

ANNUAL REPORT 2012



**ANNUAL REPORT
FRAUNHOFER INSTITUTE
FOR LASER TECHNOLOGY
2012**



Even the most spectacular awards ceremonies or prize-giving events pale into insignificance compared to the feeling of being the first to cross the finishing line. When it comes to competitive spirit, the world of innovations is no different than the world of sports. It is when years of research and development work finally come to fruition and the first batch of record-breaking results comes in that success really comes to life for the engineers and scientists involved. Any awards and prizes that follow in their wake are the icing on the cake – with a positive impact that generally spreads far and wide.

Research scientists at Fraunhofer ILT were in the happy position of receiving awards on three occasions this year. The Stifterverband Science Prize 2012 went to a team that together developed ultrashort laser pulses. Its members were drawn from Fraunhofer ILT, the Max Planck Institute of Quantum Optics, RWTH Aachen University, EdgeWave GmbH, JENOPTIK Laser GmbH and AMPHOS GmbH. The Joseph von Fraunhofer Prize 2012 went to a team from Fraunhofer ILT, Fraunhofer IOF and Fraunhofer IWS that developed and optimized beam sources and collector, illumination, and projection optics for extreme ultraviolet (EUV) light. Finally, 13 employees of Fraunhofer ILT and its spin-offs EdgeWave and AMPHOS came through at the Berthold Leibinger Innovationspreis awards for applied laser technology to win second prize with their INNOSLAB-Laser project.

Everyone involved has enjoyed the recognition of the whole photonics community. But that is no reason for us to rest on our laurels. We know that true motivation is to be found in constant renewal. And we have a great many plans for the coming years. We discussed our visions with external representatives from the science and business communities in a thorough strategy audit process, and the results were enriching.

One area we will focus on is digital photonic production, in which photon-based production processes are connected intelligently both with upstream planning processes, including design and layout, and with downstream production and logistics processes, allowing flexible production of customized or complex products. We can draw strength from the fact that, together with the Chair for Laser Technology at RWTH Aachen University, we were selected to be one of 10 recipients of support from the German Federal Ministry of Education and Research BMBF's "Research Campus – Public-Private Partnerships for Innovation" funding initiative. With up to 2 million euros of annual funding, we can ensure that our Aachen location, in collaboration with our industry partners, will systematically drive digital photonic production forward over the long term and at all levels of basic and applied research. But in this discipline there's no first place: everyone's a winner. We're convinced that we can seize the opportunities that come our way as we enter the era of "stimulated innovation". And we warmly welcome you to join us!

Best wishes
Yours

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

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PROFILE OF THE INSTITUTE

SHORT PROFILE

ILT - this abbreviation has stood for combined know-how in the sector of laser technology for more than 25 years. Innovative solutions for manufacturing and production, development of new technical components, competent consultation and education, highly specialized personnel, state-of-the-art technology as well as international references: these are guarantees for long-term partnerships. The numerous customers of the Fraunhofer Institute for Laser Technology ILT come from branches such as automobile and machine construction, the chemical industry and electrical engineering, the aircraft industry, precision engineering, medical technology and optics. With around 400 employees and around 11,000 m² 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.



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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.

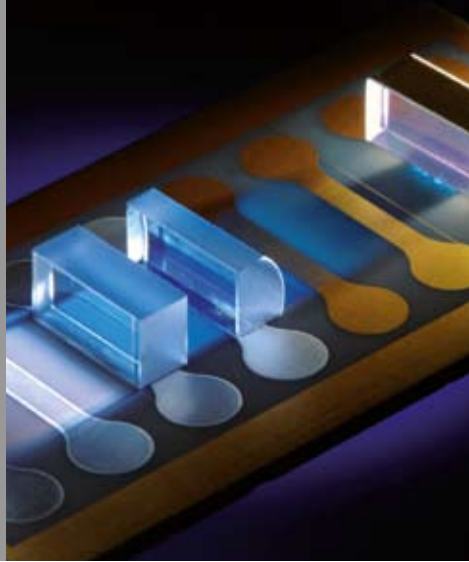
Furthermore, this technology field has a great deal of expertise in beam shaping and guiding, packaging of optical high power components and designing optical components. This field also specializes in dimensioning highly efficient free form optics. In general, the lasers and optics developed here can 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 patient on the basis of data from computer tomography. The material variety ranges from titanium through polylactide all the way to resorbable man-made bone based on calcium phosphate.

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

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

LASER MEASUREMENT TECHNOLOGY AND EUV TECHNOLOGY

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

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

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

PRODUCTS AND SERVICES

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STRUCTURE OF THE INSTITUTE

BOARD OF DIRECTORS



Prof. Dr. Reinhart Poprawe M.A.
Director



Prof. Dr. Peter Loosen
Vice Director

ADMINISTRATION AND CENTRAL FUNCTIONS



Dr. Vasvija Alagic MBA
Administration and Infrastructure



Dipl.-Phys. Axel Bauer
Marketing and Communications



Dr. Alexander Drenker
QM Management



Dr. Bruno Weikl
IT Management

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Lasers and Laser Optics



Dr. Arnold Gillner
Ablation and Joining



Dr. Konrad Wissenbach
Additive Manufacturing
and Functional Layers



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

BOARD AND COMMITTEES

Board

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

- Dr. Norbert Arndt, Rolls-Royce plc
- C. Baasel (Chairman), Carl Baasel Lasertechnik GmbH
- Dr. Hans Eggers, Bundesministerium für Bildung und Forschung BMBF
- Dr. Thomas Fehn, Jenoptik AG
- Dr. Ulrich Hefter, Rofin-Sinar Laser GmbH
- Dr. U. Jaroni, ThyssenKrupp Stahl AG
- Dipl.-Ing. Volker Krause, Laserline GmbH
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- Dr. Ulrich Steegmüller, Osram Opto Semiconductors GmbH & Co. OHG
- Dr. Klaus Wallmeroth, TRUMPF Laser GmbH & Co. KG

The 27th Board of Trustees meeting was held on September 12, 2012 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.

Staff Association

In March 2003 the staff association was founded by the employees of the Fraunhofer ILT and the Department of Laser Technology. Members are: Dipl.-Ing. P. Abels, M. Brankers, Dipl.-Ing. A. Dohrn, C. Hannemann, M. Janssen, Dipl.-Phys. A. Temmler, B. Theisen (Chair), Dr. A. Weisheit, Dipl.-Ing. N. Wolf.

FACTS AND FIGURES

EMPLOYEES

Employees at the Fraunhofer ILT 2012	number
Personnel	205
- Scientists and engineers	143
- Technical staff	38
- Administrative staff	24
Other employees	189
- Undergraduate assistants	178
- External employees	5
- Trainees	6
Total number of employees at the Fraunhofer ILT	394

- 10 members of staff completed their doctorates
- 46 undergraduates carried out their final year projects at the Fraunhofer ILT

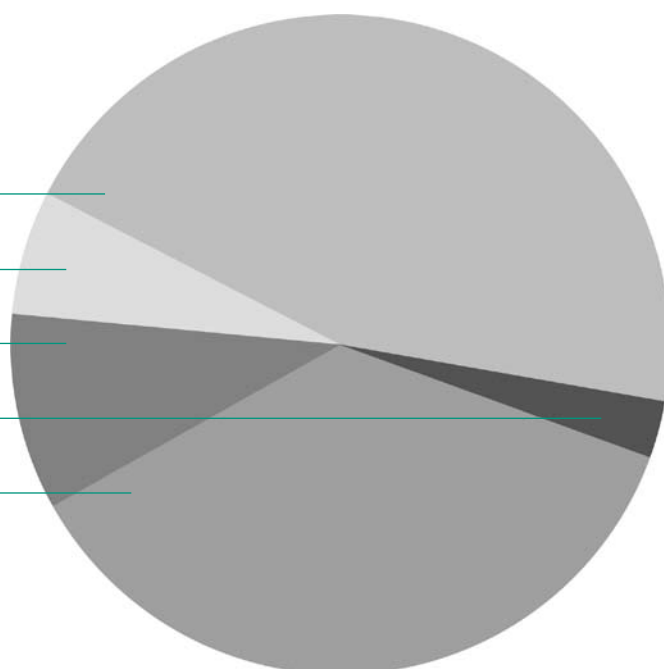
45 % Undergraduate assistants

6 % Administrative staff

10 % Technical staff

3 % External employees, trainees

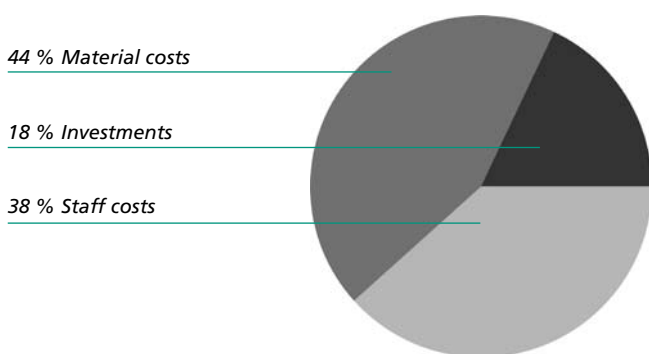
36 % Scientists/engineers



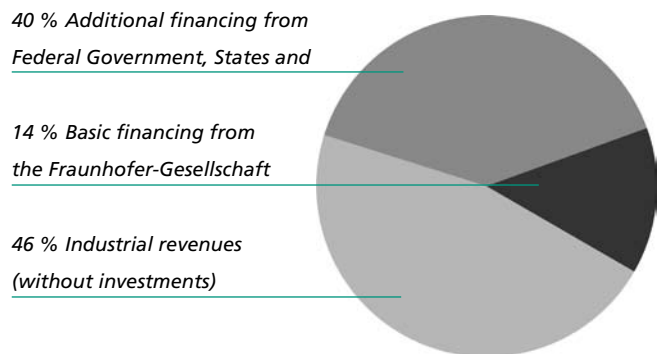
REVENUES AND EXPENSES

Expenses 2012	Mill €
- Staff costs	14,0
- Material costs	16,3
Expenses operating budget	30,3
Investments	6,7

Revenues 2012	Mill €
- Industrial revenues	14,1
- Additional financing from Federal Government, States and the EU	12,0
- Basic financing from the Fraunhofer-Gesellschaft	4,2
Revenues operating budget	30,3
Investment revenues from industry	0,4
Fraunhofer industry ρ_{Ind}	47,9 %



(100 % Operating budget und Investments)

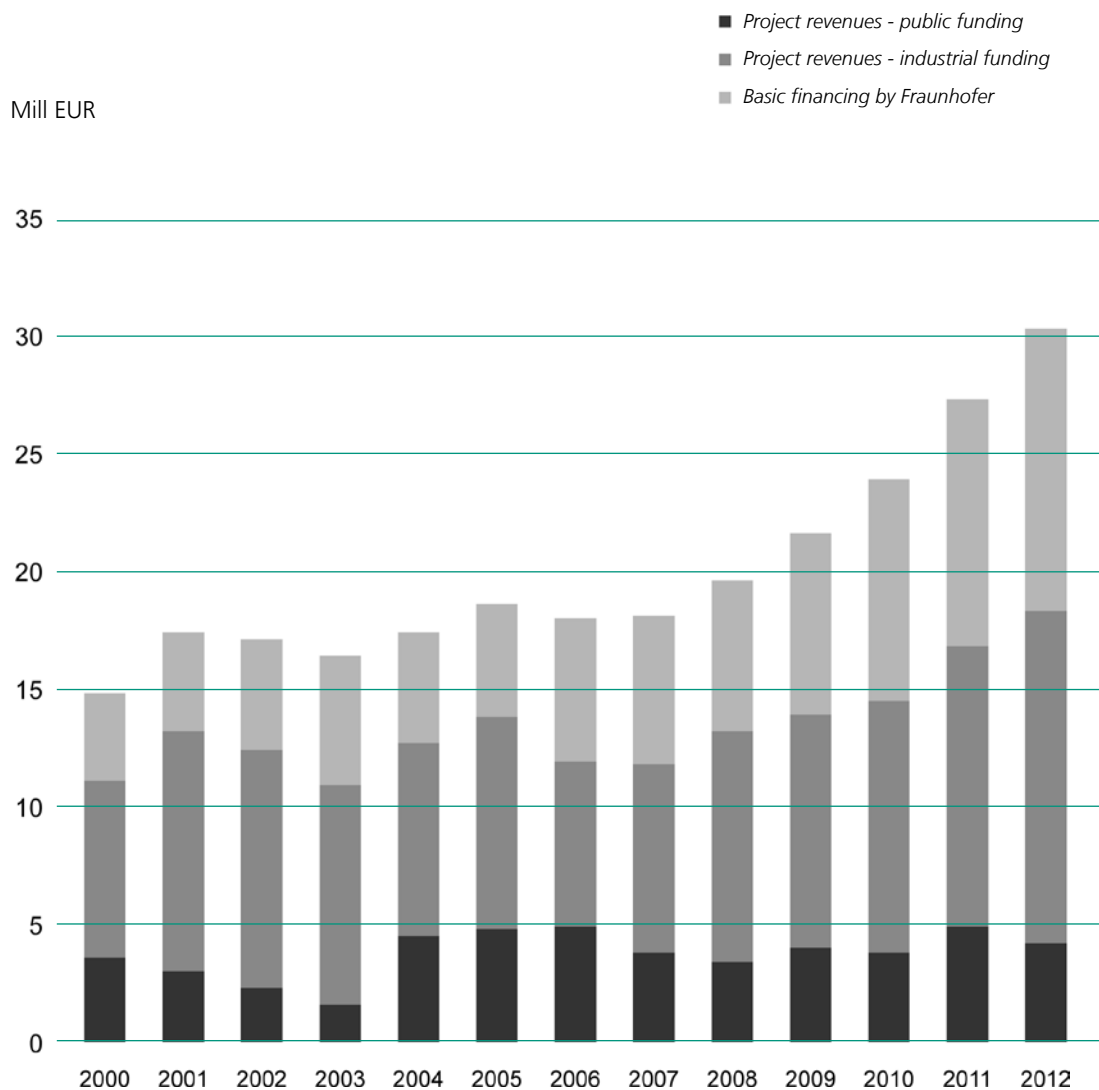


(100 % Operating budget)

FACTS AND FIGURES

BUDGET GROWTH

The following graph illustrates the budget trend over the last 13 years.



REFERENCES



ZWIESEL KRISTALLGLAS

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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 laboratories 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 m².

Technical Infrastructure

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

Scientific Infrastructure

The scientific infrastructure includes a library with international literature, patent and literature data bases as well as 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:

- CO₂-lasers up to 12 kW
- lamps pumped solid state lasers up to 3 kW
- disc lasers from 1 to 10 kW
- fiber lasers between 100 W and 4 kW
- diode laser systems from 1 to 12 kW
- SLAB laser
- excimer lasers
- ultra short pulse lasers up to 1 kW
- broadband tunable lasers
- 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. The patented technology has been licensed to Direct Photonics Industries in Berlin, which is tasked with further commercialization of the high-powered diode lasers.

The Fraunhofer CLT is also collaborating with the University of Michigan to develop cost-efficient manufacturing processes for alternative energy production and storage. The focus is on solar cells and lithium-ion batteries. Laser-induced separation and joining of similar, but also dissimilar, classes of material form the technological basis for these processes. At the moment the research results are transferred to industry in bilateral projects.

Lasers are being successfully used to improve efficiency in solar cell manufacturing. At Fraunhofer CLT, high-speed drilling processes are being developed for EWT cells and the productivity of laser drilling improved six-fold. In the area of additive manufacturing, one focus of development work is on processing heads with multiple beam technology that use diode lasers. Here optimized temperature control is to enable the high-quality application of difficult-to-weld alloys.

The University of Michigan and the Fraunhofer-Gesellschaft set up an alliance to conduct research into renewable energy for transport applications. For the two-year pilot phase five projects were selected covering the fields of innovative energy and power-storage devices, the associated cost-effective manufacturing, redox batteries and dynamic 3-D diagnostics of combustion processes. In the course of the project, the participating partners raised over \$ 500,000 in third-party



funding and submitted project proposals worth more than \$ 20 million. The work conducted during this phase resulted in two patent applications, numerous scientific papers, and joint conference appearances. It also led to the creation of the spin-off company Inmatech, in which Fraunhofer holds a share.

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 CO₂ lasers as well as diode lasers are available for process developments involving micro technology.

Operating budget 2012

	Mill US \$
Operating budget	1.8
- Staff costs	1.1
- Material costs	0.7

References

- DARPA
- Department of Energy
- U.S. Air Force Research Laboratories
- U.S. Army Research Laboratory
- State of Michigan
- Dow
- Ford
- General Motors
- Magna
- Federal Mogul
- Medtronic
- SolarWorld
- Procter & Gamble
- Roche

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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, ARMINES and the Institut CARNOT Mines in Paris, 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 2012 CLT participated in the joint Fraunhofer booth at the JEC Composite Show in Paris as well as in the MICRONORA in Besançon and the national laser conference JNPLI in Mulhouse.

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 mid-sized 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.

Locations

Paris – at the École Nationale Supérieure des Mines de Paris, MINES ParisTech.

Evry - on the premises of the Centre des Matériaux Pierre-Marie Fourt, roughly 40 km south of Paris.

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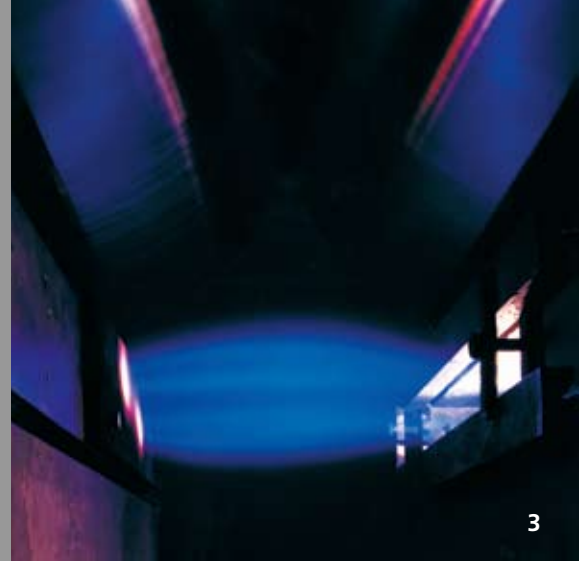
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1



2



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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, plasma-activated 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 350 patents since 1985 the Fraunhofer Institute for Laser Technology ILT develops innovative laser beam sources, laser technologies, and laser systems for its partners from the industry. Our technology areas cover the following topics: laser and optics, medical technology and biophotonics, laser measurement technology and laser material processing. This includes laser cutting, caving, drilling, welding and soldering as well as surface treatment, micro processing and rapid manufacturing. Furthermore, the Fraunhofer ILT is engaged in laser plant technology, process control, modeling as well as in the entire system technology.

www.ilt.fraunhofer.de

Fraunhofer Institute for Surface Engineering and Thin Films IST

As an industry oriented R&D service center, the Fraunhofer IST is pooling competencies in the areas film deposition, coating application, film characterization, and surface analysis. Scientists, engineers, and technicians are busily working to provide various types of surfaces with new or improved functions and, as a result, help create innovative marketable products. The institute's business segments are: mechanical and automotive engineering, aerospace, tools, energy, glass and facade, optics, information and communication, life science and ecology.

www.ist.fraunhofer.de

Fraunhofer Institute for Physical Measurement Techniques IPM

Fraunhofer IPM develops and builds optical sensor and imaging systems. These mostly laser-based systems combine optical, mechanical, electronic and software components to create perfect solutions of robust design that are individually tailored to suit the conditions at the site of deployment. In the field of thermoelectrics, the institute has extensive know-how in materials research, simulation, and systems. Fraunhofer IPM also specializes in thin-film technologies for application in the production of materials, manufacturing processes and systems. www.ipm.fraunhofer.de

Fraunhofer Institute for Material and Beam Technology IWS

The Fraunhofer Institute for Material and Beam Technology is known for its innovations in the business areas joining and cutting as well as in the surface and coating technology. Our special feature is the expertise of our scientists in combining the profound know-how in materials engineering with the extensive experience in developing system technologies. Every year, numerous solution systems have been developed and have found their way into industrial applications.

www.iws.fraunhofer.de

THE FRAUNHOFER-GESELLSCHAFT AT A GLANCE

The Fraunhofer-Gesellschaft

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

At present, the Fraunhofer-Gesellschaft maintains 66 institutes and independent research units. The majority of the more than 22,000 staff are qualified scientists and engineers, who work with an annual research budget of 1.9 billion euros. Of this sum, more than 1.6 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.

