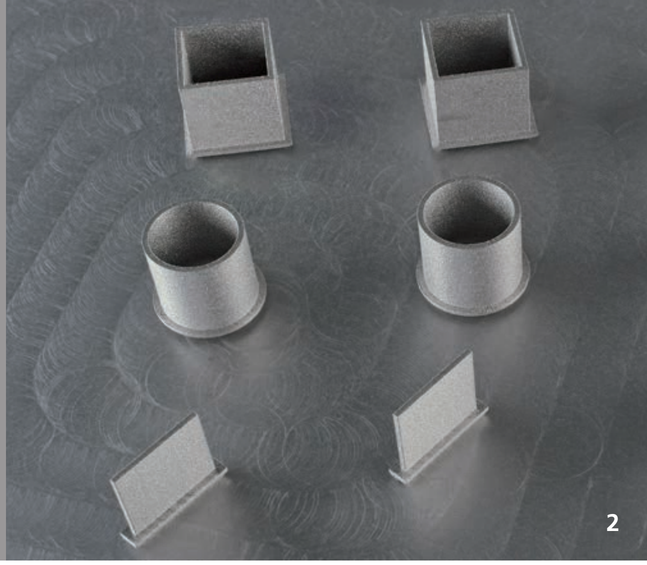
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COMPARISON OF ADDITIVE MANUFACTURING TECHNOLOGIES SLM AND LMD

Task

Selective Laser Melting (SLM) and Laser Metal Deposition (LMD) are the most important procedures in the field of laser-based additive manufacturing with metallic materials. The two methods differ with regard to their inherent properties. These involve differences in the component properties (e.g. geometric fidelity) that can be attained and that have a direct impact on an application-specific method qualification. Within the Fraunhofer Innovation Cluster AdaM, Fraunhofer ILT aims to compare the processes in order to develop a basis for deciding on the appropriate method specific to a particular application.

Method

The comparison of the methods SLM and LMD involves three categories. These are the geometric properties attainable, the mechanical properties under static load and the microstructure of the material. The material used was Inconel 718 (grain fraction 15 - 45 µm). The comparison of these geometric properties was based on five test geometric structures (hollow square, hollow cylinder, full-square, solid cylinder and vertical tab). For statistical purposes, each test geometrical structure was built four times for each process and parameter set, and measured both tactilely and visually. The wall thicknesses obtained in the test structures were measured with micro-structural cross sections.

Result

The test geometric structures were produced with both methods. For all of them, the smallest deviations in shape (< 50 µm) were attained by the SLM process with a beam diameter $d_{Laser} \approx 100$ µm. The lowest surface roughness was exhibited with the LMD process, which used beam diameters of $d_{Laser} \approx 1300$ µm and $d_{Laser} \approx 2000$ µm (R_a approx. 6 µm).

Applications

The current investigations for Inconel 718 are primarily directed at applications in turbomachinery; however, the findings here (e.g. determining the geometric properties) can also be used in other fields.

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

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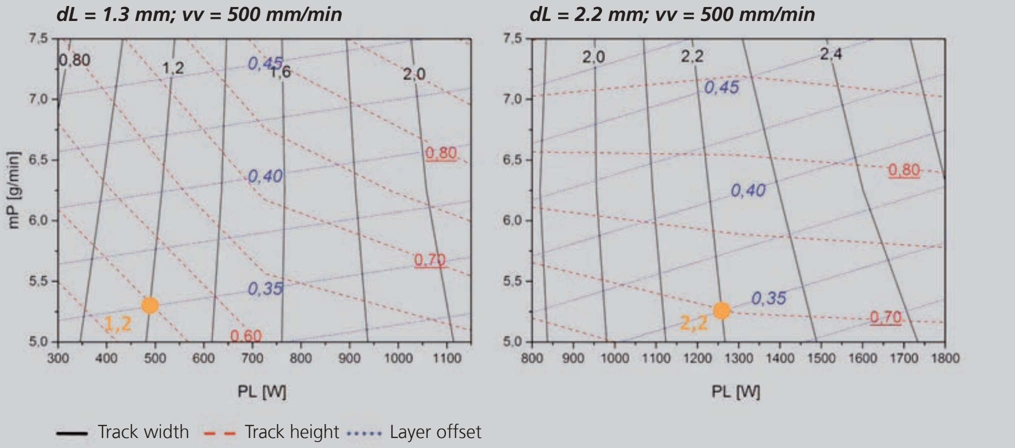
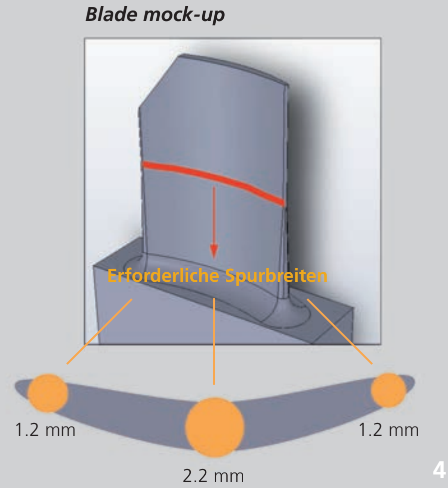
1 Test geometric structure produced with LMD.

2 Test geometric structure produced with SLM.





DEVELOPMENT OF PROCESS DIAGRAMS FOR LASER CLADDING

Task

To develop a process for repairing of turbomachines, e.g. blade tips, with Laser Metal Deposition (LMD), the geometry and the material combination (substrate and filler material) are decisive factors. To reduce the required development effort, a »technology processor« has been developed within the Fraunhofer Innovation Cluster AdaM. On the basis of experimental and model-theoretic results obtained from a database and a modeling tool, this processor will provide initial values for process parameters and proposals for developmental strategies to use LMD for blade tip geometries. To represent the experimental knowledge for the user, process diagrams are developed for LMD.

Method

By means of a design-of-experiment approach, a process parameter field was created for three laser beam diameters dL, three feed speeds vv and, in each case, three laser powers PL and powder mass flows mP for the filler material Inconel 718. Then, tracks and thin walls were cladded with these parameters, analyzed metallographically and the track width, track height and the layer offset were documented. The geometries achieved are presented as a function of the process parameters (see Fig. 3).

Result

Thanks to the process diagrams, a representation has been developed with which the process parameters laser power PL, beam diameter dL, powder mass flow mP and feed speed vv can be depicted in a plane and welding results can be read with respect to the geometry. Figure 4 shows a blade with a profile width of 1.2 to 2.2 mm, which should be cladded in the region of the blade tip. The laser power required and the layer offset (see Figure 3: track width as vertical black lines; layer offset as diagonal blue dotted line) can be read out of the process diagrams as the initial process parameters for the track widths 1.2 and 2.2 mm at a constant powder mass flow (e.g. mp = 5.25 g/min). Furthermore, the identified test results serve as a basis for further model-theoretical investigations.

Applications

The process diagrams developed here can be applied to many repair cases. Fields of application are, in particular, turbomachinery construction and general mechanical engineering.

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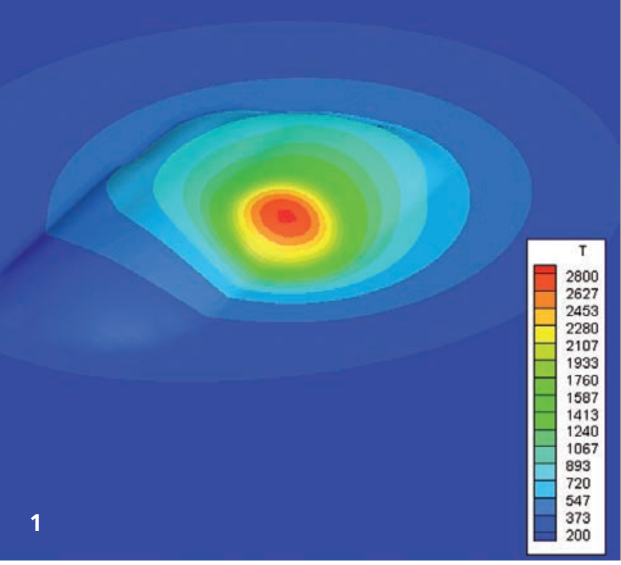
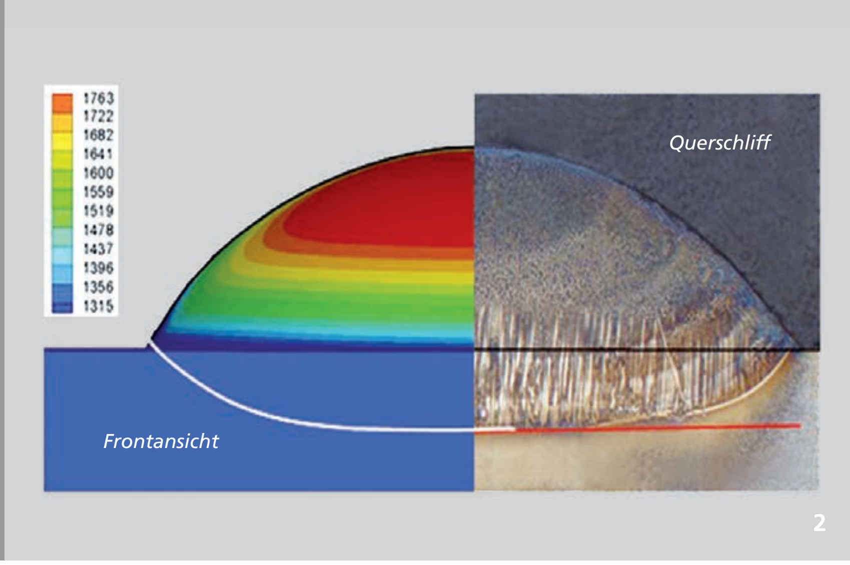
3 Process diagrams for the beam diameter dL 1.3 and 2.2 mm for Inconel 718.

4 Blade which should be cladded in the tip area. The process parameters result from the process diagrams.





PROCESS SIMULATION FOR LASER METAL DEPOSITION

Task

For the powder-based Laser Metal Deposition (LMD), the current state of research and technology has not yet created a basic methodological approach that limits materials and components specific to process strategy and parameters so that experimental costs can be reduced significantly.

Therefore, a simulation tool for LMD should be created. With this tool, the user should be able to simulate a process under different process strategies and parameter settings for a concrete task in advance; based on these results, a process window should be narrowed down so that the remaining experimental development costs can be significantly reduced.

Method

LMD creates a free boundary problem mathematically, whose solution is based on integrating the transient heat conduction equation and the pressure balance equation. All the while, a mass balance must be taken into account with respect to the powder particles captured by the melt per unit of time. For the simulation tool, two modules have been created. With the first, the interaction of the particles with laser radiation is analyzed, and the transmitted laser radiation and particle temperature are calculated as input for the second module. With the second module, the track geometry and the temperature distribution are time-resolved as a function of the process strategy and parameters, and the thermo-physical material properties are calculated (Figure 1).

Result

The simulation tool is currently in the validation phase, and initial comparisons show good agreement between experimental and theoretical results (Figure 2).

Applications

The simulation tool can be used for tasks that require a material and component-specific adaptation of the process control.

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

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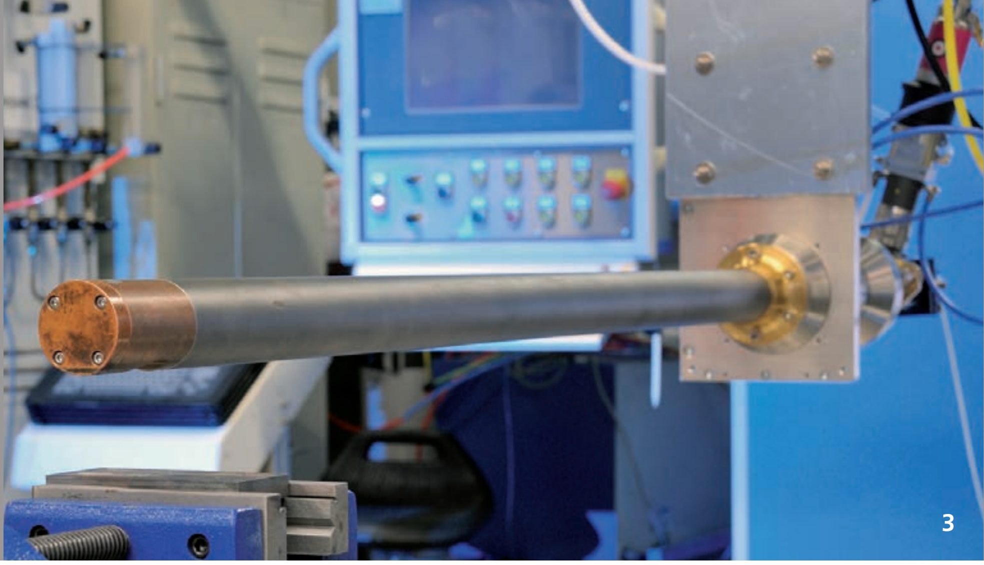
1 Track geometry and temperature distribution.

2 Comparison of experiment and model calculations.



PROCESS MONITORING DURING HARD CLADDING OF INTERNAL PIPE SURFACES

Task

A growing field of application for laser cladding technology (Laser Metal Deposition, LMD) is the armoring of highly loaded interior surfaces of, e.g., bearings, housings or cylinder bores. Thanks to specially developed internal coating optics, an armoring and repair technology has been developed for components whose inner surfaces were not previously accessible with standard processing heads. Thanks to the integration of sensors and systems for coaxial process monitoring, the machine operator can observe the process online and, therefore, control it.

Method

The development and the dimensioning of INCLAD optics were carried out in consultation and cooperation with the system supplier and its industrial users. To transfer the process safely, the system configuration is being conceptualized and operated according to the industrial user's requirements. The technological maturity (Technology Readiness Level, TRL) and the production-acceptance test will be carried out both at the supplier as well as the industrial user.

Result

So far, the design has been tested using inner coating optics with a length of 800 mm. Through an optical fiber, the optics is connected to a high power laser with a rated output of 4 kW and an emission wavelength of 1085 nm. A dichroic deflection mirror between the collimator and the INCLAD optics enables the coaxial measurement of temperature radiant flux emitted by the process as well as the process visualization by means of a CMOS camera.

Applications

The LMD process can be used to repair expensive components whose surfaces only allow limited access and which place high demands upon stress and corrosion, such as drilling tools in the oil and gas industry, extruder barrels or sliding bearings in machine tools.

The work in the LASHARE-INCLAD project has been financed with funds from the program HORIZON 2020 of the European Union.

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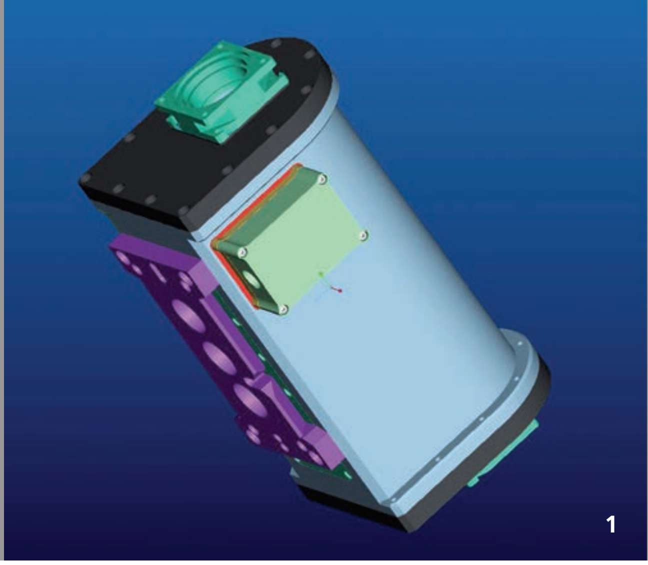
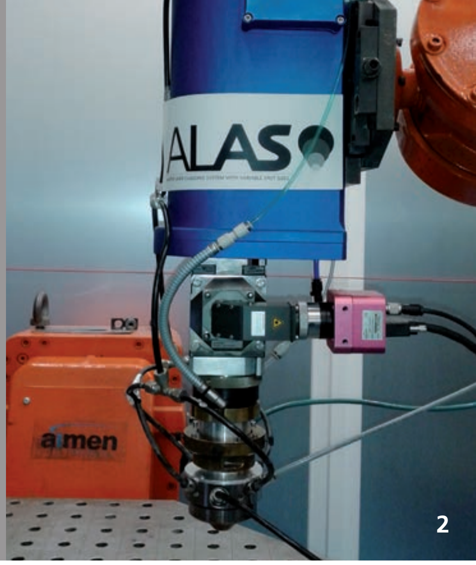
3 INCLAD optics for the interior coating of drill holes with a depth of up to 800 mm.





MODULAR ZOOM OPTICS

Task

Laser Metal Deposition has established itself as a process that can functionalize surfaces, repair and modify components and produce (generate) new parts. Its main areas of application encompass machine, tool, jet engine and motor construction. During this process, a material layer is created by melting the workpiece surface and the molten powder material. A variation of the track width during processing enables complex geometries to be built in a single track.

Method

For the controlled adjustment of the track width and thus the build-up rate, a modular optical zoom system has been developed. Via motor-controlled lenses, the laser radiation can be expanded in a stepless manner. At the same, the optical design allows the beam parameters to be preserved over the entire magnification range. This way, »top-hat« distributions of the laser power can also be used to adapt it to the tab width to be built. In contrast to beam expansion where the focus position is shifted relative to the workpiece, a targeted and defined energy input can be achieved and, thus, defined melting and cladding. The various components – such as collimation, beam splitter and focusing optics – can be easily adapted to the modular zoom optics, providing a clear advantage.

Result

With the modular zoom optics, a processing head can be easily built with existing beam guidance components for cladding with laser radiation; this head allows track width to be controlled or regulated dynamically during processing.

Applications

Among the areas of application include all activities in the field of cladding with laser radiation in which an adjustment of the track width is advantageous.

The research was funded by the EU within its 7th Framework Program via the REA (Research Executive Agency) under the grant notification FP7-SME-2012-315614-ALAS.

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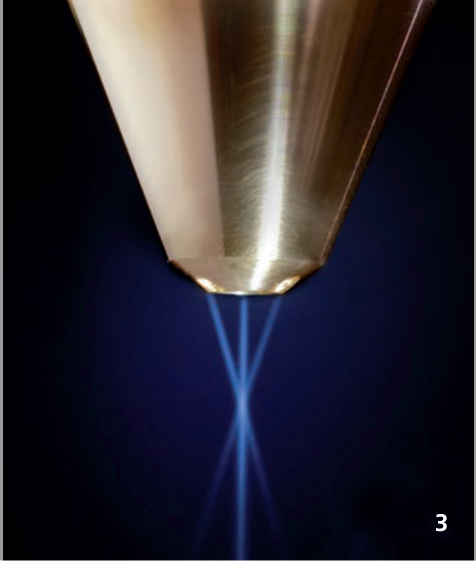
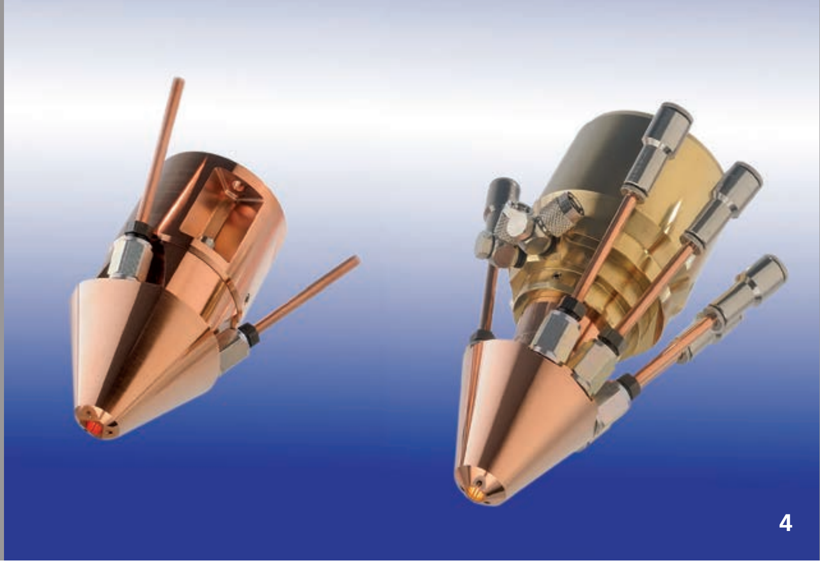
1 CAD view of the zoom module.

2 ALAS prototype.





THREE-JET POWER FEED NOZZLES WITH IMPROVED PERFORMANCE

Task

An important goal of laser cladding is to increase powder efficiency. Three-jet powder nozzles are characterized by high robustness and 3D capability. Until now, however, these nozzles have reached powder efficiencies in the range of 50 - 70 percent in a powder focus of approx. 2.5 mm and a cladded track width of 2 mm. Increasing the powder efficiency, therefore, requires the development of new, improved powder feed nozzles. For laser cladding, a three-jet powder nozzle is currently being developed that generates a smaller powder focus (< 1.5 mm).

Method

Thanks to its three powder channels, the three-jet nozzle generates three individual powder jets that are brought together to form one powder focus beneath the nozzle. As part of the development of these nozzles, the powder hole diameter has been designed to be variable between 0.5 mm and 2.0 mm. The different channels are created by means of inserts made of carbide with different internal diameters. The inserts reduce, on the one hand, the wear on the powder channels caused by, e.g., abrasive powder materials, thereby increasing the stability of the nozzle. On the other hand, these inserts can easily be exchanged (in case of repair).

Result

Tests have been carried out with different powder bore diameters and the powder focus has been photographed. A comparison with the conventional three-jet powder nozzle shows three advantages: a significant reduction in the powder jet diameter from 2.5 mm to < 1.5 mm, an increase in the service life of the powder nozzles and an increase in the powder efficiency to over 80 percent on a track width of 2 mm.

Applications

Applications include the cladding of structures < 2 mm that require the powder nozzle to have 3D capability and high powder efficiency: for example, the 3D deposition of web-like structures or the repair of z-notches in turbomachinery. In addition, costs are also lower as the powder usage is reduced thanks to the improved powder feed nozzles.

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3 Powder gas jet of the three-jet powder nozzle with inserts made of carbide.

4 Three-jet powder nozzles with inserts made of carbide.

ROBOT-BASED SYSTEM TECHNOLOGY FOR LASER METAL DEPOSITION

Task

As part of the Fraunhofer Innovation Cluster AdaM (Adaptive Production for Resource Efficiency in Energy and Mobility), different process chains have been examined for the repair of turbomachinery components. Because of their low cost and the great flexibility, robotic systems are increasingly being used. In the innovation cluster, therefore, a robot-based system, consisting of a six-axis articulated robot with a tilt and turn module, has been built and tested to repair turbomachinery parts.

Method

Various components (4 kW laser, six-axis articulated arm robot, rotary-tilting module, zoom optics, powder feeder) have been combined to create a flexible robot cell. Thanks to the additional axes, the robot has a total of ten axes (6 + 1 rotary and 1 tilting, and 2 optics axes), which are controlled simultaneously via the PLC. A three-beam nozzle developed by Fraunhofer ILT has been mounted to the zoom lens, with which cladding can also be conducted in confined spaces.

Result

With this zoom lens, differently sized laser beam diameters (and, therefore, track widths) can be created, which are infinitely variable from approx. 0.2 to 2 mm, or changed during the process. Manual adjustment of the optical components is not necessary. It can perform most repairs needed in turbomachinery construction. In further studies, test samples will be cladded and an offline programming system developed by Fraunhofer ILT will be implemented.

Applications

Due to its high flexibility, the robot is principally suitable for all types of repair applications in various industries (e.g. aerospace, turbomachinery, tool construction). Since it has a greater freedom of movement than Cartesian systems, it may be of particular interest for applications where access to the processing site is severely limited.

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

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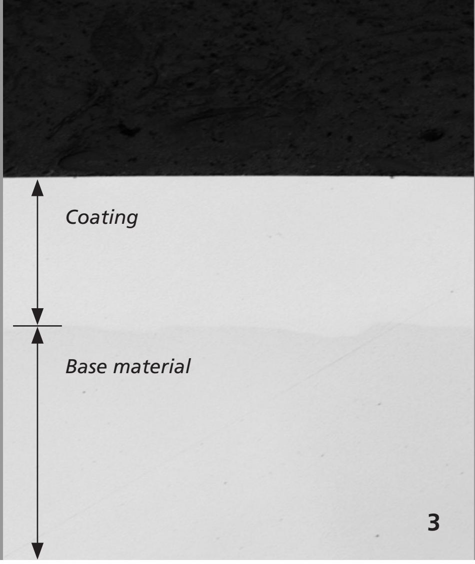
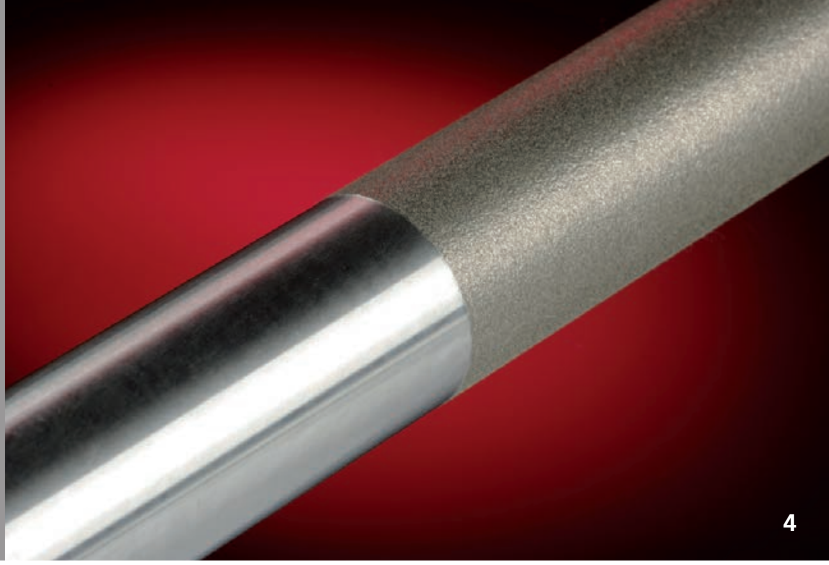
1 Laser Metal Deposition process by robots on blisk blades.

2 Laser-cladded blade tips.





COATING OF HYRAULIC CYLINDERS WITH HIGH-SPEED LASER MATERIAL DEPOSITION

Task

To date, electrochemically produced chromium coatings have been mainly used to protect high-quality hydraulic cylinders against wear and corrosion. Since substances harmful to both health and environment are used in the production process, research into alternative coating methods is becoming increasingly important from an ecological and economic point of view. In the field of wear and corrosion protection, Laser Material Deposition (LMD) has only been able to establish itself for individual applications. With LMD, high quality, pore-free and crack-free layers with metallurgical bonding and low dilution can be produced from a wide range of materials. Typical layer thicknesses (> 500 µm), however, are often too large for wear and corrosion protection, and the surface rates achievable – in the range 10 - 40 cm²/min – significantly too low for large-area coatings.

Method

In this context, Fraunhofer ILT is developing high-speed Laser Material Deposition (HS-LMD) as a new version of LMD to produce coatings in the layer thickness range of 10 - 300 µm and surface rates of > 50 cm²/min. The approach consists in significantly increasing the achievable process speed of LMD such that the powdered filler material is already heated by the laser beam to a temperature close to its melting point before it is fed into the melt pool. Since the loss of the heat flow is reduced by the temperature equalization between the powder particles and the melt pool, the time needed to melt the powder is reduced in the melt pool. This, in turn, reduces the time necessary for the layer to form.

Result

With HS-LMD, a pore- and crack-free wear and corrosion protection layer (Stellite 6), approx. 150 µm thick, has successfully been applied to a piston rod at a surface rate of approx. 50 cm²/min. The hardness of the coating is about 600 HV0.3.

Applications

HS-LMD is currently being developed for the coating of rotationally symmetrical components to protect against corrosion as well as against abrasive and adhesive wear. The high feed rates of 10 - 500 m/min needed for this can be achieved by rotating the components.

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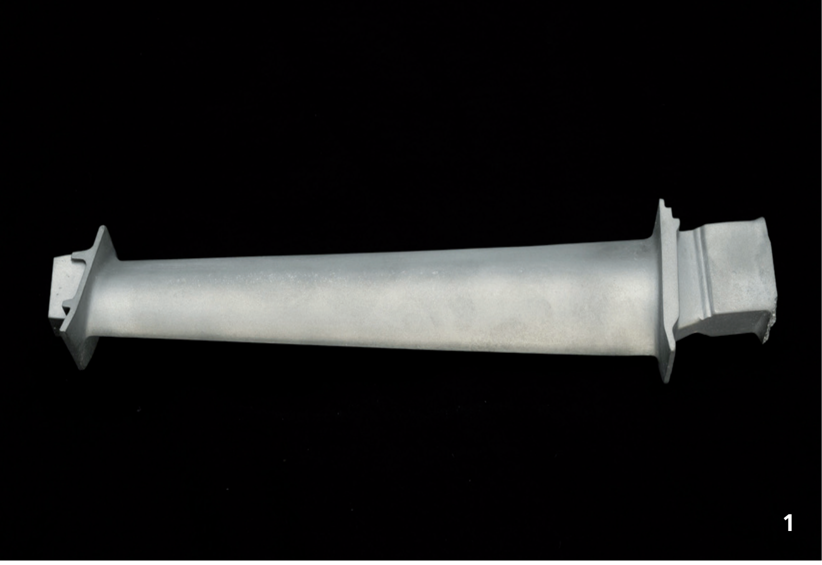
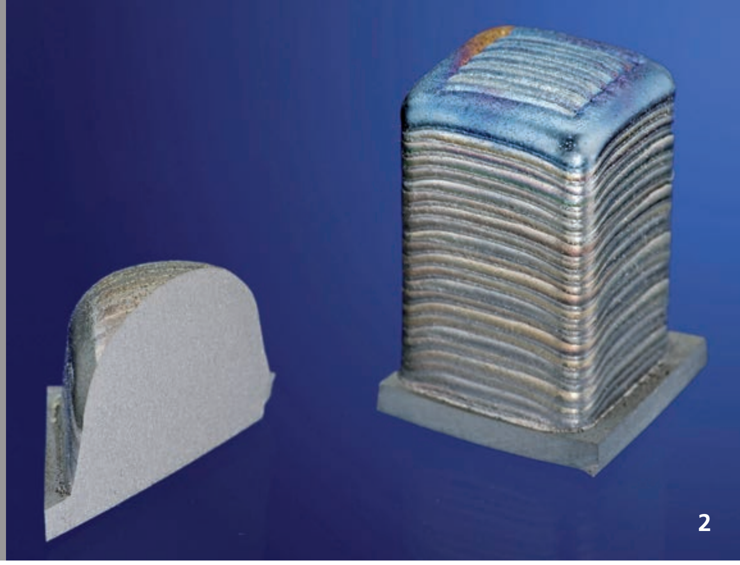
3 Cross section of a coating with Stellite 6, layer thickness approx. 150 µm.

4 Piston rod coated with high-speed Laser Material Deposition and subsequently finished.





LASER METAL DEPOSITION FOR REPAIR OF JET ENGINE BLADES OUT OF TITANIUM ALUMINIDE

Task

Titanium aluminides combine light weight and high strength with high corrosion resistance. For these reasons, they are increasingly being used in the aerospace industry, especially for low pressure turbine blades, which operate at temperatures of approx. 700 °C. While Laser Metal Deposition has already become established as a repair method in the field of aircraft engines, e.g., for Ni-based super and titanium alloys, an appropriate technology for the repair of TiAl blades (manufacturing defects and wear) does not yet exist. Both brittleness and great oxygen affinity present particular challenges when using LMD with and on TiAl.

Method

Within the LuFo project »REPTIL« (funded by the BMWi), partners from industry (Laservorm, Mabotic, TLS) and research (Access) have been jointly developing a full process chain since the beginning of 2014. This chain reaches from component detection, via LMD to repair similar materials, all the way to reworked and operational turbine blades. Fraunhofer ILT is developing the process control for the preheating (> 750 °C) and suitable protective gas shield to produce both crack-free and low-oxygen volumes. To this end, appropriate process parameters have been determined in the first step. Subsequently, machining strategies will be adapted to the geometric conditions of the respective service areas of a turbine blade.

Result

First cubic test samples (edge length approx. 10 mm) from the TiAl alloy GE4822 could be produced without cracks in an Ar-inert atmosphere at preheat temperatures of 780 °C. Currently, the project partners are examining heat treatment, determining the microstructure and identifying mechanical properties.

Applications

The project has focused on developing a technology transferable to a variety of blades, types of defects and other brittle metallic materials. The process is, thus, attractive for a variety of applications in the aerospace industry and energy generation.

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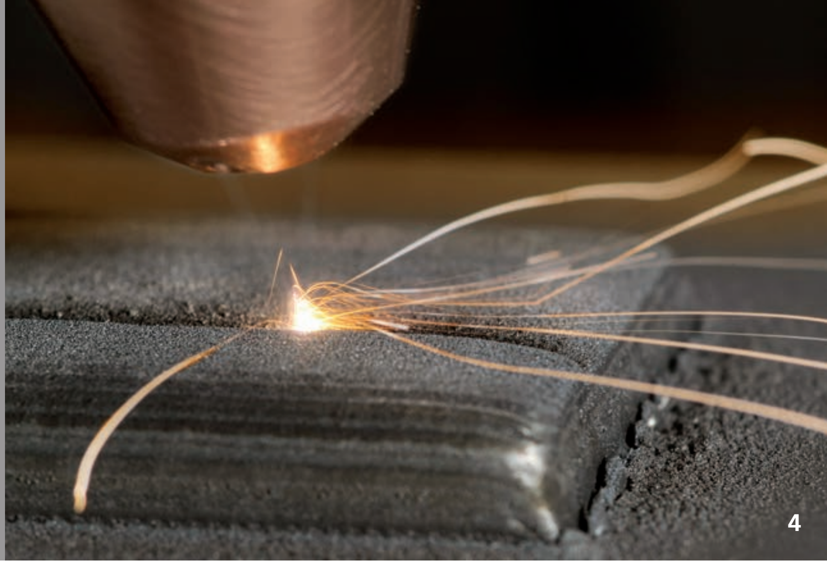
1 TiAl turbine blade.

2 LMD-generated specimens out of TiAl.



ADDITIVE LASER METAL DEPOSITION FOR 3D-COMPONENT MODIFICATION IN AUTOMOBILE CONSTRUCTION

Task

By using forged aluminum components, the automobile industry can contribute to saving weight in its vehicles. A continuous challenge is, among other things, reducing production costs for as many vehicle models as possible while simultaneously maintaining the highest demands on the structural durability of the components. As an alternative to costly new production of different component types, additive Laser Metal Deposition (LMD) has been studied for the modification of functional prototypes and small series in cooperation with the BMW Group. The aim is to modify properties with minimal material and production costs.

Method

First, the process parameters were developed for laser cladding the 3D surfaces of a chassis component out of aluminum. In the second step, the component was optically scanned, a surface model created and a contoured building strategy designed using the ILT's own software LMDCAM. This strategy was applied to the original chassis components of the BMW Group in a final step.

Result

With a strategy adjusted to the geometry, both surface and ridge-like volumes could be precisely bonded metallurgically to the component with an allowance in the magnitude of 0.3 - 0.5 mm. By successfully combining the steps – surface mapping, path generation and LMD – the partners could demonstrate the potential to automate the process, even with complex tasks.

Applications

In addition to modifying aluminum components additively, the process can be adapted to diverse geometries for numerous other metallic materials and 3D surfaces. Targeted functional integration of mechanical and surface properties makes its use particularly attractive for component modification of prototypes and small series.

Courtesy of the BMW Group.

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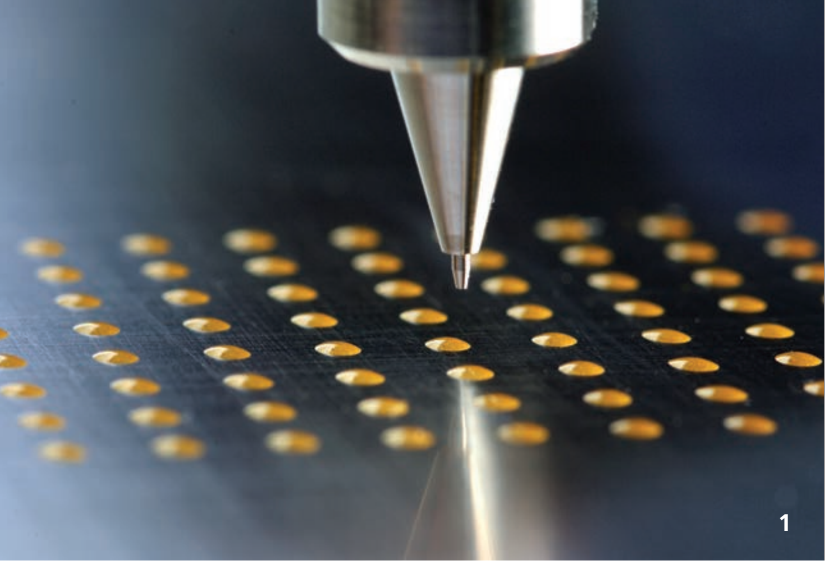
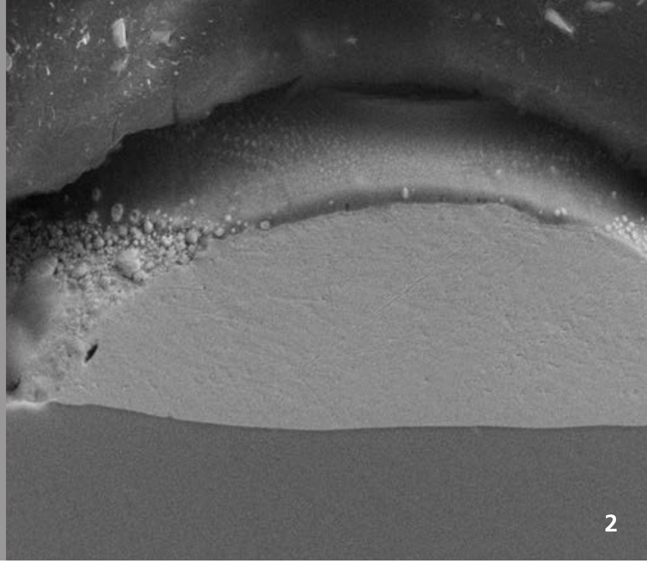
3 Forged aluminum component.

