Fraunhofer ILT

FRAUNHOFER-INSTITUTE FOR LASER TECHNOLOGY ILT

ANNUAL REPORT 2013

ANNUAL REPORT FRAUNHOFER INSTITUTE FOR LASER TECHNOLOGY 2013

Dear Reader,

Wouldn't you also agree that innovative processes are not only becoming more and more complex, but that the intervals between them are getting shorter and shorter? Indeed, this development has direct consequences for how innovative teams are composed and who has access to new knowledge. Thus, not unexpectedly, we scientists are currently seeing a paradigm shift in how the industry is exploring appropriate know-how. While previous innovators had to know what the current »state of knowledge« was, now they need to know who owns knowledge. Tomorrow, in contrast, technology pioneers will have to know where knowledge emerges! Exactly this is what several technology concerns have already internalized to such an extent that they can spot global hot-spots of knowledge and embed themselves there in various ways. As we sustainably sight and generate knowledge on the »pulse of the time« and at »the place it happens«, we can then open up decisive competitive advantages.

For this reason it is obvious that relevant centers of science have to increasingly consider how they can integrate industrial R&D partners into their own work processes, not only via short-term projects, but much more by developing ways to cooperate that run over the medium and long-term, ones that are aligned strategically. Since our very foundation at Fraunhofer ILT, we have been practicing a spin-in strategy: companies can set up their businesses in our institute's building, but in their own offices and laboratories; this way, they can cooperate closely with the institute's expert teams. We are not interested here in conducting individual, complex projects, but rather in fostering a continuous exchange of know-how and the use of a modern laser infrastructure.

Now, on location in Aachen, we have another new format for this kind of cooperation in the sector of production-oriented optical technologies – the RWTH Campus. Here, companies can take up residence in their own building directly next to the university's institutes and the Fraunhofer-Gesellschaft for the long-term. Within the scope of »enrolling at the university«, they can fall back on the entire range of services RWTH Aachen University has to offer. This format will do justice to the complexity of innovations since it makes interdisciplinary, strategic cooperation possible. At Fraunhofer ILT and the co-operating optical RWTH university chairs, we are coordinating this new form of interaction with the industry in the field of Digital Photonic Production. If you would like to make use of the added value of a high-performance German cluster for production-oriented optical technologies, please talk with us! We'll gladly cooperate with you to help create your tailor-made solutions.

Yours sincerely,

Reinhart Poprawe

Prof. Dr. rer. nat. Reinhart Poprawe M.A.

CONTENTS

PROFILE OF THE INSTITUTE

SHORT PROFILE

ILT - this abbreviation has stood for combined know-how in the sector of laser technology since 1985. 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 around 400 employees and around 11,000 m^2 of usable space, 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

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.

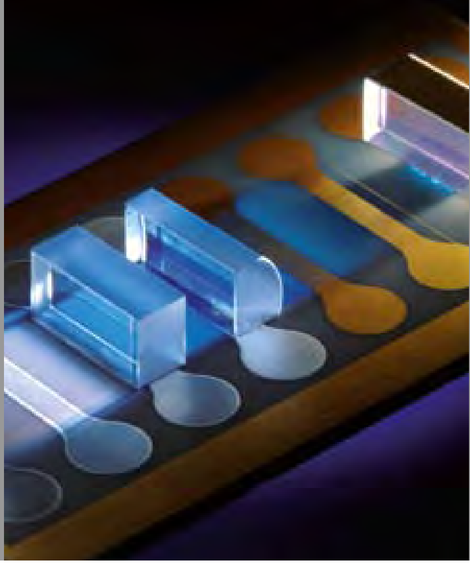
Furthermore, this technology field has a great deal of expertise in beam shaping and guiding, packaging of optical high power components and designing optical components. This field also specializes in dimensioning highly efficient free form optics. In general, the lasers and optics developed here can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

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.

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STRUCTURE OF THE INSTITUTE

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Director

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Vice Director

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Dr. Arnold Gillner
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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
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The 28th Board of Trustees meeting was held on September 11, 2013 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. Vasvija Alagic MBA, K. Bongard, M. Brankers, A. Hilgers, A. Lennertz, E. Neuroth, Dipl.-Ing. H.-D. Plum, 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, B. Theisen, Dr. C. Janzen.

Workers' Council

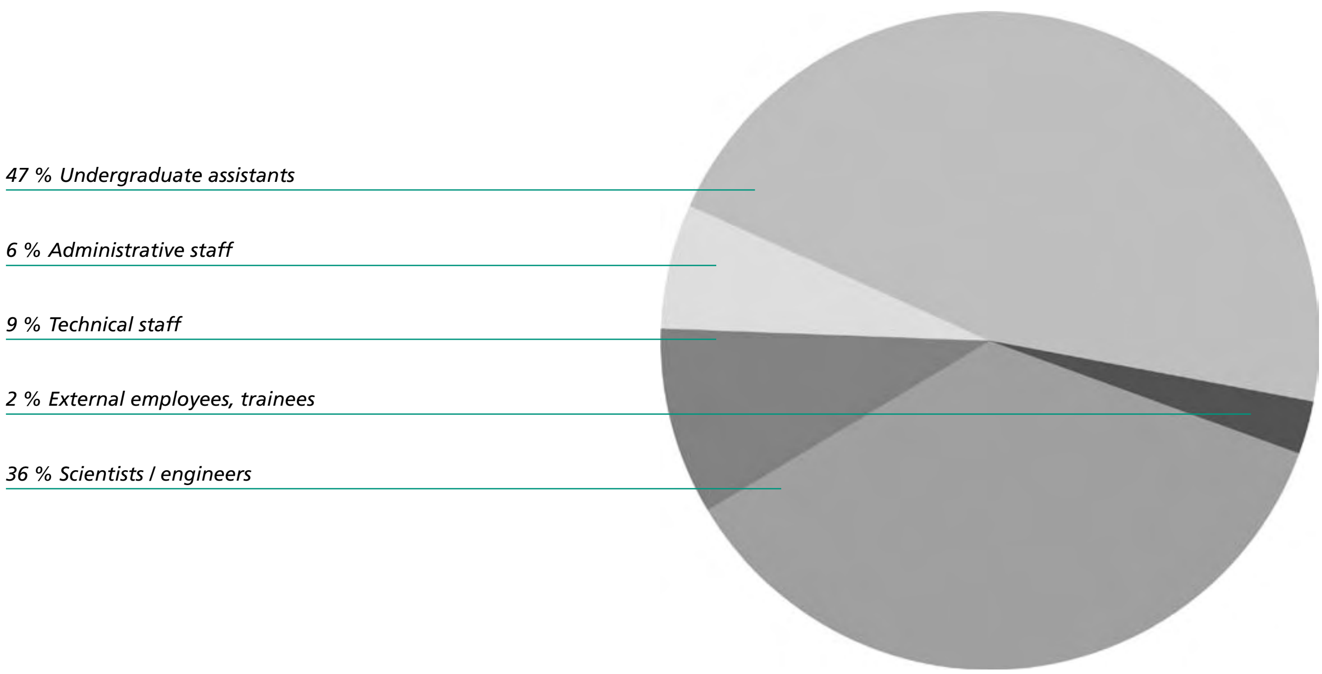
In March 2003, the employees of Fraunhofer ILT and the cooperating university chairs elected a workers' council for the first time. Members of this council since the election in 2010 have been Dipl.-Ing. P. Abels, M. Brankers, Dipl.-Ing. A. Dohrn, C. Hannemann, M. Janßen, Dipl.-Phys. A. Temmler, B. Theisen (chair of council), Dr. A. Weisheit, Dipl.-Ing. N. Wolf.

FACTS AND FIGURES

EMPLOYEES

Employees at the Fraunhofer ILT 2013	number
Personnel	**217**
- Scientists and engineers	152
- Technical staff	39
- Administrative staff	26
Other employees	**204**
- Undergraduate assistants	196
- External employees	4
- Trainees	4
Total number of employees at the Fraunhofer ILT	**421**

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



REVENUES AND EXPENSES

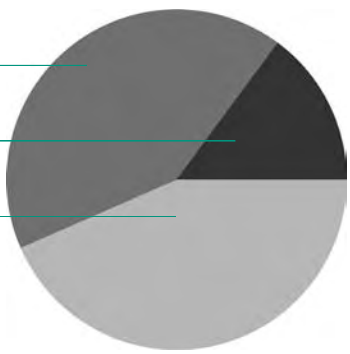
Expenses 2013	Mill €
- Staff costs	14,9
- Material costs	14,3
Expenses operating budget	**29,2**
Investments	**5,1**

Revenues 2013	Mill €
- Industrial revenues	12,1
- Additional financing from Federal Government, States and the EU	11,6
- Basic financing from the Fraunhofer-Gesellschaft	5,5
Revenues operating budget	**29,2**
Investment revenues from industry	**0,9**
Fraunhofer industry ρ_{Ind}	**44,4 %**

42 % Material costs

15 % Investments

43 % Staff costs

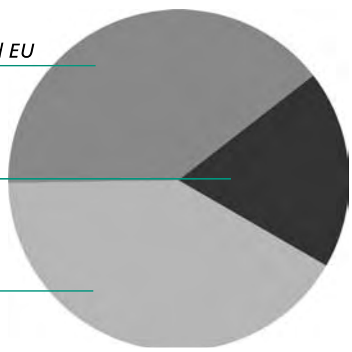


(100 % Operating budget und Investments)

40 % Additional financing from Federal Government, States and EU

19 % Basic financing from the Fraunhofer-Gesellschaft

41 % Industrial revenues (without investments)

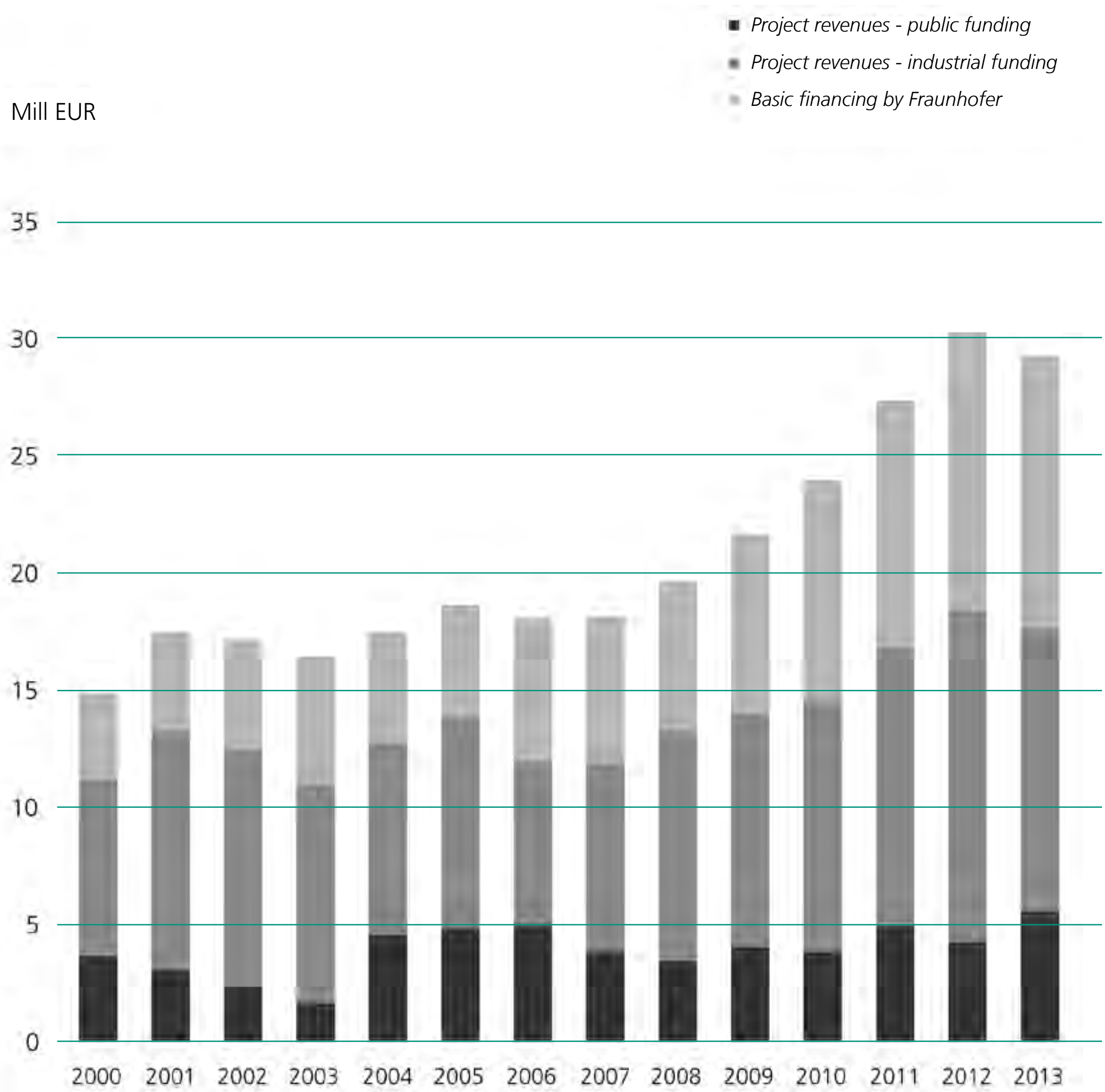


(100 % Operating budget)

FACTS AND FIGURES

BUDGET GROWTH

The following graph illustrates the budget trend over the last 14 years.



REFERENCES

ABB · arnold RAVENSBURG · Aurubis · Bartels mikrotechnik · BASF
BEGO · Berlin Heart · BMW · BOMBARDIER · BOSCH
BRAUN · COHERENT · CONCEPTLASER · DILAS · DILLINGER HÜTTE
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reis REIS ROBOTICS · rofin · Rolls-Royce · Sempell · SIEMENS
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TRUMPF · Valeo · voestalpine · VYGON · ZWIESEL KRISTALLGLAS

***As at December 2013.** 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 usable floor space at the Fraunhofer Institute for Laser Technology ILT amounts to more than 11,000 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 USA CENTER FOR LASER TECHNOLOGY CLT

Short Profile

The Fraunhofer Center for Laser Technology CLT, located in Plymouth, Michigan, has a 1250 m² development center. This area has established itself as the center for laser production, system integration and industrial users in the USA.

The goals of Fraunhofer CLT are:
1. Integration in scientific and industrial development in the USA
2. Accumulation of know-how at the German parent institute through early recognition of trends led by the USA
3. Know-how growth at Fraunhofer CLT through close cooperation with the University of Michigan and the Wayne State University as well as other leading US universities
4. Local provision of services to international companies on both continents
5. Student exchange programs

The central philosophy of Fraunhofer USA is the creation of a German-American cooperation where give and take occur in harmony. The American partner universities' interest concentrates on:
1. Using the competence of the Fraunhofer Institutes
2. Using the experience in the introduction of new technologies into the market
3. Providing the connection between industry and university
4. Providing practical training for students and graduate students

Powerful, highbrilliance fiber lasers are developed in collaboration with the University of Michigan. The basic research and concepts of new fiber geometries to achieve high (pulse) energies with diffraction limited beam quality are developed at the university, while Fraunhofer undertakes the development of high-brilliance pump sources, system integration, prototype construction and application tests. In this context, the CLT has implemented new technologies and manufacturing methods for multi-single-emitter diode lasers that make diode lasers comparable to solid-state lasers in terms of their performance. Constant work done over the last 10 years in this area has led to innovative designs and new assembly techniques that allow a threefold increase in beam intensity and hence a considerable widening of the field of machining applications for diode lasers.

Another key activity of CLT is developing cost-effective manufacturing processes for alternative energy generation and storage. Here, the institute is focusing on solar cells, lithium-ion batteries and super capacitors. For this, laser-induced ablating, cutting and joining processes, also for dissimilar materials and material composites, form the technological foundations. In bilateral projects, the CLT is currently transferring the research results into industrial applications.

For the manufacturing of solar cells, lasers have been successfully applied to increase their efficiency. At Fraunhofer CLT, high-speed drilling processes have been developed for EWT and MWT cells, thereby improving the productivity of laser drilling by a factor of six. Developmental work for the drilling of vias as well as for doping the cells was conducted successfully in cooperation with the US branch office of a large German solar cell manufacturer and was financed by the Department of Energy (DOE).

In the field of additive manufacturing, CLT is focusing on using diode lasers to develop new processing heads with multi-jet technology. By optimizing temperature control, the institute aims to clad – free of defects and with high quality – crack-sensitive nickel-based super alloys for applications in turbine engines. The development of the processing head was financed with public funding and occurred in cooperation with the University of Michigan. Along with Fraunhofer ILT, CLT will be optimizing processes for specific materials and their

applications.

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Services

The CLT offers services in the field of laser processing as well as the development of optical components and special laser systems. This covers the entire spectrum from feasibility studies, process development, pre-series development as well as prototype production of laser beam sources to laser systems which are ready to use. Our customers predominantly come from the automobile industry, energy and medical engineering.

Facilities

At the moment facilities at the CLT include a host of lasers for micromaterial processing along with several high-power lasers. Fiber lasers with diffraction-limited beam quality with up to 500 W cw and 25 kW pulse output with flexible pulse parameters, frequency-tripled Nd:YAG and CO_2 lasers as well as diode lasers are available for process developments involving micro technology.

Operating budget 2013

	Mill US $
Operating budget	**1.8**
- Staff costs	1.0
- Material costs	0.8

References

- U.S. Navy Research Laboratory
- U.S. Army Research Laboratory
- Department of Energy (DOE)
- State of Michigan
- Continental
- DirectPhotonics Industries
- Dow
- Federal Mogul
- Ford
- IDEX Health & Science
- Magna
- Medtronic
- Procter & Gamble
- SolarWorld
- Visotek

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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, including the university MINES ParisTech, the École Nationale Supérieure de Mécanique et des Microtechniques ENSMM in Besançon, the engineer university ECAM Rennes Louis de Broglie and other major laser application centers in France. 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, and actively participates in the organization of regional and national conferences and exhibitions. Thus in 2013 CLT participated in the joint Fraunhofer booth at the JEC Composite Show in Paris as well as in the national laser conference JNPLI.

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 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 and is a result of increasing link of application oriented research and development in the field of laser technology in Europe.

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. On an international scale this cooperation further strengthens the leading position of European industry in the laser supported manufacturing process.

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 and graduate students

The CLFA has strong cooperations especially with midsized companies. In 2007 the CLFA staff, together with their French partners, spun off a new company called Poly-Shape, which provides French customers with services in the field of generative manufacturing processes. Poly-Shape cooperates with the CLFA and the Fraunhofer ILT in the framework of regional and European projects.

Major research projects

In the »PROBADUR« collaborative research project, co-funded by the BMBF and the French National Research Agency ANR, the Fraunhofer ILT investigated the mechanical properties of laser-joined fiber-reinforced thermoplastics. The results of this work, conducted in collaboration with Fraunhofer LBF and the French Carnot institutes Cetim and M.I.N.E.S., provide an improved basis for predicting the performance of this type of material after machining. Fiber-reinforced thermoplastics are increasingly being used to replace conventional materials in the automotive and aviation sectors, in particular, owing to their light weight.

In another research project being conducted jointly with scientists at the Centre des Matériaux in Evry, France, we are evaluating the ability of laser-based structuring processes to improve the adhesive properties of various surface coatings.

All of these projects have provided undergraduate and postgraduate students from Germany and France with an opportunity to complete their dissertation and thesis papers, and allowed holders of Erasmus scholarships to gather their first experience in an international research environment.

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. The open development platform allows the French customers to test and qualify new laser supported manufacturing processes.

Employees

At the CLFA employees from France and Germany work together. A mutual exchange of personnel occurs between Aachen and Paris for joint projects. The employees therefore have the opportunity to improve their competence especially with regard to mobility and international project management.

Equipment

In addition to the technical resources available at the Fraunhofer ILT in Germany, the CLFA possesses its own infrastructure at the Centre des Matériaux Pierre-Marie Fourt, an outstation of MINES ParisTech based in Evry, south of Paris. Facilities include access to the center's material science laboratories. The technical infrastructure of other French partners can also be shared on a project- or customer-specific basis.

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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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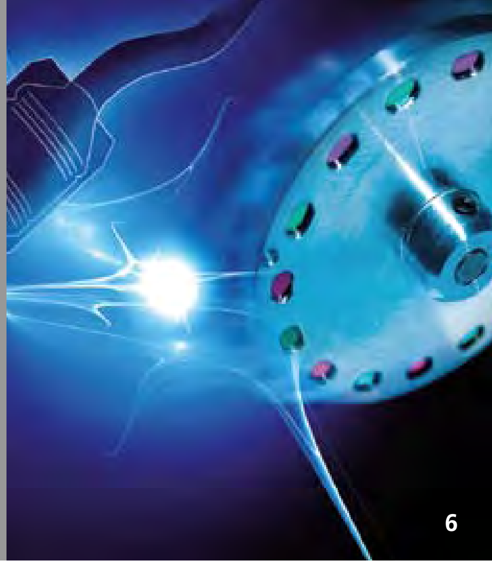
www.light-and-surfaces.fraunhofer.de

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 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 67 institutes and research units. The majority of the more than 23,000 staff are qualified scientists and engineers, who work with an annual research budget of 2 billion euros. Of this sum, more than 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 km², making it one of the leading national and international knowledge and research centers. The location will be the former university extension site in Aachen Melaten along with part of the Aachen Westbahnhof (Aachen West Train Station). This setup will connect for the first time the core areas of the RWTH Aachen in the city center, in the Hörn district and in Melaten, to create an integrated campus.

Research Catalyst and Innovation Generator

The RWTH Aachen Campus offers a groundbreaking symbiosis between industry and university education in the form of »university enrolment« for staff at locally based companies - an unrivalled setup in Germany. This enables companies to actively participate in key fields addressed by the competence clusters, as well as in research, development and teaching, while incorporating their own areas of interest and resources. At the same time, it ensures access to qualified young staff and facilitates accelerated practically based PhD programs.

Interested companies can relocate to the RWTH Aachen Campus by leasing space or with their own building. This generates a unique, more intensive form of collaboration between university and business; no other university in Europe currently boasts a greater number of major application-oriented institutes than the RWTH Aachen.

A holistic concept underpins the entire project: Research, learning, development, living. The RWTH Aachen Campus creates an ideal, prestigious working environment for more than 10,000 employees, with research institutions, offices and training center. The campus also offers superb quality of life, through hotel and living accomodation, top-class restaurants, shopping facilities, childcare facilities and a range of service and relocation organizations.

Development and Timetable

The RWTH Aachen Campus will be created in three stages. The first stage was started in 2010 with the development and construction of Campus Melaten with its 6 clusters. The land-use plan and development of the Campus Westbahnhof will follow, involving another 9 clusters. The second stage will see the development and construction of Campus Westbahnhof with 4 clusters. And the final 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.

Clusters

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

Prof. Dr. Reinhart Poprawe M.A. from Fraunhofer ILT and from the Chair for Laser Technology LLT is director of the Photonics Cluster.

Source:
Machine tool lab at the RWTH Aachen,
Project planning RWTH Aachen Campus.

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1 3D view of the »Campus-Boulevard«, 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 are currently being used in an initial batch of facilities for series 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.

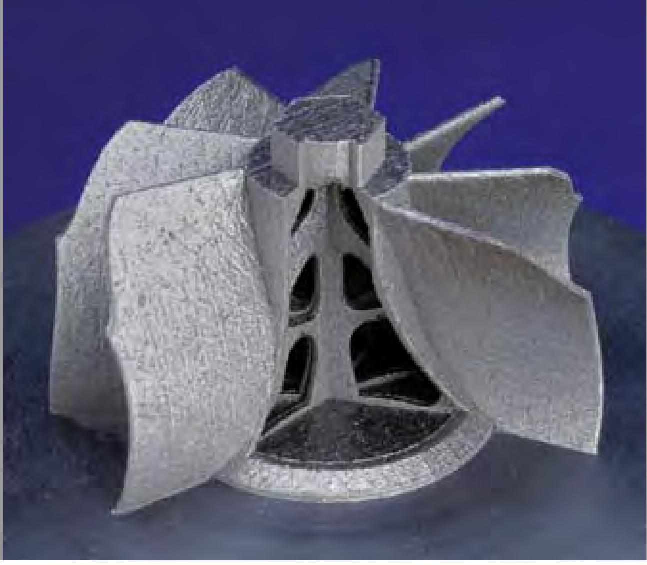
Mass customization

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 new BMBF Digital Photonic Production Research Campus in Aachen now 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 ten winners, having coordinated a proposals consortium. This new initiative will see 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 automotive 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 2013

Selected Research Results of the Fraunhofer ILT

Note from Institute Director

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

TECHNOLOGY FOCUS
LASERS AND OPTICS

This technology field - Lasers and Optics - focuses on developing innovative laser beam sources and high quality optical components and systems. Fraunhofer's team of experienced laser engineers builds beam sources which have tailor-made spatial, temporal and spectral characteristics and output powers ranging from µW to GW. These sources span a wide range of types: from diode lasers to solid-state lasers, from high power cw lasers to ultrashort pulse lasers and from single frequency systems to broadband tunable lasers.

In the field of solid-state lasers, oscillators as well as amplification systems with excellent power data hold the center of our attention. Whether our customers are laser manufacturers or users, they do not only receive tailor-made prototypes for their individual needs, but also expert consultation to optimize existing systems. In the realm of short pulsed lasers and broad band amplifiers in particular, numerous patents and record-setting values can be provided as references.

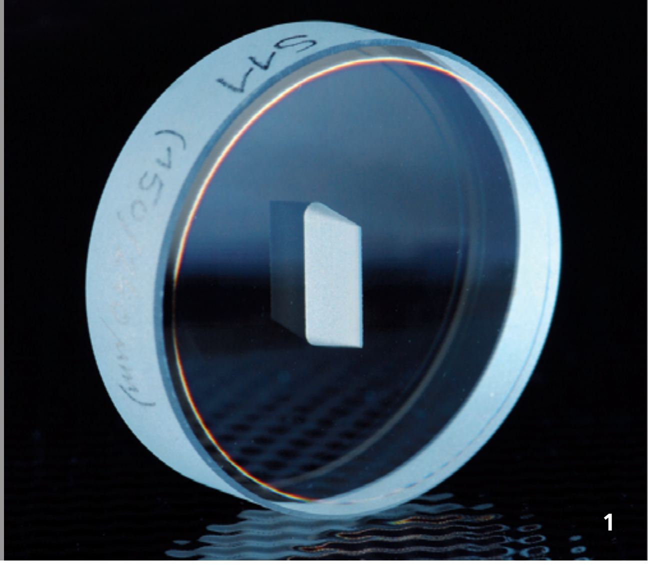
Furthermore, this technology field has a great deal of expertise in beam shaping and guiding, packaging of optical high power components and designing optical components. This field also specializes in dimensioning highly efficient free form optics. In general, the lasers and optics developed here can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

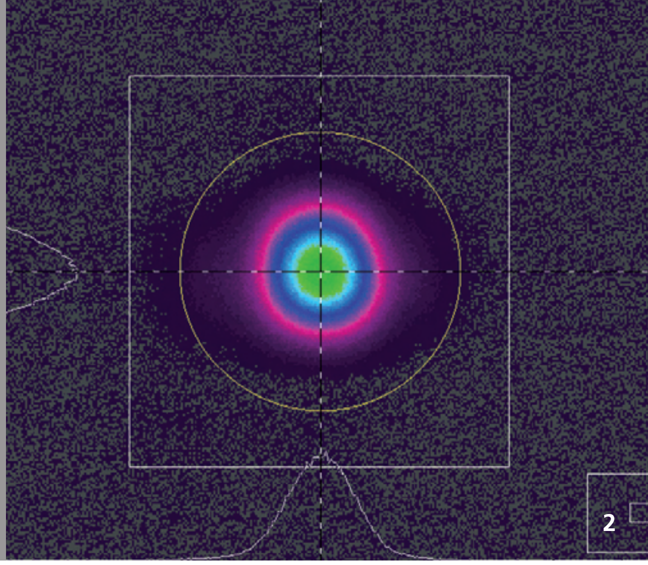
RESEARCH RESULTS 2013

LASERS AND OPTICS

CONTENTS

Fiber amplifier pumped at 1010-1030 nm.





HIGH-POWER YB:INNOSLAB AMPLIFIER WITH SPACE FILTER

Task

Ultra-short pulse lasers have found a wide range of applications in science and industry. From a beam source for particularly precise applications, for example in micro-structuring, a very excellent beam quality is expected, in an ideal case, one that is diffraction limited. At the same time, for a cost-efficient use of the expensive beam sources, a large throughput and, therefore, high mean power is desired.

When fs oscillators and Yb:INNOSLAB amplifiers are combined, output powers up into the kW range can be generated, all with a beam quality of a minimum of $M^2 = 1.05 \times 1.40$. This is, however, not sufficient for some applications. The varying beam quality in the transversal directions can also present a limitation.

Method

In order to improve the beam quality of Yb:INNOSLAB amplifiers with sub-picosecond pulse durations, a compact high-power spatial filter was developed.

The main component is a dielectric mirror in which a 300 µm wide slit has been inserted through the use of inverse laser drilling. This mirror is used in an intermediate focus position in the cylinder telescope needed for beam forming. The typical diffraction structures of an INNOSLAB laser are, thus, cut off in the far field. The laser radiation filtered out is carefully guided into a beam dump.

Result

At 600 W of mean output power, the beam quality could be improved to $M^2 = 1.05 \times 1.15$ by cutting off less than 10 percent of the power. When the slit mirror is combined with a linearly formed intermediate focus, stable operation is secured at high mean power and a simple adjustment of the aperture.

Applications

Inverse laser drilling can be used to drill as complex a geometrical shape as desired with high aspect ratios in 2.5 D in mirror substrates or other glass bodies. This way, compact spatial filters for lasers with high mean power can be generated. The diffraction-limited high-power ultra-short pulse laser is, thus, only one of many possible fields of application.

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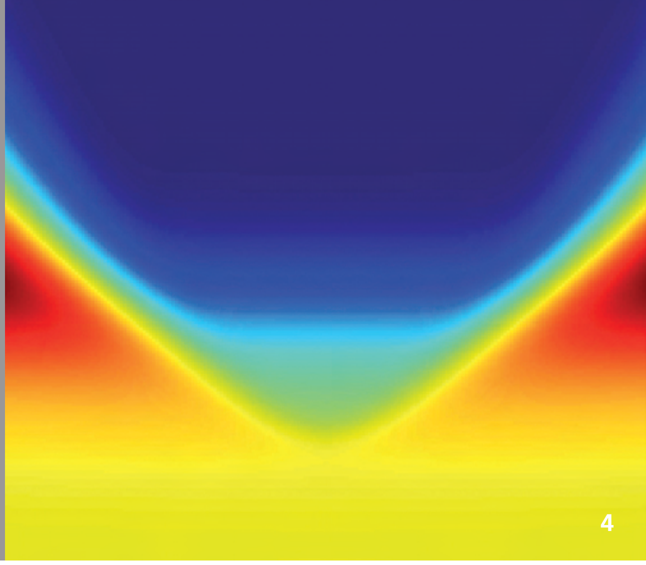
1 Laser-drilled slit mirror.

2 Beam profile of the filtered beam.



MODELLING QUASI-THREE-LEVEL LASER CRYSTALS

Task

Pulsed, resonantly pumped quasi-three-level lasers in the nanosecond range have many fields of application: materials processing, remote sensing, as well as in science and the military. With such laser media, the pump light absorption is dependent upon the intensity and a redistribution of the excitation occurs due to the laser emission. Due to this increased dependency, it is hardly possible to optimize these laser types with analytical or one-dimensional numerical models.

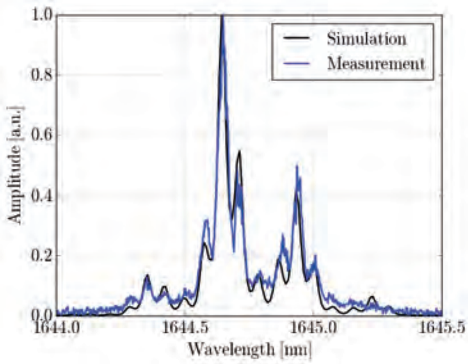
Method

The characteristics of relevant quasi-three-level laser media are replicated in a simulation. For this, the rate equations in the laser medium are solved numerically for pulsed operation in one temporal and three spatial dimensions; a spectral dimension is optional. In addition to material parameters of the crystals, their temperature as well as resonator parameters can also be set. With respect to the distribution of pump and laser radiation, several parameters – such as doping, crystal dimensions, host crystal and resonator design – can be optimized.

Result

The model implemented here was used within the scope of a project with the German Aerospace Center (DLR) to explain spectral characteristics of an Er:YAG laser (see graphics) and to optimize its design. To develop a MOPA system to detect carbon dioxide in projects with the DLR and the European Space Agency, different holmium- or erbium-doped crystal systems were simulated in order to find the optimal amplifying medium for the application in question. Data from literature could be reproduced and the system is now set up experimentally. In addition, different methods to generate pulse sequences were compared and improved.

Comparison of a measured laser spectrum with the simulation.



Applications

In addition to aiding in the design of new beam sources, the comparison can also be used to analyze, better understand and optimize experimental measurement values.

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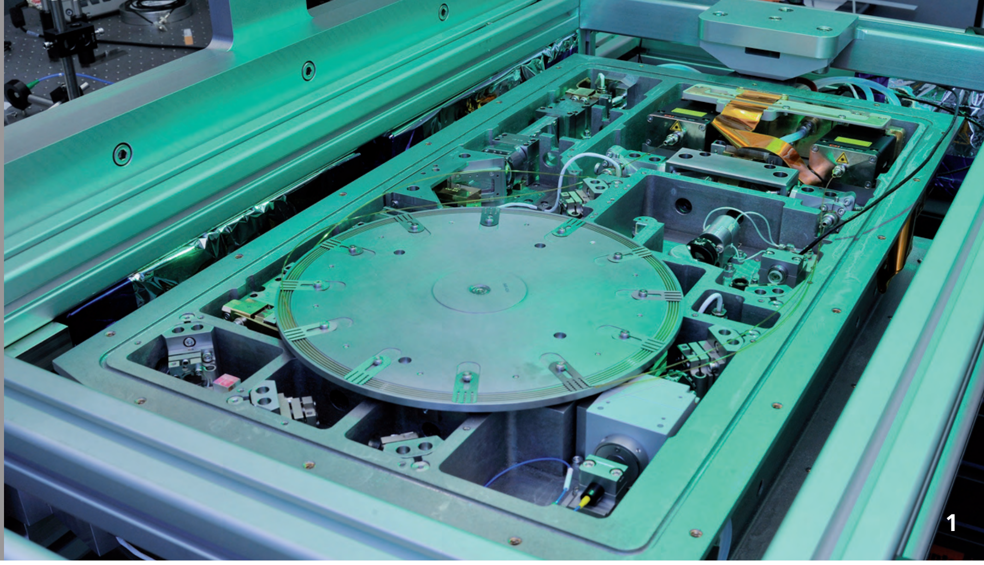
3 Pumped Er:YAG crystal in a heat sink.
4 False color image of the excitation in a Ho:YLF crystal after a laser pulse.



COMPACT LASERS FOR AIRPLANE-SUPPORTED LIDAR SYSTEMS

Task

In climate research, scientists have a long-term goal: to be able to identify, both completely and globally, all the data relevant to the climate with high spatial resolution and then use them as the basis for improving climate models. In the future, these data should be generated using satellite-based LIDAR systems. As technology demonstration models, airplane-supported systems are an important step in that direction.

A beam source to measure wind speed profiles as well as OPO pump sources to conduct density measurements of CO_2 and CH_4 were developed for research projects of the German Aerospace Center (DLR). They fulfil the special requirements upon efficiency, compactness, robustness and security resulting from use in aviation.

Method

The three lasers were conceived as a multi-stage MOPA system with Nd:YAG crystals. The spectral beam characteristics are generated in an oscillator in longitudinal single-mode operation at low pulse energy (~ 10 mJ) and then amplified in an INNOSLAB amplifier stage to 100 – 200 mJ. The target wavelength needed for each application is generated in a down-stream frequency converter stage. The optical components are compactly arranged on both sides of a monolithic carrier structure optimized by means of R&D simulations.

Result

The stable longitudinal single-mode operation of the oscillators was demonstrated at pulse energies of 8 to 10 mJ, a repetition rate of 100 Hz and a pulse duration of 35 ns, and then it was optimized to the special requirements of each of the measuring methods. The pulse energy was scaled to 80 mJ in a first amplifier stage and to 150 mJ in a second stage. The CH_4 system was used successfully to pump an OPO on the customer's premises.

Applications

In the field of climate research, further climatic values can be captured, in addition to the named measurement tasks, by adapting beam parameters, e.g. wavelength. In the industrial sector further applications follow: monitoring industrial plants, conducting leak tests of gas pipelines or surveying wind fields. The system's compact and robust construction technology can be used to develop beam sources spanning many different systems.

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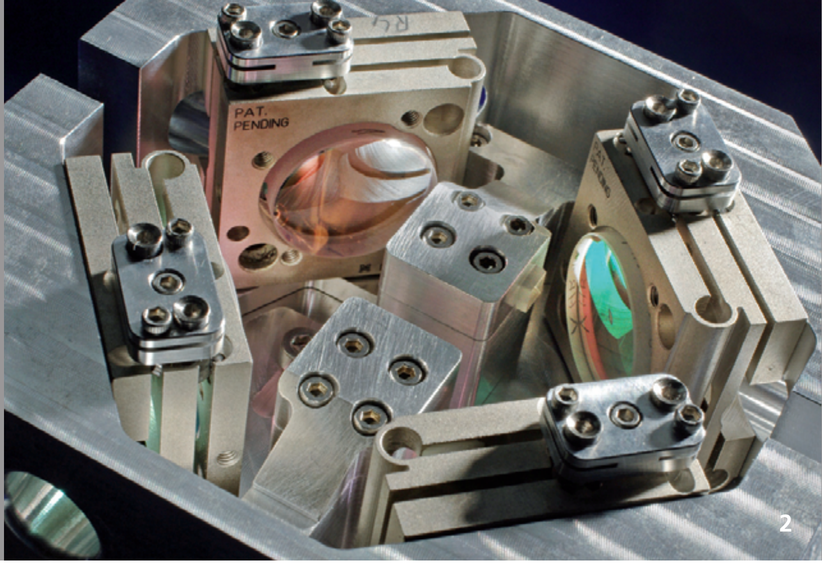
1 Oscillator and INNOSLAB amplifier of the pump beam source for the CH_4 measurement system.



OPO FOR A SATELLITE-SUPPORTED METHANE LIDAR

Task

As a greenhouse gas, methane has a significant impact upon climate change. By comparison, however, the global distribution, the origin and the decomposition of this gas have been researched very little. Within the scope of the German-French climate mission MERLIN, a satellite-supported LIDAR system should be used to collect detailed data with global coverage. As a transmitter, a Q-switched Nd:YAG laser as a driver laser will be combined with an optical parametric oscillator (OPO) as a frequency converter. The OPO shifts the laser output wavelength from 1064 nm to that of methane absorption at 1645 nm. In parallel to this driver laser, an OPO is being developed at Fraunhofer ILT, which fulfils the requirements of the satellite mission on efficiency and frequency stability as well as mechanical stability.

Method

The optical design of the OPO is based on a concept of the German Aerospace Center (DLR-IPA) in Oberpfaffenhofen, Germany, and was optimized at Fraunhofer ILT by means of numerical simulations, in order to enable the required output parameters while loading the optic components minimally and with high adjustment stability. For the testing in the laboratory, an Nd:YAG-based MOPA system is used as a driver laser, which generates pulse energies of more than 30 mJ at pulse durations of 20 ns and a repetition rate of 25 Hz. Through an active control, the laser runs in longitudinal single-mode operation. These pulses run through a seeded, single-resonant OPO, which consists of four mirrors and two KTP crystals. The position of one mirror is moved with a Piezo element, in order to adjust the resonator length of the OPO to the signal wavelength. This way, the OPO again provides a longitudinal single-mode signal.

Result

The behavior of the OPO corresponds well with the calculations. From a pump energy of 30 mJ, a signal energy of 9 mJ is generated with a stable frequency. After the required laser parameters were demonstrated in the laboratory, the development of a highly stable set-up will follow, one which is based on monolithic mounts and soldered optics.

Applications

The optical design as well as the developed simulation tools and mechanical components can be used for OPOs in other wavelength ranges. This way, a large number of relevant gases can be detected.

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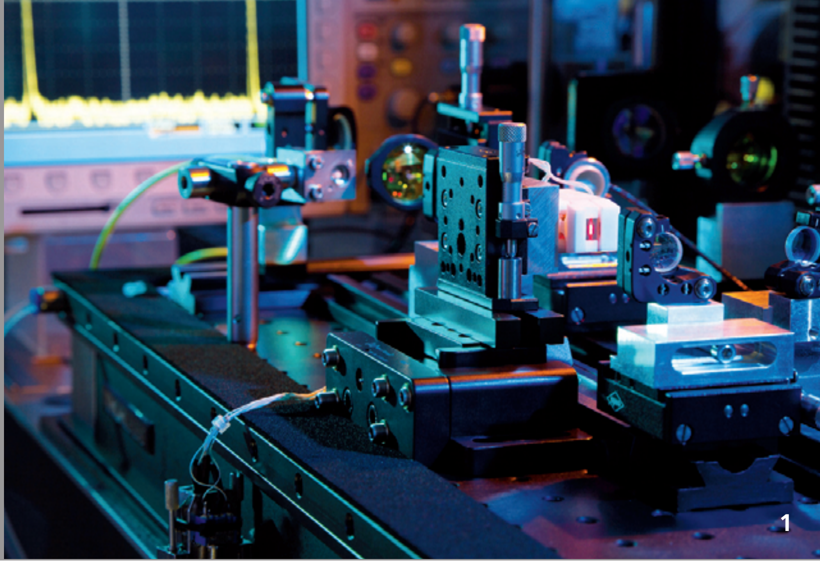
2 Laboratory set-up of the single frequency OPO.



CW-OPO IN MID INFRARED RANGE PUMPED BY A SEMI-CONDUCTOR DISK LASER

Task

The spectral range that can be addressed by using innovative optically pumped GaSb semiconductor disc lasers (OPSL) can be expanded considerably when the frequency is converted by optical parametric oscillators (OPO). As a design for a compact and cost-efficient tunable laser beam source in the mid-infrared, an OSPL-pumped OPO is to be demonstrated with an output wavelength above 4 µm in continuous wave operation.

Method

An appropriate OPSL at 1.9 µm was provided within the scope of a joint project with Fraunhofer IAF. Since the power of today's GaSb-OSPLs is not sufficient to operate the OPO in a singly resonant (SRO) setup, the single frequency operation of the OPSL is used to enhance the power in an external cavity. Stable input coupling is maintained by a Pound-Drever-Hall control. In addition, the enhancement cavity serves as a resonator for one of the parametric waves. In the literature, such a configuration is called a pump-enhanced singly resonant oscillator (PESRO).

Result

With the commercially established crystal material ppLN as nonlinear medium, an OPSL-pumped cw-PESRO has been demonstrated, having a MIR power of 20 mW at 3.3 µm (signal) and 4.5 µm (idler). With a laboratory setup, mode-hop-free operation over several minutes has been shown. When other crystal materials are used, the wavelength range can be expanded up to 15 µm.

Applications

Potential fields of application include optical near-field microscopy, spectroscopy with absorption bands in the MIR and photo-thermal common-path interferometry (PCI) to characterize optical components at MIR wavelengths.

Additional applications include the use as a narrow-band seed laser for high-power lasers in the spectral range of up to 15 µm.

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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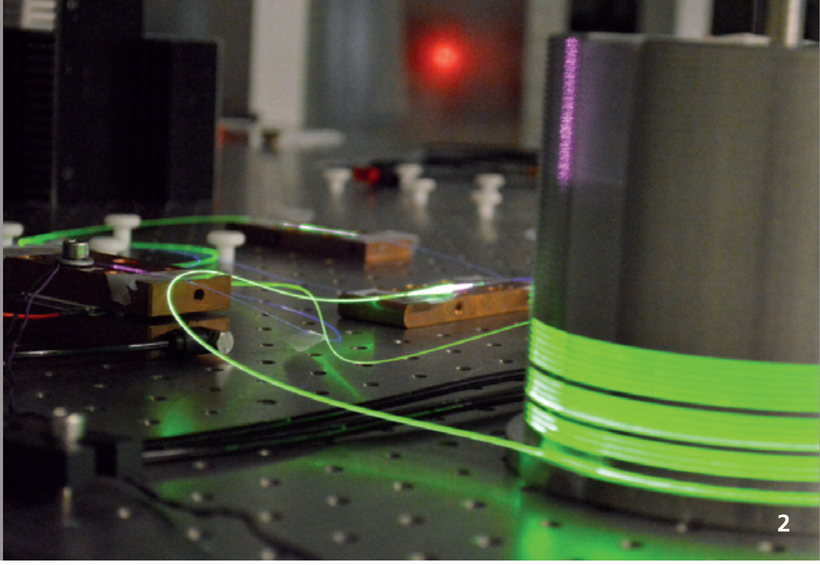
1 PESRO cw OPO with a ppLN crystal.



DIODE-PUMPED SINGLE-MODE CW FIBER LASER AT 1532 NM

Task

In a LIDAR system, a single-mode Er:YAG laser is used, which emits at 1645.2 nm, the absorption wavelength of methane. As a pump source, a single-mode cw laser is needed, which should reach a wavelength of 1532.4 nm and a bandwidth of below 1 nm. Furthermore, as this laser shall be used in satellite-based applications, special attention needs to be placed on its efficiency.

Method

Developed at the ILT and already in use, a simulation is temporally and spatially resolved and should be expanded for use with Er/Yb fibers. Thanks to this simulation the laser will be dimensioned for pump wavelength, fiber length and principle laser design (resonator or amplifier). Subsequently, it will be built on the basis of these results. For this, a completely fiber-integrated laser will be developed, with a commercially available Er/Yb co-doped glass fiber as an active medium, which emits at 1532.4 nm.

Result

The experimental set-up consists of a fiber resonator, which by means of a fiber-coupled multi-mode pump diode as pump source, reaches a signal wavelength of 1532.4 nm and a spectral full-width half maximum (FWHM) bandwidth of $\Delta\lambda = 0.32$ nm and emits single-mode signal light with a $M^2 \sim 1.05$ at over 3 W. In the process, the fiber laser reaches an electro-optical efficiency of ~ 10 percent. With this, almost a doubling of the efficiency could be demonstrated compared to a commercial system available at Fraunhofer ILT. Furthermore, the fiber laser exhibits significant scaling potential of the output power and the electro-optical efficiency.

Applications

Thanks to its narrow FWHP bandwidth, easily adjustable central wavelengths and high efficiency compared to commercial systems, this laser is ideally suited as a pump source for applications in the aerospace industry, e.g. for Er:YAG crystal lasers for methane detection. In addition, the laser can be used as a signal source for further applications, as in, e.g., satellite communication.

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2 Er/Yb fiber laser.

FIBER AMPLIFIER PUMPED AT 1010 - 1030 NM

Task

Particularly in pulsed Ytterbium-doped fiber lasers, amplified spontaneous emission leads to losses in the temporal and spectral quality of the laser light due to the high amplification per round trip. This issue constitutes a limit pulse duration and repetition rate. In order to expand the possible parameter range of the fiber laser to lower repetition rates, the reduction of the amplified spontaneous emission should be investigated in pulsed fiber lasers by pumping at wavelengths in the range over 1000 nm.

Method

Through pumping Ytterbium-doped fiber lasers in the wavelength range from 1010 - 1030 nm, the inversion is limited to approx. 15 percent, in contrast to pumping at wavelengths of 915 nm or 976 nm. This inversion cannot be exceeded so that a homogeneous distribution of the inversion and thus the amplification are both reached, whereas the appearance of amplified spontaneous emission can be reduced significantly. In addition, through low and controlled inversion, the formation of color centers, the so-called photo darkening, is reduced.

Result

To investigate this concept, a fiber-integrated amplifier with pulse durations in the range of 10 - 100 ns and repetition rates of < 20 kHz was developed. This laser emitting at 1064 nm is core-pumped with a fiber laser at a wavelength of 1030 nm.

Limited by pump power, the polarized single-mode fiber amplifier reaches a signal peak power of 1 kW at a signal-to-noise ratio of over 50 dB. In comparison to conventional fiber amplifiers pumped at 915 nm with similar efficiency and same peak power, the signal-to-noise ratio can thus be improved by several orders of magnitudes at low repetition rates.

Applications

With its single-mode beam quality and adjustable pulse duration and repetition rate, the fiber laser can be used, with subsequent amplification, for applications in which a low thermal load is necessary, such as materials processing, medical and measuring technology and special communication-technical applications.

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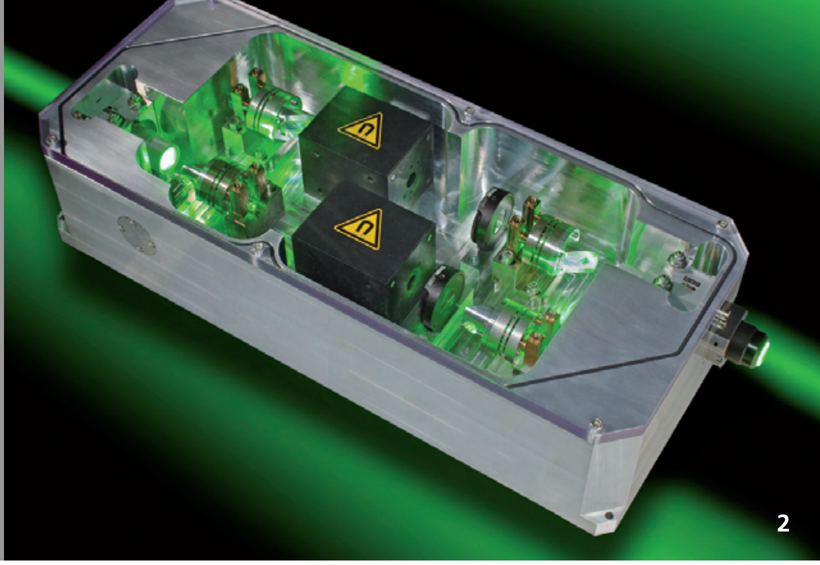
1 Fiber amplifier pumped at 1010 - 1030 nm.



FIBER-COUPLED FARADAY ISOLATOR FOR HIGH-POWER FIBER LASERS

Task

Fiber lasers are a standard tool for the industrial processing of metals, in sheet form as well as powder. When they are processed, the laser beam can reflect back into the beam source due to the dynamics in the melt pool or an unfavorable positioning of the beam path. Since the fiber laser is principally sensitive to such back reflections, isolators should prevent the back coupling of the reflected radiation into the source and enable the laser to operate stably and trouble-free.

Method

The isolator presented here has been dimensioned for non-polarized fiber laser radiation with a beam parameter product of 3 mm x mrad. For this, the incident radiation is divided into two components, polarized perpendicularly to each other, with each then subsequently guided through a Faraday rotator. Before being coupled into the output fiber, both of the components are recombined. The isolator has input as well as output couplers for standard 100 µm fibers with a core numerical aperture of 0.2.

Result

The isolation amounts to over 24 dB at low power, and at 1 kW coupled power, it is larger than 20 dB, whereas the decrease of the isolation can be traced back to depolarization of the light by thermally induced stress birefringence in the TGG crystals. The transmission of fiber to fiber lies at approximately 80 percent at 1 kW coupled power.

Applications

In all applications where materials are processed with fiber lasers, in particular for high power ranges, e.g. cutting, welding or selective laser melting, an isolator can be used to stabilize the process and, simultaneously, to protect the beam source from damage. Double-sided fiber coupling enables the isolator to be better integrated in the laser systems by the fiber-based beam guidance all the way to the processing optics.

This work was funded by the German Federal Ministry of Education and Research under the grant number 13N9890.

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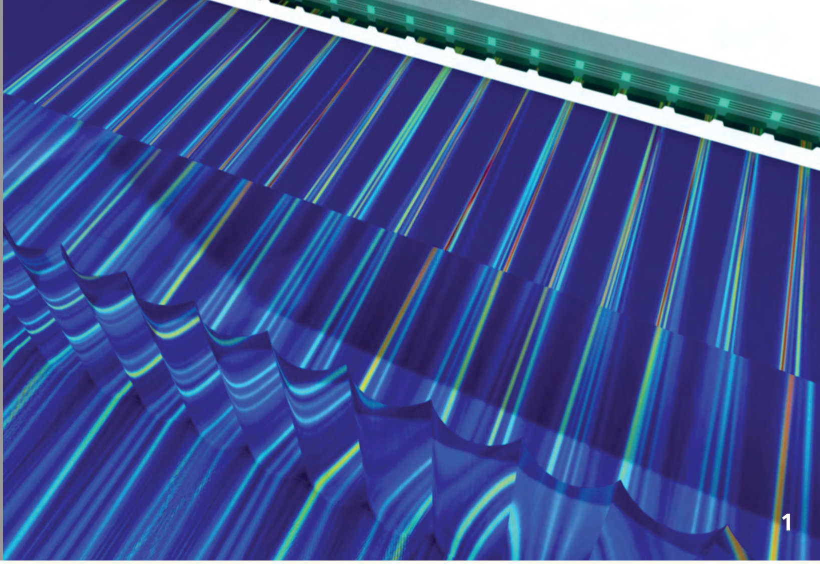
2 Fiber-coupled Faraday isolator.