Affiliated international research centers and representative offices provide contact with the regions of 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 Institute (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 accommodation, 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 until 2015:

- Integrative Production Technologies Cluster
- Logistics Cluster
- Heavy Duty & Off-Highway Powertrain Cluster
- Digital Photonic Production 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 Digital Photonic Production Cluster.

Source:

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

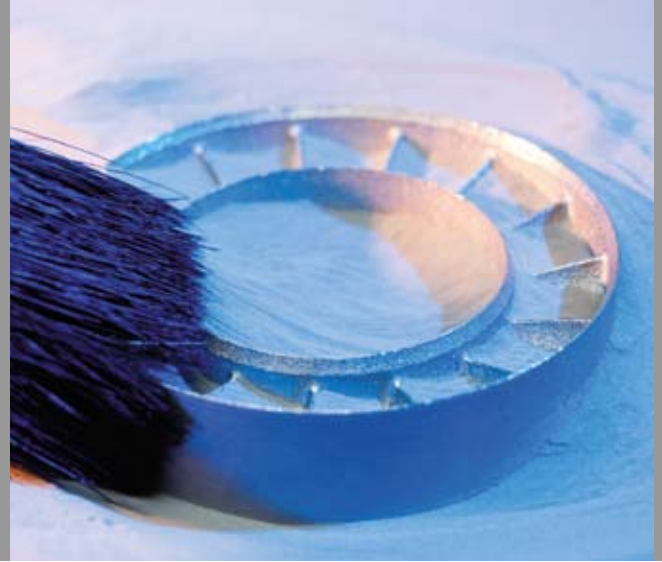
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- 1 RWTH Aachen Campus I - Westbahnhof,
Sketch: RKW Rhode Kellermann Wawrowsky,
Düsseldorf.
- 2 RWTH Aachen Campus II - Melaten,
Sketch: rha reicher haase + assoziierte, Aachen.

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 put to the test in an initial batch of pilot facilities for use in 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

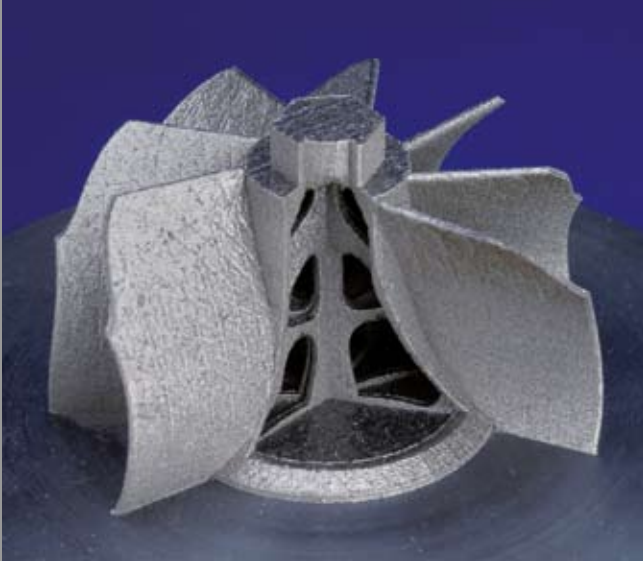
Digital photonic production goes far beyond laser-based additive manufacturing processes. New high-output ultrafast lasers, for example, can achieve very fast ablation almost regardless of material – allowing the finest of functional 3D structures to be produced down to the nanometer region. This new 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 2012

Selected Research Results of the Fraunhofer ILT

- Lasers and Optics 39 - 60
- Laser Material Processing 61 - 114
- Medical Technology and Biophotonics 115 - 122
- Laser Measurement Technology
and EUV Technology 123 - 129

Note from Institute Director

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

TECHNOLOGY FOCUS

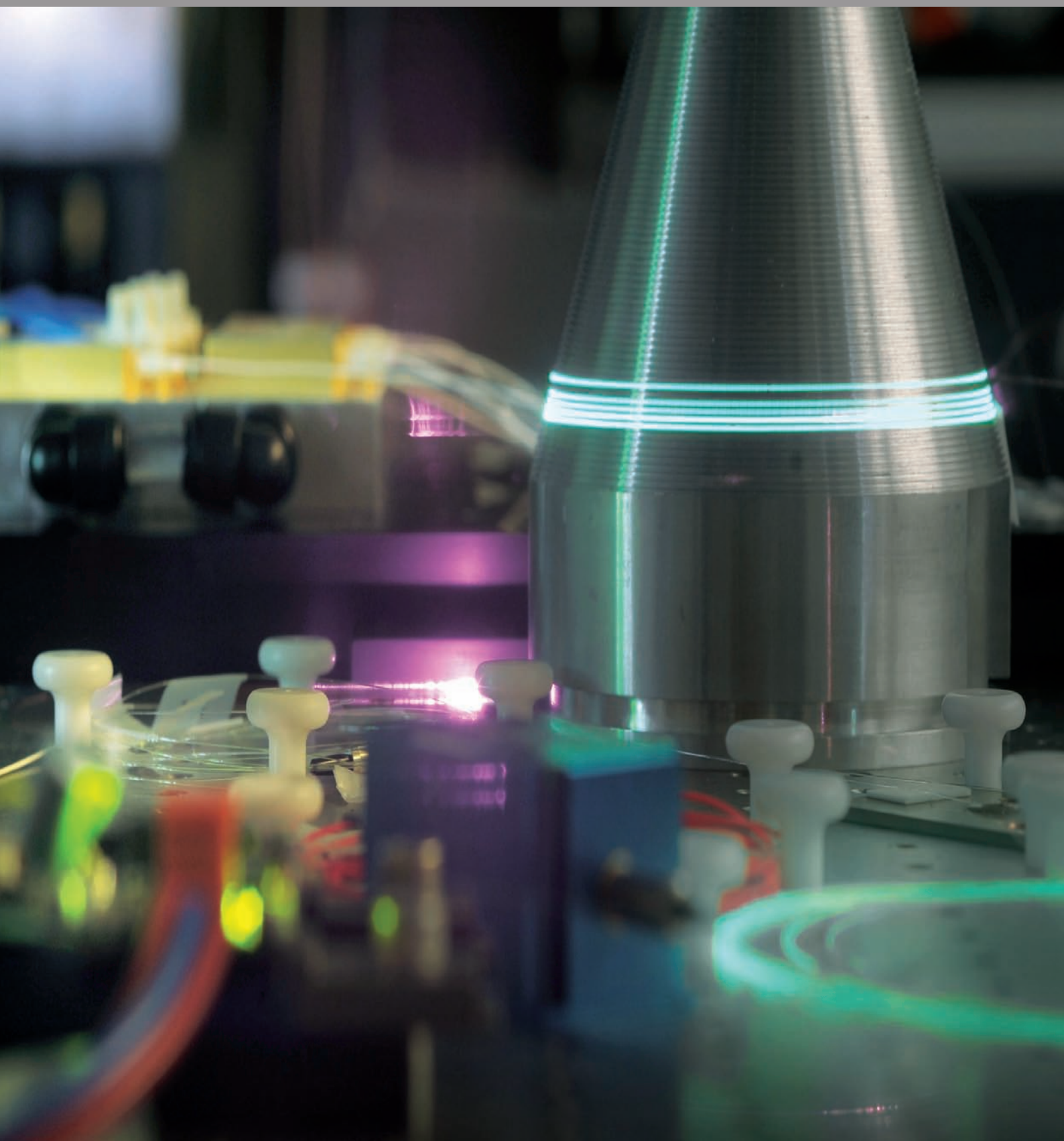
LASERS AND OPTICS

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

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

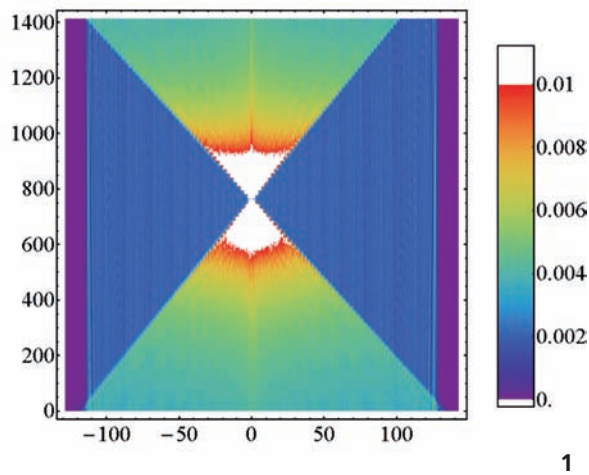
Furthermore, this technology field has a great deal of expertise in beam shaping and guiding, packaging of optical high power components and designing optical components. This field also specializes in dimensioning highly efficient free form optics. In general, the lasers and optics developed here can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

LASERS AND OPTICS

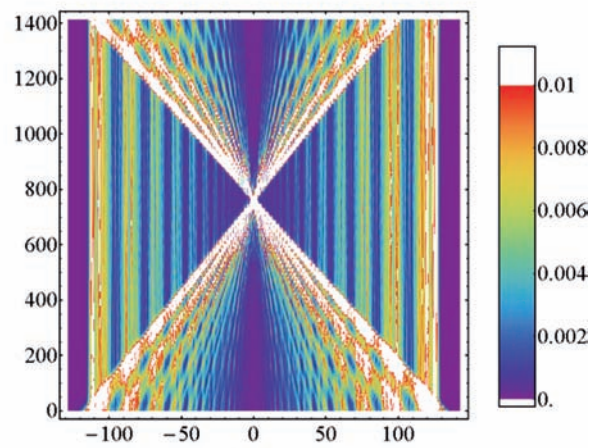


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1



2

MODELING AND SIMULATION OF UNSTABLE LASER RESONATORS

Task

On account of increasingly higher output powers for material processing applications combined with brilliant beam quality, two concepts for multi-kW systems have become commonplace in industry for gas lasers: the multiple folding of stable resonators, and unstable resonators. The advantage of unstable resonators relates to the excellent utilization of the active medium. Current research is focusing on analyzing the dynamics in various operating states (transient behavior, startup, power modulation, power scaling).

Method

To explain, predict and control the laser output power that varies over time and the intensity distribution of transiently operated multi-kW systems, a simulation was developed that can describe the beam distribution in the resonator, the influence of spatially and temporally distributed radiation quantities in the resonator, and the influence of the active medium.

Result

Almost the only way to describe unstable resonators is by using numerical calculations, since no analytical solutions are available for this resonator type. The frequently encountered fractal properties of the eigenmodes of these kinds of resonators pose specific numerical challenges when calculating the modes (numerical resolution, convergence, etc.).

Applications

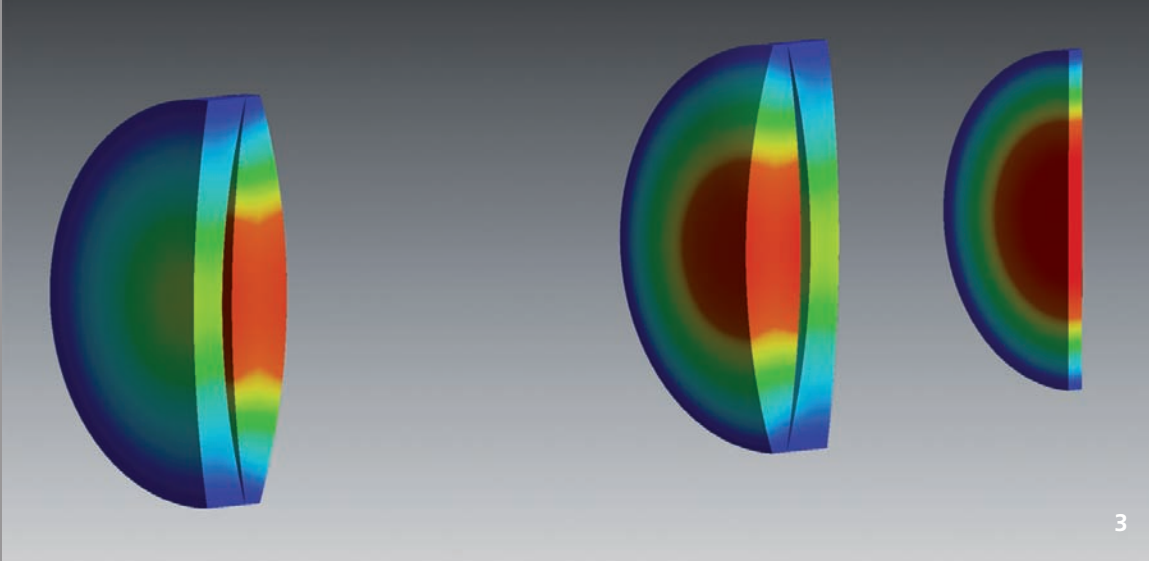
The presented modeling and simulation is particularly suited to radiation propagation in unstable resonators and can therefore be used to optimize existing multi-kW systems for material processing both in cw mode and in pulsed mode.

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Intensity distribution of the 1st mode (Fig. 1) and the 50th mode (Fig. 2) of an unstable resonator.



3

OPTICS SIMULATION WITH THERMAL ABERRATIONS

Task

Thermal inhomogeneities in optical systems (temperature profile, deformation, stress distributions), arising for instance from local absorption of laser radiation, may lead to a significant change in optical properties and, in turn, to a reduction in imaging performance. Sophisticated ray-tracing software, which enables system properties to be optimized, is now used to design optical systems. Thermal inhomogeneities cannot, however, be simulated adequately at present; hence the need to augment the capabilities of the optics simulation. The aim is to support end-to-end thermo-optic simulation, which will allow thermally aberrated systems to be analyzed and optimized.

Method

The link between thermal and optical simulation is achieved by means of an interface between the software packages Ansys (FE method) and Zemax (ray tracing). The thermal simulation (FE) is based on degrees of absorption, which are calculated as part of the ray tracing. Following an approximation step, the ray tracing can be used to analyze the changed beam path taking thermal effects into account.

Result

Current extensions and improvements within the approximation process enable the simulation of both symmetrical and asymmetrical loads and temperature distributions. This facilitates the analysis of laser systems subject to high thermal loads, which allows investigations of focus shifts as well as of higher aberrations and opens up the prospect of offsetting these factors.

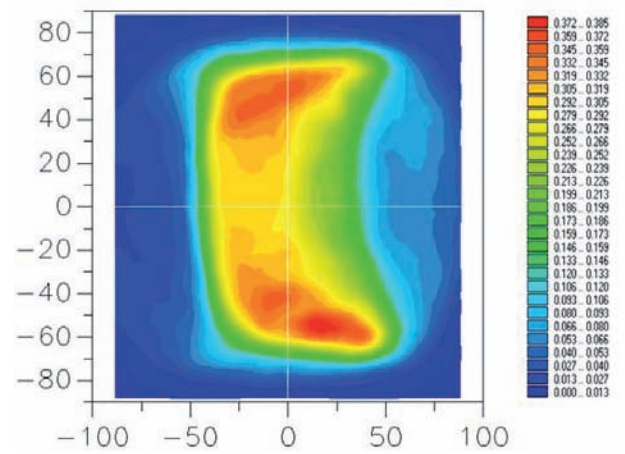
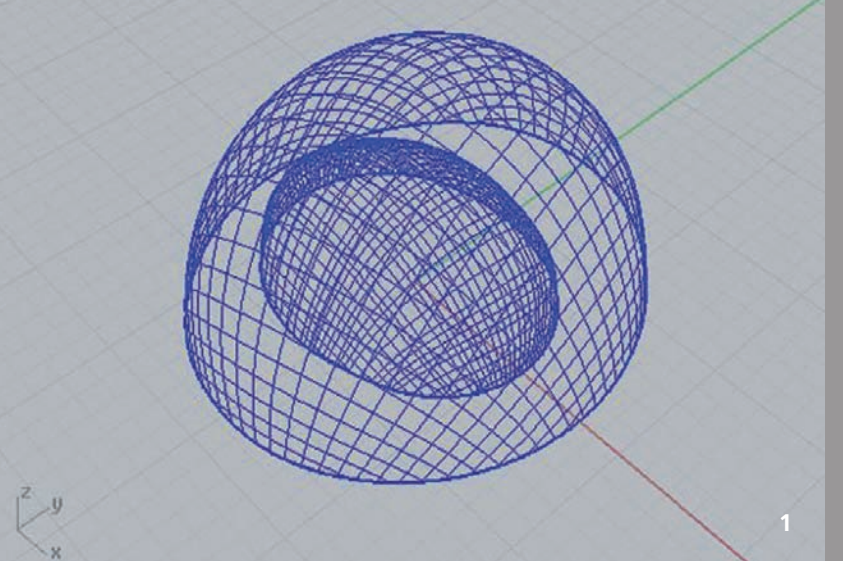
Applications

This simulation link facilitates research in the field of laser technology as well as other applications such as lighting technology. At the same time, the functionality is not limited to thermal effects and can in principle be extended to all inhomogeneities that influence the refractive index. These include stress distributions caused by thermal or mechanical loads as well as simulation of inhomogeneities arising in polymer lenses as a result of the injection molding process.

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FREEFORM SURFACES FOR STREET LAMPS

Task

Street lamps must meet legal requirements relating to brightness, but must also be cost-effective to install and, in particular, to run. The major factor in this besides maintenance costs is the cost of energy. The remit was to develop a street lamp that meets the legal requirements while consuming as little energy as possible.

Method

The legal requirements set out, in particular, the minimum brightness across the entire illuminated area. Since in the case of conventional lamps the brightness is considerably higher directly under the lamp than in outlying areas, ensuring a minimum brightness across the entire area entails producing much more light in the central area near to the lamp – with consequently higher energy consumption. A combination of highly efficient LEDs and freeform optics allows light to be distributed much more evenly on the road and sidewalk.

Result

Algorithms were developed and implemented as part of the project and these were used to design the freeform lens shown in Fig. 1. This lens enables the necessary light output and, in turn, the energy consumption to be almost halved. Fig. 2 shows the intensity distribution in the angular space. This produces a largely homogeneous distribution on the road and sidewalk.

Applications

Algorithms relating to optical freeform design devised as part of the project provide a superior solution in all lighting areas, including interior lighting or automotive lighting.

The research was funded by Germany's Federal Ministry of Education and Research (BMBF) as part of the "OptiLight" project (reference code 02 PO 2464).

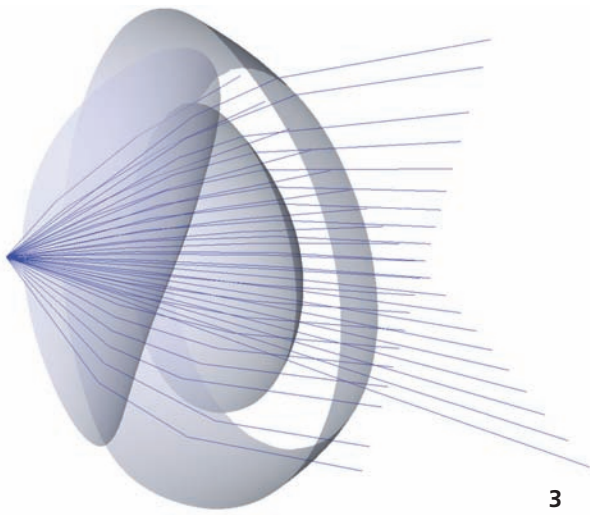
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1 CAD model of the freeform lens for use as a street lamp.