4 LMD process.





MICRO-LASER METAL DEPOSITION WITH GOLD PASTE

Task

In the electronics industry, the increasing integration of functions and the resulting variety of assemblies are driving factors that advance the development of location-selective and flexible coating processes. Conductive contact layers of, e.g. gold and silver, are predominantly applied using two-dimensional area coating methods such as electroplating. Thanks to powder-based micro Laser Metal Deposition (LMD) of individual precious-metal contact points, the same functionality be can achieved but with significantly less material consumption. A variant of this process is the printing of a paste with a high content of precious metals, > 70 percent, followed by functionalization with laser radiation.

Method

By means of a dispenser, the paste is applied to the substrate in a contact-free manner. The mean diameter of the dispensed spots is about 700 µm at a thickness of about 40 µm. It is essential for the subsequent laser processing that paste dry completely in order to prevent the solvents from evaporating abruptly when they are remelted. Subsequently, the laser beam melts both the metal particles and a surface layer of the substrate material creating a metallurgical bonding.

Result

Both the drying and the functionalization can be carried out with the same beam source. The best results of both steps were achieved with pulsed laser radiation. Within 50 ms, the gold paste was completely melted and metallurgically bonded to the substrate. The welded gold contact points have a homogeneous structure without pores. The dilution with the base substrate is low (Au: 95 - 97 wt.%), so that the contact properties of gold largely remain intact. By combining printing techniques and laser treatment, Fraunhofer ILT can, thus, create resource-efficient contacts at selected locations.

Applications

Micro-LMD with gold pastes can be used wherever the excellent electrical properties of precious metals are needed selectively, but where conventional large-scale coating is not economical. Application fields are found in electronics, fuel cell production but also in heat conductors.

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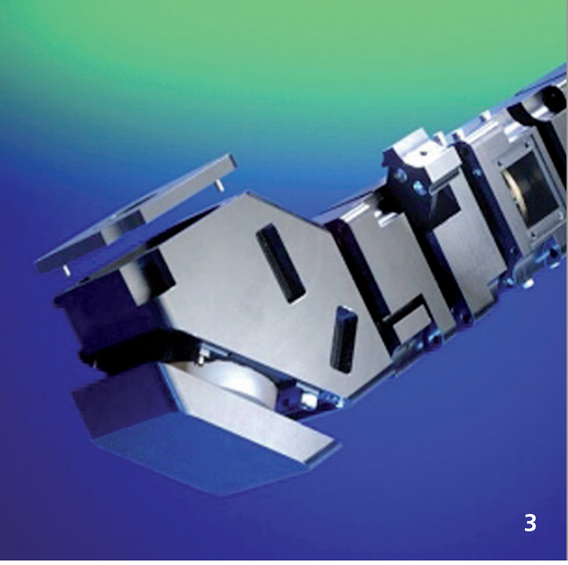
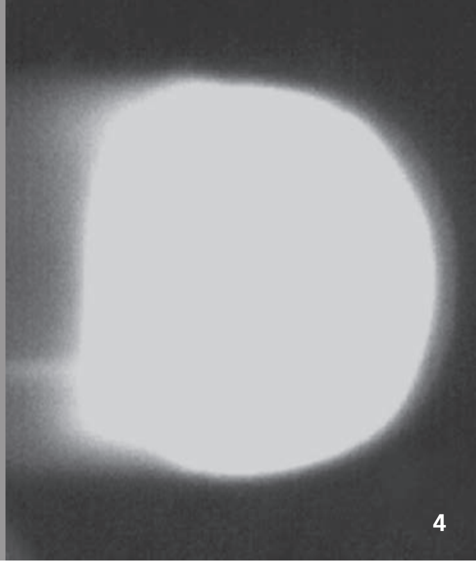
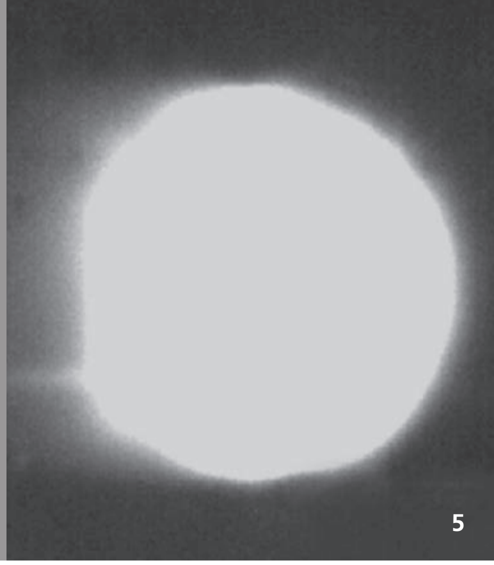
1 Contact-free dispensing of gold paste.

2 SEM image: cross section of gold contact point.







CORRELATION BETWEEN MELT POOL GEOMETRY AND PROCESS PARAMETERS DURING LASER METAL DEPOSITION

Task

The quality of additive manufactured components and coatings by Laser Metal Deposition (LMD) is highly dependent on process stability. For the most part, modern high-performance materials, e.g., of the aerospace and tool industry, can only be manufactured free of defects in a small process window, whereby small deviations already change the process result. In order to minimize variations in the process, those caused e.g. by the part's geometry or continuous heating during the process, by adjusting the process parameters, it is necessary to know how to correlate these deviations to the melt pool geometry.

Method

To observe the melt pool during the process, Fraunhofer ILT has placed a coaxially integrated camera system, operating at a frame rate up to 1000 Hz, in the beam path of the laser. Using it, researchers can systematically analyze the extent to which the essential process parameters – laser power, feed rate and powder mass flow – influence the melt pool geometry. In addition, the institute has also examined the impact by other variables such as the heating of a component, e.g. by heat build-up in the construction of thin-walled structures, upon the melt pool behavior.

Result

By means of correlations determined between process parameters and weld pool geometry, thin-walled structures can be produced with a constant melt pool geometry (see Fig. 4 and 5). For this purpose, process parameters are adjusted in dependence upon the measured melt pool geometry during the process, or, if necessary, even within a single layer.

Applications

The findings help to improve part quality and process reliability in all areas of additive manufacturing and coating of components with LMD. In particular, the processing of materials that place high demands in terms of consistent operating conditions, such as in the aerospace industry and tool making, may thus be significantly improved.

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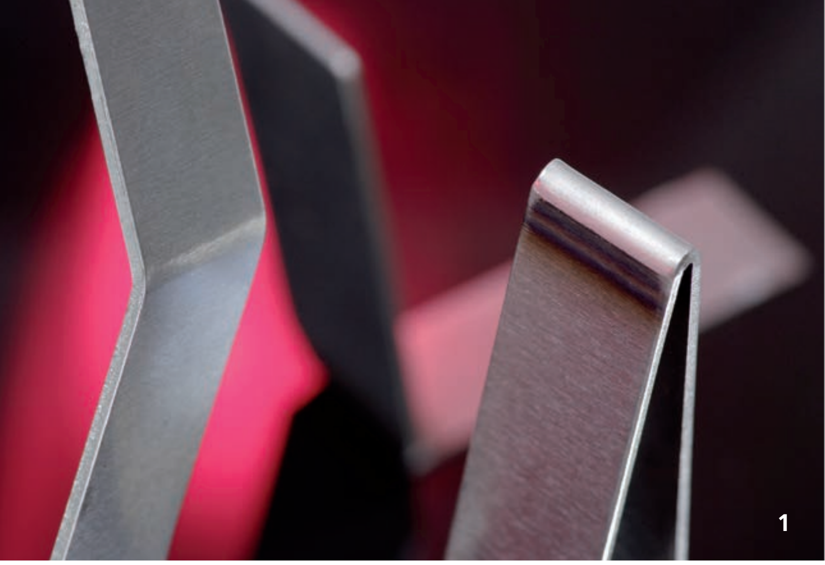
3 Coaxial process monitoring system.

4 LMD of a thin wall: Melt pool geometry without parameter adjustment.

5 LMD of a thin wall: Melt pool geometry with parameter adaptation.



IMPROVING COLD FORMING OF ZE-GRADES BY LOCAL LASER HEAT TREATMENT

Task

Discussions on climate change and legal demands for CO_2 reductions are accelerating lightweight construction in many applications. For cold-rolled strip, for example, the trend is towards thinner and thinner sheet thicknesses and, thus, inevitably toward high-strength materials. These materials should, nevertheless, allow complex forming operations. For this, the company BILSTEIN has developed micro-alloyed ZE-grades that achieve a yield strength of up to 1200 MPa, but allow decreased degrees of deformation in further processing. Within the framework of the Federal Ministry of Education and Research's project »KLASSE«, local heat treatment with laser radiation is being investigated, a process which should improve local, cold formability of ZE-grades significantly. Laser heat treatment is used to soften the high-strength steel blanks locally in areas critical for reformation by thermally induced structural transformation (e.g. recrystallization). This way, ductility is increased, thus making high degrees of deformation possible without cracking the working material.

1 Bending tests without (left) and with local softening (right).

2 Collar-drawing experiments without (top) and with local softening (below).

Method

Strain-hardened plates were heat treated locally with laser radiation. The heat treatment was temperature-controlled with a fiber-coupled 12 kW diode laser and a rectangular beam with power density distribution similar to that of a top hat.

Result

In the heat-treated area, the work-hardened structure is recrystallized. On ZE 1100, the elongation A80 was increased by about two- to three-fold while strength decreased simultaneously. The formability was studied in collaring and bending tests. With work hardened plates, only one collar height h of 4.55 mm was achieved until the first crack appeared. With a softened area of 15 x 15 mm^2, the collar height increased by 36 percent and by 43 percent with a softened area of 20 x 20 mm^2. Thanks to the local softening, the bending angle increased from 30° to 127° in a simple bending test before the first cracks occurred.

Applications

The main area of application is the automotive industry (body, chassis), but applications in the furniture industry (bars and profiles with tight bend radii) are also of interest.

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LASER-BASED PRODUCTION OF POLYMERIC CORROSION PROTECTION COATINGS

Task

As the global consumption of energy and materials continues to increase, sustainable anti-corrosion strategies are beginning to play an increasingly important role. In particular, in the field of renewable energy generation, such as wind power and solar thermal power, the construction of new plants often involves exploiting areas with a high corrosive potential. In this case, the use of high-temperature resistant thermoplastics such as polyetheretherketone (PEEK) as a coating material represents a promising alternative to conventional anticorrosion coatings. A particular challenge results from the use of temperature sensitive steels with annealing temperatures in the range of 180 - 200 °C as base material to be coated.

Method

The steel substrates to be coated are first pre-treated by means of pulsed laser radiation. The induced formation of a thin oxide layer is used to promote adhesion between the substrate steel and polymer. The PEEK powder (Ø 5 - 20 µm) is then applied to the substrate as a dispersion by spraying or a knife-coating. Thereafter, the dispersion is heated by means of IR laser radiation above the melting temperature of 340 °C. In the molten state, the layer densifies and the base material adheres to the substrate. Thanks to the short interaction times of the laser procedure, when compared to a furnace process, the thermal load on the temperature-sensitive base material is reduced, thus preventing a functionally relevant influence on the coated component.

Result

By means of the proposed laser-based process, adherent and dense PEEK layers can be produced on steel substrates. In climate change tests, these layers already exhibit good corrosion protection. Since the annealing temperature in the base material is still exceeded, future studies will focus on reducing the thermal load even further.

Applications

For the most part, these layers can be used for high-precision components in the renewable energy, in particular, in the field of solar thermal power plants, offshore wind turbines and tidal power plants.

The R&D project »RESKORR« underlying this report has been carried out on behalf of the Federal Ministry of Education and Research under the grant number 03X3564F.

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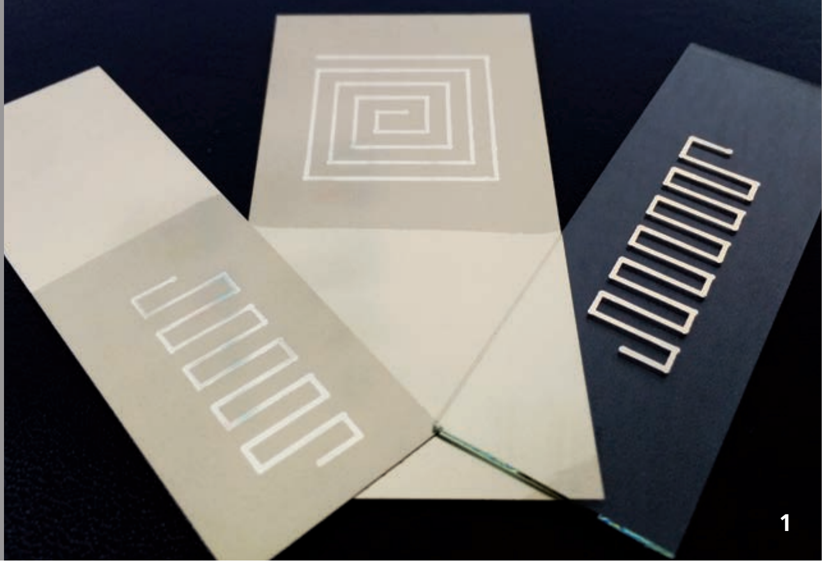
3 PEEK-coated steel substrate, rear: initial state (right) and after laser treatment (left), front: laser-based front (right) and after (left) functionalization.

4 Offshore wind farm, Baltic Sea, © BWE / C. Hinsch.



MULTI-MATERIAL LAYERS FOR ELECTRONIC APPLICATIONS

Task

Modern electronic devices often consist of cheap but complex multi-material layers. Particularly on electrically conductive components, insulating layers are necessary to shield conductors or other functional layers from the substrate. Digital printing processes make it possible to apply these structured and flexibly designed functional layers in an inline process. Thanks to the laser-based thermal post-treatment of the layers, it is possible to functionalize these, i.e. to dry, to harden, to sinter or to crystallize them. Especially in the field of temperature-sensitive components and substrates, the local and short-term energy input by laser radiation can provide great benefits.

Method

As part of the BMBF-funded project »KombiFun«, Fraunhofer ILT has developed a laser method for drying and curing of sol-gel-based insulation coatings. The insulating layers are heated by laser radiation at a wavelength of 1064 nm and thereby dried and hardened. Other functional layers such as silver conductor tracks can be selectively applied with a printing process and functionalized by subsequent laser processing.

1 Printed and laser-processed functional layers: insulation layers with silver conductor paths on metallic substrates and glass.

Result

In close cooperation with the varnish manufacturer FEW Chemicals, Fraunhofer ILT has developed optimized and electrically insulating varnishes for the laser process. These can be hardened in the shortest amount of time (< 1 s) by laser radiation, thereby achieving dielectric strengths of up to 1 kV. Conductive coatings of the coating materials can be prepared in the form of laser-sintered silver conductor tracks, which are based on nanoparticle inks. Here, conductivities of up to 50 percent of the bulk material can be achieved. These values meet the requirements of many products from the electronic mass market, such as sensors, signal cables or individual lighting.

Applications

The areas of application include insulated flexible and complex electronic components. Both metallic substrates as well as temperature-sensitive plastics or component assemblies can be used.

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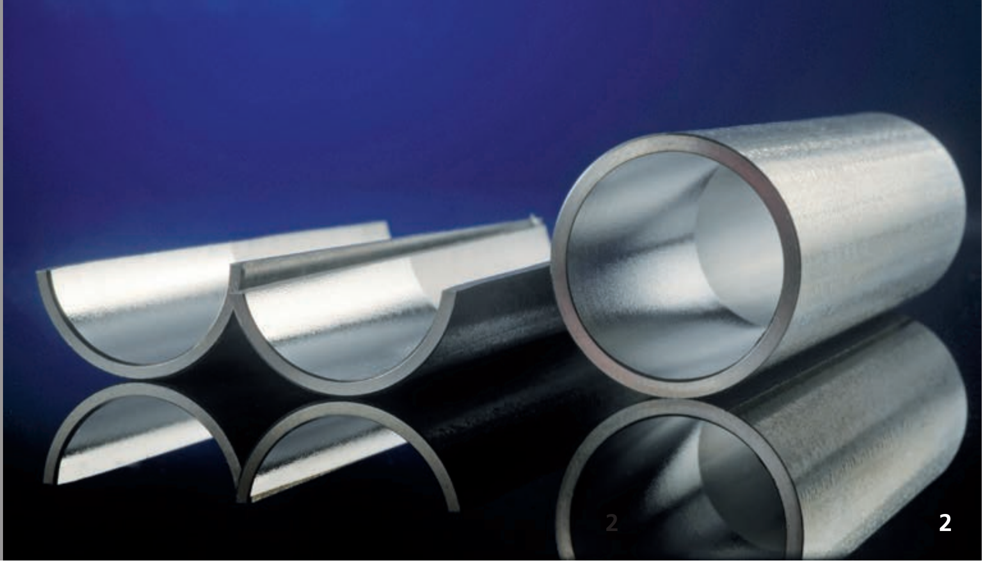

INTERIOR PROCESSING OPTICS (IPO) FOR LASER POLISHING

Task

So far, polishing by means of laser radiation has been developed for 3D freeform surfaces. The laser polishing of the inner surface of bores or tubes is constrained, however, since the scanner systems used have limited accessibility to the workpiece. The maximum ratio of hole depth to diameter is about 1.5 and, thus, too low for many applications. For this reason, a processing optics should be developed, one which allows the polishing of cylindrical internal surfaces with higher ratio of hole depth to diameter.

Method

The goal is to develop a suitable optical system to laser polish the inner surfaces of pipes that have a maximum length of 100 mm and an inner diameter of 15 - 30 mm. Due to the high scanning speeds, especially when polishing with pulsed laser radiation, these internal processing optics (IPO) must be suitable for rotating speeds of up to 700 min^{-1}. The requirements are, thus, much higher than in internal processing optics for Laser Metal Deposition, which are used at speeds of up to 5 min^{-1}.

Result

The IPO consists of a mounted hollow shaft, which is driven by a belt drive and has a deflection mirror arranged on the end. In the shaft and in front of the deflecting mirror, there is a focusing lens whose position can be varied by using different spacers which make it possible to adjust the focal position to inner tube diameters from 14 to 30 mm. The ratio of hole depth to diameter can be up to 6.7. The maximum speed of the optical system is 1000 min^{-1}.

With the IPO, half of the inner surface of the pipe – made of grade 2 titanium shown above (internal diameter 16.5 mm, length 80 mm) – was polished with pulsed laser radiation. The processing time is approx. 2 - 3 minutes (net) at a rotating speed of 600 min^{-1}.

Applications

The internal processing optics can be used to laser polish pipes for various applications. These are, for example, blood-carrying implants for medical technology or components for the automotive and chemical industries. In addition to its use for polishing, the optical system is also suitable for other laser-based material treatment processes.

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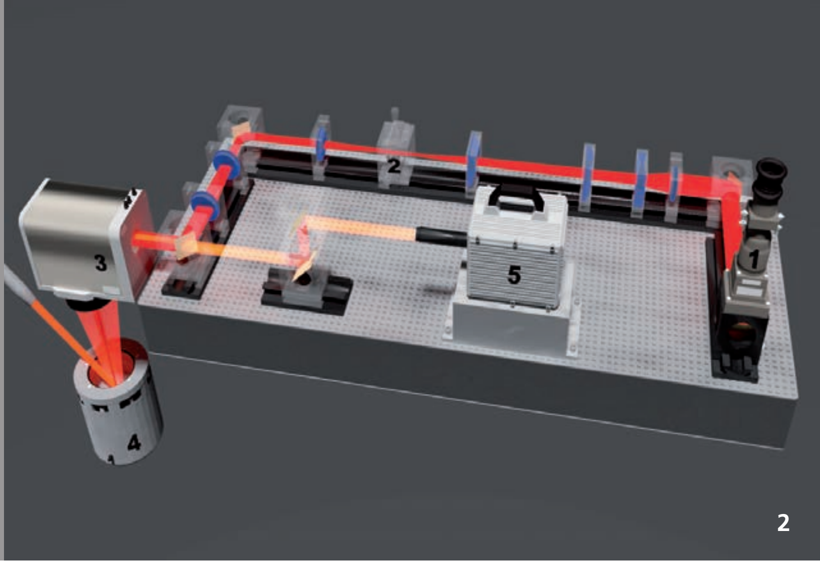
2 Partial (front) internal-polished pipe made of grade 2 titanium with an inside diameter of 16.5 mm.



INCREASING THE AREA RATE OF LASER POLISHING BY USING SPATIALLY ADAPTED INTENSITY DISTRIBUTIONS

Task

Laser polishing is an innovative process for automated polishing of metal workpieces. In this process, a thin boundary layer is remelted, thereby smoothening the surface as a result of interfacial tension. The state-of-the-art in laser polishing with continuous laser radiation is the use of circular, Gaussian and top-hat intensity distributions. The process typically employs laser beam diameters of 150 to 600 µm and a track offset dy between 30 and 75 µm. Partial multiple crossings are necessary in order to achieve the required surface quality. This results in area rates in the range of 1 cm^2/min. For many applications in mechanical and plant engineering, the area rate of laser polishing of 1 cm^2/min is, however, still too low for economical use. By using an intensity distribution adapted to the material and its initial state, the area rate should be improved by increasing the track offset dy.

1 Light microscopy of a polished surface with line-shaped intensity distribution on the material 1.4435, FR = 7.2 cm^2/min, Ra = 0.7 µm.

2 Flexible test set up (1: collimation, 2: flexible diaphragm, 3: scanner, 4: process chamber, 5: high-speed camera).

Method

Within the framework of the BMBF project »polieren10X«, an experimental setup was used to examine laser polishing with different intensity distributions. This setup has a flexibly adjustable aperture, in which an intermediate focus was positioned and which was uniformly illuminated with laser radiation, then mapped to the workpiece surface. The tests were carried out on the austenitic stainless steel 1.4435.

Result

On the material 1.4435, the area rate could be increased from FR = 1.2 cm^2/min with a circular intensity distribution to FR = 7.2 cm^2/min with a line-like intensity distribution at a constant surface quality of Ra = 0.6 µm. The process is not yet easily transferable to other materials, however. The intensity distribution of the increase in surface rate must be adapted to the material used.

Applications

Possible fields of application can be found in areas where metallic surfaces with an average quality (Ra = 0.1 to 0.8 µm) have to be polished. In particular, tool and mold manufacturing, but also in medical technology, the automotive industry and general mechanical engineering, laser polishing can be used with increased surface rates as an economical, automated polishing process.

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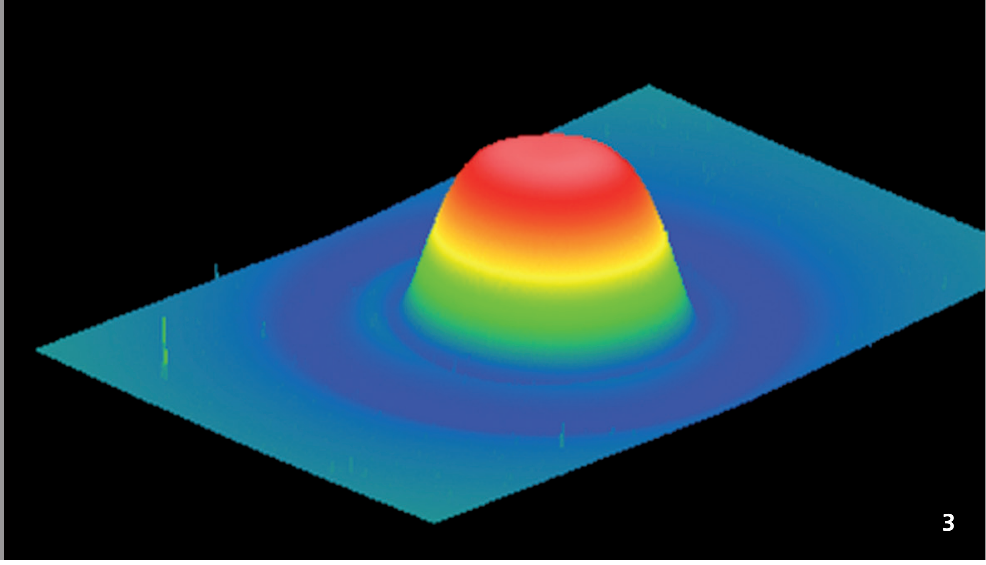

GLASS-BUMP SPACERS MADE FOR VACUUM-INSULATED GLASS WITH LASER REMELT STRUCTURING

Task

Vacuum-insulated glass offers new opportunities for energy-efficient facade design since the overall window thickness can be significantly reduced. In particular, vacuum insulated glass panes can replace single glazed windows in older buildings and, therefore, reduce heat loss. The individual glass panes in vacuum-insulated glass are currently separated from each other by metallic spacers. However, these are visible and require a complex installation process. These metallic spacers should be replaced by glass-bump spacers structured with laser radiation directly from the surface of the pane itself.

Method

CO_2 laser radiation can be used to heat the surface of float glass locally. With sufficient interaction time and intensity, a melt bath is produced on the surface. Thanks to melting movement, the material is redistributed in such a way that a glass-bump spacer is generated out of the rapid solidification.

Result

Structuring by laser remelting was used to generate glass-bump spacers with a height of up to 50 µm and a width of 1 - 2 mm on float glass. By varying the process parameters such as laser power or interaction time, Fraunhofer ILT can customize the height and shape of the glass-bump spacers. The process time is less than 500 ms per glass-bump spacer. The total process time to generate several glass-bump spacers is further reduced by parallelization, in which many glass-bump spacers are generated simultaneously. The current work is focused on reducing the width of the glass-bump spacers, so as to further reduce their visibility.

Applications

The glass-bump spacers are to be used, after their visibility has been reduced further, on glass surfaces as spacers in vacuum-insulated glass panes. Thus, they can replace the visible metallic supports. The manufacturing process of vacuum-insulated glass can be significantly shortened when the process of structuring by remelting is integrated into the manufacturing process of float glass.

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

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 EFRE (»Regionale Wettbewerbsfähigkeit und Beschäftigung 2007-2013«) under the grant number 290047022.

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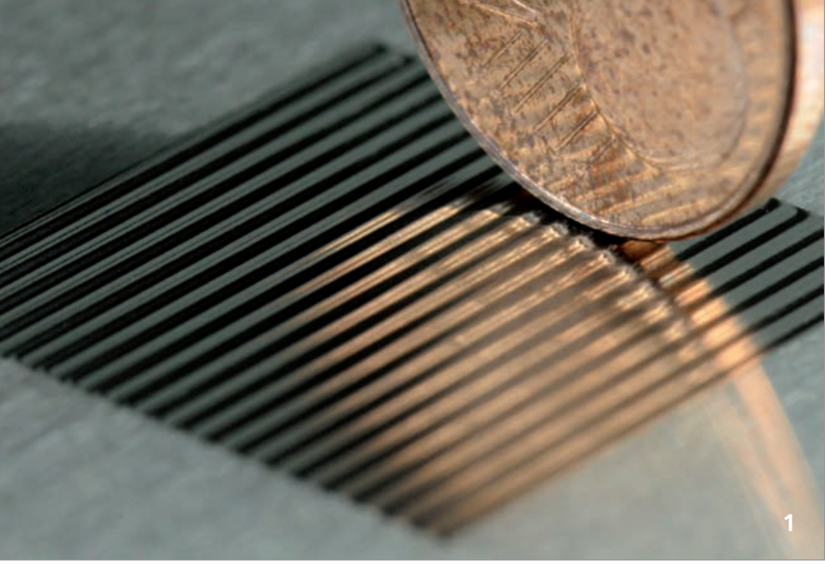
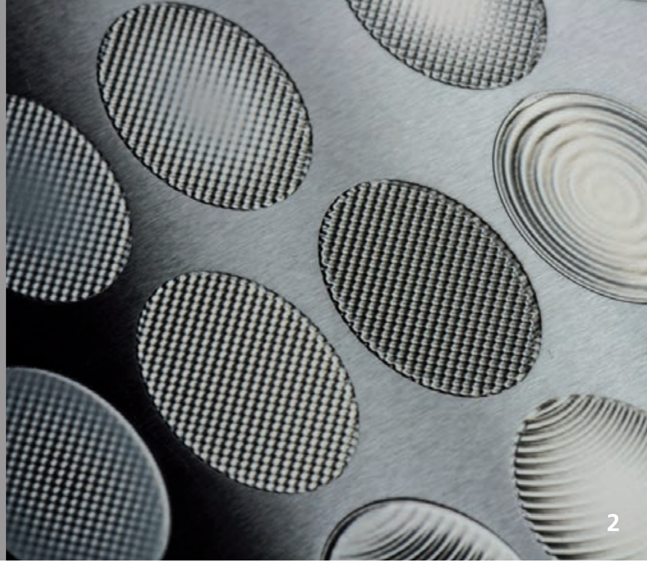
3 White-light interferometric image of a glass-bump spacer (height about 25 µm, width about 2 mm).





LASER REMELT STRUCTURING (LUST) OF INCONEL 718

Task

In many industrial fields, components with structured surfaces have become indispensable. In many fields nowadays, the nickel-based superalloy IN 718 can be found in a broad range of applications, particularly for components in the aerospace, automotive and power generation sectors. However, the structuring methods currently used (e.g., etching, laser ablation ...) are often time-consuming and/or expensive and are based on structuring by removing material. Both methods often produce rough surfaces, which only have limited use for flow-optimized applications in motor or jet engine areas. Furthermore, they still have shortfalls owing to the low removal rates.

Method

Therefore, a novel method – laser remelt structuring (LUST) – has been developed. In this process a laser beam melts the metal surface by local heat input. At the same time, the laser power is modulated at frequencies between 10 Hz - 100 Hz. This results in a continuous change in the melt pool volume and surface so that the material is redistributed. This way the process generates peaks and valleys which are half above and half below the initial level. The surface layer solidifies directly from the melt, thereby polishing the surface. At the same time it is structured. In order to expand the spectrum of materials that can be processed by LUST (previously, tool steel 1.2343 and titanium alloy Ti6Al4V), Fraunhofer ILT carried out systematic experimental studies of IN 718 based on single tracks. The investigations took place within the scope of »WaveShape«, funded by the Volkswagen Foundation.

Result and Applications

The investigations show that IN 718 is basically very well suited for LUST (Figure 1). On the basis of single tracks, it is shown that structures with a height of more than 10 µm can be produced in a single processing step. This corresponds to about twice the structural height that can be generated with comparable process parameters on tool steel 1.2343. Furthermore, the studies show that the scan speed – 100 mm/s also approximately twice as large – can be selected with a corresponding adjustment of the process parameters so that processing times of 1 min/cm² will allow for structures with a height about 200 µm. The process is thereby suitable for generating a wide range of aperiodic and periodic structures (Figure 2). In this case the structured surfaces have a small micro-roughness (Ra < 0.1 µm). Applications for such structures are, among others, in all areas where new functional, i.e. flow-optimized, elements should be used.

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 EFRE (»Regionale Wettbewerbsfähigkeit und Beschäftigung 2007-2013«) under the grant number 290047022.

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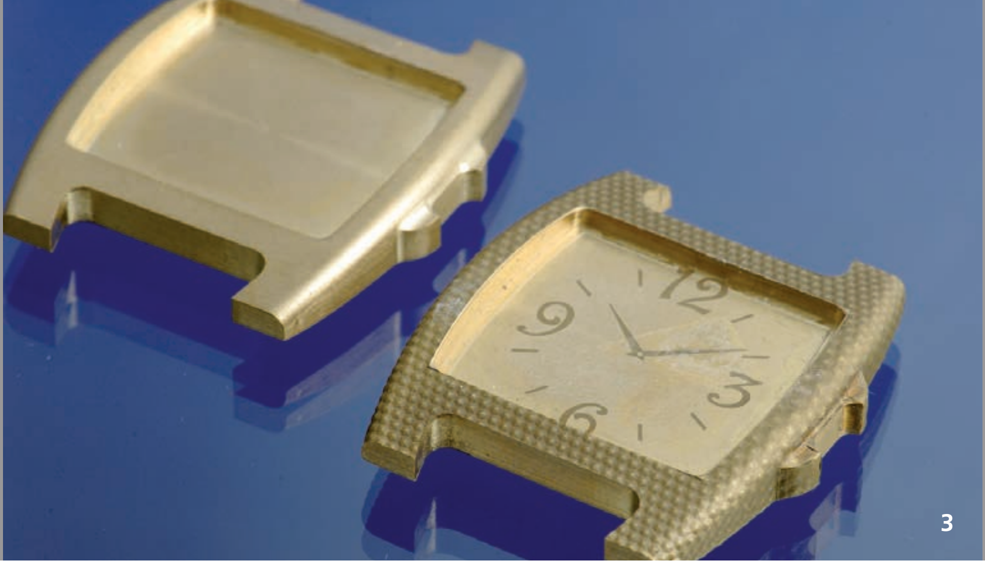
1 Wave structure on IN 718.

2 Demonstration structures generated with laser remelt structuring.



TEXTURING FREEFORM SURFACES WITH ULTRASHORT LASER PULSES

Task

Design structures on components, such as dashboards as well as household appliances, often have to meet optical, haptic and functional requirements. In essence, etching and mechanical processes have been used for a long time to produce such micro-structures on large-sized molding tools so as to generate decorative surfaces in injection molding and embossing processes. For some time, however, laser machines have been available that provide the freeform surfaces of such molds with any textures, both seamlessly and in a large format. The fiber lasers used in these machines have pulse lengths in the nanosecond range, are powerful and relatively cheap. Because of these pulse lengths, the laser ablation, however, creates a melt, thereby limiting resolution and quality.

Method

Laser ablation with ultrashort pulses (UKP, ps, fs) can deliver pulse frequencies up to several MHz and pulse energies 10 µJ at accuracies in the sub-µm range. The process can generate structure sizes of less than 10 µm for functional component surfaces as well as design surfaces with structures of 50 - 100 µm. While maintaining the necessary pulse energy for ablation, the technology of the ps-laser ablation makes it possible to increase the pulse rate to up to several 10 MHz. In addition, it can reach and exceed the removal rate of ns lasers when coupled with fast scanning strategies.

Result

For some time now, the five-axis machining of freeform surfaces with ultrashort laser pulses has been available for components weighing several kg. For large components, however, the current processing times are too long. Together with machine manufacturers, Fraunhofer ILT is, therefore, developing solutions to increase efficiency through multi-beam approaches or ultrafast scanning techniques.

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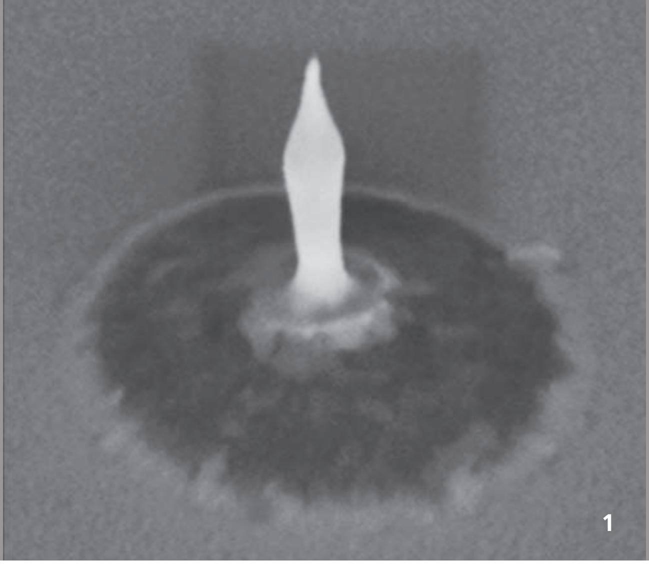
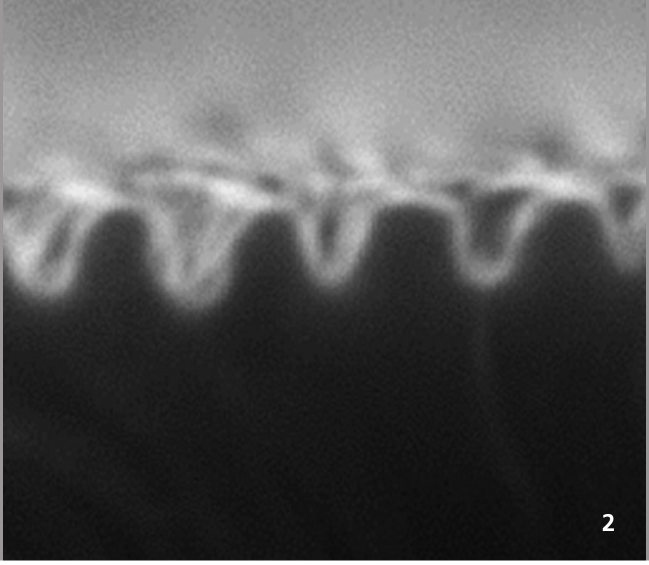
3 Brass demonstrator watch.





LASER-INDUCED NANO-STRUCTURES FOR NEAR-FIELD OPTICAL APPLICATIONS

Task

Highly sensitive spectroscopy methods are increasingly being used to detect very low concentrations of compounds such as explosives, narcotics or toxins. The sensitivity of this method may be increased to a few ppm (parts per million) when near-field amplifying substrates are employed. The reinforcing effect of the substrates is caused by structural field increases of appropriate micro- and nanostructures. So that the sensitivity can be increased, the natural resonances of the structures must be adapted to the compound to be analyzed. In a DFG project, relevant interaction processes for the development dynamics have been examined in detail, thereby making it possible to generate laser-induced nanostructures in a reproducible and tailor-made fashion.

Method

When a gold thin film is irradiated with an ultrashort laser pulse, gold antennas can be produced (Figure 1). In the irradiated thin gold film, a stress-based melt pool dynamic is induced, which results in a material ejection in the center of the irradiated region. Due to the high cooling rates of the thin film, the expelled material solidifies in the form of a jet. During the structuring of semiconductors, the large intensity of the ultrashort laser pulses used enables the excitation of electromagnetic surface waves. The interference of these waves with the incident laser radiation on the surface leads to periodic ripple structures (Figure 2) with a parameter-dependent period in the sub 100 nm range.

Result

Based on the experimental data, model-based theoretic approaches have been developed that describe the causal processes of the respective formation dynamics. Arising from these developments are structure sizes, dependent upon the process parameters, which allow nanostructures to be generated for customized applications and have a precision in the range of some 10 nm.

Applications

The near-field amplifying effect of micro- and nanostructures is increasingly being used in the fields of analytical chemistry, biology and security technology. Furthermore, ripple structures can be used to increase the absorption of semiconductors in photovoltaic applications.