SIMULATION OF HIGH-POWER DIODE LASERS

Task

When high-power diode lasers are used for coherent or incoherent beam superposition and for pumping solid-state lasers, the requirements upon them are high power and spectral stability for line widths of < 1 nm. Non-linear effects, such as the thermal refraction index variations and refractive index variations induced by charge carriers, lead to filamentation of the light field. By frequency-selective external optical back coupling, the spectral width of the emitted radiation is reduced and the shifting of the centroid wavelength, dependent upon operating point, is reduced. The specific values of the spectral stabilization are determined according to the state-of-the-art in the experiment.

Method

The goal is to develop models to calculate the dynamics of the electromagnetic field in diode laser edge emitters with coupled frequency-selective external resonators. To simulate diode laser edge emitters and micro-optics, such as volume Bragg gratings and aspherical collimation lenses, software solutions have been developed, whose use enables the analysis of innovative micro-cavity lasers with external resonators for longitudinal or transversal mode selection.

Result

The laser model calculates spatial and spectral distributions of the field parameters, radiation characteristics, including near and far-field distributions of the astigmatic laser radiation, emission spectrums and the optical output power dependent upon the operating current. The wavelength is stabilized by an external spectral filter, which can be simulated numerically. The underlying semiconductor theory serves to determine amplification, refraction index variations as well as spontaneous emission dependent upon frequency, local temperature, charge carrier- and photon density. The stabilization range and the optical output power have been calculated in dependence upon facet reflectivity, thermal resistance and back coupling efficiency of the external optical system.

Applications

The results of the numerical analyses deliver dimensioning criteria and parameters for the design of optical systems for high-power diode lasers while the relevant properties of semiconductor structure and material are taken into consideration.

The work was funded by the German Federal Ministry for Education and Research within the scope of the project »SpektraLas« (grant number 13 N 9729).

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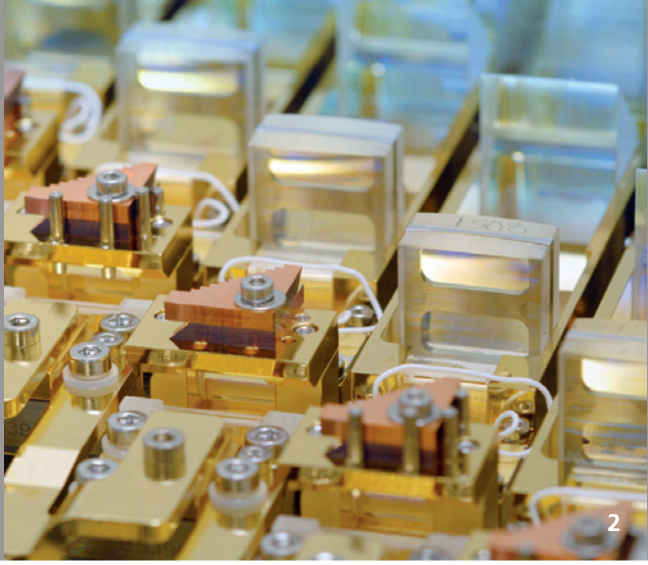
1 Diode laser bars: simulation of lateral field distribution.



HIGH-POWER DENSE WAVELENGTH DIVISION MULTIPLEXING WITH VOLUME BRAGG GRATINGS

Task

Direct materials processing with diode laser radiation as well as the efficient pumping of several laser-active media require a comparatively large radiance. Thanks to the high-power multiplexing of diode laser radiation, frequency-stabilized diode laser beam sources are overlapped spectrally dense, whereby the radiance is increased when compared to conventional diode laser beam sources.

Method

The compact multiplexer presented here consists of four identical Volume Bragg Gratings (VBGs) with a diffraction efficiency of 99 percent and an incidence angle of 15°. The input wavelengths are 973 nm, 974.5 nm, 976 nm, 977.5 nm and 979 nm. Five mirrors are used to compensate for beam displacement and angle errors of the beam sources. An optional temperature control (DTC dynamic temperature control) of the VGBs enables the central wavelengths of the multiplexer to be adapted to the emitted wavelengths of the input radiation.

2 Detailed view of a spectrally stabilized diode-laser module.

3 Detailed view taken within the multiplexer.

Result

The optical-optical efficiency of the multiplexer is dependent upon the residual divergence and, thus, the beam quality of the input radiation. Fundamental mode radiation is superimposed at an efficiency of 97 percent; radiation at an average beam propagation factor of $M^2 = 45$ is superimposed at an optical-optical total efficiency of 85 percent. The output power of the laboratory demonstration model amounts to a maximum of 200 W, the beam density approx. 70 $GWm^{-2}sr^{1}$.

Applications

The multiplexing technology presented here has been primarily developed to scale the power of diode laser systems for direct materials processing. Furthermore, the pumping of solid-state and fiber lasers is enabled by means of highly brilliant diode laser radiation. This multiplexing technology, based on VBGs, is not limited to use with diode laser radiation, but can also be used in the same design for solid-state lasers such as fiber laser and disc laser sources.

This work was funded by the German Federal Ministry of Education and Research within the scope of the project »SpektraLas« (grant number 13 N 9729).

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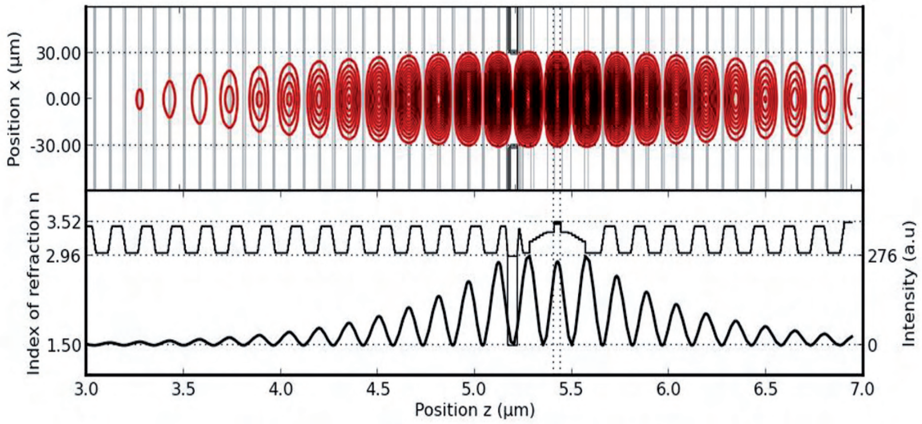

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MODELLING AND SIMULATING SURFACE-EMITTING SEMICONDUCTOR LASERS

Task

Thanks to their advantages – lower manufacturing costs, modularity, symmetry of the beam profile and the simple implementation of arrays – surface-emitting semiconductor lasers with vertical resonators have been able to successfully compete against conventional edge-emitting models. Monolithic emitters (VCSEL) with output power of a few mW have long been used for optical data transfer and sensor technology. By means of arrays from high power emitters, output power in the range of several kW at low brightness can be reached. Emitters of high brightness and medium output power can be made when the semiconductor chip is combined with external resonator optics. To date, optically pumped single emitters (OPSL), with up to 100 W output power in the fundamental mode, could be demonstrated. Electrically pumped emitters with external resonators (VECSEL) represent a promising compromise between reducing the complexity of the beam source and its brightness. In the last three years, simulation software has been developed at Fraunhofer ILT for Philips Photonics to optimize resonator geometries and semiconductor layer structure of single mode VECSELs.

Method

To optimize the single mode VECSEL, simulation software was developed to predict the power and emission characteristics in dependence upon the operating parameters as well as upon the geometry parameters of the resonator and the composition of the semiconductor heterostructure. The model approach consists of solving microscopic equations to calculate the resonator eigenmodes, the band structure and gain spectrum of the active layers as well as the light-medium interaction. Electrical and thermal characteristics are taken into account through phenomenological laws, whose parameters are identified experimentally.

Result

In close cooperation with accompanying experimental work, the tendencies observed in the laboratory, or favorable resonator geometries in dependence upon the quality of the epitaxial material, could be understood. In addition, a central design criterion could be identified for dielectric layers for lateral current confinement (oxide aperture) with good optical properties in VECSELs. Subsequent to the cooperation, the output power of the single mode VECSELs from Philips Photonics could be increased by a factor of four.

Applications

Potential fields of application of VECSELs are pumping solid-state lasers, laser materials processing, printing and lettering technology as well as spectroscopy.

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1 Numerically calculated fundamental mode of a VECSEL.

HEAVY-DUTY REFLOW SOLDERING FOR COMPACT OPTIC MODULES

Task

For laser systems to operate reliably, their optical components must be mounted with precision and long-term stability. In particular, space-based applications require, due to the harsh environmental conditions, a secure and compact joining technology, one which fixes glass substrates with high stability and true to position in the µrad range.

Method

Since it does not use welding flux, the Reflow soldering process in a vacuum oven is used here for the joining of optical components to specially adapted, metal mounts. For example, cylindrical beam shaping optics are arranged in a lens tube and, simultaneously, soldered to a module in vacuum conditions. The frame design of the optic mount can be adapted to cylindrical or rectangular shaped as well as to strip-formed optics.

Result

The modular set-up enables a compact arrangement of many optics of varying geometry. Lenses and mirrors with cylindrical or planar shell surfaces can be positioned at a minimal distance to each other and soldered together to form one module. Investigations in a climatic chamber set to a temperature range of -30°C to +50°C confirm the robustness of the soldered joints across these changing temperature loads.

Applications

The Reflow soldering process developed at Fraunhofer ILT for optics is currently being used for LIDAR systems in the aerospace industry. The modular arrangement of several optics enables their compact integration in laser systems. As an alternative to clamping or adhesive technologies, this soldering process offers advantages concerning exhaust gas behavior, long-term stability and durability along a wide temperature range.

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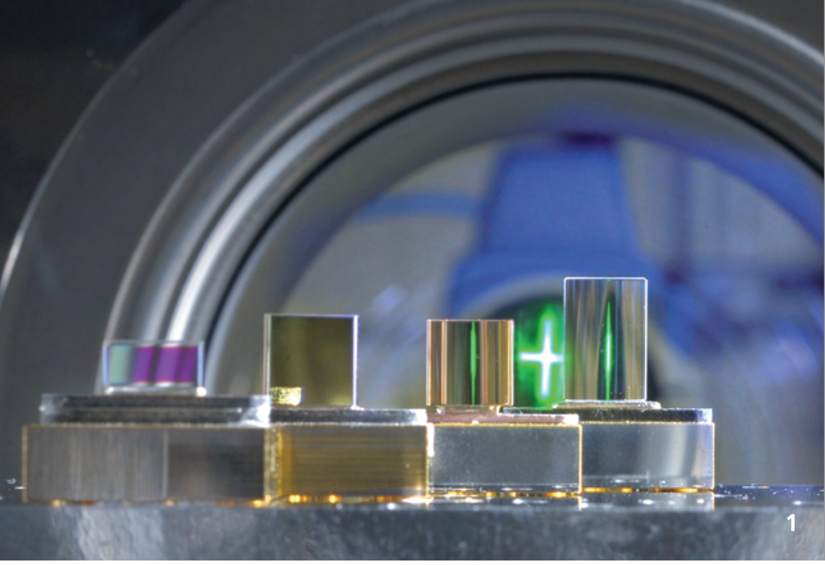
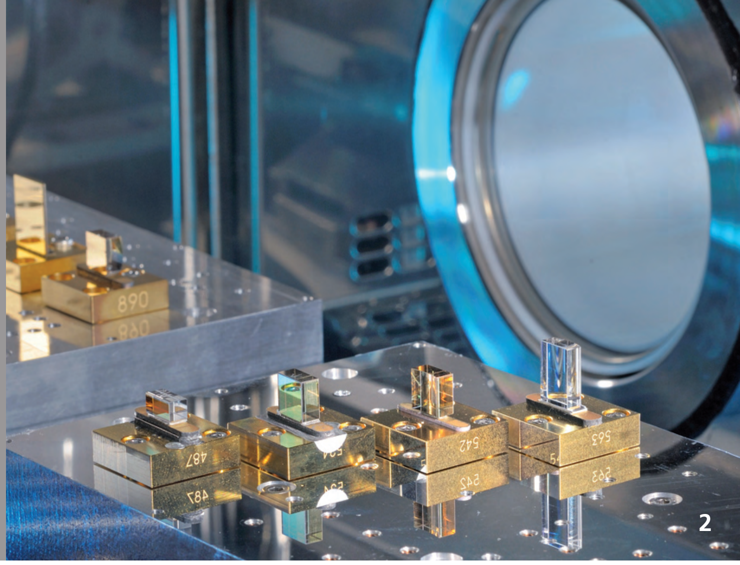
2 Aspherical lenses of pump optics soldered in a strip form.

3 Soldered cylindrical optics and homogenizer of pump optics.





AUTOMATED ENVIRONMENTAL TESTS ON LASER COMPONENTS

Task

To develop innovative mounting techniques for laser optics, directional stability reaching into the 10 µrad range (≈ 2″) is required. This stability should also be proven for optics used in space-based laser systems which are subjected to harsh temperature loads. Since tests that simulate such harsh temperature loads can last for several days, a significant increase in capacity was necessary to conduct the required number of qualification tests in the scope of the project's running time.

Method

The alignment of mirrors can be determined by means of an autocollimator. To investigate the influence of changing temperature loads, a common climatic chamber was provided with windows on the sides so that the alignment of mirrors can be measured externally with an autocollimator; the mirrors are subjected to defined temperature cycles inside the chamber. To automate the measurement process, two autocollimators each were arranged on a linear axis in such a way that measurements could be made over the entire width of the windows of the climatic chamber. This way, each individual autocollimator can measure up to eight mirrors under the prevailing conditions. The process data, to be processed simultaneously, are prepared so that the results can be analyzed both quickly and simply.

1 Mirror with autocollimator.

2 Mirror in climatic chamber.

Result

Due to the automation thus performed, up to 32 mirrors can undergo a climate test. This means capacity can be expanded significantly, thus also enabling comprehensive long-term tests to be conducted. The angle resolution of the measuring system currently amounts to about 2 µrad.

Applications

The climate tests conducted at the Fraunhofer ILT are an essential component of the qualification of laser components for LIDAR systems in the aerospace industry. Furthermore, the system developed here can be used in any situation where the change of the alignment of (reflecting) surfaces has to be investigated under changing temperatures.

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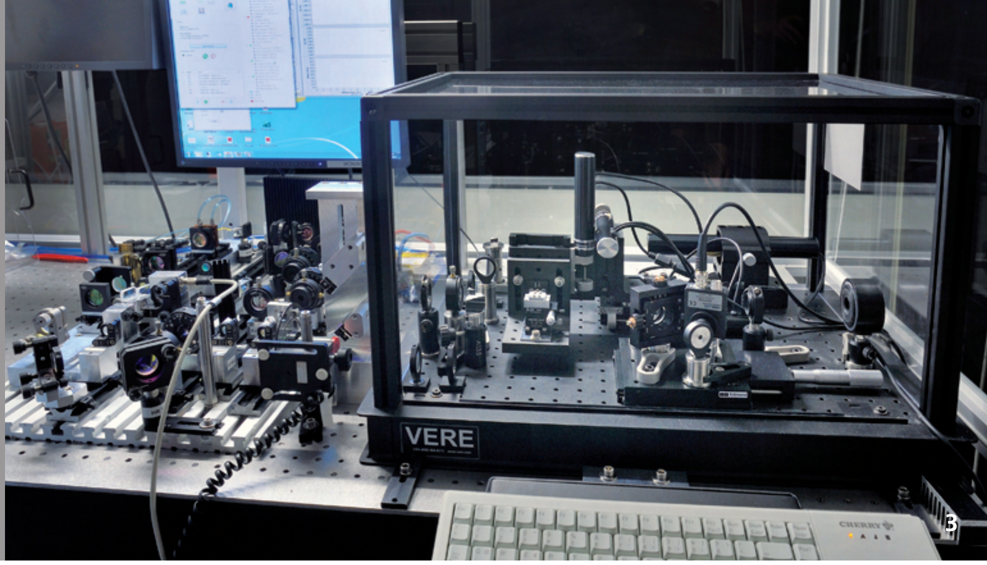

SPATIALLY RESOLVED ABSORPTION MEASUREMENTS IN PPM RANGE

Task

In optical components for high power lasers, the absorption constitutes a limiting factor. The measurement of the absorption – in volume and on the surface of the components – is, therefore, an important aid when selecting and qualifying appropriate optics. If the absorption should be determined in the ppm range, conventional measurement processes (e.g. calorimetry) reach their limits. Moreover, they do not allow space-resolved measurements to be made, as they, for example, are typically required within the scope of quality controls.

Method

By means of a photo-thermal common-path interferometer (PCI) and a dual-wavelength pump laser, absorption measurements can be conducted at 1030 nm and 515 nm or simultaneously at both wavelengths. In addition, measurements are possible on transmissive and reflective optical components. This measurement process allows a distinction to be made between absorption in volumes and on the surface, while scatter and reflection losses have no influence upon the measurement results.

Result

The combination of pump lasers and interferometer enables absorption to be measured at a sensitivity of 1 ppm/cm in volumes and 0.1 ppm on the surface. The spatial resolution amounts to 50 µm transversally, 600 µm longitudinally.

When further pump lasers are coupled into the system, the absorption for additional wavelengths can be determined. This has already been successfully demonstrated with a beam source at 2021 nm.

Applications

Since even minimal heating of the crystal has an influence upon process efficiency and beam quality during frequency conversion by means of non-linear optical crystals, the absorption determination plays a key role in process dimensioning and material selection. This enables, for example, the generation of more than 400 W average power output at 515 nm with pulse durations under 1 ps at Fraunhofer ILT.

In addition, another interesting field of application is the characterization of substrates and coatings for process optics of high-power lasers.

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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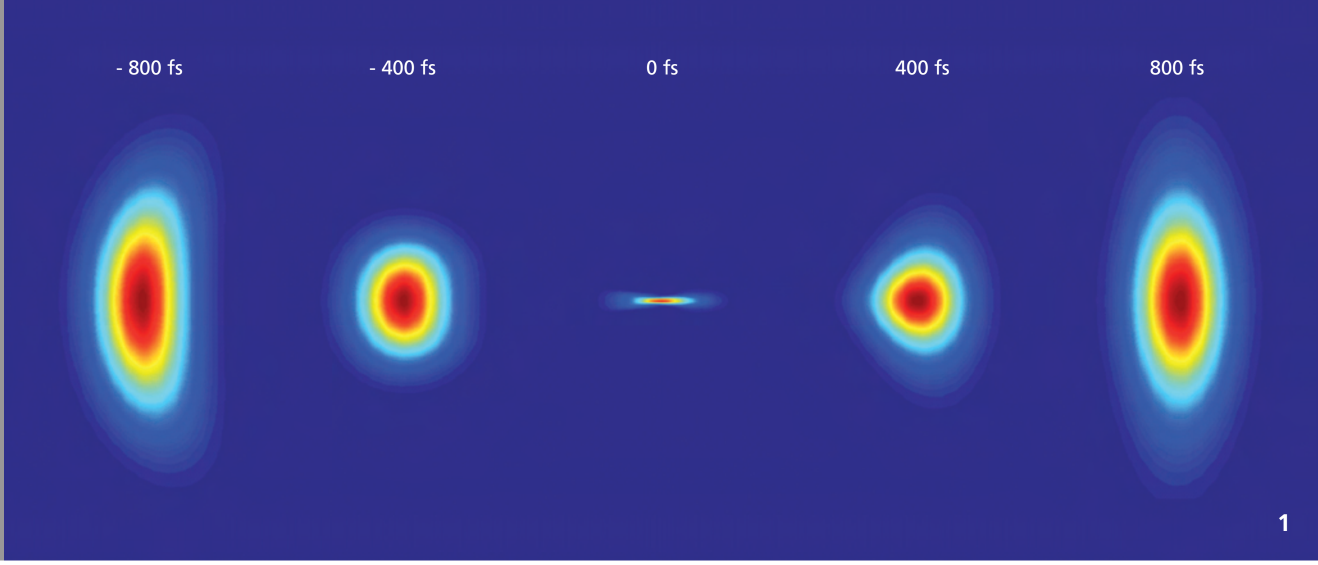
3 Interferometer and pump laser.



DEFORMATION OF ULTRA-SHORT LASER PULSES BY OPTICAL SYSTEMS

Task

The use of scanning systems has been proven valuable in laser material processing, but, for processing operations with ultra-short laser pulses (< 1 ps), it places new requirements upon the optical systems that focus the radiation behind the scanner. Dispersion in the beam guiding and forming optics causes delays between pulse and phase front, leading to a scanning angle-dependent deformation of the pulse front. Consequently, locally varying pulse characteristics upon the workpiece result during material processing, which cause undesirable processing results dependent upon the processing location. This projects aims to simulate scanning angle-dependent pulse front deformations for optical systems and to develop methods to compensate for them.

Method

The complete field information consisting of amplitude and phase is simulated at the observation plane behind an optical system on the basis of wave-optical methods. From this, the pulse front as well as the phase front is extracted, whose temporal difference is calculated and, subsequently, the deformation is determined, or rather the tilt of the pulse front in relation to the phase front.

Result

First simulations show that the pulse front of a laser pulse, which passes through an f-theta optic at an angle, is tilted compared to the propagation direction. This so-called pulse front tilt is dependent upon the scanning angle. Deformation and tilting of the pulse front lead to a significant extension of the pulse duration in the focus as well as an enlargement of the focusing volume.

Applications

The simulations enable a user to estimate how much optical systems influence the focusing behavior and, thus, material processing itself. Further steps in developing the process consist in integrating the described analysis process in the design process of optical systems in order to reduce scanning-angle dependent effects upon pulse shaping.

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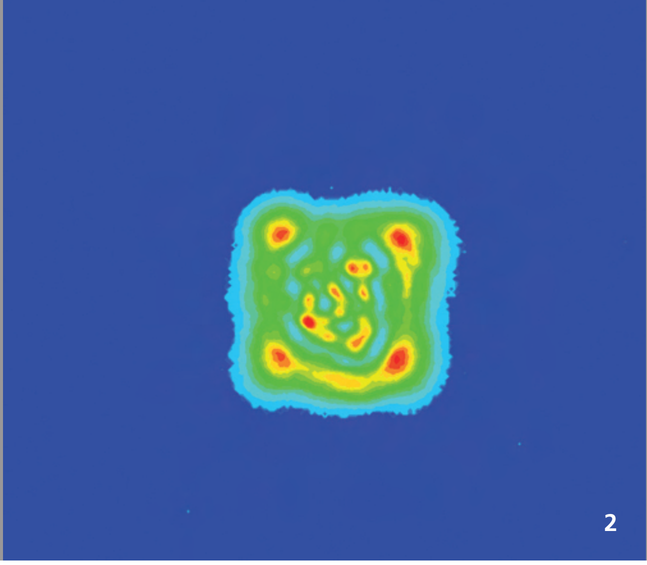
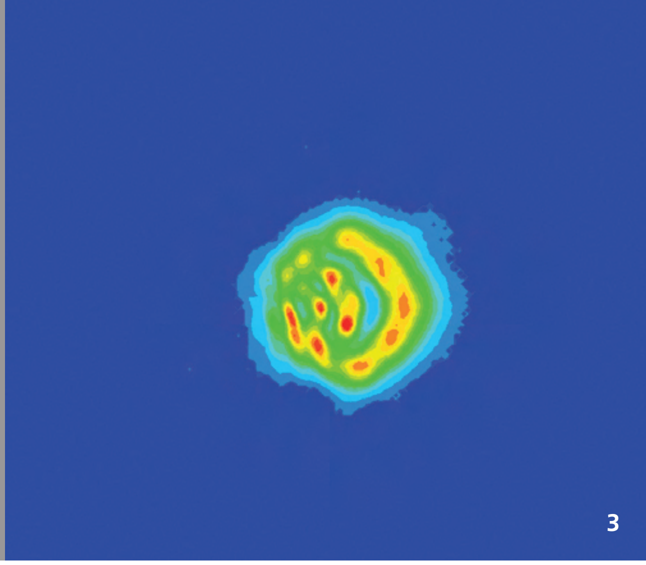
1 Spatial intensity distribution of a focused laser pulse at different times.





PROCESS-ADAPTED LASER BEAM SHAPING WITH MEMBRANE MIRRORS

Task

The development of active optical systems is opening up new possibilities in laser materials processing. Generating flexible focal spot geometries with membrane mirrors allows the intensity distribution to be adapted to the processing situation by an active variation of the optical system behavior. This leads to improved process efficiency and a higher processing quality. Moreover, the economic manufacture, even with small lot sizes, is made possible because the often necessary change of beam forming and guiding components is not needed.

Method

An active optical system has been developed using laser beam cladding as an example. When commercially available electrostatic membrane mirror was integrated into the system, flexible, homogeneous focal spot geometries could be generated from the raw beam profile of a fiber laser (P_{cw} = 100 W, λ = 1070 nm, TEM_{00}). To generate the target intensity distribution, the available degrees of freedom of the mirror can be adapted since the intensity profile is continuously measured, while heuristic control algorithms are utilized.

Result

By using a membrane mirror, homogeneous intensity profiles can be reproduced successfully. Depending of the targets conveyed by control algorithms, the focal spot's geometries are oriented, whose dimensions, in particular, can be varied during the processing duration.

Applications

The optical system presented here was developed for laser cladding. From a process and technical point-of-view, the advantages of dynamic laser beam forming, on the basis of membrane mirrors, can be transferred to other fields of laser materials processing, in particular to the scaling to higher output powers of laser beam sources.

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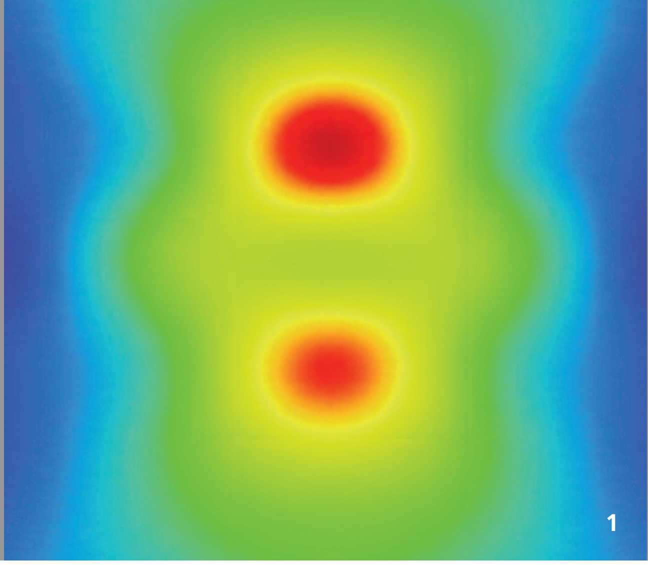
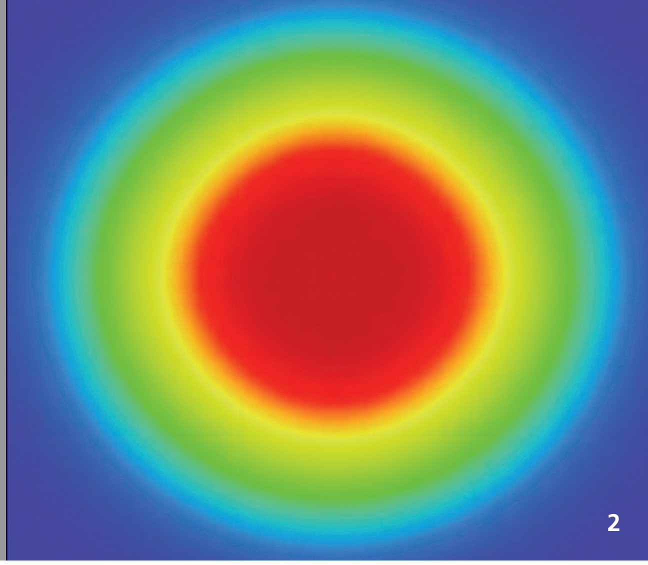
2 Adapted intensity distribution, quadratic.
3 Adapted intensity distribution, circular.





SIMULATION: SOLVING AN INVERSE TASK FOR BEAM PROPAGATION

Task

Beam shaping can be advantageous to optimally achieve application-specific criteria for a processing result, one which cannot be achieved with standard optics. The task presented here consists of indicating a systematics for calculating optimal optical surfaces and, in addition, of guaranteeing that the optimal beam shape is adjusted to the entire processing depth and not only to one position (transversal plane) of the propagation path of the radiation.

Method

In order to receive the desired radiation field along the entire processing depth, an appropriate mode decomposition is first determined. In a second step, the optical surfaces are identified which form a given beam field upon the predetermined contributions of the constituent modes. For a successful procedure, a coupled adjustment of absolute value (intensity distribution) and phase is essential by changing the optical surfaces.

The calculated optical surfaces are validated by the use of commercial beam propagation software (e.g. ZEMAX).

Result

A system to calculate optimal optical surfaces was numerically implemented and has already been successfully used. Before the experimental tests are conducted in the laboratory, the system was validated with commercial software, and the sensitive dependency on parameters of manufacturing and adjustment were analyzed.

Applications

The procedures implemented for calculating optics are independent of the manufacturing process investigated. Two relevant fields of application can be seen: analyzing the potential for beam shaping specific to an application and being better able to estimate the costs and benefits of using optimal optics in comparison to approximate solutions with standard optics.

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1,2 ZEMAX validation of beam distribution produced with calculated optical surfaces, cross-section.

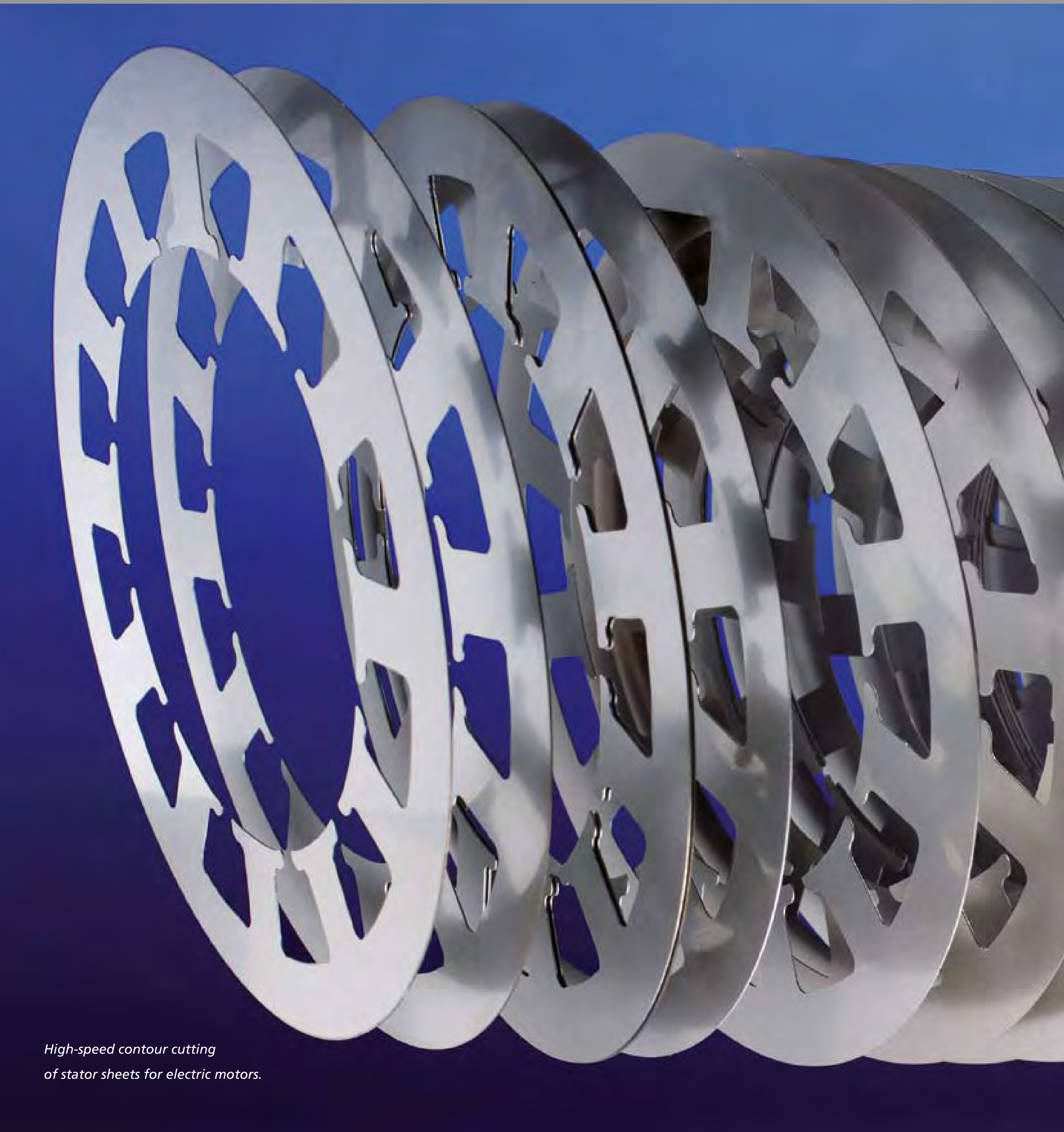
TECHNOLOGY FOCUS
LASER MATERIAL PROCESSING

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.

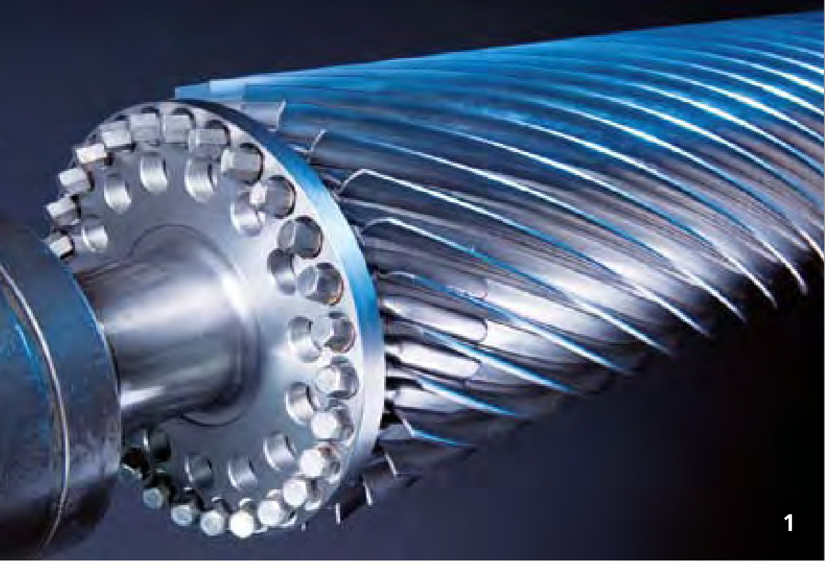
Customers receive laser-specific solutions that incorporate the working material, product design, construction, means of production and quality control. This technology field appeals to laser users from various branches: from machining and tool construction to photovoltaics and precision engineering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

LASER MATERIAL PROCESSING



High-speed contour cutting of stator sheets for electric motors.

CONTENTS



HARDENING OF SHEARING BLADES

Task

Textiles and carpets are commonly cut with shearing blades, rotating and arranged in a spiral-form, and a counter blade to an even fiber length. The company Heusch from Aachen is the world's leading manufacturer for such high-performance blades and shearing systems. To minimize the wear of the spiral-formed shearing blades, the intermeshing cutting edges have to be hardened. To date, the shearing blades are induction hardened across the entire material thickness. Distortion and embrittlement of the hardened area, which make alignment and fitting on the shaft difficult, are disadvantages of the process. When laser radiation is used for hardening, however, only the surface area required for the shearing function is hardened. The bulk material remains ductile, which eases alignment and fitting.

Method

Initially, using straight knife sections, Fraunhofer ILT developed the laser hardening process with a fiber-coupled diode laser and zoom optics with an adaptable laser spot size. In a second step, Heusch continued to develop the process under production conditions, and finally hardened spiral-formed shearing blades were tested by an end user.

Result

With an adapted laser spot dimension the hardness desired in the required area was precisely adjusted. When compared to that of induction hardening, the feed speed could be doubled. The laser-hardened blades have been successfully tested in production at an end user. The next step is to introduce the process at Heusch in its manufacturing line and replace induction hardening over the long term.

Applications

In addition to shearing blades, this process can also be generally used for hardening thin ribbon- or sheet-working materials, for example for self-sharpening cutting edges. With this process the functional integration of wear resistance near the surface and ductility in the bulk volume can be made possible in the smallest amount of space.

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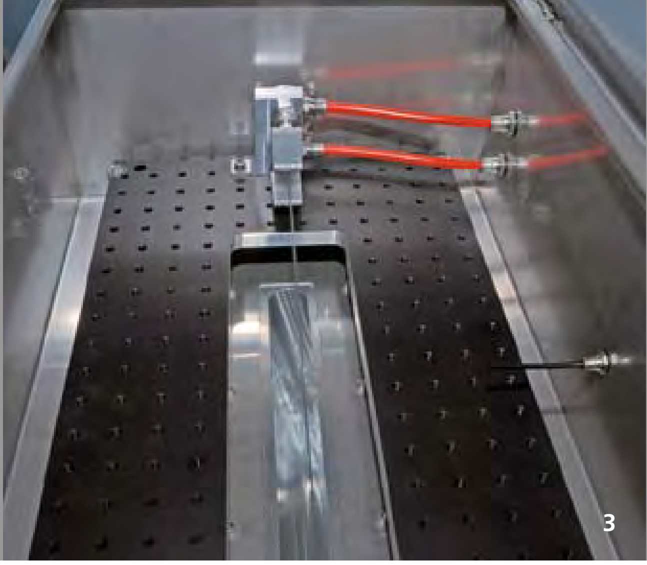
1 Shearing cylinder with spiral-formed shearing blades (source: Heusch).

2 Detailed view: shearing blade (source: Heusch).



LASER-BASED EFFICIENT MANUFACTURE OF CARBON FIBER

Task

Thanks to their 2.5 fold higher specific strength in comparison to aluminum, carbon-fiber reinforced plastics (CFRP) offer an excellent starting point to realize lightweight constructions in the automobile or aviation sectors. A reason for the limited usage to date is, among others, the high manufacturing cost of carbon fibers. Almost the half of these costs can be traced back to the two-step heat treatment (stabilization and carbonization) of the carbonaceous precursor fibers (mostly out of polyacrylonitrile, PAN) into carbon fibers. This is due to the long duration in the furnace (up to two hours) as well as the high energy costs (temperatures up to 1,500 °C), which are necessary for the heat treatment.

Method

Thanks to the use of laser radiation, it is possible that higher heating rates and, thus, shorter stabilization periods can be attained in the furnace since the arising exothermal energy can be better guided away by the cool ambient air, thus, reducing the risk of thermal damage to the fibers. The focus of the research currently lies in developing a process control that allows the precursor fibers to be processed continuously by means of laser radiation. For this a test plant was set up, consisting of a spool unit, process chamber as well as beam source with adapted processing optics.

Result

The first test results on stabilizing in continuous operation have one expect potential time and energy savings of up to 30 percent. Research is still needed, however, on the homogeneity of the stabilization degree over the fiber cross-section as well as on identifying essential influential factors upon the mechanical parameters of the fibers.

Applications

As the process develops, a significant expansion of the application spectrum of CFRP components is expected due to significantly reduced manufacturing costs.

This work was funded by the European Union as well as the State of North Rhine-Westphalia within the scope of the project »MegaCarbon« (grant number 005-1003-0025).

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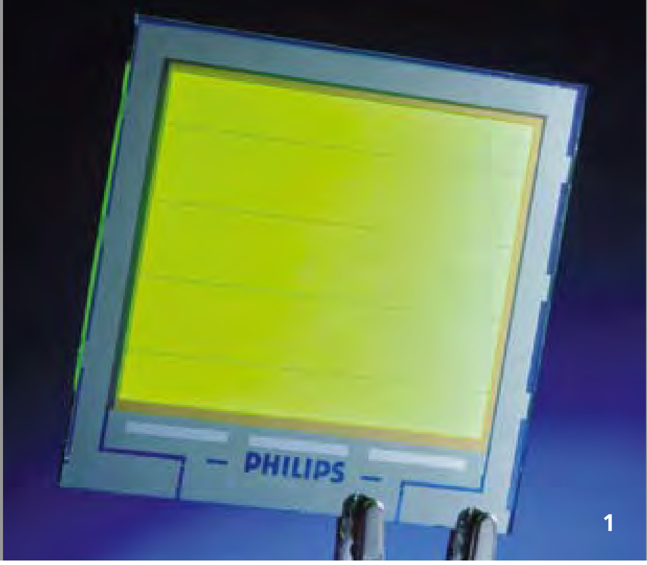
3 Process chamber for laser processing.

4 Laser processing of PAN fibers.



LASER-BASED TEMPERING OF TCO COATINGS

Task

TCO coatings (transparent conductive oxide) are utilized as transparent, conducting anodes, e.g. in modern computers, cellular phone displays, televisions and lighting media such as OLED (organic light emitting diodes). Conventionally, indium tin oxide (ITO) is used for such coatings, since it has the best combination of properties: high electrical conductivity (low sheet resistance) and high transparency in the visual wavelength range. More inexpensive alternatives are, for example, AZO (aluminum-doped zinc oxide) and FTO (fluoro-doped tin oxide). Their electrical conductivity is, however, not sufficient to create two-dimensional, homogeneous luminosity of large OLED lights; due to the – in comparison to metals – high sheet resistance, the luminosity drops off towards the middle of the OLED. Therefore, lowering the sheet resistance of the coating represents an important step in further development.

Method

Investigations have shown that furnace-based, thermal post-processing of the aforementioned PVD/CVD-coated glass reduces the sheet resistance. In contrast to furnaces, the laser offers the advantages of selective, locally limited thermal treatment: In addition to heating and cooling small volumes very quickly, lasers can induce high coating temperatures in short processing times all the while preserving the temperature-sensitive substrate. Inexpensive and robust fiber and diode lasers are used in the near infrared wavelength spectrum (1064 - 1920 nm) with different power density distributions (Gaussian, Top-Hat, Line).

Result

Currently, the ITO sheet resistance can be reduced by more than 20 percent at process speeds of more than 10 cm^2/s in an ambient atmosphere. The visual transparency remains nearly unchanged. Faster process speeds can be expected particularly from the use of wide, homogeneous, linear (diode) laser-beams. The next step is to treat ITO and the aforementioned alternatives in a protective gas atmosphere or a vacuum to further reduce the sheet resistance by e.g. increasing the oxygen vacancies in the material.

Applications

Low-resistance TCO coatings are utilized in all technologies that require transparent, conductive layers. Other thin PVD/CVD-manufactured or printed coatings, e.g. for corrosion protection, can also be post-processed thermally with laser radiation.

The work was funded within the scope of the North Rhine-Westphalian project »Prolux«.

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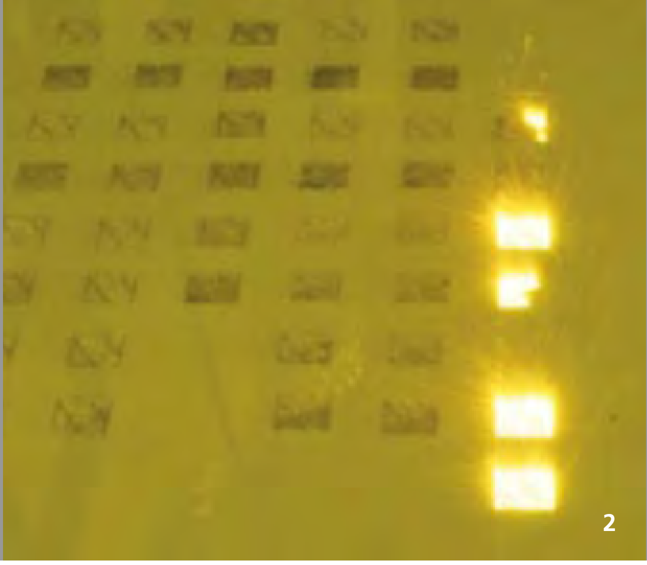
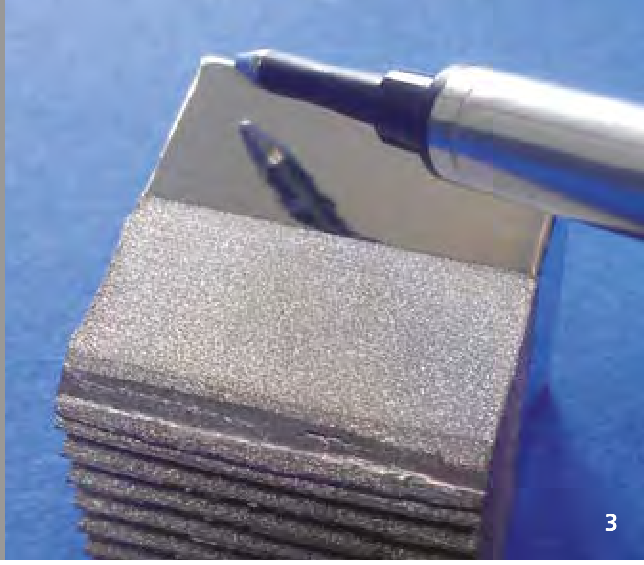
1 OLED with ITO anode and laser-applied conducting tracks.





LASER POLISHING OF SLM COMPONENTS OUT OF INCONEL 718

Task

Thanks to its nearly unlimited geometrical degree of freedom, the additive manufacturing process Selective Laser Melting (SLM) makes it possible to produce complex and unique components out of series-identical working materials. Since this process generates components layer-by-layer out of powdered material, however, they exhibit a large surface roughness (R_a of approx. 20 µm) in comparison to those finished by machining processes. According to current state-of-the-art, post-processing – e.g. machining the functional surfaces – is, therefore, necessary to improve the component's surface quality.

Method

Within the scope of the European research project »AMAZE«, Fraunhofer ILT has developed the application of the laser polishing process for the post-processing of components made out of the nickel-based alloy Inconel 718 by SLM. The laser polishing is based on the melting of a thin upper layer and the smoothening of the surface on account of interfacial tension. In comparison to conventional grinding and polishing processes, no material is ablated in SLM, but rather solely remelted. Using this fundamentally different active principle of laser polishing in combination with automation of the process, the project aims to reduce costs with respect to the time- and, thus, cost-intensive conventional surface processing of a component's functional surfaces.

Result

The surface roughness of a cubic sample produced by SLM could be reduced from R_a = 20 µm to R_a = 0.19 µm. The surface processing rate during laser polishing is 2.25 cm²/min. These results, gained from initial parameter studies, are promising and form the foundation for further developments of the process combination of SLM and laser polishing for complex free-from surfaces.

Applications

Due to their strength at high temperatures, components made out of Inconel 718 with free-form surfaces by SLM are used in the aerospace industry as well as for turbine construction.

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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2 Picture of the Selective Laser Melting (SLM) process.

3 Laser polished surface of an SLM sample out of Inconel 718.

MACHINE FOR AUTOMATED LASER POLISHING OF COMPONENTS UP TO 1 KG

Task

To date, the available laser polishing machines are dimensioned for larger component parts such as dies and mold inserts. To polish smaller components such as implants for medical technology, these machines are over-dimensioned and, thus, unnecessarily expensive. And up to now, no component could be laser polished completely automatically while maintaining the required protective gas atmosphere when a tool or mold insert is changed.

Method

The goal is to set up a machine for automated laser polishing of small components weighing up to 1 kg. The protective gas atmosphere in the process chamber should remain when the component tray is inserted and removed so that continuous polishing is made possible.

Result

The laser polishing machine is built according to the glove-box principle, which uses a structure out of granite on a base frame out of steel. The optical system is placed in a box above the process chamber, and the required process control is housed in the base frame. The component parts can be inserted in the process chamber through an antechamber. For this laser polishing machine, a six-axis robot is used as an axis system, which transports the component part as well as guides the component during polishing. As a laser beam source, a pulsed rod laser from Fraunhofer ILT is currently being used, having pulse durations in the range of 100 - 500 ns, whereby the integration of laser beam sources with other specifications is possible. Since a laser protection window is used as a viewing window, the machine constitutes a laser device of Class 1 such that no additional protective measures are necessary at the location it is installed.

Applications

The laser polishing machine can be used for the automated laser polishing of small components out of different materials. These parts can range from, for example, implants for medical technology to components for precision mechanics or mechatronics. Thanks to the modular basic principle of the machine, it is possible to adapt it to other laser material treatment processes.

The work presented here was funded by the Federal Ministry for Economic Affairs and Energy (BMWi) within the scope of the project »MediSurf« (grant number 16IN0716).

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1 General view of the laser polishing machine.

2 Process chamber (view without front door).


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TESTING A LASER POLISHING MACHINE IN TOOL AND MOLD MANUFACTURING

Task

For the surface finishing of dies and molds, e.g. for the production of glass bottles, manual polishing is currently still the state-of-the-art. And yet the increasing lack of specialized labor as well as the high costs and processing times, in particular for free-form surfaces, have led to a great need for automated polishing processes. Therefore, Fraunhofer ILT, in cooperation with industrial partners, has developed a machine tool for the laser polishing of metal surfaces. This machine, conceived for tool manufacturing, unifies a five-axis portal machine with a dynamic three-axis laser scanning system. For the processing of free-form surfaces all eight axes can be moved simultaneously, thus achieving a seamless finish. After users take a short training seminar, they can program this machine, in spite of its complex kinematics, with standard CAM software (e.g. PowerMill or SiemensNX) and a postprocessor developed at Fraunhofer ILT.

Method

The industrial testing of the machine took place in the mold construction of an industrial partner from the sector of glass bottle production. After the machine operators were trained in the machine control (Siemens Sinumerik 840D sl) and the CAM programmers in using the ILT-postprocessor, the laser polishing machine was used in the manufacture of glass-blown molds. The emphasis during testing lay in the assessment of ergonomic operation, process stability of the machine under industrial conditions, as well as operational behavior of the laser-polished surfaces during glass production.

Result

Within the scope of the running tests, the machine tool has proven to be fully industry ready and easy to operate after the machine operators as well as the CAM programmers take a brief training seminar. The good accessibility of the machine tool table, both manually as well as via crane loading, the adaptive measuring system to determine the position of the clamped workpiece and the automated polishing process all ensure good ergonomics. The mold inserts out of grey cast iron (EN-GJS-400-15) can be laser polished reproducibly and prove to be more resistant in production than hand-polished surfaces due to the increased hardness of the remelted surface layer.

Applications

Fields of application can be found, above all, in tool and mold manufacturing, with a focus on applications with surface qualities in the range of Ra 0.15 µm to 0.40 µm. Among these count mold inserts for glass production and tools for cold or warm forming.

The work presented here was funded within the scope of the ERA-NET MANUNET project »Alpine«.

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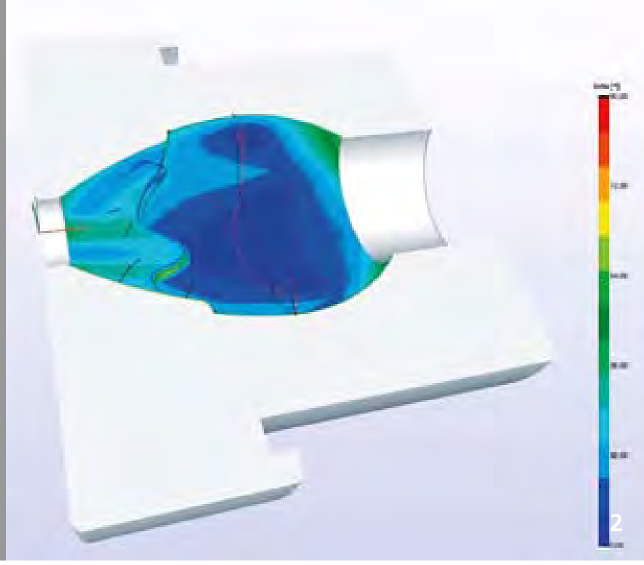
3 Machine tool for laser polishing.

4 Laser-polished tool.



NINE-AXIS SIMULTANEOUS PROCESSING

Task

Whenever high speed and dynamics are required for laser materials processing, galvanometer laser scanners – the state-of-the-art – are used to fulfil such demands. On account of their low inertia, these systems are able to guide the laser beam focus over a component surface at several meters per second. To process 3D parts, a conventional mechanical axis system with translational and/or rotatory axes is necessary as well. When both systems are combined, processing large and complex components can be done at high dynamics and great flexibility. In previous approaches, the mechanical axes are used to position the component, which, subsequently, is processed using a laser scanner. Larger or curved surfaces are incrementally processed as several subareas in whose overlapping areas significant visible transitions appear.