2 Simulated intensity distribution in the angular space, implemented using the freeform lens.



3



4

DEVELOPMENT OF POLYMER FREEFORM OPTICS FOR AUTOMOTIVE LIGHTING

Task

Compared with glass optics, optics made out of polymers are lighter and can be mass produced cost-effectively using injection molding. This in turn provides much greater flexibility in designing the optical surfaces. Limitations associated with the injection molding process need to be considered when manufacturing polymer optics. The aim is to minimize structural dimensions and weight as well as minimizing the power input of automotive lighting in conjunction with efficient LED light sources.

Method

Conventional optics for automotive lighting, which are used for applications such as dipped headlights and fog lights, tend to use a shutter imaged onto the road, thus ensuring good illumination without dazzling other road users. While this does provide a sharply defined light-dark cutoff, it nonetheless also limits the efficiency of the optics, since the shutter shades part of the emitted light. Freeform optics allow the angular distribution of light emitted by LEDs to be transformed into a required target distribution without shading, thus maximizing the efficiency of the configured optics. Using a combination of two freeform optics at the entry and exit surfaces allows the component geometry to be optimized for injection molding process requirements.

Result

An initial demonstrator for a fog light with two freeform surfaces was optimized and successfully qualified by project partner HELLA in relation to legal requirements for luminance distribution. For a second demonstrator, manufactured as an injection-molded component, daytime running lights were integrated as a further lighting function alongside the fog light, achieving an efficiency of 60 percent.

Applications

The algorithms developed for the simultaneous optimization of multiple freeform optics can be used in all areas of lighting technology where an application-tailored target distribution is required with a given input distribution, e.g. street lighting as well as interior and exterior architecture.

The research was funded by Germany's Federal Ministry of Education and Research (BMBF) as part of the "Autolight" project (reference code 13N10832).

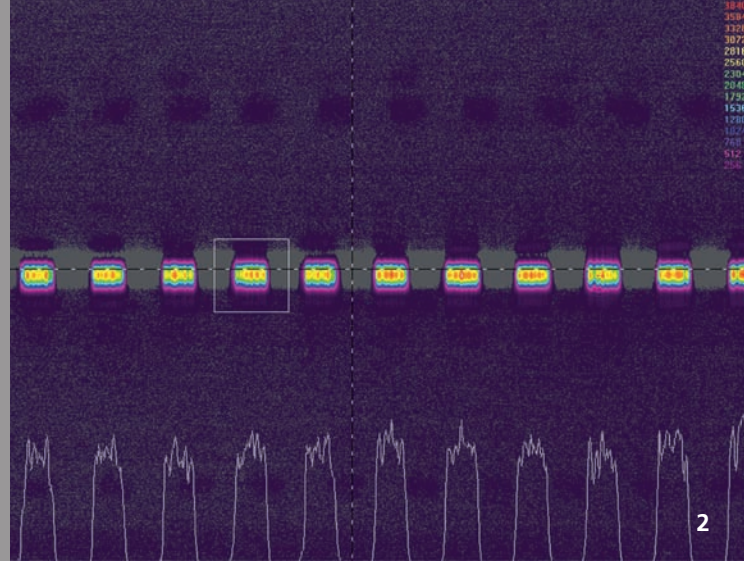
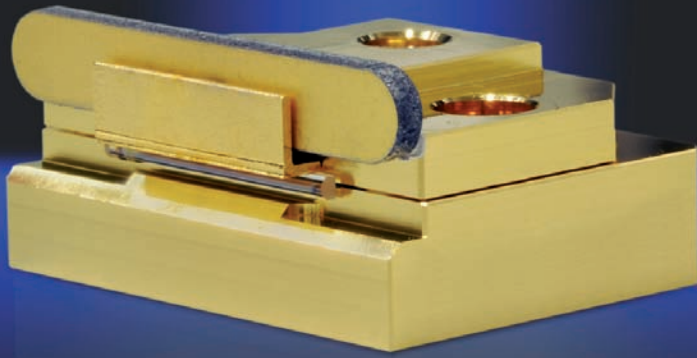
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3 Ray-tracing model of the freeform fog light optics.

4 Implemented prototype of the freeform fog light optics.



MECHANICALLY AND THERMALLY STABLE MICRO-OPTICS ASSEMBLY USING SOLDERING TECHNIQUES

Task

Stable high precision joining techniques for assembling micro-optics are a prerequisite whenever diode laser modules are to be used under extreme environmental conditions with large mechanical and thermal loads. Consequently, the research will focus on assembling the FAC (Fast Axis Collimation) lens for diode laser bars using resistance soldering techniques. In addition to modifying the soldering technology developed at Fraunhofer ILT, a particular focus lies on assembly accuracy and the behavior of the FAC lens during the thermal alternating load cycle from -30 °C to +50 °C.

Method

The soldering technology used to assemble the FAC lenses needs to be modified for the tests that will be conducted on account of the use of conventional laser bars, heat sinks and FAC lenses. To this end, the peripheral equipment and the processes are being modified so that soldering can be completed in a vertical position. The ceramic required for the resistance soldering is applied on the heat sink. The FAC lens is then actively aligned on top of the ceramic and soldered. The beam

properties (size and position of the emitters) are determined using a camera. If the deviation of the spot size exceeds the preset tolerance (> 10 percent) after the solder hardens, the join can be melted and the lens readjusted.

Result

The assembly technology for FAC lenses developed at Fraunhofer ILT guarantees a thermomechanically stable join. The modification of the beam properties through hardening of the solder is around 1 percent. The thermal alternating load cycles were successfully completed.

Applications

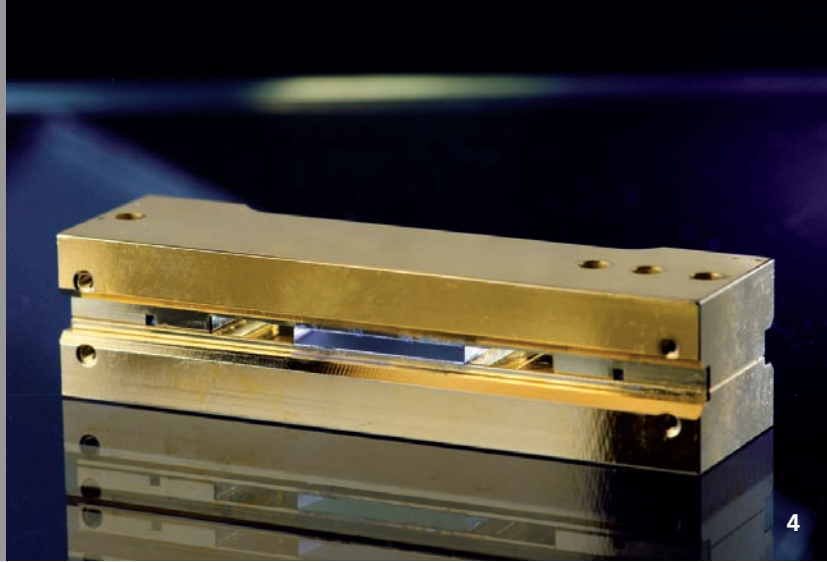
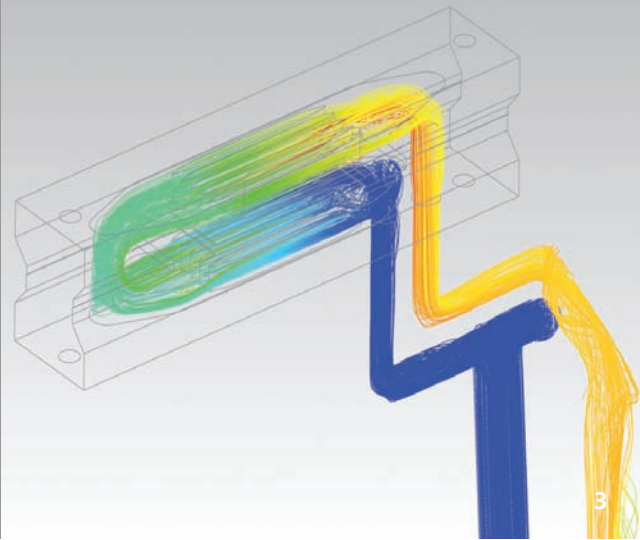
The process described for assembling FAC lenses is suitable for use in optical systems for aerospace applications, for pumping of solid state lasers, in medical technology and direct materials processing. The technology also boasts major potential regarding automated assembly.

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- 1 FAC lens assembled in front of the diode laser bar (experimental setup).
- 2 Camera image of the emitters following the temperature cycle test.



REFLOW SOLDERING PROCESS FOR LASER CRYSTALS

Task

Laser crystals constitute the key component of any solid-state laser. A reliable, good thermo-conductive connection between crystal and heat sink is therefore crucial in meeting the increasing requirements in relation to beam quality, pump and output power, thermal stability and robustness. To improve the thermal performance and long-term stability, in particular, reflow soldering is replacing clamping and adhesive techniques. The process needs to be suitable for various types of crystal.

Method

Actively or passively cooled heat sinks are used, taking into account the properties of the crystal materials such as Yttrium Aluminum Garnet (e.g. Nd:YAG or Yb:YAG) or Yttrium Vanadate (e.g. Nd:YVO₄), and optimized in relation to homogeneous cooling with low thermal resistance. The reflow soldering process developed at Fraunhofer ILT generates the thermal interface between the crystal and metallic joining partner. The process chain, consisting of solder application, metallization of the components and soldering process is coordinated and defined depending on the specific task.

Result

A fluxing-agent-free soldering process was developed for assembling rectangular crystals (= slab) in particular. The results were applied to various crystal geometries and applications. Thus reliable connections with high thermoconductivity were generated. Mechanical distortion of the laser crystals is also prevented. In temperature cycle tests the reliability of the connection was demonstrated in a range of -30 °C to +50 °C. With the Yb:YAG laser crystals measuring 10 x 10 x 1 mm³ that were cooled in this way, an average laser output power of more than 700 W was achieved. Areas measuring 10 x 10 mm² are used as the cooling interface.

Applications

Laser crystal modules produced using the reflow soldering process are used in laser oscillators and amplifiers for solid state lasers, i.e. both for high-output ultrafast lasers and in LIDAR beam sources for aerospace applications. Expertise in fluxing-agent-free, low-tension and robust soldering technology can also be used to join other thermally and mechanically loaded components.

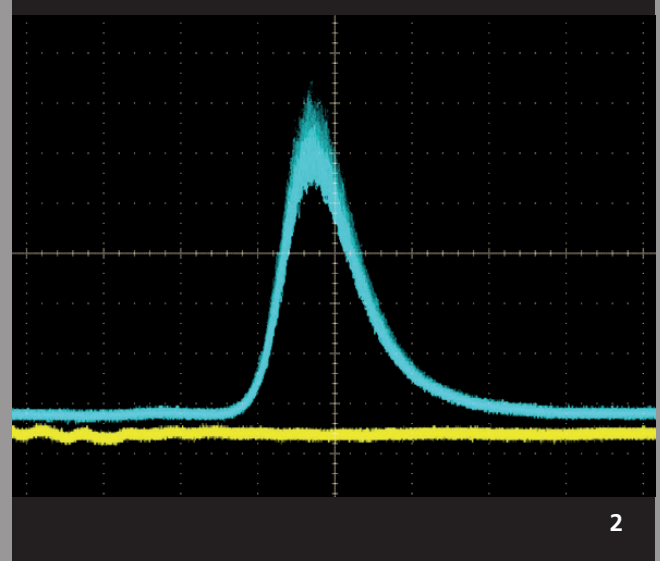
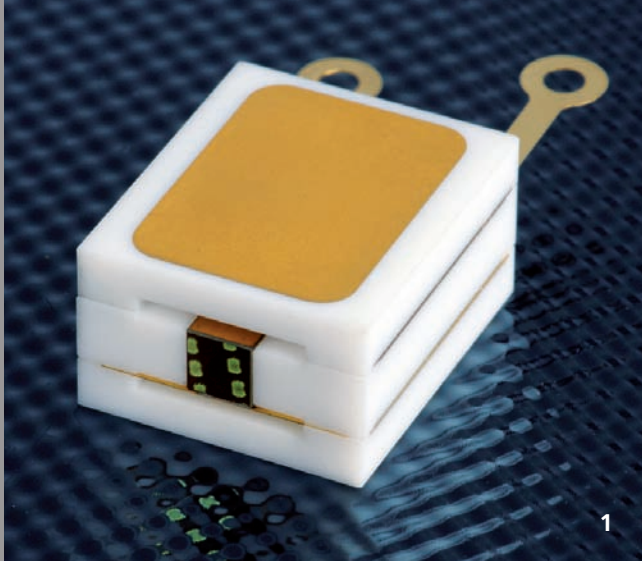
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3 Cooling circuit in the laser crystal module.

4 Soldered laser crystal module.



THERMOMECHANICALLY ROBUST POCKELS CELL

Task

Mechanically and thermally stable laser components are required for use in LIDAR systems for atmospheric research. The assembly of Pockels cell crystals poses major challenges due to the optical, electrical and thermomechanical conditions. The research aims to investigate how a Pockels cell module can be assembled using a soldering process. Varying coefficients of thermal expansion along the crystal layers ($\alpha_1/\alpha_{33} = 1/9$) pose a particular challenge. The assembly concept needs to support alternating temperatures of -30 °C to $+50\text{ °C}$.

Method

The elastic design of the supporting structures reduces the load on the BBO crystal during soldering and the temperature cycle. The BBO crystal is soldered between two metal sheets which are themselves soldered to the ceramic housing. The metal sheets are designed to prevent an electrical sparkover. The entire Pockels cell module is soldered simultaneously, eliminating the need for any further steps to mount the module in the housing. The module thus mounted can be aligned in the laser and joined as a whole.

Result

The assembly method developed at Fraunhofer ILT for Pockels cells ensures that thermomechanically stable modules can be manufactured. Following the completed temperature cycle test, the quarter-wave voltage at 3.85 kV was achieved with a crystal measuring $4 \times 4 \times 20\text{ mm}^3$. The Pockels cell was successfully tested in Q-switched mode.

Applications

The range of applications of the process described for assembling Pockels cells goes well beyond aerospace applications. The concept presented can also be used in laser beam sources for laser material processing, for metrology and medical technology applications.

The work is funded by Germany's Federal Ministry of Economics and Technology (BMWi) as part of the »OptoMech II« project (reference code 50 EE 0904).

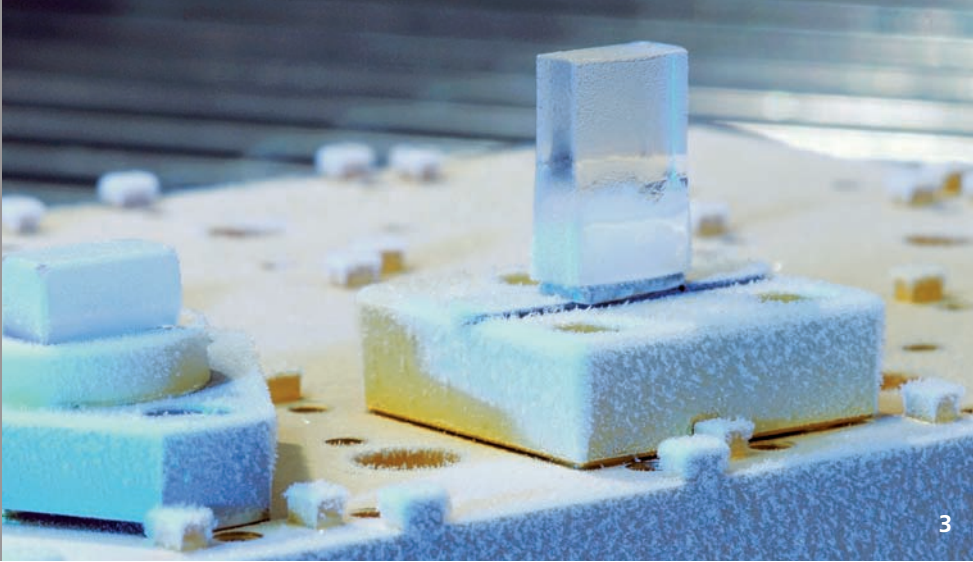
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1 Pockels cell in ceramic housing assembled using solder.

2 Oscilloscope image of the laser pulses in Q-switched mode.



ENVIRONMENTAL TESTS ON LASER COMPONENTS

Task

Laser systems that are operated or transported under extreme environmental conditions must be qualified beforehand – a requirement that applies particularly to the satellite-based use of these laser systems. Environmental tests are conducted on the individual laser components to provide overall qualification of the laser systems.

Method

The environmental tests include temperature change and vibration tests. In the course of the temperature change tests e.g. from -30 °C to +50 °C, the laser components are subjected to a fixed number of temperature cycles using a controlled-environment chamber. As materials with different coefficients of thermal expansion often have to be joined, the stresses and deformations induced by the temperature changes attract particular interest. Many of the modules assembled in the laser system (e.g. mirrors) rely on very precise angular positioning. Fraunhofer ILT therefore used an autocollimator to take angular measurements on components with plane mirrors during the temperature change tests. These measurements record the change in the plane mirror's angular position over the duration of the climate test. In the course of the vibration tests, a shaker is used to test components mechanically by applying shock and vibration loads at room temperature. Following the environmental tests, the components can undergo optical measurements or mechanically destructive tests where necessary.

Result

The environmental tests allow for determining the extent to which components are thermomechanically stable against temperature changes and/or mechanically stable against shock and vibration loads. The findings from subsequent optical measurements or mechanical destruction tests provide further insights into the thermal or mechanical behavior of components and modules.

Applications

The climate tests conducted at Fraunhofer ILT are a core component of qualifying laser components for LIDAR systems for aerospace applications. They can also be used as qualification methods for any components that are exposed to harsh environmental conditions.

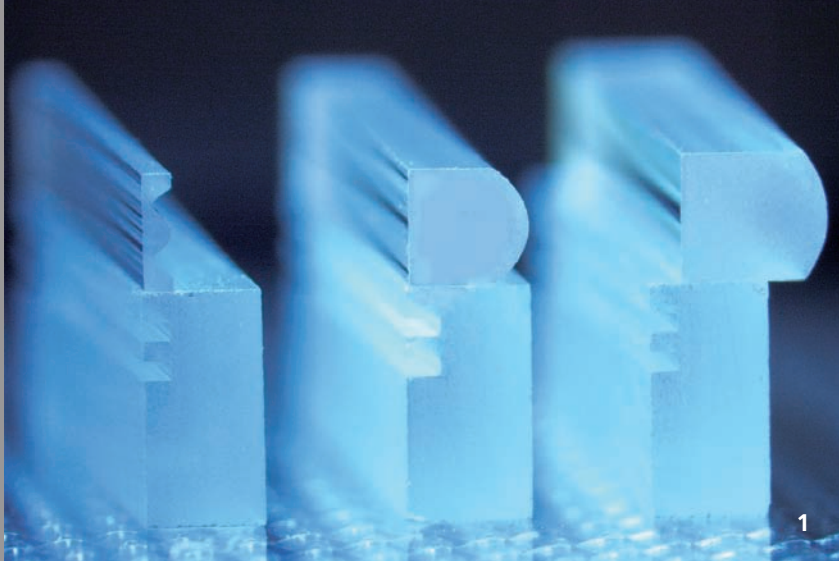
The work is funded by Germany's Federal Ministry of Economics and Technology (BMWi) as part of the »OptoMech II« project (reference code 50 EE 0904).

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3 *Laser components during
the temperature change test.*



ALGORITHMS FOR THE AUTOMATIC ALIGNMENT OF MICRO-OPTICAL COMPONENTS

Task

The vast majority of manufacturing processes in the production chain for high-powered diode lasers are fully or partially automated, with alignment of the micro-optical components for beam formation as the only manual process. Assembling the micro-optics manually is a fairly time-consuming and costly process during the manufacture of diode laser modules. There are still no suitable beam-analysis algorithms that support the fully automated alignment of micro-optical components – especially fast-axis collimation lenses for high-powered diode laser bars – in six degrees of freedom.