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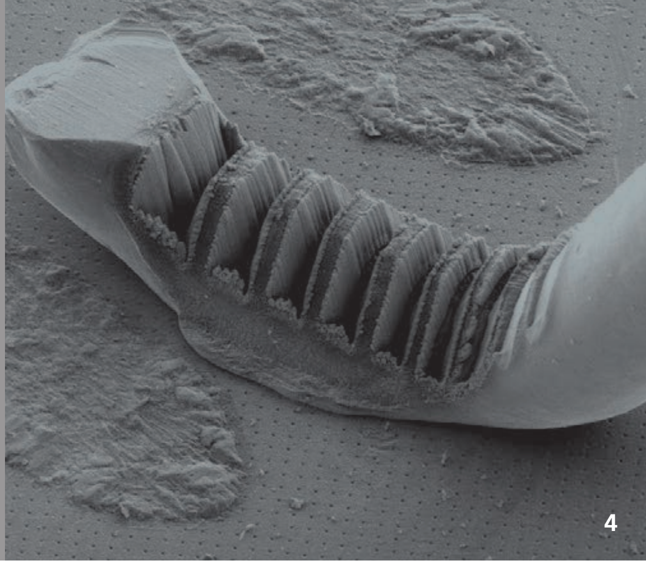
1 Gold nanojet.

2 Cross-section of a corrugated surface.

3



4

LASER STRUCTURING OF BONDING WIRE CONNECTIONS

Task

Advances in power electronics and increasing the efficiency of these components require new set-up and connection techniques with higher electrical and mechanical reliability and reproducibility. Wire or ribbon bonding is an established electrical connection technology, which, however, places considerable forces to the contact surfaces with larger cross sections and connection sites. For this application, the achieved level of reliability should be retained or improved by means of selected laser cuts. This is done on the back of carrier substrates (direct copper bond) directly below the power devices and to the contacting points of the wires.

Method

The laser structures are inserted so as to improve the thermomechanical properties of bonding wire and terminal connections. When the cuts were introduced, the build-up of tension thereby hampers the material from developing thermally induced and unavoidable elongations. The cuts have to be made such that the processed structure or the component is not weakened or even damaged. To ensure this, ultrashort laser pulses in the picosecond range have to be used.

Result

To generate stress-reducing cuts in bonding wires, ablated cavities were introduced in the wires with different depths and arrangement after the bonding process. It could be shown that the electrical function of bonding wire and assembly was not damaged. Subsequently, the assemblies were subjected to an endurance test that showed a significantly improvement in the reliability of the connection.

Applications

Industries are just beginning to enter many branches with power electronics; in terms of increasing efficiency and reliability, however, these electronics are still far from having fully penetrated the market. In particular, as renewable energy resources are increasingly being used, a wide range of inverters with high long-term stability will be required. With the method shown here, laser processing has positively changed the ageing behavior of electronic components and can specifically increase their service life.

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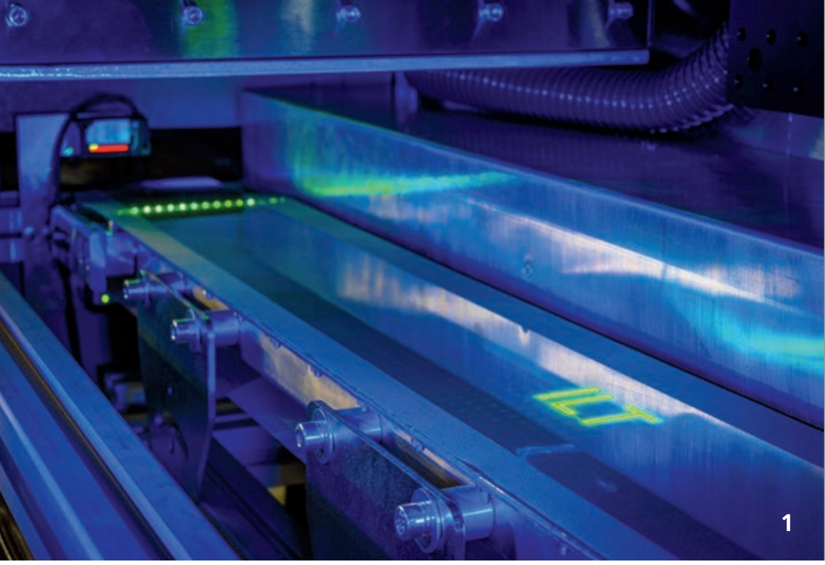
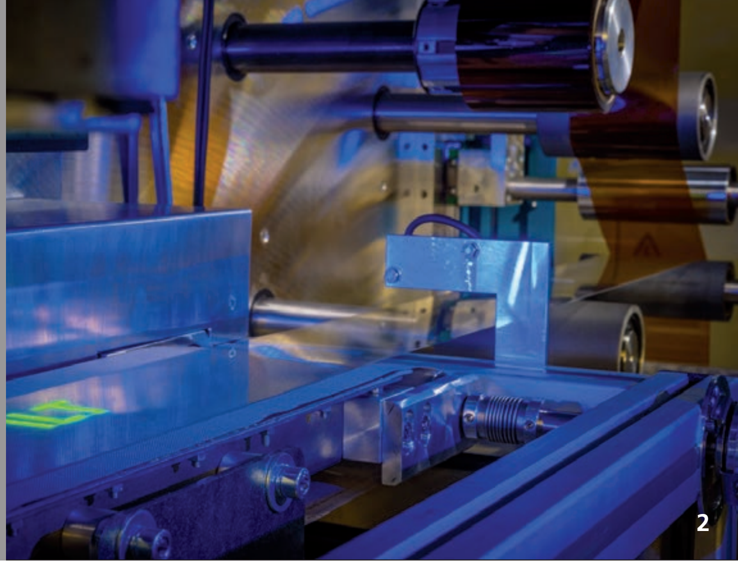
3 Comparison of an untreated and a laser-structured bond.

4 SEM image of a 0.7 mm thick bonding wire with laser-generated cuts.





STRUCTURING THIN LAYERS IN A ROLL-TO-ROLL PROCESS

Task

In polymer electronics, products are generally produced in a roll-to-roll process. Cost-effective products can be made for a wide range of applications, since both inexpensive substrate materials as well as highly productive roll-to-roll processes are used. However, conventional patterning methods such as lithography can only be partly transferred to this type of component manufacturing. Today, however, laser-based processes can be used to structure both polymeric and inorganic functional layers as well as increase resolution significantly.

Method

By using high-repetition ultrafast laser sources combined with optical systems for beam guidance and parallelization, Fraunhofer ILT has integrated powerful method components in a roll-to-roll manufacturing system. With customized ablation strategies and temporal and spatial power modulation, it has been able to achieve high process speeds and selective functionalization of thin film systems. The laser processing method has been applied to the line structuring of organic and inorganic photo-absorption layers and is being qualified for the roll-to-roll production.

Result

For continuous laser-based structuring of semiconducting layers in the field of thin-film photovoltaics, a demonstrator plant has been implemented in the roll-to-roll system. By means of adapted optical systems, the production system is able to selectively process materials at high continuous throughput rates. In connection with the use of a galvanometer, geometrically flexible processing is also possible thanks to the sensory monitoring of the strip material to be processed.

Applications

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

The work was funded by the State of North-Rhine Westphalia and the European Union's European Regional Development Fund EFRE (»Regionale Wettbewerbsfähigkeit und Beschäftigung 2007-2013«) under the grant number EN2061.

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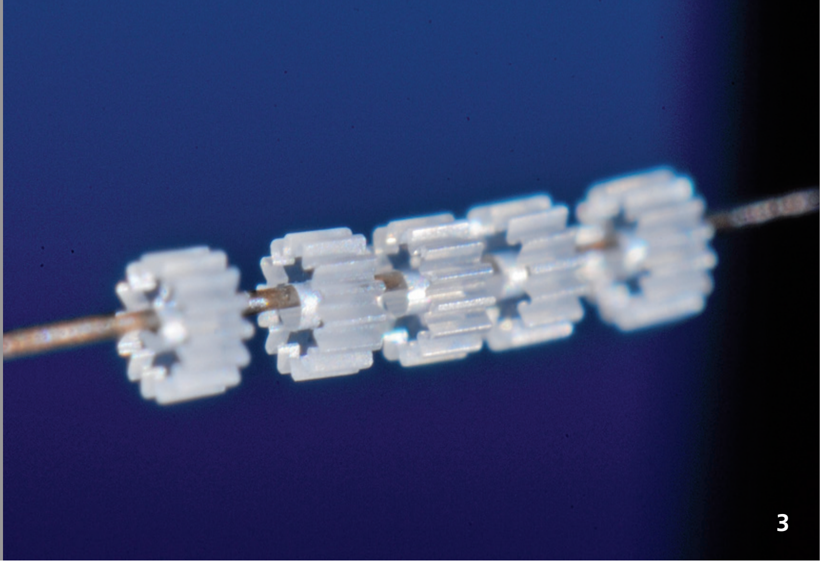
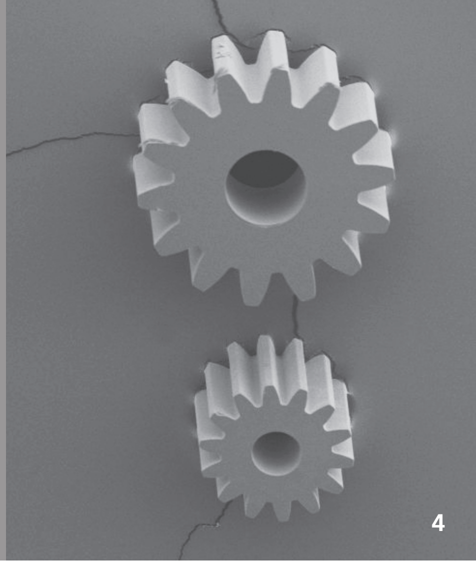
1 Inline structure with fixed optics and scanning unit.

2 Roll-to-roll system path.





SAPPHIRE PROCESSING BY SELECTIVE LASER-INDUCED ETCHING

Task

Selective Laser-induced Etching (SLE) is an innovative laser-based manufacturing process for the production of micro and macro components and micro complete assemblies from transparent materials. It also allows complex parts to be manufactured directly from digital data (CAD) and is, therefore, particularly suitable for the production of small series, prototypes and individual pieces. As part of a project funded by the DFG, the SLE-handling mechanism for sapphire has been studied in collaboration with the Chair for Laser Technology at the RWTH Aachen University. The high-precision machining of sapphire and ruby opens up many new applications for these materials, among others, in the field of microsystems technology as well as in medical and chemical industries.

Method

Selective Laser-induced Etching is a two-step process. In a first step, the inside of the transparent material is modified by the laser radiation. For this, ultra-short pulsed laser radiation (500 fs - 5 ps) is focused (1 - 2 µm). By moving the focus, a contiguous volume is modified, which has contact with the outer surface of the workpiece. In a second step, the modified material is selectively removed by wet chemical etching. For digital photonic production of complex components, the path data for the laser focus are created from digital CAD data and, by means of the CAM software, the micro scanner system is controlled synchronously.

Result and Applications

Holes, cuts or complete components were produced in sapphire. The diameter of the gears shown in the figures is 300 or 500 µm. The microstructures produced can also be used as molding tools due to very high hardness of the base material. The process is characterized by very small kerf widths of < 5 µm. By using a specially developed micro scanner, Fraunhofer ILT can cut any form desired down at accuracy of 1 µm. Such microstructured components are mainly used in microsystems technology, precision engineering, medical, chemical and biotechnology.

By optimizing and adjusting the parameters to the requirements of customers, Fraunhofer ILT can provide feasibility studies for specific shapes and geometries, production of samples and small series as well as the further development of this technology.

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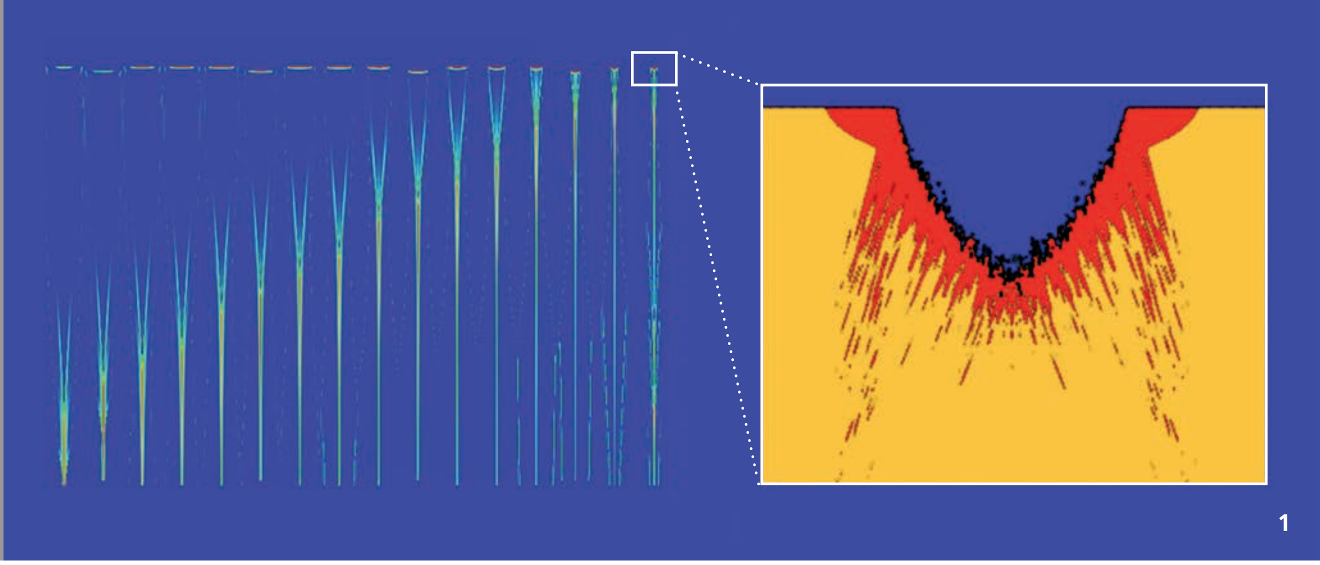
3 Gears (d = 500 µm) of sapphire on a hair.

4 Gears made of sapphire (500 µm and 300 µm).



MODELING AND SIMULATING THE GENERATION OF OPTICAL FILAMENTS WITH USP LASER RADIATION

Task

When (semi-) transparent materials are irradiated with ultra-short pulsed laser light, filament structures (i.e. modifications covering a wide area in the propagation direction and with a greatly limited extension perpendicular thereto) can be generated in the material volume. With enough time and effort, an experimental procedure can principally examine how the technical parameters influence the formation and characteristics of optical filaments; however, the physical causes and mechanisms remain hidden without the supporting explanation of a numerical model. Therefore, mathematical-physical models and their numerical implementation (simulation) are essential tools to enable users to systematically explore filament structures.

Method

The existing simulation code to describe the nonlinear absorption, propagation and ablation has been expanded to include the effect of self-focusing, thus allowing the description of the optical filament as well as the investigation of parametric dependencies of this formation.

1 Simulated filaments and ablation while varying the focal position (Detail: enlarged ablation contour).

Result

The expanded simulation code is in excellent agreement with experimental results both in the description of dielectric material removal as well as of induced optical filaments modifications in the volume of the material. The newly acquired possibilities have already been used to reproduce the influence of parametric variations (e.g. focal position variation) on optical filaments investigated in laboratory experiments in the context of a numerical calculation (see Figure 1).

Applications

The numerical tools created and findings derived from this work – of the physical mechanisms – are essential so that filament formation can be used adequately or its influence appropriately in laser manufacturing processes such as filament cutting and in-volume material modification (e.g. as the writing of waveguides).

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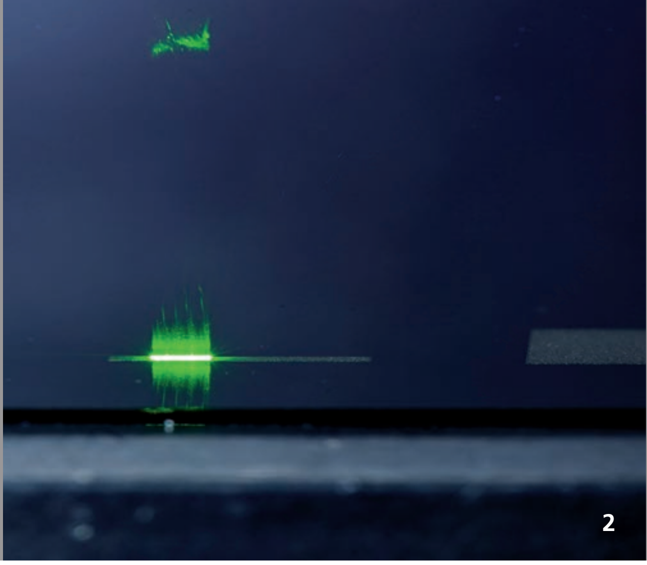

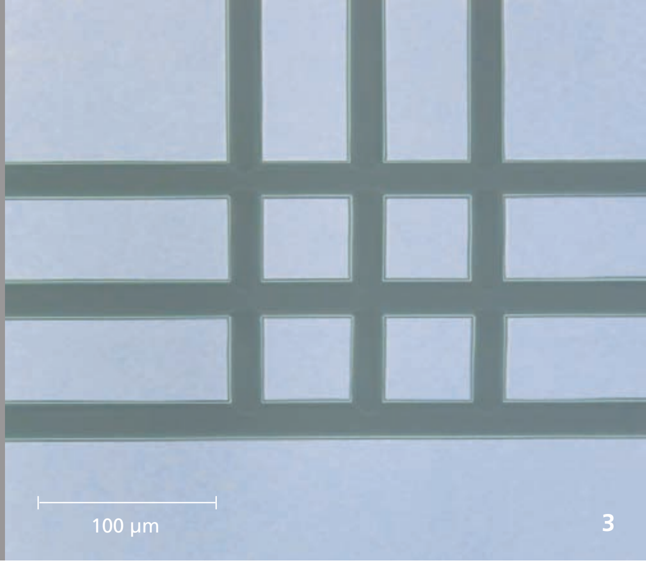

LASER ABLATION OF BARRIER LAYERS IN OLED PRODUCTION

Task

Organic light emitting diodes (OLED) are a lighting technology with great potential for many applications. For their production, the components need to be encapsulated to be oxygen- and vapor-proof, which largely determines the lifetime of the organic materials. The most promising solution is the so-called thin-film encapsulation, in which thin inorganic layers or organic-inorganic layer stacks hermetically seal the OLEDs. For their subsequent contact with the electrodes, this encapsulation must be removed locally, but the electrodes must not be damaged and the barrier effect must remain effective.

Method

The transparent encapsulating layer is made of silicon nitride or other ceramics that have typical layer thicknesses of 300 nm to 1 µm. In the contact area the electrode is located directly below the barrier, and is made of a transparent, electrically conductive material such as indium tin oxide (ITO). With ultrashort pulsed laser radiation with a pulse duration range of some 100 fs to 10 ps, the transparent barrier layer was removed and the process examined without the transparent electrode being impaired in its conductivity.

Result

The sheet resistance of the electrode is typically 10 Ω□. This value must remain after the barrier layer has been ablated. When laser radiation with pulse durations of about 10 ps and a wavelength of 532 nm is used, the threshold fluence for a planar ablation is approximately 0.3 J/cm². The layer is ablated and the sheet resistance of the electrode does not increase significantly within a process window of approximately 0.3 J/cm². The area rate is 78 cm²/min at an average power of less than 10 W. In this way, a more robust and productive process is possible, which can be used in industrial environments.

Applications

Many applications of thin-film technology can greatly profit from the selective ablation of thin layers from underlying layers at high area rates and without functional damage. The process developed in this project can be used in organic electronics and thin film photovoltaics, but also in other fields, in which thin layers are deployed for, e.g., wear protection.

The work presented here was funded by the State of NRW and the EU as part of the Ziel 2 joint project »PROTECT«.

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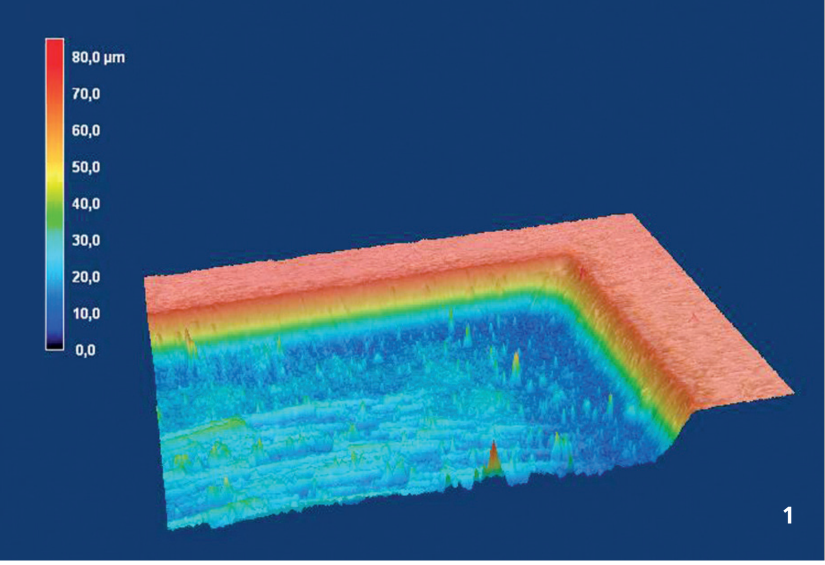
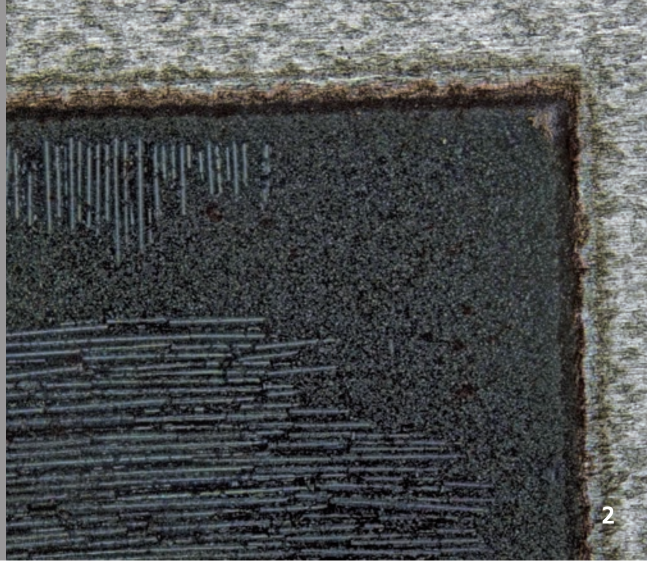
2 Selective ablation of a layer of a layer stack.

3 Multi-beam ablation of ITO film on glass.





PRECISE ABLATION THROUGH PROCESS-ADJUSTED BEAM FORMING

Task

Increasingly, electronic systems are becoming highly integrated, with electronic components placed in circuit boards and optoelectronic components used in hybrid circuits. For this scale of integration, metallic coatings need to be ablated from polymeric component carriers with great precision. In this case, the industry needs to focus on flexibly producing both microscale circuit structures as well as 3D circuit structures on injection molded parts. Here, the thermal influence has to be reduced, above all when laser ablation is used, so that the substrate is damaged as little as possible. Process control plays an equally important role as it has to ensure uniform quality even with variable output conditions.

Method

To achieve these goals, Fraunhofer ILT tracked different approaches to local energy deposition by means of modulated ultrashort pulse laser radiation. Different beam geometries, such as top-hat, and various scanning strategies were examined. The experiments were also carried out at different wavelengths of the processing radiation.

Result

Thanks to beam shaping specially adapted to the process, material can be ablated precisely, selectively and with high homogeneity. An interferometric distance measuring method was used to determine the topology needed to reach the final geometry without any contact in the clamping fixture. Likewise, the machining strategy is adapted to the materials and layer sequences to be processed. Through the suitable choice of the beam shaping and machining strategy, metallic layers can be selectively ablated while damage to the substrate is avoided.

Applications

The fields of application can be found, in particular, in the market for flexible electronic substrates, especially the market for printed circuit board substrates which should soon be introduced in LEDs.

The R&D project »MaLDeAn« underlying this report was carried out on behalf of the Federal Ministry of Education and Research under the number 13N12057.

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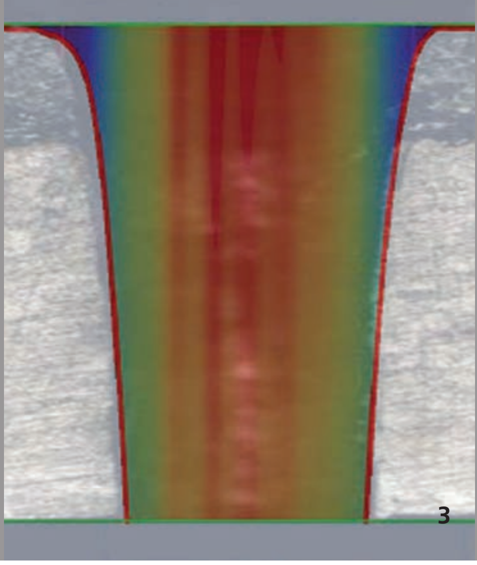
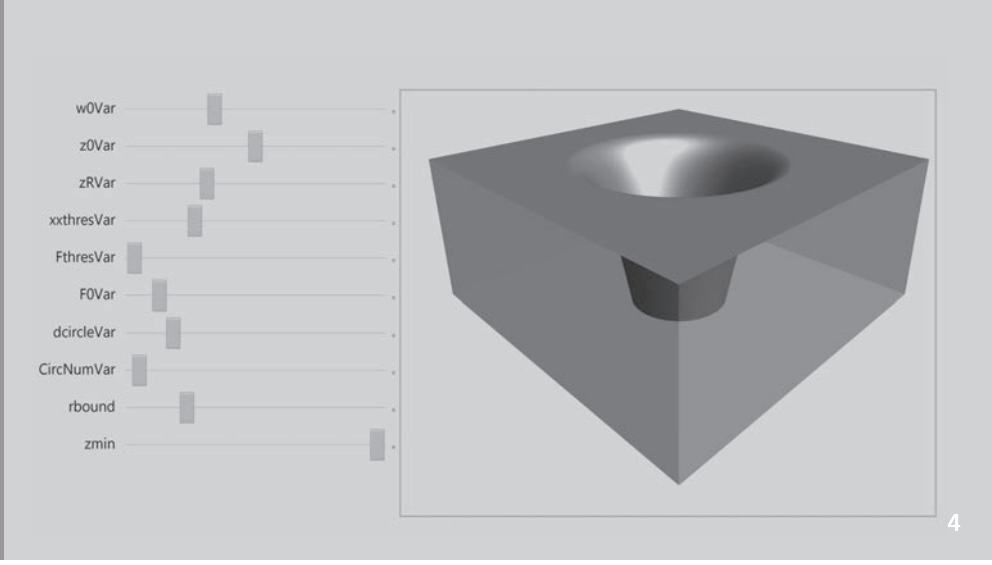
1 3D representation of ablation geometry.

2 Ablated copper layer on PCB substrate.
Two-dimensional ablation of the copper layer on GRP.





MODELING AND SIMULATION OF DRILLING WITH LASER RADIATION

Task

When holes are generated with long pulsed laser radiation, it can be demonstrated that the ablation shape that is formed initially approaches, at the borderline of many pulses, a so-called asymptotic shape such that it changes only slightly or not at all with irradiation by further pulses. These findings are already known from the USP ablation of dielectric and semiconducting materials. Moreover, they have been explained by Fraunhofer ILT with the projected intensity falling below the intensity threshold.

Method

Modeling and simulation aims to describe and predict the final, i.e. asymptotically arising hole contour, or the hole shape, that no longer changes when further irradiation is applied. Moreover, the task of modeling is to identify and explain the cause or the mechanism that leads to such asymptotics in the shape of the drill hole. This explanation cannot be extracted from the experimental findings simply by plain examination.

Result

The explanation for the occurrence of an asymptotic shape of the hole was identified, its underlying mechanism numerically implemented, tested and clearly confirmed by comparison with experimental data (see Figure 3). There now is an interactive numerical tool that can illustrate the impact of changes in process parameters on the shape of the hole in real time (see Figure 4).

Applications

Originally, the basis for the consideration of an asymptotic hole shape comes from findings on USP ablation, in which an asymptotic ablation contour occurs in the same way (as described above) and was observed first. This principle now proves valid even for the removal with long pulses, a fact suggesting that the same or similar principles can be applied to many other laser manufacturing processes.

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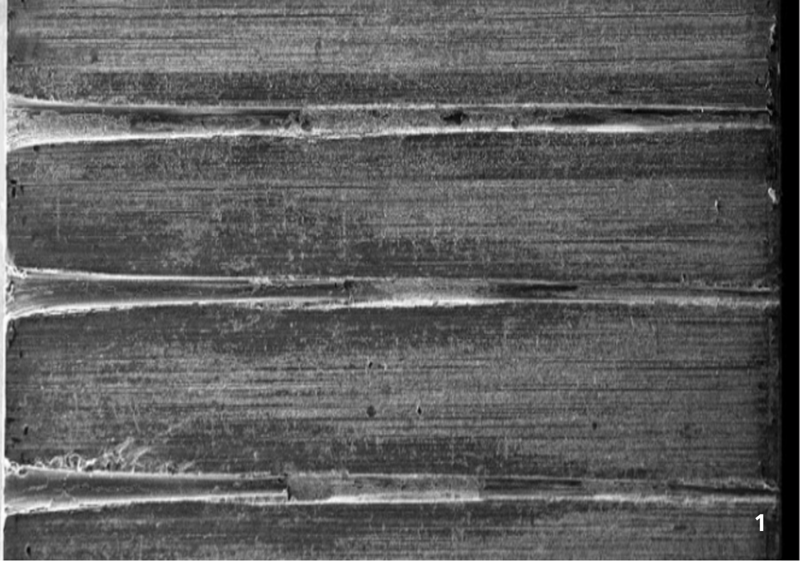
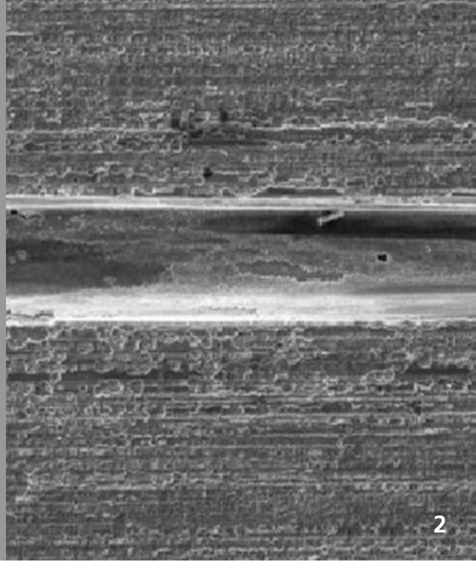
3 Overlay of simulated hole contour, exp. observation and the real beam distribution used.

4 Developed interactive tool for predicting asymptotic hole shapes.





PRECISION HELICAL DRILLING WITH A HIGH ASPECT RATIO

Task

The industry faces a major challenge in manufacturing precision drill holes which have a diameter of approx. 100 µm and a high aspect ratio. While laser-beam helical drilling is a suitable technology for this question, the removal rate rapidly decreases with increasing drilling depth, and it may even cause plasma to build up in the drill hole. Moreover, in large drilling depths the hole geometry is not solely determined by the laser intensity distribution, but rather by a combination of many parameters, such as gas pressure, focal position, etc. To produce precision micro holes in thick material, therefore, the laser and process parameters have to be carefully matched to each other.

Method

Deep holes were drilled in 2 mm and 3 mm thick stainless steel with optics Fraunhofer ILT developed for helical drilling and a frequency-doubled ps laser with maximum single pulse energy of 150 µJ. By varying optical parameters such as incidence and offset of the laser beam and laser parameters such as focus position and pulse energy, the institute can precisely adjust the diameter and taper of the drill hole. The processing speed can be significantly increased by dynamically varying the parameters and optimizing the drilling strategy. To examine the drill geometry and quality, the institute recorded the drill inlets and outlets and their cross sections by scanning electron microscopy.

Result

With the adjusted drilling precision, holes can be produced with a diameter of about 140 µm in 3 mm thick stainless steel. When the helical track and optimization were adapted to the drilling strategies, aspect ratios of more than 20:1 were achieved. Only minor melting deposits and heat-affected zones were detected at the inlet and outlet or on the wall of the hole. The roughness on the wall is Ra < 2 µm.

Applications

Precision holes with a high aspect ratio are currently used for spinnerets, injection nozzles and injectors. Increasingly, these kinds of holes are also being used in sensor technology.

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1 Hole cross sections in 3 mm thick stainless steel.

2 Hole wall of a deep drilling.

LASER DRILLING OF THE PRIMARY NOZZLE OF A JET ENGINE

Task

Approximately 74,000 holes with a diameter of 1.5 mm shall be drilled in the primary nozzle of a jet engine. The nozzle has a diameter of about 900 mm and a length of about 350 mm. The holes should be distributed in 2048 rows, each with 36 holes around the circumference of the nozzle. With a material thickness of 1.5 mm, the material consists of titanium alloy Ti 6-2-4-2.

Method

To produce these holes, a pulsed fiber-laser beam source from IPG Photonics was used. Its advantages are the flexible beam guidance by means of a beam-guidance fiber and process stability thanks to an almost maintenance and adjustment-free fiber-laser beam source. Since the diameter of the drill hole is 1.5 mm, the trepanning drilling method is used. Preliminary experiments identified a pulse peak power of 1.4 kW, a pulse duration of 0.5 ms and a repetition rate of 200 Hz as suitable process parameters. As a process gas, argon is used to protect the processing optics from melting splashes as well as to expel the melted material from the holes. To avoid distortion, the holes are divided into 32 segments distributed around the nozzle circumference. Two rows of holes are produced per segment before the process continues with two rows at the next segment.

Applications

Fluidic tests are carried out on the primary drilled nozzle. Through the drilled area, a defined volume flow shall be derived.

The drilling process can be applied to many components. Since suitable plant technology is available, large-dimensioned components can be processed. Thanks to an appropriate programming system and to the stable beam source, time-consuming, fully automated drilling processes can be carried out having processing times greater than 40 hours.

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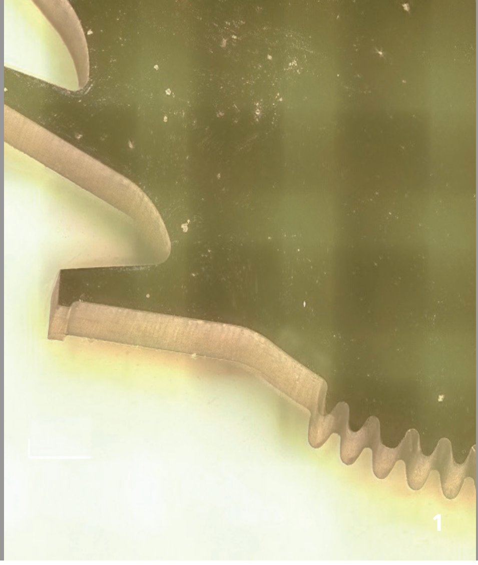
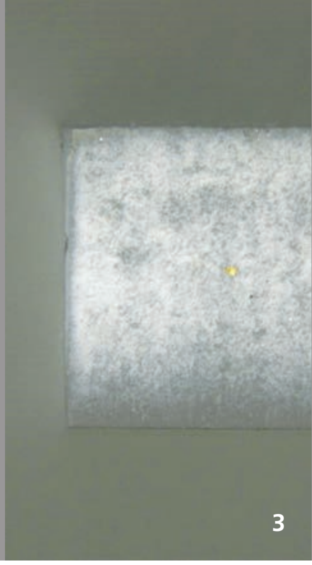
3 Laser drilling of a primary nozzle of a jet engine.

4 Close up of the drilling process.





PRECISION HELICAL CUTTING OF DIELECTRIC MATERIALS WITH LASER RADIATION

Task

Manufacturing technology is faced with special challenges when it has to precisely separate dielectric materials such as glass, ceramics, sapphire, etc., due to their material properties like extreme high hardness and brittleness. The cut edge quality (depth of striation, rectangularity and burring) is critical to how well precision mechanical components function. Laser cutting, especially with ultrashort pulse lasers in the femtosecond and picosecond range, makes it possible to process these materials flexibly and with high quality.

Method

Compared with the classical laser cutting process, a new process – helical cutting – was used to cut the dielectrics. Here, the laser beam is placed in circular oscillation and, thus, not only takes over the cutting process, but also an evaporation-based reworking of the cut edge. With helical optics mounted on a rotating Dove prism and a frequency-doubled ps laser, precision cuts can be generated in different thicknesses of ceramics, silicon and sapphire.

1 Precision cutting of 0.5 mm silicon.

2 Overview of the cut edge.

3 Cross-sections of 0.5 mm ceramic.

Fundamental parameters such as feed rate, gas pressure, power and oscillation can be tuned depending on the material thickness. The width of the cutting kerf can be adjusted in the range of about 30 µm to 200 µm by varying the angle of incidence and of the helical diameter of the laser beam in the drilling optic. Laser scanning microscopy is used to analyze the cut edge.

Result

The new helical cutting method can be deployed to make edge-defined and rectangular precision cuts in 0.5 mm thick silicon with minimal furrow and burrs. Thanks to ultra-short pulse lasers and optimization of the laser parameters, the ablated material evaporates, so no recast layers and melt deposits can be detected. The roughness Ra of the kerf is < 0.8 µm.

Applications

Precision helical cutting can be applied mainly in areas where a high cut-edge quality is required. In particular, the process can close the gap between etching and mechanical production in terms of quality and productivity both in the watch industry and in the production of micro-mechanical components.