Method

The goal here is to process complex 3D geometrical shapes continuously without visible transitions. For this, a conventional five-axis system is combined and synchronized with a three-axis laser scanner so that simultaneous processing with all eight axes is possible without disruptive transitions. If, in addition, a measuring probe is used, which determines the position and orientation of the component in the machine, a further ninth axis is required, which rotates the scanning field of the laser scanner. The necessity of the further axis results from the non-existent rotation symmetry of the laser scanner as a »tool«.

Result

By integrating the aforementioned measuring probe, Fraunhofer ILT was able to develop a continuous CAM-NC chain. The simultaneous processing can be planned and calculated on a computer using conventional CAM software in combination with an advanced post processor developed at Fraunhofer ILT. The complete CAM-NC chain has already been successfully tested in cooperation with a partner in an industrial application.

Applications

The nine-axis simultaneous processing can be used for surface-based laser processes for which a laser scanner is needed. Among these count laser marking, laser structuring and laser polishing.

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1 Component part measured by a measuring probe.

2 CAM planning for laser polishing.

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LASER REMELT STRUCTURING (WAVESHAPE) ON TI6AL4V

Task

Today, components with structured surfaces have become essential in many industrial areas. Used for such components, the titanium alloy Ti6Al4V has found a wide range of applications in many branches, beginning with turbine engine components for the aviation and space industry via implants in medical technology all the way to functional and design surfaces for the jewelry sector. The processes currently used to structure surfaces – etching, laser ablation – are, however, time or cost intensive and based on structuring through material ablation. Both of these processes generate rough surfaces, which can only be used to a limited degree in the design sector or in those with high hygienic standards. Moreover, their low ablation rates often constitute a clear shortcoming.

Method

With the newly developed process of laser remelt structuring (WaveShape), a laser beam is guided over the workpiece and melts the surface locally. Simultaneously, the laser power is modulated with frequencies between 10 - 100 Hz so that the melt pool size changes continuously. Thanks to this modulation of the melt pool size, the material is distributed, thus generating mountains and valleys: one half of the arising structure lies above the initial level, one half below. The surface layer hardens directly from the melt pool so that the surface, in addition to being structured, is polished at the same time. To expand the spectrum of materials that can be processed with WaveShape (to date only 1.2343), systematic experimental tests were conducted for Ti6Al4V within the scope of the project »WaveShape«, funded by the VW Foundation.

Result and Applications

The investigations show that Ti6Al4V is basically suitable for use with laser remelt structuring. In the process, it is shown by means of single tracks that structures can be generated with a single processing step and have a height of more than 20 µm. This corresponds to more than the four-fold of the structure height that can be generated with comparable process parameters on 1.2343 tool steel. Furthermore, the investigations show that the scanning speed can be increased when the process parameters are adapted accordingly, by a factor of four – to 200 mm/s – making it possible to process 200 µm high structures at 30s/cm^2.

This process is suitable for generating a wide spectrum of aperiodic (Figure 3) and periodic (Figure 4) structures. The structured surfaces exhibit a small micro-roughness (Ra < 0.1 µm). Fields of application for such structures lie, among others, in all areas where innovative functional elements (streaming, light scattering) and design elements (optics, haptics) 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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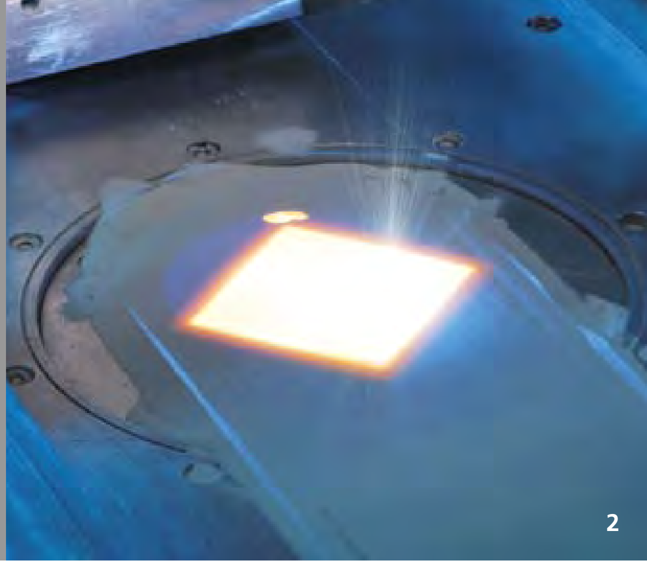
Demonstration object out of Ti6Al4V

3 ... with aperiodic structuring (leather grain).

4 .... with different periodic structures.



USING SLM WITH NICKEL-BASED SUPER ALLOYS FOR TURBOMACHINERY APPLICATIONS

Task

While resources are becoming more and more scarce, energy and mobility needs are growing – this places great economic and ecological challenges upon manufacturers of turbines for the energy and aerospace sector. The possibility of producing complex, functionally optimized component parts out of heat-resistant nickel-based super alloys such as MAR M-247 by means of Selective Laser Melting (SLM) offers great potential for meeting these challenges. The task here consists in developing the SLM process for processing such working materials free of cracks.

Method

The working material MAR M-247 is considered to be difficult to weld and, according to the current state-of-the-art, cannot be processed by SLM. Within the scope of the market-oriented preliminary research project »NanoGen«, concepts were developed for processing this working material free of cracks using SLM. A promising approach emerged from these ideas – using high-temperature preheating to reduce thermal gradients and stress during SLM.

Result

To implement high-temperature preheating, an equipment design was developed using an inductively heated construction platform. This approach enables preheating temperatures of > 1200 °C in an inert gas atmosphere of < 10 ppm oxygen content. By using this equipment design, Fraunhofer ILT succeeded in processing MAR M-247 without cracks. In addition, the altered cooling conditions allow material isotropy to be enlarged by a reduction of the directed grain growth. Further work should evaluate the mechanical specific values of the samples produced this way as well as the possibility to generate complex structures with a surface quality of Ra < 20 µm.

Applications

Complex nickel-based super alloys such as MAR M-247 are used, above all, in the field of steel turbines and of turbomachine construction for the energy and aerospace sector. Furthermore, these materials can also be used for complex, lightweight motor components in automobile construction.

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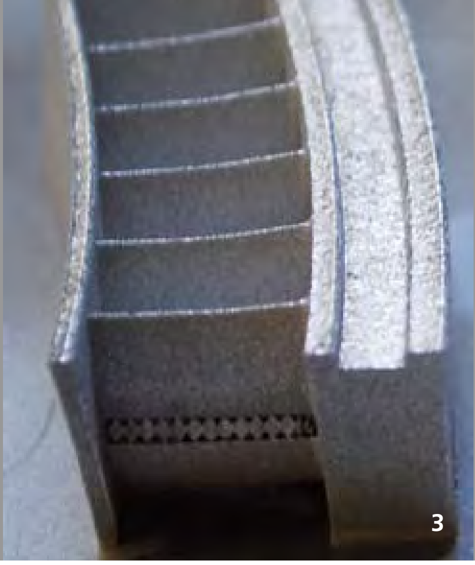
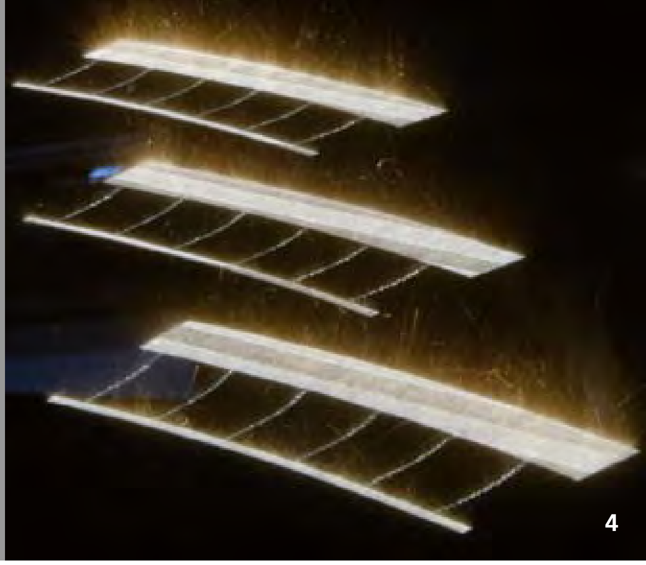
1 Micro gas turbine out of IN-718.

2 Process image of high temperature SLM.





ADAPTIVE SLM PROCESS STRATEGY

Task

As the SLM process undergoes further development, a central focus lies in the increasing productivity for series production. The conflict between better surface quality and quick building rates constitutes a hurdle in this development. To begin solving this conflict, Fraunhofer ILT has developed the skin-and-core process strategy. In it, the component part is separated into skin and core areas dependent on geometry, to which different process parameters are assigned. In view of the overall process chain, the skin-and-core process strategy does not, however, offer the best possible solution to the aforementioned conflict. Fitting surfaces, which need a milling process after the SLM process, are produced, for example, with better surface quality and lower build rate. Consequently, a function-dependent classification of component parts is necessary, one which takes the post-treatment processes (e.g. high build rate for sectors that are machined afterward anyway) into consideration. Adaptive process strategy makes such a classification possible. Therefore, the task here consists in implementing adaptive SLM process strategy and quantifying the savings in process time.

Method

A double-row vane cluster is used to investigate adaptive SLM process strategy on the working material Inconel IN718 within the scope of the innovation cluster AdaM. In a first step, the process parameters are identified for the respective area of the adaptive SLM process strategy. In a second step, the vane cluster is manufactured with the conventional process strategy, the skin-core, as well as the adaptive process strategy, and the process times are determined.

Result

As a result, process parameters were identified that result in a density of $\rho \geq 99.5$ percent for the respective areas of adaptive SLM process strategy as well as for the transition between these areas. In the manufacture of the vane cluster, the process time is reduced by a factor of 1.9 compared to conventional process strategy and by a factor of 1.6 compared to the skin-core process strategy.

Applications

The current research on adaptive process strategy is addressing turbomachine construction and can be transferred to other branches using series production (e.g. the automobile industry).

The Fraunhofer innovation cluster »AdaM« is funded by the European Regional Development Fund (EFRE): »Investment in Our Future«.

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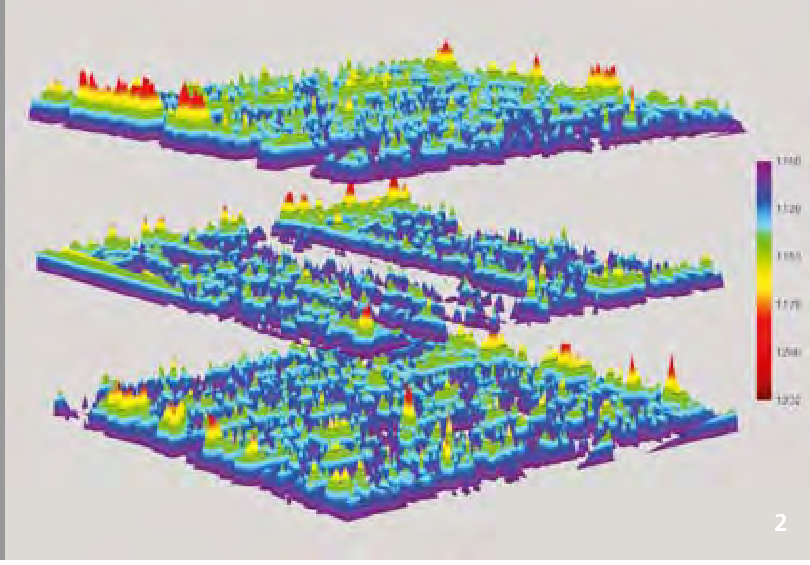
3 Vane cluster produced with SLM.

4 SLM production of vane clusters.



QUALITY CONTROL FOR SLM BY MEANS OF SIGNAL ACQUISITION FROM THE INTERACTION ZONE

Task

Quality control is one of the most important research topics in the additive manufacturing process Selective Laser Melting (SLM) since one of the significant hindrances for a wide introduction of the process in series production is the insufficient acquisition of manufacturing flaws and defects. It is often not possible to examine an SLM component after manufacture without destroying it completely. A first step toward such an examination is to develop suitable methods for process observation, whereby the behavior of the melt during the process should be recorded. For this, investigations have been conducted by means of pyrometry to capture the heat radiation from the laser/material interaction zone.

Method

The process observation unit used is described in more detail in the report »Spatially Resolved High Speed Pyrometry for Selective Laser Melting«. In the pyrometric investigations, the heat radiation of the melt is captured by two pyrometers, and the measuring fields of these pyrometers can be directed toward each other and across from the melt pool position with a precision of down to 20 µm. This does not only enable the heat radiation to be detected coaxially, but also to be done so at staggered positions, which can be optimized to discover defects. For example, measurements right behind the melt pool reduce the signal disturbances caused by melt movements. Furthermore, the use of two pyrometers makes it possible to correlate respective measurements to each other to better detect any defects. To test the suitability of the system, components with predefined defects have been built.

Result

Simulated imperfections with dimensions > 100 µm can be detected by representing the pyrometer signals in a temperature map (Figure 2). Through Fourier analysis of the pyrometric data, distinctions could be made between samples of high density (> 99.5 %) and ones with lower density (> 88 %), although the lower density was caused by many small pores (10 - 30 µm) which could not be resolved individually.

Applications

A system for process monitoring is fundamentally advantageous for the SLM process in all fields of application.

The work presented here was funded within the project «Genergie« of the funding initiative »SME Innovation« by the Federal Ministry of Education and Research.

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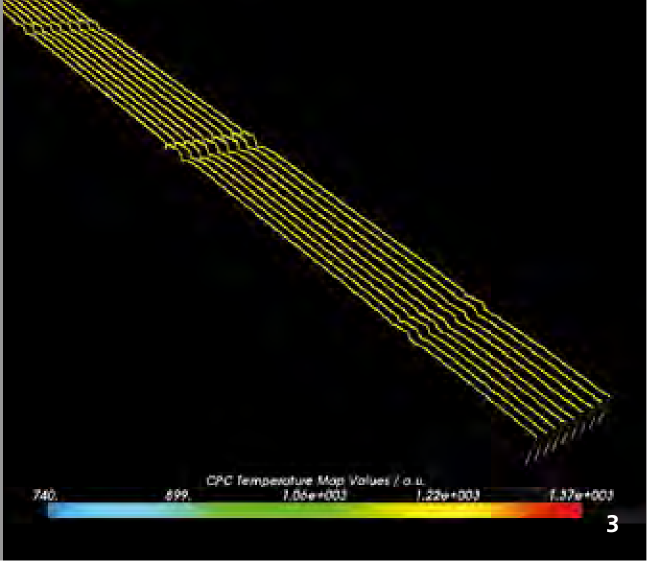
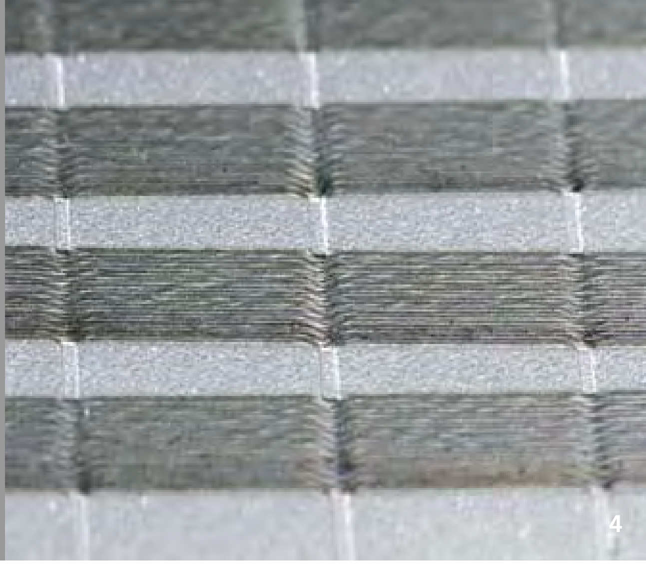
1 Measurement set-up.

2 Temperature map.





SPATIALLY RESOLVED HIGH SPEED PYROMETRY FOR SELECTIVE LASER MELTING

Task

In the production of individual components, additive manufacturing processes are becoming more and more important. They allow products with geometric properties to be manufactured, products which can differ from component to component without generating extra costs. Thanks to the process Selective Laser Melting (SLM), component parts can be constructed layer-by-layer through the selective melting of the basic working material from a powder bed. The quality of the manufactured component part results, above all, when the process operates trouble-free. This is determined essentially by process temperature, which results from the interaction of the laser with the powder bed.

Method

In a typical SLM system, a scanner system is used to position the laser beam inside the construction space according to the component geometry. The powder is melted by laser radiation, thereby generating a melt pool whose emitted heat radiation can be detected.

A high speed pyrometer is coupled coaxially with the scanning system, thus allowing the process emission to be detected in situ. In the process, the radiation emitted from the melt pool is guided along the same optical path as the processing radiation via the scanning mirrors to the pyrometer. From the correlation of the measurement to the location of the emission, a »map« can be created, which reflects the course of the temperature.

Result

The process sensor technology implemented allows temperature maps to be recorded during processing, which correlate the respective emission of the molten pool to the point of processing. At typical recording rates of 100 kHz, spatial resolutions result which are less than the diameter of the laser focus, even at high scanning speeds. This enables the process temperature to be monitored almost completely and serves to track the course of the process. By means of suitable signal processing, a great deal of information about the course of the process can be gained based on these data.

Applications

The system can be used for process control in additive manufacturing of component parts that are generated by means of laser radiation from a powder bed.

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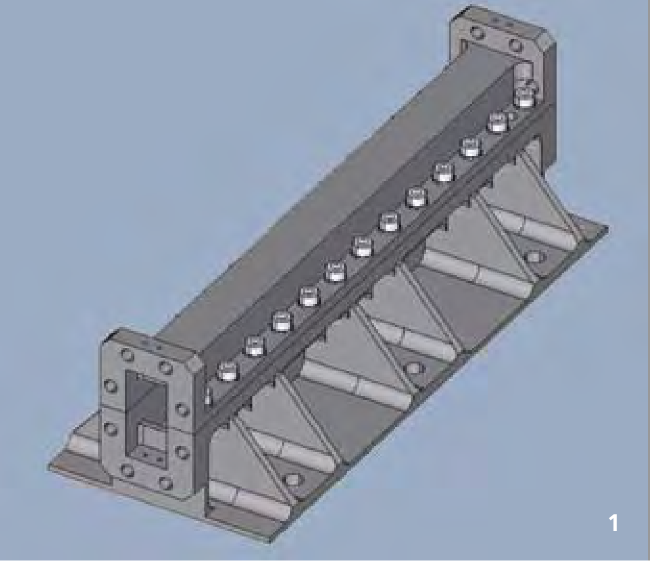
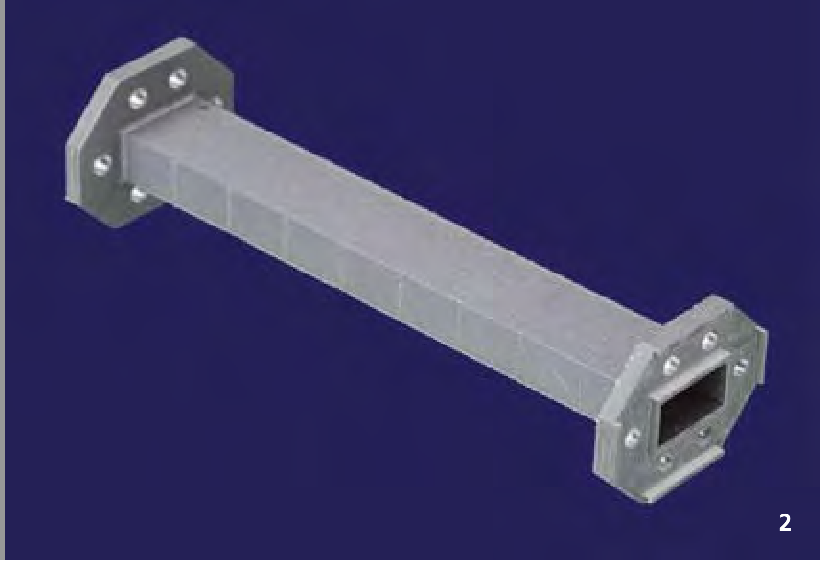
3 Emission map.

4 Inconel sample with powder coat.





MANUFACTURING ANTENNA COMPONENTS FOR SATELLITES OUT OF ALSI10MG WITH SLM

Task

Aluminum wave guides are utilized in satellite antennae due to their favorable strength-to-weight ratio along with their good electrical and thermal properties. Indeed, the costs for transporting the satellite into space depend decisively upon its weight. A waveguide's actual functional geometry, which is needed to conduct the electromagnetic waves, is normally confined to a thin-walled (< 1 mm) hollow profile. Nonetheless, manufactured components have often massive bonding structures, necessary solely because the currently available manufacturing techniques do not allow monolithic manufacture. When SLM is used to produce this wave guide geometry, bonding elements are not needed, thereby reducing the weight while simultaneously retaining the roughness, dimensional and shape accuracy as well as the electrical characteristic values.

Method

Basic investigations were conducted regarding the surface quality, shape and dimensional accuracy and the connection between roughness and electrical values of the waveguide components. The processing of AlSi10Mg in SLM processes at high power (up to 1 kW) and high speed (up to 5,000 mm/s) were investigated for the first time. In this process, all the steps of the SLM process for AlSi10Mg were studied, beginning with the single tracks up to complex components.

1 Conventionally manufactured waveguide (source TESAT).

2 Waveguide manufactured with SLM.

In addition, examinations were made on the shape and dimensional accuracy and their dependence upon a preheating temperature as well as investigations of different construction strategies (e.g. component orientation) of diverse lightweight geometrical shapes.

Result

A lightweight geometrical shape was produced by means of SLM, which reduced the weight of the waveguide by up to 60 percent as compared to the conventionally manufactured shape. The surface roughness currently possible with SLM is, however, coarser than the roughness attainable with the conventional process. It could be shown, however, that the roughness is not a gauge for electrical characteristic values as previously assumed since these values of the waveguides produced conventionally and with SLM are largely identical.

Applications

SLM can be used for manufacturing short connection pieces in the highly demanding Ka band. The insufficient shape accuracy currently limits the wider usage in satellite technology.

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. The work presented here was conducted in the project »GenSat« funded by the Federal Ministry of Education and Research.

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FUNCTIONAL INTEGRATED RIM SUPPORT WITH INTERNAL LATTICE STRUCTURE

Task

Conventional manufacturing processes can only fulfill the increasingly high demands on functional component parts to a limited extent. Additive manufacturing processes such as Selective Laser Melting (SLM) offer the unique opportunity to build complex components while saving resources. Conventionally, the automobile rim support is manufactured out of four different individual parts by means of aluminum die-casting and then welded together in an additional manufacturing step. When the individual parts are bonded together, distortions can occur due to heat input. The goal of this project is to design the rim support stiffer and lighter with an internal lattice as a functionally integrated component part and to build the part using SLM.

Method

To design the rim support anew, it is necessary to quantify the mechanical properties of additively manufactured lattice structures. For this, individual lattice structures were built with different unit cells and underwent compression tests according to DIN 50134. A f2czz structure was integrated into the conventional design of the rim support. The individual parts of the component were aggregated into one part. To remove the powder in the cavities, two openings are placed on each side. SLM was used to build this innovative component design on an EOS M270 with a laser power of 195 W out of AlSi10Mg powder. A subsequent heat treatment increased the strength of the basic material.

Result

In terms of load and manufacture, compression tests according to DIN 50134 show that an f2czz lattice structure type is ideally suitable for use as in a rim support. Thanks to the anisotropic character of the f2czz lattice structure, a 30 % higher stiffness can be attained in the load direction by reducing the weight of the component. In a successfully completed Formula Student competition, the rim support stood up to conditions in a race situation proving the durability of SLM parts.

Applications

Important fields of application are in the aerospace and automobile industries as well as in medical technology.

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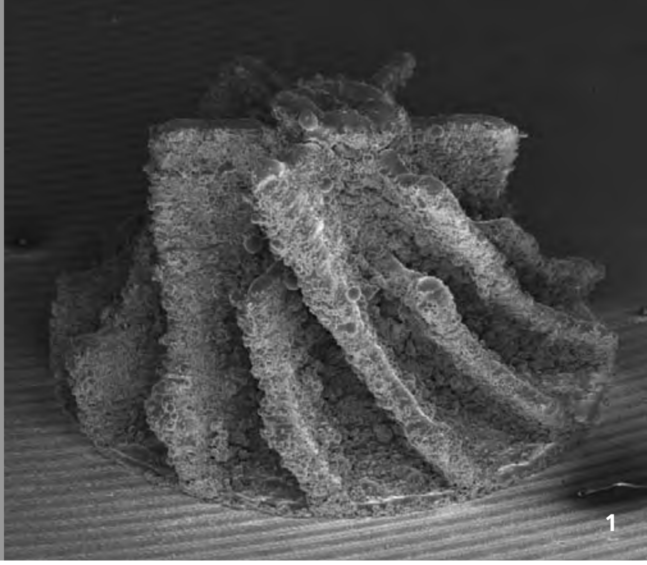
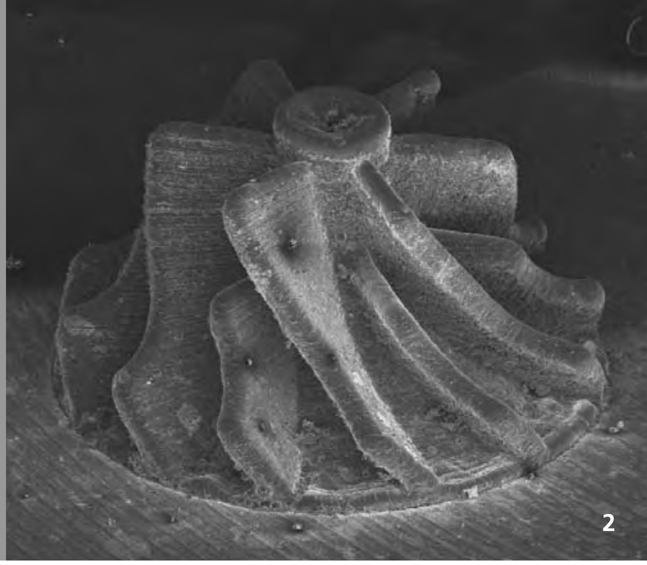
3 View in the wheel bearings of the »Formula Student« racing car with integrated rim support.

4 Rim support built by means of SLM with internal lattice.





ADDITIVE MANUFACTURING OF MICROSTRUCTURES WITH SLM

Task

If the range of applications of SLM as a manufacturing process is to expand, it has to undergo constant further development. Within the scope of the joint project »MikroGen«, funded by the German Ministry of Education and Research, SLM should be developed for the manufacture of micro-technical components with structural sizes smaller than 100 µm. The structural sizes producible and the surface quality attainable depend primarily upon the layer thicknesses and the size of the focused laser beam, as well as upon the grain fraction of the powder material and its safe and reliable application. With SLM, surface roughness values (S_a approx. 10 - 30 µm) result, which limit the attainable detail resolution. These aspects make a new process strategy necessary, which should enable the surface quality to be improved and, thus, the detail resolution as well.

Method

In order to reach the goal of manufacturing micro-structures, a process strategy was applied with discontinuous energy input. Thanks to this pulsed laser power modulation, the melt can solidify in between pulses. Thus, in turn, the fluctuation of the molten pool size is reduced, which also reduces the surface roughness. In addition, the amount of powder particles adhering to the surface of the component part is also reduced.

1 Radial compressor, manufactured with continuous (cw) energy input.

2 Radial compressor, manufactured with discontinuous (pulsed) energy input.

Result

Due to the discontinuous energy input, the surface roughness can be improved and thus also the detail resolution as well as the dimensional accuracy of micro-scaled SLM components (S_a approx. 1 - 2 µm). Thanks to this process strategy, micro-components, as well as those with local microstructures, can be built, the latter of which have structure sizes less than 100 µm, with corresponding detail resolution, form/contour accuracy and improved surface quality.

Applications

As the process has been expanded to create structural sizes ≤ 100 µm, the potential applications for SLM have been enlarged. This way, new fields of application can be opened up for SLM in various branches, including medical technology, electronic engineering and optical technologies, among others, for use in micro-channel heat sinks.

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LASER-BASED ADDITIVE MANUFACTURE WITH IRON-ALUMINIDE ALLOYS

Task

The interest in iron-aluminide alloys as a construction material for lightweight construction has been growing in the last few years due to the numerous advantages of this material. Fe-Al alloys have low density, high oxidation resistance, strength against hot corrosion as well as a low share of strategic elements: the main reasons why these alloys can replace high-temperature steel. While these alloys exhibit low ductility and low creep resistance, they do not, however, stand in the way of their wider usage. From a technical point of view, additive laser processes, thanks to quick cooling rates, make it possible to get components with a fine-grained micro-structure, in order to reach the desired properties. A first goal in the joint project RADIKAL, funded by the Federal Ministry of Education and Research, is to test how easily a binary Fe-Al alloy can be processed. For this, simple bulk volumes were built and tested for density and cracks.

Method

Initial tests were conducted with the binary Fe 28at.% Al alloy. These were processed with Laser Metal Deposition (LMD) and Selective Laser Melting (SLM). The goal was to produce crack-free bulk volumes with low porosity.

Result

The selected alloy can be processed into crack-free bulk volumes with low porosity. When SLM was used, a density of > 99.9 percent was reached, and with LMD > 99.5 percent. Cracks were prevented by preheating (100 - 200 °C). Initial mechanical tests have shown that, in comparison to cast samples, SLM testing specimens exhibit higher strength. Adapting the process parameters did not, however, lead to grain refinement. Nonetheless, the results attained form the foundation for the processing of, e.g., ternary alloys, which form grain refining precipitations through a further alloying element and, thus, hold great interest for applications of the future.

Applications

Applications of the future of Fe-Al alloys lie in mechanical, chemical, thermal and corrosive heavy-duty components. Examples can be found in turbine engines, in assemblies for energy conversion or in the aerospace industry.

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3 LMD solid body out of Fe-28At.%Al.

4 Solid body of an Fe-Al alloy manufactured with SLM.

COATING THROUGH HIGH-SPEED LASER MATERIAL DEPOSITION

Task

The wear and corrosion protection of large, high-quality components of the manufacturing industry is becoming more significant, not only from an economic but also an ecological perspective. In addition, this protection has become more and more important to the market as it constantly demands innovative products with increasing performance density and functional variety. To date, conventional laser material deposition (LMD) has been able to establish itself only for individual applications in this range of uses. With LMD, high-quality pore- and crack-free coatings can be produced with metallurgical bonding and low dilution from a large spectrum of working materials; however, typical coating thicknesses (> 500 µm) for the wear- and corrosion-protection are commonly too large and the surface rates attainable, in the range of 10 - 40 cm²/min for large-scale coatings, far too small.

Method

Against this backdrop, Fraunhofer ILT has been developing high-speed LMD as a new variation of LMD in the coating thickness range of 10 - 300 µm and at coating rates > 250 cm²/min. This approach consists of achieving a significant increase in the attainable process speed during LMD by guiding the powdered additives into the laser beam with a coaxial powder nozzle above the melt pool generated by the laser radiation. The powder is then heated to a temperature as close as possible to the melting temperature before it enters the melt pool. Since the loss of the heat flow is reduced by the temperature equalization between powder particles and melt pool, the time necessary for a layer to form, in turn, decreases. The high feed speeds needed, in the range of 10 - 500 m/min are made possible by rotating the component.

Result

The high-speed LMD process was used to apply an approx. 100 µm thick wear- and corrosion-protection layer (WC/IN 625) successfully on a brake disc made out of cast iron with lamellar graphite.

Applications

The main focus is the further development of high-speed LMD for the coating of large, rotationally symmetrical components to protect them against corrosion, abrasive and adhesive wear, for example for hydraulic or oil field components.

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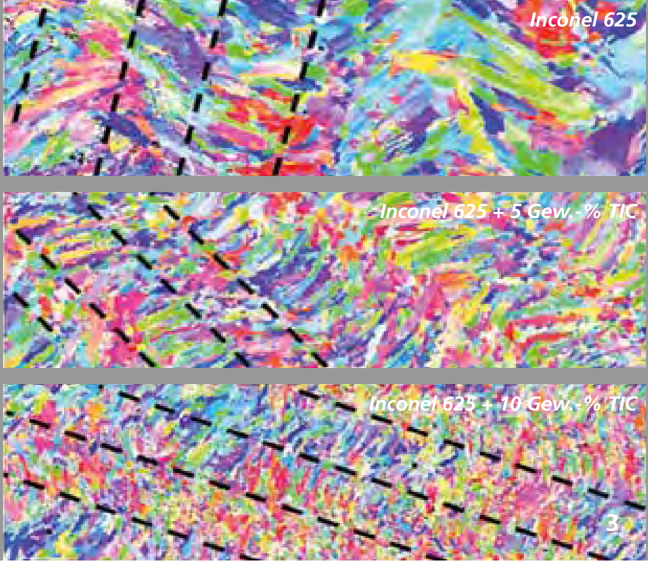
1 A brake disc coated for wear and corrosion protection.

2 High-speed laser cladding of a shaft.



LASER METAL DEPOSITION OF MICRO-PARTICULATE METAL-MATRIX COMPOSITE MATERIALS

Task

Micro-particulate additives from ceramic hard material phases in a metal matrix can contribute to reducing abrasive and adhesive wear as well as to improving static mechanical strength properties. These additives can significantly improve such properties in nickel-based alloys, e.g. Inconel 625, which are commonly used at operating temperatures > 400 °C. Decisive for the properties of particulate-reinforced composite materials is a homogeneous distribution in the matrix material and an exact spatial and temporal control of the energy input and additives. These requirements can be fulfilled by Laser Metal Deposition.

Method

To investigate to which extent the percentage of TiC particles in the micron range within the metal matrix of Inconel 625 (IN 625) influences the mechanical properties, powder mixtures with different TiC contents (2.5, 5, 10 weight percent) were first produced by mechanical alloying. Tensile test samples were cladded with the process parameters adapted to the TiC percentages and then underwent a metallographic examination. Subsequently, the tensile test samples were tested at room temperature and at 600 °C.

Result

An increasing percentage of TiC in the IN 625 matrix leads to an increase of hardness, up to 410 HV 0.3 at 10 weight percent TiC (260 HV 0.3 without TiC additives). The elastic limit Rp 0.2 increases in the same interval from approx. 660 Mpa to approx. 940 Mpa. The maximum tensile strength Rm is reached with 10 weight percent TiC and amounts to 1270 MPa; at the same time, with increasing TiC percentage, a grain refinement of the micro-structure could be identified (cf. Figure 3). The effect of grain refinement also remains at an operating temperature of 600 °C. The elongation at fracture tends to fall as the TiC percentage rises. The samples with 10 weight percent titanium carbide exhibit a significantly reduced elongation at fracture of 3 percent.

Applications

Particulate-reinforced metal-matrix composite materials can be used in the aerospace industry as well as in the energy sector for repairing and manufacturing heavy-duty components that have to withstand high operating temperatures. For example, in turbine components, the strength, the wear resistance and the creep resistance can be improved with these materials.

The work presented here was funded within the scope of the Sino-German Research Project »nPR MMC by LMD«.

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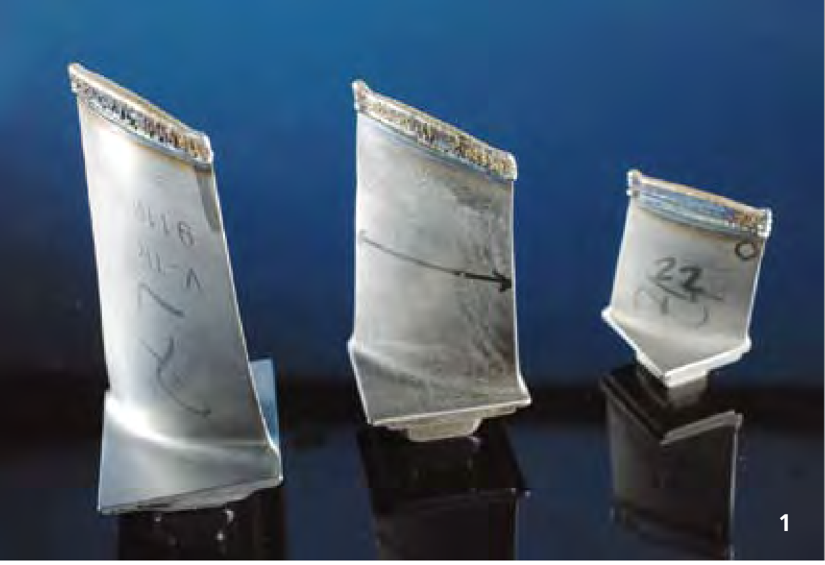
3 EBSD images from microstructures of IN 625 with differing TiC percentages.

4 3D volumes for tensile test samples.



DEVELOPING A METHODOLOGY FOR CLADDING BLADE TIPS

Task

In operation, turbine and compressor blades are subject to wear that limits the operational lifetime of the component due to material removal at the blade tip. With Laser Metal Deposition (LMD), a process is available, which can build up the removed volume. The development of such an LMD-based process, however, is bound up with high experimental costs. At Fraunhofer ILT, within the scope of the Innovation Cluster »TurPro«, a methodology was developed for the LMD of blade tips, which enables similar blade tips to be repaired without additional process development.

Method

The parameter development for LA was conducted using individual tests on edges of sheet material of different widths. For this purpose, the adapted parameters have been identified for the respective sheet thicknesses. The process behavior at the leading and trailing edges has been investigated by means of high-speed camera images as well as numerical simulations. Strategies have been developed to prevent these edges from melting.

The results from the sheet material have been extracted, transferred to three sample blades out of Inconel 718 and then tested. The geometry of the blade tip was recorded by means of a laser line scanner, and a center contour track calculated on the blade tip. From this data as well as the parameters identified, an NC program has been developed in which laser power and beam diameter are adapted to the local blade width. The beam diameter during the process was adjusted using an optic from TRUMPF, which makes it possible to change the track width along the path.

Result

With the methodology developed here, LMD parameters can be transferred from sheets (of constant width) to blades and the parameter sets can be determined for the three blade types.

Applications

The methodology developed here can be transferred to a large number of blade types (aviation and energy generation) and to different materials.

With courtesy of TRUMPF Laser and Systems Technology GmbH.

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1 Sample blade geometrical shapes repaired with the method developed.

2 Detail of a sample blade tip after laser cladding.

3

DEVELOPMENT OF A »TECHNOLOGY PROCESSOR« FOR LASER METAL DEPOSITION

Task

To develop a process for repairing blade tips with Laser Metal Deposition (LMD), the geometry and material combination (substrate and additive) have to be considered. Transferring these processes to different blade geometries with different material combinations generally requires a large amount of experimental development. To reduce this, a »technology processor« is being developed within the scope of the Fraunhofer Innovation Cluster AdaM. This processor is consisting of a data base, a simulation tool for LMD and component-specific process strategies, the latter of which only require fine tuning of the process parameters. For the data base, experimental investigations will be conducted on iron- and nickel-based alloys in various geometries. The following presents the first experimental results for the iron base material 17-4PH, exemplified using a BLISK blade tip repair.

Method

Using methods of experimental design, Fraunhofer ILT has developed process windows from which model equations have been derived. These, in turn, are used to understand the interactions between different process parameters and characteristic values for the welding bead geometries. The experimental investigations concern individual and overlapping tracks as well as the fillet geometries of different wall thicknesses. On the basis of this data base, a process window can be defined for LMD of blade geometries with locally varying wall thicknesses, with the window then only requiring fine adjustment.

Result

Thanks to this methodical approach, process parameters have been identified for LMD of BLISK blade tips, which were then cladded. The post-process machining was conducted at Fraunhofer IPT (Figure 3).

Applications

The results so far show that the methodology chosen to transfer an LMD process to other geometries and material combinations is suitable to reduce the experimental cost for this transfer. A graphic user interface is being developed so that in the future external users can also profit from this technology.

The Fraunhofer innovation cluster »AdaM« is funded by the European Regional Development Fund (EFRE): »Investment in Our Future«.

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3 Segment of a BLISK. Left: cladded BLISK blade tip. Right: machined, reworked BLISK blade tip.

WEAR PROTECTION OF COMPONENTS OUT OF COPPER IN HOT RUNNER TECHNOLOGY

Task

In hot runner technology, copper working materials are first choice due to their high heat conductivity. A disadvantage, however, is their low service life as a consequence of high abrasive wear, which results from high current speeds and pressures of up to 2500 bar. The state-of-the-art technique to increase the lifetime of gate tips is the soldering or pressing of steel into the copper-based component. As a consequence of thermal loads, cracks can form or the tips can come loose during industrial operation.

Method

During Laser Metal Deposition (LMD), metal powder is applied in the interaction zone between laser beam and substrate and melted in the laser beam. Here, the coating is fused to the base material in a metallurgic connection. With this process, it is possible to apply layers up to a thickness of several millimeters. For the company Schmelzmetall, Fraunhofer ILT has developed an LMD process by applying a cobalt-based alloy on the copper alloy K265. In a second step, gate tips were made at Schmelzmetall out of coated preforms, which are currently being tested in industrial operation, compared to conventionally manufactured gate tips in terms of service life.

Result

The cobalt-based alloy (JetKote 7206) can be applied free of cracks and pores on the copper alloy K256. The coating fuses metallurgically to the base material and has a hardness of 600 HVO.3. Field tests are currently being conducted. Parallel to this, the LMD strategy is being adapted in order to attain short processing times so that the process fulfills industrial requirements.

Applications

The main field of application is found in the plastic processing industry and its suppliers. Further applications are wherever the high heat conductivity of copper is needed, but also where high wear protection is required, thus, for example, in the die cast industry.

The work presented here took place within the scope of a ZIM project of the Federal Ministry for Economic Affairs and Energy and funded by the AiF.

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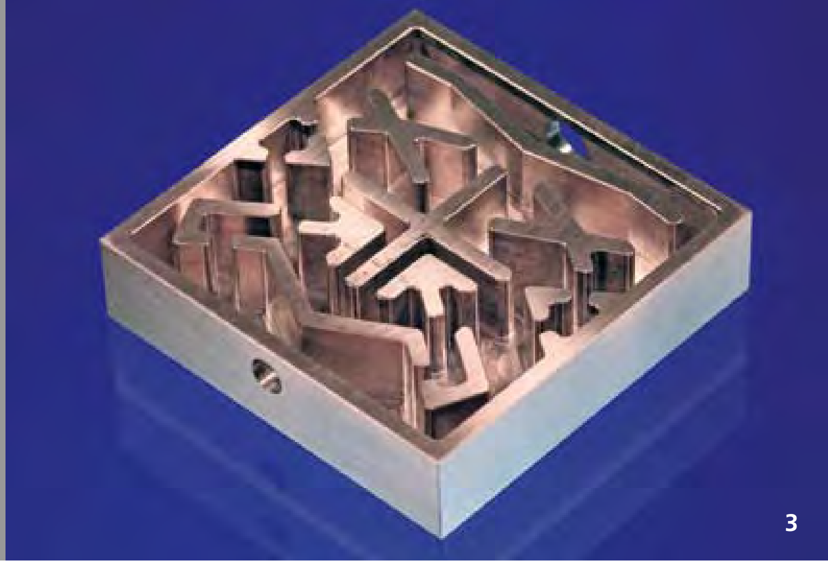
1 LMD-coated gate tip from the company Corvaglia.



GENERATING OXIDATION-RESISTANT COPPER ALLOYS BY ADDING CHROMIUM

Task

The heat conductivity of pure copper or its alloys (200 - 400 W/mK), in comparison to iron- and nickel-based alloys, is larger by more than a factor of ten, which makes copper materials attractive for increasing the efficiency of cooling structures. They tend to oxidize, however, which confines the applications of pure copper to temperatures below 200 °C. To improve its oxidation resistance, the manufacture of copper-chromium alloys was therefore investigated, made using laser metal deposition (LMD).

Method

Thanks to the use of powder-formed additive materials in LMD, their composition can be varied while they are fed into the process. First, the buildup of sample grains out of copper with different contents of chromium (10 – 80 weight-percent) was investigated. By means of these samples, the thermal conductivity and the oxidation resistance were determined in dependence upon the percentage of chromium.

Result

The low solubility of chromium in copper (less than 0.3 percent) and the quick solidification during LMD led into fine homogeneously distributed chromium precipitates in the copper matrix. Crack-free samples with a density > 99.8 percent could be produced with a chromium content of up to a maximum of 60 weight-percent. Depending upon the percentage of chromium, the heat conductivity lies at 90 - 200 W/mK. Through formation of a passivation layer out of chromium oxide on the surface, the oxidation resistance can be increased significantly. With small chromium contents (~10 weight-percent) the copper alloy already shows an increased oxidation resistance up to 500 °C. In long-term tests (1,000 h), the oxidation resistance up to temperatures of 750 °C could be proven for a chromium content of 30 weight-percent.

Applications

Through the addition of chromium, copper materials can be applied to significantly higher temperatures. LMD can be used to produce coatings or complete cooling bodies which provide an outstanding combination of heat conductivity and oxidation resistance for continuous operation at high operating temperatures.

The work presented here was conducted within the scope of »EFCOPOST«, a project funded by the Federal Ministry of Education and Research.

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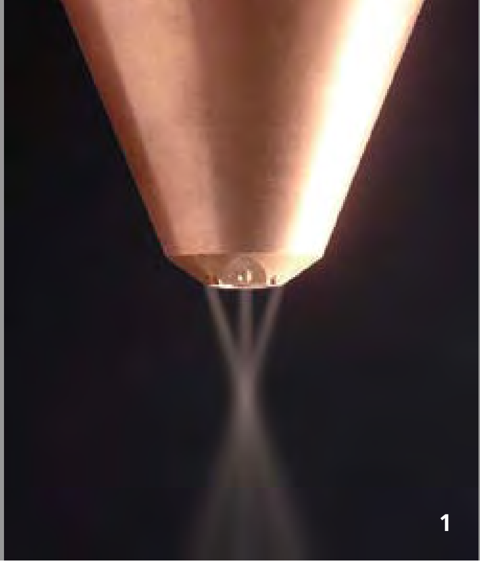
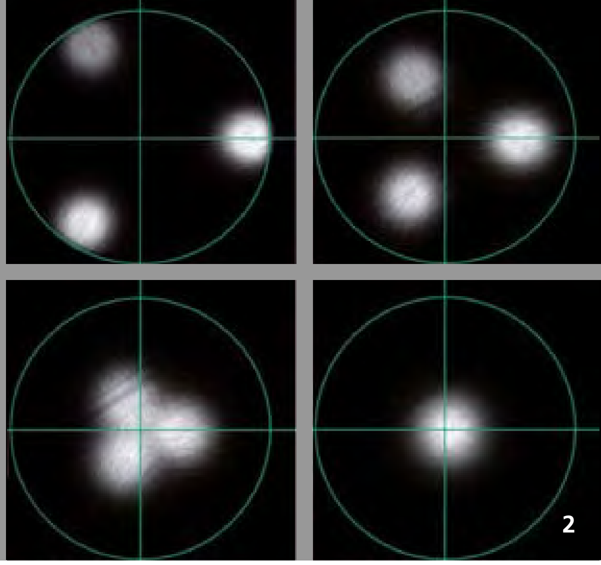
2 Microstructure with a chromium percentage of 20 weight percent.

3 Cooling body made and finished by LA out of Cu-Cr.





CERTIFICATION OF POWDER NOZZLES FOR LASER METAL DEPOSITION

Task

When laser radiation is used for Laser Metal Deposition (LMD), the powder feed in the melt pool plays a decisive role. To a large extent, this determines the degree of powder use, the oxidation by the surrounding atmosphere as well as the geometry and roughness of the layer. Therefore, there is a great necessity to characterize the powder gas stream in order to secure process quality. To date, no standardized process is available for certifying powder nozzles.

Method

Important parameters that need to be monitored are the symmetry of the gas stream, the position and size of the powder focus as well as the particle density distribution. In order to measure and capture the required parameters, the powder gas stream is illuminated with a laser line from the side and observed using a camera arranged coaxially through the powder nozzle. A high frame rate allows the individual powder particles to be captured in number and position. Through step-by-step movement along the powder gas stream, individual layers are recorded in order to reach the particle density distribution with corresponding algorithms. From this distribution, key figures can be derived for certification of powder feed nozzles. This information allows the adjustment and wear state of a nozzle to be documented and the processes to be set-up reproducibly.

Result

The measurement process opens up, for the first time, the possibility to characterize a powder gas stream completely. The process could be qualified for different powder nozzles and powder grain fractions. A testing stand for automated and standardized measurement of powder feed nozzles is available to certify individual powder nozzles.

Applications

Among potential applications count all activities in the sector of LMD by which the exact knowledge of the powder gas stream is required. This knowledge can be used for process development, nozzle development and for the production of components with high requirements upon quality.

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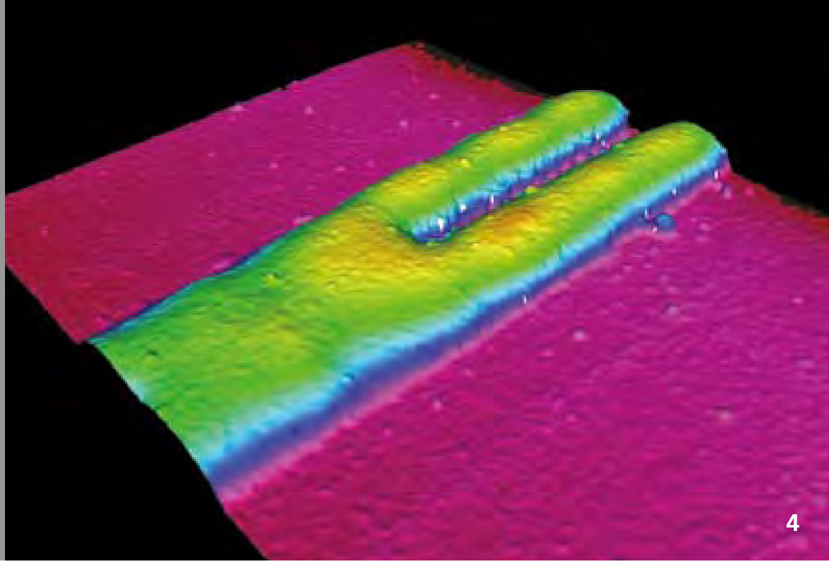
1 Powder gas stream of a three-stream nozzle.

2 Particle distribution of a three-stream nozzle.



MICRO LASER METAL DEPOSITION WITH MULTI-BEAM OPTICS

Task

In the electronics industry, gold coatings are used to generate a large number of electrical contacts. Conventional processes are only able to do this over a large area. When micro laser metal deposition (μ-LMD) is used to selectively clad gold contacts, however, only the contact area is coated, thus saving a significant amount of the precious additive. While the basic suitability of such contacts has already been proven, coating thicknesses and mixture with the substrate have to be reduced further. To do this, Fraunhofer ILT is currently developing and testing adapted optics.

Method

For μ-LMD of gold contacts, a nozzle is used to place the additive in the interaction zone of the laser beam and substrate material where the additive is melted. By miniaturizing the contact points (d < 100 μm), a significant amount of the substrate material (10 – 30 percent) melts and mixes with the applied gold, thereby degrading the electrical conductivity. To reduce the dilution, new optic designs are being tested. A laser optic separates the incident laser beam in two partial beams. These are positioned on the workpiece directly next to each other so that both melt pools flow into each other. In comparison to single-beam optics, a wide welding track can be generated without increasing the melt depth in the middle of the track.

Result

The aspect ratio (height: width) of the gold tracks can be doubled (from 1:2 to 1:4), when compared to the single-beam optic, while maintaining constant melt depth. Thanks to flatter tracks with a high share of gold, the excellent contact properties of the noble metal can be preserved and, at the same time, the welded coating thickness and, thus, the consumption of this metal reduced.

Applications

μ-LMD of noble metals can be used wherever the excellent electrical properties of noble metals are needed selectively, but where a conventional large-scale coating appears uneconomical. Fields of application are in the electronics industry as well as for contacts in fuel cells.

The work presented here was funded by the Federal Ministry of Education and Research within the scope of its project »Mifulas 2«.

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3 μ-LMD with two laser beams.

4 Contour of a gold conducting track on stainless steel.

LASER BEAM WELDING OF ULTRA-HIGH STRENGTH STEELS

Task

Whoever deals with the lightweight design for vehicle manufacturing cannot get around ultra-high strength steels. For this reason, there have been developments toward alternative qualities of high strength steels, whose strength can be enhanced by hot stamping or twinning-induced plasticity. In both processes, however, there has not been a process window for laser beam welding due to the material's increased carbon content. This is particularly true for hardened materials. In view of introducing such materials into this manufacturing sector, these process windows – an assessment of weldability and the appraisal of their properties – need to be identified.