Method

The power density distribution behind misaligned fast-axis collimation lenses is modeled as a function of the six-dimensional misalignment of the lens. Interrelationships are derived from the model and these provide a clear, quantitative prediction of the misalignment by analyzing the power density distribution in the near or far field. The misalignment can be corrected in a single step using the calculated prediction.

Other algorithms are also being developed that support iterative correction of the misalignment in those areas of beam distribution that are not, or not clearly, illustrated using models.

Result

The power density distribution behind the misaligned fast-axis collimation lenses allows the required correction to be predicted with a maximum uncertainty of a micrometer. This brings the time taken for a typical alignment down to less than ten seconds.

Applications

The findings can be used in the field of production technology for high-power diode lasers in order to fully automate the production chain. The developed models and algorithms can be modified and tailored to other beam sources and micro-optics.

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1 Microscope image of three FAC lenses.



HIGH-BRIGHTNESS DIODE LASER MODULES IN THE RED SPECTRAL RANGE

Task

High-brightness beam sources with emission in the red spectral range are required for direct materials processing, medical technology or pumping solid-state lasers, e.g. an alexandrite laser for climate research. A diode laser module for direct, longitudinal pumping of an alexandrite laser should achieve a pulsed output power of at least 10 W with a minimum 35 Hz pulse repetition rate and around 200 μ s pulse duration.

Method

An optomechanical concept for the tight overlay of the radiation using a minimal number of optical components for collimation and focusing was selected. The concept can be tailored quickly to individual customer requirements for the entire spectral range from UV through to IR. The optics was designed using commercial ray-tracing software for optimum intensity distribution of the pump radiation in the crystal. In order to ensure an even temperature of the diodes and hence a spectral width that is as small as possible, the shape of the heat sinks was modified accordingly.

Result

A diode laser module with an optical output power of more than 13 W (peak pulse output in the focus) was set up. The spectral width at 2.2 nm corresponds to the statistical dispersion of the individual emitters. 96.5 percent of the output power is linearly polarized. The beam quality is $M^2 = 45$ in the fast axis and $M^2 = 38$ in the slow axis.

Applications

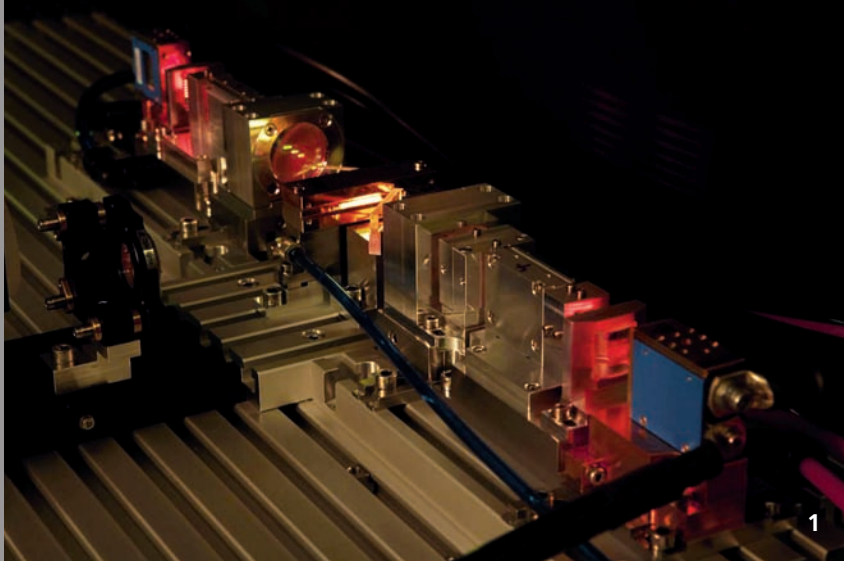
The development of high-brightness diode laser modules in the red spectral range enables flash lamps to be replaced as a pump source while substantially increasing the energy efficiency of alexandrite solid-state lasers and extending maintenance-free operating times.

The research was funded partly by Germany's Federal Ministry of Education and Research (BMBF) as part of the "SPEKTRALAS" project (reference code 13 N 8729).

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TM:YLF INNOSLAB LASER WITH 200 W AT 2 μ M

Task

The wavelength region around 2 μ m supports a variety of applications ranging from medical applications and trace gas detection in the atmosphere to processing VIS-transparent materials. A system with Thulium (Tm) and Holmium (Ho) as laser-active ions in solid-state crystals is well established as an efficient way to generate laser radiation at 2 μ m. Tm-doped materials are well suited as active materials in cw laser beam sources and can be diode-pumped directly at 800 nm. Ho-doped solids are also suitable for energy storage operation and can be pumped using Tm based lasers. The INNOSLAB concept is ideal for implementing the diode laser/Tm laser (cw)/Ho laser (pulsed) chain for large optical output powers above 100 W. The aim of the work is to study the entire chain and provide amplifiers with high average output power for scaling commercial lasers in the region of 2 μ m.

Method

A Tm:YLF INNOSLAB crystal is pumped partially from both ends using diode laser stacks at 792 nm. The produced gain volume with a rectangular cross-section and large aspect ratio is incorporated in a stable resonator whose Gaussian fundamental mode in the narrow axis is adjusted to the height of the gain volume and operated in high multimode ($M^2 > 100$) in the wide axis.

This produces a homogeneous top-hat-shaped beam distribution that is particularly suited to pumping a Ho-doped laser crystal with an INNOSLAB geometry.

Result

An optical cw output power of 200 W with a wavelength of 1.9 μ m is achieved from an absorbed pump power of 490 W. The optical efficiency in relation to the absorbed pump power is 40 percent; the slope efficiency is 50 percent. The efficiency is currently limited by the damage threshold of the mirror coatings used; other coatings are being investigated.

Applications

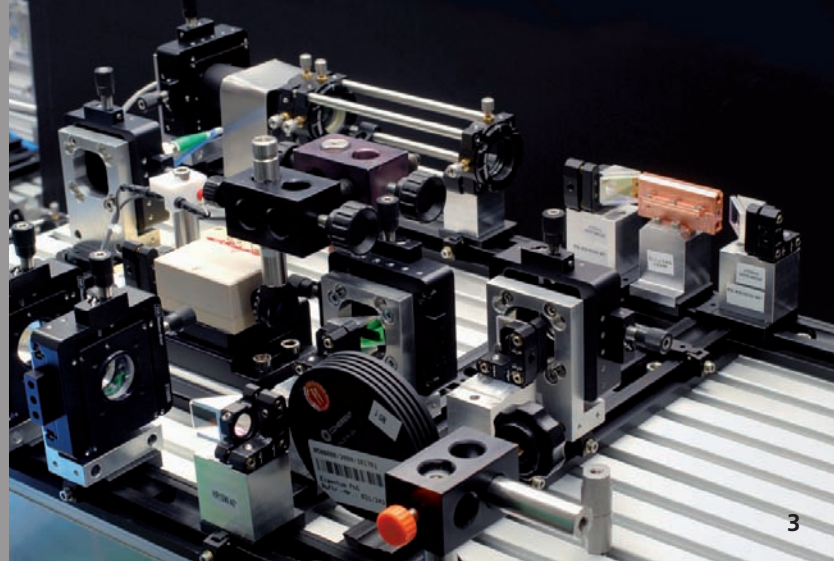
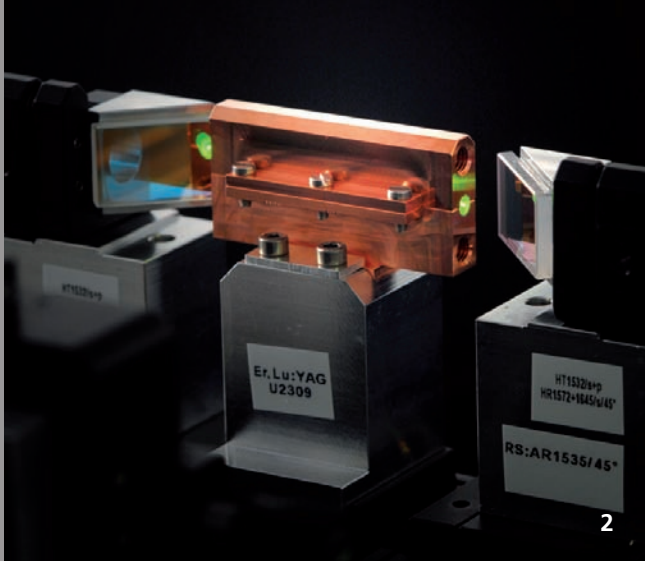
Apart from use as a pump source for Ho-based INNOSLAB amplifiers around 2 μ m, the laser is also suitable for direct material processing.

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1 Tm:YLF INNOSLAB laser. Source: Berthold Leibinger Stiftung GmbH.



SINGLE-FREQUENCY ER:YLUAG LASER AT 1645 NM FOR A METHANE LIDAR

Task

The distribution and quantity of the greenhouse gases CO₂ and CH₄ in the atmosphere influence the climate, which is why they are the subject of research. Absorption lines of molecules in the 1.6 μm range can be used to measure these gases with LIDAR techniques. These techniques require narrowband (single frequency) laser radiation with a line width under 20 MHz; to date, this has been implemented using nonlinear conversion stages (OPO/OPA). Directly generating this kind of laser radiation in solid state lasers based on erbium-doped crystals dispenses with additional nonlinear processes and promises superior efficiency and robustness. Both are important factors for subsequent use on satellites.

Method

A solid state laser with an erbium-doped laser crystal is set up, and pumped with fiber lasers at a wavelength of 1532 nm. The Er:YLuAG laser crystal has a specifically optimized composition whereby the maximum emission cross-section in the erbium ion occurs at the envisaged emission wavelength. The laser oscillator is Q-switched at a repetition rate of 100 Hz and runs in longitudinal single mode ("single-frequency") with active resonator length control.

Result

For the first time a pulsed laser was set up with this laser material; it currently achieves a pulse energy of 2.3 mJ with approx. 3 percent optical efficiency and $M^2 = 1$ in single-frequency mode. The pulse duration is 90 ns. For the first time the methane absorption line at 1645.1 nm (in air) together with its substructure was successfully measured in a methane reference cell in the laboratory without the use of nonlinear converter stages.

At present, the pulse energy is limited by the available pump power. Based on the results obtained to date, further research aims to achieve a minimum two-fold efficiency increase from improved crystal cooling and an optimized design of the laser resonator.

Applications

Laser radiation with wavelengths around 1.6 μm also has uses in medical technology. Another potential application is in laser material processing for materials that are transparent at visible wavelengths.

This research was funded by Germany's Federal Ministry of Education and Research (BMBF) under reference number 01 LK 0905 B.

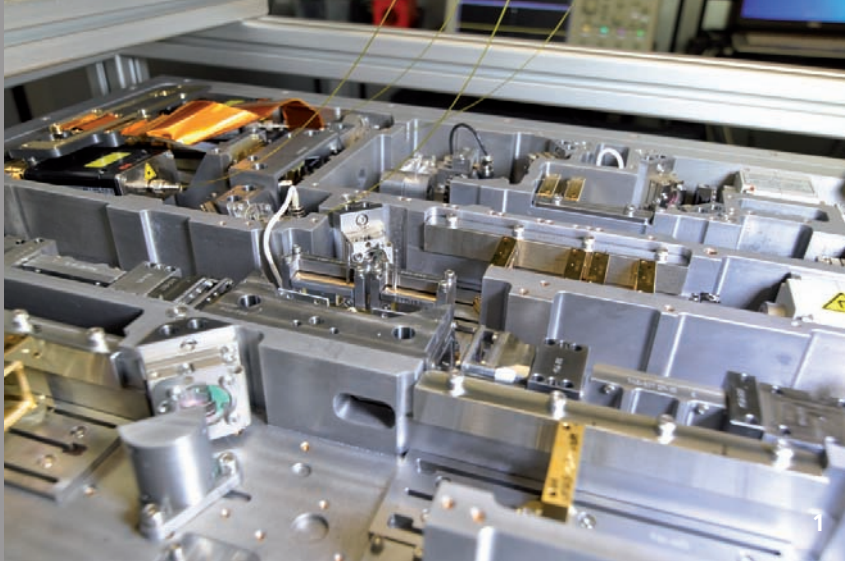
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2 Er:YLuAG laser crystal.

3 Single-frequency laser with Er:YLuAG crystal.



COMPACT LASERS FOR AIRBORNE LIDAR SYSTEMS

Task

A long-term goal of climate research is to determine all climate-relevant variables continuously and globally with high spatial resolution. This kind of data will in future be generated by satellite-based LIDAR systems. The use of airborne systems as technology demonstrators is an important step toward achieving this goal.

To this end, a beam source for measuring wind-speed profiles is being developed together with three pump beam sources for CO₂ and CH₄ density measurements. They meet the particular requirements of efficiency, compactness, robustness and safety associated with use in aerospace applications.

Method

The four lasers were designed as MOPA systems, some of them multistage, with Nd:YAG crystals. Spectral beam properties are generated in an oscillator in longitudinal single-mode operation with low pulse energy (~ 10 mJ) and then amplified in INNOSLAB amplifier stages to 100 - 200 mJ. The target wavelength required for the particular application is generated in a frequency converter stage. The optical components are arranged in a compact configuration on both sides of a monolithic support structure that was optimized by means of FE simulations. The tilt properties of the individual

optomechanical components were tested, analyzed and optimized under vibration loads and temperature variations at Fraunhofer ILT.

Result

In line with requirements, stable single-mode operation of the integrated oscillators was demonstrated at pulse energies of 8 - 10 mJ, a repetition rate of 100 Hz and a pulse duration of 35 ns as well as amplification to 75 mJ in an initial amplifier stage. The four laser systems will be handed over to the respective project partners in 2013.

Applications

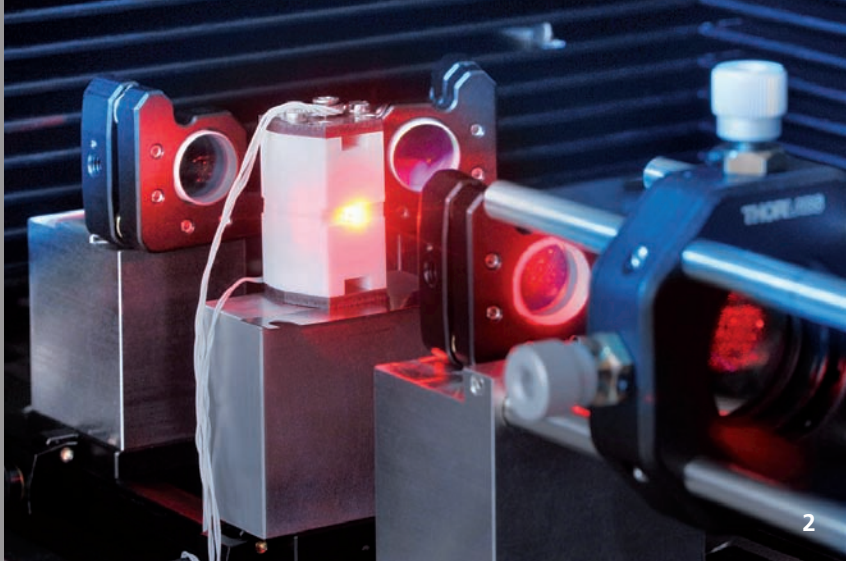
In the field of climate research, modifying beam parameters such as wavelength allows other climatic variables to be recorded in addition to the aforementioned measuring tasks. This technology can also be used in the industrial sector for monitoring industrial plant, checking gas pipes for leaks or measuring wind fields. The compact, robust design can be used for beam source development across a wide range of systems.

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1 Oscillator and INNOSLAB amplifier of the pump beam source for the CH₄ measuring system.



DIODE-PUMPED ALEXANDRITE LASER

Task

Mobile resonance LIDAR systems are being used at the Leibniz Institute of Atmospheric Physics (IAP) to measure temperature profiles of the atmosphere at altitudes between 80 and 110 km. These systems determine the Doppler width of the potassium resonance line at 770 nm and of the iron resonance line at 386 nm spectroscopically. Flashlamp-pumped alexandrite ring lasers in Q-switched single-frequency mode are used as laser emitters. Typical operational conditions include carrying out measurements on a research ship in rough seas or under polar conditions in the Antarctic. Due to harsh environmental conditions and the laser's remote operating locations, the project aims to extend maintenance-free operating times and the wall-plug efficiency. Therefore, the use of laser diodes as an alternative pump light source will be investigated at Fraunhofer ILT.

Method

A diode laser module developed at Fraunhofer ILT with emissions in the red spectral range is used to pump an alexandrite laser longitudinally. The pump radiation is linearly polarized; the depolarized power component is less than 4 percent. The pulse power is 13 W with a pulse repetition rate of 35 Hz and a beam quality factor (M^2) of 38 ± 2 and 49 ± 2 in the two spatial directions.

The alexandrite crystal used is 15 mm long and arranged in a 190 mm long laser resonator that is folded once. The temperature of the laser medium can be tuned between 30 °C and 190 °C using a thermostat.

Result

The output wavelength of the alexandrite laser in free-running mode is tunable between 755 nm and 788 nm by varying the crystal temperature. The laser achieves an optical-optical efficiency of 17.8 percent and a slope efficiency of more than 30 percent in fundamental-mode operation ($M^2 \approx 1.10$). Resonator losses are measured with the Findlay-Clay method to be around 1 percent.

Applications

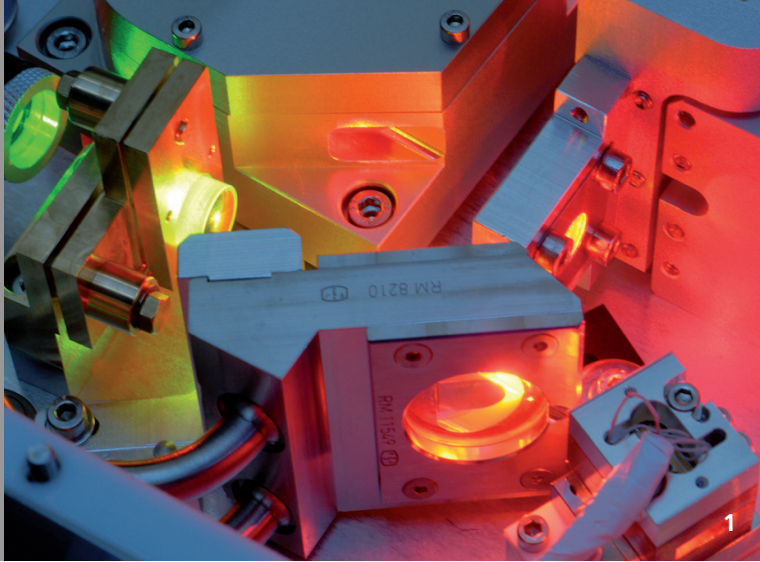
The research forms the basis for developing efficient, diode-pumped fundamental-mode lasers with freely selectable wavelengths between 700 nm and 800 nm for medical and metrological applications.

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2 *Laboratory setup of the diode-pumped alexandrite laser.*



TUNABLE UV LASER FOR AIRBORNE MEASUREMENTS

Task

Measurements of climate-relevant gases make a valuable contribution to our understanding of atmospheric processes. The hydroxyl radical plays an important role in the decomposition of pollutants in the air and is relevant to predicting phenomena such as smog. The Institute for Energy and Climate Research – Troposphere (IEK-8) of Forschungszentrum Jülich GmbH (FZJ) is using a tunable dye laser with intracavity frequency doubling and an emission wavelength of 308 nm to measure hydroxyl radical concentrations using laser-induced fluorescence (LIF). Since the radicals are extremely short-lived, measurements must be taken at the relevant altitudes. Therefore, the laser is mounted on top of an airship. Temperatures of 10 - 40 °C and ambient pressures of 800 - 1000 hPa occur when measurements are taken up to an altitude of 1500 m. The laser system previously used was unable to take continuous measurements under these operational conditions.