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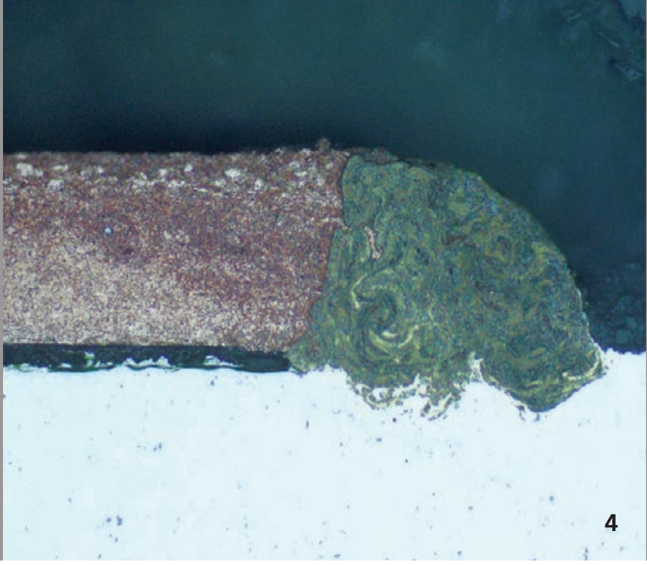
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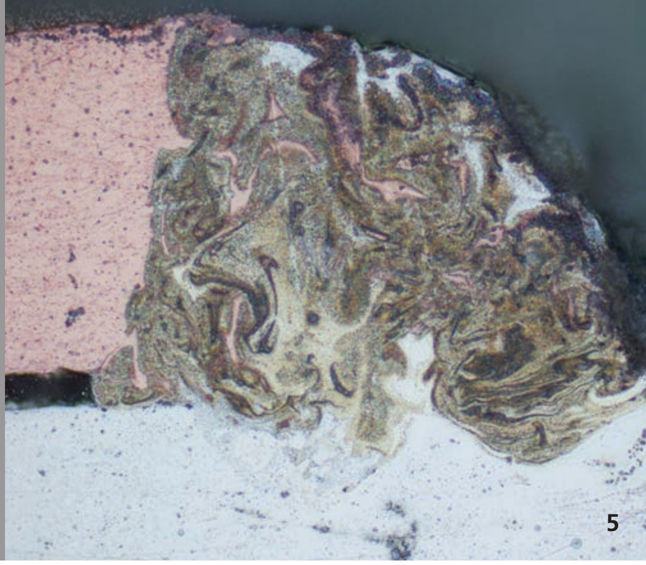
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LASER-BEAM MICROWELDING OF COPPER BERYLLIUM ON SILVER

Task

When precipitation hardened, copper beryllium alloys can achieve the highest strengths among copper alloys. The high wear resistance, hardness, Young's modulus and high conductivity allow broad applications of copper beryllium alloys in electrical engineering. Here, the spring material properties are paramount when this alloy is compared to highly conductive pure copper materials. In particular, copper components with spring properties in the plug connector industry have to be connected to coated copper plugs. Within a study, laser micro welding was evaluated and qualified in a process comparison with arc and resistance welding.

Method

An overlap fillet weld was used for the process comparison. It used a single-mode fiber laser and a scanner system that allowed rapid spatial power modulation. A beryllium copper strip (d = 0.1 mm) was welded to a silver-coated copper strip (d = 0.2 mm).

Result

The process of the spatial power modulation makes it possible to create a smooth and gentle transition of the fillet weld geometry with sufficient welding depth and connection width. In addition to this homogeneous weld geometry, the process can bridge wider gaps. The cross-section of the weld seam shows how positively spatial power modulation influences the homogeneous joint structure.

Applications

This process can be used, for the most part, to generate electrical contacts for connectors and mechanically stressed contacts in power electronics, the automobile and aircraft industries. In addition to plug-in connections, the main applications can be found in contact technology, springs and switches.

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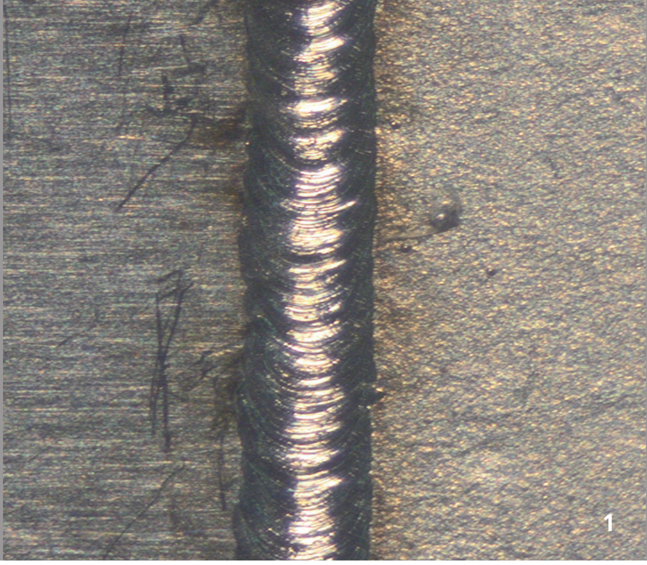
4 Cross-section 100:1.

5 Cross-section 500:1.



MICROWELDING OF THERMAL INSULATORS MADE OUT OF TITANIUM

Task

Titanium is commonly used as lighter and more resistant material (mechanical strength, good corrosion properties) in aerospace engineering. For example, thermal insulators are manufactured out of titanium for the assembly of various elements in satellites which must be protected against thermal effects. Here, a butt joint is used to connect a thin-walled sleeve (0.1 mm wall thickness) and a plug (6 mm outside diameter). Since these two components are produced using machining processes (such as turning and milling), the joint gap and play within two components cannot, however, be avoided.

Method

Within the scope of the project, a laser welding process has been developed to join the two elements of the thermal insulator. The main goal is to generate a stable connection and low distortion. Thanks to local power modulation, where a global feed movement is superimposed with a circular oscillating movement, weld and connection width can be controlled as well as the ability to bridge larger gaps.

Result

By selecting a suitable beam source and adjusting the joining parameters – power, feed rate, oscillation amplitude and oscillation frequency – Fraunhofer ILT can bridge the joint gap and generate a stable connection (weld depth about 300 µm, seam width about 460 µm). Gaps of up to 50 µm can be bridged reliably and reproducibly.

Applications

The results of the project can be transferred to various components in the fields of aerospace engineering and medical technology.

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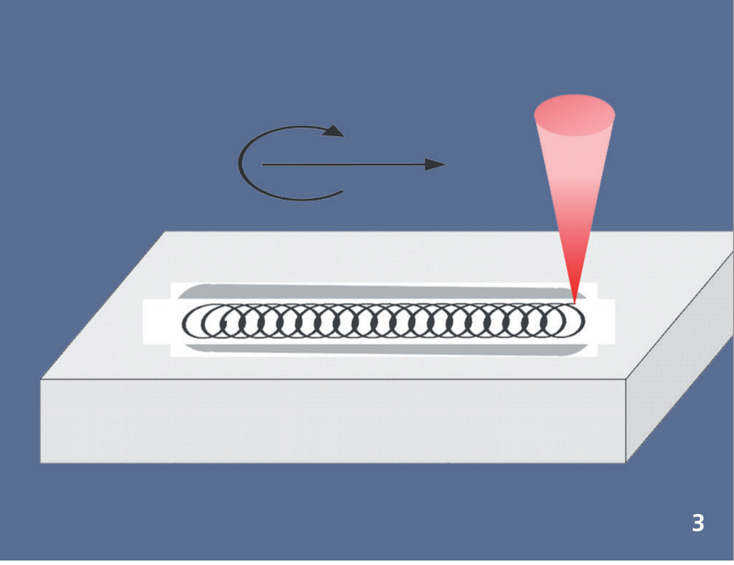
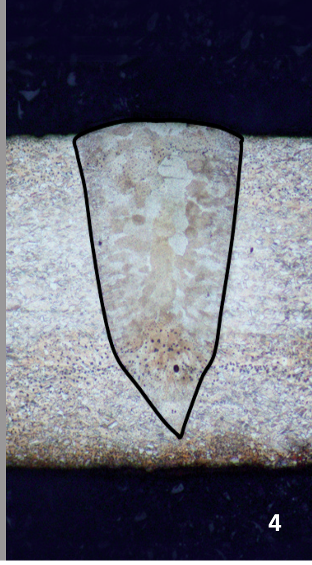
1 View of the generated seam.

2 Cross-section of the generated seam.





SEAM FORMING BY LOCAL POWER MODULATION DURING MICROWELDING

Task

Thanks to its high electrical conductivity, copper is one of the most important materials in microelectronics and in the electrification of automobiles. When copper materials are welded with laser radiation, there are particular challenges: a high thermal conductivity and a low degree of absorption of the laser radiation in the near infrared wavelength range. Through the use of fiber lasers with high beam quality, focus diameters of several 10 microns can be generated, thus enabling energy to be selectively applied to the material. However, smaller focal diameters cause a small connection area of the weld, which can be compensated for by the use of spatial power modulation.

Method

For spatial power modulation, the feed movement is superimposed by an additional oscillation, which significantly extends the structural framework in laser welding. In addition to the parameters laser power, beam diameter and feed speed, the spatial power modulation generates additional parameters that can be used to check melt pool and to form seams and structure selectively.

Result

The dominant form of the laser beam movement was identified through an observation of the melt pool dynamics during welding with spatial power modulation, which decisively influences seam shaping. Since the laser beam oscillates, regions of higher thermal energy will again be traversed so that, in contrast to conventional welding, a larger volume of material is melted, meaning the efficiency increases.

Applications

This laser welding technology in the fine and micro range can be applied, for example, in power electronics and battery technology. The improvements made to enhance the reproducibility and the targeted seam shaping can be transferred to other fields of application such as in medical technology.

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

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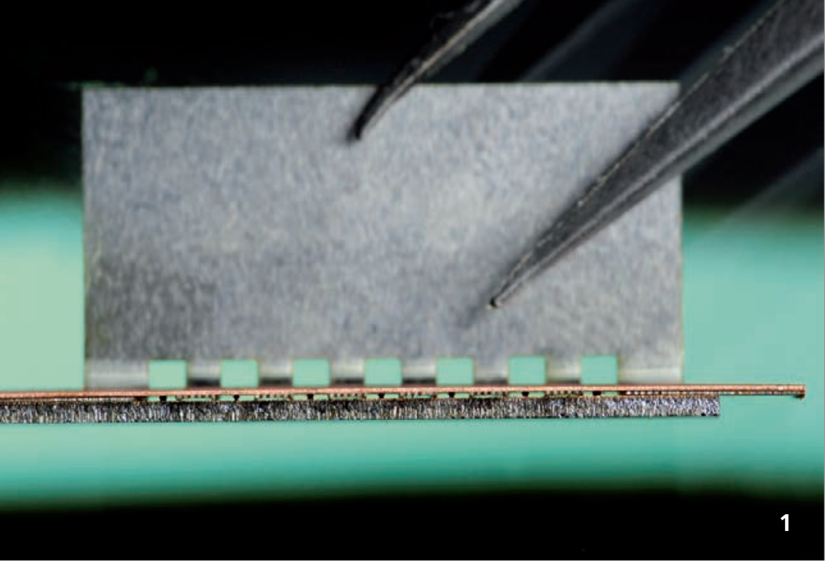
3 Path of the laser beam at a spatial power modulation.

4 + 5 Cross sections of copper alloys with and without spatial power modulation.



LASER IMPULSE MELT BONDING (LIMBO)

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 cable 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 Melt Bonding« (LIMBO), the phases of the process and melting contact are separated energetically. As the components are separated through a defined gap, the melt volume is generated in the thicker parts to be joined in a first phase of the process. By means of laser beam modulation, the melt is accelerated toward lower joining partner. This way, metallized layer can be wetted and melted by the melting energy and the thermal stress minimized in the substrate.

1 Copper sheet contacted to metallization layer.

2 Cross-section of a copper weld on a metallized silicon wafer.

Result

The process makes it possible to weld 200 µm copper sheets on 35 µm metallization layers on silicon wafers with reproducible bonds. The penetration depth in the lower joining partner is less than 20 µm. It is possible to control melt dynamics in the process by adjusting the laser modulation.

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 firm bonding of metal components with high gap tolerances.

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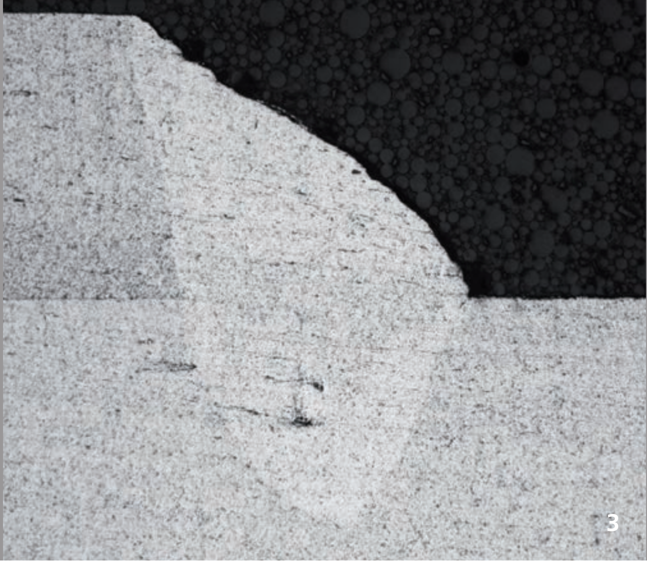

LASER-BEAM WELDING OF LITHIUM-ION BATTERY CELLS

Task

Electric mobility is dependent on highly stable and reproducible electrical connections to the lithium-ion batteries cells used in this sector. As part of a process study, reliable welds should be tested on prismatic lithium-ion cells. Lithium-ion battery cells were installed in a fixed housing made out of aluminum. The aluminum poles which exit the housing were either screwed or welded in place. Since aluminum forms an electrically insulating oxide layer in air, a consistently good electrical contact between the two aluminum poles can only be ensured by a welded connection if no other additional measures are taken. The temperature rise in the cell due to the welding may reach a maximum of 120 °C during the welding process.

Method

To generate the connection, the welding process uses local power modulation in the form of circular oscillating movement superimposed on a linear feed movement. The parameters oscillation frequency and amplitude thus expand the design freedom of the weld seam considerably. The process allows a constant weld and connection width. When the power is modulated spatially, the melt pool can be positively influenced and the temperature gradient controlled in the melt pool.

Result

The increase in process stability through local power modulation leads to a uniform weld penetration depth and connection width in an overlapping fillet weld configuration. The contact pole of aluminum 1050 (d = 1 mm) is welded on the cell pole in aluminum 3003 (d = 6 mm). The measured temperature in the cell pole was < 60 °C. The sealed battery modules were then tested on a battery test bench manufactured by FEV GmbH. This demonstrated that the joints have very low electrical contact resistance and exhibit a homogeneous temperature distribution under current load.

Applications

This process can be applied primarily in the automotive industry, mobile machinery, stationary energy storage and recreational vehicles.

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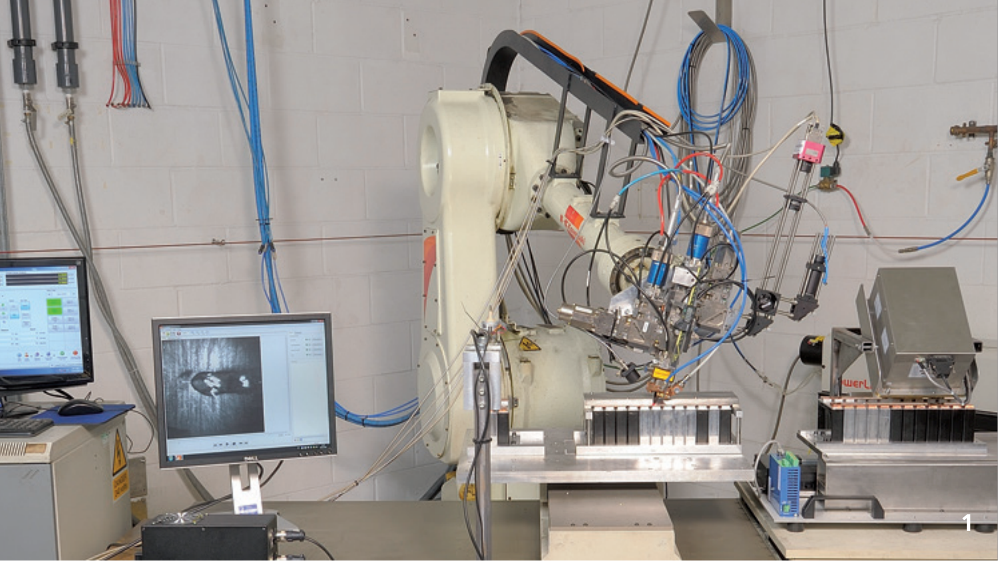
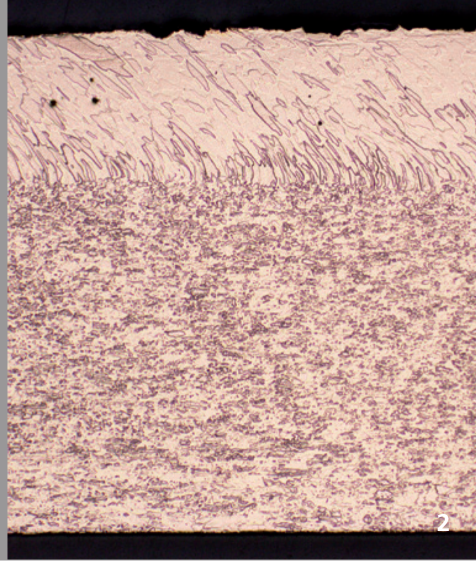
3 Micrograph.

4 Lithium-ion cell.





PROCESS MONITORING DURING LASER WELDING OF BATTERY ELECTRODES

Task

When battery modules for electric vehicles are assembled, plate-shaped power contact rails are connected with the terminals of several battery cells. Large electrodes and weld cross sections are employed according to the magnitude of currents to be conducted. An important prerequisite for reliable production technology is to guarantee a constant penetration depth and a faultless joint. Suitable process monitoring should be employed to reach this objective: reliable laser-beam welding of battery electrodes.

Method

To generate the contacts of the battery electrodes, Fraunhofer ILT expanded a laser plant by a coaxial imaging process monitoring system in order to record the melt pool and, thus, the secondary process radiation during welding. As part of the process development, suitable process parameters were initially determined to generate good bonding of the contacts. Based on the initial parameters, a specific variation of the process parameters was carried out to determine how fluctuating input variables correlate to changes in the welding depth.

1 Demonstrator model of the monitoring system.

2 Longitudinal section of a weld seam at a constant depth in copper sheet.

Result

A prototype system that collects relevant data from the welding process has been successfully demonstrated. Besides containing an industrial PC for operation and data acquisition, this prototype also uses an embedded PC with PLC software to delay critical electrical signaling. With this system, the detected melt pool in the welding process can be correlated with the welding depth. Furthermore, the correlation of the weld depth with the measured radiation power of the radiation process could be validated. In comparison to process monitoring by imaging this method requires more effort to adjust the optics.

Applications

The method can be used both in critical safety connections of battery terminals as well as in all other lap welds.

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement number 260153 (QCOALA: Quality Control for Aluminium Laser-Welded Assemblies).

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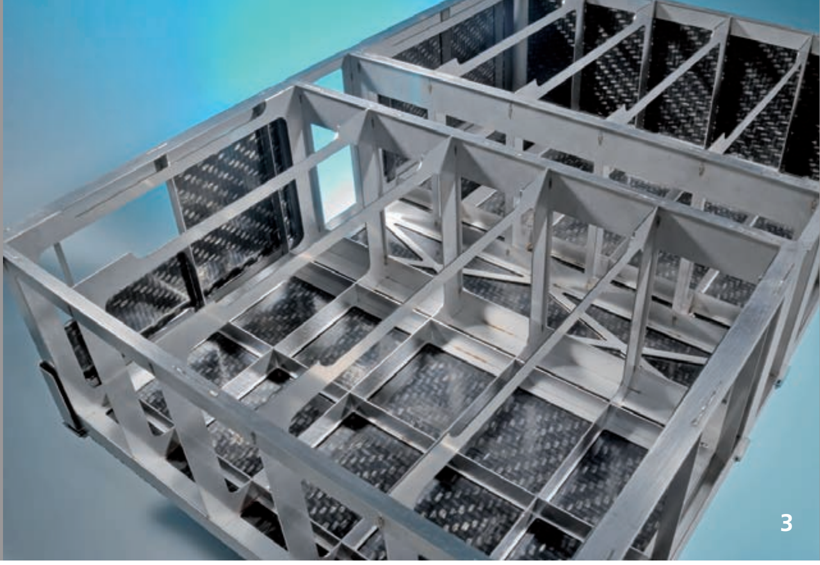

LIGHTWEIGHT POWER PACK

Task

As part of the Fraunhofer project »Fraunhofer System Research for Electromobility«, the Fraunhofer ILT is developing a »lightweight power pack«. The pack should be distinguished by the use of different lightweight technologies, new refrigeration and mounting technologies and the integration of the different components of the Fraunhofer Institutes ISE, IWM and UMSICHT. In addition to the development of battery systems, the production and construction techniques for the creation of a lightweight power pack housing are essential for the safe and cost-effective use in electro-mobile applications.

Method

To reduce the weight of the packs, the project partners have combined a high-strength steel (1.4034 press hardened), having a thickness of 1.5 mm, with low density organic sheet. Since the housing of the power pack has to be built in a modular fashion and has replaceable components, users need to be able to access the components easily. This is why a frame construction with integrated stiffening plates has been created. A complex welding device to position and fix the elements is not necessary due to a selected tooth system at the edges. Fraunhofer ILT has developed a positive hybrid connection, which bonds the organic sheet to the steel.

Result

The structure of the lightweight power pack housing was built as demonstrator model in a scale of 1:1 and 1:3. The steel elements were welded in a keyhole-welding process with CO_2 laser radiation at a process velocity of 6 m/min and a power of 2.4 kW. By arranging the connection joints, Fraunhofer ILT could minimize residual stress and distortion so that only a local annealing treatment after welding is required.

Applications

High-strength steels are commonly used in applications where both high strength and low weight are required – for example, in the automotive sector. When the elements are carefully interlocked together, complicated equipment can be omitted. This creates great potential, in particular, for small quantities within flexible manufacturing chains.

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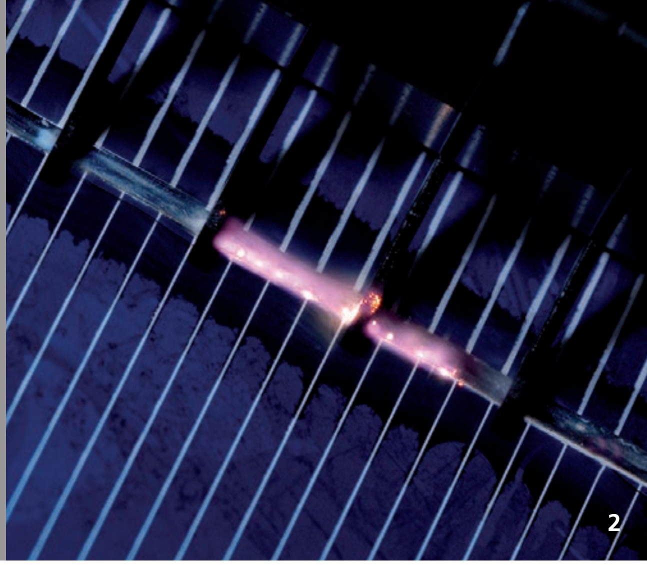
3 Lightweight power pack housing (scale 1: 3).
4 Inner assembly of the lightweight power pack housing (scale 1: 1).



CONTROLLED LASER-BEAM SOLDERING OF SOLAR CELLS

Task

To advance future cell and module designs in photovoltaics, new sensors and control technology are needed to improve the quality of the laser-beam soldering process. The process development presented here pursued different approaches to laser soldering, such as locally fixed energy input by line optics and locally variable energy input with scanner optics. This project's reported goal is to meet the requirement for thinner cells as well as lower energy input; in addition it aims to increase production quality and, thus, improve the ecological balance in the production of solar modules.

Method

Using pyrometric signal acquisition during the different soldering processes with varying process parameters, Fraunhofer ILT identified a characteristic curve of the temperature profile even with very different processing parameters, e.g. the irradiation time. The pyrometric signal was calibrated with high-speed imaging of the upper cell connector so as to characterize the temperature profile in the visible process phases during the soldering process. The visual analyses were compared with the pyrometric signal, which in turn make it possible to determine the individual process stages and a characteristic feature, the latter of which can be used for process control.

1 Pyrometric Controller (Source: Amtron GmbH).

2 Laser soldering process.

Result

As an example, in the control system, a high-speed pyrometer was integrated in the beam path for the scanner-based soldering. Thanks to a novel control strategy, an absolute temperature measurement is not required and aberrations of the optical system can be compensated. The cell connectors to be brazed to the solar cell have been divided into several sections. For each of these sections, the laser power can be controlled during the soldering process depending on the temperature profile measured.

Applications

By tapping into the quality optimized laser soldering through innovative application engineering (among others, multisystem pyrometry, multi spot optics), Fraunhofer ILT has been able to combine simultaneous energy input, adapted laser beam geometry and multiplication means thanks to multispot optics. This expands the application spectrum of the laser soldering far beyond photovoltaics to other electronics products.

The R&D project underlying this report, »Innovative Quality-optimized Laser Joining Technology for Photovoltaic Modules (LaVeTe)« was carried out on behalf of the Federal Ministry for Environment, Nature Conservation, and Nuclear Safety under the research number 0325265.

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TWIST-LASER WELDING OF PLASTIC FILMS WITH 1567 NM ERBIUM FIBER-LASER RADIATION

Task

When lasers are used to weld plastics, an overlap joint is almost exclusively used, having a contour, simultaneous or quasi-simultaneous configuration. Since highly brilliant fiber lasers with 1060 nm (ytterbium-fiber laser), 1567 nm (erbium) or 1940 nm (thulium) have been in use, TWIST has provided another variant of the method, based on the superposition of a slow welding speed with a quick circular motion. This distributes the high intensity of a fiber laser beam to a larger geometric area. The homogeneity of the heat-affected zone is, thus, improved when compared to its counterpart when the typical lens shape is used in diode welding. In addition, the weld width can be varied within the same contour. Apart from their usual dependency upon parameters such as laser power, welding speed and focus diameter, TWIST-welded seams are influenced by the TWIST-circle diameter and oscillation feed rate, which determine the circular overlap.

Method

With a collimated beam diameter of 5 mm and a lens focal length of 345 mm, the focused beam diameter is 152 µm within the 150 x 150 mm large working field. To demonstrate the TWIST process, the welding contour was generated consisting of three circles, each 15 mm in diameter and 2 mm circular ring width. The TWIST oscillation feed rate was changed for each circle to demonstrate a low, medium, or high overlap of the TWIST circles, see Figure 3.

Result

A transparent and a black film with 300 µm thickness were welded in an overlap joint. The welded seams appear distinctly as black lines since the milky light scattering of PET is reduced at these points by the melt connection with the lower foil. The laser power is 10 watts at 20 mm/s feed rate.

Applications

TWIST is preferably used to generate thin seams in microfluidic components and to reduce the welding depth for ordinary 1 - 3 mm wide weld widths. The wavelength of 1567 nm is well suited to weld brilliant white pigmented polymers since such TiO_2-filled plastics have significantly higher levels of transmission at 1567 nm than at 1060 nm.

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3 300 micron PET film, transparent on black, TWIST-welded with 1567 nm fiber-laser radiation and three TWIST overlaps.

NON-DESTRUCTIVE TESTING OF LASER WELDS ON PLASTIC

Task

In many industrial sectors, laser transmission welding of plastics has become established as a production process. Increasingly, the range of applications has expanded as the lightweight construction of components critical for safety is becoming more important. The processing of such components, however, increases the demands on quality assurance and component testing. The plastics typically used in industry, in particular fiber-reinforced plastics, are opaque or non-transparent in the visible wavelength range and also exhibit strong scattering. The component located in the interior of the laser welds cannot, therefore, be analyzed by microscopy methods, but often only via destructive methods. For this reason, the industry needs alternative non-destructive testing methods which make it possible to inspect the welds one-hundred percent so as to meet the more demanding testing requirements.

Method

Under a system comparison, several non-destructive testing methods on the market or in development were tested if they were able to detect defects in laser welding seams on plastic. For this purpose, test specimens were produced out of representative plastics, and laser welds with defined voids were introduced into the specimens. In addition to the X-ray testing, ultrasonic, terahertz and ultrasound testing, the lock-in thermography in particular was examined. In this method, the test specimen is excited with laser radiation, and the heat conduction detected by means of thermography. The same test specimens were analyzed in the investigation with the different test methods to finally obtain a basis to compare their suitability.

Result

The test results are strongly dependent upon the individual plastics, their structure and additives. Defects, flaws as well as the welds can be detected and identified well depending on the procedure. The appropriate test procedure must, therefore, always be selected individually for the inspection task.

Applications

The results and the applied non-destructive testing are suitable for various applications in which defects or flaws – in addition to welds located in the interior of the part tested – must be detected in plastic components.

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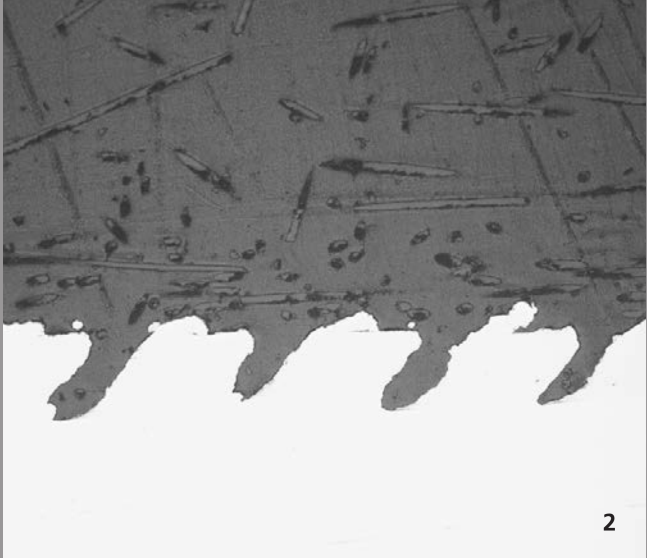
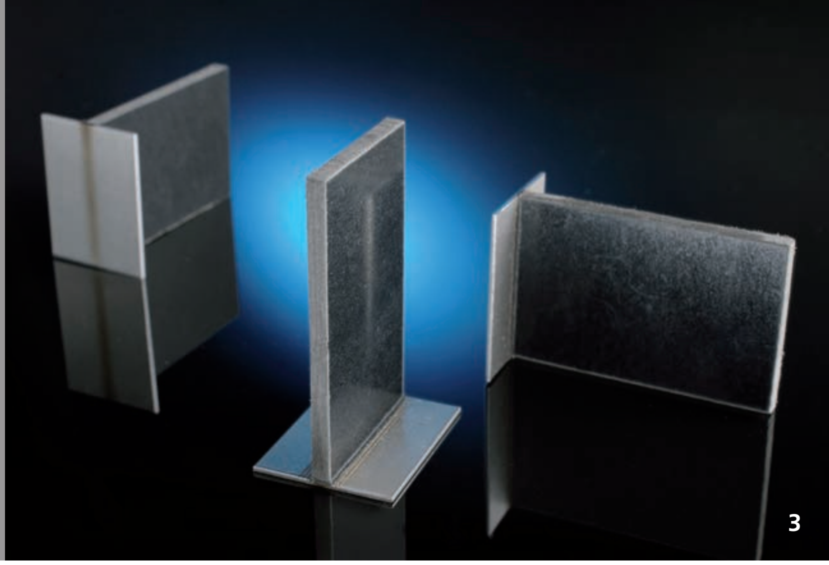
1 Plastic sample with internal welds tested non-destructively.





T-JOINT CONNECTION OUT OF PLASTIC AND METAL

Task

Particularly in the automotive industry, the combination of dissimilar materials presents manufacturing engineering with major challenges. Notably, the adapted use of plastic and metal opens up further potential for weight savings. While plastics are characterized by their low weight, low price and almost unlimited shape, metals can withstand significantly higher mechanical stresses due to their mechanical properties. Directly and firmly bonding the two materials together fails, however, on account of the chemical and physical dissimilarity of plastic and metal. To create such a connection, a positive locking fit or the use of additional materials is, therefore, required.

Method

At Fraunhofer ILT, a process chain has been developed to connect plastic with metal, in which microstructures are generated in the metallic bonding partner by means of laser radiation. In the subsequent laser joining process, the plastic is plasticized and interlocked into the microstructure through a clawing mechanism. In the specific case of a T-joint connection, an incident laser angle is used to structure the metal component, thus generating larger undercuts that can withstand higher tensile loads.

Result

The generated T-joint connection consists of a micro-alloyed steel and a short glass-fiber reinforced polyamide. In comparison to vertical structuring, a 45° incident angle increases the tensile strength of the T-joints by 30 percent. At an incident structuring angle of less than 45°, the sample breaks at a load of 18 MPa; in comparison, the vertically structured sample, however, already fails at 14 MPa. If this strength is applied to the load-bearing cross-section – i.e. the structure width* structure length*structure quantity – the base material strength of the plastic material is reached.

Applications

By using hybrid combinations of components, the ILT engineers can take advantage of the material-specific characteristics of different materials, making it possible to generate simultaneously light and rigid components. For this reason, the two-step method presented here is especially appropriate for the aerospace and automotive industry.

The work presented here was financed within the EU-funded joint project »PM-Join«.

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2 Cross-section of a T-joint structured with a 45° incident angle.

3 T-joint of a metal-plastic connection.

MODULAR PRODUCTION CHAIN FOR PLASTIC OUTER SHELL COMPONENTS OF VEHICLES

Task

As vehicles become more and more individualized, their production requires flexible manufacturing processes – especially in small series models – that enable the industry to design and equip automobile components in a modular fashion. Using the electric vehicle StreetScooter, Fraunhofer ILT shall identify and optimize new laser-based processes in terms of potential cost reductions.

Method

In this project, three models of StreetScooter were used to test the concept of modular component manufacturing. The StreetScooter's exterior mirror mounts differ in the number of ducts they have (Figure 1). Through a modularization of the production chain, the base plate and ducts were initially injection molded separately. The required openings were cut into the base plates with laser machining processes and the ducts welded into them with transmission welding. By a suitable choice of dyes and absorbers, homogeneous color can be created in the part and, simultaneously, a good weldability guaranteed to join both parts with an invisible seam. Finally, a metal-plastic hybrid connection was generated; the necessary connection elements were then structured in the metal on its underside so that it can be connected with the base plate by means of positive locking. Thanks to indirect heating, the plastic melt penetrates into the structures inserted in the connection element and forms a firm connection after it cools.

Result

Based on laser machining processes, the modular production chain makes it possible to significantly reduce the number of required injection molds and, thus, the manufacturing costs of the mirror triangles with a constant variance in the component.

The proposed process chain was developed within the project »KMUProduction.NET: SME-friendly Production of Electric Vehicles and Components in NRW« (grant number: 300109102). This project's overall goal is to develop practical and cost-effective solutions for manufacturing, thus enabling small and medium-size enterprises to produce components, electrical parts and minicars.

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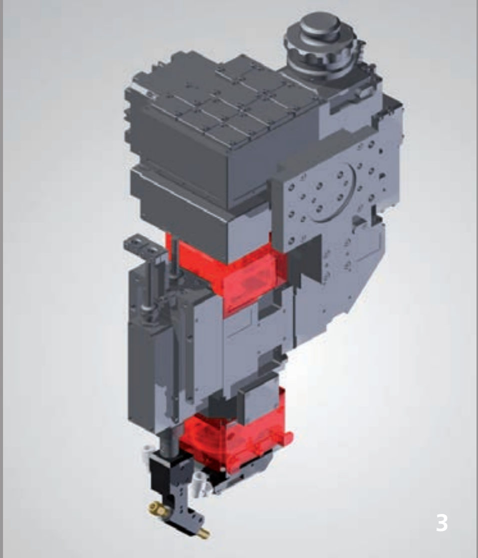
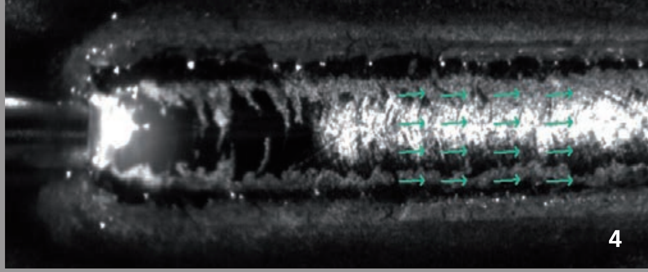
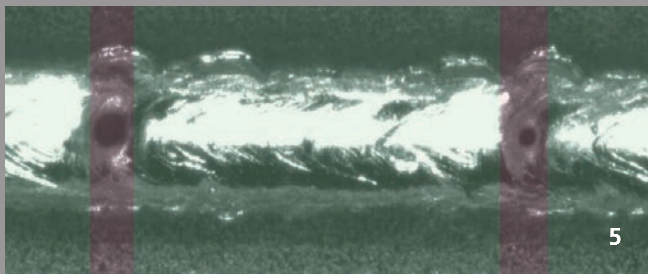
1 Various models of the StreetScooter.

2 Welding the duct to the base plate.







QUALITY ASSURANCE FOR LASER BRAZING

Task

Laser brazing is an established joining process in the automotive industry. For example, two-piece tailgates, but also the roof seams are bonded together with this joining method. In addition, the resulting visible seam is often used as a stylistic element in exterior design. Accordingly, the demands on the optical appearance of the brazed joints are very high and make quality control necessary.

Method

As part of the successful industrial project »SintALO - Sensor Integration in ALO3«, the Fraunhofer ILT and the company Scansonic MI GmbH have developed a real-time quality monitoring system that is fully integrated into the adaptive brazing head ALO3. Thanks to the coaxially integrated high-speed camera, the laser-beam brazing process can be visualized without impairing the component accessibility of the processing head. Furthermore, a powerful, multi-directional and fully integrated lighting module provides a uniform illumination of the entire field of view of the camera, allowing the use of robust image processing algorithms.

3 ALO3 with fully integrated sensor system.

4 Visualization of laser brazing with measurement of feed rate in real time.

5 Pore recognition.

Result

In addition to the visualization of the brazing process with up to 350 frames per second, the project partners have implemented real-time algorithms to assess the brazing quality and to monitor process parameters:

- Thanks to a classification algorithm, even the smallest pores with a diameter of 200 µm can be detected.
- The feed rate is determined by calculating a displacement vector between two successive images acquired by the coaxial camera.

Both evaluation methods can be used in real time thanks to the programming of a Field Programmable Gate Array (FPGA). Thus, the measured process parameters can be used in control applications.

Applications

The fully integrated and, therefore, industrial-grade sensor system also offers deep insight into the laser material processing. Beyond laser brazing the sensor concept might also be used for other laser processes, such as laser soldering, welding or cutting. The imaging process monitoring continuously provides the basis to increase an understanding of the process as well as to document product quality completely.