Method

In welding trials upon thin sheet metal, process parameters were developed for several representatives from ferritic-martensitic chromium steels, nickel-alloyed bainitic and martensitic hardened steels and high manganese austenitic steels. The first were welded in a normalized as well as in a hardened state. Subsequently, metallographic inspection was used to investigate the welding microstructure, which in turn led to a better understanding of the factors enabling weldability. Hardness measurements were carried out in the welded zone to estimate the expected mechanical properties.

1 Microstructure of weld in 1.4034.

2 Microstructure of weld in Fe-0.4C-4Ni-1.5Cr-0.5Mo.

3 Molten line in a strip cast Fe-0.29C-27.3Mn.

Result

Martensitic-hardened high-alloy chromium steels with carbon contents from 0.02 to 0.46 weight percent can be welded in normalized state when standard heat treatment is used. In applications for manufacturing tailored blanks, the heat treatment can be omitted. After hot-stamping, the weld will show slightly reduced hardness as compared to the hardened base material. A prerequisite of welding hardened steels for assembly purposes is an in-situ pre-heating and tempering, in order to maintain the toughness of the weld zone. The same is true for bainitic-hardened steel with 0.4 percent carbon and 4 percent nickel. Hardened metal sheets can be tempered at temperatures of up to 450°C without sacrificing strength. For high manganese austenitic steels with 0.3 percent carbon and 17 - 30 percent manganese, the formability is not impaired by the welding seam.

Applications

Ultra-high strength stainless steels can be utilized where their intrinsic corrosion resistance, along with high strengths of up to 1.9 GPa, is required, as in utility vehicles and railway cars. Nickel-alloyed Temper Tough™ is an all-round steel that is tolerant of hardening defects due to its transformation behavior. Steels containing high amounts of manganese are currently under development and hold great potential for saving energy during forming because of their ability of work hardening by twinning.

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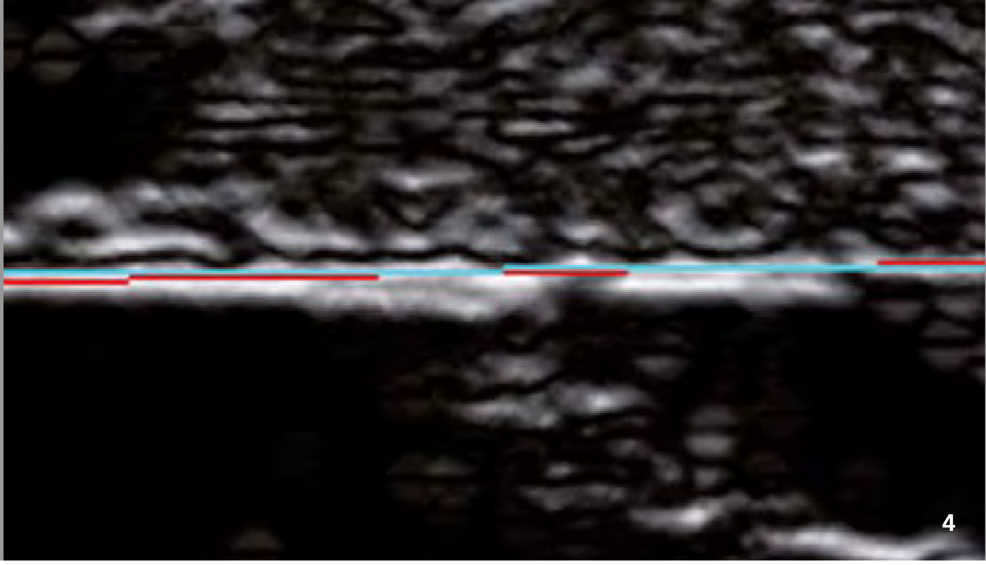

TEXTURE-BASED JOINT TRACKING CONTROL DURING JOINING WITH LASER RADIATION

Task

To guarantee the fatigue strength of a welded joint, the laser beam must be focused precisely in a narrow tolerance range along the joint seam of the workpieces. When the component dimensions exhibit fluctuations that are larger than the tolerances, a correction of the path is necessary, either by using a teach-in directly at the facility or, more economical for series production, by using sensors and controllers to automatically compensate for deviations. Industrially, light-section triangulation sensors have previously been used to detect joint positions, which enable laser focus to be corrected automatically relative to the joint seam. Since these sensors have to be arranged in advance, the accessibility to the workpiece is impaired due to its interfering contour. In addition, the edges on a butt joint have to be prepared and structured correspondingly, e.g. by a chamfer, so that these sensors can still recognize the joint. The light-section triangulation principle has yet to function on zero gaps.

Method

With hybrid laser-beam arc welding, the width and position of a joint is identified relative to the focal point of the laser beam with an image sensor arranged coaxially in its path and by means of texture-based image processing.

In the R&D project QuinLas, it has been proven, with an offline analysis of image data, that it is possible to reliably identify joint seams, largely uninfluenced by lighting conditions, using this texture-based approach. The effectiveness of current inexpensive PC hardware, such as graphic cards with graphic processors operating in parallel, can now enable texture-based image processing algorithms to be implemented in real time and economically (Figure 4).

With this technological approach, it is shown that with a coaxial texture-based approach,

- joint gaps can be identified reliably,
- edges do not need to be pre-structured,
- the flexibility of joining with laser radiation can be increased,
- the field of applications can be expanded to the autonomously guided joining of 3D structures, and
- the process chain, from planning the track to programming it, to the joining process can be shortened and optimized economically.

Result

By reaching this goal, Fraunhofer ILT has enhanced the ability to control joining with the hybrid MAG arc laser and, thus, promoted further industrial processing with this innovative joining process in the sector of automobile and steel construction industry.

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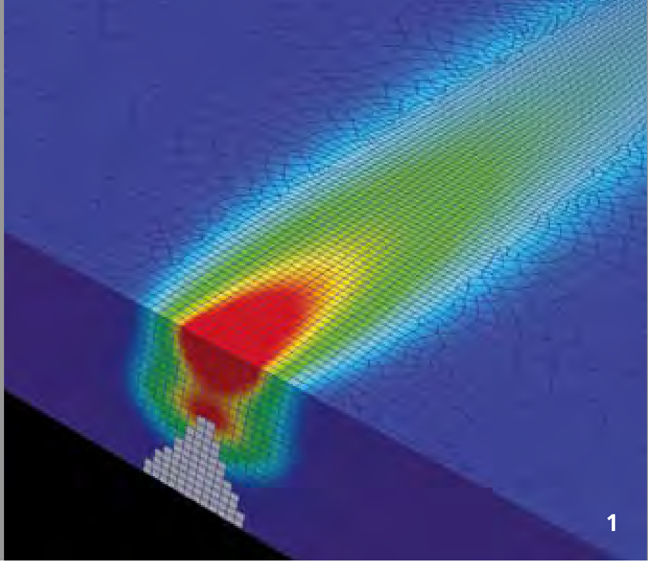
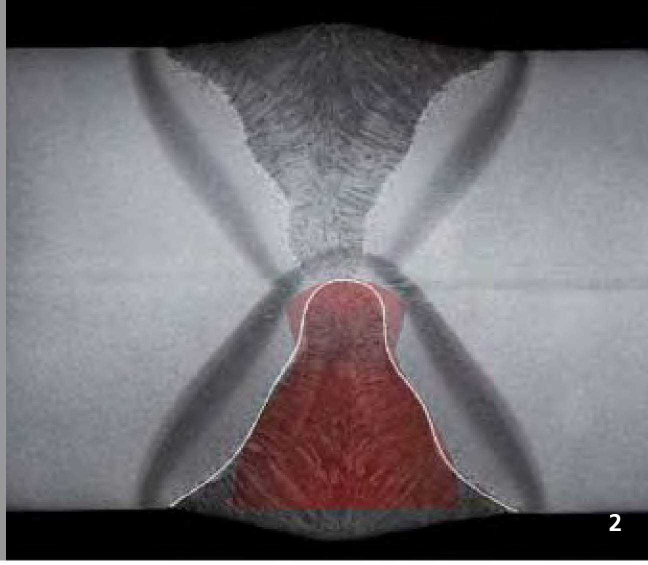
4 Identification of a butt joint by means of texture gradients.





FAST CALIBRATION OF EQUIVALENT HEAT SOURCES FOR WELDING

Task

Knowledge of the temperatures generated in a component during welding is a prerequisite to calculate material's tendency to distort and crack. To date, the use of simulation software for welding has been reserved mostly for experts since the effect of the process upon the temperature field in the component has to be abstracted by an equivalent heat source. A large number of iterative calculations are necessary until a sufficient correlation is found between the temperature field, calculated with an equivalent heat source, and the experiment. The more time the calculation of a model needs, the smaller, therefore, its applicability in an industrial environment is. The aim here is to calibrate the heat sources quickly and automatically with simultaneously increased precision in order to improve the applicability of the welding simulation.

Method

To calibrate the parameter values for the heat source, optimization processes are used. A method for numerical model reduction – the proper orthogonal decomposition (POD) – is applied to accelerate this process. On account of its flexibility, the POD method does not have any limitations regarding the material properties or component geometry.

Result

Compared to conventional R&D processes, the numerical process developed here provides significant time savings. This way, within a few hours, the parameter values of a volume source can be automatically specified with a controlled error. The applicability of the methods used here is independent of the welding process as well as of the material. When the parameter values for the heat source are determined both automatically and reliably, the calibration phase by an expert, which would consume both time and money, can be omitted.

Applications

The methods developed here enable an automated, fast and reliable calibration of parameterized heat sources. This is the basis for an efficient welding simulation to predict process quality properties such as stress, distortion and tendency to crack.

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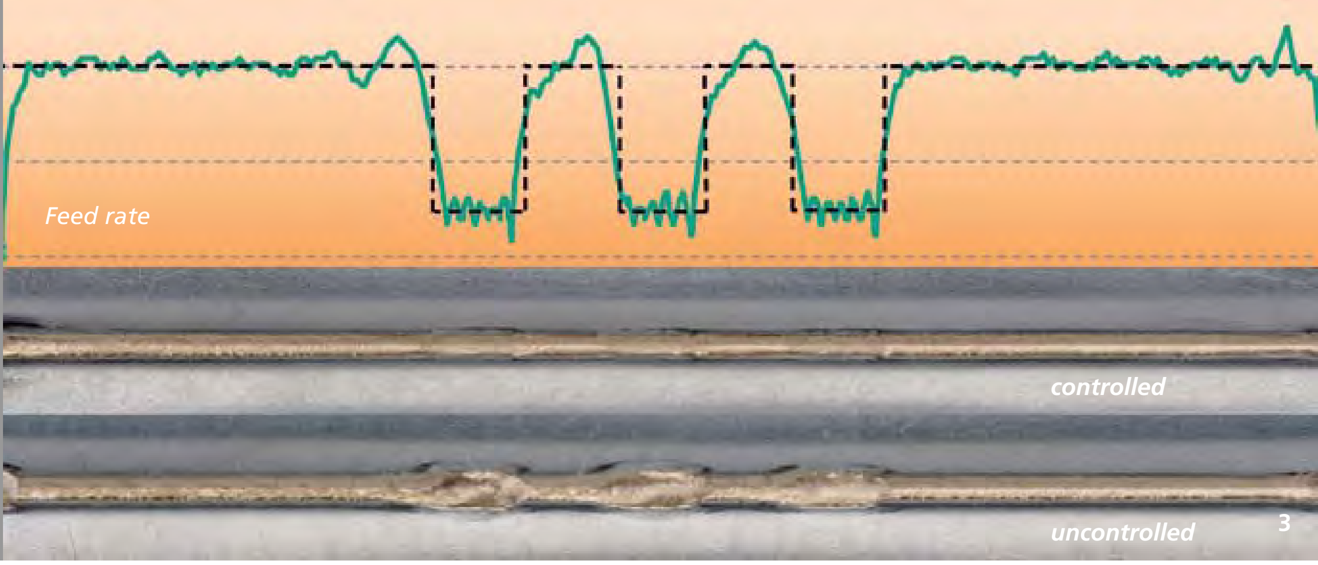
1 Temperature field calculated with POD for two-layer gas metal arc welding.

2 Comparison of simulation and experiment on a macro polish of the two-layer gas metal arc welding for the underbead.



FEED-RATE-REGULATED LASER BEAM BRAZING

Task

Laser beam brazing has become established in the automobile industry as a joining process for manufacturing car bodies. The industry uses this process to join two-piece trunk lids as well as to connect the roof and side wall with a visible seam. The requirements upon the optical appearance of the brazed seam are, thus, very high. In terms of the seam's impression, meaning surface roughness as well as lack of pores, its quality is significantly influenced by how constant the energy per unit length is applied along the seam. Depending on process control, however, dynamic speed changes can appear – for example, when the laser optic is reoriented as well as when the handling system accelerates quickly.

For these reasons, Fraunhofer ILT has developed a controlled laser beam brazing process that guarantees constant energy per unit length even when the feed rate changes.

Method

A camera-based monitoring system has been coaxially integrated in the laser beam path of an industrial processing head. The feed rate can be identified by calculating a displacement vector of two consecutive images. Here, the so-called full-search block-matching has been implemented in real time by using FPGA technology.

On the basis of the effective measured feed rate, analog control signals are made available, which can be used as input to control the laser power as well as the wire feed rate.

Result

In the first laboratory tests, the laser power as well as the wire feed rate could be adjusted to the measured feed rate. For joining of flanged seams, the feed rate of the laser was varied in a range of over 400 percent. In spite of this speed variation, the process remains stable – a smooth and nearly homogeneous seam surface was generated.

Applications

Since all of the brazing parameters can be automatically adapted to the process control, a stable brazing process is guaranteed. Moreover, set-up times can be shortened, which makes this laser beam brazing process all the more economical, especially for SMEs where lot sizes are small.

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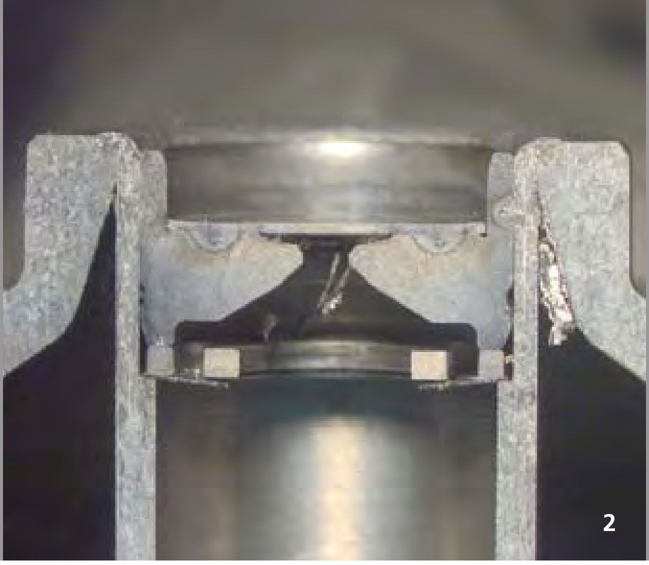
3 Measured feed rate (green), programmed feed rate (black) as well as a brazing result for each with and without feed-rate-based control.



LASER WELDING OF CARBAMIDE INJECTORS

Task

Carbamide is injected into exhaust tracts of diesel aggregates to reduce nitrogen oxides. For the manufacture of suitable injectors, several components have to be mounted and welded in different joint configurations (fillet, i-seam and overlap) in various working material combinations. In total, four different welding tasks are affected in this manufacturing process.

Method

Due to the small number of pieces when a series production is started, a complex automated production line is not profitable for the manufacture of these components. To evaluate the process capability, an optical set-up (optical fiber core diameter, collimation, focusing optics, beam source), identical for all welding tasks, was selected and mounted in a flexible portal machine with a laser scanner. The variable parameters (focus positioning, power, welding speed) were adapted to the particular requirements for the joining task in question. The strength properties attained in the tests were used to evaluate process capability indices. When the seams are dimensioned appropriately to reach high capacity indices, testing costs can be reduced and costs resulting from errors avoided.

1 View of a weld bead between carbamide injector and heat sink.

2 Cross-section of the weld seam shown in Figure 1.

To ensure the quality, the process capability was shown for the welding processes developed. In addition to the tension or shear strength that had to be reached, tightness and stability of the connection width, or the welding depth, were also relevant. Laser beam welding was identified as the most suitable welding process because it offers short processing times, reduces heat input and welds with small seam dimensions.

Result

For the manufacture of carbamide injectors, a process (c_{pk} >> 1.67) using an optical set-up common to all four joining tasks could be established, which is currently being used to produce in small series. Thanks to the high capability indices, the costs and efforts for testing (in process development and series manufacture) could be limited significantly.

Applications

The results of the welding process development illustrate the possibilities and the flexibility that a laser system offers in a non-automated plant with manual fitting. Due to a suitable dimensioning of the welding processes and, thus, the seam properties resulting from this, costs resulting from errors and testing can be reduced.

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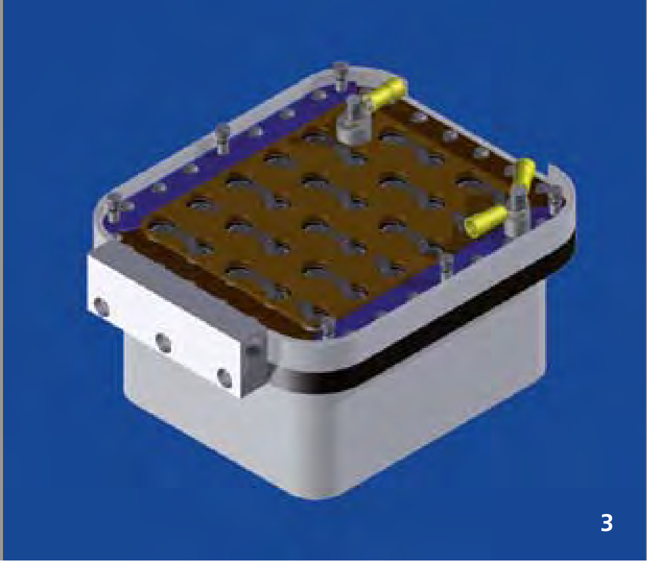
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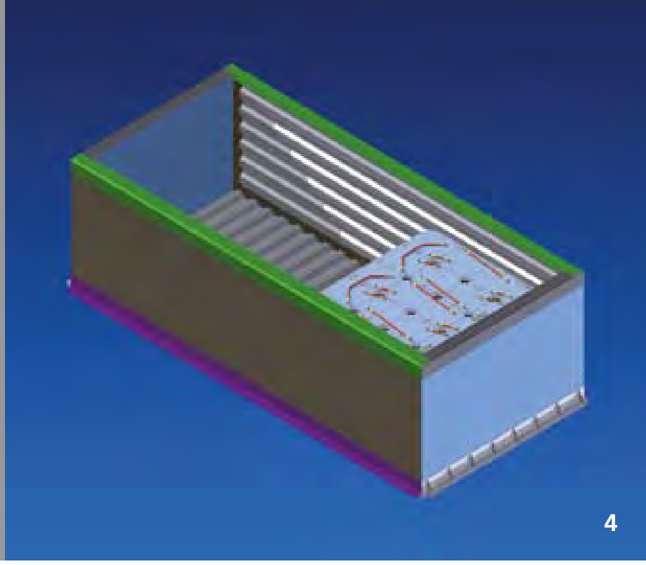
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LIGHTWEIGHT POWER PACK

Task

In electromobility, the energy pack constitutes an important component, which firstly has to have a high energy density and secondly low weight. Within the scope of the Fraunhofer project, »Fraunhofer System Research on Electromobility«, the Fraunhofer ILT, along with the Fraunhofer Institutes for Solar Energy Systems ISE, for Mechanics of Materials IWM, and for Environmental, Safety, and Energy Technology UMSICHT, developed a »lightweight power pack«. This pack consists of highly integrated and exchangeable energy components in the sector of battery packs and of thermo aggregates. It is planned to be used in an all-electric, multi-user vehicle. The »lightweight power pack« should distinguish itself from other batteries through its use of different lightweight technologies as well as innovative cooling and set-up strategies.

Method

In the scope of the project, the project partners worked on three sectors – battery pack, housing/lightweight construction and cooling.

The work group 'Battery Pack' has developed a process whereby the strings of the battery pack are built out of small-format cylindrical cells of the type 18650. These cells offer, on account of their metal housing, possibilities for direct cooling. By means of laser micro welding, both poles of the cell are contacted on the upper side and the cells are switched in parallel into units (blocks), which act as individual cells for the battery management system (Fraunhofer ISE) and the overall system. To directly cool the individual cells internally, one block is provided with PCM slurry (Fraunhofer UMSICHT) without additional heat conducting structures inside the block.

For the housing, a lightweight construction made out of high-tensile steel, plastic-metal composites and organic sheets is used. For this, crash simulations at the Fraunhofer IWM were conducted in order to guarantee a corresponding safety and, simultaneously, a low weight along with inexpensive production.

Result

The development of the power pack and the proof that individual components can be produced currently stand in the foreground. The components designed from organic sheets, reinforcement structures and plastic-metal composites are all currently being tested. Positive results have been demonstrated by investigations on the wear of the cells with a copper alloy concerning the electrical resistance and stability of the connections during thermal cycle.

Applications

The processes applied to battery technology presented here can be used in many sectors of electrical contacts and of lightweight construction. They go far beyond the use in electromobility.

This project is funded by the internal program of Fraunhofer Gesellschaft under grant number 826 472.

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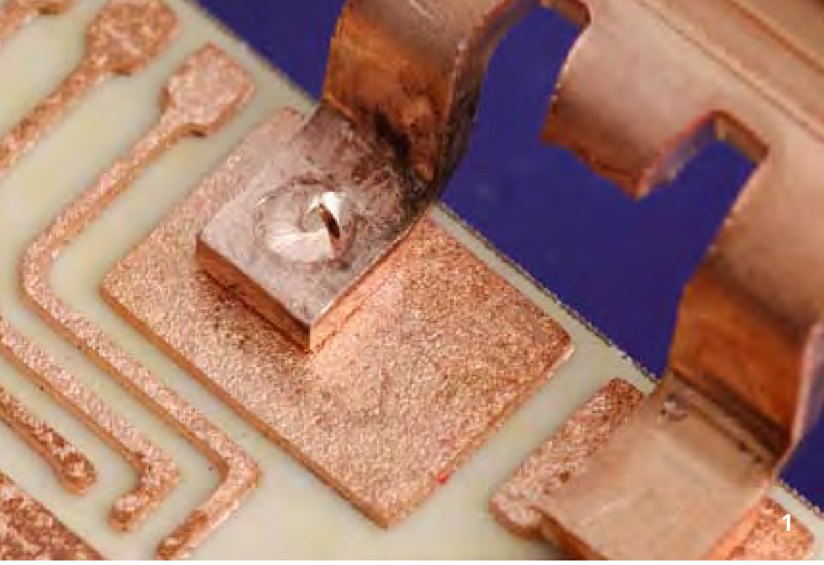
3 CAD model of a unit (without cover).

4 CAD model of a housing (without cover).



LASER BEAM WELDING OF DCB SUBSTRATES WITH SINGLE MODE LASERS

Task

In power electronics, the use of direct copper bonded substrates is becoming more and more important. In this process, the high power semi-conductor element is mounted directly onto a special ceramic substrate (aluminum oxide ceramic or aluminum nitride), which is coated with copper. In the joining process currently used for electrical contact on metal sheets with thicknesses of only a few hundred microns, there is the danger of fractures and microcracks in the ceramic substrate.

For a long-term stable bond of the DCB substrates with high-power diverters, a bonding technology is sought, which firstly enables a high bonding stability, secondly a minimal influence upon the substrate, and thirdly a connection with large terminal cross-sections.

Method

To make such joining connections possible, a new laser welding process was investigated, one which generates welding seams with constant welding penetration depth. In addition to the variation of steel diameter, steel specification and feed rate, a quick, local power modulation was used. For this, the feed movement is overlapped by a circular oscillating movement. The local power modulation positively influences the melt pool geometry and the temperature gradients in the melt pool and, thus, leads to a significant increase in process stability.

Result

Through the use of local power modulation in the range of a few hundred hertz, the melt pool dynamics of the welding seam can be inspected and a nearly even welding depth reached, for a Cu-ETP thickness of 1 mm on DCB with a thickness of 0.25 mm in overlap joints. By reducing the laser power and increasing the feed speed at the seam end, the heat congestion is reduced and the damage to the ceramic plate prevented.

Applications

The new joining technology is currently used in the high power packaging in power electronics with large terminal cross-sections. The high laser intensities used make it possible to weld difficult to weld working materials, such as copper or aluminum, which should especially have a positive effect in power electronics or battery technology.

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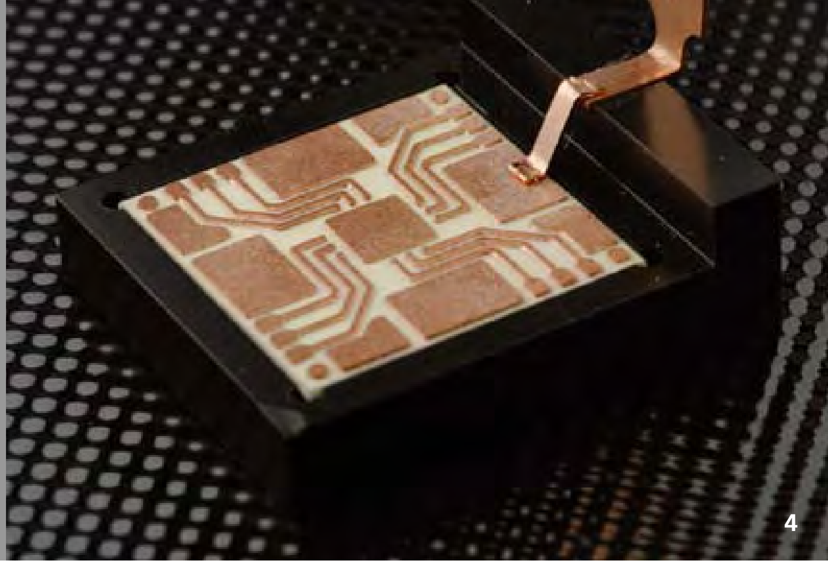
1 DCB substrate with electrical contact in a lap joint.

2 Cross-section through electrical terminal, copper layer and ceramic substrate.

LASER-INTEGRATED BONDING MACHINE FOR HEAVY RIBBON BONDING

Task

In power electronics systems, bond connections constitute the central electrical connection between the semi-conductor elements as well as between the substrates and connection terminals. These bond connections are responsible for the reliability and operational readiness of the drive of electric vehicles. Within the scope of the project funded by the Federal Ministry of Education and Research (BMBF) »Robust Bonds in E-Vehicles«, the Fraunhofer ILT developed, along with partners, an alternative laser-based process for creating these bonds without ultrasonic welding.

Method

For this, laser beam micro welding is used as the actual joining process. In particular for copper materials, it creates more possibilities for the use of the bonding technology. Based on the use of modern laser beam sources with very good beam quality, this process can join copper and aluminum materials very precisely and reproducibly. In addition to the design of the connection zone between the wire and ribbons, the laser process is expanded by the addition of an oscillation welding process, which reaches higher bonding powers in comparison to joining without oscillation. In contrast to conventional ultrasonic bonding, surface quality and cleaning processes are less exacting. In addition, the process is less dependent upon the substructure and vibration behavior.

Result

To combine the laser beam bonding process with the well-known bonding technology, a conventional bonding machine was equipped with a laser welding unit. This allows joints to be made by means of quickly scanned laser radiation. The primary use of this plant is ribbon bonding, among others, of DCB substrates and copper terminals in the housings of power electronics.

Applications

Particularly in the sector of power electronics, but also wherever high currents have to be transported over small connections, as, for example, in battery technology, the use of copper ribbons is being tested as a powerful alternative to aluminum ribbons. In this context, laser beam micro welding creates new possibilities for such bonding needs.

This research and development project has been funded by the Federal Ministry of Education and Research (BMBF) within the topic »Key Technologies for Electromobility (STROM)« (grant number 13N11464) and is supervised by VDI/VDE Innovation+Technik.

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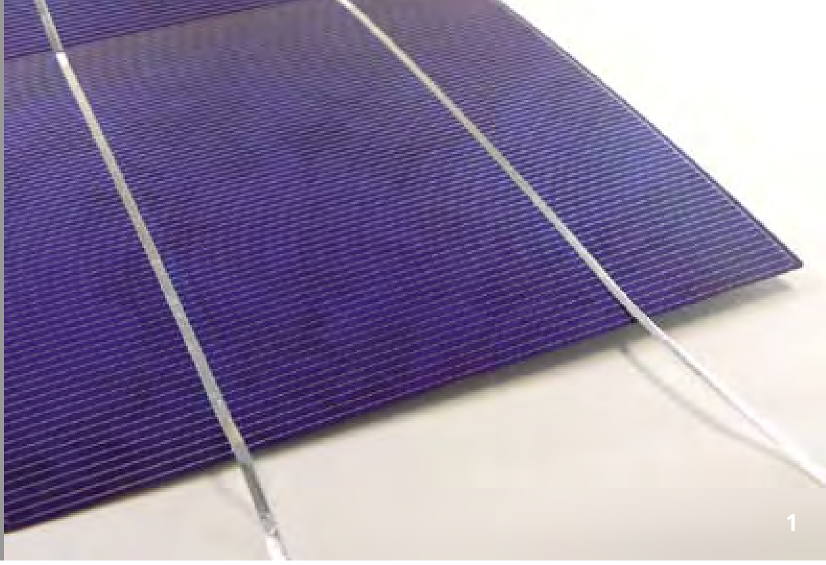
3 Bond head of the »Laser Bonder«, consisting of bonding tool and optic head.

4 Laser-welded Cu ribbon on DCB substrate and terminal.



LASER SOLDERING SOLAR CELLS

Task

The requirements upon the service life of photovoltaic modules and their production quality related to this have increased continuously in the last few years. At the same time, the production costs have had to be lowered by reducing the wafer thickness to below 150 µm and by raising process cycles. A key process in module production is the cell contact, by which the metal cell interconnectors are soldered onto the solar cell. The goal here is to minimize the mechanical and thermal load while the cell interconnectors are joined, to avoid cell breakage caused by induced stress. In the course of this, the process time should remain under three seconds.

Method

Thanks to its lower energy input, laser soldering has great potential to fulfill the demands placed upon it when compared to conventional processes. For the radiation of the cell interconnectors, a process approach has been chosen which uses a laser scanner as well as fixed optics with linear beam forming. The integration of a pyrometric measuring system with a galvometer scanner enables the temperature distribution to be identified in the joining zone in order to make an individual energy input possible. In the course of optimizing the process parameters, such as laser power, feed speed and processing strategy, the cause for arising microcracks was analyzed. Through the beam forming with fixed optics, the entire joining zone is simultaneously heated. At the same time, thermal imaging cameras were used to test the process for processing errors.

Result

When linear fixed optics are used, the cell interconnector can be joined over the entire length in a time down to 0.2 s. The galvanometer scanner enables process times in the range of 1 - 2 s and creates contacts with peeling forces of up to 6 N due to distortion-minimized processing strategies. Crack formation in the contacting process can be prevented by minimal energy input.

Applications

This laser bonding technology is used to contact conventional crystalline silicon solar cells. Thanks to its geometrical freedom during the scanning processing, it is possible to expand the applications to back-side contact solar cells with punctual contacts. Potential further applications are possible in bonding technology in the electronics sector.

The work presented here was funded by the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMU) for its project »Innovative Quality-Optimized Laser Bonding Technology for Photovoltaic Modules« under the grant number 0325265.

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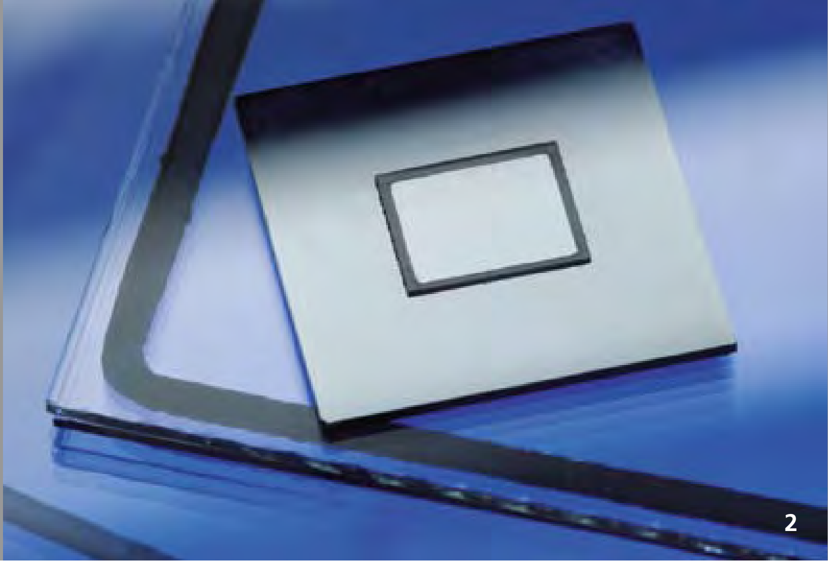
1 Solar cell with joined cell interconnectors.



LASER-BASED PACKAGING OF SILICON-GLASS COMPONENTS BY MEANS OF GLASS SOLDER

Task

When precision components, such as sensors, are manufactured, combinations of inhomogeneous working materials are being used more and more often to produce hermetically sealed packaging. The material pair silicon and glass (borosilicate glass) is frequently used for this. Since the packaging often encompasses temperature-sensitive components, furnace-based processes, such as the anodic or the conventional glass frit bonding, cannot be used, because for this, integrated, temperature-sensitive components would be damaged. Adhesive processes can also be ruled out, since these do not guarantee long-term stabile gas tightness to prevent oxygen or moisture from permeating the packaging.

Method

The process of laser beam-based glass frit bonding enables the energy deposition to be minimized since only the energy needed to melt the solder is applied directly to it. A thermal load to sensitive, integrated components can, thus, be avoided. To manufacture the packaging of inhomogeneous working materials, a compatibility of the coefficient of thermal expansion (CTE) is, however, required of the individual components of the overall compound structure. The actual soldering process takes place nearly simultaneously. With a quasi-simultaneous process the laser beam is guided, by means of a scanner, over the solder contour at speeds of approx. 1,000 mm/s several hundred times, in order to guarantee even bond formation.

Result

Thanks to the quasi-simultaneous process a homogeneous soldered bond between both of the joining parts can be made. To connect a 5.5 x 6.5 mm^2 glass cover to a corresponding silicon base, a process time of 10 s was reached, with the bond fulfilling the adhesive force requirements.

Applications

Potential applications for this process are the encapsulation of sensors, components of optical or medical-technical products and the packaging of displays.

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2 Laser-based packaging of a silicon/glass component by means of glass solder.

LASER TRANSMISSION BONDING OF GLASS WITH GLASS

Task

In hybrid micro-systems technology, but also in medical-technical fields, hermetic sealing of functional components is of great importance to continuously protect them from ambient conditions. With substrates made, in part, of glass, the encapsulation currently takes place via adhesive or soldering processes. These processes lack long-term stable gas tightness and have a high thermal load in the furnace-based soldering process – clear disadvantages. Laser-based processes provide an alternative. The advantages of the laser are, in addition to an exactly controllable heat affected zone, high geometrical freedom.

Method

Laser transmission bonding is based on transmission joining: The laser radiation is transmitted through a joining partner and absorbed by the other joining partner. With joining partners out of the same working materials, absorbing intermediate layers are used. The selective laser transmission bonding of glass with glass is currently being conducted at Fraunhofer ILT with a disc laser (λ = 1030 nm).

The laser radiation used is not absorbed by the basic glass material, so for the absorption metallic intermediate layers are used. Within the scope of process development, suitable process parameters, such as laser power, feed or scanning speed and contact pressure, are being investigated for different metallic intermediate layer materials.

Result

To date, glass-glass bonds can be produced successfully with titanium as the intermediate material. Bonds were generated at chip level (5 x 5 mm^2), both those with only one joining partner coated with a metallic intermediate layer as well as those by which both joining partners were overlaid with intermediate layers. Thanks to adapted process parameters and scanning strategies, large-area and selective bonds were generated with bond widths ≥ 50 µm.

Applications

Fields of application can be found, e.g., in hybrid micro-systems technology, microfluidics and medical technology. Possible applications for this process include encapsulating micro-sensors or micro-actuators or components of optical or medical-technical products.

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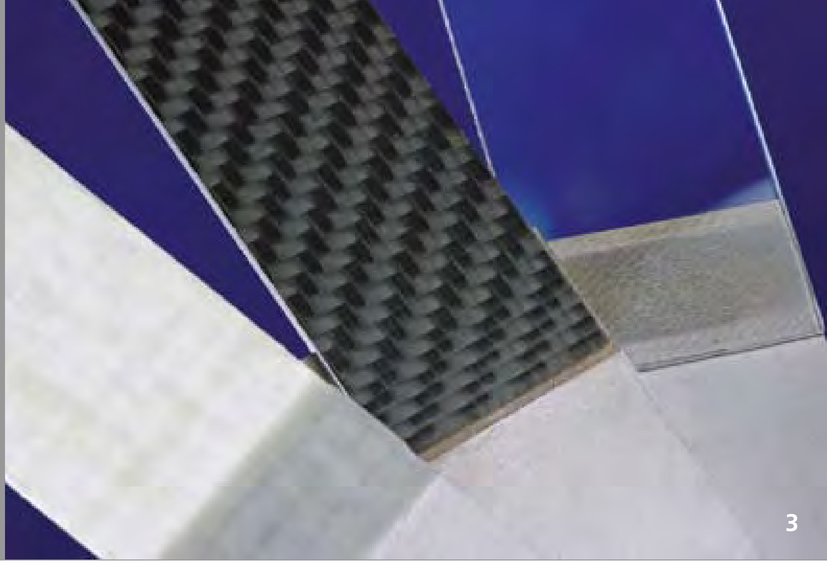
1 Laser transmission bonding of a glass microfluidic chip with a glass injection tube.



JOINING PLASTIC-METAL HYBRID COMPOUNDS

Task

Particularly in automobile construction, bonding heterogeneous working materials is an important requirement. The use of different working materials, such as plastics and metals, adapted to local loads should open up new paths for further weight optimization. While plastics are characterized by low weight, favorable price and a nearly infinite number of forming possibilities, metals can withstand, thanks to their mechanical properties, significantly higher mechanical loads. A direct and firm bond between plastics and metals, however, fails due to the chemical differences between them. A connection through a positive-locking fit or the use of additives is, thus, necessary.

Method

At Fraunhofer ILT, a process chain has been developed which uses laser radiation to generate microstructures in metallic joining parts. In a subsequent laser joining process, the plastic is bound due to an interlocking in the microstructure in a positive locking manner. For the bond to fix well, the plasticized material has to flow into the generated structures, which have an undercut geometry, and to harden there.

Result

The bond's mechanical strength depends decisively upon the structural density and the temperature during the joining process, in addition to the mechanical properties of the plastic. During laser penetration joining, a targeted joining temperature is used to plasticize the polymers through the temperature-based control of the laser power. This way, strength levels above that of an adhesive joint can be obtained without any specific disadvantages. With this innovative joining process, different plastics and metals can be joined (Figure 3), and an appropriate constructive dimensioning of the joint enables high powers (> 16,000 N, Figure 2) thanks to a double strap bond.

Applications

As components become more and more hybridized, the working piece-specific advantages of different materials can be combined, allowing light and stiff components to be manufactured. For this reason the two-step process presented here is especially suitable for the aerospace industry and automobile construction.

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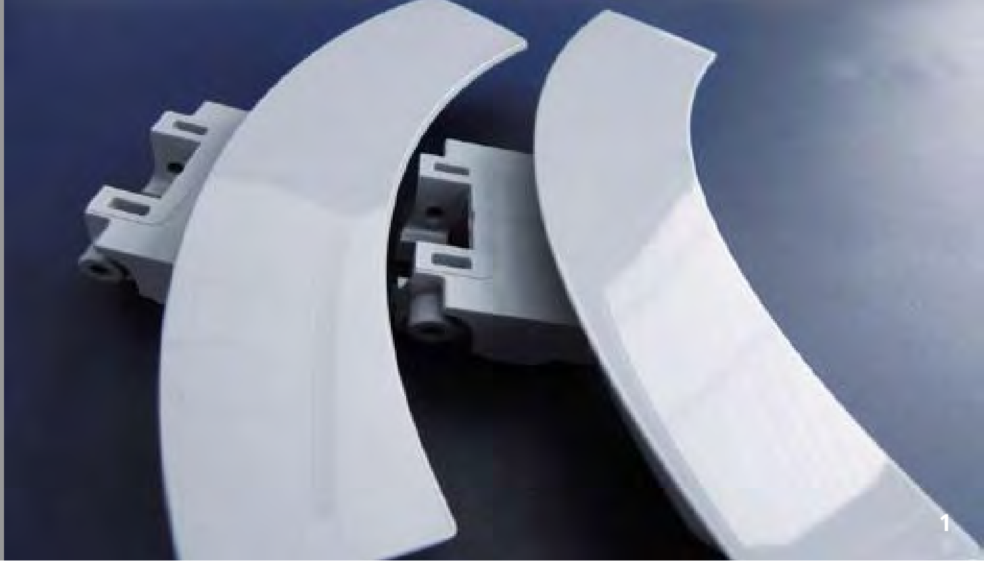
2 Metal-plastic double-strap bond (maximum load capacity > 1.6 t).

3 Combination of steel (1.4301) with different plastics (GFK, CFK, PC).



LASER WELDING OF POLYMERS WITH CLASS A SURFACES

Task

When polymers need to be welded free of marks with overlap joints, (diode) laser radiation in the range of 1000 nm is the preferred process to accomplish this. In contrast to ultrasound, friction and hot plate welding, this laser-based welding process not only limits the heat affected zone to a small area around the contact area of both joining partners but also does not extend this zone to the surface. For shiny, bright colors of the polymers used, as is typical for household appliances, this laser-based process has not yet established itself since the transparency of the upper joining partner is too low.

Within the scope of a joint project funded by the EU – »Extending the process limits of laser polymer welding with high-brilliance beam sources - PolyBright« the welding of white-white connections should be demonstrated through the use of alternative fiber laser wavelengths around 1500 nm.

Method

In close cooperation between the participating project partners, a door handle was initially chosen as a concrete application (Electrolux) and modified slightly. Additionally, the previously developed color additives and radiation absorbers were selected. Subsequently, the welding took place in a prototype plant built at Fraunhofer ILT, which contains a 1567 nm fiber laser (IPG).

Result

The cover out of bright gray, glossy PC was welded onto the same colored lower part free of marks by means of the TWIST® contour process, which used 1567 nm erbium laser radiation at v = 15mm/s and P = 30 W. The components were pressed against a glass plate in a common mount; a scanner (Arges) ensured that the laser beam, with 1.8 mm diameter, moved in a circular path along the outer edge of the welding contour of the door handle as well as that there was an overlapping circular wobble movement with a 0.5 mm radius. In addition to the availability of high-power 1500 nm lasers, this application is based on the high transmission of many polymers at these wavelengths.

Applications

Bright, glossy plastics are mostly used where the optical appearance is of great importance. This is the case for household appliances, furniture, consumer items and automobile interiors.

The work presented here was funded within the scope of the EU project »PolyBright« under the grant number NMP2-LA-2009-228725.

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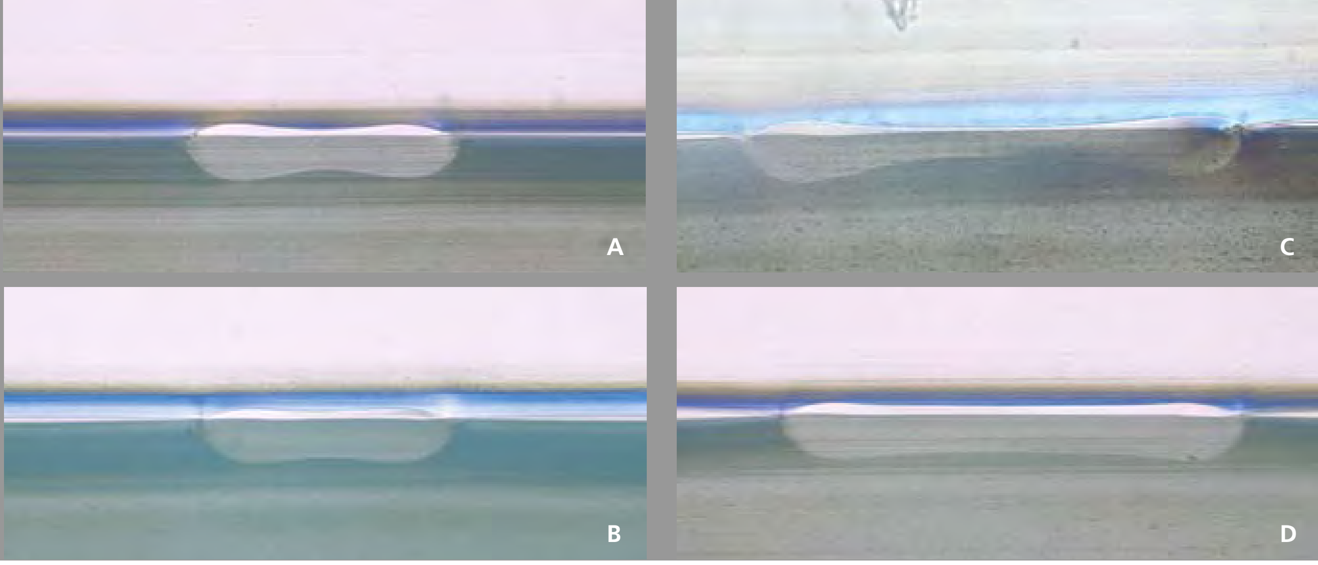
1 Door handle out of PC (cover) welded onto lower part out of ABS by means of 1567 nm erbium fiber-laser radiation.



OPTIMIZED SCANNING STRATEGIES FOR HIGH SEAM STRENGTH DURING POLYMER WELDING

Task

Laser penetration welding of polymers with the TWIST® process is characterized, among others, by high flexibility and high strength of the connections it generates. The seam strength depends upon the beam diameter and on both amplitudes of the periodic scanning movement, which determines the temperature distribution and, thus, the seam strength.

Method

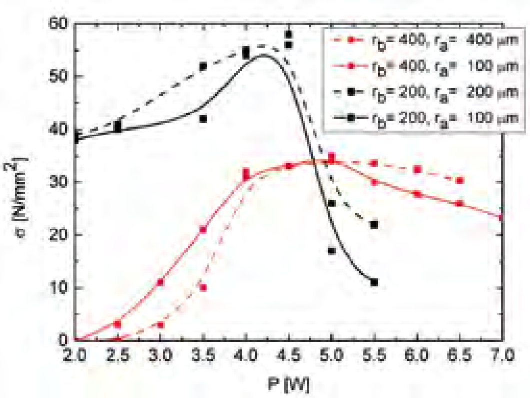
To optimize the scanning strategies in TWIST® welding, different scanning strategies with variable beam movements were evaluated with a fiber laser at a wavelength of 1060 nm. Compared were circular and elliptical periodical scanning movements. The strength is determined by tensile tests on double T samples as a function of the laser power P. The geometry of the welding seam was investigated with microtome sections.

Result

Microtome sections for different amplitudes show that the welded seam is more homogenous for elliptical scanning movements than for circular ones. This effect is more pronounced for large seam widths, or for amplitudes r_b. If the strength (σ) is plotted over power, it takes on a local maximum. For powers over the maximum, the probability of decomposition rises. For large amplitudes r_b, the elliptical scanning movement leads to a larger process window.

Applications

Flat, homogeneous bond cross-sections are particularly important for the joining of polymer components free of marks, as they are used in the field of vision for the automobile industry, as well as for the bonding of thin components and foils from the fields of packaging and sensor technology.



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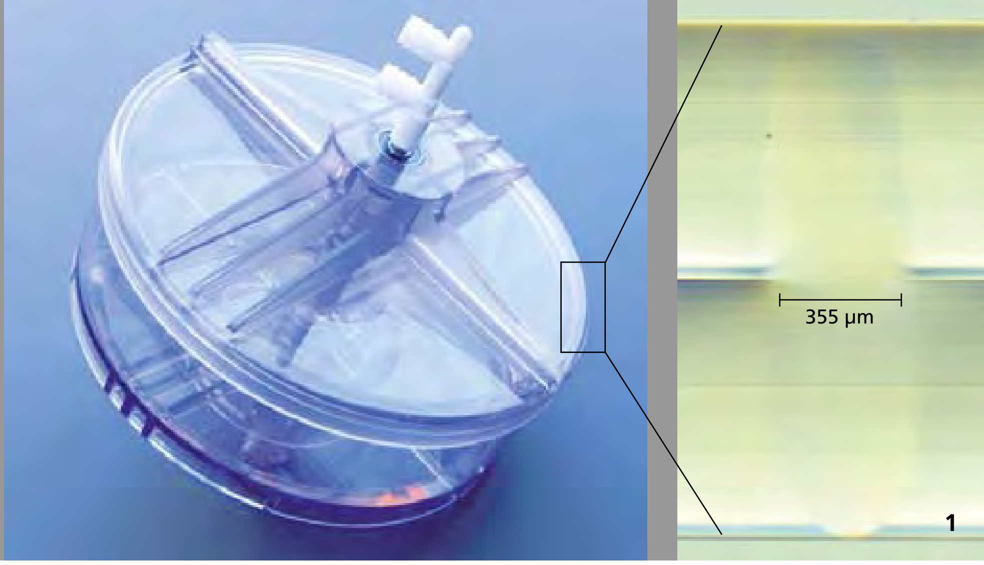
1 Microtome sections with 2 W (A and B) and 4 W (C and D) power.



LASER BEAM WELDING OF TRANSPARENT POLYMERS WITHOUT ABSORBER ADDITIVES

Task

Laser beam welding of polymers is characterized by a targeted and contactless energy input and is ideal for the welding of medical components (Figure 1, left) because the process is free of dirt and particles. Complete transparency is often needed for such components, however, which to date could not be guaranteed since laser beam welding needed absorbers. Costly and time-consuming material qualification is also required when additive materials are used, above all in the food and medical branches.

Method

A large share of polymers exhibit characteristic absorption bands in the near infrared range above wavelengths of 1.1 µm. Through the selection of a beam source with suitable emission wavelengths, these bands can be exploited so that absorbers no longer need to be used. When absorbers are omitted, both joining partners have the same optical properties; consequently, the absorption of the laser radiation occurs not only on their surfaces. In order, however, to introduce the energy selectively at the joining level, the laser beam is focused by means of an optic with a high numerical aperture (NA). As a result, the beam reaches the intensity necessary to melt the material in the joining area, and yet the material at the outer surface remains solid.

Result

When high-power diode lasers are used, ones which have emission wavelengths that lie in the absorption bands of the polymers, the process could be demonstrated as suitable by means of a washing chamber out a biotechnical field of application. With the process, welding seams with minimum widths under 100 µm could be generated as could clearances over 100 µm be bridged. The welding is impermeable to all media and does not cause optical impairment to the component (no bubbles/surface marks, Figure 1, right).

Applications

The process presented here finds applications mostly in medical and packaging sectors, in which transparent materials are often required. In addition to the transparency, the process offers cost savings, since not only can the costs for the absorbers be saved, but also those for the approval procedures needed for their use.

The research results are a part of the project »POLYNIR«, funded by the Ziel-2 program of the European Union under the grant number 300119502.

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1 Washing chamber for cell separation with cross-section (source: Miltenyi Biotec).

CONTOUR-FLEXIBLE AND MATERIAL-INDEPENDENT LASER TRANSMISSION SEALING FOR FOIL PACKAGING

Task

The packaging industry requires, on the one hand, more and more individualized packaging forms and, on the other, smaller lots sizes and higher format flexibility – all of which place great demands for innovative solutions upon the process used to seal packages. To date, the sealing processes used, such as heat-contact sealing or ultrasound sealing, use tools with a fixed sealing contour and need, in addition, special sealing layers. These processes, however, do not allow a flexible selection of working materials and packaging geometry.

Method

In cooperation with the Fraunhofer Institute for Process Engineering and Packaging IVV, Fraunhofer ILT has investigated the use of a new generation of high-power diode laser beam sources to seal foil packaging. At a wavelength range between 1.5 and 1.9 µm, where many plastics available on the market in the packaging technology exhibit an absorption peak, it is possible to seal these plastics to each other directly without having to insert additional absorbers. Moreover, every seal seam contour can be made thanks to the use of a freely positioned laser beam as the sealing tool. In addition, the format can be changed quickly.

Result

For several packaging foils or foil combinations commonly found on the market, laser transmission sealing could prove itself as a superior sealing process. The seal separating forces according to DIN 55529, which are necessary to open foil packaging, lie within the required or common values and exhibit a low coefficient of variation. In addition, thin cuts conducted in seal seam sectors display homogeneous bonds.

Applications

Laser transmission sealing is suitable for applications in the food, cosmetics, pharmaceutical and medical product sectors as well as in the consumer goods segment. Particularly in those sectors where the use of additives is difficult and can only be done at high cost, laser penetration sealing shows enormous potential.