Method

First, the previous laser was analyzed in terms of current shortcomings. This involves both a theoretical tolerance analysis of the optical design as well as experimental testing of the components and the entire laser system in a climatic test chamber at Fraunhofer ILT.

To increase stability against environmental influences and to create power reserves, experiments were conducted on the optical redesign and the stability of optimized components tested in temperature cycles.

Result

Based on the results of the analyses and experiments, an optically, thermally and mechanically stable design was implemented together with the Forschungszentrum Jülich. This setup provided continuous LIF measurements over several weeks as part of the European PEGASOS campaign.

Applications

The methods and results of the theoretical and experimental analysis of the laser can be applied to other laser systems. Thereby, for the layout of a new or the revision of an existing optical design, the susceptibility to changes in environmental conditions can be decreased.

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1 Resonator of a tunable dye laser
with intracavity frequency doubling.



2



3

INVERSE LASER DRILLING FOR MANUFACTURING FIBER PREFORMS

Task

Optical fibers play an important role in telecommunications technology and in materials processing. Undoped fibers are used for low-loss guidance; doped fibers for generating and amplifying laser radiation. These kinds of fibers are manufactured by drawing preforms into which geometrical structures have already been incorporated. These structures then determine the optical properties of the fibers. Common techniques for manufacturing preforms include ultrasonic drilling or bundling a large number of individual tubes. A laser-based technique allows the manufacturing process to be automated, largely avoids contamination of the surfaces, and provides greater flexibility in relation to the geometry of the holes.

Method

To manufacture holes, the material being removed is ablated in successive layers. Each layer is scanned using a focused laser beam. The ablation takes place from the underside of the transparent material. The laser beam propagates through the unprocessed volume. In this way virtually any hollow volumes can be generated in the glass, including holes with an extreme aspect ratio and adjustable conicity.

A Q-switched INNOSLAB laser with a wavelength of 532 nm and a pulse duration of approx. 15 ns is used for the machining process. To improve the achievable drill depth, the influence of various process parameters is being investigated. A preform is manufactured with the ascertained process parameters and is subsequently drawn.

Result

Inverse laser drilling has been used to manufacture initial fiber preforms out of silica glass with a photonic structure, consisting of multiple drilling channels with a diameter of 800 μm and a length of 100 mm. The diameter of the fibers is 109 μm after the drawing process; the incorporated structures have a diameter of 3.9 μm .

Applications

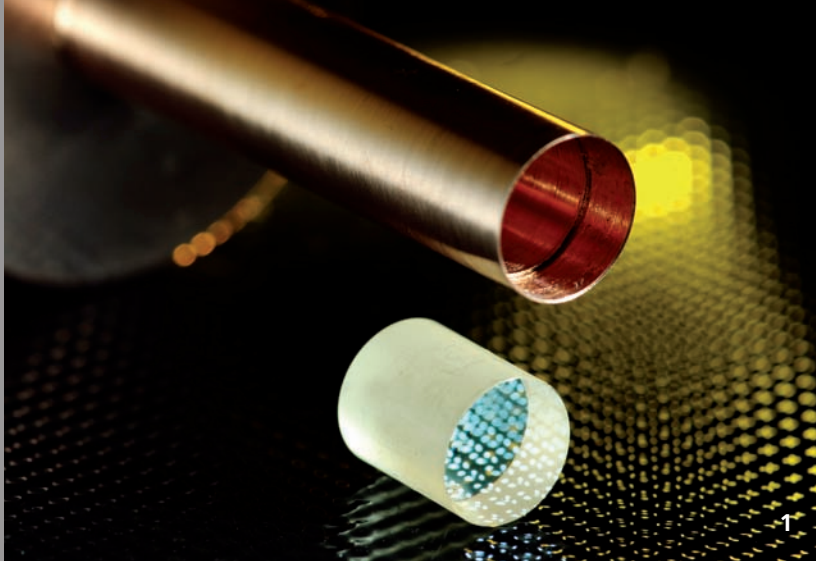
Possible applications of inverse laser drilling include all fields requiring drilling channels in glass with a high aspect ratio and low or adjustable conicity. The contactless machining process is particularly suited to manufacturing optical components such as fiber preforms.

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- 2 Drawing onion of a photonic fiber with a diameter of 26 mm.
- 3 Various fibre preforms for photonic fibers: drill diameter 600 μm , external diameter 43 mm.



FARADAY ISOLATOR FOR HIGH-POWER FIBER LASERS

Task

Fiber lasers have become a standard tool for the industrial processing of sheet and powdered metals. During processing, the dynamics within the weld pool or an unfavorable positioning of the beam path may cause the laser beam to be back-reflected into the beam source. Since fiber lasers are by their very nature sensitive to back-reflections, there is a need for optical isolators to prevent the reflected radiation from being recoupled into the source and to ensure stable, fault-free operation of the laser. This setup paves the way for additional applications and enables processes that have always suffered from back-reflection problems to be implemented reliably with laser output powers in the kW region.

Method

In order to maintain the excellent beam quality of the fiber laser, an initial stage investigated improved Faraday rotator crystals made from terbium gallium garnet (TGG) with extremely low absorption. The crystals were exposed to a laser beam with up to 1 kW of output power and a beam parameter product of 3 mm x mrad, and both the beam quality and the signal polarization behind the crystal were measured as a function of the transmitted power.

1 Cylindrical TGG crystal for the Faraday rotation
(length: 11 mm, Ø 10 mm).

Result

The project partner further optimized the absorption characteristics of the crystals so that operation was possible with 1 kW fiber laser radiation with a beam parameter product of 3 mm x mrad without any measurable degradation of the beam quality. The degree of polarization of the transmitted radiation decreases from 17 dB with no TGG crystal (reference measurement) to 16 dB with a TGG crystal, which is attributable to thermally induced effects, especially stress-induced birefringence. The influence of the thermally induced lens is minimal and can, if necessary, be compensated by adding an appropriate aspherical lens to the setup. The Faraday rotator thus meets the requirements for laser material processing. On this basis, an isolator for average output powers of 1 kW is currently being implemented, and will subsequently be tested in an industrial environment.

Applications

Wherever material is processed using fiber lasers, especially for applications in the high-power segment such as cutting, welding or selective laser melting, an isolator can be used in order to stabilize the process while protecting the beam source from damage. The usability of such a device can be increased further by means of double-sided fiber coupling. This research was funded by Germany's Federal Ministry of Education and Research (BMBF) under reference code 13N9890.

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DIODE-PUMPED GAIN-SWITCHED FIBER LASERS

Task

In addition to diode-seeded fiber amplifiers and Q-switched fiber lasers, the gain-switched fiber laser constitutes an alternative concept for pulse generation, especially at low repetition rates. In the gain-switched fiber laser the signal pulse is generated by pulsing the pump source. Subsequent frequency conversion poses a particular challenge since it calls for a pulse power that is as high as possible combined with low spectral bandwidth of the gain-switched fiber laser. This is being investigated experimentally and theoretically as part of the "Fazit" project, which is funded by Germany's Federal Ministry of Education and Research (BMBF).

Method

The gain-switched fiber laser can be configured as an entirely monolithic resonator with fiber Bragg gratings using multiple fiber-coupled pump modules in pulsed mode. In addition to implementing a resonator pumped from both sides, a setup optimized for frequency conversion with narrow bandwidth and linear polarization needs to be demonstrated as a gain-switched fiber master oscillator with subsequent pulsed-pumped fiber amplifier.

Result

The gain-switched fiber laser pumped from both sides achieved repetition rates up to 10 kHz, a peak pulse output power up to 10 kW, and a pulse duration down to around 40 ns.

The setup optimized for frequency conversion with subsequent fiber-integrated amplification provides linearly polarized output radiation with a peak power of over 2 kW and approx. 150 ns pulse duration with a spectral width of less than 350 pm at 90 percent enclosed power. The subsequent frequency conversion to 532 nm already achieved an efficiency of approx. 37 percent in an initial test.

Applications

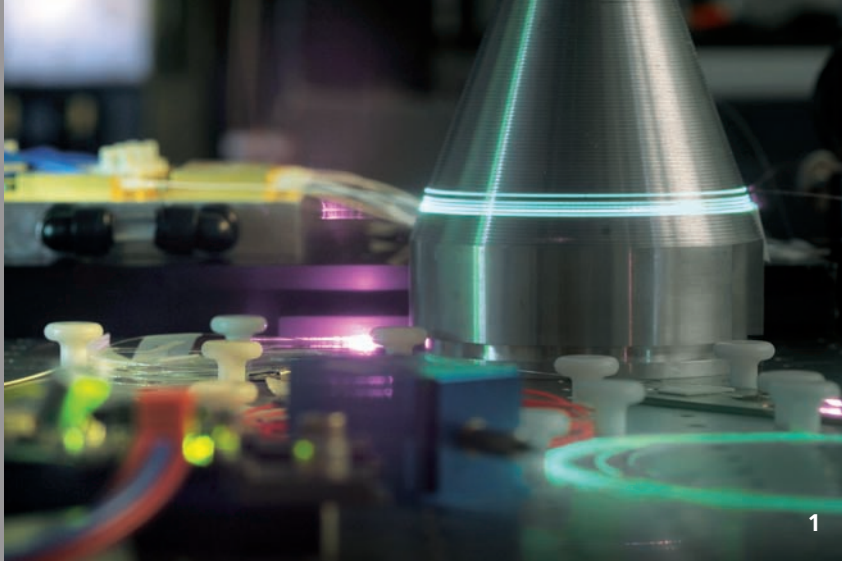
Due to the excellent beam quality, pulsed fiber lasers are used in many areas of materials processing, metrology and telecommunications technology. However, their tendency toward amplified spontaneous emission (ASE) means the potential parameter scope of conventional fiber lasers is limited in terms of repetition rate to over 10 kHz. The concept of the gain-switched fiber laser provides a solution to this problem. Hence, gain-switched fiber lasers are used wherever high peak power is required in the region of several kW with fundamental-mode beam quality at low repetition rates down to single-shot operation.

This research was funded by Germany's Federal Ministry of Education and Research (BMBF) under reference code 13N9671.

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FIBER AMPLIFIER WITH ADJUSTABLE PULSE SHAPE

Task

In the project »Fazit« diode seed sources with variable pulse parameters and the subsequent amplification are investigated. Based on pulsed diode drivers delivered by the project partner Picolas, compact fiber amplifiers with variable repetition rate and pulse duration in the region of 0.5 ps to 10 μ s and peak power in the kW region are being developed for further power scaling. A fiber amplifier with arbitrary pulse shape is also to be implemented as part of the project. On the one hand, the adjustable pulse shape can be used to pre-compensate the pulse deformation that occurs in the fibers during amplification, thus reducing the influence of nonlinear effects. On the other hand, a freely adjustable output pulse shape is also advantageous for a host of materials processing applications.

Method

A two-stage, linearly polarized fiber amplifier for pulse duration in the ns region with arbitrary pulse shape is to be set up using commercial step-index fibers. Thanks to direct pulse shaping via the seed diode driver, no free-space optical elements such as acousto-optic modulators are required, meaning the fiber amplifier can be configured as a completely fiber-integrated solution.

Result

The implemented experimental setup of the fiber amplifier produces an average output power of more than 10 W and peak power of around 10 kW with pulse durations in the region of 20 - 200 ns.

The adjustable pulse shape enabled the time-dependent signal saturation and the associated pulse deformation to be pre-compensated successfully, allowing rectangular output pulses to be generated. In addition more complex output pulse shapes such as stepped pulses, trapezoids, sine modulations can be generated.

Applications

With a flexible repetition rate and flexible pulse duration, diode-seeded fiber amplifiers already cover a wide range of applications in material processing and metrology. Thanks to the additional degree of freedom of a freely adjustable pulse shape, the laser is ideal for setting the optimum temporal process parameters for materials processing such as drilling or ablation.

This research was funded by Germany's Federal Ministry of Education and Research (BMBF) under reference code 13N9671.

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1 Active fibers.

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



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1



2

LASER CUTTING OF THIN GLASS

Task

Fast and precise cutting of any shapes out of thin glass (thickness of glass < 1 mm) is currently showing an increasing market potential due to an increasing demand of OLEDs and LCDs. Conventionally manufactured glass, when it is cut or mechanically scribed and cleaved, often exhibits poorly cut edges. These, in turn, have to be ground and polished in a time consuming process. Manufacturing contours according to any wish is also difficult. In particular, the cutting of strengthened glass, which is commonly used in the display technology, causes difficulties for conventional processes.

Method

By using ultra-short pulse lasers, the thin glass can be cut quickly and precisely, so that no further post processing is needed. When glass is machined with ultra-short pulse lasers, however, the material cannot be cut through at once. The material is ablated layer by layer until it is cut through by repeated scanning of the cutting contour. Depending on the material thickness, several cutting lines have to be positioned in parallel and on top to be able to cut through the material completely.

For cutting thin glass, a frequency-doubled ps-laser is used. The laser beam is moved by a scanner and focused by an f-theta lens on the glass surface. The laser beam is moved at a scanning speed of up to several m/s.

Result

When ps lasers are used it is possible to precisely cut thin glass. Damages in the glass can be minimized by adapting the cutting parameters. This way, cut glass samples with a breaking strength of more than 200 MPa can be produced.

Applications

This technology is of interest for all applications where complex structures have to be cut out of thin glass. This glass can be used e.g. for smart phone or tablet displays but also for the solar industry. In addition, new application areas like design glass elements can be manufactured due to this technology.

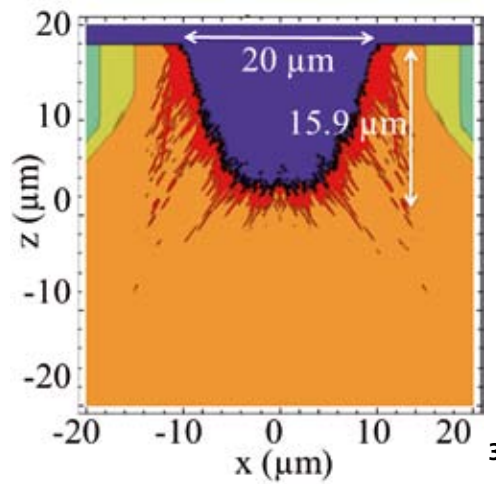
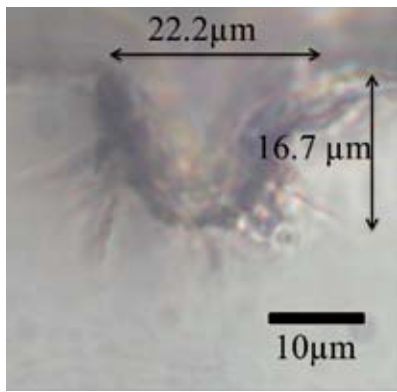
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1 Cutting of thin glass with a green ps laser.

2 Cross-section of a 300 μm thick laser cut glass.



MODELING AND SIMULATION OF THE ABLATION OF GLASS

Task

The sharp increase in demand for smartphones and other flat-panel displays has given rise to substantial market potential for the processing of transparent dielectric materials (e.g. glass) using ultrashort pulsed laser radiation. However, the mechanisms relating to ablation and material damage when using the laser are still barely understood.

Method

The aim of modeling is to provide a spatially resolved description of the beam propagation and energy deposition as well as the damage or ablation of dielectric materials when using ultrashort, high-intensity laser pulses. To this end, the dynamics of the electronic system are illustrated, the effect on the propagating radiation field calculated, and the ablated volume and the damage in the material volume determined based on these findings.

Result

A model that includes the subprocesses of nonlinear absorption, radiation propagation and ablation was implemented, and tested by means of comparison with real cuts in glass. The comparison shows a perfect match between the simulation's prediction and the experimentally determined micrograph. Not only is the ablation geometry demonstrated very precisely,

the material damage inside the glass volume (average damage depth [black on the micrograph, red in the simulation], peak-shaped damage structures, etc.) is also illustrated correctly. This damage in particular is extremely interesting for assessing the breaking strength of the final component and can now be reliably predicted.

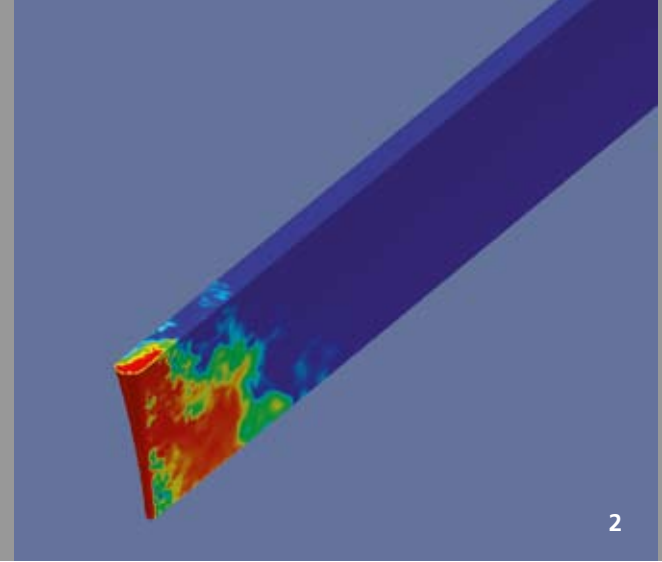
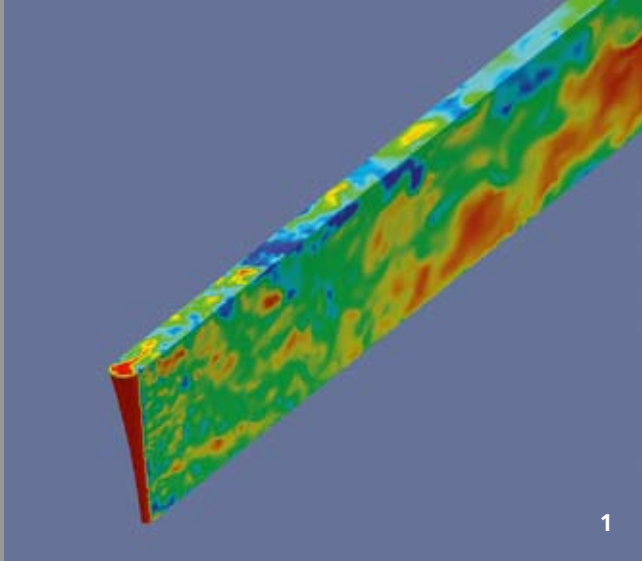
Applications

The implemented model can be applied to any material that absorbs incident radiation through nonlinear processes such as multiphoton or cascade ionization. Such materials include glass, aqueous solutions or biological tissues. The developed methodology can also be applied to other dielectric materials and even semiconductor materials used in the solar and electronics industries.

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CLEAN LASER CUTTING OF PRINTED CIRCUIT BOARDS

Task

Printed circuit boards essentially consist of hardened epoxy resins and embedded glass fiber that combine to create a mesh. Decomposition products tend to be deposited on the blanks and on the cut edges whenever printed circuit boards are cut using laser radiation.

Method

Since these depositions impair quality, they should be prevented. In order to do this, a model is required that describes the decomposition and optimizes the flow of decomposition products by suitably designing the cutting gas flow.

Result

A Discontinuous Galerkin method for calculating the three-dimensional flow of gas mixtures in a complex geometry was implemented. The decomposition was described by means of a model that takes into account experimentally determined deposition rates and the key decomposition channels. For the cutting processes investigated to date, the depositions that impair quality were almost entirely prevented by means of multi-chamber nozzles and a suitable design of the cutting gas flow.