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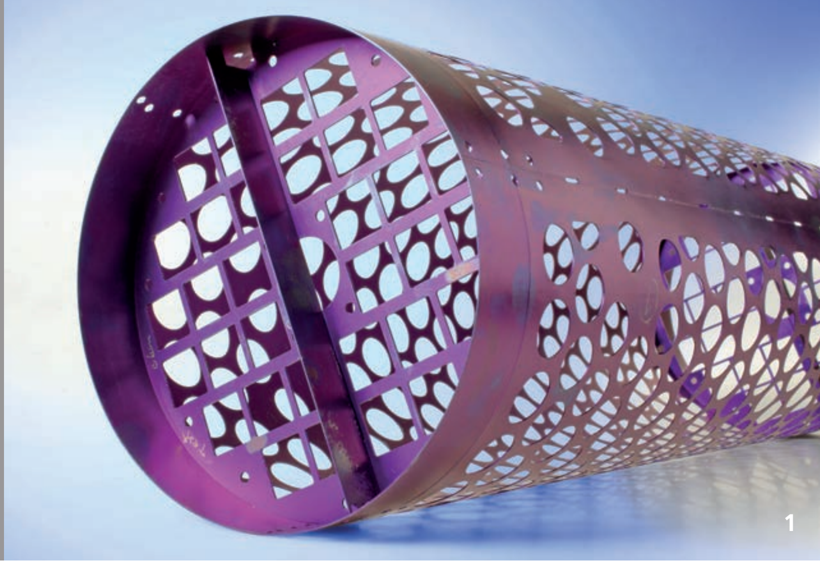

PRECISION WELDING OF SENSOR SUPPORTS IN THE AEROSPACE INDUSTRY

Task

The space probe Solar Orbiter will examine the interaction between the sun and heliosphere. One of the sensors on board of the satellite is called STIX, which is responsible for the imaging spectroscopy of thermal and non-thermal X-rays of the sun. For this sensor, a support tube had to be fabricated and capable of withstanding the mechanical and thermal loads in transport and operation.

Method

Starting from a base construction made of aluminum, Fraunhofer ILT searched for a more rigid, thermally stable and lighter construction. To accomplish this, a tailored welding process including the heat treatment and surface treatment was developed. The production was divided into a development and a production phase. The overall project will be documented according to the guidelines of the ESA.

Result

Given the high loads, the original design out of an aluminum alloy was rejected and replaced by a structure of high-strength titanium. Due to the high strength, the wall thickness could be reduced, so that the new component has a weight of only one ninth compared to the original design.

Allowing for the small wall thicknesses of 0.5 and 1 mm with high manufacturing precision, a special device concept has been developed, making it possible to laser weld with an integrated shielding gas guide. Process, machine and welding were inspected and approved according to the rules of the ESA.

After welding, the component was subjected to a heat treatment for stress-relief annealing so that it would comply with the tight tolerances concerning dimensional and shape accuracy. Thermal and mechanical properties, as well as the surface resistance, were improved by anodizing.

Applications

The development described here is a classic single-piece production process for space travel applications. It could be shown that this process makes it possible to produce other components for instruments and support structures under industry-specific requirements. For terrestrial applications, information was gained on material behavior, especially for welding thin-walled titanium pipes. Here, fields of application are, in particular, apparatus engineering and the design of centrifuges, where new potential solutions have been developed.

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1 View of the support from the lens terminal.

LASER WELDING OF STEELS WITH HIGH MANGANESE CONTENT

Task

Supra-ductile steels are able to absorb high energy under dynamic loads. This makes them ideal materials for the construction of components that provide impact protection in the automotive industry. In this context, twin-roll casting (TRC) is a cost-effective manufacturing process. High carbon content, segregation of manganese and inclusions are suspected, however, of limiting weldability of such steels. Therefore, the suitability for welding and mechanical properties of welded steels shall be tested using a butt joint.

Method

After the parameters and process guidance were set, the metallurgical effects and the mechanical properties were determined. The destructive test was carried out in a quasi-static and dynamic tensile test as well as in crash tests. The investigations were carried out on alloys with 17 and 30 percent mass fraction of manganese and 0.3 and 0.6 percent mass fraction of carbon.

Result

A study of 1.5 mm thick sheets showed that welding under the parameters for austenitic steels is possible. A root protection needs to be applied in order to achieve a high bead quality and to limit the burn-off of manganese. On the beam side, a local feed with inert gas is sufficient. Thus, the loss of manganese could be absolutely limited to 1 percent. The inner segregation of manganese is about 2 percent, wherein the manganese tends to segregate at the dendrite boundaries.

In the tensile test aluminum-alloyed grades broke outside of the weld seam. An aluminum-free alloy broke in the weld seam, and while the tensile strength was reduced by 50 percent, the fracture strain was preserved at 40 percent. After deformation under crash conditions, the weld seams showed no failure.

Applications

High ductility steels are primarily used in vehicle construction when deformation and strength of the overall structure have to be adjusted. In this context, crash boxes are two examples in automobiles and railroad cars. Also in building construction, these materials can be used for collision protection, e.g. for bumpers and guard rails. In connection with twin-roll casting, a resource-saving and energy-efficient component production can be set up when forming and welding lines are integrated downstream.

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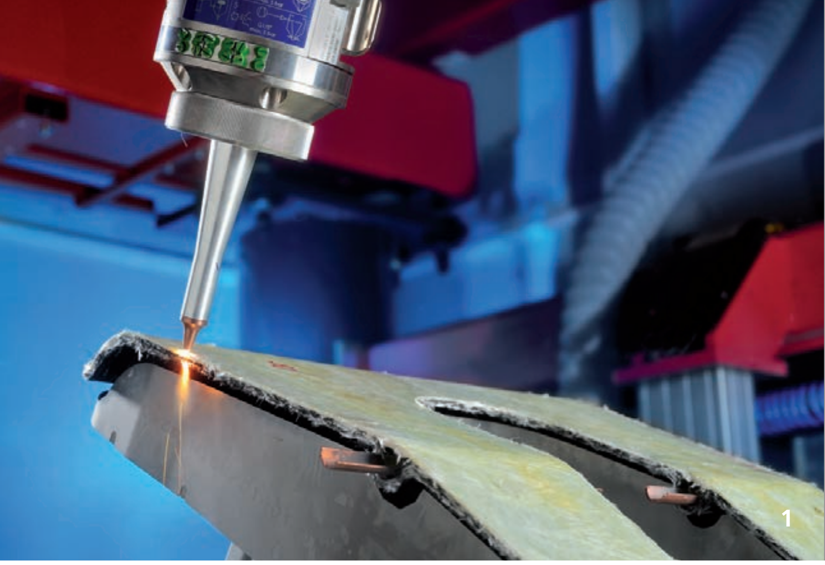
2 + 3 Structure and distribution of manganese in the weld.
4 Deformed sample of Fe-0.3C-18Mn-1.5Al.



WELDING AND CUTTING OF FRP COMPONENTS

Task

In Europe, all vehicle manufacturers have to reduce the average CO_2 emissions of their vehicles to under 95 grams per kilometer by 2020, which corresponds to a fuel consumption of about four liters of gasoline per 100 kilometers. Innovative lightweight concepts based on fiber-reinforced thermoplastics (TP-FRP) can make a significant contribution to achieving this goal. For such TP-FRP components to be used economically, however, production costs and production times need to be reduced significantly, while the component complexity is increased.

Method

With a new laser-based approach, an innovative process chain shall be implemented, which, having few process steps, will lead to quick, automated and mass production of structural components made of TP-FRP. First, an easily manageable 3D preform with adjustable fiber orientation is made in a fiber spraying process, then equipped with metallic inserts and subsequently consolidated by variothermal tooling technology. In the final process steps, the sub-components are laser welded to increase their stiffness and laser cut for trimming. Thanks to these technologies, an economical process chain can be created for lightweight components with high stiffness.

Result

Components were made for truck seats with the process chain described here. To increase the stiffness, the component was constructed of two shells and welded all around the edge with a diode laser and trimmed with a CO_2 laser along the weld edge. With line optics (spot ~ 1 x 10 mm^2) a process time of about 1.5 min has been achieved at a welding speed of 30 mm/s. The processing time is about 1.5 min for the cutting process in the 6 mm thick material (glass fiber/polyamide, fiber content 60 wt.-%).

Applications

The method demonstrated in this process chain for welding and cutting thermoplastic FRP components is an alternative to mechanical processing and gluing for the production of a widely variety of components and materials.

The work was supported by the Federal Ministry of Education and Research (BMBF) within the project »InProLight« (grant number 02PJ2070ff).

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1 Trimming of the component demonstrated.

2 Lightweight components of a truck seat.

LASER CUTTING OF FIBER-REINFORCED PLASTICS

Task

For fiber-reinforced lightweight components to find wider appeal in the industry, it is crucial that efficient process chains are developed to manufacture components made of these materials. Separation processes are often needed, both to cut the raw material and semi-finished parts as well as to trim the edges or cut holes of cured or consolidated parts in the final process steps. Laser cutting offers inherent advantages over mechanical separation processes or water-jet cutting thanks to its wear and force-free operation. The cutting process has to be designed, however, so that the thermal stress on the material at the cutting edge is minimal and the processing speed allows economical operation.

Method

Since there is such a variety of materials and ways of processing fiber-reinforced plastics, the cutting process has to be adapted to the specific cutting job. In particular, the absorption properties and thermal behavior of the materials, described by e.g. thermal conductivity and transition temperatures, require precise adjustment of the processing strategy. In reinforced fiber-glass or dry CFRP fibers, therefore, cutting is conducted in one step, while in the case of CFRP components, the cut kerf is formed in several cycles.

Result

The laser cutting process consistently produces high-quality cut edges. The use of lasers in the multi-kW range allows cutting speeds of several meters/minute. For example, a single-mode fiber laser can be used to separate components made of CFRP with 2 mm wall thickness at an effective speed of 15 m/min. The heat affected zone of the cut edge is < 200 µm.

Applications

As the aviation and automotive industry are increasingly using this material, they spur on the development of efficient methods for cutting holes and trimming edges of CFRP and GFRP. Production in machine and container construction, leisure and sporting goods can also profit from the laser cutting process for FRP.

The work was funded as part of the EU project »FibreChain«.

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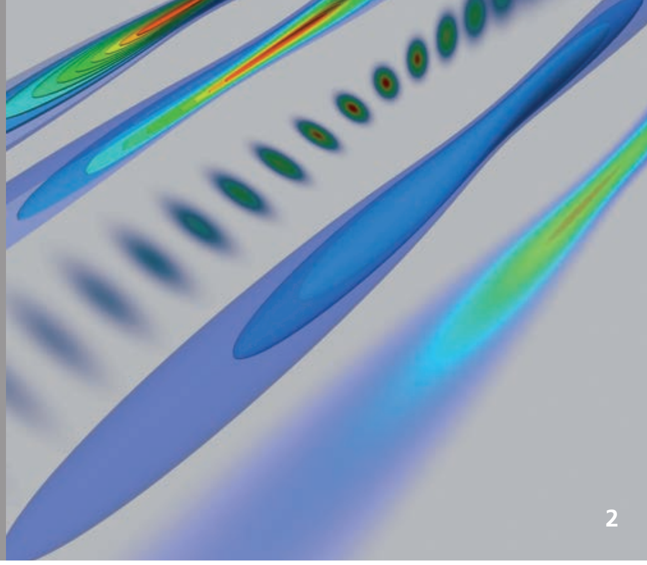
3 Laser cutting of glass-fiber reinforced plastics (GFP).

4 Cut edge of a CFP profile.



LASER CUTTING WITH ELLIPTICAL BEAM SHAPING

Task

Laser-based precision cutting plays a central role in the metalworking industry. Among the high-power lasers used are solid-state lasers that, when compared to CO_2 lasers, are considerably more efficient. They generate cuts in thick sheets with insufficient quality, however, owing to the unstable process. Research activities in this area aim to improve the quality of the cuts decisively by modifying the beam forming. The highest absorption of the radiation from solid-state lasers ($\lambda \approx 1$ µm) is achieved for metals at an angle of approximately 11° to the surface. If the cutting front is at this angle to the incident laser beam, not only is the energy insertion maximized but melt film dynamics are also stabilized. These dynamics reduce surface roughness and, thus, improve cut quality.

Method

Thanks to suitable beam forming, laser radiation can be better inserted into the material. In particular, by an elliptical intensity distribution in the beam focus, the desired inclination of the cutting front brings about an increase in absorption and, at the same time, a narrow kerf. In computer simulations of roughness formation, elliptical beams are tested with different ellipticity. Based on the results, an optical setup was designed and implemented, which generates a beam shape corresponding to the simulation and allows variable adjustment of the beam ellipticity. In cutting tests on 8 mm thick stainless steel sheets, a broad parameter range was investigated. Moreover, the process was observed with a high-speed camera to determine how the melt film dynamics are affected by the different beam formation.

Result

First experimental results already show that furrow and dross formation is reduced compared to comparable cuts with a symmetrical beam. Thanks to the process observation, the process could be better understood regarding the formation of melt film instability.

Applications

The results of this research are aimed at manufacturers of laser cutting systems and should increase efficiency and create more economical systems. The research was funded as part of the EU project HALO (High Power Adaptable Laser Beams for Materials Processing).

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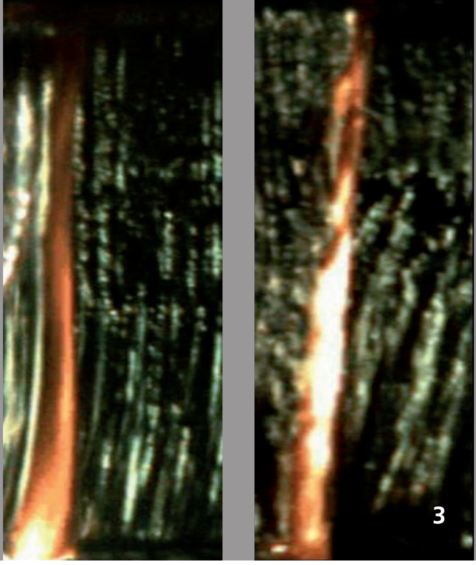
1 Observation of the cutting process with a high-speed camera.

2 Simulated shape and intensity distribution of an elliptical beam.



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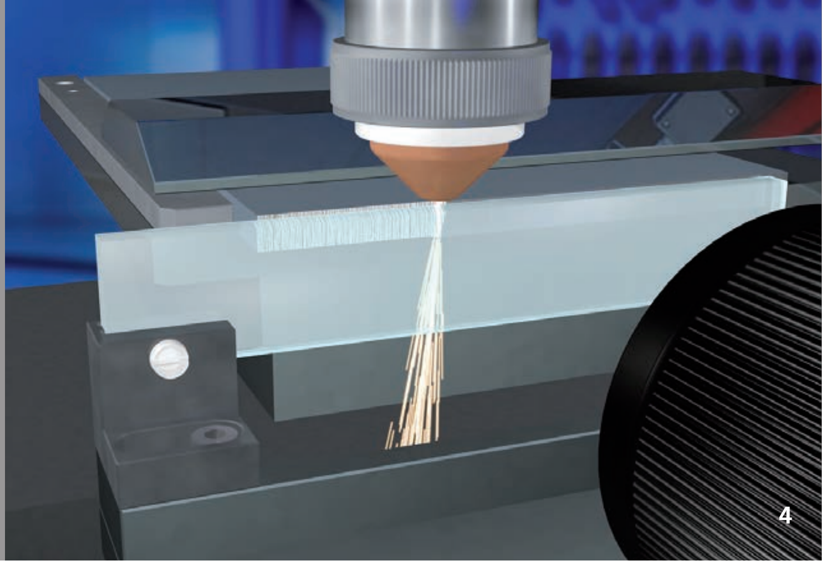

4

IN-SITU DIAGNOSTICS DURING LASER CUTTING

Task

Instabilities of the laser cutting front cause unwanted loss of quality in the form of material removal and solidification striations during laser cutting. They can also lead to the generation of dross. For in-situ diagnosis of the melting and solidification dynamics in laser fusion cutting, a trimming test bench was created in order to allow the cutting kerf to be observed optically during the process.

Method

During trimming, a cut is generated along an existing straight workpiece edge. The laser beam is displaced, relative to this cut edge, by less than a kerf width in the direction of the sheet metal. This process creates a half-cylinder shell-shaped cutting front as well as a new cut edge. Without additional measures, the cutting gas jet expands during trimming in the half space freed by the lack of a second cutting edge. To maintain a guided supersonic gas beam path along the melt film, the missing cut flank is simulated by a transparent replacement edge out of quartz glass. As the protective glass moves parallel to the cutting edge and a gap is clearly defined between the protective glass and cutting edge, both the thermal and the material impact of the protective glass can be reduced.

Result

The mobile trimming test bench can be used in different laser systems. Automatic linear axes are used to make it possible to vary the cutting speed for different material thicknesses, to move the protective window, to automatically adjust the beam displacement and, thus, the trimming width. During cutting, the normally inaccessible dynamic processes at the cutting front can be recorded with a high-speed video camera through the transparent protective glass.

Applications

The in-situ diagnosis of the processes involved in formation of the cutting edge serves as the basis for developing customized process parameters to reduce cut edge roughness while avoiding dross formation. In addition to improving the understanding of the cutting process, the collective findings will also benefit other melt-prone processes such as laser welding.

The work was funded by the German Research Foundation (DFG) as part of the Collaborative Research Centre 1120.

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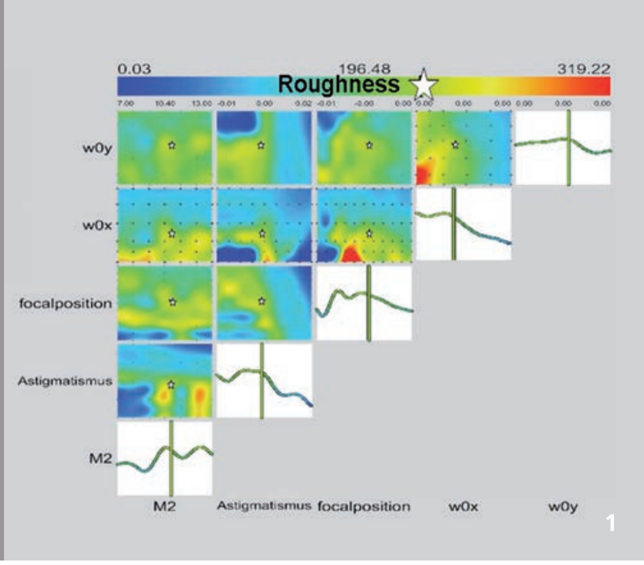
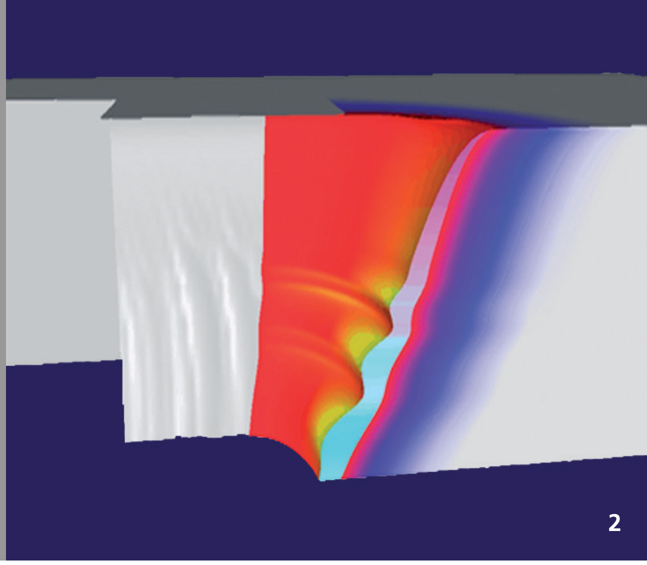
3 Photographs of trimming created with provisional test bench.

4 Design of a new automated trimming test bench.





METAMODELING AND PARAMETRIC OPTIMIZATION OF LASER CUTTING

Task

The parameters of an elliptic laser beam used for laser cutting and, consequently, the parameters of the beam-shaping optical system were the subject of a numerical analysis which aimed to optimize the design of the beam-generating optics in terms of cut edge roughness.

Method

The analysis began by creating a so-called multi-dimensional process map with the beam parameters of a laser beam with an elliptical intensity profile, which was done with the help of an already developed cutting model (see Figure 2). This was followed by a sensitivity analysis and an automated or optionally interactive search for optimum values in the parameter space. Exploring this five-dimensional parameter space examined in this case is unthinkable without the virtual process map. In cooperation with the Virtual Reality Group at RWTH Aachen University, Fraunhofer ILT has been working on a user-friendly, interactive display/visualization of the process map within the Cluster of Excellence »Integrative Production« (see www.production-research.de and Figure 1). This way, the technology can also be used for other laser manufacturing processes and even in real production environments.

Result

With the multi-dimensional, so-called process map, which contains the beam parameters of an elliptical beam, it is now possible to explore a continuous representation of how beam properties influence process properties (here: the roughness of the resulting cut edges). This process map is now initially available for the laser-cutting manufacturing process and, moreover, has already been used for the parametric design of a cutting optics in the EU-funded project »HALO« (see www.halo-project.eu). Optimal beam parameters were determined and used to design a new cutting optics.

Applications

The same procedure serves as an example for all laser manufacturing processes in which a parametric optimization is possible and useful. In addition, it is also desirable for processes for which an overview of the solution properties of the corresponding physical system needs to be generated.

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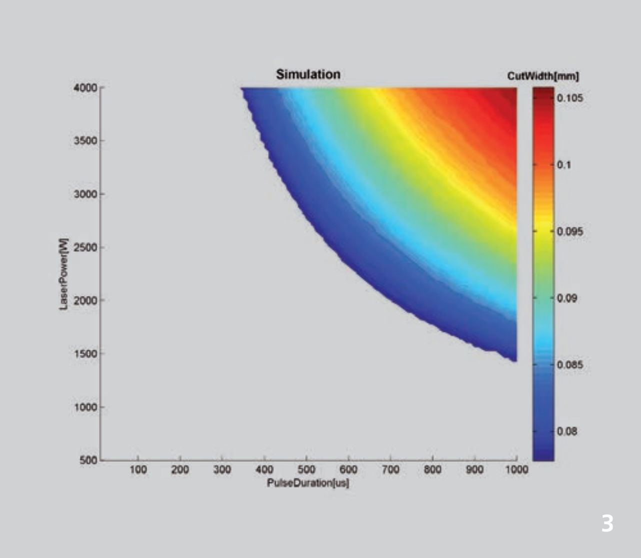
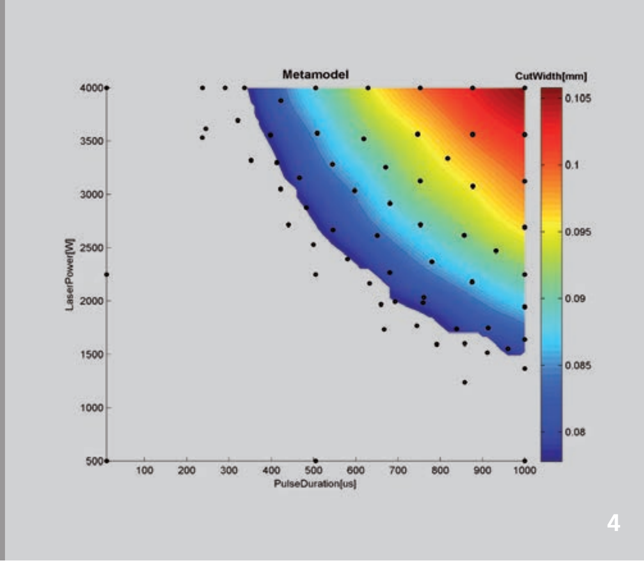
1 Process map of laser cutting generated by simulation.

2 Cutting simulation.





METAMODELING FOR ANALYSIS OF MULTI-DIMENSIONAL PARAMETER DEPENDENCIES

Task

The physical limits (e.g. the so-called cut-off during laser cutting) of laser manufacturing processes are, on the one hand, important to understand the process. On the other, they must also be recognized within the scope of numerical modeling. This way, models for representing parameter dependencies (so-called meta-models) and their analysis can restrict/focus on the physically and technically sensible range of parameter space, i.e. to the area where a cut is possible at all.

Method

Recognizing detection limits of processes has, therefore, been pursued in the context of meta-modeling, because it plays an important role in the sensing of the parameter space (the so-called sampling) by means of simulations or real experiments. This detection is iteratively operated during the scan of the parameter space with corresponding process simulations.

Result

Fraunhofer ILT has developed so-called smart sampling methods to scan, adapted to a process, the multi-dimensional parameter space of a laser manufacturing process. These methods are based on subdividing the parameter space according to the classification in feasible and non-feasible domains. Smart Sampling recognizes feasible domains automatically and will only increase sampling of the parameter space in them with simulations, thus ensuring an improvement of the model quality.

Applications

The procedure of Smart Sampling developed here is applicable to all purposes of the »design of experiments« (DOE), whereas numerical experiments are also to be understood as experiments.

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3 Simulation forecast made out of 10,000 numerical simulations.

4 Metamodel forecast made out of 65 sampling points (black dots).

LASER-BASED EQUIPMENT ASSESSMENT

Task

In their laboratories, technicians and scientists in both industry and research frequently demonstrate new approaches to current issues in the field of laser-based manufacturing. Many of these approaches are technologically promising, while their implementation is associated with significant economic risk. Often such approaches never leave the status of laboratory experiments due to undetermined risks and a lack of proven market potential.

Method

When a strategic approach is designed and applied to systematically monitor and guide the technology development process, it has potential to minimize these risks and ensure success.

All relevant stakeholders need to participate in this process, each playing an essential role from demonstrating the functional principle at the laboratory bench through to validating a prototype in an industrial environment. Consisting of the supplier of the prospective solution, the user and the research partners, a team conducts a so-called laser-based equipment assessment (LEA). During the assessment, the team identifies the requirements for the equipment's use in production, the steps required to implement the necessary development steps and compares the results achieved continuously with the target definition.

1 Beam splitter for process monitoring.

Result

Under the umbrella of LASHARE, fourteen individual laser-based equipment assessments (LEAs) were conducted. In the four phases of the Assessment Circle, the team created a prototype aligned to the needs of the user, which was verified scientifically by the research partner and validated by the user in a robust industrial environment.

Applications

The »Laser-based Equipment Assessments« have been designed and tested by the LASHARE consortium and, through an open call in spring 2015, will open up possibilities for new teams to carry out funded assessments. As a coordinator, Fraunhofer ILT is one of six European centers of excellence that offer laser-based equipment assessments.

The project is funded by the EU under the grant number 609 046.

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TECHNOLOGY FOCUS
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 micro-scopy. Optical systems for applications in EUV engineering are calculated, constructed and manufactured as well.

RESEARCH RESULTS 2014

LASER MEASUREMENT TECHNOLOGY AND EUV TECHNOLOGY

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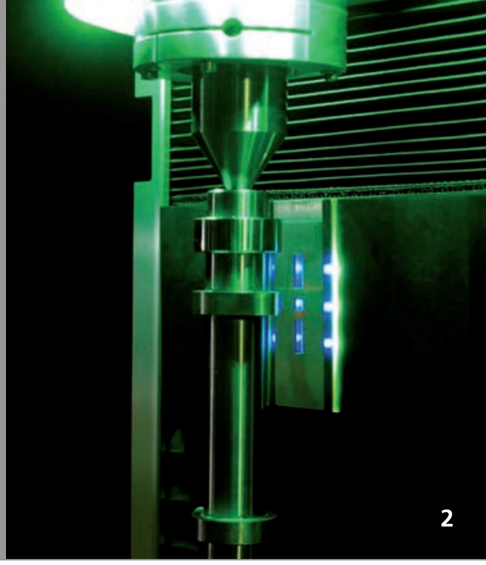
Inline measurements of shafts.



INLINE MEASUREMENTS OF SHAFTS

Task

As the demands upon the tolerances of shafts – camshafts, crankshafts or drive shafts – continue to increase, new optical sensors are required that check the dimensional accuracy of shafts in a production line both contact free and with sub-micron precision.

Method

As part of preliminary research, Fraunhofer ILT has developed the new interferometric sensor »bd-1«, which measures absolute values and overcomes the boundaries of conventional triangulation. The sensor has a compact rotationally symmetric probe with bi-directional beam control. The beam to the shaft and its reflection run along the same line. This offers significant advantages in terms of integrating these sensors into testing machines. Thanks to the interferometric principle, »bd-1« carries its scale quasi in itself, reaches maximum precision this way and provides high dynamics with respect to scattered radiation on the object measured.

1 Testing of geometrical tolerances on a camshaft.

2 Exhibit of Fraunhofer ILT at Control in 2014: camshaft measurement with »bd-1«.

Result

»bd-1« reaches a measuring frequency of up to 70 kHz and a measurement accuracy of better than 200 nm in a range of 8 mm. The measuring head has a size of, for example, 55 mm x 18 mm (L x ∅) and is connected to a measuring unit via a fiber optic cable. Due to its high dynamics, almost all types of metal surfaces, i.e. shiny, polished or rough, can be measured. In addition, »bd-1« can also capture roughness values. At the trade fair Control in 2014, the »bd-1« sensor was presented for the in-line testing of camshafts to a professional audience for the first time.

Applications

»bd-1« is predestined for the geometric inline measurement of metallic semi-finished products, such as all kinds of shafts, but also sheet metal, formed or stamped parts all the way to tools. Since it offers high accuracy and measurement frequency in a compact design, it can easily be integrated into processing or testing machines, thereby opening up a new level of inline inspection of geometrical parameters for efficient process control.

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

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IDENTIFICATION TESTING OF ROLLING BILLETS WITH SCALED SURFACES

Task

Even with highly automated production processes there is always a risk of mixing up different materials. In the production of steel ingots, several hundred different grades of steel are processed; when they are fed into the beginning of the rolling mill, they are controlled mostly manually, meaning that mix-ups cannot be completely ruled out. This may result in substantial economic losses, ranging from damage to tools in the production line to subsequent losses at customers. To recognize such mix-ups before processing begins, all the blocks used should be examined as to their chemical composition.

Method

Laser-induced breakdown spectroscopy (LIBS) has proven itself for the quantitative analysis of metals and material identification of semi-finished products, even under industrial conditions. The challenges in this project are the variety of materials and primary scale layer of the continuously cast billets, which thus have a non-representative surface layer. By using laser pulse repetition optimized for ablation, however, Fraunhofer ILT has been able to expose the base material locally and – in a further step, also laser-based – analyze it directly in the production line.

Result

In the laboratory, laser-induced descaling has been developed in view of the LIBS analysis and of reaching a reasonable ablation depth. Both the removal and the analysis are carried out with the same laser. With cycle times of less than one minute, the optical system has been adapted to the position of the billets and the verification testing has been performed. With a functional model, the procedure is being examined on location for its suitability, thereby helping ILT engineers and industrial partners gain valuable operating experience.

Applications

The primary application is the analysis of metal billets and other intermediate products with scaled surfaces in metalworking. Another field where the combination of ablation and analysis can be applied is measuring depth profiles of the chemical composition down to a depth of several mm.

The project was co-financed by the European Union and the Federal State of North-Rhine Westphalia.

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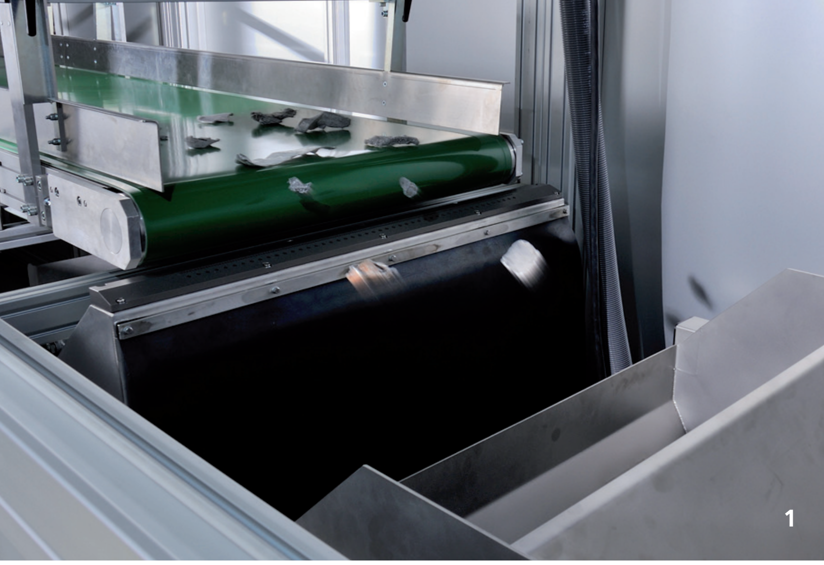
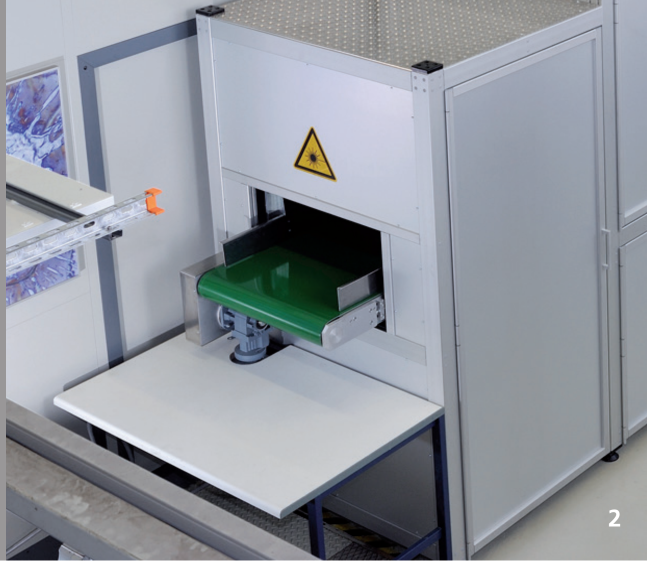
3 Section of a continuously cast billet with scaling.





HYBRID LASER IDENTIFICATION OF MOVING MATERIAL FLOWS – HYLIBS

Task

In order to mechanically recycle secondary raw materials and to extract mineral resources, the processing industry has to generate material flows having clearly defined compositions. The inline analysis needed for this, however, is only partially available. Fraunhofer ILT has developed an inline method for the direct laser analysis of moving objects; it has already been successfully tested for sorting flat production scrap metal. In order to make this method more economically attractive for other applications and to thereby open up further markets, it shall be transferred to material flows comprised of individual grains with any possible 3D geometry.

Method

In the project HyLIBS, laser-induced breakdown spectroscopy (LIBS) has been combined with a laser-light section measurement of surface geometry and optical detection in order to create an integrated process approach. Here, surface features of a moving stream shall form the basis for optimizing the measurement positions. The geometric information will be used to minimize the dependency of the analytical results on the material topography and to gain additional criteria for object classification.

1 Ejection of bulk material after the direct laser analysis.

2 iSort sorting plant.

Result

HyLIBS has made a laser-measuring method available which enables the inline analysis of economically important material flow rates, in particular of metallic shredder scrap. As it is a combined process with simple interfaces, customers can integrate it without significant development of their own into a process line. The solutions developed here were implemented in the iSort demonstration plant at Fraunhofer ILT.

Applications

Sorting based on LIBS is particularly suited to differentiating and classifying different materials in the shortest possible time thanks to a multi-element analysis. It can be used not only to segregate various metals such as steel, aluminum, copper, zinc, and titanium, but also to finely differentiate individual alloys. The new demonstration plant can be flexibly adapted to different materials so as to provide practical solutions for customized sorting tasks.

The work was supported with funds from the Fraunhofer-Gesellschaft.

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MATERIAL DETECTION FOR THE RECYCLING OF REFRACTORY MATERIALS

Task

Refractory materials are an essential element in all high-temperature processes and constitute a substantial global market. By recycling refractories, the industry can tap a great potential to prevent the generation of waste and to reduce the consumption of primary raw materials. Due to different thermal, chemical and mechanical stress, a variety of materials – primarily based on aluminum, calcium and magnesium oxides – are used in the processes. To ensure high-quality recycling and reuse of refractory materials, the various types need to be efficiently separated on the basis of their chemical composition.

Method

Together with European partners, technology is being developed to automatically sort refractory materials from steel production without crushing them. For the direct chemical analysis, the method of laser-induced breakdown spectroscopy (LIBS) is used to individually examine all refractory bricks with masses which can exceed 10 kg and to place them into the associated material category in the sorting machine.

Result

Thanks to the LIBS measurements, the main components of the materials can be directly identified for an initial screening stage. Further additives are also recognized so that it is possible to divide the materials into a large number of sub-classes. The LIBS measurements are done in less than a second and use a series of laser pulses in order to obtain representative results of the bulk material, even when surfaces are contaminated. The work in the project has shown that this identification is not possible with other measurement techniques under industrial requirements.

Applications

A LIBS-based sorting is particularly suited for differentiation and classification of different refractory materials in the shortest possible time by means of multi-element analysis. The method may be used also for other minerals and oxide materials.

This project is financially supported by the European Union and the Fraunhofer-Gesellschaft.

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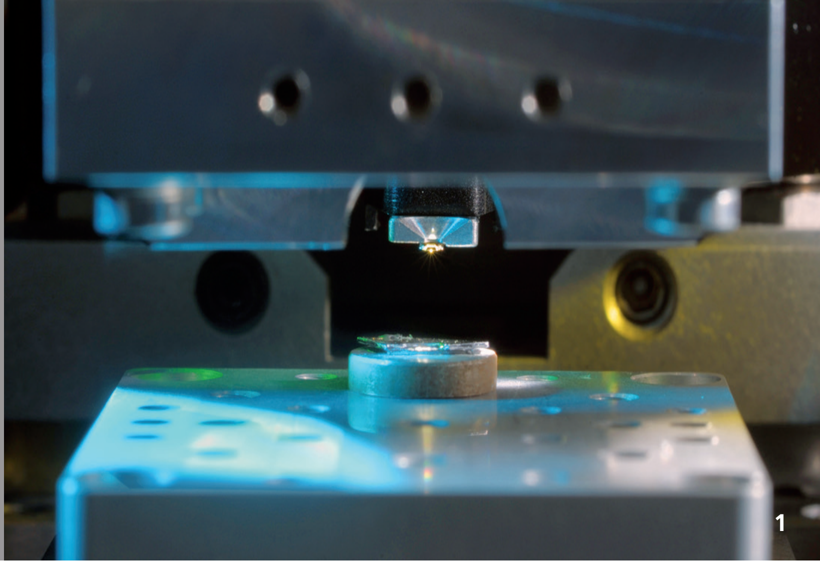
3 Various refractory materials.

4 Laser-direct analysis of a refractory brick.



NEAR-FIELD MICROSCOPY OF GALLIUM NITRIDE

Task

Gallium nitride (GaN) is considered to be a material difficult to produce and manage. Blue light emitting diodes are manufactured from it, and the scientists who developed them were awarded the Nobel Prize in Physics in 2014. Indeed, scientists and engineers worldwide are involved in analyzing and improving this material. In close cooperation with the I. Institute of Physics (IA) of the RWTH Aachen University, Fraunhofer ILT has developed an analysis methodology that enables the structural and electronic properties of gallium nitride and gallium nitride composites to be examined optically in the nanometer range, for the first time.

Method

The resolution of conventional optical microscopes reaches its physical limits with objects in the nanometer range. Small structures in the nanometer range, as they, among others, are found in advanced semiconductor devices, can no longer be resolved as isolated objects. On account of this shortcoming, optical analyses are no longer acceptable. The methodology of near-field microscopy overcomes this fundamental limitation and advances optically into the nanometer range. An IR-laser developed at Fraunhofer ILT enables engineers to make a detailed analysis of this material, GaN.