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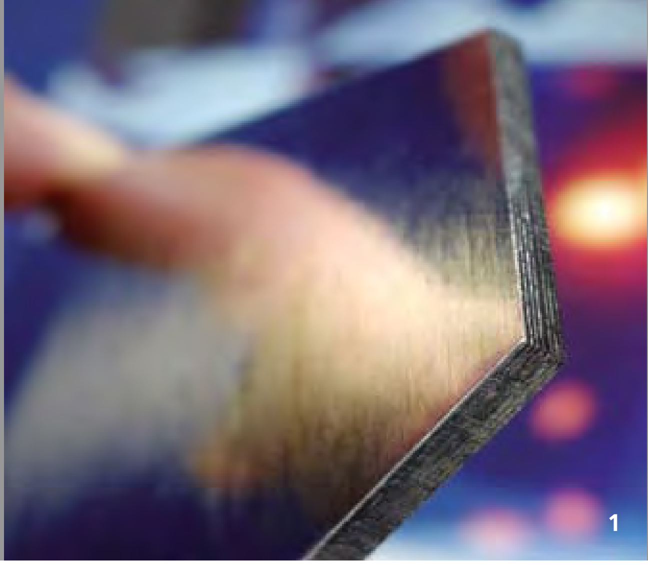
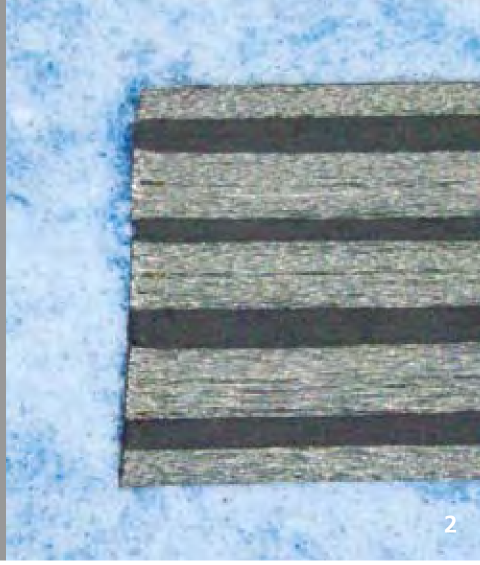
2 Laser-sealed food packaging.

3 Flexible seal seam contour.





CUTTING OF CARBON FIBER REINFORCED POLYMERS (CFRP)

Task

Fiber reinforced polymers (FRP) are an important class of materials for putting lightweight concepts into practice, for example, within the material mix of lightweight vehicles. Additionally, as more and more consumers use electric and hybrid cars, manufacturers are seeing the need to promote efforts to develop such lightweight design. Mechanical processing of FRP is difficult because high tool wear reduces quality during the use of a tool and the tool's life time. These issues can be solved by contact and load-free laser cutting, which can provide constant quality. To accomplish this, however, laser cutting processes are needed with economic cycle times – commonly in the range of one minute in mass production – and low thermal influence on the cut edge.

Method

High quality cuts can be accomplished with ultra-short pulsed lasers, but at low feed rates. Nanosecond lasers with pulse durations from 10 nanoseconds to some 100 nanoseconds feature laser radiation with the high intensity needed for high cutting quality, combined with high average power to realize the required high cutting speed. To achieve high cutting quality and speed, good absorption of laser radiation is a prerequisite, which is reached with typical nanosecond lasers at a wavelength of 1 µm for the fiber, but not for the matrix material.

Result

With a CO_2-nanosecond laser having an average power of 1.5 kW, a heat affected zone of 100 µm width could be reached for cuts in CFRP. This is a process regime between fast processing with multi-kilowatt lasers and high quality processing with ultra-short pulsed lasers.

Applications

The development of efficient cutting processes for holes and trimming of carbon or glass fiber reinforced parts are being stimulated by the increasing use of FRP materials in aerospace and automotive applications. In addition, products in mechanical engineering, consumer goods and the sports equipment industry will profit from these new cutting processes.

This research has been funded as part of the EU project »FibreChain«.

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1 Cut edges of CFRP parts.

2 Cross section of a CFRP cut edge (thickness: 2.6 mm).

PROCESSING CFRP WITH ULTRA-SHORT PULSED LASER RADIATION OF HIGH AVERAGE POWER

Task

On account of their extraordinary mechanical stability-to-weight ratio, carbon fiber reinforced plastics (CFRP) have found a wide range of applications in lightweight construction for the automotive and aerospace industries. Due to the inhomogeneous mechanical and thermal properties of carbon fiber and matrix materials, processing them is, however, comparatively difficult. The difficulties arising are the delamination of fibers from the matrix, the thermal load upon it, which has a negative effect upon the mechanical strength, as well as high tool wear originating from the hard carbon fibers. For these reasons, laser radiation as a contact- and wear-free tool exhibits great potential to realize a quicker and more efficient CFRP processing.

Method

To keep the thermal influence on the workpiece as small as possible, the use of ultra-short pulsed (USP) laser radiation with pulse durations < 10 ps is evaluated. Through the use of high-power USP lasers with an average output power up to 400 W, great productivity should be reached, in comparison to the use of established USP lasers.

Result

Ultra-short pulsed laser radiation with an average power of 30 W is used to process CFRP with a heat-affected zone of under 5 µm at ablation rates of 30 mm^3/min (Figure 3). When the average output power is increased to 400 W, however, maximum ablation rates rise to 380 mm^3/min with a heat-affected zone of approx. 65 µm.

Applications

A potential application is the manufacture of CFRP components for use in lightweight construction. The process could also be used for the targeted ablation of defective sectors on lightweight parts during a repair process.

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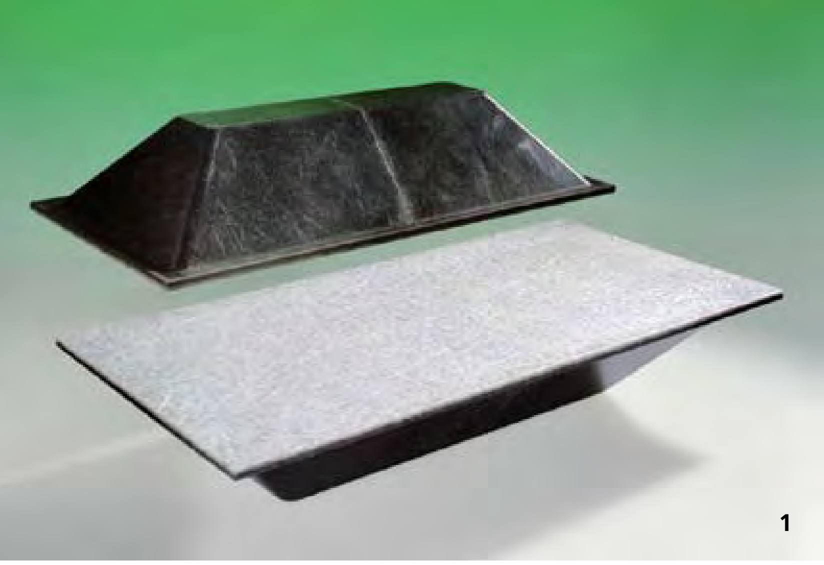
3 Microscopic picture of a cutting edge.

4 Holes drilled in CFRP by means of USP laser radiation.



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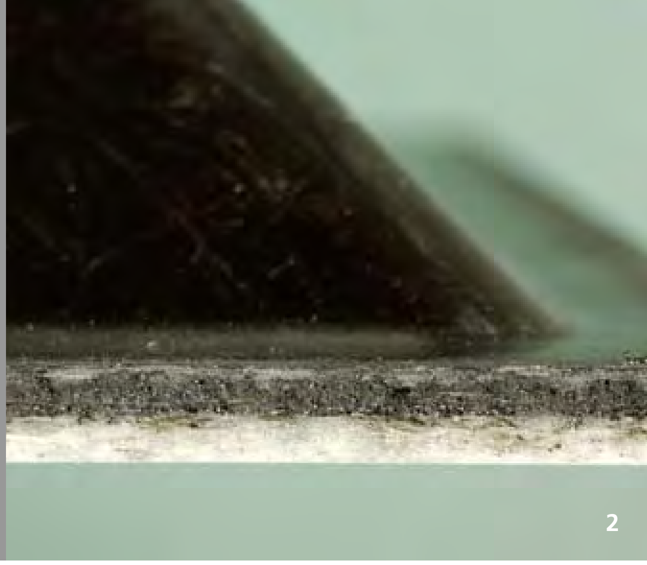

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PROCESS CHAIN FOR THE PRODUCTION OF FRP LIGHTWEIGHT COMPONENTS

Task

Saving both raw materials and energy in production while simultaneously improving efficiency is becoming an increasingly important challenge for the automobile industry. Innovative lightweight construction concepts based on fiber reinforced thermoplastics (FRP) can make a significant contribution to this. However, before FRP components can be employed economically, production costs and time have to be reduced significantly while a component's complexity increases, all in order to meet the industry's functional requirements.

Method

This approach aims at developing an innovative process chain with a low number of process steps. This chain should enable fast and automated production of structural components made of long fiber reinforced thermoplastics which have a high potential for use in lightweight construction. The main idea underlying this approach is the manufacture of three-dimensional FRP raw components produced by a fiber spraying method for generating tractable preforms with adjustable fiber orientation. Afterwards, these preforms are consolidated in a variothermic tool and completed by laser cutting and laser welding to create a finished component. A CO_2 laser is used to trim the component; a diode laser to join the preforms.

Result

The process chain improves the lightweight potential and suitability for mass production while reducing cycle time to less than three minutes, a significant advance. Through the further development of the classic laser method, the thermal damage zone during laser cutting can be reduced considerably and thermoplastic FRP can be welded.

Applications

The reduction of process steps will give the manufacturing and supplier industry new impetus to manufacture lightweight products with significantly reduced costs. For the automotive industry in particular, which is increasingly focusing on lightweight components, new opportunities are opened up for the production of sustainable lightweight components.

The work was funded by the BMBF project »InProLight«.

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1 Demonstration part of the process chain.

2 Joint bond and cut edge.

HIGH-SPEED CONTOUR CUTTING OF STATOR SHEETS FOR ELECTRIC MOTORS

Task

When lasers are used to cut stator sheets, cutting geometries can be flexibly adapted to a particular motor size and motor geometry. In contrast to common die cutting of the stator sheets at high production volumes, for which a new tool has to be manufactured for each contour, a laser cutting system can create any geometry desired at the smallest of lot sizes. Custom manufactured parts or components at low production volumes can be produced economically and adapted to a customer's wishes cost-effectively.

Method

Laser beam cutting allows cutting speeds of more than 100 m/min at 4 kW laser power and 1 mm sheet thickness for steel sheets, for aluminum sheets at speeds over 150 m/min. In order to utilize the potential of the higher speeds the process offers, also for complex contours, highly dynamic machines are necessary. Typically, the cutting head is moved in an axis relative to the workpiece, because lower masses have to be accelerated than is the case with a moving workpiece. This arrangement is, however, unsuitable for process developments by which the observation of the process is desired. On account of the static processing location, the accessibility is optimal for high speed cameras, photodiodes and further sensors in a coaxial or off-axial observation perspective.

Result

The high jerk and acceleration values of the machine developed at Fraunhofer ILT – of 5000 m/s^3 and 5 g – enable a complex geometrical form of a stator to be cut with a diameter of 130 mm in a processing time of less than 6 seconds. Since the laser power can be flexibly adapted to the available or attainable process speed, the energy efficiency of such a cutting operation is optimized.

Applications

In addition to the high-speed processing of metals and plastics with low wall thicknesses, the axis system can be used for process analysis in the entire thickness range.

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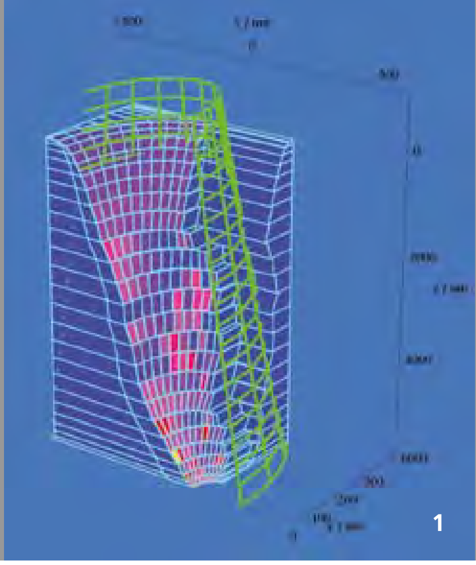
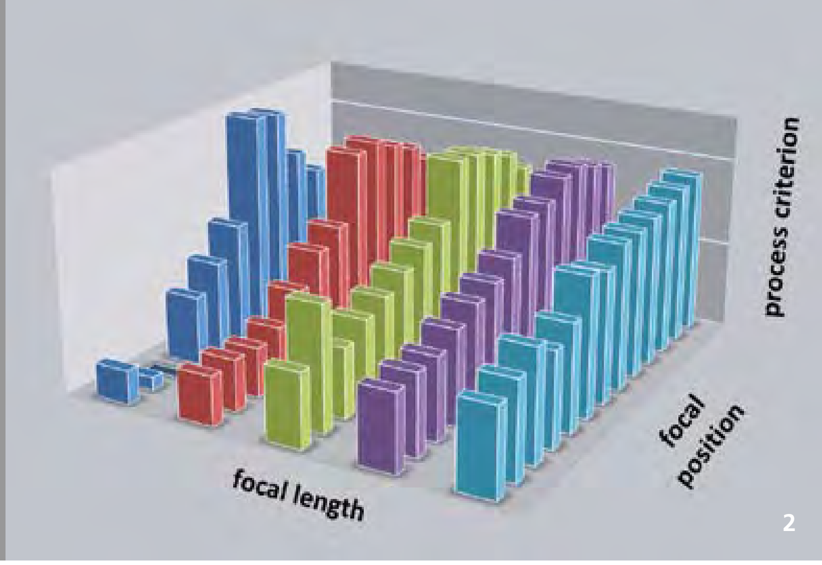
3 Cutting operation.

4 Laser-cut stator sheet.





PARAMETER SCREENING AND OPTIMIZING FIBER LASER CUTTING THROUGH PROCESS SIMULATION

Task

Laser system manufacturers and end users in the sheet processing industry are desperately searching for solutions to connect the advantages of fiber-coupled beam sources, as compared to the established CO_2 lasers, in terms of flexibility and productivity along with a higher cutting quality. Above all, questions remain on what the mechanisms of melting stage formation are, on how horizontal and vertical melting strings arise as well as on which melting film surface temperatures occur and how far vaporization as well as multiple reflections contribute to the process.. The experts have hardly come to a consolidated understanding of parameter dependencies important to the user. In addition to experimental investigations, now systematic simulation calculations should support parameter screening.

Method

In the EU project »FILCO« and on behalf of five European high-tech SMEs, Fraunhofer ILT has taken over the task of screening the parameter field »focal length x focal position« with the simulation program CALCut and to develop an optimized laser cutting optic on the basis of the simulation results.

1 Cutting front simulated with CALCut (6 mm, stainless steel).

2 Example of screening result.

Result

In the first project phase, more than 600 CALCut simulations were calculated for a reference application selected by the project consortium. With the aim of reaching cutting processes that are as efficient as possible and that provide high-quality cutting results, the following simulation values were assessed:
- maximum cutting speed,
- range of the cutting gas stream in the kerf,
- homogeneity of the cutting front geometry,
- homogeneity of the absorbed power density, and
- robustness with incremental changes of parameters.

As a result, an efficient and robust regime was identified in order to select optical parameters and the design of the optics.

Applications

The simulation-supported parameter screening will soon take on a key role in laser process development.

The research results were funded by the EU under the 7th Framework Program via the REA – Research Executive Agency under the grant number FP7-SME-2012-315405-FILCO.

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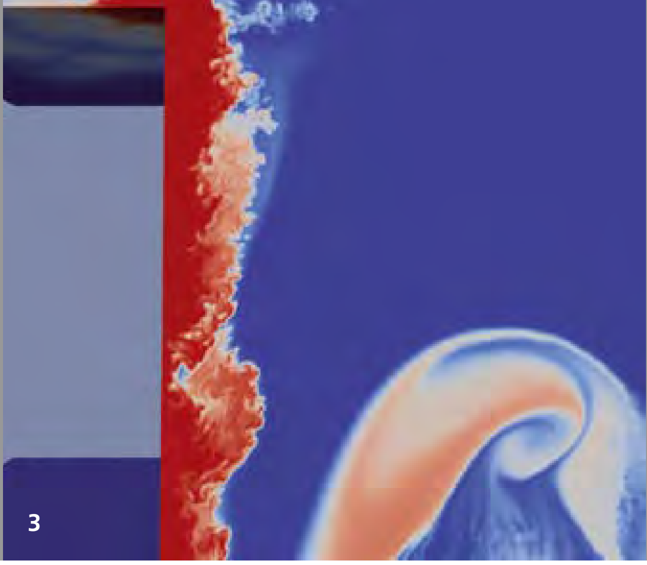

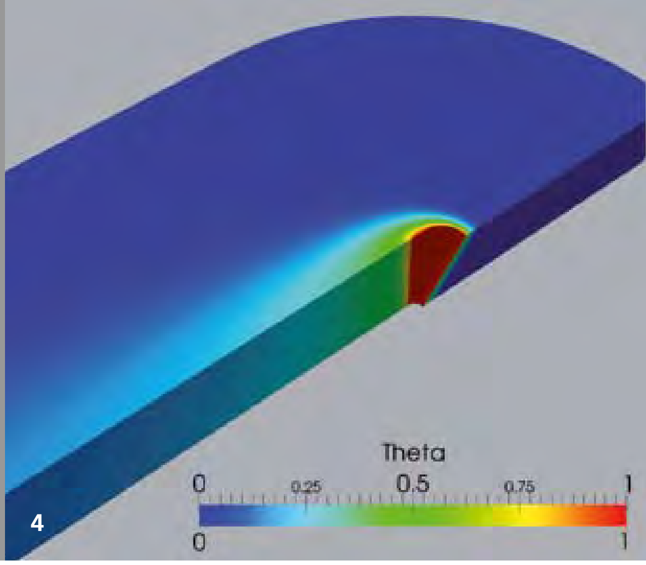

SIMULATION – A NUMERICAL LIBRARY FOR LASER APPLICATIONS

Task

For laser materials processing, the correlation between the parameters and the quality of the processing result is often strongly non-linear and can even be discontinuous. For this reason, simulation is becoming more and more important for the analysis of dynamic processes, ones difficult to access at an experimental level. The multi-scale tasks to be solved are coupled to free boundaries. Simulations can only be utilized effectively, if the numerically task is quickly solved at sufficient spatial and temporal resolution.

Method

Beginning with the requirements of such multi-scale tasks and of high precision and spatial resolution in a boundary layer at simultaneously low calculation times, spectral elements and discontinuous Galerkin methods have been implemented. Using massive parallelization with MPI and OpenMP, the calculation times were drastically reduced. The motion of the free boundaries is described numerically with an interface capturing method, the so-called level set method. Level set methods represent robust and simultaneously precise numerical methods for describing complex surface movements, even when extreme changes in topologies appear.

Result

The numerical methods were implemented in a modular C++ library. This offers the ability to quickly and flexibly develop parallelized simulations according to the building block principle. Examples are the fast solving of a multi-component gas flow during laser oxygen cutting (Figure 3) and a calculation of surface movements and temperature during laser fusion cutting (Figure 4).

Applications

With this new calculation process, complex problems for laser materials processing can be simulated with high resolution in short computing times. Applications are, for example, the dimensioning of nozzles for gas flow during cutting, welding and drilling with laser radiation.

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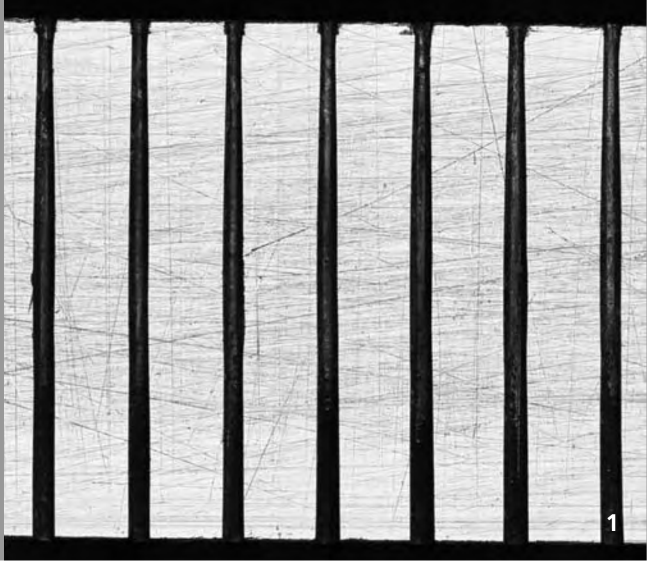
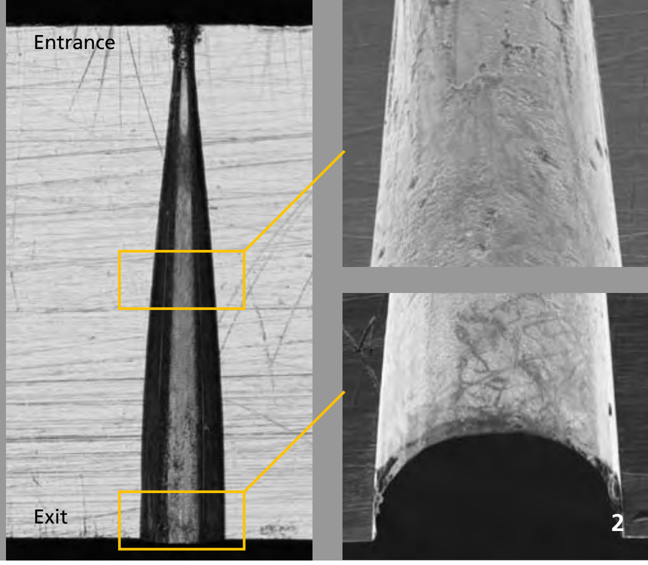
3 Simulation of a turbulent multi-component flow during laser flame cutting.

4 Simulation of temperature distribution during laser fusion cutting with level set and spectral element methods.





HELICAL DRILLING OF PRECISELY SHAPED HOLES

Task

Laser beam drilling has established itself in many applications where micro holes with diameters less than 100 µm have to be drilled. What is decisive here is generating either very round holes or a defined drill form – no matter if it is symmetrical, positive tapered or negative tapered. For these cases, helical drilling has proven itself as a good process with which round holes with defined shapes can be made.

Method

To investigate the helical drilling process, a frequency-doubled ps laser was used to drill holes in metals. Thanks to the very short pulse durations, the heat affected zone in the metal is minimized and very little melt generated. The helically drilled holes were made with a helical drilling optic developed at Fraunhofer ILT, whose optical rotation speed can be varied up to 36,000 rpm. By varying the pitch angle and the spiral diameter of the laser radiation in the drilling optic, the drill diameters as well as the conicity can be adjusted. To investigate the drill-hole quality, scanning electron microscopes images of the drill-hole entrance as well as exits and of cross sections were examined closely.

1 Cylindrical drill holes in steel.

2 Cross-section of a negative tapered conical drill hole in steel.

Result

In steel with a thickness of > 1 mm, defined cylindrical, positive tapered and negative tapered holes could be generated. On account of the short pulse duration used, no melt was generated so that no melt deposits could be detected at the hole entrance, exit or on the drill wall itself. The roughness of the drill wall is Ra < 2 µm.

Applications

The applications of the process lie in all fields where very precise drill holes are necessary. Examples of this are, e.g. drilling of injection nozzles, starting drill holes or ventilation holes.

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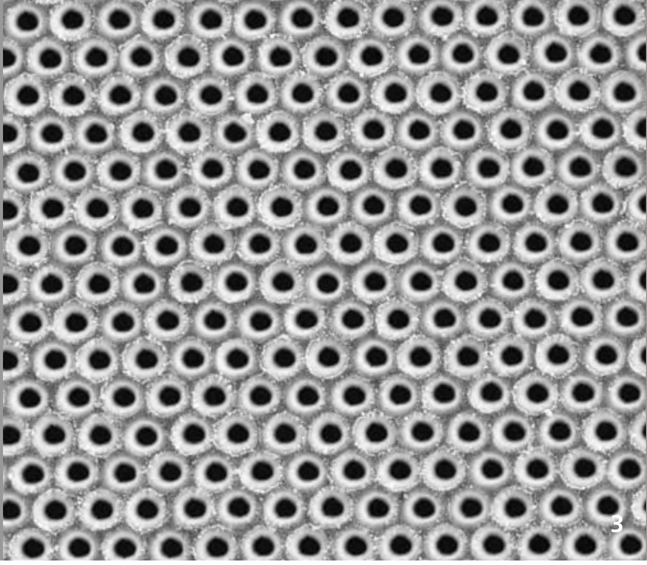

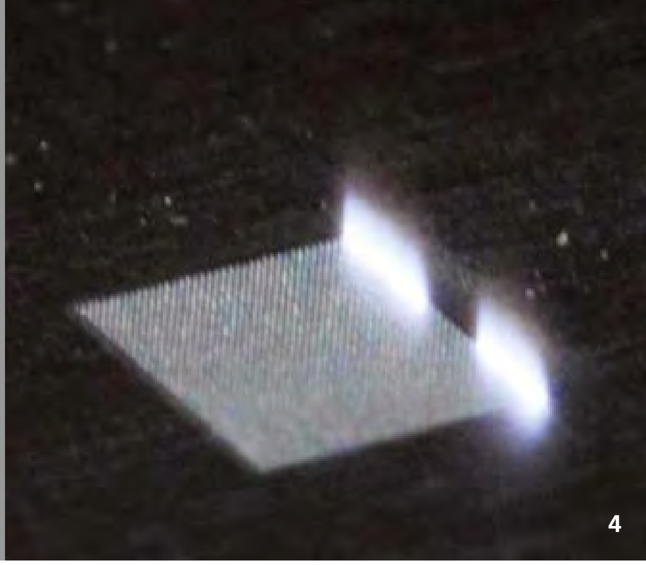

PROCESS STABILITY FOR PERFORATION WITH ULTRA-SHORT LASER PULSES

Task

Sectors in engineering and medicine increasingly require perforated materials, e.g. as filters and microstrainers. The perforation diameter of these strainers often lies in the range of < 20 µm at a material thickness of typically < 200 µm. The materials to be drilled are thin foils of different materials such as metals, glass, ceramics or also plastics. The number of drill holes per foil can amount to several thousands. Since these perforated foils are commonly used as filters, the most important requirements are defined hole diameters and geometry with small hole spacing. In order to reach this, factors are still being examined as to their influence upon process stability while thin foils are perforated with ultra-short pulses.

Method

In order to reach very small hole diameters at equally small hole spacing, a frequency-tripled Nd:YAG ps laser is used. The ps laser allows the thermal load upon the foil to be minimized during processing. The laser beam is focused by means of a lens with a short focal length. To position the material flexibly and quickly, a galvanometer scanner is used.

Result

Thanks to the use of the ultra-short laser pulse, holes can be drilled with diameter of approx. 5 µm and a minimum hole spacing of 13 µm. The process window to generate round holes is limited by two effects. First, the ellipticity of the holes is influenced by the sequence in which they are drilled into the foil. Second, polarization effects can cause the hole outlet to become irregular.

Applications

The applications of this process lie mainly in the micro- and ultrafiltration technology used in mechanical water purification. Further applications can be found in photovoltaics for the generation of back side contacts in solar cells or also in the field of lithium-ion rechargeable batteries.

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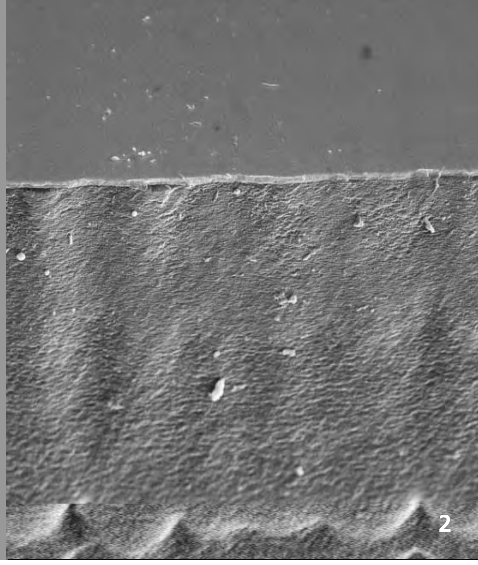
3 Perforated aluminum foil with a hole diameter of 6 µm and hole spacing of 19 µm.
4 Perforation process of an aluminum foil.



ABLATION CUTTING OF SILICON WAFERS WITH ULTRA-SHORT PULSED LASER RADIATION

Task

Micro-electronic components, such as LED chips, are currently produced in a batch process, the state-of-the-art. This means that a multitude of identical components are processed on a silicon wafer and subsequently separated from it. In the course of continuous miniaturization of electronic components, the dimensions of component parts are shrinking, which means, in turn, that conventional manufacturing techniques to separate components from wafers are reaching their processing limits. In contrast to this, ablation cutting with ultra-short pulsed laser beam sources offers significant advantages due to the gentle and selective ablation regarding separation line widths and modulus of rupture of the cut component part.

Method

Through the use of ultra-short pulsed laser radiation in the fs and ps range, Fraunhofer ILT is pursuing a direct ablation process as an approach for wafer dicing. First, in fundamental ablation tests, the influence of different wavelengths and beam forms was examined and an ablation model set up. Furthermore, the limits of laser power in combination with spot velocity were established in extensive investigations, which led to an optimal cutting result. The process parameters identified in this way were finally investigated as to their scalability. The scaling occurred by increasing pulse repetition rates together with quick beam deflection using a polygon scanner.

Result

The ablation with ultra-short pulsed laser radiation led to a lowering of the separation line widths down to 25 µm with a very homogeneous cut edge quality and a marginal heat-affected zone. Beam sources with high pulse repetition rates in the MHz range can be made useful for the application through the use of a polygon scanner.

Applications

The results generated can be implemented, in particular, in the field of LED manufacture to increase the chip yield per wafer and, thus, the production efficiency significantly. Since the cut edge quality also can be improved, the chip's modulus of rupture increases, which leads to enhanced process stability.

The project was funded by the Federal Ministry of Education and Research within the scope of its project »SEMILAS«.

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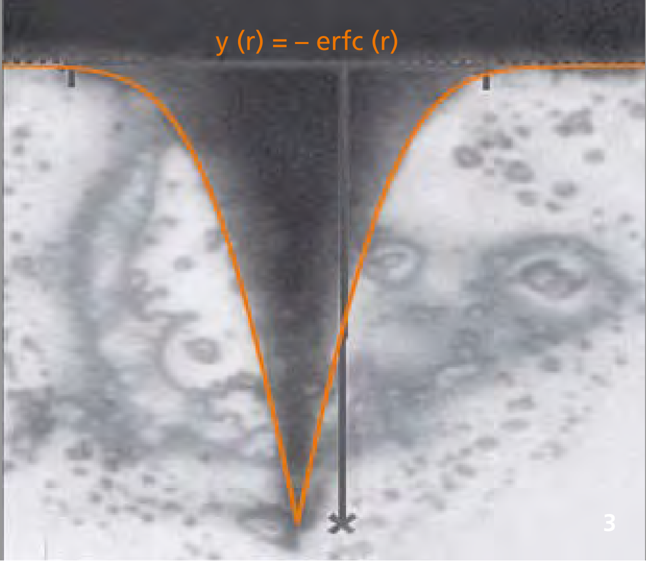
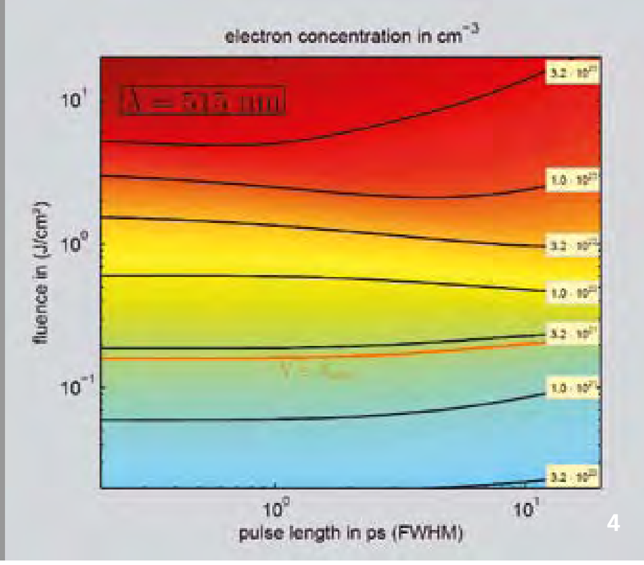
1 Polygon scanner.

2 Cut edge of a separated silicon chip.





SIMULATION OF SILICON ABLATION

Task

The semi-conductor industry has been using ultra-short laser pulses to separate chips from silicon wafers in many ways. This process allows for high integration density, features high cutting speeds at large curvature and, in particular, can process very thin wafers. Among others, the successful LED production can open up great market potential thanks to this process. To expand the potential of this cutting technology, however, the mechanisms of ablation and the formation of damages along the cut joint have to be examined.

Method

The modelling and simulation aims to depict the ablation of silicon wafers, resolved spatially, for the case of ultra-short, high-intensity laser pulses. This depiction combines a macroscopic model, which depicts the form of a cut joint, and a microscopic model, which captures the dynamics of electron systems, the thermodynamics in solid bodies and the ablation itself.

Result

As a result, the asymptotic form of the cut (e.g. the maximum cut depth attainable) depends upon the beam profile of the laser and the ablation threshold of the wafer material. The cross-section in Figure 3 shows that the model's prediction, which can even be approached analytically in this case, reproduces the experimentally determined result well.

In order to predict the local ablation behavior as a function of the laser parameters (fluence, pulse shape, wavelength), the model has been implemented in a simulation; Partial processes – non-linear absorption, radiation propagation and excitation of electrons – are contained in this model. The creation of »process maps« of the relevant microscopic parameters (Figure 4) allows optimization, also in parameter ranges that are not yet accessible experimentally.

Applications

The models and approaches developed here can be transferred to other substrates relevant to the industry. Such substrates are, e.g., sapphire (also LED production), and glass (display manufacture, photovoltaics) for which pulsed laser ablation is also characterized by an »ablation threshold«.

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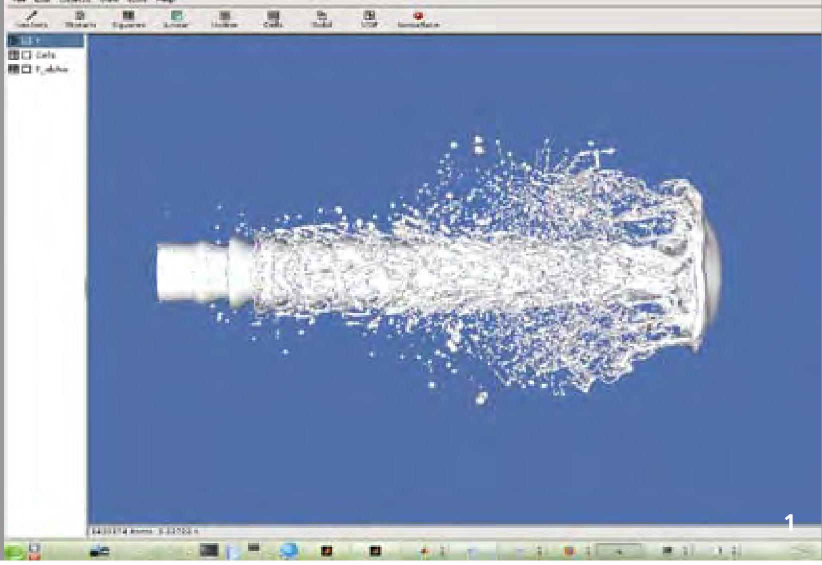
3 Experimental cross-section and simulation of asymptotic cut form.

4 Process map: electron density over fluence and pulse length.



SIMULATION OF A LIQUID JET FOR BEAM GUIDING

Task

While gas-jets are commonly used in ultra-short pulsed laser ablation (e.g. in the pulse duration regime of nanoseconds), meanwhile liquid-jets are also used to guide the beam as well as to cool the workpiece. This application of liquid jets requires extensive knowledge of flow properties, as fluid jets in particular tend toward hydrodynamic instabilities.

Method

The modelling and simulation presented here aim to describe, both spatially and temporally, the free surface of the water jet as well as its speed. Therefore, the hydrodynamics are calculated, in the frame of reduced models (slender-jet equations) as well as completely numerically by means of volume-of-fluid methods, all to specify how applicable such reduced model equations are.

Result

Models of both approximation levels were implemented numerically and are available for comparison with experimental data.

Applications

The simulation can be adapted to the modelling of other fluid jets and, thus, applied to simulations of other laser manufacturing processes for which the flow of liquid phases is relevant.

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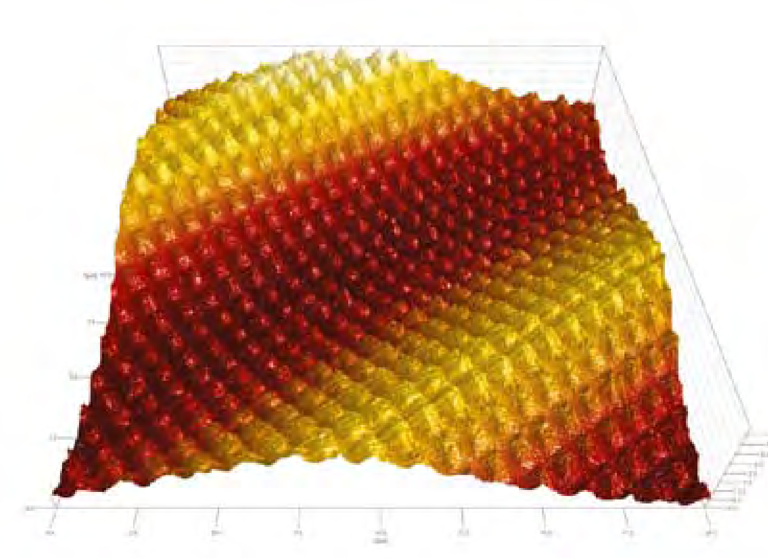
1 Simulation of a fluid stream.



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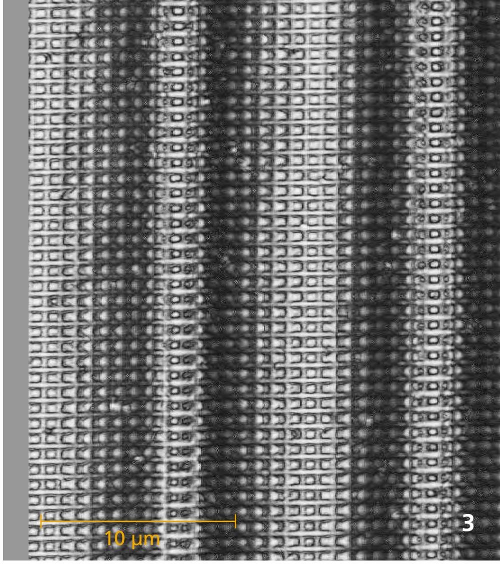

3

GENERATION OF HIERARCHICAL MICRO- AND NANOSTRUCTURES THROUGH LASER ABLATION

Task

The use of surface functionalization is becoming more and more important both in the industry as well as in research. Many of these functionalized surfaces imitate those found in nature, whereby the imitation of the lotus leaf with its hydrophobic properties counts among the most prominent examples. These surfaces are often double structures, i.e. they consist of a µm-scaled structure that is covered by a nanostructure. Surfaces generated technically mostly only implement single scaled structures, since conventional manufacturing processes cannot generate defined nanostructures on non-planar surfaces or can only do so with great difficulty.

Method

With a new approach, such hierarchical structures can be generated by a two-step laser process. In a first step, the microstructure is inserted in the surface with a UV picosecond laser. Through the use of pulse bursts, the minimally possible structural size can be reduced to less than 10 µm. In the second step, a nanostructure is applied to the microstructure with multi-beam interference. In this process the intensity created by the interference of coherent laser beams can be used to generate structures in the nm range. The advantage that this approach offers is that modulations appear in the entire overlapping volumes so that not only thousands of structures can be generated laterally and simultaneously, but also non-planar surfaces can be processed.

Result

With this two-step laser process, defined hierarchical double structures can be implemented successfully in the polymer polyimide. This process reached minimal structural sizes of 200 nm for the nanostructures on periodic microchannels in the single-figure µm range.

Applications

These results can be used for optimizing existing functionalized areas as well as for combining different functionalized areas in varying magnitudes. This way, on hydrophobic surfaces for example, the stability of the effect can be significantly increased by a double structure.

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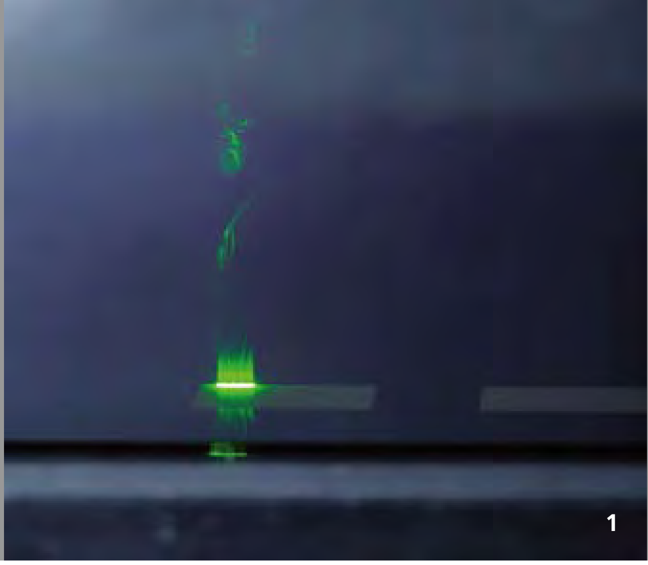
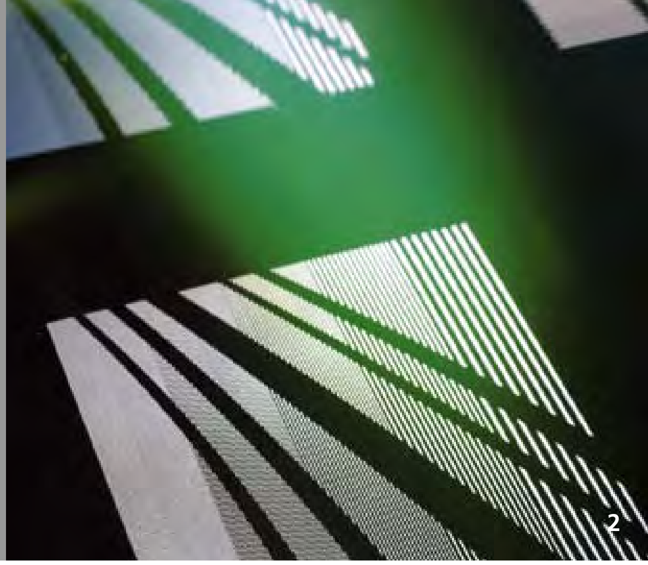
2 Laser scanning microscope picture of a double structure.

3 Atomic force microscope picture of a flat double structure.





LASER PATTERNING OF THIN FUNCTIONAL LAYERS FOR ORGANIC ELECTRONICS

Task

Components in organic electronics, such as organic light emitting diodes (OLEDs) or organic solar cells (OPV) are built using thin layers of conductive, semi-conductive, insolating materials. Theses layers have thicknesses in the range from several nanometers to a few microns. They have to fulfill both electrical as well as optical functions. In order to generate a functional component, individual layers have to be patterned, made possible by using laser radiation at high resolution and selectivity along with simultaneously high process speeds.

Method

The transparent, electrically conductive indium-tin oxide is mostly used as the transparent electrodes of OLEDs. Lithography is normally used to structure this oxide. To reduce the use of acids and cleaning agents during the patterning process, as well as to increase the freedom of design, Fraunhofer ILT is developing patterning processes which use laser radiation. These new processes have to prevent material bulging and particles, since these can lead to short-circuits in the component part.

1 Patterning thin films on glass.

2 Laser radiation allows selective ablation of individual layers.

Result

Transparent, conductive layers can be patterned when wavelengths in the deep UV range or ultra-short laser pulses are used. In addition to conventional patterning by means of ablation, when radiation is used below the ablation threshold, conductive or semi-conductive layers can be modified in such a way that they subsequently become electrically insulating in the radiated zones. Since no material is ablated during modification below this threshold, material bulging and particles can be prevented. Due to the low power needed, extremely high structuring speeds can be attained on account of multi-parallel processing.

Applications

Thanks to its ability to ablate and, in particular, to modify, this high-resolution, minimal-damage patterning process is becoming more and more important for the production of organic electronics. Further applications of thin-film electronics, such as monolithic series circuitry of thin-film solar modules, can also profit from the processes developed here.

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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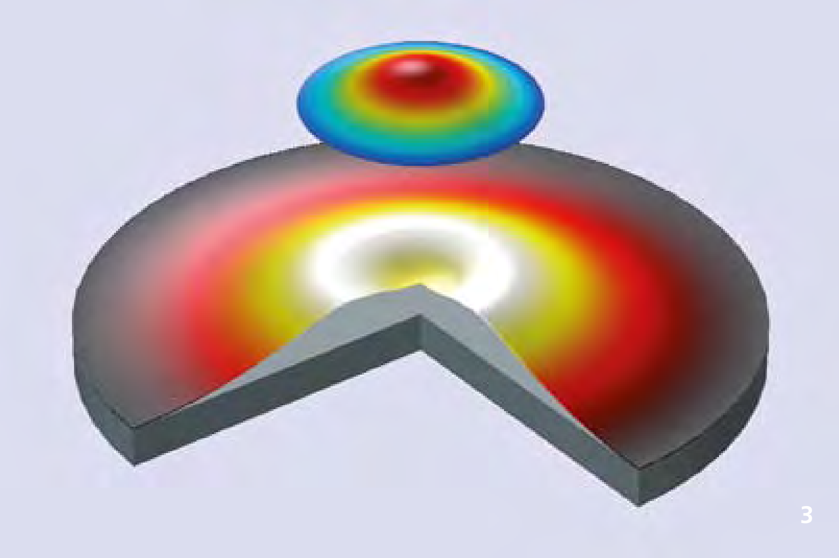

SIMULATING THE ABLATION OF THIN FILMS

Task

When thin films are ablated (e.g. in the semi-conductor industry) with ultra-short pulse durations and comparably small fluencies near the ablation threshold, efficient ablation occurs mainly on account of a thermo-mechanical effect of the laser radiation. The ablation takes place dominantly through bulging (delamination) and subsequent tearing of the bulged, stretched layer. In order to maintain the quality of a subsequent coating, semi-peeled coating remains and the effect of thermal phase transitions (melting, evaporation) have to be prevented, which, in particular, can be observed in the neighborhood of the ablation regions.

Method

The modelling and simulation aims to provide a spatially resolved depiction of the ablation of thin films so that the observed ablation threshold and the mechanical ablation process can be explained. For this purpose, both the dynamics of the electronic and phononic system are calculated in the solid state as are the thermo-mechanical effects within the workpiece.

Result

A model was used to simulate the deposition of the irradiated laser energy and the consequent mechanical deformation to the point at which the breaking stress was exceeded.

Applications

The simulation depicts the thermo-mechanical ablation of thin films on substrates. It can, thus, be used to simulate laser delamination processes, ones which use low power, thus for the manufacture of photovoltaic cells (P1, P2, P3 ablation) or for the cleaning of surfaces by means of laser radiation. In particular, this form of ablation is relevant when the underlying layers or substrates are only allowed to undergo a low thermal load or none at all.

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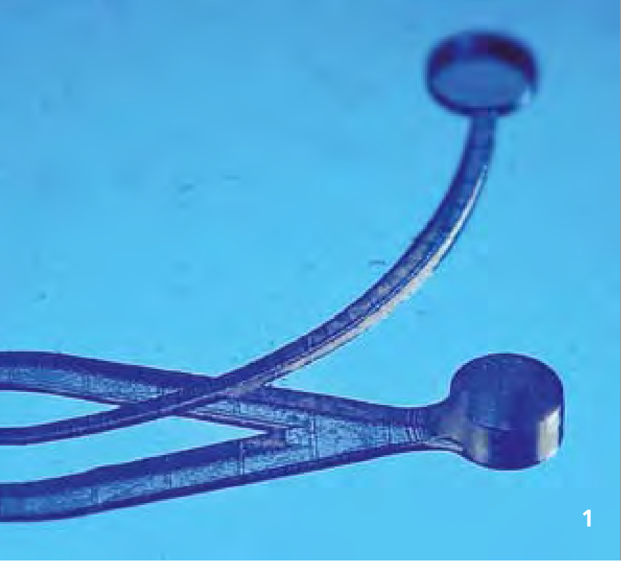
3 Simulation of a bulge.



GENERATING COMPLEX STRUCTURES IN GLASS THROUGH SELECTIVE LASER-INDUCED ETCHING

Task

To micro-structure dielectrics, such as glass and crystals, mask-based and impressing processes as well as direct ablation are commonly used today. These processes are confined, however, on account of their limited ability to produce undercuts, pre-assembled components or internal cavities. In contrast, the simplified manufacture of such structures directly from CAD data (Digital Photonic Production) opens up new possibilities to fabricate micro-fluidics or assembled micro-mechanisms. Selective laser-induced etching is a process that is suited to producing 3D structures in glass.

Method

Selective laser-induced etching (SLE) is a two-stage process. In the first step, the transparent material is modified by the laser radiation. To do this, ultra-short pulsed laser radiation is focused into the inside of the workpiece (ø 1 - 2 µm). As the beam focus moves, a continuous volume is modified, which has a contact to one of the outer surfaces. In the second step, the modified material is removed by wet-chemical etching. To produce complex component parts with digital photonic production, our software routine automatically creates the track data derived from digital CAD data. The laser beam is deflected by the micro-scanner system, thereby exposing the glass according to the track data. The micro-scanner system and the component parts are available commercially from the spin-off company LightFab.

Result

It is now possible to manufacture a mounted, double-helical planetary transmission in quartz glass. The diameter of the demonstration model is 10 mm. A possible drive can occur through a six-round formed drill hole in the sun gear (Figure 2). Microfluidics with features of 3-dimensional geometry, such as bridging in micro-channels, enable a larger functional integration density for lab-on-chip applications (Figure 1).

Applications

Users for the newly developed processes come from micro-system technology, bio- and medical technology, as well as chemical analysis and process technology.

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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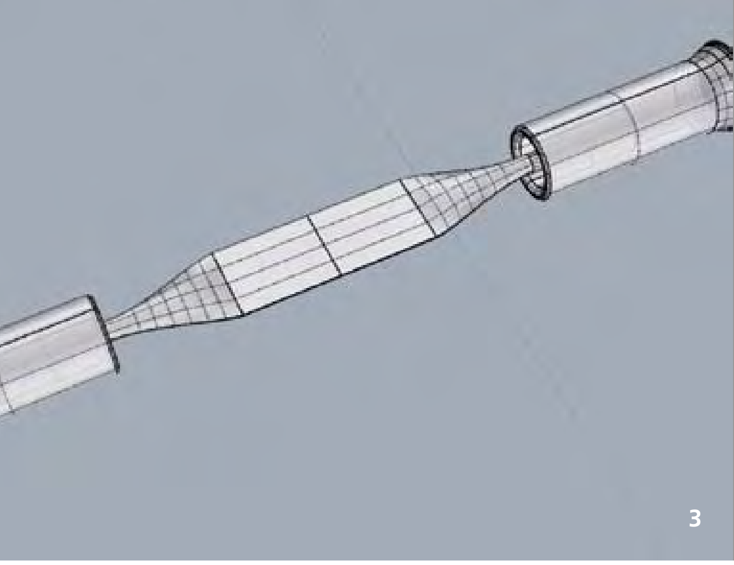
1 Micro-channel bridge inside a biochip.

2 Double-helical planetary transmission in quartz glass.



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4

INDIVIDUALIZED PRODUCTION THROUGH SELECTIVE LASER-INDUCED ETCHING

Task

To produce component parts for microsystems technology, masks, molding tools or injection molds first have to be manufactured. Therefore, it is costly to produce micro component parts as prototypes or in small series. The aim in this project is, thus, to individualize photonic production: laser-based manufacture directly from digital data (CAD). Selective laser-induced etching (SLE) is an appropriate tool to implement digital photonic production for transparent working materials.

Method

SLE is a two-step process: first, the transparent material is exposed to ultra-short pulsed laser radiation in the interior of the workpiece with a three-dimensional movement of the focus and, second, the structure is developed by removing the exposed material through wet-chemical etching.

By means of a CAD model of the structure to be produced, the track data for the movement of the laser focus is automatically derived. These track data are then transferred to CAM software, which synchronizes the controls of a microscanner system and guides automatic illumination of the desired structure.