Applications

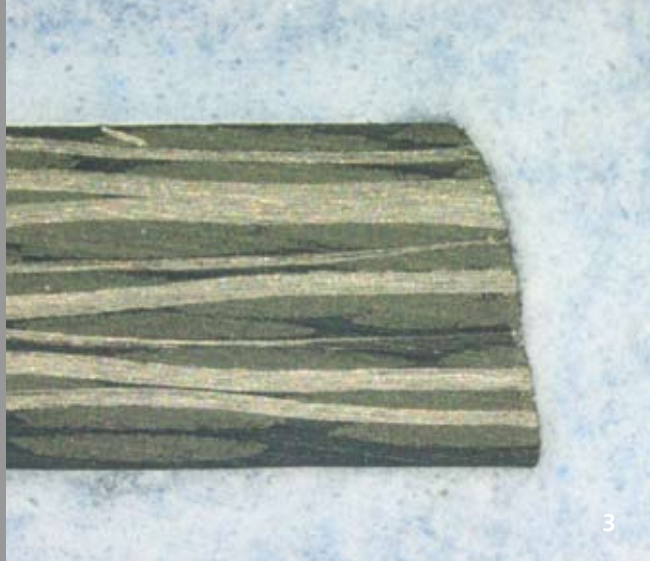
The presented simulation enables the gas flow to be calculated taking into account the decomposition/vaporization of materials. It can be used for machining processes where the design of a gas flow assures quality.

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Mass fraction of the ablated material in the kerf for an unmodified cutting gas flow (Fig. 1) and for a modified cutting gas flow (Fig. 2).



CUTTING OF FIBER-REINFORCED THERMOPLASTIC POLYMERS

Task

The use of fiber-reinforced polymers (FRP) with thermoplastic matrix is gaining increasing importance in the mass production of fiber-reinforced parts due to short cycle times. The ability to shape thermoplastic FRPs by heating and pressing, similar to conventional process chains for metal part production, enables production processes with large lot sizes at reasonable production costs. However, trimming and assembly of sub components still require new approaches that do not affect the outstanding properties of the new lightweight materials. Flexible production methods, such as tape laying or fiber spraying, achieve near net shape parts, but cutting holes and precise trimming remain as indispensable manufacturing steps. Therefore, productive cutting processes are required, which lead to a low thermal influence on the cut edge.

Method

Laser cutting of FRPs, in principle, is a preferred process, but must be modified from conventional process approaches to avoid overheating the matrix material and negatively influencing the material properties. Thus, low heat input to the material can be achieved by short interaction times, made possible by short pulsed laser radiation and high processing speeds. In multiple passes the material is successively ablated with a newly developed ns-CO₂-laser in the kilowatt power range until a complete cutting kerf is produced.

Result

The heat affected zone is reduced by the multi-pass process, compared with a cut in a single pass at correspondingly lower cutting speed. The effective cutting speed is the same for both cases. By using lasers in the kilowatt power range and above, researchers at the Fraunhofer ILT have achieved cutting speeds of several m/min, thereby making the process suitable for serial production.

Applications

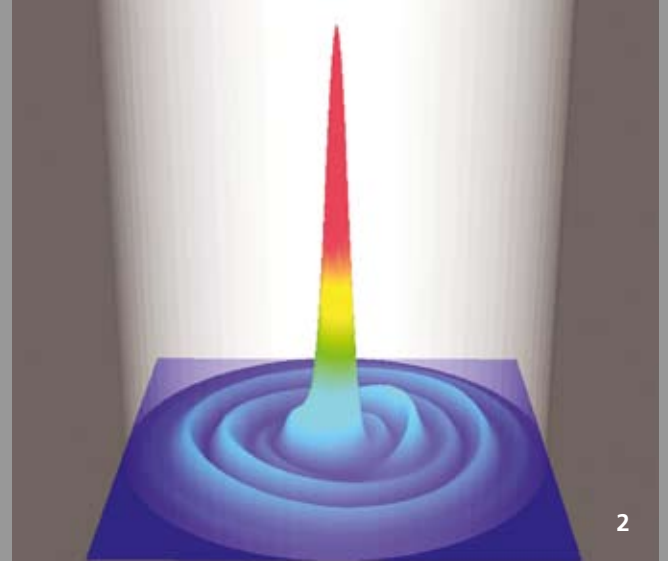
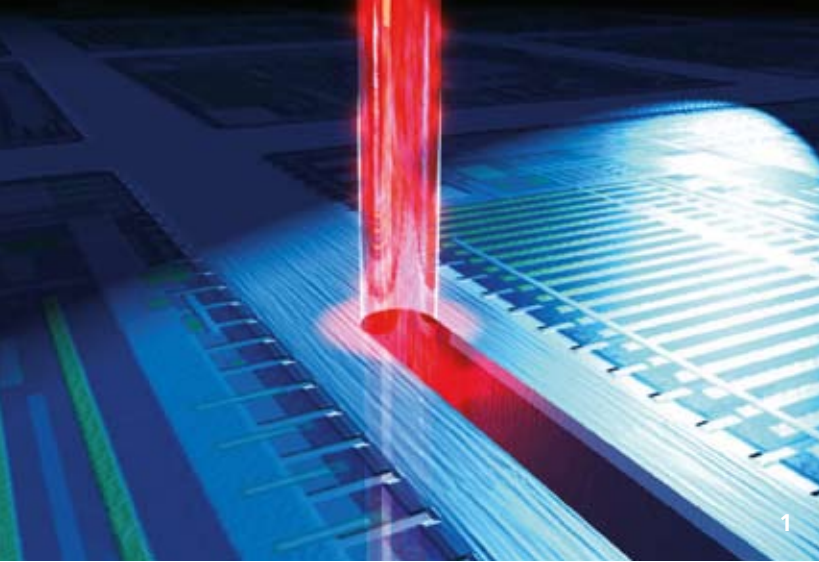
FRP is a core material in lightweight design, and laser cutting can be an essential step in the production chain. The applicability for glass fiber-reinforced polymers opens up a broad field of applications, e. g. in vehicle manufacturing, mechanical engineering, consumer goods and the sports equipment industry. This research has been funded as part of the EU project »FibreChain« and the BMBF project »InProLight«.

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3 Cross section cut edge carbon fiber/PA6
(thickness: 2 mm).



CUTTING USING WATER JET GUIDED RADIATION

Task

Precision cutting, of metals but in particular of brittle-hard materials (e.g. semiconductors, glass), places exacting demands on precision and processing quality. Special attention must be paid to the breaking strength of the workpieces and to the need to prevent recast and debris. Water jet guided laser cutting is an innovative process variant which boasts considerable potential for meeting these requirements. To fully utilize its potential, research aims to deepen the current understanding of nonlinear radiation propagation in the water jet, of workpiece cooling, and of the vaporization of water during the process.

Method

Fraunhofer ILT has at its disposal a Laser MicroJet (LMJ) system, diagnostic systems and a local high-performance computer system with which to open up new applications and new application-specific LMJ variants on the basis of model-based development.

Result

Models for simulating water jet specific subprocesses are being continually extended and honed. Based on Fraunhofer ILT know-how, a wide range of precision-machining applications is being tested locally as preparation for subsequent use in industry.

Applications

Users involved in the precision cutting of a wide range of materials, but especially of brittle-hard materials, that are looking to improve conventional "dry" laser machining and ultrashort pulse processing will benefit from the results.

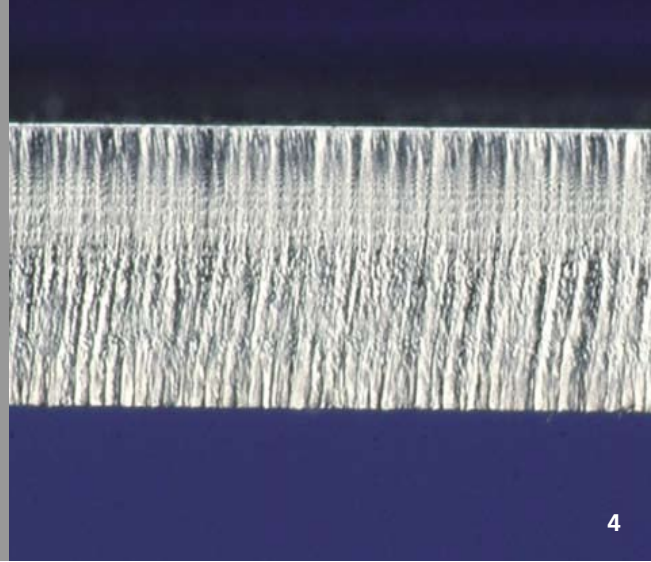
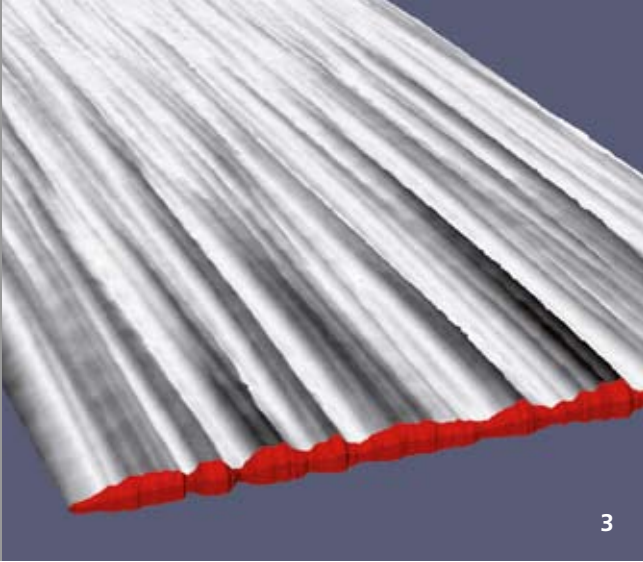
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1 *Illustration of the process.*

2 *Simulation of beam propagation in the water jet.*



SURFACE ROUGHNESS IN LASER CUTTING

Task

Minimal roughness and the visual appearance of the cut edge are key quality requirements when laser cutting sheet metal. The optimal cutting parameters are being determined in an extensive series of experiments.

Up to now fluctuations in the process parameters, such as laser output, have been regarded as the sole cause of surface roughness. Mathematical analysis shows, however, that even if the process parameters are ideally constant, roughness can be caused by unstable flow of the melt.

The aims are to provide a model-based prediction of the cut edge quality, to determine the relevant influencing variables and to establish the optimal cutting parameters.

Method

The key variables for the spatial distribution of roughness on the cut edge are calculated using a cutting model. By means of a stability analysis the factors that cause and suppress the defect are calculated as a function of the cutting parameters. The stability limits are analyzed and the process domains for stable cutting determined using the mathematical method.

In numerical simulations based on the cutting model the dynamics of the melt flow are calculated as a function of the process parameters. The predictions from the simulation are validated by comparing them with experimental data.

Result

The newly developed QuCut simulation software permits a space-time analysis of the melt flow and its effect on the cut edge quality. It also enables the optimal cutting parameters to be determined and measures for stabilizing the melt flow to be derived.

Applications

The results will benefit manufacturers and users of laser cutting systems.

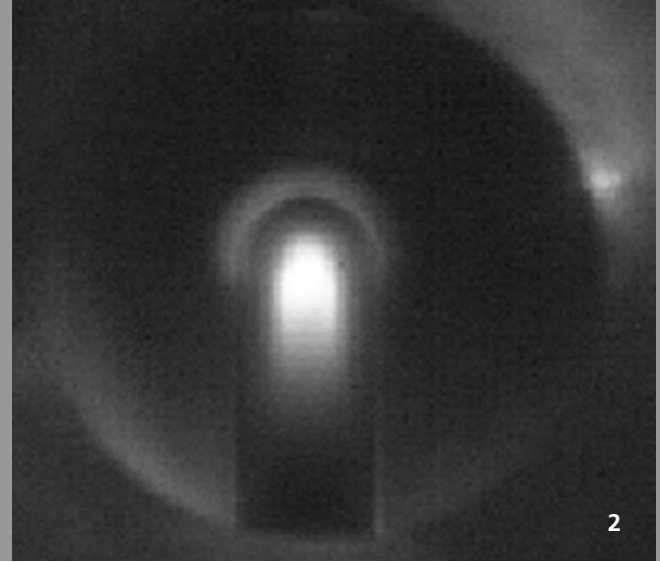
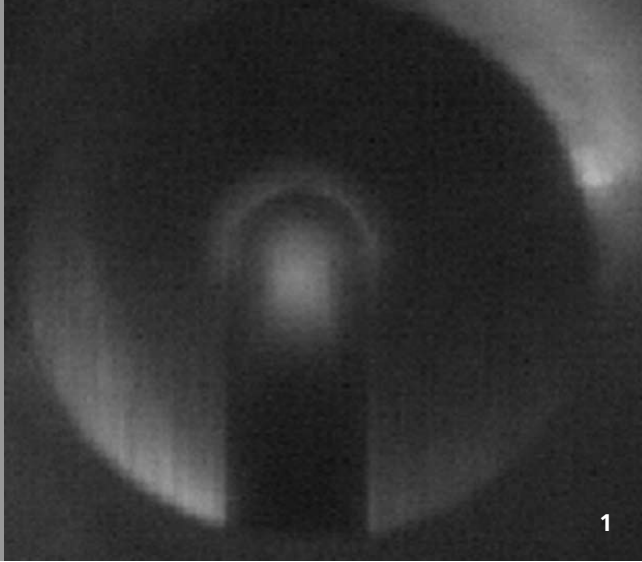
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3 Ripples simulated using QuCut.

4 Ripples in an actual cut edge.



PROCESS DIAGNOSTICS IN LASER CUTTING

Task

A central question in the investigation and optimization of laser cutting processes is the exact visualization and the extraction of characteristic data of the process and its changes when process parameters are modified. Only with a precise analysis of melt dynamics, melt film thickness and the varying melt formation can the cutting efficiency be optimized.

Method

For the process diagnostics a monochrome high-speed camera and a fast photodiode were used. The optical paths of these two systems are connected to the machining beam path via a beam splitter. The combination of these two systems offers users the ability to interpret the process signals and the benefits of the extended temporal resolution of the photodiode. Today's laser cutting machines are often equipped with a photodiode, which is integrated in the beam path. Hence, the achieved results can be rapidly implemented into the industrial production process without having to significantly change system technology and machine setup.

Result

As result of this analysis, the dominant signal of the photodiode could be mapped. The largest contribution to the brightness results from the lower part of the cutting front. Due to the geometric and thermal properties of the cutting front, the upper part of the front is similarly dark as the cold sheet surface. The cutting speed showed a significant influence for the allocation of a specific process response to a process parameter. As seen in the figures, with an increase in speed, the brightness increases at the cutting front and in the kerf. From these developments, a control system can be implemented for achieving high cutting quality.

Applications

Current developments respond to specific questions in laser cutting processes of stainless steel sheets up to a thickness of 12 mm. In the medium term, the developments can be applied to other materials such as aluminum, or other processes such as oxygen cutting.

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1 Temporal averaged process recordings at 0.7 m/min.

2 Temporal averaged process recordings at 2.7 m/min.



ONLINE-QUALITY DIAGNOSIS FOR LASER-ARC HYBRID WELDING IN SHIPBUILDING

Task

The shipbuilding industry increasingly requires thin three-dimensional structures. To join such structures cost efficiently, laser-assisted remote stitching and hybrid welding show great promise. Due to their low thermal distortion they are profitably employed for joining of thin 3D structures ($t = 4 \text{ mm}$ to 10 mm). But new methods are required to evaluate the process to meet quality demands regarding reliability and fatigue strength. The process monitoring task is solved with the help of the CPC system, developed at Fraunhofer ILT. The CPC system is integrated into a demonstrator plant for remote stitching and hybrid welding.

Method

During laser hybrid welding, intensive radiation is emitted from the process zone across the full optical spectrum (UV, VIS, NIR). For non-contact optical process monitoring, imaging sensors as well as spatial integrating photo detectors are employed. The CPC system consists of a coaxially mounted high speed CMOS camera which acquires images from the process zone through the laser beam focussing optic. A laterally mounted super pulse diode laser with a wavelength in the NIR spectrum provides the required flash light illumination. The image acquisition and the simultaneous flash light illumination is synchronized and delayed with respect to the current pulses of the arc welding current source to prevent images from over exposure by the radiation emitted from the electrical arc during its high current pulse phases. The intention is to monitor online the stability of the hybrid welding process.

Result

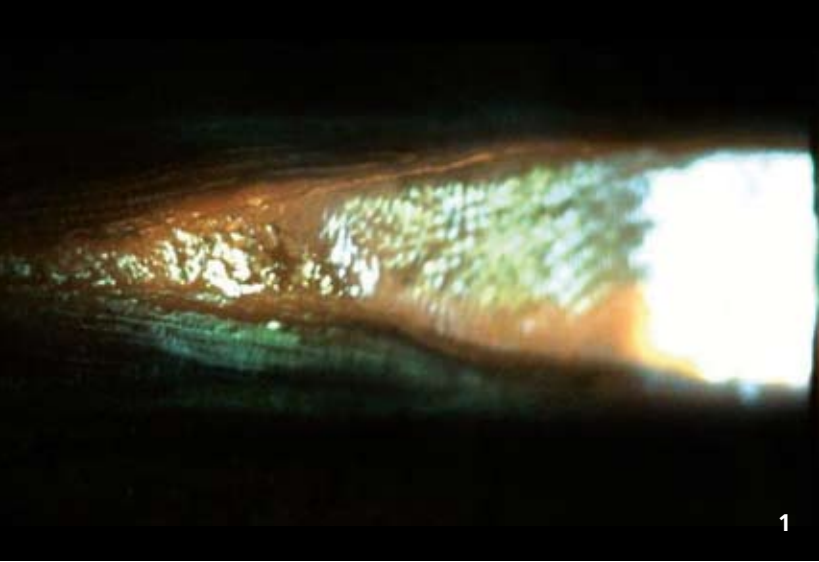
Due to their synchronous acquisition, the images show the melt pool and the joint groove very clearly. Figure 3 shows a single image from a sequence recorded with the CPC system. Since the camera is mounted coaxially, the laser-induced key hole is positioned exactly in the centre of the picture. The joint groove on the left is illuminated by the super pulse diode laser. On the right side there is the filler wire tip, the hot melt pool and the electrical arc generated by a base current of 80 A. The drop of filler material flying from filler wire tip towards the melt pool was molten with 500 A-current pulse 2 ms before the picture was taken. When the arc welding process runs stable, the molten drops are generated periodically. Due to the stroboscope effect the molten drop always occurs at the same position in the synchronously acquired pictures. This effect is used to evaluate the stability of the monitored laser-based joining processes for applications in shipbuilding industry, tank construction and tube manufacturing.

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3 CPC-image taken during
laser-arc-hybrid-welding.



ULTRASONIC LASER WELDING

Task

The production of homogeneous weld seams in joints of dissimilar metals often poses major challenges for welding technology. To homogenize the weld micro structure, the joining process must be able to minimize intermetallic phases and significantly reduce brittle-hard areas, rough graining and dendritic anisotropies.

Method

In order to resolve the aforementioned issues, a temporally and spatially modulated laser beam is combined with ultrasonic excitation of the weld pool. In an initial stage, the effect of structure-borne noise at 20 kHz on the formation of the microstructure in a ferritic stainless steel is tested. To this end, the sound field was coupled into the workpiece from various directions in relation to the weld direction. The weld seams were subjected to a metallographic analysis. Process monitoring using high-speed cinematography provided insights into the sound distribution in the melt and solidification.

Result

Under the aforementioned test conditions, coupling parallel to the weld direction provided the best results. Power output of up to 500 W could be coupled. Contrary to the literature, other coupling directions produced no effects. Additionally crack formation occurs above a certain threshold of sound power. In the case of a material with pronounced columnar solidification, the area with a rectified microstructure was widened, while the grain size increased slightly. Coupling of the sound waves to the melt was observed in the antinodes.