1 Near-field microscope.

Result

Coupled with the newly developed laser radiation source, the near-field microscope has allowed, for the first time, scientists to characterize several GaN wafers in cross-section with high-resolution. The relaxation of the crystalline structure along the growth direction could be examined in high resolution on an undoped GaN wafer. On a multi-layered wafer for LED production, it was possible to determine the doping of the individual layers as well as to show the smallest differences within the layers.

Applications

In close cooperation with the developers of new semiconductor devices, employees of Fraunhofer have developed a method which can help, for example, to selectively optimize the process parameters. At a very early stage of development, the physical processes, particularly at the interfaces of the individual layers, can be better understood thanks to the analysis. In the end, these findings may determine subsequent development steps decisively. In the field of high frequency and power electronics as well, the semiconductor material GaN is becoming more and more established due to its physical properties, and analytic processes in the infrared range using near-field microscopy are predestined for the study of these materials.

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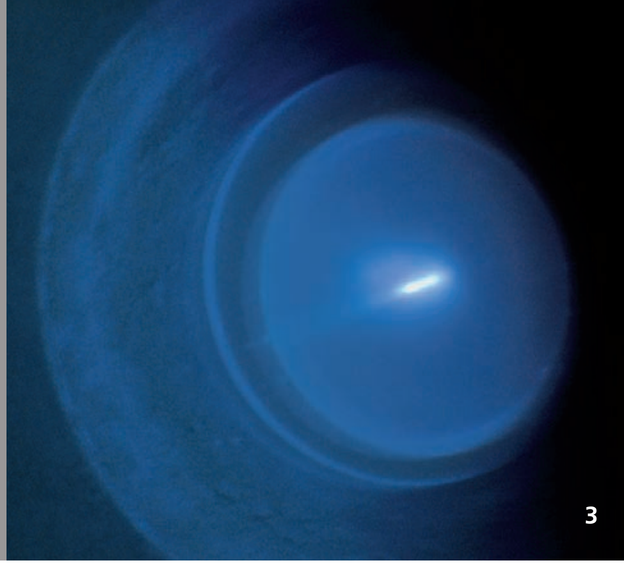

RADIATION SOURCES FOR THE NEXT GENERATION OF LITHOGRAPHY IN THE EXTREME ULTRAVIOLET [EUV]

Task

In addition to the EUV sources required in lithography for the production of the next generation of computer chips, such sources are also needed for metrology. This field requires preferably inexpensive and compact radiation sources that, nevertheless, exhibit a high power density and brilliance. Particularly in metrology and the technology development for lithography, the possible applications use a central wavelength around 6.x nm, which is considered a possible successor to the currently examined technology at an operating wavelength of 13.5 nm. To date, compact EUV sources for 6.x nm are not available.

Method

In the past, Fraunhofer ILT developed a compact, discharge-based system, which has been commercially available since 2013 and is used at 13.5 nm in applications supporting EUV lithography. In the conceptual design, a gas is so strongly compressed and heated by an electrically pulsed current of a discharge that characteristic radiation is emitted. There are few restrictions with respect to the working gas, thus resulting in a high spectral emissivity. Current studies are exploring the potential of this concept in terms of the efficient excitation of radiation at 6.x nm.

Result

By using krypton as the working gas and adjusting the discharge parameters, Fraunhofer ILT has generated photon fluxes that have made first applications possible, for example, the characterization of optics. Repetition rates reached so far are up to 1,000 Hz in steady operation. In the spectral range between 6 nm and 7 nm, values of 15 W / (2π sr) are currently reached.

Besides the use of krypton, nitrogen (intensity of the emission line at $\lambda = 2.88$ nm at 15 W / (2π sr)) and xenon (40 W / (2π sr) @ 13.5 nm +/-1 %) can also be used as working gases.

Applications

- Mask inspection for EUV lithography
- Technology development in the EUV environment, e.g. resist development, characterization of optics
- EUV-based metrology for nanosciences

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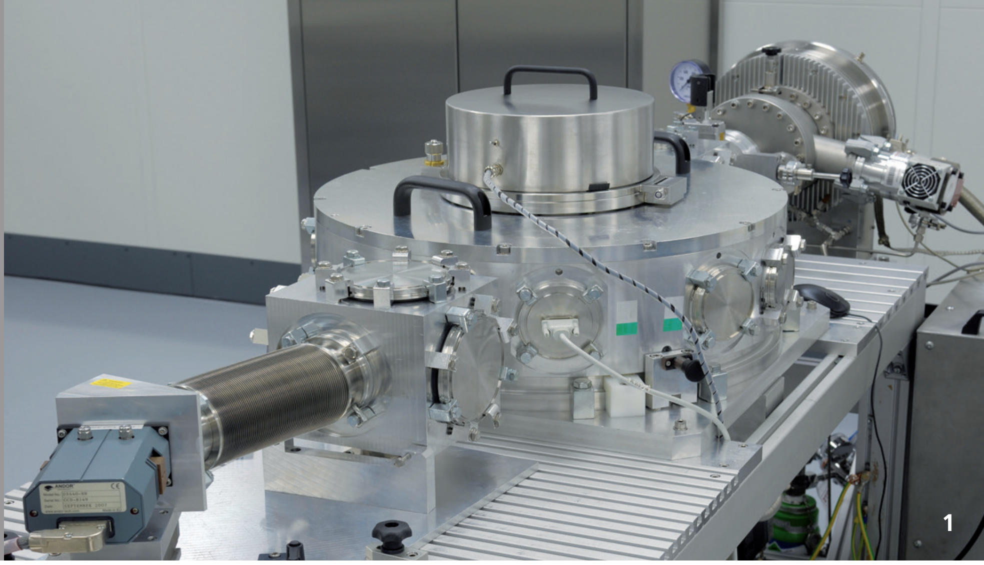
2 Radiation source for extreme ultraviolet light.

3 Photograph of the pinch plasma (VIS) of the EUV radiation source.



EUV REFLECTOMETRY TO CHARACTERIZE THIN FILMS

Task

Angle-resolved reflectometry in grazing incidence using polychromatic, extreme ultraviolet (EUV) radiation in the range 5-40 nm allows thin layers to be characterized with nanometer precision. Composition, thickness and surface roughness of a layer system can be indirectly identified from its reflectivity. Previously, such measurements were only possible with costly synchrotron-based radiation sources, where the wavelength and the angle of incidence have to be varied stepwise with long measuring times of several hours.

Method

EUV light of a polychromatic plasma source is used to measure wavelength and angle-resolved spectra. These spectra are detected with a spectrograph before and after reflection on the sample in order to obtain the reflectivity of the sample from the ratio of the spectra. Thanks to an additional mirror, mounted in parallel to the sample on a common rotary table, different angles of incidence can be compensated for. The properties of the sample can be determined through the modeling of a layer system and the step wise convergence of the modeled reflectivity spectrum to the measured spectrum. The typical measurement duration amounts to several minutes.

Result

The method has been used on various industrially relevant samples. For this purpose, samples of HfO_2 with different thicknesses on a silicon substrate were examined. The variation in the layer thickness produced – between 1 nm and 9 nm HfO_2 – could be detected with this method as well as a parasitic SiO_2 interlayer with a thickness of 0.2 nm.

Applications

The newly developed method for angle-resolved measurement of reflectivity is particularly suitable for applications in the silicon-based semiconductor industry, since the spectral range of the plasma source is tailored to the silicon L-edge at 12.4 nm.

The work was funded within the EFRE Program (»Regionale Wettbewerbsfähigkeit und Beschäftigung 2007-2013«) for the State of North-Rhine Westphalia under the grant number 300169702.

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1 Reflectometer.

TECHNOLOGY FOCUS
MEDICAL TECHNOLOGY AND BIOPHOTONICS

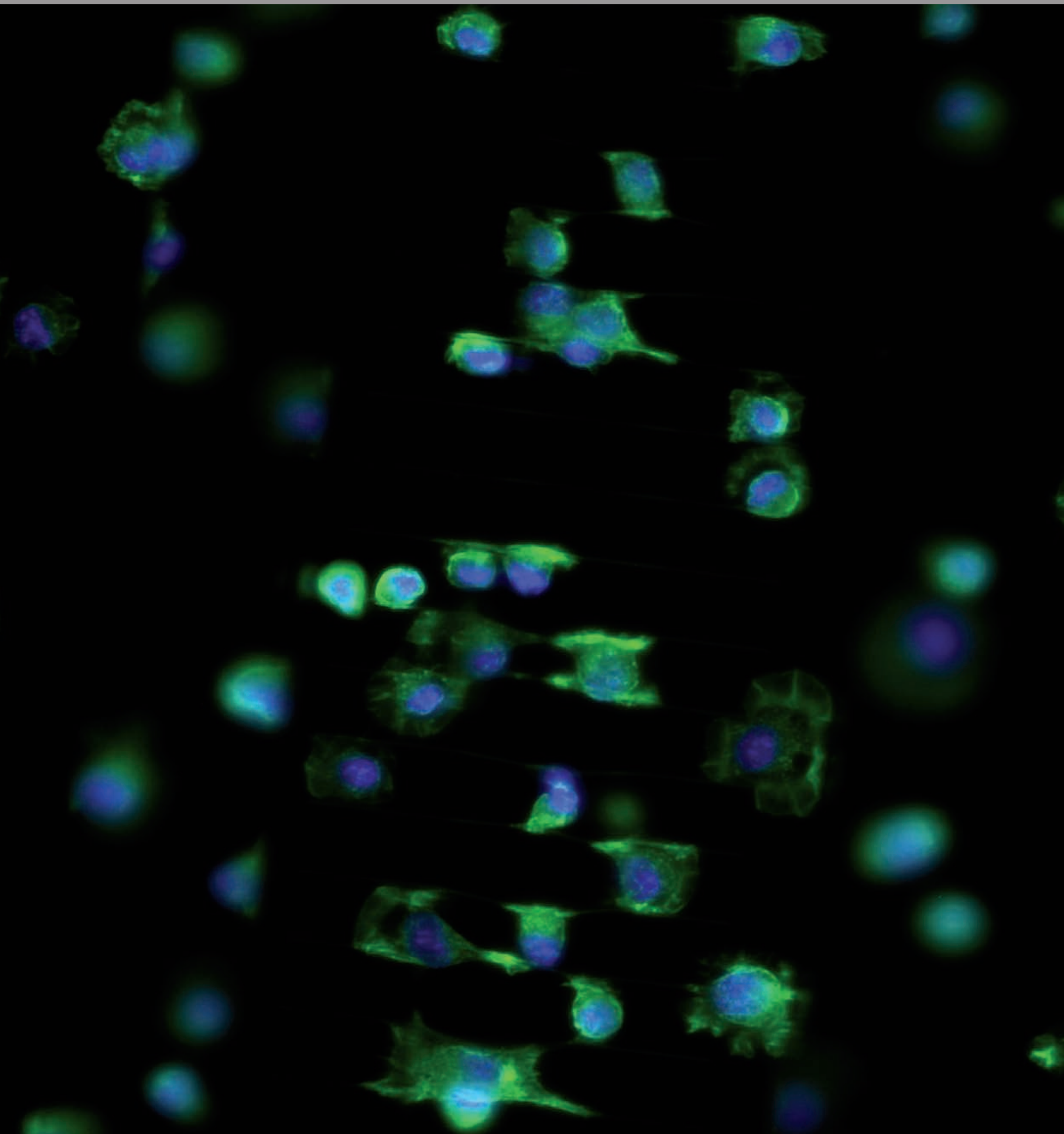
Together with partners from the Life Sciences, the technology field Medical Technology and Biophotonics opens up new areas of applications for lasers in therapy and diagnostics as well as in microscopy and analytics. The process Selective Laser Melting, developed at the ILT, allows implants to be generated, 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.

RESEARCH RESULTS 2014

MEDICAL TECHNOLOGY AND BIOPHOTONICS



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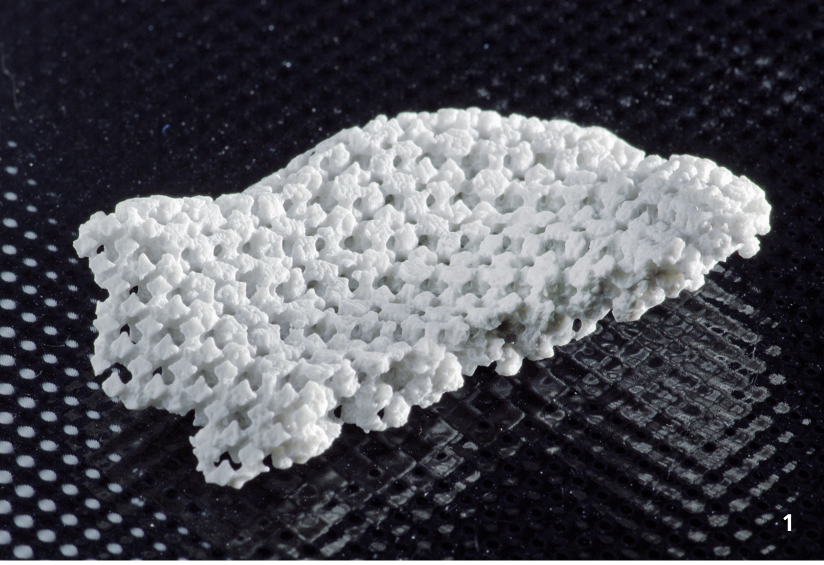
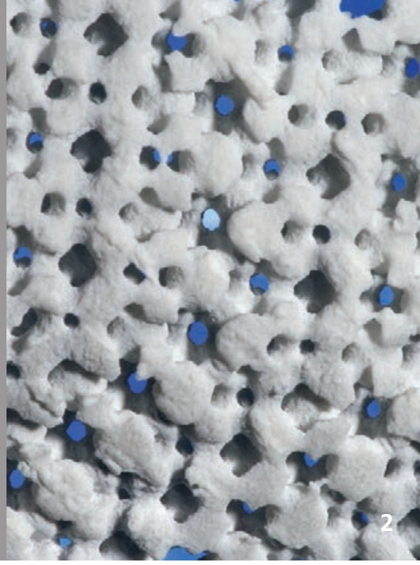
Fluorescence image of cells growing on protein fibers (green: cytoskeleton, blue: nuclei).





SELECTIVE LASER MELTING OF POLYMER-BASED BIORESORBABLE IMPLANTS

Task

Composites made of polylactic acid, β-tricalcium phosphate (β -TCP) and calcium carbonate can be used to manufacture bioresorbable bone replacement implants with controllable resorption kinetics and adjustable mechanical properties. So far, however, there has not yet been a shaping production method that enables the manufacture of patient-specific implants with an interconnecting pore structure so as to optimize the ingrowth of the bone. In the future, Selective Laser Melting (SLM) could make the production of such customized implants possible. Fraunhofer ILT can already process a composite material of polylactic acid and β-TCP by means of SLM on a laboratory scale. Since the build-up rate achieved is currently too low for the industrial to implement the method, however, it is attempting to increase productivity.

Method

To increase the build-up rate, SLM process and material have been specifically matched to each other. For the process, the SLM process parameters (e.g. scan speed and laser power) have been varied and adapted to the material. For the material, the filler and the polymer chain length have been varied to improve the processability of the material.

Result

By suitably adjusting the SLM process parameters and the material composition, the institute has achieved a 14-fold increase in the real build-up rate. In this case, for simple specimens, a part density of > 95 percent was reached. In addition, complex geometries with an interconnecting pore structure were produced. In the next step, the material shall be improved by the addition of buffering-capable calcium carbonate to neutralize the acid degradation products of the polylactide.

Applications

The method can be used for the production of patient-specific bioresorbable bone replacement implants, whereby the main application field is the maxillofacial area.

The work was carried out within the framework of the project »ActiveBone«, funded by the BMBF (Federal Ministry of Education and Research) on behalf of EOS GmbH, SCHAEFER KALK GmbH & Co. KG and Karl Leibinger Medizintechnik GmbH & Co. KG.

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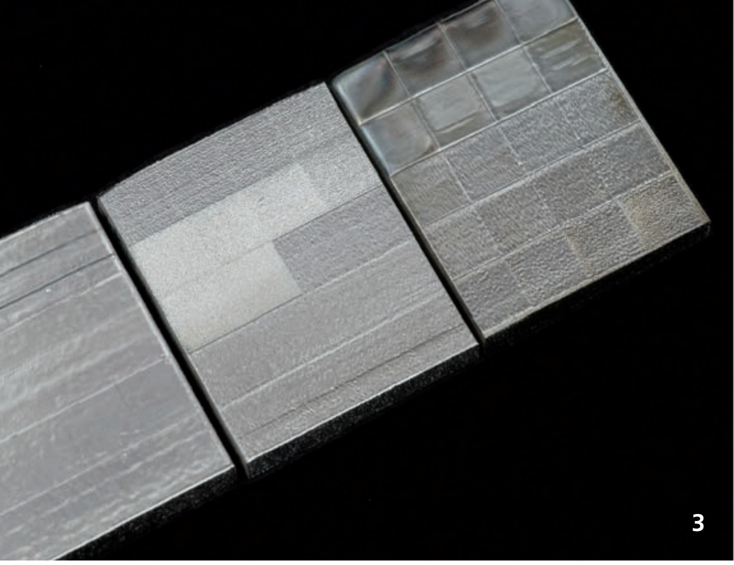
1 Bioresorbable skull implant manufactured with SLM (Ø approx. 65 mm).

2 Detail photograph of an interconnecting pore structure (Ø pore channels: 0.7 mm).



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IMPLANT MANUFACTURE OUT OF COCR BY MEANS OF SLM AND LASER POLISHING

Task

In recent years, there has been a steady increase in operations to implant knee prostheses. Compared to standard knee prostheses, patient-specific knee prostheses have advantages with respect to their life and functionality. Thanks to modern imaging techniques such as CT, MRI or US combined with a personalized biomechanical simulation, an individual knee joint can be reconstructed. Today, most knee implants are made of CoCr by casting and additional machining. The functional surface (sliding surface on the femur) is mainly hand polished. A new approach to better solve this task is the combination of the additive manufacturing process SLM with the post-processing by laser polishing. To produce tailored knee implants, the specific task, then, is to create an SLM process control with subsequent post-processing by means of laser polishing for CoCr according to the ASTM F75 standard.

Method

In the first step, process parameters have been developed to process CoCr using SLM and reach a density of > 99.8 percent, and to significantly improve the surface quality of the SLM prostheses by the adjustment of process parameters in contour area. In the second step, the process parameters for laser polishing have been developed and transmitted to the relevant 3D geometry of the sliding surface of a knee prosthesis.

Result

Fraunhofer ILT has identified the process parameters for SLM that result in a density of $\rho \geq 99.8$ percent and a mean surface roughness of $Ra < 7$ µm. These parameters were used to produce a knee prosthesis with a standard size by SLM. Furthermore, process parameters were determined for laser polishing SLM samples made of CoCr. After this polishing step, the average surface roughness is $Ra < 0.3$ µm. This example has, therefore, demonstrated that these methods are feasible for the production and post-processing of implants made of CoCr.

Applications

The project was conducted within the scope of the NRW-funded project »RapidGEN«. The current research on the SLM processing of CoCr addresses prosthesis manufacturing in medical fields and can be transferred to other applications that use CoCr as the working material.

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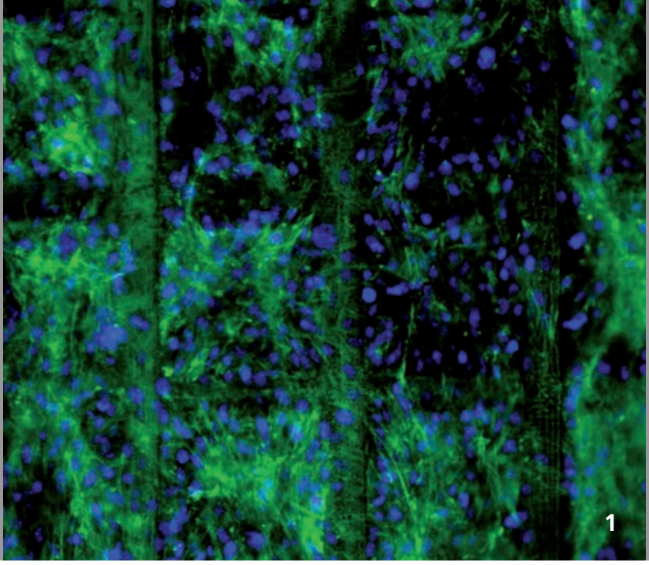
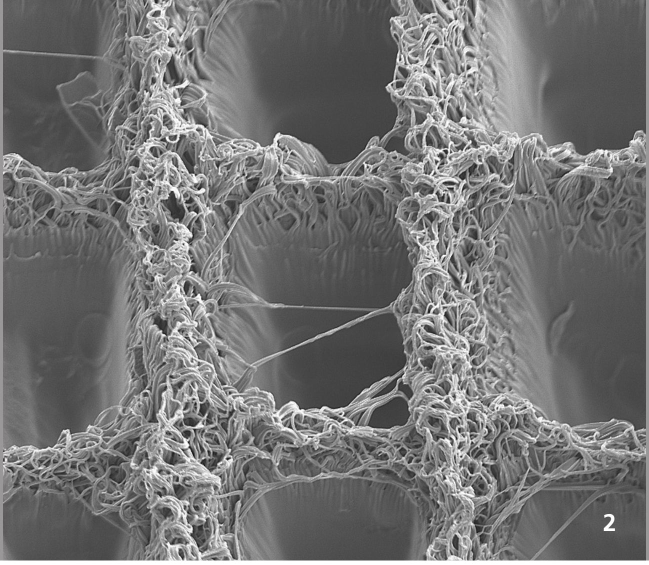
3 Laser-polished SLM sample out of CoCr.

4 SLM-manufactured knee prosthesis, sliding surface partially laser polished.





BIOCOMPATIBLE PHOTORESIN FOR STEREOLITHOGRAPHY

Task

Tissue engineering is a field of science that, by combining cell biology, generative process technologies and chemical material development, can replace or repair biological tissue. One approach tissue engineering takes is the additive manufacturing of scaffolds, which are seeded and cultivated with the body's own cells. Through the use of mechanical and biological stimuli, artificial tissue-like structures can be produced. The challenge is to create skeletal structures that meet the specific requirements in terms of mechanical stability, elasticity and biocompatibility. At the same time 3D freeform shapes have to be produced, tailored to the patient with resolutions in the range of ~ 10 µm.

Method

By using local photochemical polymerization, Fraunhofer ILT has built 3D polymer components layer by layer. The monomers here are linked together via thiol-ene click chemistry, whereby the use of potentially cytotoxic factors, e.g. photoinitiators and absorbers, can be minimized. Elastic 3D polymer components, which swell upon contact with water, can thus be manufactured by means of lithography-based 3D printing processes, such as digital light processing (DLP) or stereolithography (SLA).

1 Light microscopic fluorescence image of a cell-populated scaffold (green: cytoskeleton, blue: cell nucleus).

2 SEM image of a biocompatible scaffold.

Result

Fraunhofer ILT has developed a photoresin for the additive manufacturing of biocompatible and elastic polymer 3D freeform shapes. Thanks to proliferation and cytotoxicity assays, the biocompatibility of the polymers has been demonstrated, and after coating with poly-L-lysine, cell adhesion of fibroblasts was shown at the surface.

Applications

The new material can be used primarily in the production of scaffolds for implants and cell assays. In addition, the material and technical investigations form the basis for a new class of stereolithographically processable materials for technical applications.

The project was financed by the Exploratory Research Space of the RWTH Aachen University and the Hans Hermann Voss Foundation.

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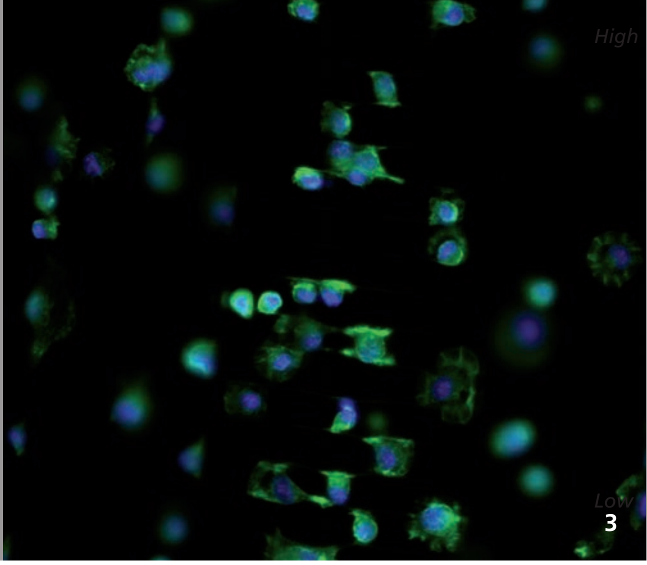

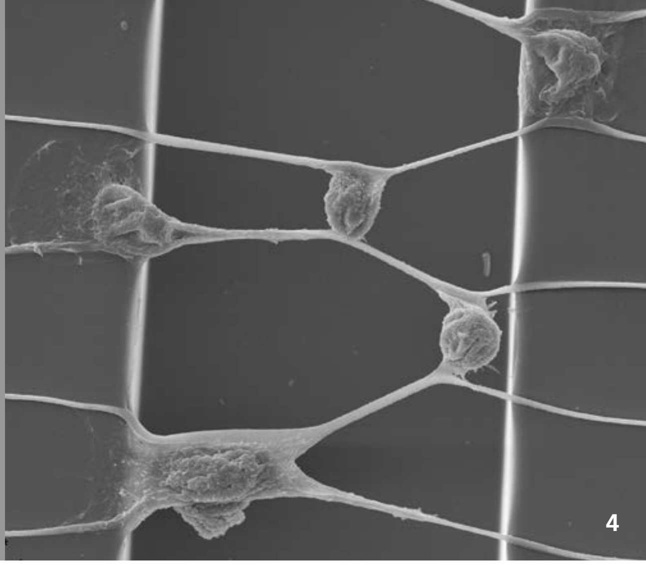

DEFINED MICRO-ENVIRONMENTS FOR 3D CELL CULTURES

Task

Today, cell-based biological studies are mainly carried out on hard two-dimensional surfaces, such as a Petri dish. However, this environment does not match the natural environment of cells in living organisms, which are embedded in a dense network of extracellular matrices and cells. This three-dimensional environment fulfils diverse tasks, which range from the supply of nutrients, to cell-cell and cell-matrix communication all the way to physical stimuli. The study of these complex interactions is necessary to understand basic biological contexts, which, for instance, can enable the development of novel drugs for the treatment of cancer. Thanks to these studies, a defined three-dimensional cell microenvironment has been developed, thus providing researchers with a decisive advantage.

Method

To create defined microenvironments, Fraunhofer ILT is researching the two-photon induced crosslinking of synthetic and natural polymers. This technology allows the generation of three-dimensional crosslinked structures from a variety of photosensitive materials, ranging from elastic to inelastic functional polymers all the way to biomaterials, such as proteins. The achievable resolution lies in the micro- to submicro range and hence one to two orders of magnitude under the typical size of a cell.

Result

Two-photon technology can be used to create protein microstructures with high resolution. An example of application can be freely suspended protein microfibers with a width of approx. 0.5 µm and a height of 2 µm. These protein microfibers may additionally be chemically functionalized. Thanks to such protein microfibers, scientists can examine how cells mechanically interact with protein networks, an aspect which, among others, influences metastatic spreading of tumor cells.

Applications

This technology can be used in the area of 3D cell cultures, from the research into basic mechanisms to drug development, as well as in tissue engineering.

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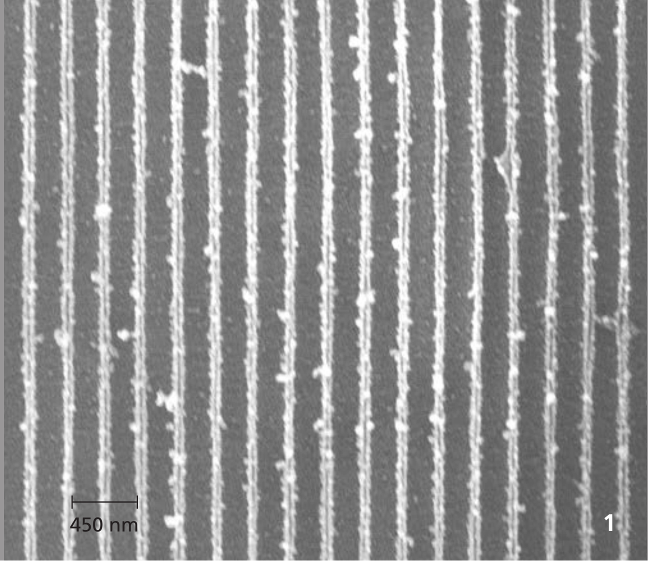
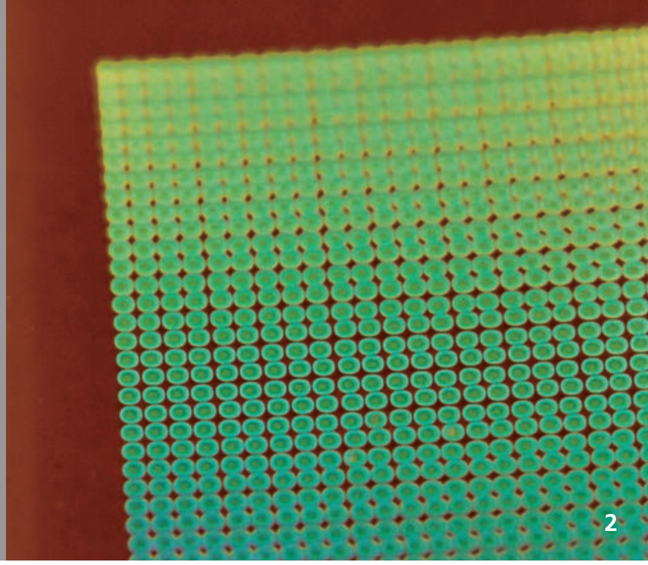
3 Fluorescence image of cells growing on protein fibers (green: cytoskeleton, blue: nuclei).

4 SEM image of protein microfibers spanned across gaps on which cells grow.





NANOSTRUCTURING WITH A MULTI-BEAM INTERFERENCE PROCESS

Task

Functionalized surfaces with structures in the nanometer range are of great interest for many applications. As an example, antireflection layers in particular require a structural size below the wavelength of visible light. Generating such structures is, however, very costly since their production is typically based on complex, multi-stage lithographic processes. Direct multi-beam interference ablation, however, makes it possible to reach significantly more cost-effective, direct nanostructuring without further process steps.

Method

To structure a surface, multi-beam interference uses an intensity modulation in the superposition of two or more coherent partial beams of a laser. The periodicity of the corresponding pattern can be flexibly adjusted by the angle of incidence of the partial beams and lies in the range of the wavelength used. In this technology, the structure size is not diffraction limited so that structure sizes below the wavelength used are possible. In the results presented here, Fraunhofer ILT used a UV-ns laser with a two-beam interference setup. At an incidence angle of about 50°, the interference pattern has a periodicity of 230 nm, which is transferred in a polyimide surface by laser ablation.

1 SEM image of a nanostructured surface.

2 Macro image of a structured sample.

Result

With this multi-beam interference technique, deterministic nanostructures could successfully be introduced directly into the plastic in a simple process step. The structures shown in the picture were simultaneously generated with a single nanosecond pulse that has a spot diameter of 700 µm. The generated structures have a line structure with a ridge width in the 100 nm range and with a maximum depth of 120 nm.

Applications

The work presented here focuses on generating cell guiding structures for bone marrow, blood and induced pluripotent stem cells (iPSCs) within the DFG research priority program SPP1327. Thanks to its cost-efficient, flexible nanostructuring, this technology lends itself to other potential applications in optical functionalization, such as the antireflection coating of surfaces to increase input or output efficiency.

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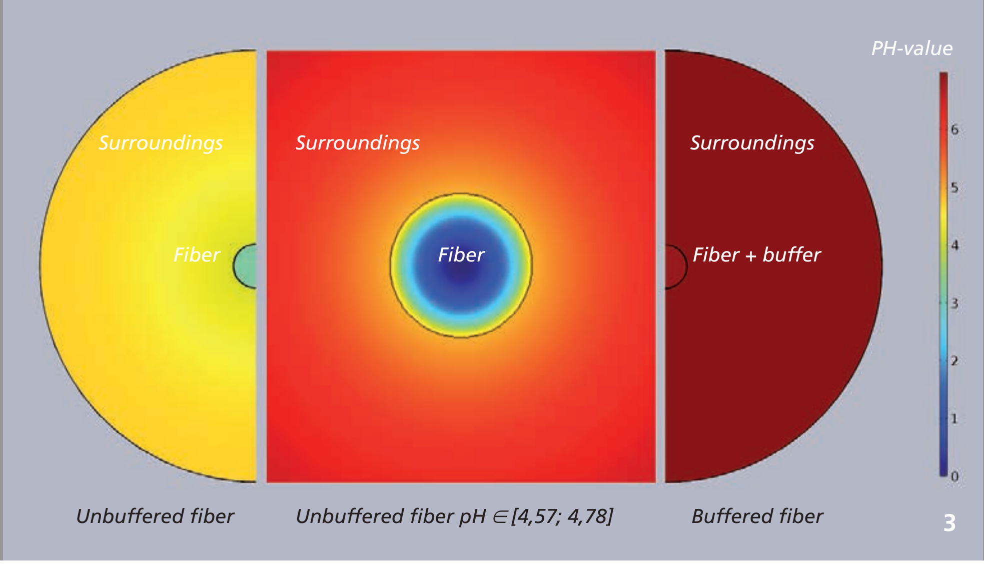

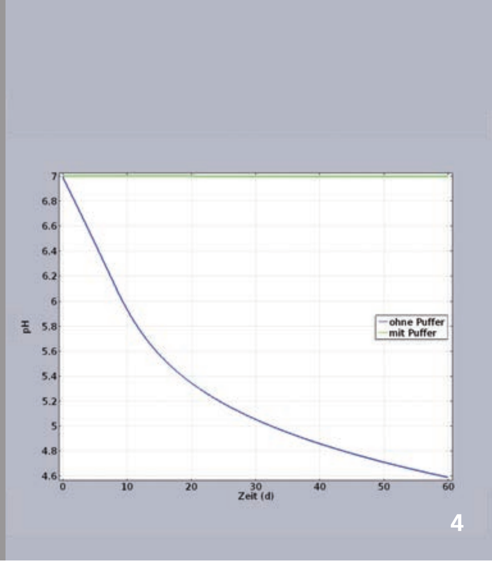

SIMULATION OF PH-BUFFERED BIODEGRADATION

Task

Biodegradable polymers play an important role in medicine for implants, sutures or support structures, since, among other things, their use can make secondary surgery – to remove the foreign body from the body – unnecessary. When pure polymers are used, their decomposition leads to a large drop in pH in the vicinity of the polymer, which means difficulties for complication-free healing and should be prevented by the addition of chemical pH buffers. Modeling and simulation of the processes is a promising tool to reduce the large number of necessary experiments and, thus, to minimize animal testing.

Method

The decomposition of the polymers can be described by a system of rate equations in which the temporal evolution of their concentration is given for each molecule size traversing the polymers in their decomposition. In the course of degradation, the concentration of the molecules with a small size increases, those which have a higher mobility and diffuse into the environment. Due to the cleavage of positively charged hydrogen, these short-chain molecules cause the pH levels to drop. The binding of the positively charged hydrogen in the pH buffer molecules occurs on a small time scale. Therefore, the equilibrium state of the reaction buffer can be calculated at any time during the degradation.

Result

The result indicates the pH value as a spatially two-dimensional distributed quantity for a polymer fiber with pH buffer content and its surroundings as a function of time. The simulation tool is available to assess the impact of concentration and distribution of the pH buffer in the fiber on the pH value in the vicinity of the fiber.

Applications

In the project (pH)aser, funded by the Exploratory Research Space at the RWTH Aachen University, pH-neutral degradable support structures are being examined for use in cardiovascular vessels (stents). Other applications include the optimization of implants, sutures or support structures in tissue engineering processes.

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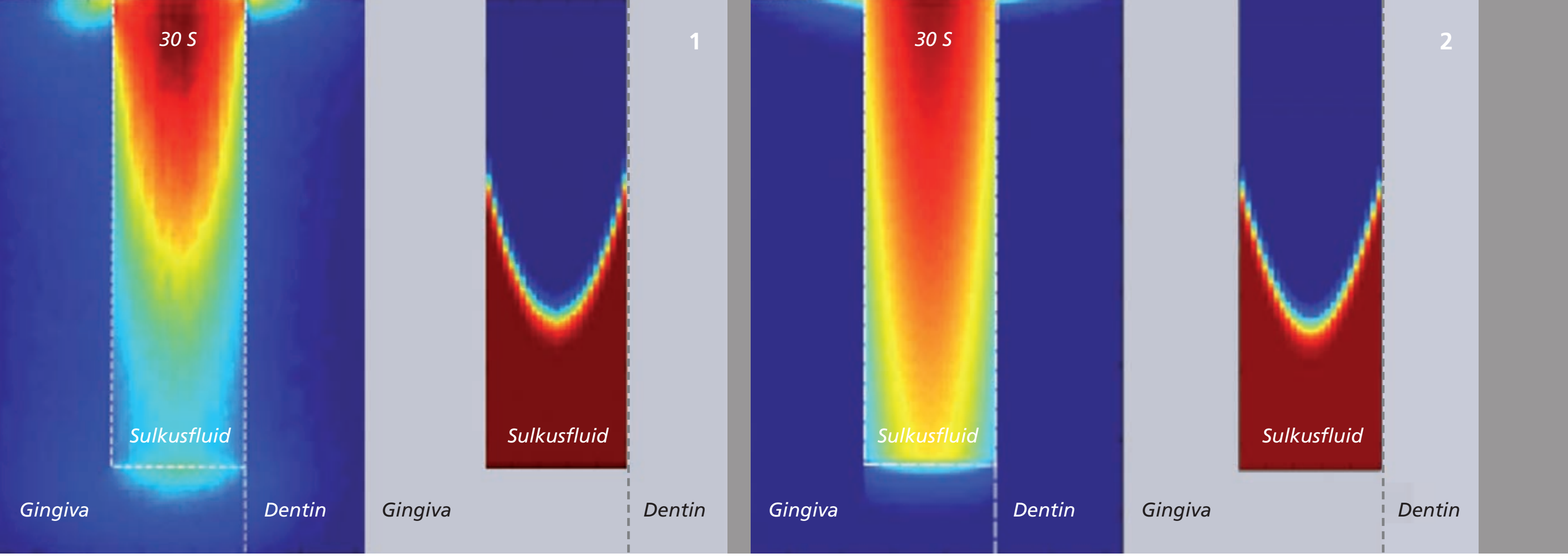
2 Distribution of the pH value in the fiber and its surroundings after 60 days of degradation.