Result

A microscanner system and a CAD/CAM software were developed and adapted to the process-based requirements of SLE, making the individualized photonic production possible, in this case, of a flow-through cell for medical diagnostics for automated cell count.

Applications

The system technology developed here finds applications in prototype and small-series production using SLE for microsystems technology, bio- and medical engineering as well as chemical analytics and process engineering. Further applications for systems technology are 2-photon polymerization and microablation with laser radiation.

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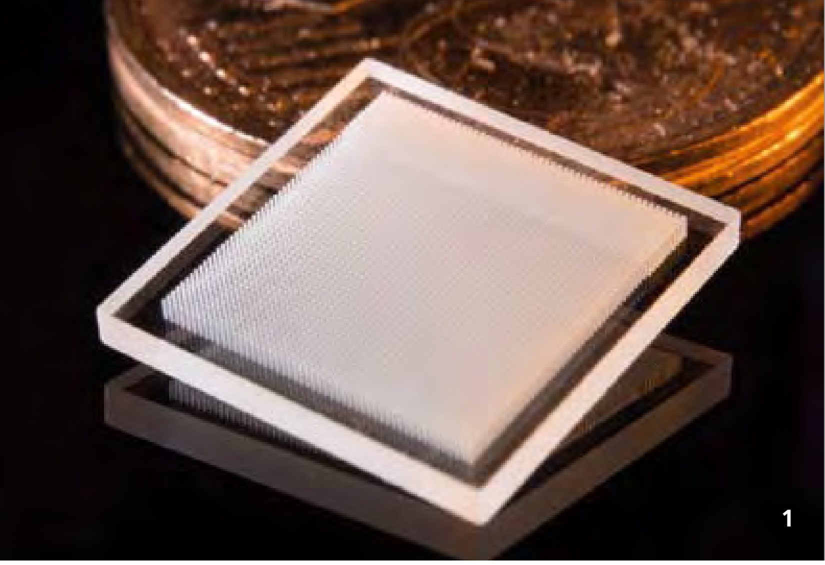
3 CAD model of a microfluidic system.

4 Microfluidic system producing by means of CAD model.



GLASS DRILLING: SCALING THE SLE PROCESS

Task

When combined with new high speed scanners, high power, ultra-short pulsed lasers (50 – 500 W) with pulse repetition rates from 4 - 40 MHz can increase productivity when used to process transparent materials. In particular, with the new laser manufacturing process Selective Laser-Induced Etching (SLE), efficiency increases can be expected since the material is not vaporized, but rather melted into a 3D contour, which is selectively removed in a subsequent wet-chemical etching process.

Method

A newly developed 3D high speed scanner (Figure 2, commercially available from the spin-off LightFab) reaches speeds of up to 200 m/s with a f = 160 mm lens (12 m/s with f = 10 mm lens for SLE, or 2 m/s with a f = 1.6 mm microscope lens for two-photon polymerization); In addition, it is used for exposing quartz glass with fs- and ps-laser beam sources in order to generate through holes by means of SLE. For this, the focus is moved on a circular path and simultaneously guided through the 1 mm thick workpiece. What has been investigated here is whether the hole diameter and process speed can be scaled with the laser power.

Result

A minimal hole diameter < 25 µm in quartz glass with a thickness of 1 mm has been drilled using fs-laser radiation starting at a laser power of 0.5 W. When ps-laser radiation is used, drill holes can be made with a diameter of 100 µm at 6 - 12 W, 200 µm at 11 - 30 W and 400 µm at 23 - 80 W. The SLE process can be scaled very well to large process speeds with larger USP laser power.

Fifty drill holes per second can be made in 1 mm thick quartz glass with diameters from 25 to 500 µm. At a drill hole diameter of 400 µm after etching, this corresponds, for example, to an ablation rate of 370 mm^3/min and a maximum efficiency of 16 mm^3/min per watt of ps-laser power used over an average amount of time. Now investigations are being performed as to how these results can be transferred to other types of glass.

Applications

The drill holes and microchannels can be used for microfluidics, for example in medical diagnostics, for filter applications in the food industry and as vias in the electronics industry.

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1 Drill holes of 120 µm diameter in 1 mm thick quartz glass.

2 A high speed scanner.

TECHNOLOGY FOCUS
LASER MEASUREMENT TECHNOLOGY AND EUV TECHNOLOGY

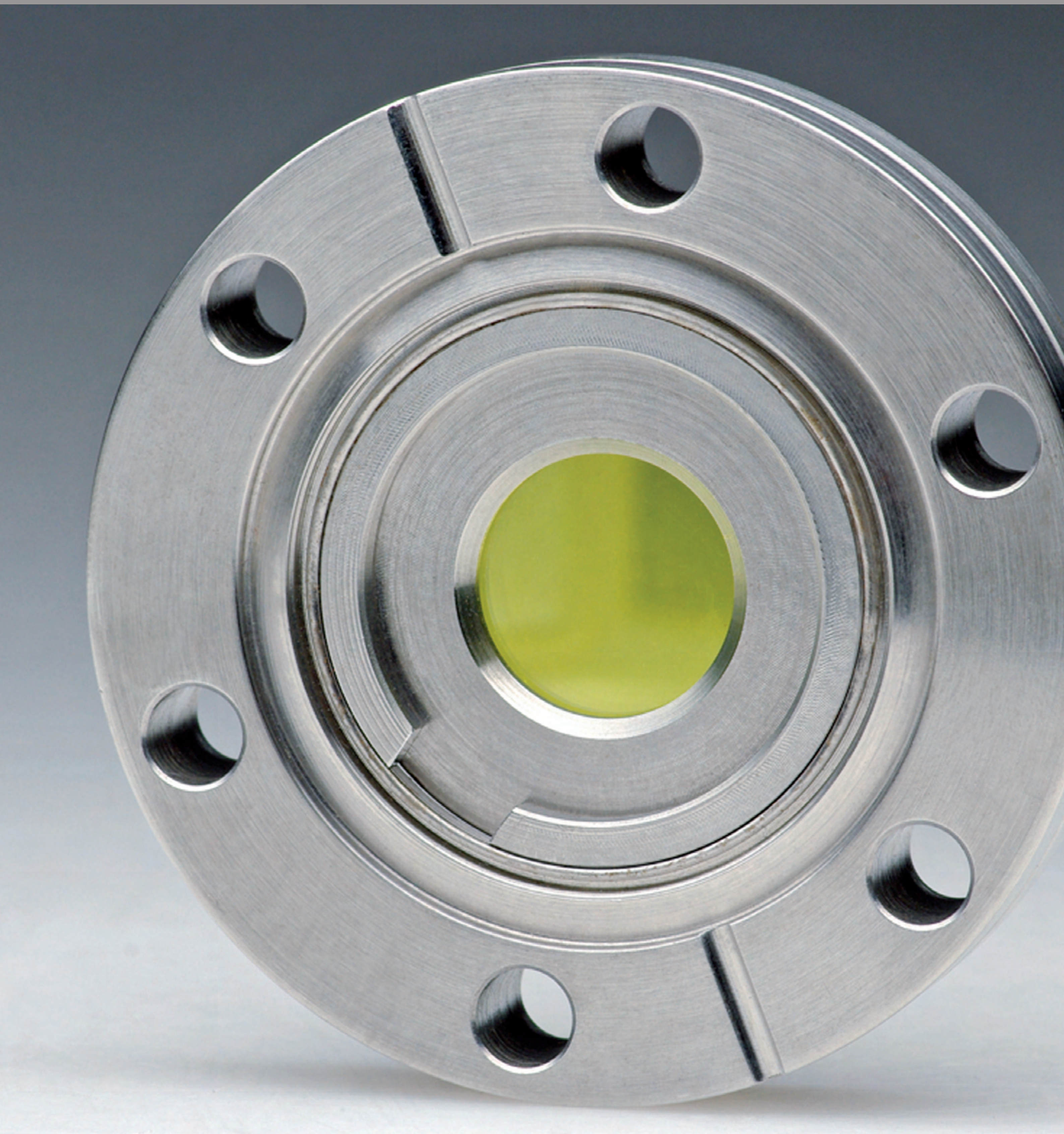
The focus of the technology field Laser Measurement Technology and EUV Technology lies in manufacturing measurement technology, materials analysis, identification and analysis technology in the areas of recycling and raw materials, measurement and test engineering for environment and security, as well 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 microscopy. Optical systems for applications in EUV engineering are calculated, constructed and manufactured as well.

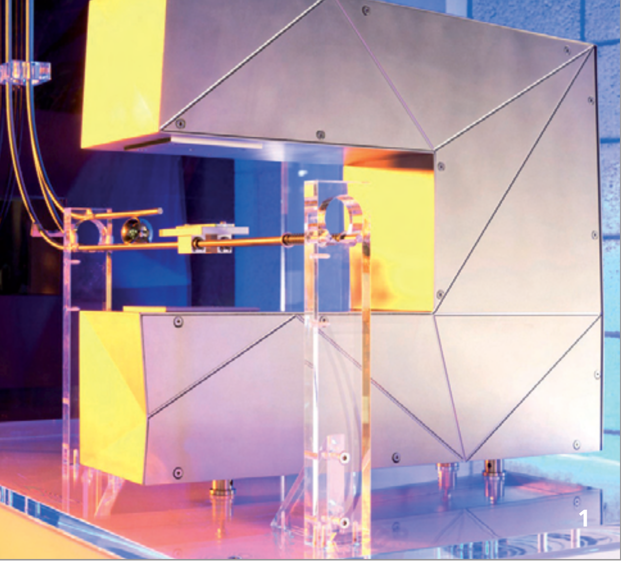
RESEARCH RESULTS 2013

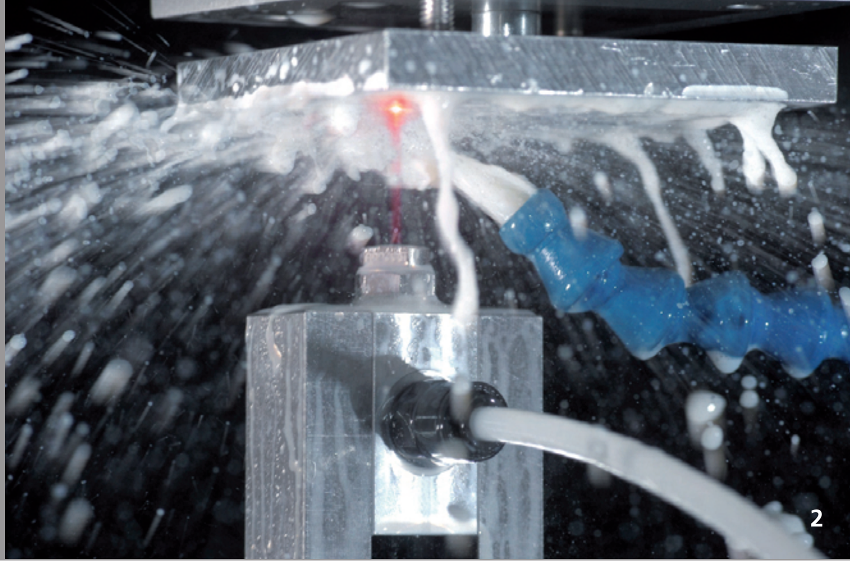
LASER MEASUREMENT TECHNOLOGY AND EUV TECHNOLOGY



CONTENTS

Investigations of fluorescent substances for the EUV spectral range.





MEASURING THICKNESS ON SHEETS AND METAL FOILS

Task

The aviation and automobile industries are placing more stringent requirements upon material and quality control. When thickness is measured, for example, sensors up into the micrometer range have to be precise, as quick as possible and securely measure directly in the production line.

Method

For these requirements, Fraunhofer ILT has developed an innovative optical thickness and distance sensor. This technology is based on the interference ability of the radiation from semi-conductor light sources. A measurement beam is sent to the surface of the material and from the reflected signal, the distance is measured at a precision of less than 200 nm.

Result

The thickness measuring system »bd-2« was developed especially for metal processing and is used to measure the thickness of rolled strips, sheets and metal foils in the range of 10 µm to 10 mm. Matt surfaces are measured as reliably as glossy ones. In comparison to other optical methods – such as laser triangulation – this new process offers a decisive advantage: Only a small measuring head is needed to emit and measure the distance signal. The space requirements are significantly smaller than, for example, for triangulation. The single measuring head sends and receives through a single, small window with a diameter of only two millimeters and can be reliably protected from impurities in the harshest of environments by a stream of air. In direct comparison with conventional triangulation sensors, the new sensor leaves the competition far behind, for example, with reference to linearity errors.

1 Robust stainless steel housing of the thickness measuring system »bd-2«. Live measurements at CONTROL 2013 in Stuttgart, Germany.

2 Measuring under harsh environmental conditions.

Applications

With the thickness measuring systems »bd-2« the distance to the surface is measured during running manufacture absolutely and continuously. Two measuring heads in a C-frame measure the product thickness. Measuring frequencies of several 10 kHz allow inline measurement even at high product speeds. Thus the sensor can be used for the active process control.

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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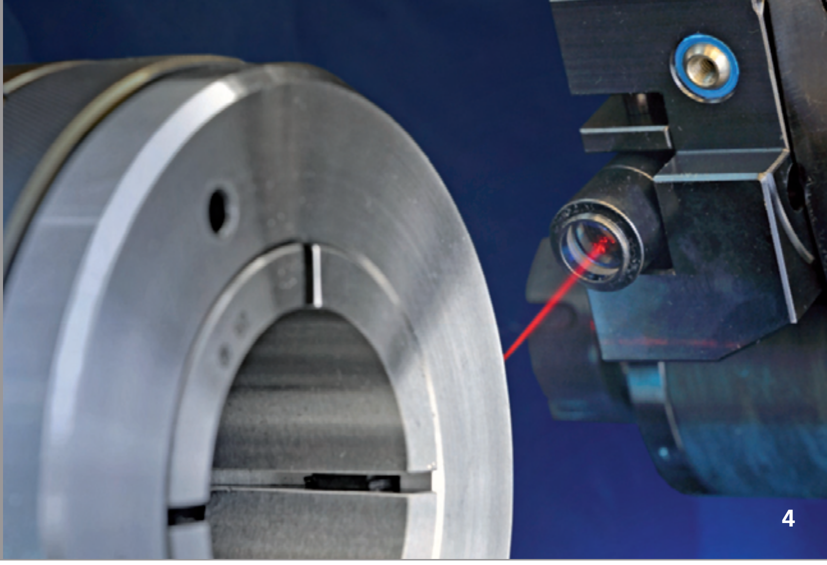


OPTICAL SENSORS FOR TOOL MACHINES

Task

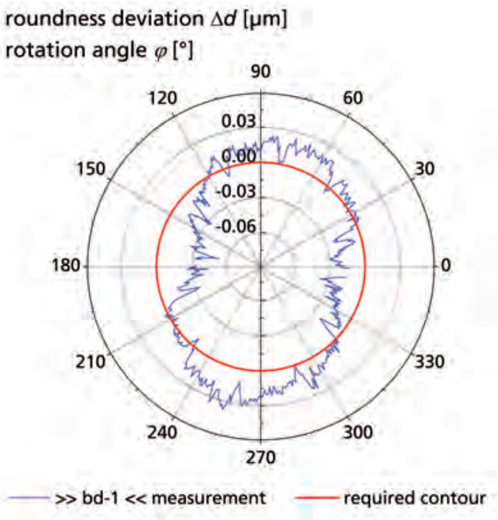
Increasing requirements upon manufacturing tolerances from machine tools are currently placing challenges on measuring technology. Established tactile measuring processes are suitable, as a rule, for measuring the workpiece in separate measuring devices, but not, however, for measuring during or immediately after the processing on the machine.

Method

Fraunhofer ILT has developed a new optical process to measure roundness deviations of parts turned on lathes without contacting the pieces. The measuring plant consists of a fiber-coupled measuring head attached to the machine tool. The measuring beam is directed upon the surface of the turned part and is reflected there back to the measuring head. From the reflected beam, a signal processor ascertains the measuring distance at a precision of less than 100 nm.

Result

The sensor »bd-1« was used on an ultraprecise CNC lathe to measure the roundness of a spindle with a diameter of 200 mm at a revolution speed of 5000 rpm at sub-micrometer precision. At a measuring frequency of 50 kHz deviations of under 30 nm were measured (see diagram).



Applications

In addition to measuring roundness deviations, »bd-1« can also be used to precisely record other geometry tests, e.g. the alignment of machine tools and workpieces as well as thermal linear expansion on the machine.

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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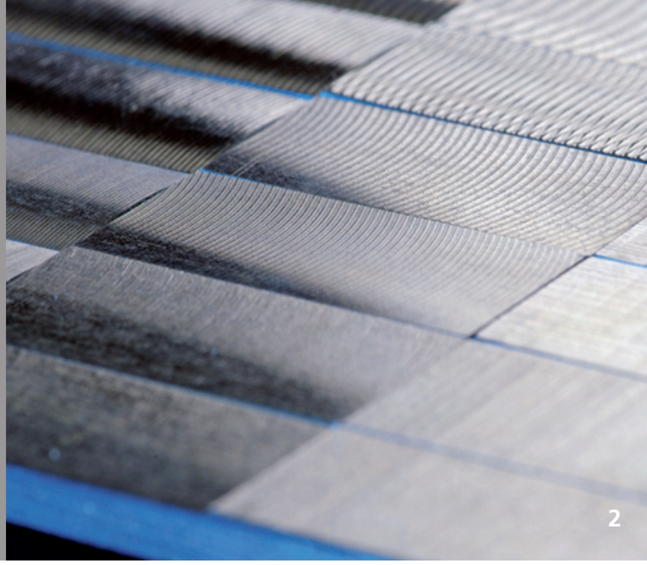
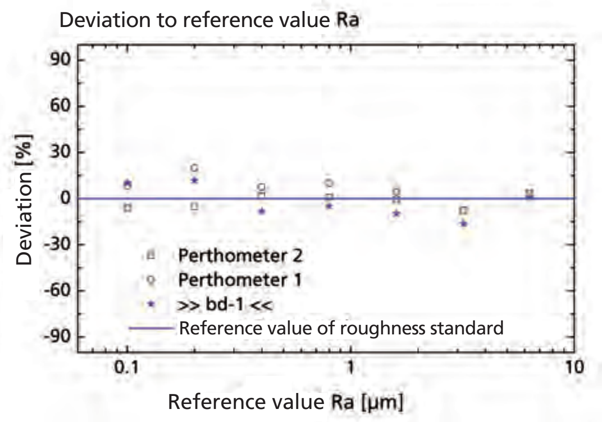
3 Fiber-coupled measuring head of »bd-1«-sensor technology on a turret.
4 Measurements on a spindle.



OPTICAL SENSOR TECHNOLOGY FOR INSPECTION OF SURFACES



Task

The surface of a component can influence its function and service life decisively. Therefore, during its manufacture special attention must be paid to the quality of a component's surface, especially for machine parts subject to high stress. Examples include bearings and gliding surfaces of motor components. In the automobile industry the surface quality, among others, is determined by surface roughness. Parameters for the roughness are, for example, the arithmetic average of roughness values Ra or the identified roughness depth Rz according to DIN 4287.

Method

Fraunhofer ILT has developed a new optical distance sensor to measure the roughness of technical surfaces without contacting them. The method and computing algorithms used for determining Ra and Rz are oriented to DIN standards by means of the profile method. The distances to be measured can be adjusted and reach up to 20 cm. Due to the measuring frequency for single distance measurements of 70 kHz, the feed can be adjusted to run much faster than the case with tactile processes.

Result

With the sensor »bd-1«, test measurements were conducted on roughness standards with Ra values in a range from 0.05 µm ≤ Ra ≤ 10 µm. The measurement results correspond within the tolerances with the results of commercial tactile measuring devices from well-known manufacturers.

Applications

With this sensor »bd-1« roughness values can be measured in-line for the first time. Furthermore, »bd-1« measures distance and geometrical features simultaneously at a precision below a micron. On turning parts, roundness deviations can be identified down to 100 nm.

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 Measurement on a ground shaft.

2 Roughness measurement standards.

HAND-GUIDED DIRECT ANALYSIS OF METAL

Task

In recycling and in quality control, chemical analyses are becoming increasingly important, and more and more hand-held systems are being used to conduct measurements on site. Currently used, spark discharge spectrometers or X-ray fluorescence analysers require an extensive cleaning of the sample and exhibit measurement durations of over 15 seconds. For laser direct analysis, preparation and measurement are combined in one process so that a significantly higher throughput is reached. The goal here is the development of a process and the set-up of a demonstration model for mobile laser direct analysis of metal pieces with a hand-guided measurement probe.

Method

Investigations with a fiber laser demonstrate that it can generate sufficiently strongly emitting laser-induced plasma on metal workpieces due to its high repetition rate, in spite of the small pulse energy. For spectral analysis, the signal of several single micro plasmas is integrated on the detector chip. The process parameters – as, e.g., pulse-to-pulse signal stability and gas exchange – were investigated experimentally to optimize the system's measuring accuracy.

Jointly with the project partners, Fraunhofer ILT has developed a demonstrator model, consisting of a freely movable measurement probe, which can be guided by hand, a fiber-optical interconnector and a base unit. The demonstrator model was tested in the field at recycling companies and compared with the state-of-the-art systems to evaluate its precision and throughput.

Result

The analytical comparison with conventional processes shows similar and, in part, better precision for the identification of element concentrations in steel and aluminum alloys. The total measurement duration, at approximately one second, lies more than one order of magnitude below that of conventional systems.

Applications

In addition to various metals, such as steel, aluminum or titanium, other solid materials such as minerals or glass can be analyzed. The measurement probe can be integrated into a robot arm so that automated tests can also be conducted.

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3 Demonstrator model.

4 Hand-guided measurement probe for laser-based direct analysis.

DETERMINING THE LIME STANDARD FOR LIQUID SLAG WITH LIBS

Task

Converter slag from raw steel production at voestalpine Steel, in Linz, Austria, should be analyzed with Laser-Induced Breakdown Spectroscopy (LIBS) directly in the ladle of slag transporters to determine the lime standard. The slag in the ladle is liquid or partially solidified on the surface at temperatures in the range of 600 °C to over 1300 °C (Figure 1). The measurement serves to classify the slag for targeted use. The laser measuring system is to be designed, developed and installed for automatic operation 24/7.

Method

In preliminary investigations, the feasibility and the analytical performance for the given conditions were demonstrated, and the process parameters determined. During the process development and the dimensioning and selection of the components, a great deal of attention had to be paid to the requirements of 24/7 operation, large measurement distances, and the exposure to heat and dust. The interfaces were defined in close cooperation with the customer. Adaptions and improvements of the measuring process were carried out before starting the trial operation.

Result

The laser measurement system has been installed at the plant and is running in trial operation. The inline measurement of the chemical composition from the release to the transfer to the control system lasts less than two minutes. In comparison to a reference analysis conducted in the customer's laboratory, the accuracy lies within the specified range.

Applications

The methods developed here and equipment are suitable for the automated analysis of mineral materials in the production process under the most difficult of conditions. Thus, materials accruing in production processes can be classified early and provided to targeted use.

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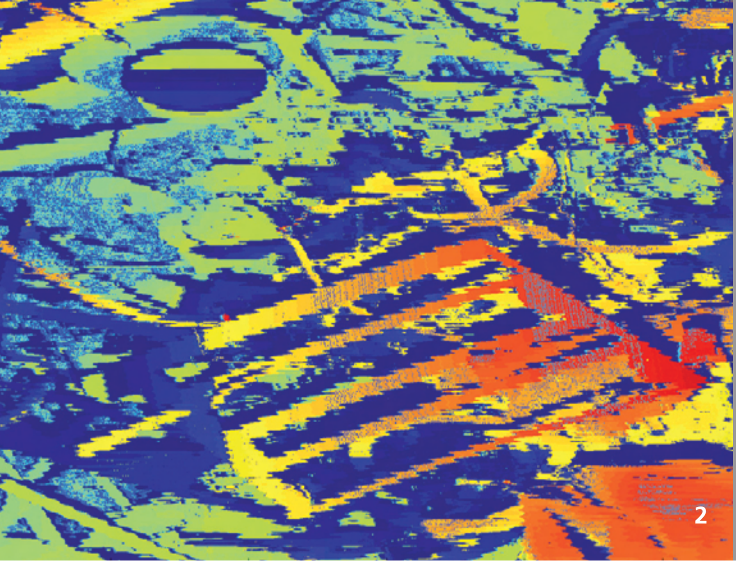
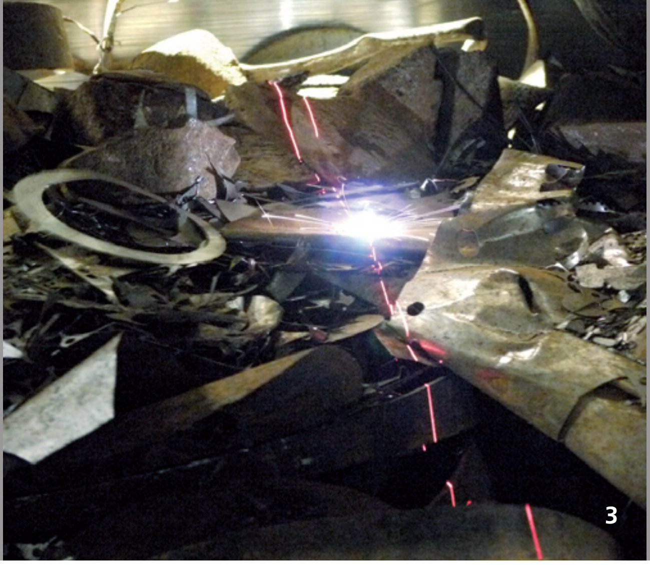
1 Liquid slag poured out in a slag yard (Source K. Pilz, BHM [2012] Vol. 157 [6-7]: 250-257).





MULTI-ELEMENT ANALYSIS IN MASS STREAMS

Task

Steel can be recycled with metallurgical processes and reused in steel alloys as new. The process to do this is in wide use and treats millions of tons of steel annually. Since the composition of the scrap metal is normally not known and the alloy composition itself has to be defined accurately, the melted steel first has to be purified, e.g. through oxidation of undesired accompanying elements. To ensure stable process control and to save energy, the composition of the scrap metal should be measured as it is charged into an electric arc furnace in a European steel works.

Method

An LIBS analysis system (Laser-Induced Breakdown Spectroscopy) was tested at Fraunhofer ILT and at a steel works. The demonstrator model is arranged over the conveyor system for the scrap metal and measures the composition of the stream continuously. The surface topology is scanned optically and a measuring position determined which enables an accurate LIBS measurement to be made on the surface. From a distance of 900 to 1400 mm, 15 chemical analyses are made per second, distributed over the entire width of the scrap metal flow, whose spectral data are then evaluated fully automatically.

Along with the measurements of the level and the conveyor speed, the total mass of silicon in the melt can be determined and the load can be adapted while a melt is being fed.

Result

The system was tested on over 800 melts at 150 tons each during a six-week measurement campaign. For reasons of comparison, slag samples of the melt were tested in the laboratory as well. The results of the LIBS measurements correlate with those from the laboratory. The inline analysis with the laser measuring system makes it possible for the first time to obtain feedback directly so that the furnace charging can be optimized.

Applications

The process is suitable for multi-element analysis of different materials that are present in mass streams. In addition to analyzing metal scrap, the laser direct analysis can also be used for metallic ore as well as for salts and coal.

This work was funded by the Research Fund for Coal and Steel of the European Community (RFCS) within the framework of a European Cooperation project.

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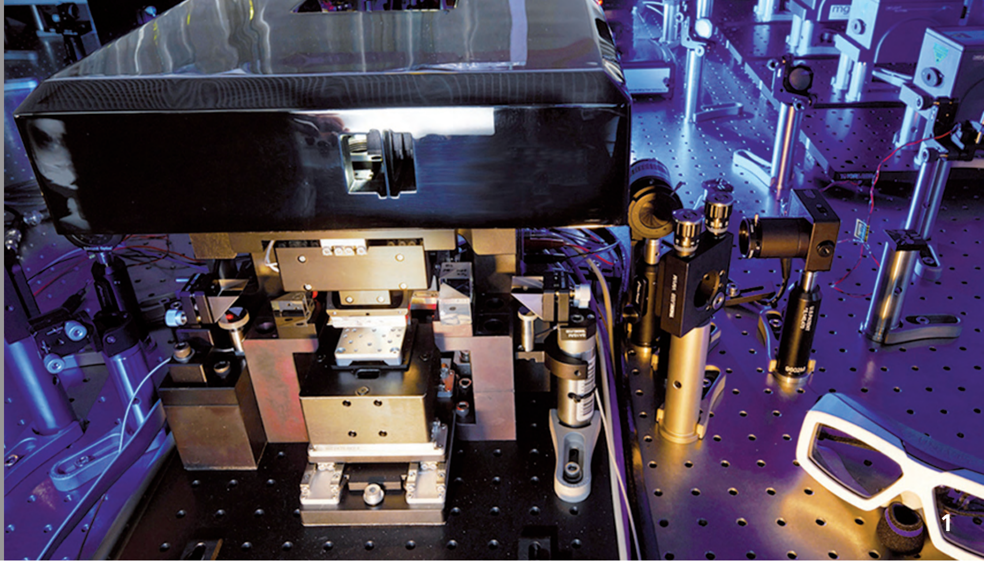
2 False-color image of the profile topology of the scrap metal stream.

3 LIBS plasma in the mass stream.



NEAR-FIELD MICROSCOPY FOR SEMI-CONDUCTOR ANALYSIS

Task

To develop new construction elements in the semi-conductor industry, engineers have to characterize them both structurally and electronically as well as with extreme precision. Conventional optical analysis techniques are principally able to examine these properties; However, their spatial resolution, confined by diffraction, has long been insufficient for modern semi-conductor structures.

Method

Near-field microscopy (or Scattering Near-Field Optical Microscopy, SNOM) circumvents the classical diffraction limit and allows optical analyses at a spatial resolution of less than 10 nm – independent of the wavelength of the laser light used. Thanks to a broadband tunable laser system, emitting in the middle infrared and developed at Fraunhofer ILT, new spectral fields can be opened up, thereby addressing new issues. For example, tensions in gallium nitride can be examined for the first time, a topic gaining more and more significance for the industry. Equally, doping concentrations or free charges in different materials can be investigated. The unique spectral width of the laser system developed here, in combination with the high spectral beam strength, enables spectroscopic analyses on a nanometer scale within the shortest amount of time.

Result

For the first time, induced tensions in the crystal structure of gallium nitride could be made visible at spatially high resolution and, additionally, the dominant forces could be quantified spectroscopically. By analogy, the distribution on doped indium arsenite nanowires was displayed and identified. The transition of this measuring technology to further material systems is currently being planned.

Applications

In addition to applications for characterizing semi-conductor components, near-field microscopy can be used in other fields. Nanocomposite materials can be examined as can common consumer products, e.g. cosmetics with nanoparticles. In order to do this wide spectrum of applications justice, a SNOM application laboratory is being founded at Fraunhofer ILT, which will have access to further microscopy and analysis technologies, such as SEM, SEM-EDX and FTIR.

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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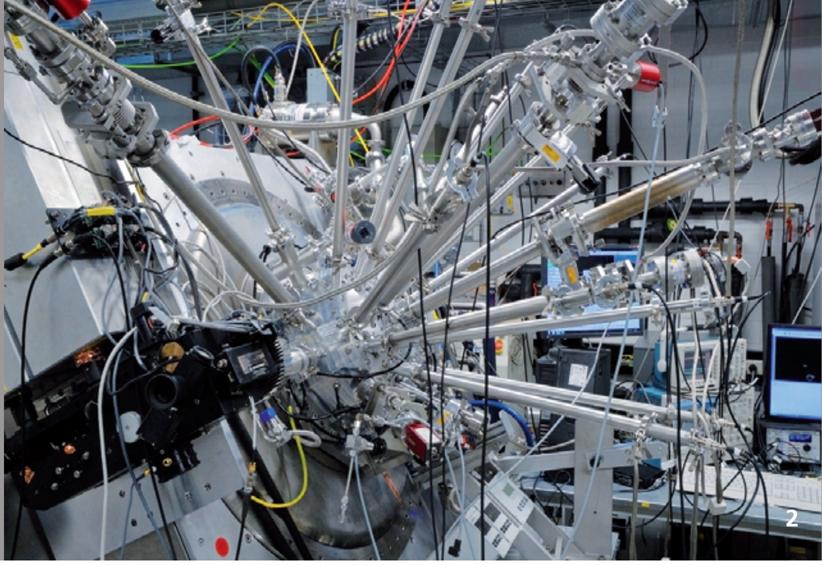
1 Near-field microscope.



POWER SCALING OF A RADIATION SOURCE FOR EXTREME ULTRAVIOLET LITHOGRAPHY (EUVL)

Task

To produce computer chips of the future, based on EUV lithography (EUV = extreme ultraviolet), manufacturers need high-power radiation sources with a central wavelength of 13.5 nm. For several years, Fraunhofer ILT has been developing such radiation sources in close cooperation with industry partners. The technical basis for these sources is the vacuum arc in tin vapor: here, in a pulsed electrical discharge, tin plasma is excited to emit characteristic radiation at 13.5 nm. As a developmental goal for these radiation sources several kilowatts light power in a spectral bandwidth of 2 percent around the central wavelength of 13.5 nm into half- space is challenged by the industry. This technical goal can then only be achieved if the source parameters are identified which enable an efficient EUV radiation generation. From these parameters, mean electrical input power in the range of over 100 kW can be optimally converted into EUV light power.

Method

An experimental EUV source was set up to investigate the fundamental physical mechanisms and their correlations of light generation. The source allows high flexibility in the variation of its parameters as well as the possibility of installing a multitude of diagnostics for the plasma in parallel. This guarantees a comprehensive characterization of the radiation source itself and the interrelations between parameterization and EUV radiation generation. Of essential interest here are the plasma geometry, the beam characteristic in the EUV and the conversion efficiency of the electrically stored energy in EUV light. What was varied was, among others, the electrical current pulse form, given by the capacitance of the electrical circuit, the electrical pulse energy and the distribution of the tin vapor between the electrodes, which can be influenced by a pulsed trigger-laser with adjustable parameters.

2 Beam source in extreme ultraviolet on the basis of a tin vacuum spark.

Result

For the first time, a parameter space could be identified with which the vacuum arc in tin vapor can fulfill the requirements upon a prospective production source.

Applications

The technology will be chiefly used in EUV lithography either to expose wafers or in EUV metrology, e.g. in reticule inspection.

The results are outcome of the collaboration with Xtreme Technologies GmbH on laser assisted discharge plasma (LDP) sources for EUV lithography.

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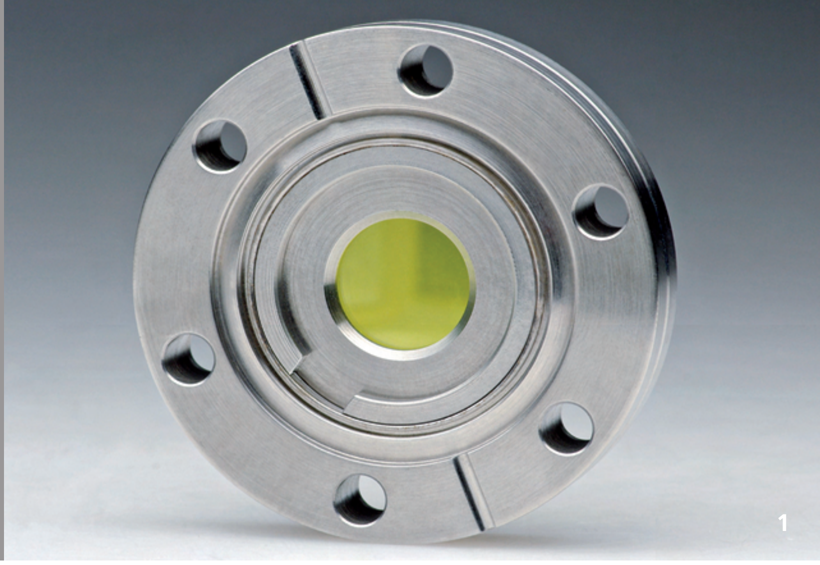

INVESTIGATIONS OF FLUORESCENT SUBSTANCES FOR THE EUV SPECTRAL RANGE

Task

Fluorescent substances are commonly used in the extreme ultraviolet (EUV) spectral range as imaging components, which convert short-wavelength radiation into visible light. A camera can then be used to detect this reemitted light in the visible spectral range. The choice of an appropriate fluorescent substance for a particular application depends upon its properties regarding its conversion efficiency, self-absorption and degradation. These properties have hardly been examined in EUV before. The work presented here aims to investigate different fluorescent materials as to their efficiency and self-absorption.

Method

The fluorescent materials examined were illuminated with EUV radiation and the converted light was measured in the transmission direction with a photodiode. A dose monitor in the EUV beam path measures the intensity of the incident light at the same time. From the ratio of incident to converted light, the conversion efficiency can be determined. Separately, the self-absorption is measured in a spectrometer, in which each fluorescent substance is radiated by its peak emission wavelength and the transmission detected.

Result

Five scintillators and seven phosphors were examined as to their conversion efficiency and self-absorption. The scintillators revealed principally lower efficiencies and lower self-absorptions than the phosphors. The most efficient phosphor is P43 with an efficiency of approx. 16 percent. In comparison, the most efficient scintillator, YAG:Ce achieved an efficiency of 1.5 percent. When the sample thickness is decreased and thus that of the self-absorption, a higher efficiency can be reached: 25 percent for P43 as well as 3.5 percent for YAG:Ce.

Applications

The results can be used to improve the manufacture of fluorescent coatings on cameras for the detection of EUV radiation. By making a significant improvement to the properties of such a camera, a manufacturer can create a cost-efficient alternative to the current standardized back-illuminated CCD cameras.

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1 Scintillator crystal YAG:Ce in a holder suitable for use in a vacuum.

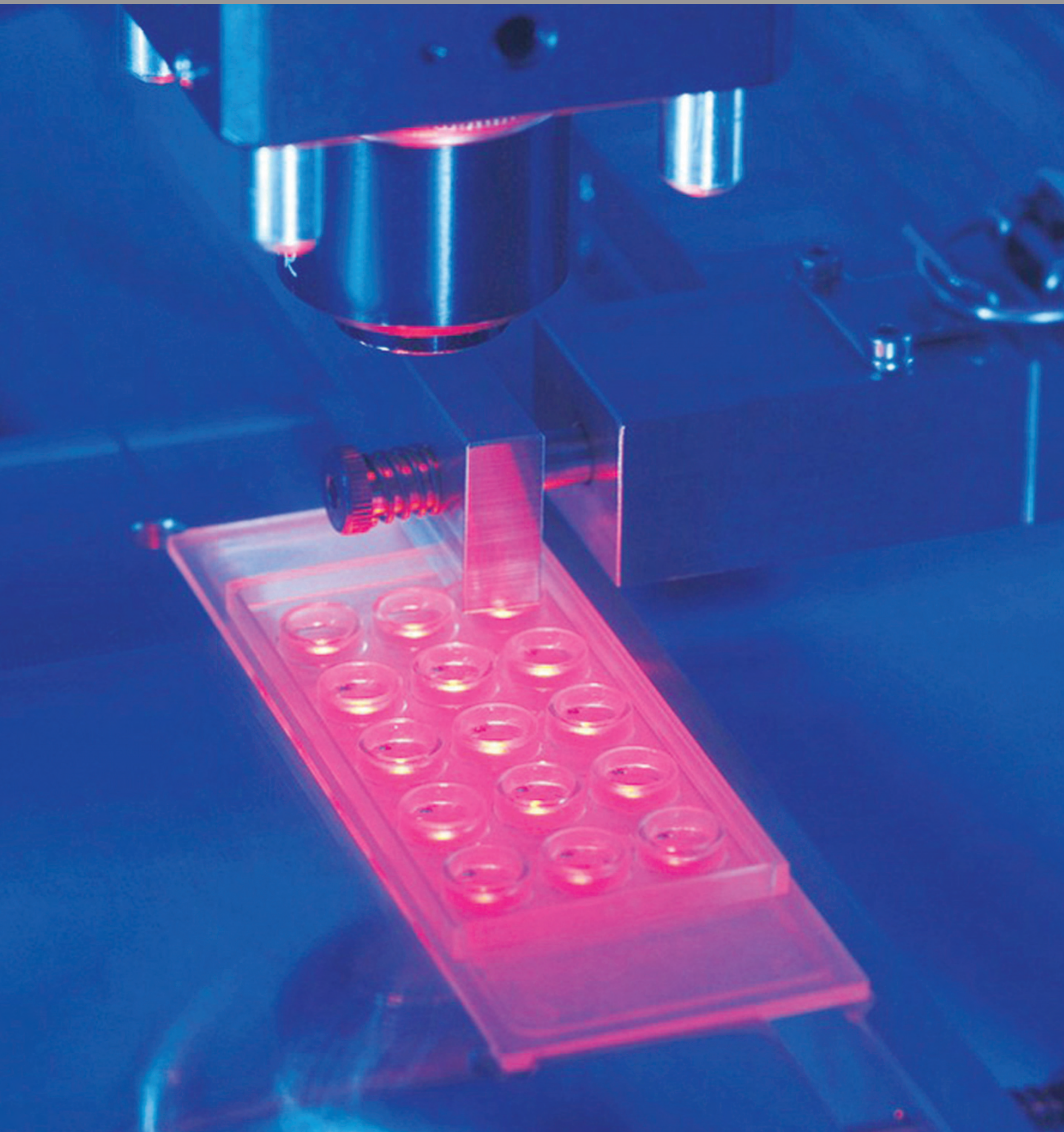
TECHNOLOGY FOCUS
MEDICAL TECHNOLOGY AND BIOPHOTONICS

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.

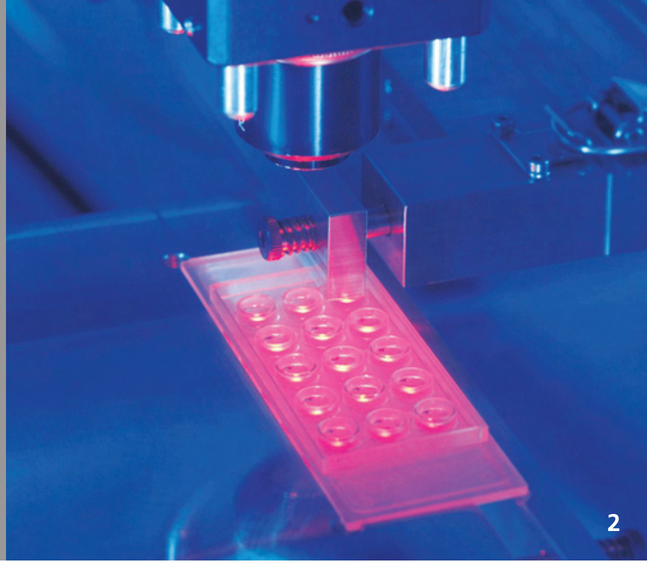
Nanoanalytics as well as point-of-care diagnostics demand inexpensive single-use microfluidic components. These can now be manufactured with high precision up into the nanometer range using laser-based processes such as joining, structuring and functionalizing. Clinical diagnostics, bioanalytics and 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.

MEDICAL TECHNOLOGY AND BIOPHOTONICS



CONTENTS

LIFTSYS – Laser Printing System
for Cells and Biomaterials.



LIFTSYS – LASER PRINTING SYSTEM FOR CELLS AND BIOMATERIALS

Task

The manufacture of biological testing systems is often confined by the viscosity of the biological materials applied to an analysis chip. Up to now, printing technologies have required highly aqueous carrier solutions and have not allowed the analyte to be positioned with pinpoint precision. Glycoproteins, living cells or metals can only be partially printed with conventional systems. A technology with which biomolecules and cells can be placed with micrometer precision in any arrangement needed on a substrate would enable new possibilities in high-throughput or high content screening.

Method

The LIFTSYS system, which the Fraunhofer ILT developed using laser-induced forward transfer (LIFT), makes it possible to place the smallest amounts of biological materials or even individual living cells precisely and without any restrictions. A receiver substrate is situated beneath a transfer substrate, a glass slide, bearing the biomaterial to be transferred on its underside and an intermediate titanium absorber layer. A pulsed laser beam evaporates the titanium layer, and the resulting forwards impulse transfers the biomaterial onto the receiver substrate. This laser-based process functions without a printing head and can transfer biomaterials such as RNA, DNA, proteins and cells independent of viscosity.

1 LIFTSYS tool in the laboratory.

2 Set-up of a cell-based test system by means of LIFT.

Result

As a result of its technical development upon the device, Fraunhofer ILT has created an innovative technology – a five-axis tool with positioning systems for transfer and receiver carriers. The integrated beam source can be adjusted to the wavelengths 355 nm or 1064 nm. Focusing position, laser power and pulse number can be automatically regulated. This enables the user to transfer a wide range of substances, from biomaterials to metals, with the LIFTSYS machine. The tool also enables users to program complex transfer patterns and assign them to a specific processing result.

Applications

A wide field of applications is, for example, medical and pharmaceutical research, in which the reaction of cells to active substances is examined. In particular, the system can be used to reproduce basic investigations of microscopic interactions of different cells with each other. With LIFTSYS, microstructures can, furthermore, be fabricated from different technical materials for the manufacture of sensors or bio-hybrid sensor systems.

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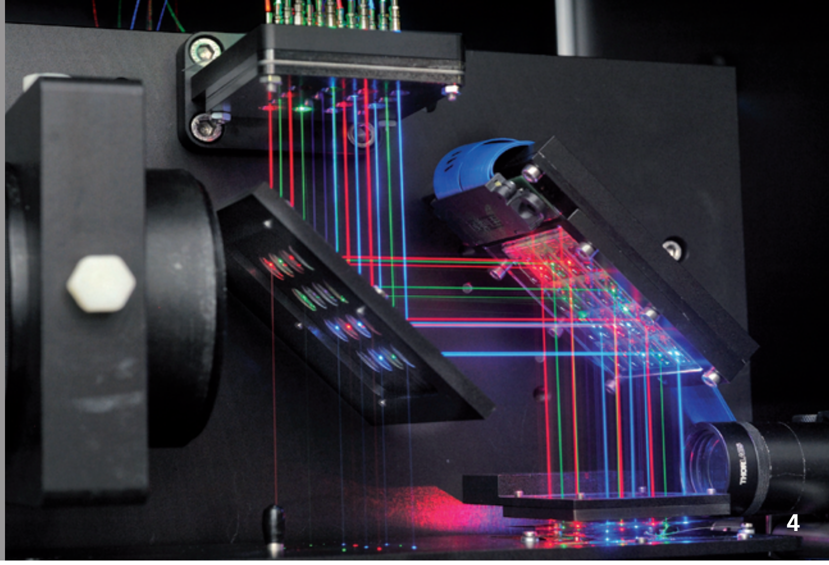

MULTISPECTRAL MULTI-CHANNEL SENSOR FOR INFECTION DIAGNOSTICS

Task

To diagnose infections, multiplex analyses are being conducted more and more often. These analyses can prove the existence of different pathogens in one single test step. To achieve this result, an assay is used, composed of different antibody dye conjugations, from which each specifically binds to a pathogen and can be distinguished from the remaining ones due to the spectral properties of its fluorophore.

Method

To conduct a multiplex test, Fraunhofer ILT has developed a fluorescent sensor that has 16 excitation and 16 detection channels. Every 4 of the 16 excitation channels have the same laser wavelength. In total, four excitation wavelengths are available: 405 nm, 473 nm, 514 nm and 638 nm. Each detection channel is spectrally tuned to the emission spectrum of a specific fluorophore, by which 16 different marked pathogenic agents can be detected simultaneously. Excitation as well as detection light is guided through optical fibers, which can be arranged according to the sample geometry. At the end of each fiber there is a micro-lens that focusses the excitation radiation in the analyte solution to be examined and collects the fluorescent light originating from it. A multichannel discriminator (MCD) was developed to deliver the sensitive detection of single photon events. This device transforms the short current pulses of a multi-anode photomultiplier (PMT) into TTL signals.

Each channel has a pulse shaper, with which the lengths of the voltage pulses of the PMT output can be adapted to the signal-processing electronics. A discriminator threshold adjustable for each channel allows the signal-to-noise ratio to be optimized.

Result

The multispectral multichannel sensor was set up for 16 channels. The detector noise, as well as the crosstalk between neighboring channels, was quantified. Crosstalk could not be detected. For the near-infrared sensitive photo cathode used, signal-to-noise ratios of the counting rate larger than 10 dB were reached under typical measuring conditions with the fluorescence markers used for detecting the pathogenic agents.

Applications

The multispectral multichannel sensor can be used to detect infectious diseases, auto-immune diseases or tumor markers in clinical diagnostics. It is suitable for examining research questions in the fields of bioanalytics, biochemistry and pharmacology.

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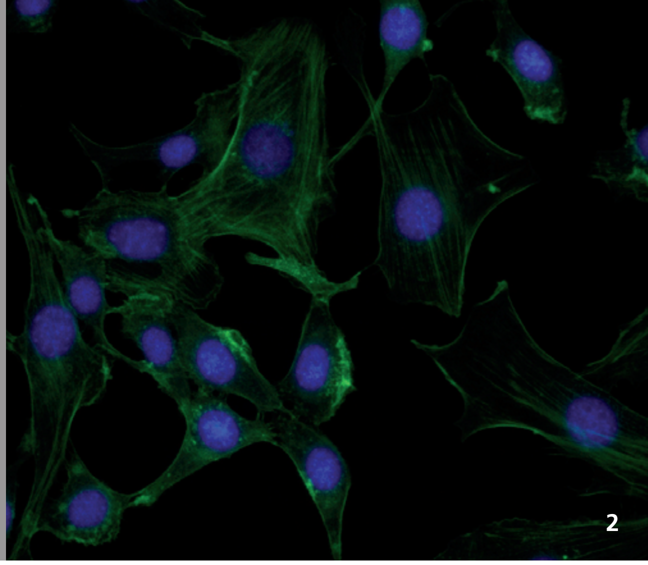
3 Multi-channel discriminator for sensitive detection of single photon events.

4 Excitation laser radiation of different wavelengths for the spectral multiplex test.



FUNCTIONALIZING SOFT TISSUE IMPLANTS

Task

A tissue fracture denotes a tear in the abdominal wall which allows inner organs, for example, the intestine, to penetrate outwards. The most common form (approx. 2 to 3 percent of the population) stems from hernias. Defects in the abdominal wall can be inborn or a consequence of operations. After operation upon such a tissue fracture, 30 percent of the patients suffer from chronic pain, and 10 percent of the patients require further operations. When an appropriate bioactive implant is used, however, these aftereffects can be reduced.

Method

The implant under examination consists of a side pointing outwards, which should grow well into the abdominal wall. Thanks to the other, smooth side lying in the abdominal cavity, the implant should prevent the inner organs from growing together. Silk from silk worms is used to produce a raw fleece and a smooth membrane, which are bound together. Both sides receive a specific bioactive functionalization from laser radiation. In addition to doing basic investigations, Fraunhofer ILT is also researching concepts to transfer the different processes from the laboratory to industrial production. The silk membrane is irradiated with light having a wavelength of 330 - 370 nm in a Sulfo-LC-SDA and TGF-ß solution.

1 Silk membrane with fleece surface for integration in the abdominal wall.

2 Silk membrane cultivated with 3T3 cells after UV functionalization.

In this solution, a photochemical reaction takes place, which binds bioactive molecules onto the silk membrane. In a subsequent washing step, the adhesive-bound molecules are removed so that only the covalently bound anchor groups remain in the laser-functionalized areas.

Result

A process has been established for coupling the anchor groups using UV light. The proof of the photochemical bonding was furnished by means of binding a fluorescent dye. Here, it could be shown that the share of photochemical bonds lies higher than unspecified adsorption by approximately a factor of ten. With the help of contact angle measurements, the binding of the growth factor TGF-ß could be demonstrated.

Applications

The process of functionalization observed here is still in a laboratory stage and should be transferred into reliable and reproducible fabrication processes. Innovative and improved implants can be produced thanks to the different kinds of functionalization.

The work was funded by the Federal Ministry of Education and Research within the scope of its project »HYPA B« (grant number 13N12252).