Applications

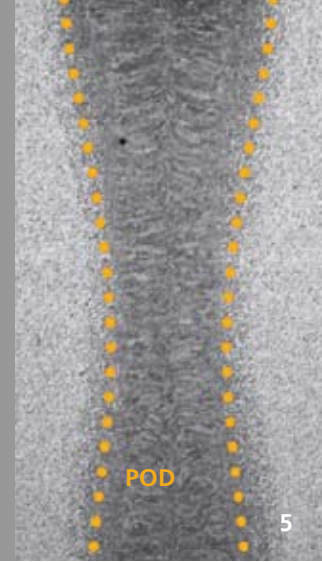
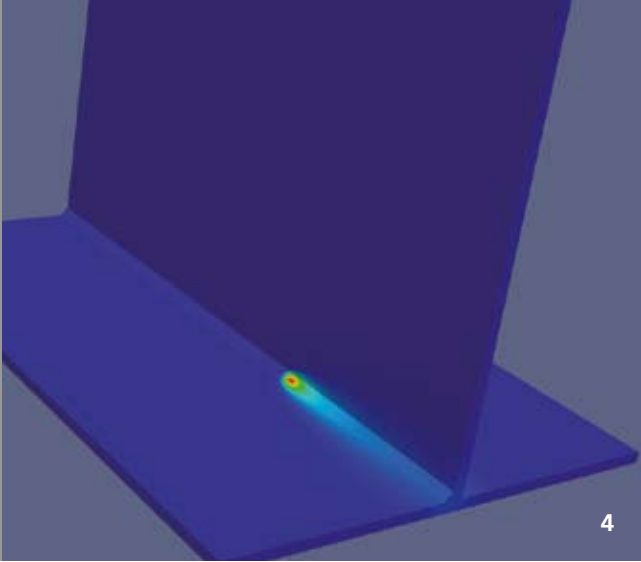
The results can be used wherever an isotropic microstructure is required in weld seams. Applications include the prevention of center dendrites when welding austenitic materials and the associated risk of cracking as well as microstructure homogenization with dissimilar joints. Here phase seams are resolved and the associated components finely dispersed over the weld seam cross-section. This reduces the crack frequency while increasing strength by means of dispersoids.

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- 1 Snapshot of melt pool.
- 2 Flat section of a weld seam in 1.4512, welded without acoustic irradiation.
- 3 Flat section of the weld seam in 1.4512 subject to a sound power of 100 W at 20 kHz, irradiated parallel to the weld direction.



AUTOMATED HEAT SOURCE CALIBRATION WITH LASER WELDING

Task

Commercially available software for simulating laser welding normally does not incorporate all the physical phenomena, but rather maps the energy input on the basis of a parameterized volume source. In order to achieve an equivalent description of the heat input, the values of the parameters are calibrated in an iterative process by trial and error until there is sufficient agreement between the calculated and experimental values for the temperature. In each iteration step, a partial differential equation (PDE) is solved in three spatial dimensions; using conventional finite element (FE) methods, this entails considerable calculation effort. The number of iteration steps depends largely on the skillful adjustment of the parameters and requires sound expert knowledge.

Method

This project aims to automate and accelerate this calibration process while achieving at least the same reliability as the established method. Optimization techniques are used to adjust the parameter values and to assess the match between simulation and experiment. Parallelized efficient numerical techniques as well as the Proper Orthogonal Decomposition (POD) model reduction method are used to solve the PDEs.

Result

Rapid, automated and reliable determination of the parameter values eliminates the need for a phase of time-consuming and hence costly calibration by an expert.

The developed efficient numerical techniques combined with the POD method save a great deal of time compared to conventional FE methods. In this way, the parameter values of a volume source can be automated within a few hours and determined with a controllable error.

Applications

The methods developed support automated, rapid and reliable calibration of the parameterized heat source. This provides the basis for efficient weld simulation to predict process quality features such as distortion and residual stress.

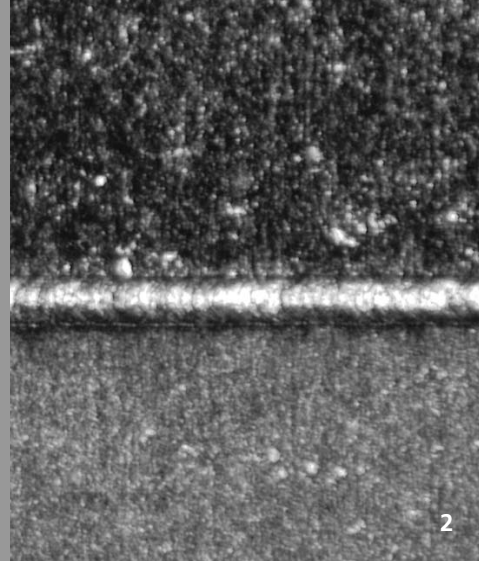
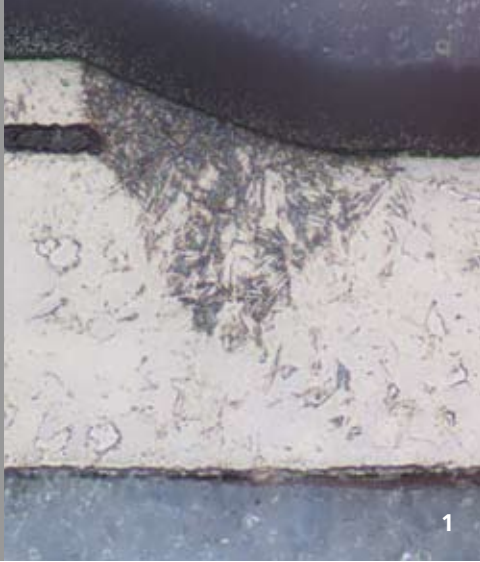
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4 Temperature for welding a T-joint calculated using POD.

5 Calculated melt line and associated micrograph.



LASER WELDING OF TITANIUM MEMBRANES FOR THE PRODUCTION OF PRESSURE SENSORS

Task

New high-brilliance beam sources such as fiber lasers – having a fiber diameter $< 15 \mu\text{m}$ and excellent focusability – allow fine welding seams in the range of a few microns in thickness and depth. Due to these parameters, fiber lasers are suitable, in particular, for joining thermally sensitive components on account of their minimal energy input. For example, a membrane of about $10 - 25 \mu\text{m}$ can be welded to titanium housing for intracorporeal pressure sensors.

The special challenge when welding thin membranes is a media-tight seam, which ensures it is burr-free, i.e. groove-free and has smooth upper and lower upper beads. Thanks to these types of seams, easily sterilizable tools can be produced, essential for medical applications.

Method

To manufacture the pressure sensor, laser ablation is used to generate a rectangular opening in a casing with a wall thickness of $100 \mu\text{m}$. Subsequently, a titanium membrane of about $10 - 25 \mu\text{m}$ thickness is laser-welded onto that section, by which the pressure can be measured by a sensor. For this method, a 200 W fiber laser with high beam quality $M^2 < 1.1$ was used.

1 *Micro-section.*

2 *Welding seam.*

A welding seam was achieved both free of cracks and pores and with a smooth and gentle transition to the seam surface by means of a process-adapted welding device that enables a stable gap-free fixation of the membrane and a specific adaptation of the beam position on the edge of the component. Here, the main advantage of the new laser sources is evident, as they allow a highly accurate deposition of energy for the process and in the component ratios.

Result

Thanks to its small beam diameter, laser beam welding with fiber lasers enables the smallest melt volumes and, thus, much needed energy for welding. In this way, the previous limits of laser welding can be overcome, in particular when joining thin films and wires with low heat capacity.

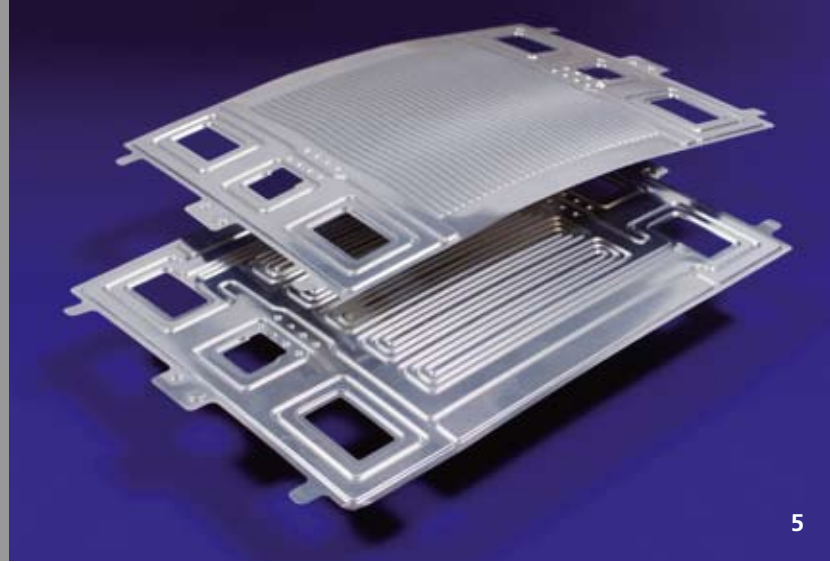
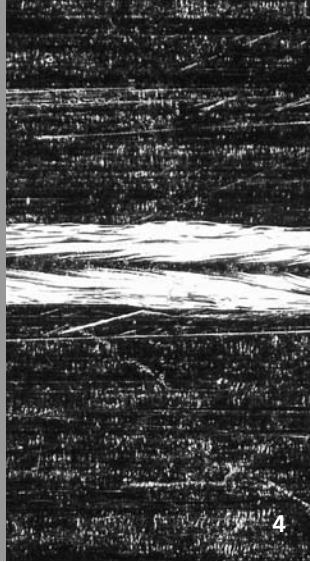
Applications

Laser welding of titanium membranes can be used to produce devices for several medical applications, such as those to measure blood pressure, intraocular pressure and bladder pressure. Further applications can be envisaged for contacting wires and lead frames.

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WELDING OF BIPOLAR PLATES

Task

The use of renewable energy sources in the form of hydrogen or methanol can help to reduce environmental pollution and increase efficiency in energy production. An example of this is the direct methanol fuel cell. Its advantages in comparison to common batteries and H₂ fuel cells are significantly longer distances at comparable system volumes. To increase the efficiency of the fuel cell even further, flow field geometries adapted to the process media (e.g. as bipolar plates) may be used. The setup as bipolar plates makes a joining and assembly technique for the build-up in stacks necessary. For the market to accept these technologies, however, joining times need to be low and dense welding seams need to be highly reproducible.

Method

To fulfill these requirements, laser welding offers the optimum prerequisites. The use of task-specific clamping devices and the adjustment of the welding parameters for different materials are key tasks in this context. For this purpose, an adapted chuck has been developed and the welding of bipolar plates with a size of about 190 x 140 mm (thickness 2 x 0,1 mm) has been carried out with a fiber laser.

Result

The welding of bipolar plates with fiber lasers can be achieved in a period of less than 20 seconds per plate pair, so that a series in production scale is possible. Process errors can be reduced by improvements in the clamping device as well as integration of protective gas and adjusted process parameters.

Applications

The use of laser welded bipolar plates with increased efficiency allows higher ranges in the mobility sector. In addition the knowledge gained regarding the clamping and process technology can be applied to other comparable joining tasks, like joining micro fluidic components or design elements.

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3 Cross section of the generated seam.

4 Top view of a weld seam.

5 Different flow field geometries of the bipolar plates.



MICRO WELDING OF COPPER COMPONENTS USING POWER MODULATION

Task

Copper is still the most important material for conductors and the setup of electrical and electronic systems. However, high thermal conductivity and low absorption of copper (alloys) in the near infrared are challenges for welding and, in particular, for the laser welding process. It is difficult to control the weld depth in copper material due to laser power spiking, which results in a local increase of the penetration depth. In addition, during the welding process of copper, instabilities are often observed, such as melt pool ejections.

Method

Within the BMBF-funded CuBriLas project, several approaches are being investigated, all of which aim at producing an improved weld quality and achieving constant weld depth. In addition to the parameters of beam diameter, laser power and feed rate, further process parameters have been generated by using temporal and spatial power modulation. This technique makes it possible to better control melt pool and reduce weld defects. For the temporal power modulation, a sinusoidal wave is imposed on the laser output power, which is adjusted in frequency and amplitude. When using spatial power modulation, researchers at the Fraunhofer ILT have superimposed a circularly oscillating movement onto the feed movement and, therefore, can vary oscillation frequency and amplitude.

1 *Overlap joint (CuSn6).*

2 *Cross-section of a modulated weld seam.*

Result

By using temporal power modulation in the range of several hundred Hertz, the team has achieved an almost constant welding depth when welding Bronze CuSn8 sheets (0.2 mm thickness) in overlap joint. The spatial power modulation can also be used to stabilize the weld. This is especially helpful regarding the bridging of a gap and the enlargement of the cross-section in an overlap joint configuration.

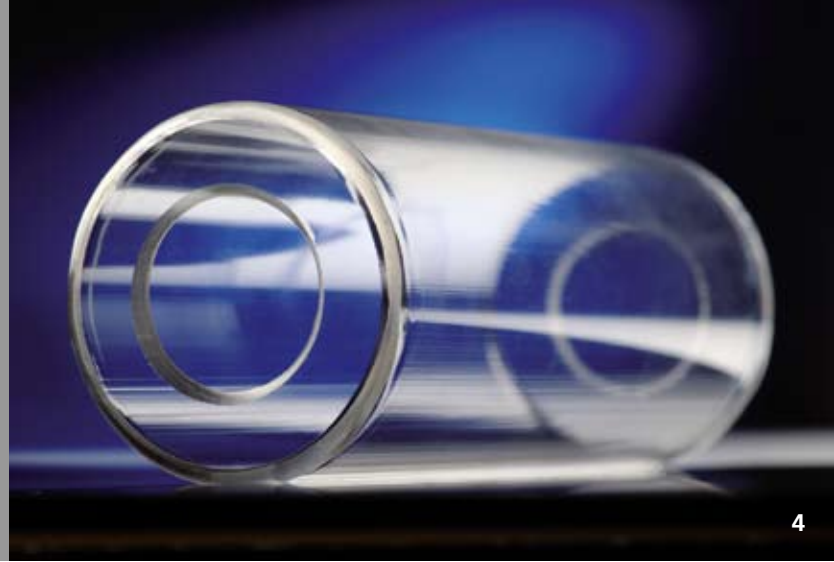
Applications

The use of laser welding is currently being discussed in the power electronics and battery technology sectors. The improved possibilities of depth control for the melt pool – in order to avoid full penetration and thus damage to the substrate or thin batteries – is the key reason for using laser welding in these areas.

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WELDING OF SILICA GLASS WITH CO₂ LASERS

Task

Conventional methods based on gas burner systems are still predominantly used to weld silica glass. But such processes are not very efficient because only a small amount of the radiant energy generated by the gas flame is actually used to melt the glass. Another disadvantage of this method is the large working area relative to the seam surface, which means that an additional processing stage is required to remove soot and other undesirable waste products. These drawbacks restrict the ability to develop an automated manufacturing process and, compared with laser welding, demand more work as well as reducing process repeatability. Instead of using a gas flame to heat the glass, more reliable results can be obtained if the glass is heated to the required processing temperature by means of a CO₂ laser source.

Method and Result

The electromagnetic radiation of the CO₂ laser at a wavelength of 10.6 μm is absorbed by the surface of the component. Energy passes through the material at its most common thickness by way of thermal conduction. But unlike gas welding processes, there is no chemical interaction with the components to be joined. In the proposed method for laser welding of silica glass, the energy is applied homogeneously and virtually simultaneously throughout the joining zone by repeatedly rotating the component and/or laser beam. A specially adapted exposure strategy suitable for any size of component currently enables fully welded joints to be produced in materials with a thickness of up to 3 mm

with a minimum input of energy. This strategy combines a continuous feed mechanism that moves the laser beam along the length of the weld seam with a quasi-simultaneous superimposed exposure pattern.

Applications

The process is suitable for applications in the pharmaceutical industry, such as the hermetic sealing of primary packaging for medicinal products, and in the manufacture of products with heat-sensitive functional coatings, e.g. UV light sources and sensor housings. It also holds promise as a substitute for certain flame-sealing processes commonly employed in the manufacture of chemical apparatus and lighting products.

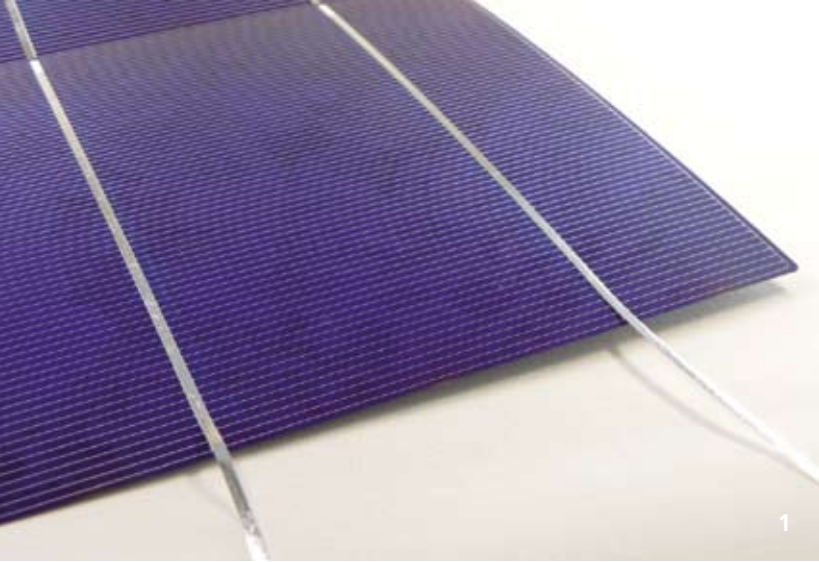
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3 Sealed drug ampoules.

4 Silica-glass cylinder with welded-on inner flange.



LASER SOLDERING IN PHOTOVOLTAICS

Task

The technical requirements for solar cells have increased constantly in the past few years regarding their life cycle and the required quality of the manufacturing process. At the same time, production costs have to be reduced by using thinner wafers and a lower process cycle time. A key process in the production of photovoltaic modules is the interconnection of the cells. In this process, the solar cells are interconnected by using laser soldering to attach metallic interconnectors. The aim of the laser soldering is to minimize the thermo-mechanical stress induced by the joining process and, hence, to reduce discard caused by cell breakage. In addition, the joining process must be done in a process time of less than 3 s.

Method

Compared to conventional processes, the laser soldering process holds the highest potential to fulfill the requirements above due to its low energy deposition. By applying a galvanometer scanner with pyrometric sensor systems, researchers at the Fraunhofer ILT are able to identify the temperature distribution in the joining zone. This information can be used during the process to control and regulate the deposited amount of energy. During the optimization of the process parameters e.g. laser output power, feed rate and motion

pattern, the cause for process-induced micro cracks is analyzed. The application of a fixed optic allows the complete joining zone to be heated quasi-simultaneously, which is checked for process failures with a thermal camera.

Result

The application of a fixed optic allows the interconnectors to be joined over the complete length in a process time of 1 s. The galvanometer scanner enables process times of 1 - 2 s and interconnections to be made with a peeling strength of up to 6 N through distortion-minimized process strategies. The crack development in the joining process can be hampered by minimal energy deposition.

Applications

The laser soldering technology is used to create interconnections of crystalline, silicon based solar cells. This application can be extended to innovative back contact cells with punctual joining zones thanks to the geometrical freedom of a scanning system. Further applications of the joining technology are possible in the electronic industry, e.g. SMT (Surface Mounted Technology).