3 pH value in the surroundings of the fiber in elapsed time.



SIMULATION OF ANTIMICROBIAL PHOTO-DYNAMIC THERAPY

Task

Antimicrobial photodynamic therapy (aPDT) can be an effective way of treating local bacterial infections, but whose further development is inhibited because therapeutic success cannot be observed during and immediately after treatment. Mathematical models and their numerical implementation represent a promising tool to identify measurable quantities in order to observe the course of therapy.

Method

Fraunhofer ILT has already developed a simulation code that describes the physical and chemical processes occurring in aPDT. Mathematical model reduction is being used to improve this code to such an extent that many simulations are feasible at an acceptable computational cost. By making use of those simulation runs, scientists can develop strategies to observe the desired treatment progress.

Distribution of intensity and successfully treated area
1 ... from the numerical model after 30 s.
2 ... from the reduced model after 30 s.

Result

The result consists of a spatially two-dimensional dynamic model, which describes the time-resolved propagation of the successfully treated area. The results show that the distribution of the laser intensity (as an initiator for the chemical reactions) and the flow of the chemical reactions (by changing the optical properties) are mutually dependent upon each other. In comparison to the existing numerical model, the reduction is such that the coupled processes between beam propagation and chemical reactions are resolved in one-dimensional strips, which are joined to form a two-dimensional simulation subsequent to the calculation.

Applications

The model Fraunhofer ILT has developed is oriented toward treating periodontitis with aPDT. Other promising applications are the treatment of wound infections or of local infections with multiresistant bacteria, photodynamic therapy for tumor treatment as well as photo-immunotherapy, by which the active ingredient is bound to the target cells by antibodies.

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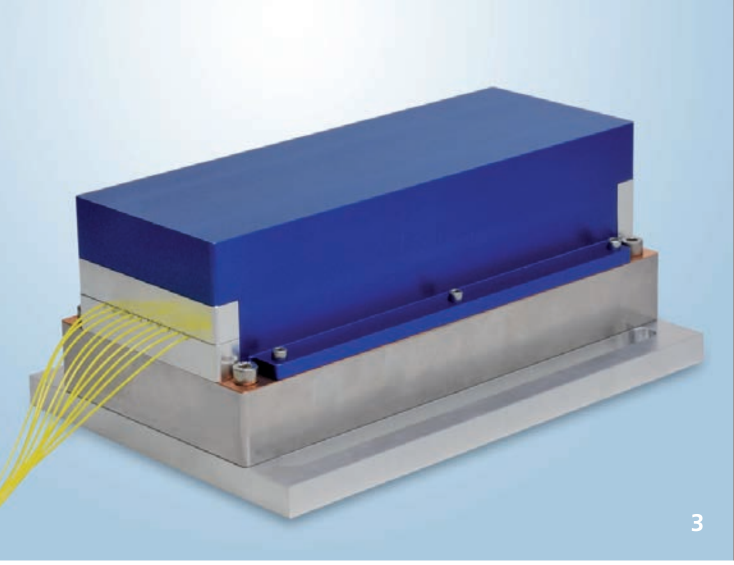

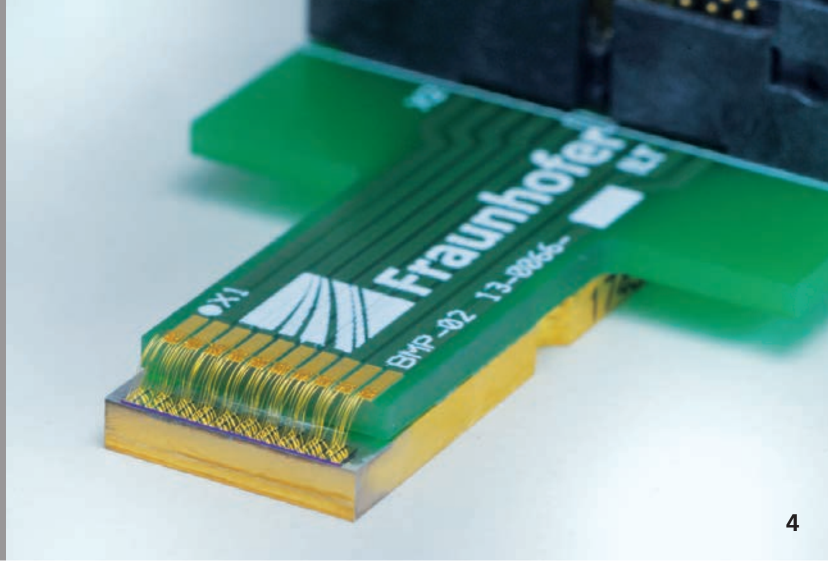

DIODE-LASER MODULE WITH TEN INDIVIDUALLY ADDRESSABLE FIBER-COUPLED EMITTERS

Task

For applications in medical technology, a compact, fiber-coupled diode laser module is required which can manipulate and switch aqueous micro-fluid flows optically. The beam source shall be integrated in a compact tabletop device and simultaneously supply multiple micro-fluid flow switches with optical power. For a sufficient absorption of radiation in water, an emission wavelength of 2 µm is required.

Method

With regard to a compact construction, a GaSb diode laser bar is used with ten individually addressable emitters at central wavelengths between 1900 and 2000 nm. The laser radiation from each of the emitters is coupled to single optical fibers with a 105-micron core diameter. The optical design is aligned to a small number of adjustable micro-optical components at high coupling efficiency.

Result

The modules built achieve a maximum optical output of 500 mW per fiber with a coupling efficiency of up to 60 percent. Here, the coupling efficiency is limited by the slow-axis divergence angle of the laser diode emitters used. The use of these diode laser modules in fluid-switch systems has been successfully demonstrated.

Applications

This diode laser module serves as a beam source for a compact medical analytical system used to select and sort pathogens. It enables physicians to make early diagnoses and targeted treatment of sepsis disease (blood poisoning). In addition, the module developed by Fraunhofer ILT can be used to reduce both the costs and size of beam sources in the field of laser marking and lithography.

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3 Diode laser module.

4 Individually addressable diode laser bar.

TWO-WAVELENGTH LASER FOR SOFT TISSUE COAGULATION

Task

To coagulate soft tissue or fix wound dressings, the laser wavelength should, if possible, be selected such that the optical penetration depth corresponds to the desired effective depth. During coagulation the thermal denaturation of proteins leads to structural changes that cause increased light scattering. As a result, there is an inherent mismatch of wavelength at the beginning or end of the process. On account of the multiple scattering of the radiation, the optical penetration depth can be reduced to such an extent that the laser cannot reach the desired and effective depth. Coagulation with constant depth in soft tissue requires, however, an adaption of optical penetration depth.

Method

To adjust the optical penetration depth and the absorbance, the wavelength is changed during the irradiation period. For this purpose, two diode lasers with different wavelengths, 980 nm and 1550 nm, are coupled in the optical fiber of the handpiece at the same time. The power control of the two laser sources is independent of each other so that either a gradual transition from one wavelength to another or quick switching is possible.

Result

The coagulation depths achieved are checked on a phantom model, which indicates denaturation as the light scattering changes when a temperature-time integral is exceeded, similar to what happens in soft tissue. By selecting different power distributions between both diode lasers, Fraunhofer ILT can set the resulting coagulation depth to values between both of these limits for each wavelength. This confirms that the basic approach, using commercially available diode laser modules, is viable.

Applications

This method has initially been considered for the coagulation of soft tissue with a controllable coagulation depth of about 1 - 5 mm. This way, the thermal cauterization of vessels or the fixing of dressings can be precisely controlled.

Moreover, the principle can be used for plastic welding to ensure that the penetration depth can be controlled locally during the manufacturing process.

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1 Laboratory sample of a handpiece for two-wavelength coagulation with integrated temperature measurement.

FAST MINIATURIZED LASER SCANNER

Task

Hand-held laser-surgical and laser-based therapy systems need fast 2D beam deflection systems, so-called scanners, to precisely distribute the power of the therapeutic radiation in the tissue. The parameters characterizing such scanners are the scanning speed v_{sc}, the scanning angle θ, the mirror aperture d and the overall volume V. The requirements for the scanner are $v_{sc} > 20$ m/s, $\theta > 10°$, $d > 8$ mm and $V < 100$ cm^3. For 2D beam deflection, there are different scanner technologies – such as galvanometers, MEMS, piezo scanners and acousto-optical or electro-optical deflectors (AOD and EOD) – each with specific strengths and weaknesses. None of the available technology, however, meets all of the requirements simultaneously.

Method

Fraunhofer ILT has developed a new compact 2D scanner technology that unifies a small unit volume with large mirror apertures and fast scan speeds along with large deflection angles. The production of such mini scanners is based on the most modern manufacturing methods of laser technology. The Fraunhofer ILT can, thus, flexibly implement designs tailored to a customer's needs without them having to pass complex process lines during manufacturing. Due to the direct implementation of digital design into a product, it is now possible to manufacture individual scanner systems in small quantities economically.

Result

The mini scanner developed by Fraunhofer ILT reaches scanning speeds of more than 35 m/s in optical deflection angles of up to 20°. The mirror aperture is 10 mm in spite of the small construction volume of $l \times w \times h = 40.5 \times 29 \times 32$ mm^3. The mirror surface can be provided with metallic or dielectric reflection coatings, therefore, making the scanner suitable for laser wavelengths in the entire optical and infrared spectral range and power range up to 200 W.

Applications

The scanner is ideal for use in laser therapy systems, since, thanks to its compact design, it can easily be integrated in a handpiece for the application of therapeutic laser radiation. Other possible applications are confocal microscopy or use in the 3D printers.

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2 Compact scanner mirror.

3 Customized production with laser technology.

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SLM-Prozessführung zur Herstellung von Funktionsbauteilen aus Aluminium-CNT-Kompositwerkstoffen

Freitag, Sebastian
SLM-Prozessführung zur Herstellung von Gitterstrukturen aus Ti6Al4V

Großbröhmer, Stephan
Online Durchbohrerkennung beim Laserstrahl-Bohren mittels Plasmaspektroskopie

Hammelstein, Christoph
Analyse der Selbstkosten einer Selective-Laser-Melting (SLM) Produktionsanlage

Hampker, Tobias
Untersuchung des Einflusses von Prozessfaserdurchmesser und Fokussierbrennweite beim Bohren mit Faserlaserstrahlung

Hirschfelder, Katrin
Vermeidung von Rückständen bei der Strukturierung dünner Schichten

Hofmann, Johannes
Untersuchungen zu optischen Eigenschaften partikulärer Schichtsysteme auf Basis von PEEK

Holly, Carlo
Lösung von *k•p* Schrödingergleichungen für Halbleiternanostrukturen mit Hilfe eines Finite-Volumen-Verfahrens

Hoppe, Nicholas
Einfluss der Scanstrategie auf die Verarbeitung von INC718 mittels High Power SLM Bearbeitung

Jaeger, Markus
Konstruktive Auslegung der Schutzgasführung in der Prozesskammer einer SLM-Anlage

Jülich, Bastian
Untersuchung zur Prozessführung für die Verarbeitung der Magnesiumlegierung AZ91 mittels SLM

Kattan, Dany Richard
Experimentelle Untersuchungen zum Einfluss von Intensitätsverteilung und Laserstrahldurchmesser beim Polieren mit gepulster Laserstrahlung

Kirsch, Dennis
Fokusabhängigkeit laserinduzierter Plasmen

Kreißig, Miriam Tabea
Vergrößerung der Ortsauflösung beim Glasabtrag mit CO_2-Laserstrahlung durch Anpassung des Stützpunktabstandes

Li, Gefei
Untersuchung des Einflusses einer Wärmenachbehandlung auf das Makro- und Mikrogefüge mittels SLM hergestellter Nickelbasis Superlegierung Mar-M247

Möllenhoff, Matthias
Ermittlung geeigneter Prozessfenster beim Laserstrahlauftragschweißen durch DoE

Pichler, Tobias
Identifikation der Kostentreiber von SLM-Produktionsanlagen

Prante, Nils
Untersuchung zur Prozessführung für die Verarbeitung der Magnesiumlegierung WE43 mittels SLM

Rauch, Korbinian
Machbarkeitsuntersuchung zur Verarbeitung einer Wolframkarbid-Kobalt Legierung mittels Selective Laser Melting

Sandker, André
Additiver Aufbau von Volumenkörpern aus Ti-30Al-11Nb-2Mo-0.1B mittels Laserstrahl-Auftragsschweißen

Schieler, Paul
Entfestigung des pressgehärteten Stahls MBW1900 durch lokale Laserstrahl-Wärmebehandlung

Schmadtke, Johannes
Einwirkung von TiC-Nanopartikeln auf die mechanischen Eigenschaften vom nickelbasierten Metall-Matrix-Verbundwerkstoff

MASTER THESES

Schmitt, Christoph
Untersuchung des Einflusses der Scanvektorlängen auf die Schmelzbadgeometrie beim SLM der Magnesium Legierung AZ91

Smolenko, Andreas
Simulation der Wärmeakkumulation während der Bestrahlung transparenter Dielektrika mittels UKP-Laserstrahlung

Vogelpoth, Andreas
Untersuchungen zur Reparatur von Turbinenschaufeln aus René N 5 mit René 142 mittels Selective Laser Melting (SLM)

Vogt, Maximilian
Generativ gefertigte Porenstrukturen in der Medizintechnik

Wein, Stephan
Evaluation der Schmelzeauslenkung beim Laserpunktschweißen von dünnen Kupferblechen

Master Theses

Arntz, Dennis
Fertigungsgerechte Konstruktion eines Leichtbau-Batteriepackgehäuses unter Berücksichtigung verschiedener Laserfügeverfahren

Bonhoff, Tobias
Experimentelle und theoretische Untersuchungen an optischen Systemen zur Formung ultrakurzer Laserpulse für die Materialbearbeitung

Börgmann, Frederik
Frequenzstabilisierung von Hochleistungsdiodenlaserbarrren zum Aufbau eines Multikilowattsystems

Boschen, Maren Lara
Experimentelle Untersuchungen zu temperaturabhängigen optischen Eigenschaften von Schichtsystemen

Brück, Daniel
Verarbeitung von Titanaluminiden mittels Hochtemperatur-Selective Laser Melting

Elsen, Florian
Erzeugung und Verstärkung von Laserstrahlung im mittleren Infrarot

Friedrichs, Marcel
Verfahrenstechnische Grundlagen für das Bohren mit ultrakurzgepulster Laserstrahlung

Gendraud, Camille
3D Mikro- und Nanostrukturierung von Metallen und Verbundmaterialien mit fs-Laserstrahlung

Genz, Dominik
Toleranzanalyse bei der simultanen 9-Achs Lasermaterialbearbeitung

Göller, Nicole
Untersuchung von neuartigen Mischkristallen für Single-Frequency-Laser

Guisado Herranz, Lidia
Optimization of heat conduction and FAC mounting for a high brightness diode laser module based on single emitters

Häusler, Andre
Betrachtung des Schmelzbadverhaltens beim Laserstrahlmikroschweißen mit örtlicher und zeitlicher Leistungsmodulation mittels Hochgeschwindigkeitsvideographie

Hasenkamp, Christof
Einfluss erhöhter Aufbauraten auf die mechanischen Eigenschaften beim 2 kw-SLM des Werkzeugstahls 1.2709

Kellermann, Lukas
Schnittqualität beim Laserstrahlschneiden von CFK

Küpper, Moritz
Untersuchung der Signalinterferenz als erweiterter Lösungsansatz zum inversen Problem des Laserumschmelzstrukturierens

Li, Xiaoxiao
Investigation to additive manufacturing of components made of Hastelloy X by using SLM with skin-core principle on SLM 280 HL

Lübbert, Lutz
Entwicklung einer mechatronischen Steuerung für eine SLM-Anlage

Olk, Andreas
Integratives Optikdesign zur Laserstrahlformung mit deformierbaren Membranspiegeln

Pongratz, Ludwig
Stereolithographie von synthetischen Polymeren und Biopolymeren mit UV-Laserstrahlung

Rahn, Johannes
Messstand zur Analyse des Langzeitverhaltens von Galvanometerscannern bei Verwendung von Hochleistungslasern

Reichenzer, Frieder
Single-Frequency-Laser mit Erbium-Kristallen im Wellenlängenbereich um 1,6 µm

Sommer, Jan
Auftragsschweißen mit Gusseisen

Straaten, Stephan
Zerstörungsfreie Prüfverfahren zur Bewertung von Kunststoffschweißnähten

Tromm, Thomas Carl Ulrich
Grundlegende Untersuchungen zum Selective Laser Melting einer binären Fe-Al-Legierung

Winkelmann, Max
Mechanische Eigenschaften mittels SLM aufgebauter periodischer Gitterstrukturen

Wolf, Marcel
Remote-Laserstrahlschweißen von Halbzeugen aus Aluminiumlegierungen der 5000er und 6000er Serie

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21.01.2014 - M. Wehner: *Laser Biofabrication – Lasergestützte Verfahren für die Biofabrikation, NRW Strategieworkshop »NanoMedizin«, Düsseldorf*

02.02.2014 - M. Livrozet: *Feasibility and performance study for a space-borne 1645 nm OPO for French-German satellite mission MERLIN, Photonics West San Francisco, CA, USA*

02.02.2014 - J. Löhring: *INNOSLAB-based single-frequency MOPA for airborne lidar detection of CO_2 and methane, Photonics West, San Francisco, CA, USA*

02.02.2014 - C. Holly: *Numerical analysis of external feedback concepts for spectral stabilization of high-power diode lasers, LASE2014, San Francisco, CA, USA*

03.02.2014 - T. Westphalen: *Automated alignment of fast-axis collimator lenses for high-power diode laser bars, LASE2014, San Francisco, CA, USA*

03.02.2014 - S. Hengesbach: *High-Power Dense Wavelength Division Multiplexing (HP-DWDM) of frequency stabilized 9xx diode laser bars with a channel spacing of 1.5 nm, LASE2014, San Francisco, CA, USA*

04.02.2014 - B. Jungbluth*: Broadly tunable, longitudinally diode-pumped Alexandrite laser, Photonics West, San Francisco, CA, USA*

06.02.2014 - S. Britten: *Quasi-simultaneous laser soldering for the interconnection of back-contact solar cells with composite foils, Photonics West, San Francisco, CA, USA*

06.02.2014 - R. Poprawe: *Laser Technology for Industry and Society – The Fraunhofer Future of Digital Photonic Production, Lawrence Livermore National Laboratory, USA*

11.02.2014 - A. Olowinsky: *FSEM II Cluster Batterie/Range Extender: Energie für Elektromobilität - sicher bereitgestellt und gut verpackt, Kongress Elektromobilität, Berlin*

12.02.2014 - A. Olowinsky: *Metall-Kunststoff verbinden mit Lasertechnik, Leichtbautagung 2014, Bremen*

19.02.2014 - M. Schulz-Ruthenberg: *Laser structuring in a roll-to-roll environment, Tag der offenen Tür, Dormagen*

03.03.2014 - R. Poprawe: *Additive / Generative Fertigung, acatech, Deutschland*

05.03.2014 - A. Gillner: *Ultrakurzpulslaser auf dem Weg in den industriellen Alltag – systemtechnische Herausforderungen und technologische Lösungen, Innovationsforum MikroLas, Rostock*

07.03.2014 - W. Schulz: *Schneiden von Glas , TRUMPF Technologie Tag, Ditzingen*

12.03.2014 - D. Buchbinder: *Selective Laser Melting of Aluminium Die-Cast Alloy, DDMC, Berlin*

12.03.2014 - M. Schniedenharn: *Current Applications and R&D Topics in Selective Laser Melting, LAM, Houston, USA*

19.03.2014 - C. He: *Laser beam precise cutting with ultrashort pulses using helical optics, Laser World of Photonics China 2014, Shanghai, China*

20.03.2014 - L. Jauer: *SLM of biodegradable metals, Biodegradable Magnesium Workshop, Turracher Höhe, Österreich*

20.03.2014 - R. Poprawe: *Laser additive manufacturing: the vision of 3D printing, Tsinghua University, China*

10.04.2014 - A. Gillner: *New perspectives for surface treatment of metals and polymers by laser processing, Vortrag Limburgenco, Geleen, Niederlande*

15.04.2014 - L. Büsing: *Design, alignment and applications of optical systems for parallel processing with ultra- short laser pulses, Photonics Europe, Brüssel, Belgien*

15.04.2014 - A. Gatej: *Methods for compensation of thermal lensing based on thermo-optical (TOP) analysis, Photonics Europe, Brüssel, Belgien*

15.04.2014 - B. Gronloh: *Ultrafast green-laser exceeding 400 W of average power, Photonics Europe, Brüssel, Belgien*

16.04.2014 - F. Elsen: *Feasibility and performance study for a space-borne 1645 nm OPO for French-German satellite mission MERLIN, Photonics Europe, Brüssel, Belgien*

16.04.2014 - A. Özmert: *Penetration depth in laser welding: Detectability of penetration depth based on weld pool geometry and process emission spectrum in laser welding of copper, Photonics Europe 2014, Brüssel, Belgien*

16.04.2014 - R. Poprawe: *Laser additive manufacturing: the vision of 3D printing, EU-Commission Brüssel, Belgien*

17.04.2014 - M. Dahmen: *Laser beam welding of new ultra-high strength and supra-ductile steels, SCT 2014, Braunschweig*

21.04.2014 - R. Poprawe: *Novel Perspectives of Laser Metal Processing, Chair for Laser Technology, MELCO, Yokohama, Japan*

22.04.2014 - R. Poprawe: *Thrust areas of laser materials processing in the past, present and future, The First Smart Laser Processing Conference 2014, Yokohama, Japan*

23.04.2014 - C. Hartmann: *Plasma expansion during laser structuring of metals with ps pulse bursts, SLPC 2014, Yokohama, Japan*

23.04.2014 - R. Noll: *Laser-induced Breakdown Spectroscopy – from R&D to industrial applications, Wuhan National Laboratory for Optoelectronics, Wuhan, China*

***06.05.2014 - J. Flemmer:** Machine tool and CAM-NC Data Chain for Laser Polishing complex shaped parts, 1st Conference on Laser Polishing, Aachen*

***07.05.2014 - A. Temmler:** Design surfaces by Laser Remelting, 1st Conference on Laser Polishing, Aachen*

***07.05.2014 - C. Nüsser:** Process- and Material-Induced surface structures during Laser Polishing, 1st Conference on Laser Polishing, Aachen*

***07.05.2014 - S. Heidrich:** Laser Polishing and Form Correction of fused silica opties, 1st Conference on Laser Polishing, Aachen*

***07.05.2014 - S. Ocylok:** Effects of nano-particles on the properties of laser cladded wear resistant layers, Friction, Wear and Wear Protection Conference, Karlsruhe*

***07.05.2014 - I. Kelbassa:** Overview Laser Additive Manufacturing in aeronautics – status quo and challenges of LMD and SLM processes, EU Innovation Forum – Laser Additive Manufacturing (LAM) in Aeronautics, International Laser Technology Congress AKL'14, Aachen*

***07.05.2014 - P. Abels:** Wie funktionieren die Laserbearbeitungsverfahren? Einsteiger Seminar Lasertechnik, International Laser Technology Congress AKL'14, Aachen*

***07.05.2014 - C. Hinke:** Aktuelle Entwicklungstrends in der Lasertechnik, Einsteiger Seminar Lasertechnik, International Laser Technology Congress AKL'14, Aachen*

***08.05.2014 - R. Poprawe:** Digital Photonic Production – Crosslinking of virtual Reality with the Reality of Laser Manufacturing, International Laser Technology Congress AKL`14, Aachen*

***08.05.2014 - T. Schopphoven:** High Speed Laser Material Deposition, International Laser Technology Congress AKL`14, Aachen*

***09.05.2014 - C. Engelmann:** Fügen von Faserverbundkunststoffen FVK / FVK und FVK / Metall, International Laser Technology Congress AKL'14, Aachen*

***09.05.2014 - B. Mehlmann:** Neue Horizonte des Laserstrahlmikroschweißens für elektrische Kontakte, International Laser Technology Congress AKL'14, Aachen*

***09.05.2014 - E. Willenborg:** Laserpolieren von Glasformen, International Laser Technology Congress AKL'14, Aachen*

***12.05.2014 - S. Rittinghaus:** Laserbasierte Herstellung funktionaler Oberflächen und Schichten, Aalener Oberflächentage*

***13.05.2014 - M. Reininghaus:** Fabrication of gold nanoantennas for infrared near-field enhancement by fs-laser radiation, Peking, China*

***23.05.2014 - A. Gillner:** Kohärente Laserquellen für Phototechnologie, DAFP Symposium, Nürnberg*

***26.05.2014 - S. Danylyuk:** Multi-angle spectroscopic EUV reflectometry for analysis of thin films and interfaces, E-MRS 2014, Lille, Frankreich*

***27.05.2014 - W. Meiners:** Process and design challenges of Selective Laser Melting in aerospace applications, International Symposium Materials Science and Technology of Additive Manufacturing, Bremen*

***27.05.2014 - J. Tempeler:** High resolution laboratory-scale EUV interference lithography, ICXRL 2014 International Conference on X-Ray Lasers, Denver, USA*

***03.06.2014 - N. Nottrodt:** Laser based functionalization for graded immobilization of biomolecules on biocompatible polymer surfaces, NanoBio Europe, Münster*

***04.06.2014 - A. Gasser:** Laser-Pulver-Auftragschweißen, Reis Livetechnikum, München*

04.06.2014 - A. Gillner: *ArtiVasc 3D – Artificial vascularized scaffolds for 3D tissue regeneration, NanoBio Europe, Münster*

04.06.2014 - R. Poprawe: *Neue Wege der Automatisierung durch Generative Fertigung, Automatika Messe, München*

05.06.2014 - K. Wissenbach: *Generative Laserverfahren in der Kraftwerkstechnik, VDI Fachseminar, Raunheim*

11.06.2014 - M. Aden: *Structural Mechanics Simulations of the Join Behaviour under Stress, Projektbesprechung PMJoin, Lüttich, Belgien*

17.06.2014 - M. Dahmen: *Laser beam welding of new ultra-high strength and supra-ductile steels, TEMA, Braunschweig*

18.06.2014 - D. Hoffmann: *Beam Forming and Propagation, Schott Expert Panel, Mainz*

18.06.2014 - N. Nottrodt: *Combined additive manufacturing processes for building up artificial vascularized soft tissue – ArtiVasc 3D, ArtiVasc 3D, Maastricht, Niederlande*

18.06.2014 - R. Poprawe: *High Performance Light sources-based Additive Manufacturing, Photonics21 Board of Stakeholders, Brüssel, Belgien*

18.06.2014 - I. Ross: *Prospects of Laser Polishing for small and complexly shaped parts, EPMT 2014, Genf, Schweiz*

18.06.2014 - J. Schrage: *Additive Manufacturing with Selective Laser Melting (SLM) and Laser Metal Deposition (LMD), Forum Produktion Nordwest 2014, Papenburg*

18.06.2014 - W. Schulz: *Simulation of glass cutting, Schott expert panel, Mainz*

19.06.2014 - S. Herbert: *Multi-Angle spectroscopic EUV Reflectometry EXRS 2014, Bologna, Italien*

19.06.2014 - N. Nottrodt: *Combined additive manufacturing processes for building up artificial vascularized soft tissue – ArtiVasc 3D, 3D Bioprinting Conference, Maastricht, Niederlande*

19.06.2014 - B. Mehlmann: *Fundamentals and recent developments in spatial power modulation for laser beam micro welding of metals, LPM 2014, Vilinus, Litauen*

19.06.2014 - J. Ryll: *Enhancing Quality and Productivity for Micro Cutting Processes using Ultrafast Laser, LPM 2014, Vilinus, Litauen*

24.06.2014 - S. Heidrich: *Highlights of LaP 2014, 1st Conference on Laser Polishing, OF&T14, Hawaii, USA*

24.06.2014 - S. Heidrich: *Polishing and Form Correction with Laser Radiation, OF&T14, Hawaii, USA*

25.06.2014 - W. Schulz: *Simulation of glass cutting, SLT 14, Stuttgart*

25.06.2014 - M. Traub: *Automatic Design of Multi-Lens Optical Systems Based on Stock Lenses for High Power Lasers, IODC 2014, Kohala Coast, Hawaii, USA*

26.06.2014 - D. Hoffmann: *Hochbrillante Strahlquellen, LASYS 2014, Short Course »Basiswissen Laser und Lasermaterialbearbeitung«, Stuttgart*

26.06.2014 - S. Merkt: *3D Printing and its emerging opportunities, Lasys 2014, Stuttgart*

27.06.2014 - F. Gaussmann: *New light source enables IR near-field spectroscopy of strained gallium nitride, 56th Electronic Materials Conference, Santa Barbara, Kalifornien, USA*

03.07.2014 - A. Gillner: *High throughput laser manufacturing processes, SU2P Solid State Laser and Nonlinear Optics Workshop, Edingburgh, Schottland*

17.07.2014 - D. Buchbinder: *Activities at Steinbachstraße 15 in Aachen, RIM Plus Workshop, Brüssel, Belgien*

24.07.2014 - R. Wester: *Freiform-Optiken für die gezielte Lichtlenkung, Workshop LED Pflanzenbeleuchtung, Duisburg*

29.07.2014 - A. Gillner: *Vergleichende Bewertung beim Laserschneiden von Faserverbundwerkstoffen, CFK-Workshop Freudenstadt, Freudenstadt*

04.08.2014 - A. Diatlov: *Manufacturing Antenna Components for Satellites out of ALSi10Mg by Selective Laser Melting (SLM), Austin, Texas, USA*

31.08.2014 - M. Dahmen: *Laser beam welding of high manganese TWIP steels produced by twin roll strip casting, HMnS 2014, Aachen*

05.09.2014 - R. Poprawe: *Laudatio zum RWTH Ingenieurpreis an Prof. Dr. Berthold Leibinger, Aachen*

08.09.2014 - P. Loosen: *Optical systems for high-power laser applications, LANE 2014, Fürth*

09.09.2014 - M. Dahmen: *Laser beam welding of ultra-high strength chromium steel with martensitic microstructure, LANE 2014, Fürth*

10.09.2014 - S. Engelhardt: *Photoinitiator free stereolithography for biomedical applications, European Symposium of Photopolymer Science, Wien, Österreich*

10.09.2014 - P. Heinen: *Helium-tight laser beam welding of aluminum with brillant laser beam radiation, LANE2014, Fürth*

10.09.2014 - H. Kind: *Laser glass frit sealing for encapsulation of vacuum insulation glasses, LANE2014, Fürth*

10.09.2014 - H. Leonards: *Stereolithography processing and biocompatibility of a Thiol-ene based resin, European Symposium of Photopolymer Science, Wien, Österreich*

10.09.2014 - R. Noll: *LIBS expanding into industrial applications, Invited talk, LIBS 2014, Beijing, China*

10.09.2014 - S. Ocylok: *Correlations of melt pool geometry and process parameters during laser metal deposition by coaxial process monitoring, LANE 2014, Fürth*

11.09.2014 - N. Pirch: *Space-Resolved Laser Beam Diagnostics for Material Processing, Darmstadt*

12.09.2014 - A. Gillner: *ArtiVasc 3D – Artificial vascularized scaffolds for 3D tissue regeneration, Österreichische Gesellschaft für Gefäßchirugie, Graz, Österreich*

12.09.2014 - A. Meissner: *Granatmischkristalle für Laseranwendungen, Deutsch-Französischer Oxidkristall-Dielektrika, Laserkristall-Workshop, Idar-Oberstein*

17.09.2014 - G. Backes: *Lasertechnik in der Oberflächenbearbeitung, IHK, Geilenkirchen*

17.09.2014 - A. Gillner: *High Power ultrashort laser processing with innovative optical systems, Vortrag Ailu. Birmingham, England*

19.09.2014 - A. Olowinsky: *Energie für Elektromobilität – sicher bereitgestellt und gut verpackt, Automechanika 2014, Frankfurt/Main*

22.09.2014 - U. Eppelt: *Metamodeling of Laser Cutting, ICNAAM2014, Rhodos, Griechenland*

22.09.2014 - T. Hermanns: *Modelling for Self-Optimization in Laser Cutting, ICNAAM2014, Rhodos, Griechenland*

***23.09.2014 - S. Heidrich:** Politur und Formkorrektur mit Laserstrahlung, Moderne Optikfertigung, Wetzlar*

***24.09.2014 - T. Biermann:** Laser Additive Manufacturing / 3D Printing, LME 2014, Schaumburg*

***29.09.2014 - R. Poprawe:** Barrieren überwinden - neue Designmöglichkeiten für integrierte Funktionen in Bauteilen durch Generative Fertigung, Stuttgart*

***01.10.2014 - S. Herbert:** Extreme Ultraviolet Dark-Field Microscopy for Defect Inspection, COST MP1203, Annual General Meeting, Dubrovnik, Kroatien*

***07.10.2014 - S. Bremen:** Increased productivity and resulting material properties for High Power SLM, Materialise Metal Day, Leuven, Belgien*

***08.10.2014 - S. Britten:** Laserstrahlmikroschweißen von elektrischen Kontakten und Verbindern - eine Alternative zum Löten, Technologie Tage Wolf, Freudenstadt*

***08.10.2014 - K. Van der Straaten:** Laser-based Joining and Cutting of Composite Materials, Composites Europe 2014, Düsseldorf*

***09.10.2014 - R. Poprawe:** Digital Photonic Production – Crosslinking of virtual Reality with the Reality of Laser Manufacturing, Lab Workshop, Tsinghua, China*

***09.10.2014 - W. Schulz**: Simulation and Diagnostics for Laser Processing – Sheet Metal and Wide Band-gap Materials, Symposium Joint Research Laboratory, Beijing, China*

***15.10.2014 - D. Buchbinder:** Selective Laser Melting of Aluminium Die-Cast Alloy – Correlations Between Process Parameters, Solidification Conditions and Resulting Mechanical Properties, ICALEO, San Diego, CA, USA*

***15.10.2014 - D. Hawelka:** Tailoring Laser Induced Temperature distributions for the Nano Crystallization of Printed Sol-gel-films on Substrates with Low Thermal Stability, Material Science and Technology 2014, Pittsburgh, USA*

***16.10.2014 - A. Gillner:** Flexible Multistrahlsysteme zur Erhöhung der Produktivität bei der Laser-Mikrobearbeitung, Laserforum, Bochum*

***16.10.2014 - A. Temmler:** Laser Polishing and structuring by Remelting, Lawrence Livermore National Laboratory, Livermore*

***20.10.2014 - S. Hengesbach:** Comparison of edge emitter and vertical emitter based diode lasers for materials processing, ICALEO, San Diego, CA, USA*

***20.10.2014 - R. Poprawe:** Digital Photonic Production – the Future of Tailored Light, Schawlow Presentation 2014, ICALEO, San Diego, CA, USA*

***21.10. 2014 - A. Temmler:** Structuring by remelting of Ti6Al4V, ICALEO, San Diego, CA, USA*

***21.10.2014 - F. Zibner**: Ultrahigh-Speed Separation Process using a combination of gas-supported laser ablation and laser cutting & Ultra-High-Precision Helical Laser Cutting of sapphire and glass, ICALEO, San Diego, CA, USA*

***22.10.2014 - V. Blattmann:** Laser Structuring of Surfaces for PV Applicatons, PV Days, Halle*

***22.10.2014 - P. Lott:** Laser-Based Production of Carbon Fibers, ICALEO, San Diego, CA, USA*

***22.10.2014 - H. Uchtmann:** Drilling of Cooling Holes by Using High Power ultrashort-pulsed Laser Radiation, ICALEO, San Diego, CA, USA*

***23.10.2014 - S. Merkt:** Scalability of the mechanical properties of slim produced micro-struts, ICALEO, San Diego, CA, USA*

05.11.2014 - W. Meiners: *3D Druck in Metall: Stand der Technik und Perspektiven, POTENZIALE-Veranstaltung, Aachen*

05.11.2014 - R. Poprawe: *Bedeutung des 3D Drucks für die industrielle Fertigung und Möglichkeiten der Zusammenarbeit mit dem Cluster Photonics, POTENZIALE-Veranstaltung, Aachen*

06.11.2014 - D. Maischner: *Einsatzmöglichkeiten des Laserauftragschweißens im Werkzeugbau, Infotage Werkzeugbau 2014, Loßburg*

06.11.2014 - R. Poprawe: *Future Challenges and Chances of 3D Printing / Additive Manufacturing, »Photonics Seminars", European Commission, DG CONNECT, Brüssel, Belgien*

12.11.2014 - M. Brosda: *New Perspektives in Laser Processing for Medical Product Manufacturing, COMPAMED High Tech Forum, Düsseldorf*

13.11.2014 - R. Poprawe: *Digital Photonic Production- Crosslinking of virtual Reality with the Reality of Laser Manufacturing, Korean society of laser processing, Fall Meeting, Shanghai, China*

17.11.2014 - R. Poprawe: *Ultrafast Lasers with kW Class Output Power for Applications in Industry and Science, Advanced Solid State Lasers Conference, Shanghai, China*

18.11.2014 - C. Holly: *Festkörperlaser und Diodenlaser für das Schweißen von Kunststoffen, Würzburg*

19.11.2014 - M. Schniedenharn: *Verbesserung der Oberflächenqualität und Detailauflösung generativ gefertigter Bauteile durch μSLM, IPA Anwenderforum, Stuttgart*

20.11.2014 - D. Hoffmann: *Femtosekundenlaser: aktuelle Trends und Anwendungspotenziale, Wissenschaftlicher Beirat Jenoptik, Jena*

20.11.2014 - W. Meiners: *Selective Laser Melting on the way to production: Recent research topics at Fraunhofer ILT, MAMC, Wien*

20.11.2014 - R. Poprawe: *SLM Production Systems: Recent Developments in Process Development, Machine Concepts and Component Design, Excellenzcluster, SAB-Sitzung, Aachen*

21.11.2014 - C. Gayer: *Generative Fertigung von Keramikwerkstoffen mittels Selective Laser Melting, AK Biokeramik, Aachen*

25.11.2014 - D. Buchbinder: *Emerging 3D Printing Materials, Euromold, Frankfurt*

25.11.2014 - F. Elsen: *Robust design and assembly technology of a 1645 nm OPO for French-German satellite mission MERLIN, Workshop on »Laser Sources for LIDAR Applications«, Wessling*

25.11.2014 - D. Hoffmann: *High Peak Power Solid State Laser Sources for LIDAR Applications, Workshop on »Laser Sources for LIDAR Applications«, Wessling*

02.12.2014 - G. Rolink: *Laser Metal Deposition and Selective Laser Melting of Fe-Al and Fe-Al-Ti, MRS-Fall Meeting,Boston, MA, USA*

11.12.2014 - J. Risse: *Latest Developments in SLM, Dissemination Workshop of MERLIN FP7 Project, Ordizia, Spain*

CONVENTIONS AND CONFERENCES

Well attended: AKL'14 – Sponsors' Exhibition.