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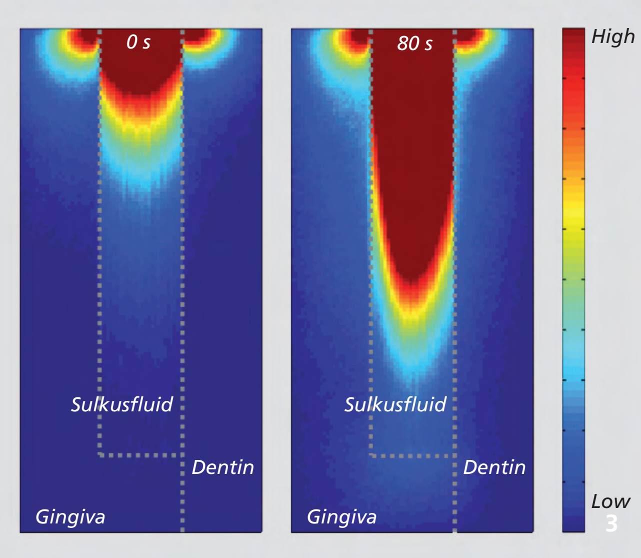

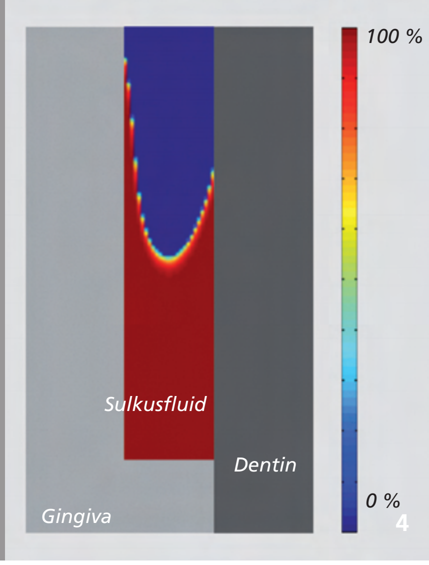

ANTIMICROBIAL PHOTO-DYNAMIC THERAPY

Task

Antimicrobial photodynamic therapy (aPDT) is used to treat bacterial infections. While this therapy becomes all the more relevant as bacterial resistance increases, its success still cannot be observed during or immediately after the treatment, which limits the benefits it could offer. To overcome such limitations, the methods of modelling and simulation are used to examine aPDT in order to identify measureable values, which, in turn, should enable the therapeutic process to be observed live.

Method

The operating principle of aPDT is based on laser-induced electronic excitation of photoactive chemicals, so-called photosensitizers, at low power (~ mW). Resonant collisions of the excited photosensitizer with molecular oxygen generate highly reactive and cytotoxic singlet oxygen. Since the singlet oxygen is close to the bacteria, the bacteria are damaged and subsequently made inactive within the short life time (~ ns) of the singlet oxygen. The spatially and temporally distributed processes (propagation, scattering and absorption of the laser radiation, progress of biochemical reactions) are depicted by a system of reaction diffusion equations.

Result

As a result, a dynamic and spatial two-dimensional mathematical model can be shown, whose resolution describes the progress of the reaction front and the successfully treated area. To resolve the model and to analyze the resolution properties, a simulation tool has been made available.

Investigations have been conducted on how dependent the therapeutic success is upon relevant parameters so that suitable treatment records can be developed. The results show that the concentrations of photosensitizers and oxygen as well as the properties of the laser radiation are all relevant. Measureable values as well as those that change with the therapeutic success will be identified and tested as to their suitability to observe the therapeutic process.

Applications

The model developed here has been designed for use with aPDT for the treatment of periodontitis. We expect that the model, when modified, can be adapted to depict the therapy of wound infections or local infections with multi-resistant germs. Another promising application of the model is a simulation to depict photodynamic therapy for tumor treatment.

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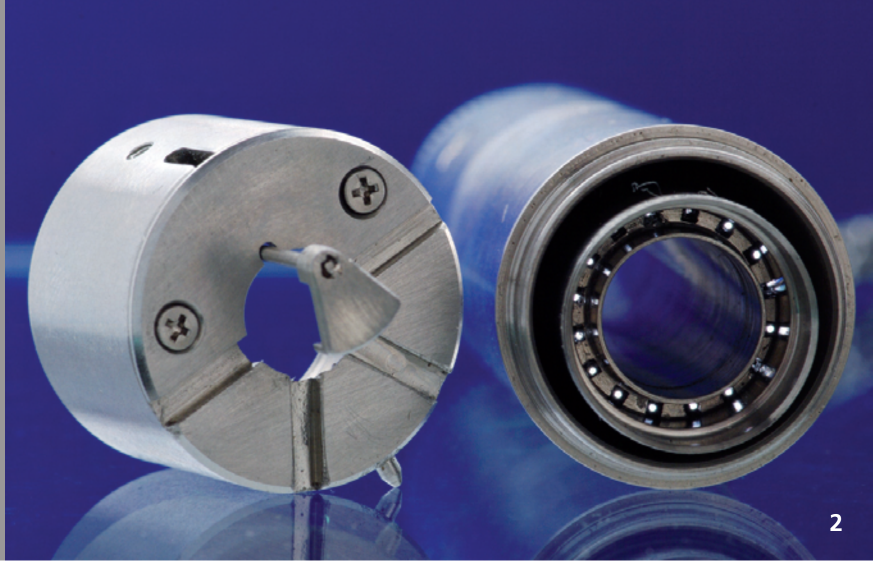
3 Intensity distribution in periodontium during aPDT after 0 sec. and 80 sec. radiation.

4 Survival rate of bacteria during aPDT after 80 sec. radiation.

1



2

ADAPTIVE HANDPIECE FOR LASER-BASED THERAPY SYSTEMS

Task

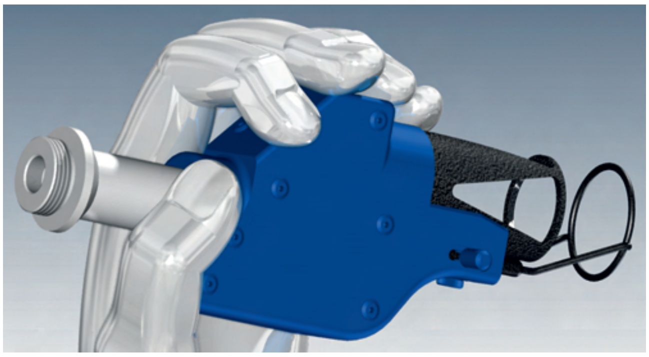
In numerous applications in dermatology, for example, when treating vascular lesions, laser radiation is used to ablate or coagulate tissue. For this process, the laser radiation has to be focused on the tissue and, via a scanner mirror, passed over the tissue surface. A handpiece developed at Fraunhofer ILT with integrated scanner technology should enable the doctor treating the patient to do this, whereby he retains complete control over the process and is supported by assistance systems.

Method

The therapeutic radiation is coupled to a handpiece that the surgeon places upon the section of skin to be treated. The micro scanner technology ensures that the laser is positioned precisely. The use of 2D image acquisition combined with scanner mirrors enables the doctor to document the treatment process and its success. In addition, the geometry of the surface to be irradiated can be adapted automatically to the results of pre-operative diagnostics. Measurement radiation of optical coherence tomography can be superimposed over the therapeutic radiation in order to monitor the coagulation process in deeper lying layers of tissue.

1 Handpiece for laser-based surgery.

2 Grip with irrigation channels and illumination via glass fibers.



CAD design of a handpiece for dermatology.

Result

At Fraunhofer ILT, handpiece technology has been developed for applications in hard tissue surgery, which enables capturing 2D images and making 3D OCT images of the treatment site while laser radiation is used to cut. The OCT system, developed at Fraunhofer ILT specifically for use in laser surgery has a measuring area of $z = 11$ mm, a measuring frequency of $f = 14$ kHz and an axial resolution of $dz = 25$ µm.

Applications

The handpiece can be used in laser therapy and surgery systems for which the laser radiation has to be applied by the surgeon with high precision in spite of being guided by hand.

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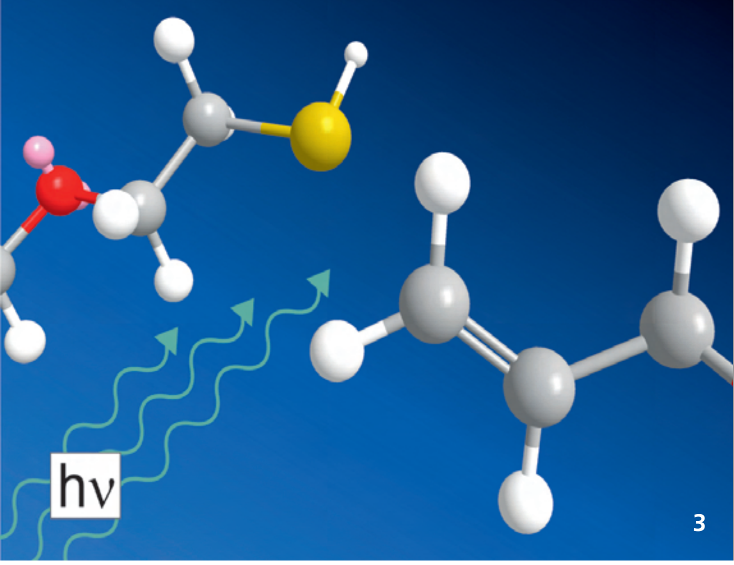

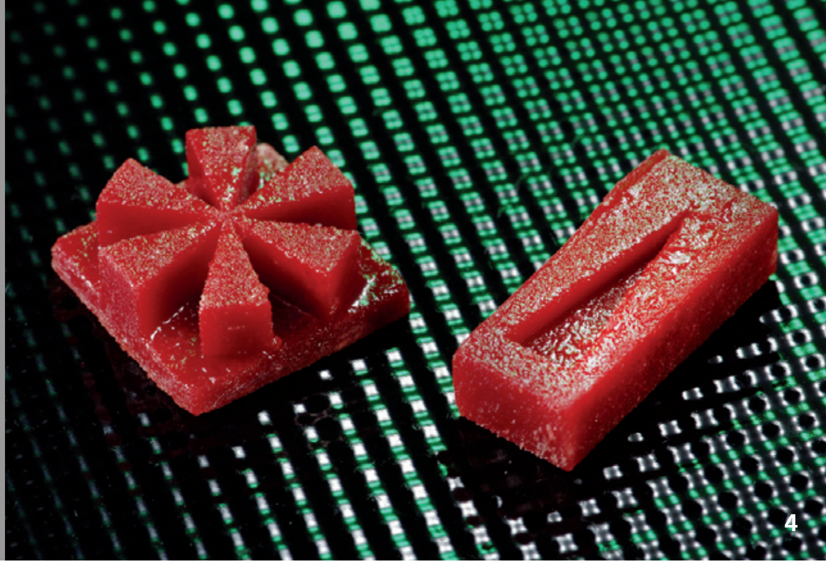

ADVANCED PHOTO-POLYMERS FOR 3D PRINTING

Task

The technology of 3D printing is conquering the world and awakens the interest of many users in the most varying of applications. These reach from building prototypes, producing polymer parts in small lot sizes all the way to personalized manufacture of implants in medical engineering. New applications require new, adapted materials. Biocompatibility, process speed, dimensional accuracy and adjustable product properties, such as high fracture strength and adjustable elasticity, are some of the requirements made during development of new light-curing polymer systems. The correlation between the materials and the 3D printing processes, such as stereolithography, projection-based printing processes and multi-photon polymerization, all present special challenges.

Method

Thiol-ene reactions have high efficiency in its reaction sequence and can be controlled via local initiation through light exposition both temporally and spatially. In combination with the high precision of 3D printing processes, this reaction type is a very promising approach for innovative photocurable resins. The selection of materials covers biocompatible, synthetic, natural or hybrid materials or composites with adjustable mechanical properties. In addition to the classic UV curing resins, such as acrylates or epoxides, the thiol-ene click reaction opens up a new class of photopolymers for 3D printing.

Result

Within the scope of the research activities in Life Sciences, biocompatible material systems could be developed on the basis of thiol-ene chemistry, which were processed into high resolution 3D objects though stereolithographic processes. By the printing of standard geometries, the high spatial and depth resolution of the material systems used and their suitability could be proven for highly precise components from stereolithographic printers (Figure 4).

Applications

In addition to biological and medical applications as well as those in the dental sector, the material systems based on thiol-ene are open to technical fields. The quick and controllable curing of the polymer systems enables an application-based composition of the photo resins. Next to formulating the photo-activated resins, Fraunhofer ILT is developing corresponding plants such that customers can be provided with optimized solutions from process and material.

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3 Photochemical thiol-ene reaction.

4 3D structures from thiol-ene photopolymers.

PATENTS

Patents Germany

10 2007 038 502
Verfahren zum Fügen von mindestens zwei Bauteilen mittels Laserstrahlung

10 2010 033 053 A1
Verfahren zum formgebenden Umschmelzen von Werkstücken

50 2008 009 626.4
Verfahren zur Materialabtragung sowie Vorrichtung zur Durchführung des Verfahrens

10 2009 059 894 A1
Optische Anordnung zur Symmetrisierung und/oder Homogenisierung optischer Strahlung

10 2012 012 981 B3
Optische Anordnung zur Laserbearbeitung einer Werkstückoberfläche sowie Verfahren zur Überwachung des Bearbeitungsprozesses

Patents Europe

EP 50 2008 009 626,4
Verfahren zur Materialabtragung sowie Vorrichtung zur Durchführung des Verfahrens

EP 2 122 413 B1
Verfahren und Anordnung zur Frequenzkonvertierung kohärenter optischer Strahlung

EP 1541723
Verfahren zum Schweißen von Werkstücken aus hocharmfesten Superlegierungen

Patents USA

US 8,350,188 B2
Verfahren zur Materialabtragung sowie Vorrichtung zur Durchführung des Verfahrens

US 8,509,941 B2
Method and device for fine positioning of a tool having a handling apparatus

Patents International

2490102
Welding Method and Component

ZL200880100407,4
Verfahren zur Materialabtragung sowie Vorrichtung zur Durchführung des Verfahrens

ZL200880100360,1
Verfahren zur Materialbearbeitung mit Laserstrahlung sowie Vorrichtung zur Durchführung des Verfahrens

Patent Applications Germany

10 2013 000 407.1
Verfahren zur Verbesserung der Benetzbarkeit einer rotierenden Elektrode in einer Gasentladungslampe

10 2013 200 888.0
Auftragschweißen im Bereich von Kanten

10 2013 001 940.0
Strahlungsquellen im Extremen Ultraviolet und weichen Röntgenbereich durch Anregung von Pinchplasmen mit Elektronenstrahlen

10 2013 003 640.2
Verfahren und Vorrichtung zur optischen Messung von Innengeometrien

10 2013 004 371.9
Verfahren und Vorrichtung zur laserunterstützten Bearbeitung mit dynamischer Kompensation feldvarianter lateraler chromatischer Aberration bei der Prozessbeobachtung

10 2013 005 008.1
Verfahren zur Herstellung von Bauteilen aus einem Kohlenstoffnanoröhren enthaltenden Werkstoff

10 2013 005 135.5
Verfahren und Vorrichtung zum Abtragen von sprödhartem, für Laserstrahlung transparentem Material mittels Laserstrahlung

10 2013 005 137.1
Verfahren zum Abtragen von sprödhartem Material mittels Laserstrahlung (Weichzeichen)

10 2013 005 136.3
Verfahren zum Abtragen von sprödhartem Material mittels Laserstrahlung (Brechung)

10 2013 005 139.8
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10 2013 008 085.1
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10 2013 011 675.9
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10 2013 011 676.7
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10 2013 012 730.0
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10 2013 012 956.7
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10 2013 014 069.2
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10 2013 015 429.4
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Vorrichtung zur Thermokoagulation mittels Laserstrahlung

WO PCT/EP 2013/003350
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102128219
Laser Processing Apparatus

201310418771.8
Laser Processing Apparatus

DISSERTATIONS

DIPLOMA THESES

Dissertations

21.01.2013 – A. Temmler
Selektives Laserpolieren für metallische Funktions- und De-signoberflächen

13.03.2013 – A. Richmann
Polieren von Gläsern und Kunststoffen mit CO_2-Laserstrahlung

27.05.2013 – D. Buchbinder
Selective Laser Melting von Aluminiumgusslegierungen

29.05.2013 – S. Jansen
Generative Fertigung von konturnah temperierten Werkzeugen mittels Selective Laser Melting

05.06.2013 – C. Vedder
Hochgeschwindigkeits-Laserfunktionalisierung gedruckter, nanopartikulärer Schichten am Beispiel von Indium-Zinn-Oxid

05.06.2013 – J. Dietrich
Synchrone Qualitäts- und Produktivitätssteigerung beim La-serstrahlbohren

24.06.2013 – A. Boglea
Laser transmission welding for thermoplastics using local laser beam modulation

09.07.2013 – M. Strotkamp
Kompakte, grün emittierende Laser auf Basis von Pr:YLF

12.07.2013 – M. Schäfer
Laserstrukturierung transparenter, elektrisch leitfähiger Schichten für die organische Elektronik

26.08.2013 – Y.-C. Hagedorn
Additive Manufacturing of High Performance Oxide Ceramics via Selective Laser Melting

27.09.2013 – A. Bäuerle
Algorithmen zur Auslegung von Freiformoptiken für die LED-Beleuchtung

22.10.2013 – T. Westphalen
Algorithmen zur automatisierten Justage mikrooptischer Komponenten

25.10.2013 – G. Bergweiler
Verfahrensentwicklung zur lokalen Wärmebehandlung mit Laserstrahlung zur Verbesserung der Umform- und Funkti-onseigenschaften von hochfesten Stählen

16.12.2013 – C. Hartmann
Laserabtrag mit zeitlicher Modulation der Energiedeposition

Diploma Theses

Alkhayat, Moritz
Bestimmung der mechanischen Eigenschaften einer laser auftraggeschweißten, mit feinen TiC-Partikeln verstärkten Inconel 625-Beschichtung

Ambrosius, Norbert
Lasertransfer von Lotpasten

Bürsgens, Gwendal
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Cozub-Poetica, Alexandru-Christian
Resonant diodengepumpte Laserstrahlquellen mit Erbium-dotierten Kristallen bei Emissionswellenlängen um 1,6 µm

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Hördemann, Christian
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Stoyanov, Stoyan
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BACHELOR THESES

Ullmann, Julian
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Wagner, Joachim
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Volker, Michael
Optimierung eines Gas-/Wasserwärmetauschers für Hochleistungs-CO_2-Laser

Bachelor Theses

Boekels, Christian
Entwicklung, Evaluierung und Integration eines Beleuchtungsmoduls zur Prozessüberwachung beim Laserstrahlhartlöten in einen industrietauglichen Bearbeitungskopf

Brück, Daniel
Evaluation von geeigneten Stützen-Geometrien für High-Power SLM Bauteile aus Inconel 718

Deuter, Valerie
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Dickheuer, Sven Oliver
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Dietz, Thomas
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Generative Fertigung einer Turbinenschaufel aus Inconel 718 mittels HP-SLM

Eisenreich, Nathanael
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Ermakova, Galina
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Hollatz, Sören
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Hopfinger, Michael
Experimentelle Untersuchungen zum Polieren von Nickelbasiswerkstoffen mit gepulster Laserstrahlung

Inacker, Patrick
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Khavkin, Evgeniy
Endkonturnahes Laserauftragschweißen einer Kompressorschaufel aus einer Nickelbasis-Superlegierung für ein Flugtriebwerk

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Coherent diffraction imaging with a discharge produced plasma EUV source

Lumberg, Dirk
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Untersuchung zur generativen Fertigung aus Hastelloy X mittels HP-SLM an der SLM280HL

MASTER THESES

Mersch, Jonas
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Mikhaylov, Dmitriy
Konstruktion eines Moduls zur automatischen Vermessung der Laserstrahlparameter in einer SLM-Maschine

Müller, Gideon Philipp
Berechnung optischer Freiformflächen in einer transver-salen Dimension für ausgedehnte Lichtquellen

Müther, Max
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Overkemping, Fabienne
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Thomas Jens Michael
Einfluss der Bearbeitungstiefe auf den Fokus beim ISLE

Tetz, Thomas
Laserbasierte Mikrostrukturierung von Dichtungsflächen einer gasgeschmierten Pumpengleitringdichtung.

Walochnik, Martin
Experimentelle Untersuchungen zur Laserumschmelzstrukturierung von Ti6Al4V

Wierling,
Maximilian Hartwig
Entwicklung eines Fügeverfahrens zur Mnotage eines optischen Isolators

Wolf, Marcel
Thermo-mechanische FE-Analyse eines mit Widerstandslöten aufgebauten optischen Systems

Yalcin, Safak
Entwicklung und Konstruktion einer Absaugvorrichtung zum Laserstrahlbohren

Master Theses

Bey, Nadine
Spektral aufgelöste Strahlqualitätsmessung

Bläsius, Jana
Untersuchung von Diffusionsvorgängen bei der zweiphotoneninduzierten Vernetzung

Caron, Jan
Untersuchung der laserinduzierten Ablationsmechanismen von Hartgewebe unter Wasser

Dai, Tao
Welding analysis of Ni based alloys

Eugen, Michel
Untersuchung des nicht-thermischen Abtrags von Graphit in Abhängigkeit der verwendetetn Wellenlänge ultrakurz gepulster Laserstrahlung

Hartung, Andrea
Untersuchungen zur Machbarkeit eines direkt diodengepumpten Alexandrit-Lasers

Hetzel, Jan Henry
Laserbasierte Herstellung von piezoelektrischen Schichten

Hu, Qi
Modelltheoretische Untersuchung der Fehlstellung mikrooptischer Komponenten für Diodenlaserbarren

Jäger, Akef Gabriel
Modifizierung der fluoreszierenden Eindringprüfung (FPI) mittels UV-Bleichung zur Prüfung von generativ mittels SLM gefertigten Gasturbinenkomponenten

Kunkemoeller, Georg
Herstellung und Charakterisierung von nanooptischen Komponenten mittels EUV-Lithografie

Lange, Lucas Christopher
Untersuchungen zur Strahlungsisolation für Faserlaser

Nolte, Frank
Untersuchungen zum Werkstoffeinfluss beim Laserpolieren mit kontinuierlicher Laserstrahlung

Rittinghaus, SiljaKatharina
Temperaturverteilung und Prozessführung beim SLM mit lokaler Vorheizung

SCIENTIFIC PUBLICATIONS

Schnitzler, Daniel
Wellenleiter in Dielektrika mittels infraroter und grüner fs-Lasereinzel- und -doppelpulse

Stittgen, Tobias
Kamerabasierte Überwachung der Längsbewegung von Tankern beim Be- und Entladen an Öl- und Gasterminals

Tempeler, Jenny
Untersuchung zum Aufbau biomimetischer Strukturen durch Multiphotonenpolymerisation am Beispiel des Flimmerepithels

Valentin, Marc
Grundlagenuntersuchungen zum Laserauftragschweißen von W-Cu- und Mo-Cu-Pseudolegierungen

Weingarten, Christian
Entstehung und Reduzierung der Wasserstoffporosität beim SLM von Aluminiumlegierungen

Aden, M., Otto, G., Duve, C.: *Irradiation strategy for laser transmission welding of thermoplastics using high brilliance laser source. Int. Polymer Processing 28 (3), 300-305 (2013)*

Aden, M., Liviany, F., Olowinsky, A.: *Joint strength for laser transmission welding of thermoplastics: A simulation approach. Int. Polymer Processing 28 (1), 79-83 (2013)*

Becker, M., Werner, M., Fitzau, O., Esser, D., Kobelke, J., Schuster, K., Lorenz, A., Schwuchow, A., Rothhardt, M., Hoffmann, D., Bartelt, H.: *Laser processed preforms for microstructured optical fibers. Proc. SPIE 8785, 8785C9 (8 S.) (2013)*

Becker, M., Werner, M., Fitzau, O., Esser, D., Kobelke, J., Lorenz, A., Schwuchow, A., Rothhardt, M., Schuster, K., Hoffmann, D., Bartelt, H.: *Laser-drilled free-form silica fiber preforms for microstructured optical fibers. Opt. Fiber Technol. 19 (5), 482-485 (2013)*

Berens, M., Bruneton, A., Bäuerle, A., Traub, M., Wester, R., Stollenwerk, J., Loosen, P.: *Multiple intensity distributions from a single optical element. Proc. SPIE. 8834, 88340M (7 S.) (2013)*

Bi, G., Sun, C. N., Gasser, A.: *Study on influential factors for process monitoring and control in laser aided additive manufacturing. J. Mat. Proc. Technol. 213 (3), 463-468 (2013)*

Britten, S., Olowinsky, A. Gillner, A.: *Stress-minimized laser soldering of h-pattern multicrystalline silicon solar cells. Physics Procedia 41, 153-163 (2013)*

Bruneton, A., Bäuerle, A., Wester, R., Stollenwerk, J., Loosen, P.: *High resolution irradiance tailoring using multiple freeform surfaces. Opt. Expr. 21 (9), 10563-10571 (2013)*

Bruneton, A., Bäuerle, A., Wester, R., Stollenwerk, J., Loosen, P.: *Limitations of the ray mapping approach in freeform optics design. Opt. Lett. 38 (11), 1945-1947 (2013)*

Buchbinder, D., Meiners, W., Hinke, C., Merkt, S.: *Generative Fertigung mit Selective Laser Melting auf dem Weg zur Serienproduktion? DVS Congress 2013. Düsseldorf: DVS-Media 2013. DVS-Berichte Bd. 296. ISBN 978-3-87155-614-2. 5 S.*

Büsing, L., Bonhoff, T., Gottmann, J., Loosen, P.: *Deformation of ultrashort laser pulses by optical systems for laser scanners. Opt. Expr. 21 (21), 24475-24482 (2013)*

Carstens, H., Holzberger, S., Kaster, J., Weitenberg, J., Pervak, V., Apolonski, A., Fill, E., Krausz, F., Pupeza, I.: *Large-mode enhancement cavities. Opt. Expr. 21 (9), 11606-11617 (2013)*

Chen, X., Yagi, M., Akiyama, Y., Machida, O., Ohta, E., Meixner, M.: *Stollenwerk, J., Boettger, U., Schneller, T. : Fabrication of multilayer Pb(Zr0.53Ti0.47)O3 film crystallized by laser annealing. Jap. J. Appl. Phys. 52, 09KA06 (4 S.) (2013)*

Crump, P., Knigge, S., Maaßdorf, A., Bugge, F., Hengsbach, S., Witte, U., Hoffmann, H. D., Köhler, B., Hubrich, R., Kissel, H., Biesenbach, J., Erbert, G., Tränkle, G.: *Low-loss, smile-insensitive external frequency-stabilization of high power diode lasers enabled by vertical designs with extremely low divergence angle and high efficiency. Proc. SPIE 8605, 0T1 (13 S.) (2013)*

Danylyuk, S., Kim, H., Brose, S., Dittberner, C., Loosen, P., Taubner, T., Bergmann, K., Juschkin, L.: *Diffraction-assisted extreme ultraviolet proximity lithography for fabrication of nanophotonic arrays. J. Vac. Sci. Technol. B 31(2), 21602/1-21602/6 (2013)*

Danylyuk, S., Loosen, P., Bergmann, K., Kim, H., Juschkin, L.: *Scalability limits of Talbot lithography with plasma-based extreme ultraviolet sources. J. Micro/Nanolith. MEMS MOEMS 12, 033002 (7 S.) (2013)*

Esser, D., Weitenberg, J., Bröring, W., Pupeza, I., Holzberger, S., Hoffmann, H.-D.: *Laser-manufactured mirrors for geometrical output coupling of intracavity-generated high harmonics. Opt. Expr. 21 (22), 26797-26805 (2013)*

Finger, J., Weinand, M., Wortmann, D.: *Ablation and cutting of carbon-fiber reinforced plastics using picosecond pulsed laser radiation with high average power. J. Laser Appl. 25 (4), 042007-1 (5 S.) (2013)*

Finger, J., Weinand, M., Wortmann, D.: *Investigations on processing of carbon fiber reinforced plastics using ultrashort pulsed laser radiation with high average power. ICALEO, 32th International Congress on Applications of Lasers & Electro-Optics: October 6-10, 2013, Miami/Fl., USA. Orlando/Fl.: LIA (2013). Paper 1905 (6 S.)*

Finger, J., Reininghaus, M., Wortmann, D., Cao, Z., Taubner, T.: *Laser fabricated nanoantennas for near-field applications. ICALEO, 32th International Congress on Applications of Lasers & Electro-Optics: October 6-10, 2013, Miami/Fl., USA. Orlando/Fl.: LIA (2013). N302 (5 S.)*

Flemmer, J., Pirch, N., Witzel, J., Gasser, A., Wissenbach, K., Kelbassa, I.: *LACAM3D, CAM solution for tool path generation for build up of complex aerospace components by laser powder deposition. Proceedings of the 37th International MATADOR Conference. Eds.: S. Hinduja, L. Li. London [u.a.]: Springer (2013). ISBN 978-1-4471-4479-3. pp. 61-64*

Fornaroli, C., Holtkamp, J., Gillner, A.: *Dicing of thin Si wafers with a picosecond laser ablation process. Physics Procedia 41, 603-609 (2013)*

Göttmann, A., Bailly, D., Bergweiler, G., Bambach, M., Stollenwerk, J., Hirt, G., Loosen, P.: *A novel approach for temperature control in ISF supported by laser and resistance heating. Int. J. Adv. Manuf. Technol. 67, 2195-2205 (2013)*

Gottmann, J., Hermans, M., Ortmann, J.: *Digital photonic production of 3D micro fluidics in glass by high speed micro scanner. MATEC Web of Conferences 8, 05003 (2 S.), (2013)*

Gottmann, J., Hermans, M., Ortmann, J.: *Microcutting and hollow 3D microstructures in glasses by In-volume Selective Laser-induced Etching (ISLE).
J. Laser Micro/Nanoeng. 8 (1), 15-18 (2013)*

Hagedorn, Y.-C., Risse, J., Meiners, W., Pirch, N., Wissenbach, K.: *Processing of nickel based superalloy MAR M-247 by means of High-Temperature Selective Laser Melting (HT-SLT). In: High Value Manufacturing. Eds.: P. J. Bartolo et. al. Boca Raton: CRC Pr. (2013). ISBN 978-1-138-00137-4. pp. 291-295*

Hartmann, C., Hambach, N., Jüngst, M., Keller, S., Holtkamp, J., Gillner, A.: *High density perforation of thin Al-foils with ultra short pulse lasers. J. Laser Micro/Nanoeng. 8 (3), 266-270 (2013)*

Hartmann, C., Hambach, N., Jüngst, M., Keller, S., Holtkamp, J., Gillner, A.: *High density perforation of thin Al-foils with ultra short pulse lasers. Proc. of LAMP2013 - the 6th Int. Congr. on Laser Advanced Materials Processing. Washington, D.C.: The Catholic Univ. of America (2013). 4 S.*

Hauschild, D., Kumstel, J., Willenborg, E.: *Produktivität bei der Laserpolitur deutlich steigern. WT-Online 103 (11/12), 1-5 (2013)*

Hawelka, D., Stollenwerk, J., Pirch, N., Wissenbach, K., Loosen, P.: *Improving surface properties by laser-based drying, gelation, and densification of printed sol-gel coatings. J. Coat. Technol. Res. 10 (8 S.) doi 10.1007/s11998-013-9516-0 (2013)*

Heidrich, S.: *Fast freeform processing. Mikroniek 53, (3), 48-50 (2013)*

Heidrich, S., Richmann, A., Willenborg, E.: *Laser-based optics manufacturing. 3rd EOS Conference on Manufacturing of Optical Components (EOSMOC 2013). International Congress Centre Munich (ICM), Germany, 13 May 2013 - 15 May 2013. (2013). 2 S.*

Hengesbach, S., Witte, U., Traub, M., Hoffmann, D.: *Design of a DFB/DBR diode laser module including spectral multiplexing based on VBGs. High Power Diode Lasers and Systems Conference (HPD), 2013. West Midlands, United Kingdom, 16-17 Oct. 2013. Piscataway, N.J.: IEEE 2013. pp. 16-17. ISBN: 978-1-4799-2747-0. doi 10.1109/HPD.2013.6706596*

Hengesbach, S., Krauch, N., Holly, C., Traub, M., Witte, U., Hoffmann, D.: *High-power dense wavelength division multiplexing of multimode diode laser radiation based on volume Bragg gratings. Opt. Lett. 38, 3154-3157 (2013)*

Hilzensauer, S., Gilly, J., Friedmann, P., Werner, M., Traub, M., Patterson, S., Neukum, J., Kelemen, M. T.: *High-power diode lasers between 1.8 µm and 3.0 µm. Proc. SPIE 8640, 86401P (10 S.) (2013) Hinke, Christian: Digital photonic production and its emerging opportunities. LIA Today 2013, 14-16 (2013)*

Holly, C., Hengesbach, S., Traub, M., Hoffmann, D.: *Simulation of spectral stabilization of high-power broad-area edge emitting semiconductor lasers. Opt. Expr. 21, 15553-15567 (2013)*

Holters, M., Loosen, P.: *Selbstoptimierende Montage von Lasern unter Berücksichtigung von Bauteiltoleranzen. DGaO-Proceedings 114, 36 (2 S.) (2013)*

Hong, C., Gu, D., Dai, D., Gasser, A., Weisheit, A., Kelbassa, I., Zhong, M., Poprawe, R.: *Laser metal deposition of TiC/Inconel 718 composites with tailored interfacial microstructures. Opt. Laser Technol. 54, 98-109 (2013)*

Ivanov, D. S., Kuznetsov, A.I., Lipp, V. P., Rethfeld, B., Chichkov, B. N., Garcia, M. E., Schulz, W.: *Short laser pulse nanostructuring of metals: direct comparison of molecular dynamics modeling and experiment. Appl. Phys. A, 111 (3), 675-687 (2013)*

Janssen, S., Uchtmann, H., Kelbassa, I.: *Determination of the bore hole diameter by analyzing process emissions. ICALEO, 32th International Congress on Applications of Lasers & Electro-Optics: October 6-10, 2013, Miami/Fl., USA. Orlando/Fl.: LIA (2013). Paper 701 (9 S.)*

Kelbassa, I., Gasser, A., Meiners, W., Backes, G., Müller, B.: *High speed LAM. Proceedings of the 37th International MATADOR Conference. Eds.: S. Hinduja, L. Li. London [u.a.]: Springer (2013). ISBN 978-1-4471-4479-3. 5 S.*

Kumstel, J., Kirsch, B.: *Polishing titanium- and nickel-based alloys using cw-laser radiation. Physics Procedia 41, 355-364 (2013)*

Larsen, C., Giesberts, M., Nyga, S., Fitzau, O., Jungbluth, B., Hoffmann, H. D., Bang, O.: *Gain-switched all-fiber laser with narrow bandwidth. Opt. Expr. 21 (10), 12302-12308 (2013)*

Li, J., Yang, S. H., Meissner, A., Hofer, M., Hoffmann, D.: *A 200 W Innoslab Tm:YLF laser. Laser Phys. Lett. 10 (5), 55002 (5 S.) (2013)*

Liu, J., Dahmen, M., Ventzke, V., Kashaev, N., Poprawe, R.: *The effect of heat treatment on crack control and grain refinement in laser beam welded β-solidifying TiAl-based alloy. Intermetallics 40, 65-70 (2013)*

Maischner, D., Barz, J., Weisheit, A., Backes, G.: *Gut gerüstet für langen Einsatz. Form + Werkzeug 2013 (1), 25-27 (2013)*

Mehlmann, B., Olowinsky, A., Thuilot, M., Gillner, A.: *Spatially modulated laser beam micro welding of CuSn6 and nickel-plated DC04 steel for battery applications. Proc. of Lamp2013 - the 6th Int. Congr. on Laser Advanced Materials Processing. Washington, D.C.: The Catholic Univ. of America (2013). 7 S.*

Meineke, G., Flitsch, D., Lenenbach, A., Noll, R.: *Fluorescence sensors for parallel measurements in multichannel microfluidic devices covering the full channel cross sections. Proc. SPIE 8615, 86151C-1 (7 S.) (2013)*

Meissner, A., Kucirek, P., Li, J., Hoefer, M., Hoffmann, D.: *Simulations and experiments on resonantly-pumped single-frequency Erbium lasers at 1.6 µm. Proc. SPIE 8599, H1-8 (8 S.) (2013)*

Meissner, A., Li, J., Lopez-Perez, I., Yang, S., Hoefer, M., Hoffmann, D.: *200-W Tm:YLF INNOSLAB laser. Proc. SPIE 8599, C1 (7 S.) (2013)*

Merkt, S., Hinke, C., Dalaee, M., Salminen, A., Purtonen, T., Bültmann, J.: *Compressive behavior of lattice structures in solid shells manufactured by SLM. 14th NOLAMP Conference, Gothenburg, Sweden, August 26th - 28th, 2013. Ed.: A. Kaplan [u.a.]. Lulea: Univ. of Technology (2013). pp. 91-100. ISBN: 978-91-7439-688-1 (Print), 978-91-7439-689-8 (Pdf)*

Mingareev, I., Bonhoff, T., El-Sherif, A. F., Meiners, W., Kelbassa, I., Biermann, T., Richardson, M.: *Femtosecond laser post-processing of metal parts produced by laser additive manufacturing. J. Laser Appl. 25 (5), 052009 (4 S.) (2013)*

Nastasi, G., Wester, R., Colla, V., Noll, R.: *Determining inclusion size distributions from OES/PDA data. Metallurgical analysis/Yejin-fenxi: shuangyuekan (3), 9-13 (2013)*

Noll, R., Hölters, S., Kämmerling, J., Lenenbach, A.: *Präzision bei 210 km/h - Laserabstandssensoren messen die Dicke von Walzbändern. QZ 58 (10), 44-47 (2013)*

Nüsser, C., Sändker, H., Willenborg, E.: *Pulsed laser micro polishing of metals using dual-beam technology. Physics Procedia 41, 346-355 (2013)*

Oezmert, A., Drenker, A., Nazery, V.: *Detectability of penetration based on weld pool geometry and process emission spectrum in laser welding of copper. Physics Procedia 41, 502-507 (2013)*

Papadakis, L., Loizou, A., Risse, J., Bremen, S., Schrage, J.: *A thermo-mechanical modeling reduction approach for calculating shape distortion in SLM manufacturing for aero engine components. In: High Value Manufacturing. Eds.: P. J. Bartolo et. al. Boca Raton: CRC Pr.(2013). ISBN 978-1-138-00137-4. pp. 613-618*

Petring, D.: *Developments in hybridisation and combined laser beam welding technologies. In: Handbook of laser welding technologies. Ed. by S. Katayama. Oxford [u.a.]: WP Woodhead Publ. (2013). (Woodhead Publishing Series in Electronic and Optical Materials. Nr. 41). ISBN 978-0857092649. pp. 478-504*

Pirch, N., Keutgen, S., Gasser, A., Wissenbach, K., Kelbassa, I.: *Modeling of coaxial single and overlap-pass cladding with laser radiation. Proceedings of the 37th International MATADOR Conference. Eds.: S. Hinduja, L. Li. London [u.a.]: Springer (2013). ISBN 978-1-4471-4479-3. pp. 377-380*

Pütsch, O., Temmler, A., Stollenwerk, J., Willenborg, E., Loosen, P.: *Active optical system for laser structuring of 3D surfaces remelting. Laser Beam Shaping XIV. Ed.: Andrew Forbes, Todd E. Lizotte. Proc. SPIE 8843, 88430D (8 S.) (2013)*

Pütsch, O., Bahrenberg, L., Loosen, P.: *Opto-mechatronisches System zur Erzeugung prozessangepasster Intensitätsverteilungen für die Lasermaterialbearbeitung. Fachtagung Mechatronik 2013. Aachen, 06.03. - 08.03.2013. Aachen: RWTH (2013). ISBN 3-86130-958-0. 9 S.*

Pupeza, I., Holzberger, S., Eidam, T., Esser, D., Weitenberg, J., Rußbüldt, P., Rauschenberger, J., Limpert, J., Udem, Th., Tünnermann, A., Hänsch, T. W., Apolonski, A., Krausz, F., Fill, E.: *Compact high-repetition-rate source of coherent 100 eV radiation. Nature Photonics 7 (8), 608-612 (2013)*

Reinhard, R., Al Khawli, T., Eppelt, U., Meisen, T., Schilberg, D., Schulz, W., Jeschke, S.: *The contribution of virtual production intelligence to laser cutting planning processes. In: Enabling Manufacturing Competitiveness and Economic Sustainability. Proceedings of the 5th International Conference on Changeable, Agile, Reconfigurable and Virtual production (CARV2013). October 6th - 9th 2013, Munich. Heidelberg [u.a.]: Springer 2013. ISBN 978-3319020532. pp. 117-124*

Reinhard, R., Eppelt, U., Al-Khawly, T., Meisen, T., Schilberg, D., Schulz, W., Jeschke, S.: *How virtual production intelligence can improve laser-cutting planning processes. 22nd International Conference on Production Research, ICPR 2013. July 28th - August 1st, 2013, Iguassu Falls, Brazil. Iguassu Falls: Int. Found. for Production Research (IFPR) [u.a.] 2013. 7 S. CD-ROM : ISBN 978-85-88478-47-3*

Reininghaus, M., Wortmann, D., Cao, Z., Hoffmann, J. M., Taubner, T.: *Fabrication and spectral tuning of standing gold infrared antennas using single fs-laser pulses. Opt. Expr. 21 (26), 32176-32183 (2013)*

Reininghaus, M., Wortmann, D., Cao, Z., Taubner, T.: *fs-laser fabricated gold antennas for infrared near-field enhancement. Proceedings of LAMP2013 – the 6th International Congress on Laser Advanced Materials Processing. Washington, D.C.: The Catholic Univ. of America (2013). 5 S. (2013)*

Risse, J., Golebiewski, C., Meiners, W., Wissenbach, K.: *Einfluss der Prozessführung auf die Rissbildung in mittels SLM hergestellten Bauteilen aus der Nickelbasislegierung IN738LC. Tagungsband der Fachmesse und Anwendertagung für Rapid-Technologie. Erfurt : Desotron Verl. Ges. (2013). ISBN 978-3-932875-35-9.7 S.*

Rösner, A.: *Der Laser verbindet Kunststoffe mit metallischen Bauteilen. MM Maschinenmarkt Nr. 18, 36-38 (2013)*

Rösner, A., Olowinsky, A.: *Laser welding of polymers. Ind. Laser Sol. 28 (1), 29-31 (2013)*

Russ, S., Siebert, C., Eppelt, U., Hartmann, C., Faißt, B., Schulz, W.: *Picosecond laser ablation of transparent materials. Proc. SPIE 8608, 86080E-1 (11 S.) (2013)*

Sandner, T., Kimme, S., Grasshoff, T., Todt, U., Graf, A., Tulea, C., Lenenbach, A., Schenk, H.: *Micro-scanning mirrors for high-power laser applications in laser surgery. Int. Conf. on Optical MEMS and Nanophotonics 2013. August 18-22, 2013, Kanazawa, Japan. Piscataway, N.J.: IEEE (2013). ISBN 978-1-4799-1512-5. pp.83-84*

Schaefer, D., Schnitzler, D., Kelbassa, I.: *Fundamental processes of refractive index modifications during femtosecond laser waveguide writing. Proc. SPIE 8613, X1 (7 S.) (2013)*

Schaefer, D., Gottmann, J., Hermans, M., Ortmann, J., Kelbassa, I.: *High speed micro scanner for 3D in-volume laser micro-processing. Proc. SPIE 8608, 860808 (6 S.) (2013)*

Scharun, M., Noll, R.: *Analyse von Sekundärrohstoffen durch mikrowellenunterstützte Laser-Emissionsspektroskopie. In: Innovative Technologien für Ressourceneffizienz in rohstoffintensiven Produktionsprozessen. Hrsg.: J. Woidasky [u.a.]. Stuttgart: Fraunhofer Verl. (2013). pp. 38-51*

Scharun, M., Fricke-Begemann, C., Noll, R.: *Laser-induced breakdown spectroscopy with multi-kHz fibre laser for mobile metal analysis tasks - a comparison of different analysis methods and with a mobile spark-discharge optical emission spectroscopy apparatus. Spectrochim. Acta, Part B: Atomic Spectrosc. 87, 198-207 (2013)*

Schneider, F., Wolf, N., Petring, D.: *High power laser cutting of fiber reinforced thermoplastic polymers with cw- and pulsed lasers. Physics Procedia 41, 408-413 (2013)*

Schniedenharn, M., Belting, M., Santos Batista, R. J., Meiners, W., Weisheit, A.: *Micro scale laser based additive manufacturing for metals. ICALEO, 32th International Congress on Applications of Lasers & Electro-Optics: October 6-10, 2013, Miami/Fl., USA. Orlando/Fl.: LIA (2013). M101 (6 S.)*

Schwarz, T., Berens, M., Gronenborn, S., Kolb, J., Loosen, P., Miller, M., Mönch, H., Wester, R.: *Analysis of single-mode efficiency of electrically pumped VECSELs. Proc. SPIE 8606, 86060 H (10 S.) (2013)*

Scotti, G., Trusheim, D., Kanninen, P., Naumenko, D., Schulz-Ruhtenberg, M., Snitka, V., Kallio, T., Franssila, S.: *Picosecond laser ablation for silicon micro fuel cell fabrication. J. Micromech. Microeng. 23, 055021 (14 S.) (2013)*

Seiler, N., Leonhäuser, D., Bongard, Y., Bremus-Köbberling, E., Gillner A.: *Local ultraviolet laser irradiation for gradients on biocompatible polymer surfaces. J. Biomed. Mat. Res. A, online first (2013)*

Shah, L., Bonhoff, T., El-Sherif, A., Kadwani, P., Gebhardt, M., Gaida, C., Mingareev, I., Richardson, M.: *Backside surface machining of silicon wafers using a nanosecond Tm:fiber MOPA System. CLEO 2013, June 9 - 14, San Jose, Calif. (2013). 2 S.*

Shah, L., Bonhoff, T., Ferhat, T., El-Sherif, A. F., Ramme, M., Willis, C. C. C., Baudelet, M., Kadwani, P., Gaida, C., Gebhardt, M., Mingareev, I., Richardson, M.: *Silicon backside machining using a nanosecond 2 μm Tm:fiber laser. Proc. SPIE 8612, 861207 (6 S.) (2013)*

Steger, M., Hartmann, C., Beckemper, S., Holtkamp, J., Gillner, A.: *Fabrication of hierarchical structures by direct laser writing and multi-beam-interference. J. Laser Micro/Nanoeng. 8 (3), 210-215 (2013)*

Steger, M., Hartmann, C., Beckemper, S., Holtkamp, J., Gillner, A.: *Fabrication of hierarchical structures by direct laser writing and multi-beam-interference. Proc. of LAMP2013 – the 6th International Congress on Laser Advanced Materials Processing. Washington, D.C.: The Catholic Univ. of America (2013). 6 S. (2013)*

Stollenwerk, J.: *Energie- und ressourceneffiziente Funktionalisierung temperaturempfindlicher Substrate. Laser Mag. 2013, 8-9 (2013)*

Strotkamp, M., Munk, A., Jungbluth, B., Dahlhoff, K., Jansen, P., Broch, S., Gomm, S., Bachner, M., Fuchs, H., Holland, Hofzumahaus, A.: *Design of a rugged 308 nm tunable UV laser for airborne LIF measurements on top of Zeppelin NT. Proc. SPIE 8599, L1 (10 S.) (2013)*

Sun, M., Eppelt, U., Russ, S., Hartmann, C., Siebert, C., Zhu, J., Schulz, W.: *Numerical analysis of laser ablation and damage in glass with multiple picosecond laser pulses. Opt. Expr. 21 (7), 7858-7867 (2013)*

Sun, M., Eppelt, U., Schulz, W., Zhu, J.: *Role of thermal ionization in internal modification of bulk borosilicate glass with picosecond laser pulses at high repetition rates. Opt. Mat. Expr. 3 (10), 1716-1726 (2013)*

Thombansen, U., Purrio, M., Buchholz, G., Hermanns, T., Molitor, T., Willms, K., Schulz, W., Reisgen, U.: *Measurement of process variables in melt based manufacturing processes. ISMTII 2013 - The 11th International Symposium on Measurement Technology and Intelligent Instruments. Aachen /Braunschweig July 1st-5th 2013. (Hrsg.:) Robert Schmitt, Harald Bosse. Aachen: Apprimus Verl. 2013. ISBN: 978-3-86359-138-0. (6 S.)*

Thombansen, U., Diatlov, A.: *Sensor system for spatially resolved observation of the melt pool in Selective Laser Melting. ICALEO, 32th International Congress on Applications of Lasers & Electro-Optics: October 6-10, 2013, Miami/Fl., USA. Orlando: Fl.: LIA (2013). 31 S.*

Tulea, C., Caron, J., Wahab, H., Gehlich, N., Hoefer, M., Esser, D., Jungbluth, B., Lenenbach, A., Noll, R.: *Highly efficient nonthemal ablation of bone under bulk water with a frequency-doubled Nd:YVO4 picosecond laser. Proc. SPIE 8565, 85656 E-1 (11 S.) (2013)*

Uchtmann, H., Kelbassa, I.: *Cax process chain for laser drilling of tool molds. ICALEO, 32th International Congress on Applications of Lasers & Electro-Optics: October 6-10, 2013, Miami/Fl., USA. Orlando/Fl.: LIA (2013). Paper 702*

Unger, A., Brand, T., Bull, S., Larkins, E. C., Traub, M., Hengesbach, S., Uusimaa, P., Vilokkinen, V., Crump, P., Erbert, G., Luclas-Leclin, G., Georges, P., Rataj, T., Deichsel, E.: *The Bridle project: High brilliance diode lasers for industrial applications. High Power Diode Lasers and Systems Conference (HPD), 2013. West Midlands, United Kingdom,16-17 Oct. 2013. Piscataway, N.J.: IEEE 2013. pp. 28-29. ISBN: 978-1-4799-2747-0. doi 10.1109/HPD.2013.6706602*

Vossen, G., Hermanns, T., Schüttler, J.: *Analysis and optimal control for free melt flow boundaries in laser cutting with distributed radiation. ZAMM Zs. Angew. Math. Mech. (Early view) 20 S. (2013)*

Weisheit, A., Gasser, A., Backes, G., Jambor, T., Pirch, N., Wissenbach, K.: *Direct laser cladding, current status and future scope of application. In: Laser-assisted fabrication of materials. Ed.: J. D. Majumdar, I. Manna. Heidelberg [u.a.]: Springer (2013). Springer Series in Materials Science. Vol. 161. ISBN 978-3-642-28358-1. pp. 221-239*

Weisheit, A., Dobrzanski, D., Valentin, M., Ocylok, S., Wissenbach, K., Kelbassa, I.: *Laser additive manufacturing – a new manufacturing technology for parts of composites with refractory metals? 18. Plansee-Seminar 2013. Int. Conf. on Refractory Metals and Hard Materials. Reutte, Austria. Reutte: Plansee SE (2013). RM 39. pp. 1-12*

Wester, R., Bruneton, A., Bäuerle, A., Stollenwerk, J., Loosen, P.: *Irradiance tailoring for extended sources using a point-source freeform design algorithm. Proc. SPIE 8550, 8 S. (2012)*

Wester, R., Bäuerle, A.: *Light shaping for illumination. Adv. Opt. Technol. 2 (4), 301-311 (2013)*

Wester, R.: *Physical optics methods for laser and non-linear optics simulations. Adv. Optical Technol. 2 (3), 247-255 (2013)*

Wilkes, J., Hagedorn, Y.-C., Meiners, W., Wissenbach, K.: *Additive manufacturing of ZrO2-Al2O3 ceramic components by selective laser melting. Rapid Prototyping J. 19 (1), 51-57 (2013)*

Willenborg, E., Ross, I., Kumstel, J., Flemmer, J.: *Werkzeugmaschine für das Laserpolieren. wt Werkstattstechnik online 103, (6), 465-469 (2013)*

LECTURES

__Wissinger, A., Olowinsky, A., Gillner, A., Poprawe, R.:__ Laser transmission bonding of silicon to silicon with metallic interlayers for wafer-level packaging. Microsyst. Technol. 19 (5), 669-673 (2013)

__Witte, U., Hengesbach, S., Traub, M., Strotkamp, M., Jungbluth, B., Hoffmann, D.:__ High brightness diode laser module in the red spectral range for pumping applications. High Power Diode Lasers and Systems Conference (HPD), 2013. West Midlands, United Kingdom,16-17 Oct. 2013. Piscataway, N.J.: IEEE 2013. pp. 30-31. ISBN: 978-1-4799-2747-0. doi 10.1109/HPD.2013.6706603

__Zhu, P., Li, D., Liu, Q., Chen, J., Fu, S., Shi, P., Du, K., Loosen, P.:__ 39.1 µJ picosecond ultraviolet pulses at 355 nm with 1 MHz repeat rate. Opt. Lett. 38 (22), 4716-4718 (2013)

__Zhuang, F., Jungbluth, B., Gronloh, B., Hoffmann, H.-D., Zhang, G.:__ Dual-wavelength, continuous-wave Yb:YAG laser for high-resolution photothermal common-path interferometry. Appl. Opt. 52 (21), 5171-5177 (2013)

__Zibner, F., Ryll, J., Holtkamp, J., Gillner, A.:__ High precision 2.5D laser cutting of thin nitinol and polyurethane for medical applications. ICALEO, 32th International Congress on Applications of Lasers & Electro-Optics: October 6-10, 2013, Miami/Fl., USA. Orlando/Fl.: LIA (2013). M4154 (6 S.)