AKL'14

May 7 to 9, 2014, Aachen
International Laser Technology Congress AKL'14

From May 7 to 9, the International Laser Technology Congress AKL'14 took place in Aachen. Alongside the classic micro- and macro-processing topics, the congress for applied laser technology also focused on the hot topic for the future: Digital Photonic Production (DPP). This includes both the additive manufacturing and the ablative laser processes for preparing individual and complex components on the basis of data sets from the virtual world of IT. With up to 30 million euros, the BMBF will be funding the DPP research campus for 15 years, which will promote a new form of close cooperation between industry and research centers in the field of application-oriented basic research.

For the 10th time, the Fraunhofer Institute for Laser Technology ILT hosted the International Laser Technology Congress AKL in Aachen. The AKL takes place every two years and has developed into the largest European industry congress for applied laser technology in manufacturing. In 2014 629 experts came to Aachen to exchange views about current market and technology trends as well as future-changing research and development findings, such as additive manufacturing, precision machining, and new high-power ultrafast lasers. The proportion of international visitors, who came from over 20 countries, has risen again to reach 24 percent. The event program was based on the diverse interests of the visitors: on the first day, alongside the EU Innovation Forum »Laser Additive Manufacturing (LAM) in Aeronautics«, the seminar Laser Technology ABC's was offered for newcomers to the technology as well as the Technology Business Day for executives and marketing managers.

The second and third days were devoted to the conference proper and the Laser Material Processing – Macro, Laser Material Processing – Micro, and Laser Sources sessions.

Additive Manufacturing at the AKL conference on May 8 and 9, 2014

The main part of the congress consisted of the Laser Technology Conference. In three multiple track sessions, new developments were discussed in the following areas: Laser Sources, Laser Material Processing – Micro, and Laser Material Processing – Macro.

In his opening speech, Rudolph Strohmeier, Deputy Director General DG Research and Innovation, European Commission, surveyed the research funding landscape of the years to come.

The Gerd Herziger Session was titled »Digital Photonic Production – A New Horizon for Industrial Production.«
The presentations revealed additive manufacturing as a technology that is currently making inroads into series production.

Concerning the topic »CFRP processing with ultrafast lasers« new applications both in lightweight construction (cutting and joining carbon-fiber reinforced plastics, or CFRPs) and in display manufacturing (glass cutting) were discussed at the conference. In both cases, ultrafast lasers play a decisive role.

Laser Technology Live at Fraunhofer ILT on May 8, 2014
Live demonstrations at Fraunhofer ILT offered a good opportunity for direct exchange with laser technology experts. At 80 stations, the institute's staff presented current projects and research findings. Topics ranged from classics like joining and cutting all the way to laser material deposition, laser polishing, and new applications in the field of life science, such as the laser-induced transfer of cells (laser-induced forward transfer, LIFT). The booths of current Fraunhofer ILT spin-offs also attracted great interest; since its foundation in

AKL'14 awarding ceremony in the coronation hall of Aachen.

1985, the institute has given birth to some 30 successful laser technology spin-offs. This startup culture is supplemented by the spin-in collaboration model, whereby cooperation partners of all different sizes can take up residence on the Fraunhofer ILT premises and have their own R&D laboratories and offices there. Visitors to AKL'14 were able to see how successfully this model works and how it is now being expanded to a whole new scale by RWTH Aachen University as part of the RWTH Aachen Campus project. Fraunhofer ILT and the cooperating RWTH chairs coordinate the Photonics Cluster in this campus, where companies can move into a new innovation center in close proximity to Fraunhofer ILT. The groundbreaking ceremony for this building took place in summer 2014. On a tour of the campus, guests were impressed by the site complex: extending over some 240,000 m^2, it will be home to seven clusters – including the photonics one – each devoted to a different area of research.

Please look at www.lasercongress.org for a review of AKL'14.

May 7, 2014, Aachen
Awarding Ceremony of the Innovation Award Laser Technology 2014

The Innovation Award Laser Technology is a European research prize awarded at 2-yearly intervals by the associations Arbeitskreis Lasertechnik e.V. and the European Laser Institute ELI. The award can be conferred on an individual researcher or on an entire project group, whose exceptional skills and dedicated work have led to an outstanding innovation in the field of laser technology. The scientific and technological projects in question must center on the use of laser light in materials processing or the methods of producing such light, and must furthermore be of demonstrable commercial value to industry.

In the historical ambience of the »Coronation Hall« around 300 guests attended the awarding ceremony. The jury composed by 9 international experts had selected 3 finalists among the 23 submitted applications.

Dr. Paul Hilton, speaker of the international jury, pointed out the dedicated work of all 3 finalist´s and the outstanding innovations of the project teams in the field of laser technology. The jury conferred the 1st prize of the Innovation Award Laser Technology 2014 provided with 10 000 € prize money to Dr. Ralf Preu, director of the division »Photovoltaics – Production Technology and Quality Assurance« of the Fraunhofer Institute for Solar Energy Systems ISE in Freiburg (Germany) and his team for the innovation »Laser Fired Contact (LFC) technology for the production of highly efficient silicon solar cells«. By the use of the LFC process the industrial partner set several technological world records. Regarding cell and module efficiencies 19.5% for a large area multi-crystalline silicon solar cell and 18.5% for a standard sized module were achieved. In the meantime approximately 1 million photovoltaic modules with Laser Fired Contacts are produced and installed. The outstanding performance of these modules compared to standard technology has been confirmed in several field tests. The Fraunhofer ISE in Freiburg is an institute of the Fraunhofer Gesellschaft and contributes with its 1300 strong workforce and the cooperating industrial partners to innovations for a more efficient and environmentally friendly energy supply. The prize winner Dr. Ralf Preu has been awarded the title of »AKL Fellow« and »ELI Fellow«. The certificates for the first, second and third placed finalist teams were handed over by Dipl.-Ing. Ulrich Berners, president of the Arbeitskreis Lasertechnik AKL e.V. and Dr. Paul Hilton, president of the European Laser Institute ELI.

Awarding ceremony of the »Innovation Award Laser Technology 2014« in the town hall of Aachen: (f.l.t.r.) Dr. P. Hilton, Prof. R. Poprawe, Dr. M. Kogel-Hollacher, Dr. R. Preu, Dr. Y. Bellouard, Dipl.-Ing. U. Berners.

The 3 Finalists and their Teams

1st place: Laser Fired Contact (LFC) technology for the production of highly efficient silicon solar cells
Team: Dr. Ralf Preu, Fraunhofer Institute for Solar Energy Systems ISE, Freiburg, (Team Representative); Dr. Jan Nekarda, Fraunhofer Institute for Solar Energy Systems ISE, Freiburg; Dipl.-Phys. Martin Graf, Fraunhofer Institute for Solar Energy Systems ISE, Freiburg.

2nd place: Penetration Depth and Topography Measurement in Laser Materials Processing using Low Coherence Interferometry
Team: Dr. Markus Kogel-Hollacher, Precitec Optronik GmbH, Neu-Isenburg, (Team Representative); Dr. Stephan Bichmann, Scheidt & Bachmann GmbH, Mönchengladbach; Dipl.-Phys. Niels König, Fraunhofer IPT, Aachen; M.Sc. Guilherme Mallmann, Fraunhofer IPT, Aachen; Dipl.-Ing. Thibault Bautze, Precitec GmbH & Co. KG, Gaggenau; Dipl.-Ing.(FH) Christian Fraas, Precitec Vision GmbH & Co. KG, Neftenbach (CH).

3rd place: FEMTOPRINT: A femtosecond laser printer for three-dimensional micro- and nano-manufacturing of glass
Team: Dr. Yves Bellouard, Eindhoven University of Technology (NL), (Team Representative); Dr. Clemens Hönninger, Amplitude Systèmes, Pessac (F); Eric Mottay, Amplitude Systèmes, Pessac (F); Stefano Bottinelli, Mecartex SA, Muzzano (CH); Michael Hopper, Quintenz Hybridtechnik GmbH, Neuried; Dr. Jean-Marc Breguet, CSEM, Neuchâtel (CH); Dr. François Barrot, CSEM, Neuchâtel (CH); Prof. Peter Kazansky, University of Southampton (UK); Prof. Reymond Clavel, EPFL, Lausanne (CH); Dr. Rainer Kling, ALPhANOV, Bordeaux (F); Dr. John Lopez, ALPhANOV, Bordeaux (F); Nicoletta Casanova, FEMTOprint SA, Muzzano (CH).

Further information regarding the Innovation Award Laser Technology: www.innovation-award-laser.org.

CONGRESSES AND SEMINARS

February 11 - 12, 2014, Bremen
Third Lightweight Construction Conference
On February 11 and 12, 2014 the third Fraunhofer Lightweight Construction Conference took place in Bremen, with the involvement of Fraunhofer ILT as a member of the Fraunhofer Lightweight Design Alliance. With presentations from the industry and the alliance partner institutes, the topic »Current Trends in Lightweight Construction – Hybrid Construction Design« was presented and participants were able to debate and exchange ideas on this topic.

March 11 - 12, 2014, Berlin
Electromobility Forum – CONGRESS
To exchange knowledge on sector and interdisciplinary technologies, 230 experts from research and industry took advantage of the annual technical congress organized by the innovation network Electromobility Forum e.V. The program was completed by more than 20 exhibitors, including, among others, Rockwood Lithium, the Fraunhofer System Research for Electromobility and numerous electric vehicles (Mitsubishi Outlander PHEV, Opel, Ampera, Cetos, eSmart, EuP, eFlinkster, etc.) as well as trial runs. All of this made the new technologies literally »tangible«. Fraunhofer ILT contributed by presenting its activities in the field of batteries with contacting technologies for cells and cutting and joining technologies in the lightweight construction of battery housings.

March 12 - 13, 2014, Berlin
Fraunhofer Direct Digital Manufacturing Conference 2014
The third Fraunhofer Direct Digital Manufacturing Conference was held from March 12 to 13, 2014 in the Sofitel Luxury Hotel on the Kurfürstendamm in Berlin. Nearly 200 conference participants addressed all of the issues in the field of additive processes. The next DDMC conference will be held in Berlin from March 16 to 17, 2016.

April 8 - 9, 2014, Aachen
Aachen – Polymer Optics Days 2014

On April 8 and 9, 2014, the Fraunhofer ILT, IPT and the Institute of Plastics Processing (IKV) in Industry and the Skilled Crafts at RWTH Aachen University together organized the »Aachen – Polymer Optics Days 2014« for the first time. The international conference focused on plastic optical components and emphasized four application-oriented topics: illumination optics, fiber optics, imaging optics and special optics. Giving insight into various state-of-the-art technologies and products were 16 technical presentations by speakers from renowned companies such as Bayer MaterialScience AG, Evonik Industries AG, BMW AG, Momentive Performance Materials GmbH, Zumtobel Lighting GmbH, Hella KGaA, 3M, Thales Group and Optotune AG. They also addressed pioneering innovations and manufacturing challenges along the value chain of optical molded plastic components.

April 10, 2014, Aachen
Workshop: »Analysis on the Nanometer Scale by Means of Infrared Light«

To inaugurate the grand opening of the new application center for near-field microscopy, Fraunhofer ILT invited all those interested in the fields of analysis, research and development for a one-day workshop, »Analysis on the Nanometer Scale by means of Infrared Light«, to Aachen on 10 April 2014. The event took place in close cooperation with the 1. Institute of Physics of the RWTH Aachen University. The topics ranged from molecular spectroscopy, via the characterization of advanced semiconductor elements all the way to the exploration of novel metamaterials and effects on the nanometer scale. Scientists at Fraunhofer ILT, RWTH Aachen University and internationally renowned guest speakers gave insight into current work in the field of near-field microscopy and spectroscopy as well as their potential for industrial applications.

May 6 - 7, 2014, Aachen
1st Conference on Laser Polishing LaP 2014

The first LaP Conference for polishing with laser radiation was held from May 6 to 7, 2014 at Fraunhofer ILT in Aachen in the run-up to AKL’14. The topics ranged from the laser polishing of metals, via that of glass and laser-based processes for the production of optical surfaces all the way to structuring by laser remelting. The conference was attended by over 70 participants from 10 countries. The success of this conference prompted the organizer, Fraunhofer ILT, to continue it in 2016 once again before AKL’16.

June 11, 2014, Aachen
Seminar »Automated Assembly of Optical Systems«

On June 11, 2014 a seminar on »Automated Assembly of Optical Systems« took place at Fraunhofer IPT and was jointly conducted by Fraunhofer ILT and IPT. The seminar provided solutions for the assembly of optical systems and, thereby, addressed critical process steps, such as handling and manipulation, dispensing and curing of adhesives as well as passive and active adjustment. Moreover, the seminar treated optical design and the layout of customized machine concepts. The lectures were held by industry representatives as well as by employees of Fraunhofer IPT and ILT.

June 25, 2014, Aachen
Workshop: »Storage Technology«

On June 25, 2014, a workshop on »Storage Technology« took place at Fraunhofer ILT, which is a member of the innovation network »Electromobility Forum«. This workshop took place as part of the FSEM II cluster »Battery / Range Extender« of Fraunhofer System Research for Electromobility II. Above all, the FSEM II cluster spurs on technology in the fields of battery system development, housing technologies and production processes. The knowledge and experience gained were presented at the workshop. Selected lectures and a tour of Fraunhofer ILT provided participants with insight into the latest technologies, developments and processes.

Fraunhofer ILT demonstrations at the event »Potenziale«.

September 23 - 24, 2014, Schaumburg, IL, USA
Lasers for Manufacturing Event LME 2014

From September 23 to 24, 2014, »Lasers for Manufacturing Event« LME in 2014 was held in Schaumburg, Illinois, United States. Tim Biermann gave the keynote lecture on »Laser Additive Manufacturing/3D Printing«.

September 29 - 30, 2014, Stuttgart
Management Circle Trendforum »3D Printing«

In cooperation with Fraunhofer ILT, the Management Circle organized the second Trendforum on the topic of »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, among others, the question of the current technological and economic limits and the economic prospects of 3D printing as well as its differentiation from conventional manufacturing processes. Experts showed how companies are already using this technology successfully.

October 6, 2014, Aachen
Theme Night »Additive Manufacturing« and Specialist Group Meeting »Photonics«

The theme night »Additive Manufacturing« of the association NanoMicroMaterialsPhotonic.NMWP e.V. and the specialist group meeting »Photonics« took place on 6 October 2014, both of whom were guests at Fraunhofer ILT. The theme nights of the NMWP association serve to provide information from companies and universities on current developments, while giving their members the chance to visit facilities and talk with experts. In the run-up to the theme night, the kick-off event of the Photonics group of NMWP.NRW e.V. took place. These specialist group meetings offer members the opportunity to introduce themselves and present their latest developments, to exchange ideas and interests and initiate joint projects and collaborations.

October 16, 2014, Bochum
LaserForum 2014 »Increasing Productivity in Laser Micromachining«

After its successful start in the fall of 2013, the second LaserForum took place, covering the topic »Increasing Productivity in Laser Micromachining«, on 16 October 2014 at the Ruhr-Universität Bochum. The focus was on the issues of customized laser and optics systems, process strategies for productive laser micromachining and process monitoring for zero-failure manufacturing. Within the scope of the LaserForum, participants comprehensively present selected questions and trends on the use of laser technology along the entire industrial value chain each year. The forum, therefore, provides a platform for discussion between industry experts and is aimed at developers, manufacturers and users of laser technology solutions. The LaserForum was hosted by IVAM Microtechnology e.V. together with the partners Fraunhofer ILT, Laser Zentrum Hannover e.V., LIMO Lissotschenko Mikrooptik GmbH and Ruhr-Universität Bochum (RUB).

November 5, 2014, Aachen
POTENZIALE Event – Economy meets Science
3D Printing: Has the Future already Begun?
Chances and Limits of Application in Small and Medium-Sized Enterprises

On November 5, 2014, the Aachen Chamber of Industry and Commerce together with FH Aachen University of Applied Sciences, Fraunhofer ILT and the Arbeitskreis Lasertechnik e.V. hosted an event on the topic of 3D printing, which took place at Fraunhofer ILT. Application-oriented research institutions from the Aachen Technology Region introduced themselves to the industry in the POTENZIALE series. When research and industry exchange ideas and experience, they support the knowledge and technology transfer between them.

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The 3D-printing event was attended by entrepreneurs who, after the presentations, had the opportunity to visit the facilities of Fraunhofer ILT and exchange ideas in detail with the laser experts.

COLLOQUIUM ON LASER TECHNOLOGY AT THE RWTH AACHEN UNIVERSITY

January 16, 2014, Aachen
Chair for Laser Technology ILT at RWTH Aachen University
Colloquium on Laser Technology
Dr. Dimitri Scholz, Conway Institute – University College Dublin UCD, Ireland, »Contemporary University Imaging Facility for Cutting Edge Biomedical Research«

February 13, 2014, Aachen
Chair for Laser Technology ILT at RWTH Aachen University
Colloquium on Laser Technology
Prof. Dr. Alexander Heisterkamp, Laser Zentrum Hannover e.V., Hannover, »Laser in der Medizin und Biotechnologie«

1 Kick-off event of the Pupil's Mechanical Engineering University.

2 Closing ceremony of the MINT camp Production Technology at Fraunhofer ILT.

March 6, 2014, Aachen
Chair for Laser Technology ILT at RWTH Aachen University
Colloquium on Laser Technology
Prof. Dr.-Ing. Michael Zäh, Institut für Werkzeugmaschinen und Betriebswissenschaften (iwb), Garching
»Lasermaterialbearbeitung mit modernen Strahlquellen«

March 20, 2014, Aachen
Chair for Laser Technology ILT at RWTH Aachen University
Colloquium on Laser Technology
Prof. Dr. Klaus Behler, Technische Hochschule Mittelhessen
»Laser welding of (ultra) high strength steel«

March 27, 2014, Aachen
Chair for Laser Technology ILT at RWTH Aachen University
Colloquium on Laser Technology
Prof. Dr. Heinz P. Huber, Laserzentrum Hochschule München
»Ultrakurzzeit-Mikroskopie und Multi-Skalen-Simulation zeigen neue Aspekte der Laser-Ablation mit ultrakurzen Lichtimpulsen auf«

July 3, 2014, Aachen
Chair for Laser Technology ILT at RWTH Aachen University
Colloquium on Laser Technology
Prof. Dr. Claus Emmelmann, Laser Zentrum Nord GmbH, Hamburg, »Bionik durch Lasertechnologie – Vision oder industrielle Revolution«

July 24, 2014, Aachen
Chair for Laser Technology ILT at RWTH Aachen University
Colloquium on Laser Technology
Ph.D. M.Sc. Bart van der Schüren, Materialise N.V., Belgium
»3D Printing: A hype or a real game changer?«

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AIX-LASER-PEOPLE

May 9, 2014, Aachen
48th Seminar of the »Aix-Laser-People« Alumni Club and the Arbeitskreis Lasertechnik e.V.
Almost 60 alumni and members of AKL e.V. took part at the Aix-Laser-People meeting, which was held in the context of the International Laser Technology Congress AKL'14 from May 7 to 9, 2014. They caught up on the latest developments of Fraunhofer ILT in 80 live laser-technology demonstrations. In addition, the Arbeitskreis Lasertechnik e.V. held its general meeting at Fraunhofer ILT. In the subsequent get-together, the alumni and current employees of Fraunhofer ILT exchanged ideas in detail.

December 18, 2014, Aachen
49th Seminar of the »Aix-Laser-People« Alumni Club and the Arbeitskreis Lasertechnik e.V.
This seminar was marked by the Vertical-Cavity Surface-Emitting Laser (VCSEL). First, Hans-Dieter Hoffmann, head of the Laser and Laser Optics competence field at the Fraunhofer ILT, gave an overview of the state of the art and the potential of this particular semiconductor laser. Next, Dr. Joseph Pankert, CEO of Royal Philips Electronics Photonics Aachen, expanded on the different fields of application of the vertical-cavity surface-emitting laser in his talk »VCSEL Everywhere: Laser Technology in Everyday Objects«. Finally, the 40 participants were able to visit a semiconductor laser in use in the laboratories of Philips Photonics Aachen.

EVENTS FOR PUPILS AND STUDENTS

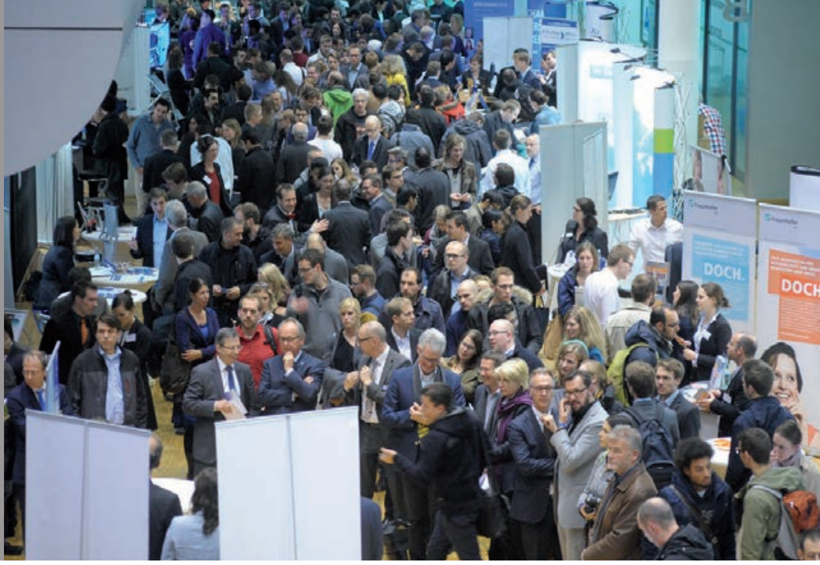
May 9, 2014, Aachen
Student Tour
The students who attended the lectures Laser Beam Sources and Introduction to Laser Applications in the winter semester 2013/14 were taken on a tour through Fraunhofer ILT, where they gained insight into current research topics. The tour was carried out as part of the »Laser Technology Live« of the AKL'14.

May, 26, 2014, Aachen
Guided Tour of the Institute
Orientation event of the Chair for Laser Technology LLT and Fraunhofer ILT for the German Society of Glass Technology (DGG) and the Glass & Optical Materials Division (GOMD).

June 20, 2014, Herzogenrath
Excursion to the company Clean Laser Systems GmbH
A group of students visited Clean Laser Systems GmbH as part of the field-trip week of RWTH Aachen University.

June 20, 2014, Aachen
Student Orientation Day
A Yb:INNOSLAB demonstrator model was exhibited in the Kármán Building at the RWTH Aachen University as part of the student orientation day on Physics for high school graduates and prospective students.

July 17, 2014, Aachen
Pupil University
In the summer break, RWTH Aachen University offers Schools at University free-of-charge on the MINT subjects (Mathematics, Information Technology, Natural Sciences, Technology) for pupils starting at the ninth grade. For one week pupils get



Well attended: Fraunhofer ILT in the »Companies' Night« in Aachen

Students experiment as part of the Mechanical Engineering Pupils' University.

to know university life. Along with other institutes from the Department of Mechanical Engineering A and the student body of Mechanical Engineering, Fraunhofer ILT contributed lectures and laboratory exercises on the topic of laser technology.

October 10, 2014, Aachen
Guided Tour for Students
Orientation event of the Chair for Laser Technology LLT and Fraunhofer ILT for first semester students from Egineering Science at the RWTH Aachen University.

October 20, 2014, Aachen
Visit by the Teaching Staff of St. Ursula Gymnasium
A meeting was organized by the Chair for Laser Technology LLT and Fraunhofer ILT to inform the teaching staff of St. Ursula High School in Geilenkirchen about current laser activities.

November 6, 2014, Aachen
Companies' Night
Under the new personnel marketing campaign of the Fraunhofer-Gesellschaft, Fraunhofer ILT presented itself using the slogan »DOCH« with a new design and location-specific content at the 7th Companies' Night. On November 6, over 2,000 graduates, students and professionals were able to gather information from some 95 exhibiting companies and institutions on how they can shape their careers.

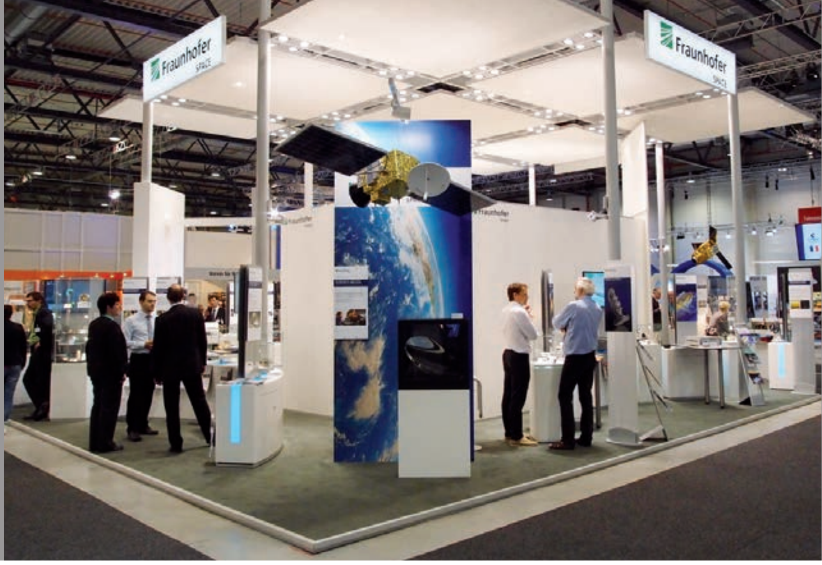
Previously, from 13 October to 6 November 2014, the modular design of Fraunhofer Employer Branding campaign was successfully rolled out as a pilot project of the Aachen institutes. There were individual and innovative marketing campaigns, such as the three-dimensional letters of the slogan DOCH. The Fraunhofer headquarters recognized the campaign as »Best Practice«.

November 15, 2014, Aachen
MINT Camp Production Technology
At this year's MINT-EC camp in Aachen, 19 high school students gained exciting insight into the world of »production technology« from the Cluster of Excellence »Integrative Production Technology for High-Wage Countries«. At Fraunhofer ILT, the high school students experimented with light and lasers for an entire morning.

November 28, 2014, Aachen
Guided Tour of the Institute
Guided tour of the institute and a short introduction into laser technology at Fraunhofer ILT for the IHK. The main topic was additive manufacturing.

TRADE FAIRS

SPIE Photonics West 2014
February 1 - 6, 2014, San Francisco, USA
International Trade Fair for Optics and Photonics
Fraunhofer ILT attended the international trade conference Photonics West and gave 12 lectures: »High-power dense wavelength division multiplexing (HP-DWDM) of frequency stabilized 9xx diode laser bars with a channel spacing of 1.5 nm«, »Feasibility and performance study for a space-borne 1645 nm OPO for French-German satellite mission Merlin«, »Green sub-ps laser exceeding 400 W of average power«, »Broadly tunable, longitudinally diode-pumped alexandrite laser«, »Cognition for robot scanner based remote welding«, »Tracking the course of the manufacturing process in Selective Laser Melting«, »Simultaneous laser and seam tracking with texture based image processing for laser material processing«,



Joint stand of the »Fraunhofer-Alliance Space« at the ILA Berlin Air Show.

Fraunhofer ILT at Photonics West in San Francisco.

»Numerical analysis of external feedback concepts for spectral stabilization of high-power diode lasers«, »Automated alignment of fast-axis collimator lenses for high-power diode laser bars«, »Utilizing the transparency of semiconductors via backside machining with a nanosecond 2 microns Tm: fiber laser«, »Quasi-simultaneous laser soldering for the interconnection of back-contact solar cells with composite foils«, and »Investigations on laser transmission welding of absorber-free thermoplastics«. In addition, Fraunhofer ILT exhibited innovative developments in laser sources and optics at the joint stand of the Federal Republic of Germany from February 4 to 6, 2014.

JEC Europe 2014
March 11 - 13, 2014, Paris, France
Composite Show & Conferences
Fraunhofer ILT exhibited economical production processes for fiber composites at the joint Fraunhofer stand. To this end, results from the EU project »FiberChain« and the BMBF-funded project »InProLight« were presented. Both aim to develop various integrative process chains, from sophisticated special solutions to large-series production of thermoplastic FRP components. The institute showed FRP components and plastic-metal hybrid components that have been processed by methods developed at Fraunhofer ILT.

LASER World of PHOTONICS China
March 18 - 20, 2014, Shanghai, China
International Trade Fair for Optics and Photonics
Along with Laserfact, the group micro- and nano-structuring of Fraunhofer ILT showed visitors helical drilling optics as well as a CombiHead tool. Within this framework, processes in the fields of drilling and cutting were shown. They presented applications for drilling injector nozzles and sapphire and for cutting and processing of wafers and metallic and nonmetallic materials.

Hannover Messe 2014
April 7 - 11, 2014, Hanover
International Industrial Exhibition
Fraunhofer ILT presented typical applications of USP lasers as well as processes for the functional coating of components and for micro-joining. The institute exhibited coated components such as laser-based manufactured interconnects and nanolayers for wear protection from the field of thin-film processes. In addition, it showed exhibits from the area of laser cladding. The exhibits dealing with micro-joining displayed to which extent this process can be used. Moreover, they revealed how diverse the applications using USP ablation are as well as demonstrating how highly selective the process is and how deep it can ablate material.

Control
May 6 - 9, 2014, Stuttgart
International Trade Fair for Quality Assurance
Fraunhofer ILT presented the new bidirectional interferometric distance sensor »bd-1« for inline process monitoring of the shape and roughness of shafts. Interested visitors were able to experience live measurements of the »bd-1« at the joint Fraunhofer stand.

ILA Berlin Air Show 2014
May 20 - 25, 2014, Berlin
International Aerospace Exhibition
At the joint stand of the »Fraunhofer-Allianz Space«, Fraunhofer ILT presented diode laser-pump modules for satellite-based free-space telecommunications, solid-state lasers for LIDAR applications, fiber lasers for a satellite-based interferometer to measure the gravitational field, laser processing of fiber-reinforced components and additive manufacturing of components for telecommunications satellites. Together with Fraunhofer IPT, Fraunhofer ILT presented the Fraunhofer Innovation Cluster »AdaM – Adaptive Production for Resource

Efficiency in Energy and Mobility«. There, Fraunhofer ILT presented, among others, blade clusters that were produced in the 3D printing process Selective Laser Melting (SLM) as well as applications for an automated process chain to repair blade tips with Laser Metal Deposition (LMD).

Biomedica
June 17 - 18, 2014, Maastricht
Summit on Life Sciences
At the joint stand LifeTecAachen-Jülich e.V., the Fraunhofer ILT group Biotechnology and Laser Therapy presented studies on the functionalization of soft tissue implants. In addition, it showed exhibits from the subject areas of bio-fabrication and 3D printing, such as tubes as supporting structures for blood vessels and scaffolds for 3D cell cultures.

LASYS
June 24 - 26, 2014, Stuttgart
International Trade Fair for Laser Material Processing
At the joint stand »Laser Additive Manufacturing«, the group Integrative Production from Fraunhofer ILT and RWTH Aachen University presented the latest results in the field of the additive production process Selective Laser Melting (SLM). Functionally optimized components of various Formula Student racing teams were exhibited to illustrate the potential of this additive manufacturing process. Furthermore, industry representatives were given deeper insight into the new research concept of the Digital Photonic Production Research Campus.

1 Fraunhofer ILT at »Medica« in Düsseldorf.

2 Fraunhofer ILT at the joint Fraunhofer stand of »EuroBLECH« in Hanover.

Composites Europe 2014
October 7 - 9, 2014, Düsseldorf
European Trade Fair & Forum for Composites, Technology and Applications
Fraunhofer ILT presented economical production methods for fiber composites at the joint Fraunhofer stand. Exhibited were FRP components and plastic-metal hybrid components processed by methods developed at Fraunhofer ILT. These exhibits included demonstrator models from the »InProLight« process chain, cross sections of front-end components, exhibits on plastic-metal hybrid compounds and others of laser-based lightweight applications.

Fakuma
October 14 - 18, 2014, Friedrichshafen
International Trade Fair for Plastics Processing
Along with Fraunhofer IPT and the IKV institute of the RWTH Aachen University, Fraunhofer ILT was present at the joint booth »Plastic NRW«. Both institutes presented their know-how on the design and manufacture of plastic optics. To this purpose, several freeform optics were exhibited: among others, a multifunctional free-form optics made of plastic, logo lenses and highly efficient free-form optics for street lighting. During the fair, the TWIST technique was also presented for the absorber-free joining of transparent plastics.

ICALEO
October 19 - 23, 2014, San Diego, USA
33rd International Congress on Applications of Lasers & Electro-Optics
In 2014 Fraunhofer ILT participated at the ICALEO, holding several presentations. Before some 350 participants of the ICALEO congress, LIA President Yongfeng Lu and LIA CEO Peter Baker awarded Prof. Poprawe the Arthur L. Schawlow Award 2014. With this award, they paid tribute to the services of the former LIA President for his outstanding contributions to basic research and applied research in laser engineering.

These have made an effective contribution to the use of lasers in the industry, medicine and everyday life. In his presentation »Digital Photonic Production - The Future of Tailored Light«, Prof. Poprawe pointed to how laser technology – in particular through networking with the virtual world – will continue to change industrial production.

glasstec
October 21 - 24, 2014, Düsseldorf
International Trade Fair for the Glass Production, Processing and Products
Fraunhofer ILT presented optical components polished with CO_2 lasers and free-form surfaces it generated as well as laser-soldered and -welded glass composites at the joint Fraunhofer stand. Likewise, it exhibited microstructurings of fluidic components and mechanisms, processed by means of inverse glass drilling and Selective Laser-induced Etching (SLE), and sub-surface interior marking in glass for anti-counterfeiting.

EuroBLECH 2014
November 21 - 25, 2014, Hanover
International Sheet Metal Working Technology Exhibition
To demonstrate how press-hardened martensitic chromium steels can be laser welded reliably for the first time, Fraunhofer ILT presented a test component for B-pillars at EuroBLECH. On the subject of weight reduction by laser-assisted hybrid processes, Fraunhofer ILT exhibited a laser heat-treated B-pillar out of MBW®1500.

Compamed/Medica
November 12 - 14/15, 2014, Düsseldorf
World Forum for Medicine and International Trade Fair
Fraunhofer ILT was present at two stands, at the joint IVAM stand at Compamed and at the joint Fraunhofer stand at Medica. At Compamed, Fraunhofer ILT presented information on laser polishing, welding and Selective Laser Melting (SLM) in medical technology. These included the topics laser polishing and surface finishing, laser welding of plastics, biophotonics and SLM. The institute exhibited components made of titanium, whose surfaces have been improved by laser polishing to improve their biocompatibility, and laser-welded multilayer films for the production and packaging of medical devices. In addition, Fraunhofer ILT presented transparent plastic components connected without absorbers by laser transmission beam welding, biocompatible support structures of hydrogels, generated with the aid of laser radiation, and resorbable scaffolds from magnesium alloy, produced with Selective Laser Melting.

At Medica, »LightSort« was presented, a device for the detection of antibiotic resistance, as was »miniScan«, a fast mini scanner for laser therapy systems. »LightSort« separates fluorescently labeled pathogens according to species in a microfluidic system so as to make them available to a resistance test afterwards. With »miniScan«, Fraunhofer ILT has developed a new compact 2D scanning technology that combines a small unit volume with a large optical aperture. »miniScan« is predestined for use in laser therapy systems because, thanks to its compact design, the scanner can be integrated in a hand-piece for the application of therapeutic laser radiation. The optics of »miniScan« can be provided with all the high-performance coatings available and is, therefore, particularly suitable for picosecond and femtosecond laser radiation of high pulse peak power.

3 Fraunhofer ILT at EuroMold in Frankfurt.

EuroMold
November 25 - 28, 2014, Frankfurt/Main
World Fair for Mold- and Patternmaking, Tooling, Design, Additive Manufacturing and Product Development
At the fair, Fraunhofer ILT presented a completely new SLM system design concept, which was illustrated by a laboratory system of ILT. This new design makes it possible to scale productivity and building space size easily, thus generating significantly lower costs than with comparable conventional systems. Exhibited were also different laser-polished tools for the manufacture of glass, sheet metal and plastic parts and laser-polished components. In the area of SLM, ILT exhibited diverse sample components in medical technology (implants of cobalt chromium, magnesium and bioresorbable composites), turbomachinery and automotive engineering.

AWARDS AND PRIZES

Prof. Poprawe receives honorary professorship in Beijing
In April 2014, Prof. Poprawe, Representative of the RWTH Aachen University Rectorate for the People's Republic of China, was appointed Honorary Professor of Tsinghua University in Beijing. This university is one of the most prestigious and strongest research universities of science and technology in China.

Schawlow Award for Prof. Poprawe
LIA President Yongfeng Lu and LIA CEO Peter Baker awarded Prof. Poprawe with the Arthur L. Schawlow Award 2014 in front of around 350 participants at the ICALEO Congress in San Diego, California on October 22, 2014. With this award, they paid tribute to the merits of the former LIA President for his outstanding contributions to basic research and applied research in laser technology.

Borchers Badge
The Borchers Badge is awarded to doctoral students who pass their doctoral examination »With Distinction« at RWTH Aachen University. The namesake of the award plaque is the Privy Professor Wilhelm Borchers, who was professor of metallurgy at the academy from 1897 until 1925. On September 5, 2014 the following employees or former employees of Fraunhofer ILT were awarded the Borchers Badge: Axel Bäuerle, Georg Bergweiler, Damien Buchbinder and André Temmler.

1 Prof. Poprawe (middle) at the ceremony of »Schawlow Award« in San Diego, USA, source: LIA.

ARBEITSKREIS LASERTECHNIK AKL 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 137 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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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 (chairman)
  TWI, Great Britain
- Dr. Wolfgang Knapp
  CLFA, France
- Prof. Veli Kujanpää
  VTT Technical Research Center of Finnland, Lappeenranta, Finland
- Dr. Filip Motmans
  Lasercentrum Vlaanderen, Belgium
- Prof. José Luis Ocaña
  Centro Láser U.P.M., Spain
- Dr. Alexander Olowinsky
  Fraunhofer ILT, Germany
- Prof. Andreas Ostendorf
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und Energie

Die Landesregierung
Nordrhein-Westfalen

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DFG Deutsche Forschungsgemeinschaft

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