__02.02.2013 - C. Tulea:__ Highly efficient nonthermal ablation of bone under bulk water with a frequency-doubled Nd:YVO4 picosecond laser, Photonics West, San Francisco, CA, USA

__03.02.2013 - M. Strotkamp:__ Design of a rugged 308 nm tunable UV laser for airborne LIF measurements on top of a zeppelin, Photonics West, San Francisco, CA, USA

__03.02.2013 - A. Meissner:__ Simulations and experiments on resonantly-pumped single-frequency Erbium lasers at 1.6 µm, Photonics West, San Francisco, CA, USA

__04.02.2013 - A. Meissner:__ 200-W Tm:YLF INNOSLAB Laser, Photonics West, San Francisco, CA, USA

__05.02.2013 - F. Schneider:__ Laserschneiden von faserverstärkten Kunststoffen, 2. Leichtbautagung - Lasertechnik im Leichtbau, Dresden

__06.02.2013 - A. Roesner:__ Laserfügen von reinen und faserverstärkten Polymeren, 2. Leichtbautagung - Lasertechnik im Leichtbau, Dresden

__06.02.2013 - M. Dahmen:__ Laserschweißen schwer schweißbarer metallischer Leichtbauwerkstoffe, 2. Leichtbautagung - Lasertechnik im Leichtbau, Dresden

__06.02.2013 - J. Gottmann:__ Fundamental processes of refractive index modifications during femtosecond laser waveguide writing, Photonics West, San Francisco, CA, USA

__12.02.2013 - C. Hinke:__ Digital Photonic Production and its emerging opportunities, LIA's 6th annual Laser Additive Manufacturing Workshop LAM, Houston, TX, USA

__08.03.2013 - O. Pütsch:__ Opto-mechanisches System zur Erzeugung prozessangepasster Intensitätsverteilungen für die Lasermaterialbearbeitung, Fachtagung Mechatronik 2013, Aachen

***13.02.2013 - S. Hoelters:** Optical coherence tomography for the inline measurement of translucent multilayer structures, Research Center for Non-Destructive Testing GmbH, Linz, Österreich*

***19.02.2013 - R. Poprawe:** Laser technology as a key enabler for solutions of the future societal challenges, Mobility Automotice Circle International, Bad Nauheim*

***21.02.2013 - A. Gasser:** Additive manufacturing in turbo-engine applications, 3rd International Conference on Turbomachinery Manufacturing, Aachen*

***26.02.2013 - I. Kelbassa:** High-speed laser additive manufacturing, 2nd International Conference on Net Shape Manufacturing, Monash University, Victoria, Australien*

***27.02.2013 - D. Hoffmann:** The Innoslab Laser Platform - ns to fs pulse duration at kW class output power, DPG Symposium Aktuelle Entwicklungen von Hochleistungslasern und deren Anwendungen, Jena*

***05.03.2013 - M. Scharun:** Mobile Laser-Direktanalyse, 20. Anwendertreffen Röntgenfluoreszenz- und Funkenemissionsspektrometrie, Steinfurt*

***06.03.2013 - R. Poprawe:** Die Zukunft von Forschung und Innovation "Wissen, wo Wissen entsteht", Vortrag Trumpf Einweihung, Schramberg*

***08.03.2013 - S. Bremen:** Selective Laser Melting (SLM) am Fraunhofer ILT - Ein generatives Fertigungsverfahren für die Produktion der Zukunft, Metall 2013, München*

***12.03.2013 - D. Petring:** Still some secrets to be disclosed about laser beam cutting, ILAS - The International Laser Applications Symposium, Nottingham, England*

***12.03.2013 - R. Poprawe:** State of the art laser applications in support of manufacturing industry, ILAS, Nottingham, England*

***19.03.2013 - D. Hoffmann:** INNOSLAB Laser, Laserstammtisch, FH Mittweida*

***19.03.2013 - R. Poprawe:** LAM – Laser Additive Manufacturing, World of Photonics China, Shanghai, China*

***21.03.2013 - R. Poprawe:** Digital Photonic Production "Ultrafast Lasers – Technologies and Applications", Fertigungstechnisches Seminar der ETH Zürich, Schweiz*

***21.03.2013 - D. Maischner:** Verbindungsschweißen und Laserauftragschweißen von Kupferwerkstoffen mittels Lasertechnik, Seminar Fügen von Kupferwerkstoffen, Duisburg*

***21.03.2010 - X. Yin:** Plasmonic collimation for laser diodes, DPG Tagung, Regensburg*

***11.04.2013 - A. Olowinsky:** Innovatives Verfahren für das Packaging großer Glassubstrate – laserstrahlbasiertes Glaslöten, Forum MicroTechnology – Innovations for Industry, Hannovermesse*

***16.04.2013 - Y. Hagedorn:** Advancements in SLM of structural ceramics, Sirris-Keramiksymposium Liège, Belgien – Journée thématique - High-end applications for Additive Manufacturing?*

***17.04.2013 - A. Gillner:** Ultrakurzpulslaser am Fraunhofer ILT – Laser, Prozesse und Systeme, 2. Aachener Ultrakurzpuls-Workshop, Aachen*

***18.04.2013 - J. Gottmann:** Digital Photonics Production of 3D microfluidics in glass by high speed microscanner, Progress in Ultrafast Laser Modifications of Materials, Cargese, Frankreich*

***18.04.2013 - P. Loosen:** Strahlführung und -formung von UKP-Laserstrahlung, UKP-Workshop, ENERGETICON Alsdorf*

23.04.2013 - R. Poprawe: *Latest trends in Laser Additive Manufacturing – Paradigm shift in production technology: "Digital Photonic Production"*

24.04.2013 - S. Merkt: *Digital Photonic Production - Optimization potentials by laser based manufacturing, 2013 Altair Technology Conference, Turin, Italien*

29.04.2013 - R. Poprawe: *Future laser applications and related innovation processes EPIC, Brüssel, Belgien*

12.05.2013 - S. Hengesbach: *High-Power dense wavelength division multiplexer (HP-DWDM) for diode lasers using volume bragg gratings (VBG), CLEO/Europe 2013, München*

12.05.2013 - M. Werner: *Inverse laser drilling of transparent materials for the production of optical components, CLEO/Europe 2013, München*

13.05.2013 - S. Heidrich: *Laser-based optics manufacturing, EOSMOC 2013 – 3rd EOS Conference on Manufacturing of Optical Components, München*

13.05.2013 - W. Schulz: *Towards high-quality laser cutting of glass, LASER World of PHOTONICS, München*

13.05.2013 - M. Schulz-Ruhtenberg: *New prospects for laser processes in future PV systems, LASER World of PHOTONICS 2013, München*

14.05.2013 - V. Mamuschkin: *Laser transmission welding of white thermoplastics with adapted wavelengths, Lasers in Manufacturing – LiM 2013, München*

14.05.2013 - W. Meiners: *Laser-basierte Generative Fertigung, Verfahrensprinzipien und Anwendungsbeispiele, LASER World of PHOTONICS, München*

14.05.2013 - J. Risse: *Influence of process management on crack formation in nickel-based alloy parts (IN738LC) manufactured by SLM, Rapid.Tech, Erfurt*

15.05.2013 - A. Roesner: *Long term stability of laser joined plastic metal parts, Lasers in Manufacturing – LiM 2013, München*

15.05.2013 - A. Özmert: *Approaches for quality assurance and dual-wavelength processing for laser welding of copper, Lasers in Manufacturing – LiM 2013, München*

15.05.2013 - S. Britten: *Stress-minimized laser soldering of h-pattern multicrystalline silicon solar cells, Lasers in Manufacturing – LiM 2013, München*

15.05.2013 - M. Ungers: *Hardware based analysis and process control for laser brazing applications, Lasers in Manufacturing – LiM 2013, München*

16.05.2013 - S. Eifel: *Laser process acceleration using beam splitting and fast scanning techniques, LASER World of PHOTONICS 2013, München*

16.05.2013 - J. Kumstel: *Laser polishing of titanium- and nickel-based alloys using cw-laser radiation, Lasers in Manufacturing – LiM 2013, München*

16.05.2013 - C. Nüsser: *Pulsed laser micro polishing of metals using dual-beam-technology, Lasers in Manufacturing – LiM 2013, München*

16.05.2013 - F. Schneider: *High power laser cutting of fiber reinforced thermoplastic polymers with cw- and pulsed lasers, Lasers in Manufacturing – LiM 2013, München*

20.05.2013 - W. Schulz: *Towards high-quality laser ablation of glass, SPIE Konferenz Shanghai IIME Industrial Machining HCMC*

***24.05.2013 - R. Poprawe:** Das Fraunhofer ILT, Baden-Badener Unternehmergespräche*

***25.05.2013 - M. Holters:** Selbstoptimierende Montage von Lasern unter Berücksichtigung von Bauteiltoleranzen, 114. Jahrestagung der DGaO, Braunschweig*

***01.06.2013 - N. Seiler:** ArtiVasc 3D – Artificial vascularized scaffolds for 3D tissue regeneration, 54. Österreichischer Chirurgenkongress 2013, Wien*

***06.06.2013 - A. Weisheit:** Laser additive manufacturing – a new manufacturing technology for parts of composites with refractory metals? The 18th Plansee Seminar - International Conference on Refractory Metals and Hard Materials, Reutte, Österreich*

***11.06.2013 - C. Hinke:** Digital Photonic Production – A new industrial revolution? Manufacturing Performance Days, Tampere, Finnland*

***12.06.2013 - G. Backes:** Laser metal deposition in the Field of Aircraft Engines, 19 Cmh, San Sebastián, Spanien*

***19.06.2013 - R. Poprawe:** Die Zukunft von Forschung und Innovation: "Wissen, wo Wissen entsteht", Fachhochschule Aachen*

***20.06.2013 - M. Leers:** Aufbau von Hochleistungsoptiken mittels hochpräziser Positionierachsen, Fachtagung Mikro Montage, Carl Hanser Verlag, Stuttgart*

***21.06.2013 - S. Herbert:** Investigations of the EUV conversion efficiency of luminophores, COST MP1203 - Advanced X-ray spatial and temporal metrology, Warschau, Poland*

***21.06.2013 - L. Juschkin:** Imaging with plasma based EUV sources, COST MP1203 – Advanced X-ray spatial and temporal metrology, Warschau, Poland*

***23.06.2010 - T. Taubner:** Infrared imaging at nanoscale resolution, Fraunhofer Multiphysics Simulation Conference, Bonn*

***25.06.2013 - D. Hoffmann:** INNOSLAB – a kW class laser amplifier for pulse durations from ns to fs range, ISPD Congress, Beijing, China*

***26.06.2013 - A. Gillner:** Lasers in biomedical engineering, ARTIVASC 3D SUMMER SCHOOL, Espoo, Finland*

***27.06.2013 - A. Özmert:** Soudage du cuivre par laser: corrélation entre le spectre émis et la morphologie du cordon, Journées Nationales des Procédés Laser pour l'Industrie, Yutz, Frankreich*

***02.07.2013 - M. Holters:** Self-optimizing approach for the alignment of optical components, The 11th International Symposium on Measurement Technology and Intelligent Instruments (ISMTII), Aachen*

***16.07.2013 - D. Hoffmann:** THE INNOSLAB AMPLIFIER, Heraeus Seminar, Bad Honnef*

***19.07.2013 - M. Wehner:** Laserprocesses for biomedical engineering, Helmholtz-Symposium on Biomedical Engineering and Related Fields, Aachen*

***23.07.2013 - D. Petring:** Mission Possible: The next generation of multi-kW laser materials processing, LAMP2013 – The 6th International Congress on Laser Advanced Materials Processing, Niigata, Japan*

***23.07.2013 - M. Steger:** Fabrication of hierarchical structures by direct laser writing and multi-beam-interference, LAMP2013 – The 6th International Congress on Laser Advanced Materials Processing, Niigata, Japan*

***23.07.2013 - M. Ungers:** FPGA-programmed detection of seam defects for the application of laser brazing, LAMP2013 – The 6th International Congress on Laser Advanced Materials Processing, Niigata, Japan*

***24.07.2013 - B. Mehlmann:** Spatially modulated laser beam micro welding of CuSn6 and nickel-plated DC04 steel for battery applications, LPM2013 – The 14th International Symposium on Laser Precision Microfabrication, Niigata, Japan*

***24.07.2013 - M. Dahmen:** Laser beam welding of ultra-high strength steel sheets, LAMP2013 – The 6th International Congress on Laser Advanced Materials Processing, Niigata, Japan*

***24.07.2013 - C. Engelmann:** Lasermikrostrukturen zum lasergestützten Fügen von FVK und Metall, IFSW CFK-Workshop, Freudenstadt*

***25.07.2013 - M. Hermans:** Selective, laser-induced etching of fused silica at high scan-speeds, LAMP2013 – The 6th International Congress on Laser Advanced Materials Processing, Niigata, Japan*

***25.07.2013 - D. Riester:** Laser tool for single cell transfer, LAMP2013 – The 6th International Congress on Laser Advanced Materials Processing, Niigata, Japan*

***26.07.2013 - A. Gillner:** Prospects and requirements for industrialisation of ultrashort pulse laser technology, LAMP2013 – The 6th International Congress on Laser Advanced Materials Processing, Niigata, Japan*

***26.07.2013 - M. Hermans:** 3D micro structures in glass by in-volume selective laser-induced etching with high speed micro scanner, LAMP2013 – The 6th International Congress on Laser Advanced Materials Processing, Niigata, Japan*

***26.07.2013 - M. Reininghaus:** Fabrication of gold nanoantennas for infrared near-field enhancement by fs-laser radiation, LAMP2013 – The 6th International Congress on Laser Advanced Materials Processing, Niigata, Japan*

***26.08.2013 - M. Berens:** Multiple intensity distributions from a single optical element, SPIE Optics & Photonics 2013, San Diego, CA, USA*

***26.08.2013 - S. Merkt:** Compressive behavior of lattice structures in solid shells manufactured by selective laser melting (SLM), The 14th NOLAMP Conference, Göteborg, Schweden*

***26.08.2013 - O. Pütsch:** Active optical system for laser structuring of 3D surfaces by remelting, SPIE Optics & Photonics 2013, San Diego, CA, USA*

***29.08.2013 - L. Jauer:** Selective Laser Melting of biodegradable metals, the 5th Symposium on Biodegradable Metals, Indonesien*

***05.09.2013 - L. Jauer:** Selective Laser Melting of light metals, LightMAT, Bremen*

***09.09.2013 - S. Merkt:** Fab Labs: A blueprint for decentral production? 3D printing technology landscape for metal production in digital manufacturing workshops, FabLabCon 2013, Aachen*

***13.09.2013 - D. Petring:** High power adaptable laser beams for materials processing, Presentation on the HALO project to the 66th Annual Assembly of the International Institute of Welding (IIW), Essen*

***13.09.2013 - J. Stollenwerk:** Thin film laser processing, Workshop "Laser RTP", Berlin*

***16.09.2013 - J. Gottmann:** ISLE: In-volume selective laser etching, ZEA-1-Kolloquium, Jülich*

***16.09.2013 - W. Meiners:** Additive Fertigung mit Selective Laser Melting auf dem Weg zur Serienproduktion? DVS Congress 2013, Essen*

***17.09.2013 - R. Wester:** Auslegung abbildender und nicht-abbildender optischer Systeme, Seminar Optische Kunststoff-Formteile in Design und Technik, Würzburg*

***17.09.2013 - K. Wissenbach:** Laserbasierte Herstellung funktionaler Oberflächen und Schichten, Vortragsreihe des Clusters NanoMikro-WerkstoffePhotonik.NRW, Philips Technology GmbH, Aachen*

18.09.2013 - C. Engelmann: *Lasermikrostrukturen zum lasergestützten Fügen von Kunststoff und Metall, DVS Congress 2013, Essen*

18.09.2013 - F. Schneider: *Laser processing of composites: New technologies for cutting and joining, Composite Europe, Stuttgart*

19.09.2013 - C. Fricke-Begemann: *Inline analysis of mineral dust for mining applications, EMSLIBS 2013, Bari, Italien*

19.09.2013 - J. Tempeler: *Directed self-assembly with EUV interference lithography, 39th International Conference on Micro and Nano Engineering 2013, London, UK*

20.09.2013 - R. Noll: *Lasers for LIBS - past, presence and future, EMSLIBS 2013, Bari, Italien*

20.09.2013 - M. Scharun: *Fibre laser-induced breakdown spectroscopy for mobile applications in metal recycling, EMSLIBS 2013, Bari, Italien*

23.09.2013 - P. Loosen: *RWTH-Aachen, Fraunhofer-ILT and the related "Photonics Campus Cluster" … from fundamental to applied research, Visit of the Eindhoven city/brainport delegation, EON Research Center, Aachen*

24.09.2013 - I. Kelbassa: *Digital Photonic Production – Laser Additive Manufacturing, IUMRS- International Conference on advanced Materials (IUMRS-ICAM) Qingdao, China*

26.09.2013 - E. Willenborg: *Designoberflächen durch selektives Laserpolieren, 14. ALasKA Seminar, Aachen*

27.09.2013 - S. Danylyuk: *Simulation of EUV proximity printing and interference lithography with plasma-based laboratory EUV sources, 11th Fraunhofer IISB Lithography Simulation Workshop, Hersbruck*

27.09.2013 - C. Engelmann: *Fügen und Trennen von Composite-Materialien, 14. ALasKA Seminar, Aachen*

27.09.2013 - S. Mann: *Qualitätssicherung beim Kunststoffschneiden mit Laserstrahlung, 14. ALasKA Seminar, Aachen*

03.10.2013 - G. Rolink: *Additive manufacturing of a binary iron aluminide by Laser Metal Deposition and Selective Laser Melting, Intermetallics, Bad Staffelstein*

04.10.2013 - Hagedorn: *Processing of nickel based superalloy MAR M-247 by means of High-Temperature Selective Laser Melting (HT-SLM), The International Conference on Advanced Research in Virtual and Rapid Prototyping (VRAP 2013), Leiria, Portugal*

07.10.2013 - M. Schniedenharn: *Micro scale laser based additive manufacturing for metals, ICALEO – The 32nd International Congress on Applications of Lasers & Electro-Optics, Miami, FL, USA*

08.10.2013 - S. Janssen: *Determination of the bore hole diameter by analyzing process emissions, ICALEO - The 32nd International Congress on Applications of Lasers & Electro-Optics, Miami, FL, USA*

08.10.2013 - U. Thombansen: *Sensor system for spatially resolved observation of the melt pool in Selective Laser Melting, ICALEO – The 32nd International Congress on Applications of Lasers & Electro-Optics, Miami, FL, USA*

08.10.2013 - H. Uchtmann: *CAx process chain for automated laser drilling of tool molds, ICALEO – The 32nd International Congress on Applications of Lasers & Electro-Optics, Miami, FL, USA*

08.10.2013 - F. Zibner: *High precision 2.5D laser cutting of thin nitinol and polyurethane for medical applications, ICALEO – The 32nd International Congress on Applications of Lasers & Electro-Optics, Miami, FL, USA*

09.10.2013 - S. Mann: *Measurement of particle density distribution of powder nozzles for laser material deposition, ICALEO – The 32nd International Congress on Applications of Lasers & Electro-Optics, Miami, FL, USA*

09.10.2013 - S. Britten: *Extension of the process boundaries for the soldering of elongated interconnectors with a simultaneous energy deposition, ICALEO – The 32nd International Congress on Applications of Lasers & Electro-Optics, Miami, FL, USA*

09.10.2013 - J. Finger: *Laser fabricated nanoantennas for near-field applications, ICALEO – The 32nd International Congress on Applications of Lasers & Electro-Optics, Miami, FL, USA*

09.10.2013 - A. Olowinsky: *Stand der Technik und neueste Entwicklungen in der Lasertechnik für das Kunststoffschweißen und Beschriften, Technologieseminar Laserbearbeitung: Kunststoffschweißen und Beschriften, Freudenstadt*

10.10.2013 - J. Finger: *Investigations on processing of carbon fiber reinforced plastics using ultrashort pulsed laser radiation with high average power, ICALEO – The 32nd International Congress on Applications of Lasers & Electro-Optics, Miami, FL, USA*

10.10.2013 - C. Hinke: *Digital Photonic Production – A new industrial revolution?, ICALEO – The 32nd International Congress on Applications of Lasers & Electro-Optics, Miami, FL, USA*

10.10.2013 - V. Mamuschkin: *Laser transmission welding of white thermoplastics with adapted wavelengths, ICALEO – The 32nd International Congress on Applications of Lasers & Electro-Optics, Miami, FL, USA*

10.10.2013 - A. Olowinsky: *Laserlöten von Kontaktteilen aus Kupferwerkstoffen – Selektive Anwendungen, Kupferlackdraht, Feder- und Kontaktteile, Fortbildungsseminar Löten von Kupferwerkstoff, Duisburg*

10.10.2013 - J. Risse: *Selective Laser Melting of nickel-based superalloys: Process development towards manufacturing of aeronautic components, 3rd International EASN Association Workshop, on Aerostructures, Mailand, Italien*

12.10.2013 - J. Stollenwerk: *Thin film laser processing, Workshop "Laser RTP", Berlin*

28.10.2013 - R. Poprawe: *RWTH Aachen Campus vision.concept.realisation, Ningbo, China*

29.10.2013 - M. Strotkamp: *Broadly tunable, diode pumped Alexandrite laser, ASSL - Advanced Solid-State Lasers, Paris*

31.10.2013 - Pütsch: *Opto-mechatronisches System für die energieeffiziente Bearbeitung von endlos-glasfaserverstärkten Bauteilen mit CO_2-Laserstrahlung, 9. Internationales Forum Mechatronik, Winterthur, Schweiz*

01.11.2013 - R. Poprawe: *Lasers and their applications in the future of digital production, Tsinghua University, China*

01.11.2013 - R. Poprawe: *Interdisciplinary research strategy of Aachen University, Peking, China*

04.11.2013 - P. Loosen: *General optics design part 2, LA3NET Topical Workshop 2: "Laser technology and optics design", Aachen*

4.11.2013 - M. Traub: *Optics Design Part II, LA3NET Topical Workshop 2: "Laser technology and optics design", Aachen*

4.11.2013 - D. Hoffmann: *Overview Laser Sources, LA3NET Topical Workshop 2: "Laser technology and optics design", Aachen*

***05.11.2013 - E. Liermann:** Optical component characterisation I – Thermomechanical Testing Part I, LA3NET Topical Workshop 2: "Laser technology and optics design", Aachen*

***05.11.2013 - M. Strotkamp:** Optical component characterisation I – Thermomechanical Testing Part II, LA3NET Topical Workshop 2: "Laser technology and optics design", Aachen*

***05.11.2013 - B. Gronloh:** Optical component characterisation II – Absorption of crystals, substrates and coatings, LA3NET Topical Workshop 2: "Laser technology and optics design", Aachen*

***05.11.2013 - A. Meissner:** Optical component characterisation II – LIDT of crystals, substrates and coatings, LA3NET Topical Workshop 2: "Laser technology and optics design", Aachen*

***05.11.2013 - B. Jungbluth:** Tunable lasers and frequency conversion, LA3NET Topical Workshop 2: "Laser technology and optics design", Aachen*

***06.11.2013 - R. Wester:** Designing optical freeform surfaces for extended sources, OSA Topical Meeting Renewable Energy and the Environment Freeform Optics, Tucson, AZ, USA*

***07.11.2013 - L. Büsing:** Multistrahloptiken zur Erzeugung periodischer Mikrostrukturen mittels UKP-Laserstrahlung, Workshop "Mustererzeugung und Laserstrahlformung", Nürnberg*

***08.11.2013 - R. Poprawe:** Licht aus Werkzeug in der Produktion, Forschungscampus RWTH Wissenschaftsnacht, Aachen*

***12.11.2013 - D. Hoffmann:** Festkörperlaser und Diodenlaser für das Schweißen von Kunststoffen, SKZ Würzburg*

***13.11.2013 - C. Fricke-Begemann:** Inline-Materialanalytik in der Metallindustrie mit Laser-Spektroskopie, Jahrestagung des GDMB Chemikerausschusses, Kassel*

***13.11.2013 - A. Gatej:** Optische Systeme für das High Power SLM, Workshop "3D Druck: Verfahren und Anwendungen", Darmstadt*

***20.11.2013 - W. Meiners:** Showcasing advances in metal additive manufacturing, identifying other materials under development & alloys to be available in the near-term, Konferenz bei ExCel London*

***26.11.2013 - R. Poprawe:** Chancen und Grenzen von 3D-Druckern in der industriellen Produktion, Wissenswerte, Bremer Forum für Wissenschaftsjournalismus*

***28.11.2013 - A. Gillner:** Digital Photonic Production – Laserabtrag als Teil einer digitalen photonischen Prozesskette, IVAM Laserforum 2013, Aachen*

***04.12.2013 - J. Holtkamp:** Overview and prospects for the industrialization of ultrashort-pulsed laser technology, Konferenz-besuch University of Tokyo Institute of Industrial Science, Japan*

***09.12.2013 - R. Poprawe:** 3D-Druck im industriellen Fertigungs-umfeld: Wird der 3D-Druck die Produktion revolutionieren? Management Circle, München*

***12.12.2013 - J. Gottmann:** Selective laser-induced etsching by high speed scanning, Seminar, Technische Universität Eindhoven, Niederlande*

***18.12.2013 - R. Poprawe:** Laseranwendungen in der Medizintechnik, Life-Tec, Aachen*

CONVENTIONS AND CONFERENCES

CONGRESSES AND SEMINARS

January 22 - 23, 2013, Aachen
ERA-NET Cluster Event
»Research for Tomorrow's Production«
In the rooms of Fraunhofer ILT, the German Federal Ministry of Education and Research organized an event for the final presentation of results from the joint project within the scope of the initiatives MANUMET and MNT-ERA.NET. In total, nine projects were presented in lectures and live demonstrations. Their spectrum ranged from laser-based manufacturing processes in the sector of »adaptive production technology« to inline measuring systems for laser structuring machines from the field of »efficient production equipment«.

February 5 - 6, 2013, Dresden
Lightweight Construction Conference
»Laser Technology in Lightweight Construction«
Within the scope of this event of the Fraunhofer Lightweight Design Alliance, scientists from Fraunhofer ILT talked about the topics of cutting and welding of FRPs and metals as well as rapid prototyping.

February 20 - 21, 2013, Aachen
ICTM – International Conference on Turbomachinery Manufacturing 2013
With the second ICTM, Fraunhofer ILT along with Fraunhofer IPT has created a platform for participants to exchange information on new technologies for the manufacture and maintenance of turbomachinery. Over 250 experts from 15 nations from the aviation and energy generation sectors took part in the conference. In addition to the 21 presentations, a particular highlight was the 38 live demonstrations in both Fraunhofer Institutes.

Using examples from repair and manufacture, the Aachen researchers showed how they implement technological innovations and integrate them in continuous process chains, all of which are relevant to current applications.

At the exhibition accompanying the conference, 12 industrial partners were present. Further information on the ICTM can be found at www.ictm-aachen.com.

April 17 - 18, 2013, Aachen
2nd Ultra-short Pulse Laser Workshop
On April 17 and 18, 2013, the Aachen Ultra-short Pulse Laser Workshop took place for the second time. Initiated by Fraunhofer ILT, the workshop welcomed over 160 participants from the industry and research, who assembled at Energeticon in the neighboring city of Alsdorf. In 18 presentations and lively discussions, they exchanged ideas on new USP laser systems and their potential applications in manufacturing. Further information on the USP Workshop can be found at www.ultrakurzpulslaser.de.

May 14, 2013, Munich
PolyBright Workshop: Laser Polymer Welding
In the European joint project PolyBright, 18 partners from 9 countries are collaborating on the laser-based welding of polymers. This workshop was aimed at engineers and scientists from the sectors of application and development of laser processing of polymer components and gave an overview of the research results achieved to that time: new laser beam sources and special wavelengths suitable for welding polymers, welding on non-conventional polymer compounds and the corresponding equipment. In particular, the close coordination between material selection and suitable laser wavelength was demonstrated using different examples. How this technology could be implemented in machine technology was also presented at K 2013, the flagship trade fair for plastics and rubber, in Düsseldorf in October.

July 9 - 10, 2013, Aachen
Automated Assembly of Laser Components and Optical Component Groups

At this two-day seminar, Fraunhofer IPT and ILT displayed interdisciplinary solutions for the automated assembly of laser components and offered the participants the opportunity of discussing their individual challenges. The professional presentations from industry and research encompassed hardware and plant engineering, handling technology, active and passive adjustment processes as well as joining technology.

November 28, 2013, Aachen
LaserForum 2013: Digital Photonic Production for Micro-components

Along with Fraunhofer ILT, the Laser Zentrum Hannover e.V., the LIMO Lissotschenko Mikrooptik GmbH and the Ruhr-Universität Bochum, the international micro-technology network IVAM tied in with the successful laser forum in the fall, which in the past annually took place as a preview of the Hannover Messe. Since optical and laser technologies have a potential that reaches far beyond industrial automation, this new event took place independent of the industrial trade fair, thus providing participants with the opportunity of hearing presentations on contemporary topics, markets and branches of the future for optical technologies. The first LaserForum took place under the title »Digital Photonic Production for Micro-components« and was dedicated to three current topics: »Additive Laser Manufacturing for Micro-components«, »Beam Source Concepts«, and »Laser Ablation and Tempering in Digital Process Chains«.

1 Dr. Arnold Gillner at the Ultra-short Pulse Laser Workshop at Energeticon in Alsdorf.

2 Exhibitors at the second ICTM – International Conference on Turbomachinery Manufacturing in Aachen.

December 9 - 10, 2013, Munich
3D Printing – the Motor of the Future for Manufacturing Companies

In cooperation with Fraunhofer ILT, the Management Circle organized the forum »3D Print« under the leadership of Professor Reinhart Poprawe. It was directed at specialists and executives from the sectors of production, R&D, design engineering, innovation and technology management, logistics, replacement part management, business development management, strategic company planning, law, marketing and sales. The event focused on topics such as, among others, what the current technological and economic limits of 3D printing are, as well as how it can be differentiated from conventional manufacturing technologies. Experts showed how companies can already make use of these technologies today.

COLLOQUIUM ON LASER TECHNOLOGY AT THE RWTH AACHEN UNIVERSITY

January 10, 2013, Aachen
Chair for Laser Technology LLT at RWTH Aachen University
Colloquium on Laser Technology

Dr. Bernold Richerzhagen, Synova S.A., Ecublens, Switzerland
»Der wasserstrahlgeführte Laser als Werkzeugmaschine: Erosionsqualität und -präzision in Lasergeschwindigkeit und -flexibilität«

January 17, 2013, Aachen
Chair for Laser Technology LLT at RWTH Aachen University
Colloquium on Laser Technology

Prof. Craig Arnold, Mechanical and Aerospace Engineering, Princeton University, USA
»Ultra-High-speed Variable Focus Liquid Lenses for Use in Laser Processing and Imaging Applications«

January 24, 2013, Aachen
Chair for Laser Technology LLT at RWTH Aachen University
Colloquium on Laser Technology
Prof. Detlev Grützmacher, Peter Grünberg Institut – Halbleiter-Nanoelektronik, Forschungszentrum Jülich
»Directed Growth for Future Nanoscaled Devices«

April 25, 2013, Aachen
Chair for Laser Technology LLT at RWTH Aachen University
Colloquium on Laser Technology
Prof. Gerd Leuchs, Max-Planck-Institut für die Physik des Lichts, Erlangen
»Fokussieren von Laserstrahlung«

May 23, 2013, Aachen
Chair for Laser Technology LLT at RWTH Aachen University
Colloquium on Laser Technology
Dr. Constantin Haefner, National Ignition Facility, Livermore, USA
»Ultra-high Intensity Laser in the Context of Inertial Confinement Fusion«

June 13, 2013, Aachen
Chair for Laser Technology LLT at RWTH Aachen University
Colloquium on Laser Technology
Christian Marx, Laser Zentrum Hannover LZH
»Laser in der Biomedizintechnik«

August 26, 2013, Aachen
Chair for Laser Technology LLT at RWTH Aachen University
Colloquium on Laser Technology
Prof. Dave L. Bourell, University of Texas at Austin, USA
»Additive Manufacturing of Lithophanes«

AIX-LASER-PEOPLE

May 15, 2013, Munich
45th Seminar of the Alumni Club »Aix-Laser-People«
For the 7th time the alumni club »Aix-Laser-People« met during the international trade fair LASER World of Photonics in Munich. Around 140 participants – 90 were employees and 50 alumni of Fraunhofer ILT and the cooperating chair at the RWTH Aachen University – got together in the restaurant Bamberger Haus. In a first group, the alumni were able to briefly talk among each other during speed networking sessions. In the second group, current employees of the chair and Fraunhofer ILT had the opportunity of directly exchanging views with the alumni and to gain insight into their industrial experiences. The members were then able to selectively intensify their new contacts they had established in over 100 brief dialogs.

September 24, 2013, Göttingen
and September 25, 2013, Wolfsburg
46th Seminar of the Alumni Club »Aix-Laser-People«
Coherent's Dr. Guido Bonati, Director Business Development & Product Line Management, and Rainer Pätzel, Director Marketing, welcomed approx. 20 participants at the »Aix-Laser-People« meeting at the company's headquarters in Göttingen. Rainer Pätzel offered the listeners an overview of the current company's technological developments and the challenges of laser applications, especially in the display market. During a guided tour, the participants were able to get an impression of the technically complicated excimer laser systems and the R&D tasks associated with them. The Coherent team was one of the three finalists of the Deutscher Zukunftspreis 2013.

1 Aix-Laser-People meeting at Coherent LaserSystems GmbH & Co KG in Göttingen, Germany.

On the following day, the group visited the pressing plant, car body construction and final assembly at the main VW factory in Wolfsburg. A professional guide explained the current technological challenges that a modern automobile manufacturer faces. In his concluding presentation, Thorge Hammer, responsible engineer for technology planning and development, body planning and mold construction at VW gave insight into the current state-of-the-art and the upcoming research and development tasks for laser applications in lightweight car body construction at VW.

December 19, 2013, Leuven, Belgium
47th Seminar of the Alumni Club »Aix-Laser-People«

The 27 participants of the »Aix-Laser-People« meeting were able to see for themselves the potential of digital photonic production at Materialise NV, one of the leading 3D print service providers. In their presentation on the topic »Cutting through the Hype of 3D Printing«, Stijn De Rijck, Marketing Manager Factory for 3D Printing at Materialise NV, and Manuel Michiels, Application Engineer at Materialise NV illustrated the wide range of applications that 3D printing offers in different branches, such as medical technology, consumer products, automobile technology or in precision mechanics. New business models resulting from them were also discussed intensively. In his final presentation on the topic of »Digital Photonic Production «, Dr. Ingomar Kelbassa, Deputy Chair for Laser Technology LLT at the RWTH Aachen University, concentrated upon the manufacture of metal components and tools as they are used in the automobile industry, tool or turbine construction. At the subsequent tour through the production rooms of Materialise, all the participants were able to see for themselves the technological state of the art in the sector of 3D printing.

EVENTS FOR PUPILS AND STUDENTS

January 31, 2013, Aachen
Guided Tour for Students

Orientation event and tour of the Chair for Laser Technology LLT and Fraunhofer ILT for students of the RWTH Aachen University. Within the scope of the institute management, employees of ILT demonstrated the practical relevance of the topics in the lecture module »Laser Beam Sources» by Prof. Poprawe using laser beam sources and laser systems.

April 25, 2013, Aachen
Girls' Day Event

On this day, female pupils starting with the fifth grade were able to experience the working world in technology, craftsmanship, engineering and natural sciences; they also got to know female role models in leadership positions in commerce, science and politics. Along with Fraunhofer IPT and Fraunhofer IME, Fraunhofer ILT took part in this nation-wide vocational orientation day for girls between the ages of 10 and 15. In total, 50 girls were guided through the institute on this day.

May 7, 2013, Aachen
Guided Tour for Pupils

Orientation event of the Chair for Laser Technology LLT and Fraunhofer ILT for a group of pupils from the Europaschule Herzogenrath from the neighboring city of Herzogenrath, Germany.

2 Dr. Stephan Brüning and Dipl.-Ing. Christian Wessling during Business Speed Networking.

3 Bamberger Haus in Munich: Meeting of the Aix-Laser-People on May 15 during the LASER 2013.

May 24, 2013, Aachen
Guided Tour for Students
Orientation event of the Chair for Laser Technology LLT and Fraunhofer ILT for a group of students from Spain.

May 24, 2013, Aachen
Guided Tour for Pupils
Orientation event of the Chair for Laser Technology LLT and Fraunhofer ILT for high school graduates from Bonn.

June 6, 2013, Aachen
Guided Tour for Students
Orientation event of the Chair for Laser Technology LLT and Fraunhofer ILT for students from Engineering Sciences and Physics at the RWTH Aachen University. The tour took place within the scope of the lecture module »Laser Applications« by Prof. Poprawe. Employees of Fraunhofer ILT and the Chair for Laser Technology LLT demonstrated laser systems and current research trends.

July 31, 2013, 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. 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.

November 6, 2013, Aachen
Companies Night
For the fourth time, Fraunhofer ILT was present with a stand at »Companies Night« in the technology center at the Europaplatz. On November 6, 2013, over 2,000 university graduates, students and skilled employees caught up on how they can shape their professional careers at the approximately 100 companies and institutes participating in this event. Judith Kumstel, Jenny Tempeler and Florian Eibl represented Fraunhofer ILT and the university chairs at ILT's own information stand. The next »Companies Night« will take place on November 6, 2014.

December 19, 2013, Aachen
Guided Tour for Pupils
Orientation event of the Chair for Laser Technology LLT and Fraunhofer ILT for a group of pupils from Liebfrauenschule in the neighboring city of Eschweiler.

1 Within the scope of the Schools at University, pupils experimented with a self-made spectrograph at Fraunhofer ILT.
2 Computer simulation for the cutting of display glass.
3 Well visited: Fraunhofer joint stand at the LASER World of Photonics 2013 in Munich.

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TRADE FAIRS

Fraunhofer ILT at the LASER 2013

This year 27,000 visitors from 74 countries came to the fortieth LASER World of Photonics in Munich, where they visited 1,135 exhibitors. Fraunhofer ILT impressed them with numerous developments from the sector of industrial laser technology.

Process Optimization through Computer Simulation

Laser materials processing demands, among others, high beam intensities applied to the smallest of surface areas, maximum processing speed, precision as well as reliability. And here, process control and control technology come up against their limits. Laser-specific computer simulations and modelling lend themselves well to assist in these cases; indeed, our scientists, having over 20 years of experience, can bring forward different processes considerably using such technologies. At the fair, five examples of applications for industrial partners from product and process development were presented: among them, the efficient cutting of display glass (TRUMPF Lasertechnik) and the optimized water-jet guided laser cutting (SYNOVA).

Polygon Scanner for the Efficient Use of Laser Power

The great advantage of ultra-short pulse lasers is their »cold« ablation, i.e. they ablate material without thermally damaging the surrounding areas. This benefit can only be achieved, however, when few pulses overlap. At pulse frequencies in the MHz range and spot sizes of 20 µm, this is not easily accomplished – to do this, the spot has to be moved at speeds of over 100 m/s. The experts at Fraunhofer ILT have developed a polygon scanner, which, at an aperture of 20 mm and a focal length of 163 mm, reaches scanning speeds of up to 360 m/s on the workpiece. This laser can process a surface of 100 x 100 mm^2 in three seconds, during which it can be controlled at up to 40 MHz. This way, the full power of modern ultra-short pulse laser sources can effectively be applied to the workpiece. To demonstrate how quickly and precisely the system can process a material, experts used the polygon scanner to engrave metal business cards live.

Digital Photonic Production in Industrial Use

At the special stand »Digital Photonic Production DPP« occupied by both the Messe München International and Fraunhofer ILT, the Aachen-based Fraunhofer Institutes ILT and IPT jointly presented – along with the Chair for Laser Technology LLT of the RWTH Aachen University and industrial partners – various plants, design software tools and components from industrial use. The partners included, among others, Concept Laser GmbH, Realizer GmbH, SLM Solutions GmbH, MTU Aero Engines AG, Bego Medical GmbH, Citim GmbH as well as Schepers GmbH & Co. KG.

Using selected examples from the automotive, aerospace, energy technology, lightweight construction, medical technology and consumer sectors, the engineers demonstrated the enormous potential of the DPP technology. Besides additively manufactured components, the institutes also presented ablating processes: a print roller was displayed, which had been structured using short-pulse lasers, as were transparent components revealing 3D hollow structures generated by Selective Laser Etching SLE. The great interest on this topic – Digital Photonic Production – was reflected by the large number of specialist visitors, many representatives of the specialist press as well as three TV film teams (among others, for the ARD Tageschau [national German news program]).

Joint Fraunhofer stand at the EuroMold 2013 in Frankfurt.

The Fraunhofer team at the Productronica 2013 in Munich.

Photonics West 2013
February 2 - 7, 2013, San Francisco, USA
International Conference and Exhibition
for Optics and Photonics

Fraunhofer ILT was present at the international conference and exhibition Photonics West and gave three presentations: »Design of a rugged 308-nm tunable UV laser for airborne LIF measurements on top of a zeppelin«, »Simulations and experiments on resonantly pumped single-frequency Erbium lasers at 1.6 µm«, and »200-W TM:YLF INNOSLAB laser«. At the German pavilion, Fraunhofer ILT took part in the following topic: New High-Power Lasers, Precise Assembly Technologies for Optical Components and Frequency Converters.

JEC Europe
March 12 - 14, 2013, Paris, France

Composites Show & Conferences
At the joint Fraunhofer stand, Fraunhofer ILT and CLFA participated in the international fair for composite materials. Processed FRP components were presented, among them an automobile seat backrest and front end components as well as further examples of how laser-based technologies could be applied to lightweight construction.

HANNOVER Messe 2013
April 8 - 12, 2013, Hannover

International Industry Fair
At the joint IVAM stand, Fraunhofer ILT exhibited processes for functionalizing surfaces, micro- and nano-structuring with USP lasers as well as for glass soldering. With the topic »Digital Photonic Production«, Fraunhofer ILT was present on the North Rhine-Westphalian stand and on the stand of the Fraunhofer Additive Manufacturing Alliance. In addition, the joint project »TurPro«, in which Fraunhofer ILT and IPT are collaborating closely, was presented at the central Fraunhofer stand.

LASER 2013
May 13 - 16, 2013, Munich

LASER 2013 World of Photonics and World of Photonics Congress 2013
Fraunhofer ILT presented the visitors current R&D results of all ILT competence areas at the joint Fraunhofer stand in Hall C2. Highlights were the polygon scanner plant, the 1 kW fs laser system with record-setting brilliance and applications from the field of simulation and modelling of manufacturing processes. At the special stand »Digital Photonic Production«, Fraunhofer ILT, IPT and the Chair for Laser Technology LLT presented, jointly with industry partners, applications for additive and ablative laser processes.

Control 2013
May 14 - 17, 2013, Stuttgart

International Trade Fair for Quality Assurance
Under the slogan »Inspired to Measure«, Fraunhofer ILT presented the interferometric thickness and distance sensor it developed, »bd-2«, for bidirectional measuring of metal foils to the public for the first time at the joint Fraunhofer stand in Hall 1/1502.

EU PVSEC 2013
September 30 - October 4, 2013, Paris, France

28th European Photovoltaic Solar Energy Conference and Exhibition
The micro- and nano-structuring group of Fraunhofer ILT presented its new concept to parallelize laser processes for the production of solar cells at the joint Fraunhofer stand. Visitors could view the set-up of a multi-beam optics.

At the BIOTECHNICA in Hannover, Fraunhofer ILT presented the prototype plant LIFTSYS for in-vitro test systems.

Fraunhofer ILT was at the JEC Europe in Paris, presenting the topic manufacturing processes for fiber-reinforced composites.

ICALEO 2013
October 6 - 10, 2013, Miami, USA
32nd International Congress on Applications of Lasers & Electro-Optics
At the 32nd ICALEO of the Laser Institute of America LIA, Fraunhofer ILT was represented at the Vendor Reception with an information stand. The employees of Fraunhofer ILT and the Chair for Laser Technology LLT held a total of 12 presentations, among others, one by Dr. Ingomar Kelbassa on »Digital Photonic Production«.

BIOTECHNICA 2013
October 8 - 10, 2013, Hannover
At the joint Fraunhofer stand, the groups Biotechnology and Laser Therapy of Fraunhofer ILT presented LIFTSYS, a prototype plant that serves to apply biomaterials onto test systems precisely and easy on resources. Furthermore, items exhibited from the field of biofabrication were, among others, scaffolds and tubes as supporting structures for blood vessels and 3D cell cultures from photopolyerizable gels and polymers.

K 2013
October 16 - 23, 2013, Düsseldorf
International Trade Fair for Plastics and Rubber
At the joint Fraunhofer stand, the Micro Joining group showed a compact plant for the laser welding of foil-like plastics. The group's members also explained processes for the laser cutting and welding of FRP components as well as the laser welding of thermoplastic polymers. On the »Science Campus«, the results of the joint project »PolyBright« were presented.

Productronica 2013
November 12 - 15, 2013, Munich
20th International Trade Fair for Innovative Electronics Production
The Micro Joining group of Fraunhofer ILT presented their »laser bonder« for ribbon bonding onto, among others, DCB substrates at the joint Fraunhofer stand. In addition, they showed a process for the resource-friendly manufacture of gold contacts and one for the functionalization of thin films.

COMPAMED 2013
November 20 - 23, 2013, Düsseldorf
World Forum for Medicine and International Trade Fair
At the joint IVAM stand, Fraunhofer ILT presented current developments on laser welding of tube components out of plastics as well as on surface finishing of metal components out of titanium. Moreover, the visitors could view the latest results on the manufacture of biocompatible supporting structures out of hydrogels.

EuroMold 2013
December 3 - 6, 2013, Frankfurt am Main
20th World Fair for Moldmaking and Tooling, Design and Application Development
Central topics of Fraunhofer ILT at the joint Fraunhofer stand and the stand of the Fraunhofer Additive Manufacturing Alliance were SLM processes for the processing of crack-sensitive super alloys for the aerospace industry as well as the manufacture of micro-engineered components. Furthermore, employees showed a process for the generation of wear protection coatings for tool inserts using Laser Metal Deposition. The topic laser polishing was illustrated using processed tools as well as the CAM-NC data chain.

Dean Prof. Schmitt confers the teaching prize of the Department of Mechanical Engineering at the RWTH Aachen University on October 26, 2016.

AWARDS AND PRIZES

AILU International Award 2013

Dr. Dirk Petring, head of the group Macro Joining and Cutting at Fraunhofer ILT, received the AILU International Award 2013 in Nottingham, England in March 2013. This honorary award recognizes exceptional services in the sector of industrial laser materials processing and was awarded for the first time in 2013. Since 2001, Dr. Petring has been assisting the Association of Laser Users, AILU, as an active member, for example, in his regular keynote presentations at workshops and with numerous professional publications. He was honored with the prize for being a leading international personality in the field of laser beam cutting and welding.

Teaching Prizes for Three Associated RWTH Chairs of Fraunhofer ILT

The Faculty of Mechanical Engineering at RWTH Aachen University bestowed an internal teaching prize for very good didactic accomplishments in 2013 for the first time. Three of the associated chairs of Fraunhofer ILT received very good grades from the students and were awarded this prize:

- Chair for Laser Technology LLT, Prof. Reinhart Poprawe
- Chair for the Technology of Optical Systems TOS, Prof. Peter Loosen
- Chair for Nonlinear Dynamics of Laser Processing NLD, Prof. Wolfgang Schulz

Springorium Commemorative Coin

For his Master's Thesis, »Experimental Investigations on Polishing with Pulsed Laser Radiation using Dual-Beam Technology«, which he passed with distinction, Hendrik Sändker, M.Sc. received the Springorium Commemorative Coin of RWTH Aachen University on June 21, 2013. On the same day, Florian Elsen also received the Springorium Commemorative Coin of RWTH Aachen University for his Master's Thesis: »Generation and Amplification of Laser Radiation in the Mid-Infrared Range« at the Department of Mechanical Engineering. The ILT employees Hendrik Sändker and Florian Elsen received the commemorative medals during a celebration with around 800 guests in the Audimax auditorium of RWTH Aachen University. In total, 163 students were honored in 2013, those who passed their diploma or master's exams as well as Magister Artium with distinction. The commemorative coins were named after the councilor of commerce Dr. Ing. E.h. Friedrich Springorium, who founded the Association of Friends of Aachen's Universities in 1918 and led it as head of the board until 1925.

Borchers Plaque

For his doctoral exam, which he passed with distinction, on the topic, »Laser Beam Sources on the Basis of an Innovative Neodymium-doped Mixed Granulate for Water-Jet DIAL Systems at 935 nm« at the Department of Mechanical Engineering, Dr. rer. nat. Jens Löhring, employee of Fraunhofer ILT, was honored at the RWTH ceremony on June 21, 2013 in the Audimax auditorium. Among the 163 doctoral students of RWTH Aachen University, who completed their doctoral exams with distinction, four alumni of Fraunhofer ILT were also present: Dr. Micha Christian Scharf, Dr. Felix Schmitt, Dr. Johannes Henrich Schleifenbaum and Dr. rer. nat. Stephan Gronenborn. The privy counselor Professor Wilhelm Borchers lent his name to this award; he was a full professor of metallurgy at the university from 1897 to 1925.

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 124 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

Board

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Prof. Dr. Reinhart Poprawe M.A. (Deputy chairman)
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Dipl.-Phys. Axel Bauer (General secretary)

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EUROPEAN LASER INSTITUTE ELI

Short Profile

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

Executive Commitee

The members of the committee representing the ELI are:

- Dr. Paul Hilton (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
  Ruhr-Universität Bochum, Germany

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INFORMATION SERVICE

If you would like more information about the research and development at the Fraunhofer Institute for Laser Technology please go to our website at www.ilt.fraunhofer.de. Information can also be ordered using this form.

☐ ***Image Brochure »Partner for Innovations«*** ☐ *German* ☐ *English*

☐ ***Annual Report 2013*** ☐ ***2012*** ☐ ***2011***
(English versions only available online at www.ilt.fraunhofer.de)

Technical Brochures

☐ ***Biofabrication***
☐ ***Laser Drilling*** ☐ *German* ☐ *English*
☐ ***Fiber Lasers*** ☐ *German* ☐ *English*
☐ **Solid State Lasers** ☐ *German* ☐ *English*
☐ ***Design of Freeform Optics*** ☐ *German* ☐ *English*
☐ ***Processing Glass with Laser Radiation*** ☐ *German* ☐ *English*
☐ ***In-Volume Micro Structuring with Femtosecond Lasers***
☐ ***Laser Processing for Fiber-Reinforced Plastics*** ☐ *German* ☐ *English*
☐ ***Laser Cleaning***
☐ ***Lasers in Biotechnology and Medicine*** ☐ *German* ☐ *English*
☐ ***Lasers in Plastics Technology*** ☐ *German* ☐ *English*
☐ ***Lasers in Photovoltaics*** ☐ *German* ☐ *English*
☐ ***Laser Ablation for Thin Film Technology*** ☐ *German* ☐ *English*
☐ ***Laser Polishing of Glass and Plastics*** ☐ *German* ☐ *English*
☐ ***Laser Polishing of Metals*** ☐ *German* ☐ *English*
☐ ***Laser Beam Cutting*** ☐ *German* ☐ *English*
☐ ***Laser Beam Welding of Metallic Materials*** ☐ *German* ☐ *English*
☐ ***Laser Technology for Repair and Functionalization*** ☐ *German* ☐ *English*
☐ ***Micro Joining with Laser Radiation*** ☐ *German* ☐ *English*
☐ ***In-Volume Micro Structuring of Tranparent Materials*** ☐ *German* ☐ *English*
☐ ***Micro and Nano Structuring with Lasers*** ☐ *German* ☐ *English*
☐ ***Modeling and Simulation*** ☐ *German* ☐ *English*
☐ ***Materials Analysis with Nano-Field Microscopy*** ☐ *German* ☐ *English*
☐ ***Nonlinear Optics and Tunable Lasers*** ☐ *German* ☐ *English*
☐ ***Optics-Design and Diode Lasers*** ☐ *German* ☐ *English*
☐ ***Packaging*** ☐ *German* ☐ *English*
☐ ***Polishing with Laser Radiation*** ☐ *German* ☐ *English*
☐ ***Process Control in Laser Materials Processing*** ☐ *German* ☐ *English*
☐ ***Rapid Manufacturing*** ☐ *German* ☐ *English*
☐ ***Selective Laser Etching of Glass and Sapphire*** ☐ *German* ☐ *English*
☐ ***System Engineering for Powder-Based Laser Cladding*** ☐ *German* ☐ *English*
☐ ***System Technology for Laser Material Processing*** ☐ *German* ☐ *English*
☐ ***Thin Film Laser Processing***
☐ ***Ultrafast Lasers*** ☐ *German* ☐ *English*
☐ ***Varioclad – Laser Metal Deposition with Variable Spot Sizes*** ☐ *German* ☐ *English*
☐ ***Heat Treatment Using Laser Radiation*** ☐ *German* ☐ *English*

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