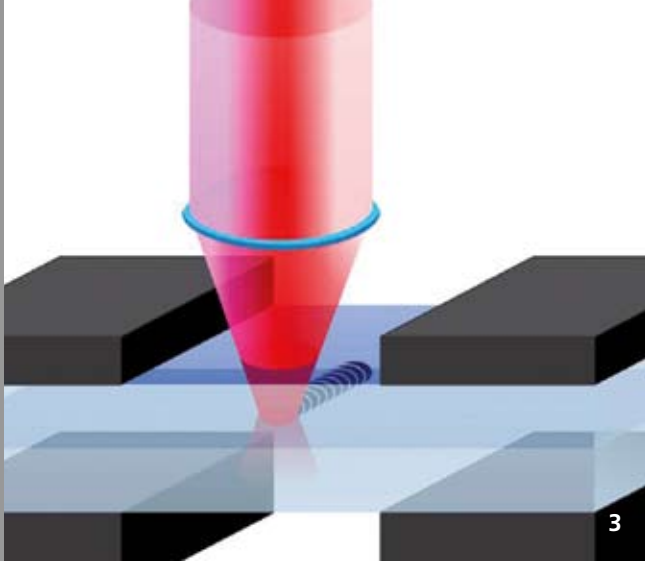
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1 Solar cell with joined interconnector.

2 Laser soldering process.



TRANSMISSION WELDING OF INFUSION TUBES WITH NIR-HIGH-POWER DIODE LASERS

Task

Laser welding of polymers is characterized by targeted and contactless energy input. In addition, the process is free of dirt and particles and hence suitable for welding medical components. For such parts, however, transparency is often required, which usually cannot be ensured when conventional transmission welding is used. The reason is that an absorber has to be employed to deposit the beam energy into the joining plane, which has prevented transmission welding from being used on medical components to date. As an example, Figure 4 presents an application where the tube end of an infusion tube and a tube nipple, both consisting of additive-free polypropylene (PP), needed to be welded together.

Method

In the near infrared range, the majority of polymers have characteristic absorption bands at wavelengths above 1.2 μm . By selecting a beam source with a suitable wavelength, researchers at the Fraunhofer ILT have been able to exploit these bands in order to allow welding without using absorbers. In the absence of an absorber, both joining partners have equal optical properties; hence the laser radiation is no longer absorbed at their interface. Nevertheless, to deposit the beam energy into the joining plane, optics with a high numerical aperture (NA) is used (Figure 3). In the focal area the focused beam has the highest intensity, which is set to a value sufficient to melt both joining partners at their interfaces. Outside the focal area, the material remains solid due to lower intensity of the beam.

Result

The measurement of the optical properties reveals a sufficiently high intrinsic absorption of PP at 1.7 μm wavelength. When a high-power diode laser was used emitting at this wavelength, both parts of the infusion tube could be welded together successfully in a process time of 10 s. The generated seam is invisible from the outside and characterized by high strength and media tightness.

Applications

The process introduced here is mainly used for medical applications, which often require transparent components. It offers an advantage that costs for the absorber can be saved. In addition, in medical fields as well as in food packaging, the use of absorber is usually connected with costly and time-consuming approval procedures which can also be circumvented by omitting the absorber.

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3 *Welding of transparent polymers using optics with NA.*

4 *Infusion tube with tube nipples.*



WELDING ASA POLYMER ANTENNA HOUSING WITH 1.5 μm FIBER LASER RADIATION

Task

3G-C antennas are active high-precision electronic systems developed for signal reception from satellite-based navigation systems currently in use. To ensure these systems operate reliably, a tight sealing of the housing is necessary, since it is exposed to harsh environmental conditions.

Method

A large number of polymers possess high absorptivity in the near-infrared wavelength range above 1.5 μm and do not need to be provided with absorbing additives to enable laser welding. Within the frame of the current EU project POLYBRIGHT fiber lasers are being developed with wavelengths 1567 nm (Erbium doping) and 1940 nm (Thulium doping) and maximum output powers of 120 W. These emission wavelengths coincide with local absorption maxima of different non-pigmented polymers, making the laser source particularly suitable for polymer welding. For the described 3G C antenna housing, the lower white joining partner has, in particular, sufficient absorptivity in this wavelength range, which in turn means that high quality weld seams can be achieved even when using colored polymers with high reflectivity in the visible spectral range.

Result

In a welding station assembled at Fraunhofer ILT, the antenna's top and bottom shell are positioned relative to each other, clamped together, and the focused laser beam is guided along the weld contour using a galvanometer scanner head. To prevent spots from forming with high radiation intensity, the focused laser beam is moved along the weld seam with a superimposed circular oscillation (TWIST® method).

Applications

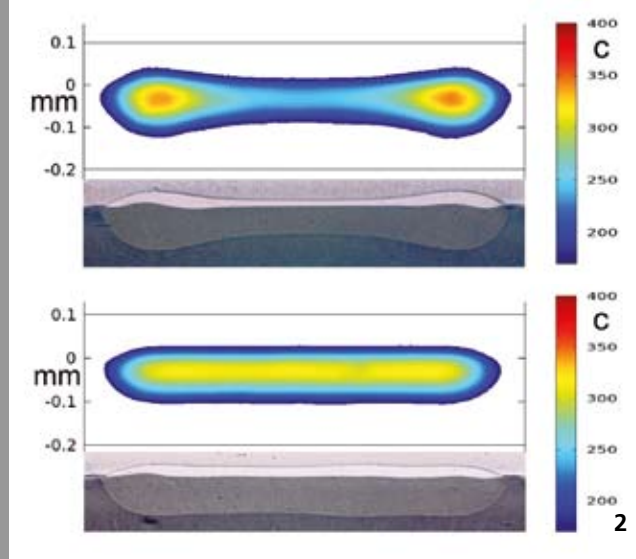
This demonstrator welding unit can be used to meet increasing industry demands for the joining of colored (Figure 1) and even transparent components, instead of standard transparent/black combination. Applications are expected in the field of consumer goods and medical components where manufacturers have to forgo carbon black pigmentation for different requirements.

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1 G3-C antenna housing (navXperience, ASA polymer), welded with 1.5 μm fiber laser radiation in combined REMOTE / TWIST®-configuration.



THERMAL SIMULATION OF WELD SEAM HOMOGENEITY DURING TWIST® LASER POLYMER WELDING

Task

During laser polymer welding with high-brilliance fiber laser radiation, the TWIST® method can be applied to homogenize energy deposition; in this process, the welding contour is superimposed by a fast circular or elliptical oscillation. Currently, researchers at the Fraunhofer ILT are optimizing oscillation parameters or oscillation contours in experimental studies. By thermally simulating energy deposition and subsequently melting the interface between both joining partners, the institute aims at verifying experimental results, as well as creating a means to predict and optimize it further.

Method

Based on calculating optical beam propagation during penetration of the upper transparent joining partner and material-dependent absorption in the lower joining partner, a heat source is simulated which provides input for an FEM heat conduction calculation inside the joining partners. Considered are light scattering due to the upper partner's semi-crystalline character as well as optical penetration depth of the absorbing partner. A comparison of the computed melt volume with microtome slice cuts of welded flat samples allows the verification and calibration of the simulation approach.

Result

For TWIST® welding with 0.8 mm seam width, 80 µm beam diameter, feed 50 mm/s and 2000 Hz TWIST® frequency, circle (0.8 mm diameter) and ellipse (0.8 mm and 0.2 mm axis lengths), oscillation contours are compared by means of their weld seam microtome cuts and their calculated spatial temperature distributions (Figure 2). This comparison shows that energy deposition and, therefore, weld seam geometry can be homogenized by using an ellipse-shaped oscillation, whereupon the axis' ratio is crucial for the homogeneity grade.

Applications

Thanks to this mathematical model to simulate TWIST® welding, users can optimize process parameters based on optical and thermo-mechanical material properties. This is equivalent to considerably reducing development times in polymer technology when this method is applied.

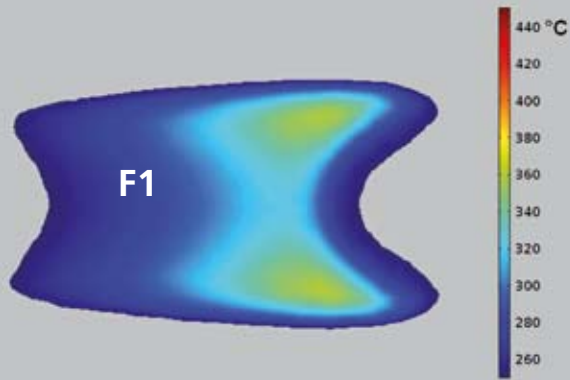
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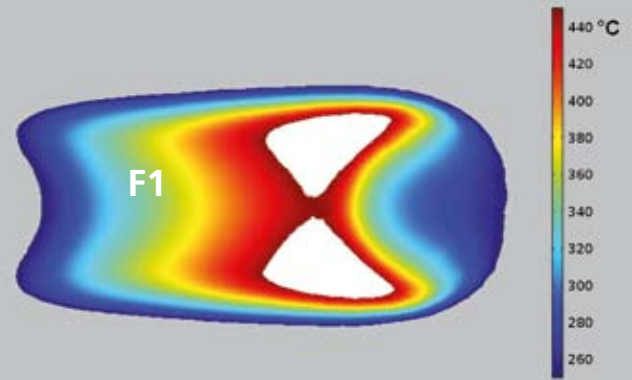
2 Computed temperature distributions and microtome cuts for circle (above), for ellipse (below).

Fg



1

Fg



2

SIMULATION OF THE WELD STRENGTH OPTIMUM IN LASER WELDING OF POLYMERS

Task

The weld strength of a polymer joint depends, first of all, on the joint section of the seam. In particular, when polymers are welded with lasers, predicting this strength accurately is nearly impossible because the area of the molten zone depends on multiple factors, such as absorption, beam diameter, welding strategy and others. To obtain the optimum weld strength for a given material and device geometry, extended experiments and analyses have to be performed.

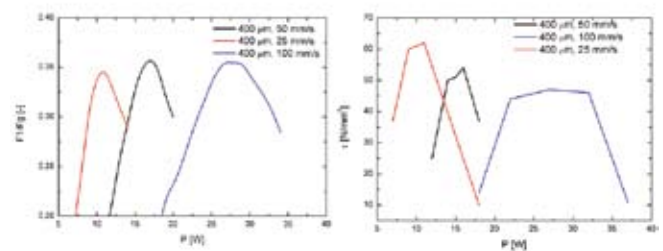
Method

Using a new simulation technique based on a combined simulation of radiation propagation and temperature development the current procedure can be reduced to a few verification trials. To do this, the weld strength is correlated with the thermal simulation results. The temperature field of the joining zone was calculated for the different experimental parameters. From this simulation, an area F1 of the joining is defined and calculated, where the temperature exceeds the melting temperature (250° C), but is smaller than the degradation temperature (450° C). This area corresponds to an optimum welding condition, thus providing the highest weld strength.

Calculated temperature fields for 2 different laser powers (Figure 1: 12 W, Figure 2: 17 W).

Result

The comparison of the measured weld strength and the area F1 shows a local maximum at the same laser power. The process parameter where the optimum weld strength is reached can be obtained by calculating the temperature field.



Applications

This new optimization approach can be used to plan and dimension laser polymer welding processes and to design the corresponding components.

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3

TOPOLOGY-OPTIMIZED COMPONENT DESIGN

Task

Topology optimization methods enable the geometry of a component to be tailored to functional requirements (e.g. force initiation, strength). In this way, for instance, very light yet very stiff components can be designed. The resulting design tends to boast a filigree, bionic structure, which may also include internal hollow structures. Since this kind of design cannot be manufactured using conventional manufacturing processes, the results of topology optimization are used only as a starting point and the design needs to be manually modified so that it can be cast or machined. In the process, components once again become more solid and heavier, i.e. the possibilities of topology optimization are only utilized to a certain extent. Additive manufacturing processes enable virtually any geometry to be manufactured so that the full potential of topology optimization can be exploited.

Method

As part of manufacturing using Selective Laser Melting (SLM), the topology optimization algorithms have to be adapted to the manufacturing possibilities offered by SLM. To this end, filter functions and lattice parameters are set to reflect minimally feasible feature sizes. This kind of topology-optimized design needs to be smoothed only slightly in order to be subsequently built up directly using SLM.

Result

The starting point is the design for a stub axle which was optimized for high-speed machining. Compared with this design that has been repeatedly optimized over many years, the SLM-specific topology optimization reduced the component weight by approx. 18 %. The SLM-optimized stub axle measures approx. 220 mm x 160 mm and was built up using High Power Selective Laser Melting (HP-SLM) with a laser output power of 500 W from a high-strength aluminum alloy (AlMgSc).

Applications

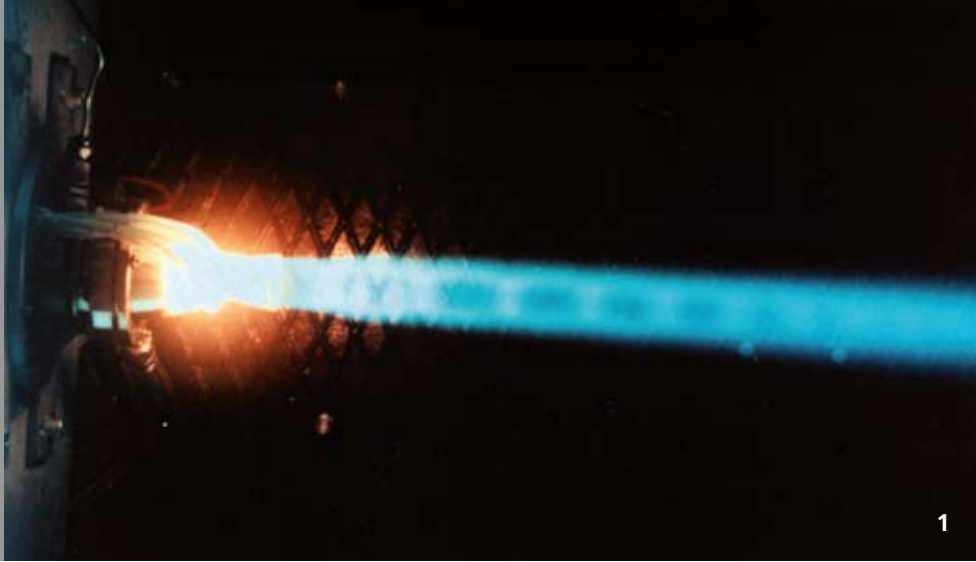
Applications for additively manufactured, topology-optimized components include automotive engineering and, in particular, the aerospace industry, where component weight plays a major role.

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3 *Additively manufactured, topology-optimized automotive component.*



ADDITIVE MANUFACTURING OF THRUSTERS FOR SATELLITE ENGINES

Task

Thrusters that can develop up to 400 N are used to position satellites in space. In order to achieve low fuel consumption and hence longer operating life, combustion temperatures need to be as high as possible. Platinum-based alloys are ideal for fulfilling the mechanical-thermal requirements placed on the thrusters as a result of the high temperatures. These materials are cast; machining proves to be extremely expensive owing to the high cost of the material. Thus additive processes such as selective laser melting (SLM), which conserve resources, are ideal for manufacturing thrusters from platinum alloys.

Method

In a research project funded by the European Space Agency (ESA), a range of additive processes are being investigated jointly by EADS Space Transportation, EADS Innovation Works and Fraunhofer ILT to establish their suitability for processing a selected platinum alloy. The processibility of the platinum alloy using SLM is being investigated at Fraunhofer ILT. To this end a suitable process window for manufacturing defect-free test specimens with a density of approx. 100 percent has been determined and the generated microstructure subjected to metallurgical analysis. Tensile strength properties for static and dynamic loading at the relevant operating temperatures

are then determined on test components manufactured using SLM. Finally, once the required mechanical properties have been obtained, a thruster will be additively manufactured and tested under operational conditions.

Result

The initial results of the investigations conducted to date show that the selected platinum alloy can be processed using SLM to create defect-free components with a density of approx. 100 percent. Further investigations to determine the mechanical properties at temperatures up to 1500 °C will soon be conducted on the test components that have already been manufactured.

Applications

If the test results prove successful, thrusters made from platinum alloys can be manufactured resource-efficiently using SLM, and hence much more cost-effectively than before.

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2



3

HIGH POWER SLM MACHINING OF INCONEL 718

Task

The additive manufacturing process Selective Laser Melting (SLM) is primarily used for manufacturing prototypes and end products in small quantities, in accordance with the current state of the art. A significant increase in productivity is, however, required if the full potential of SLM is to be leveraged for series production and components manufactured economically in larger quantities. One way of achieving this is to use High Power Selective Laser Melting (HP SLM) in combination with tailored process control (e.g. skin/core strategy). One current example application for SLM is the manufacturing of components for test engines made out of the nickel-based alloy Inconel 718. There is still no HP SLM process control for this material.

Method

HP SLM increases the build-up rate by using a higher laser output ($P_L=1$ kW). In particular with materials with relatively low thermal conductivity ($\lambda \leq 30$ W/mK), tailored process control (skin/core principle) is used to this end. The component being created is subdivided into a skin and core area, allowing different process parameters to be assigned to each area. In order to use this process control for IN 718, suitable process parameters must be determined for the skin area and the core area that enable a component density of approx. 100 % to be produced. The process control must also ensure a defect-free connection between the skin and core.

Result

HP SLM machining with tailored process control (skin-core principle) enabled components to be manufactured with a density $\geq 99.5\%$ for the skin and core area as well as for the transition area between the skin and core. Hence the use of a laser output power P_L of up to 1 kW enables the build-up rate to be increased by a factor of four, compared with the conventional SLM process with $P_L \leq 200$ W.

Applications

At present the key SLM application for processing Inconel 718 relates to turbine manufacture. Due to increased productivity, HP SLM opens up the prospect of cost-effective series production of components in large quantities.

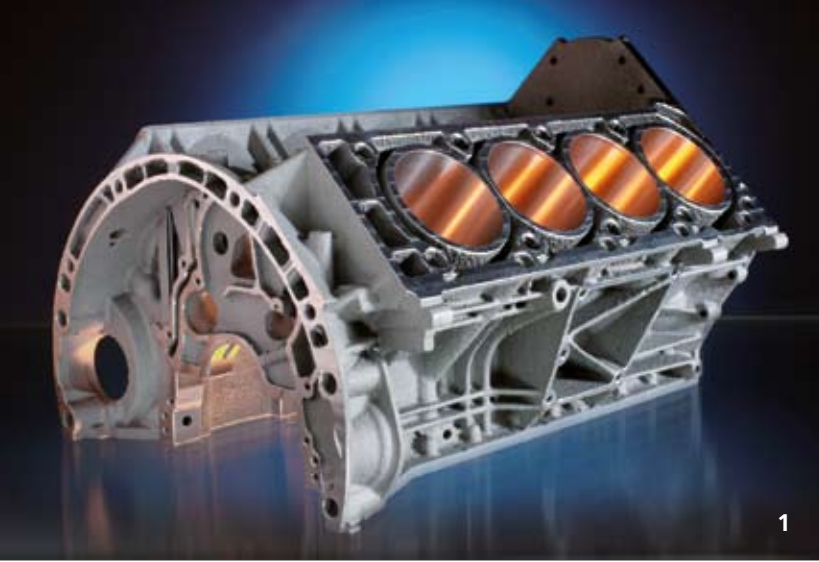
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2 Additive manufactured segment (front view) of a nozzle guide vane out of Inconel 718, source: TurboMeca.

3 Back view.



OPTICAL SYSTEMS FOR HIGH POWER SLM

Task

The pronounced trend toward the increased usage of Selective Laser Melting (SLM) for series production requires, among other things, higher productivity, reproducibility, and reliability of SLM systems. The increase in productivity through the use of laser sources in the kW region (High Power SLM) and the associated higher build-up rate achieved has already been demonstrated in the laboratory. The industrial usage of kW beam sources and material-dependent exposure strategies in commercial SLM systems call for new, robust optics concepts for beam guidance and shaping.

Method

New process control strategies are being developed to translate laser output power into build-up rate. Studies have demonstrated the feasibility of different exposure strategies with tailored beam diameters, dependent on factors including the thermo-physical properties of the materials. Tailor-made optical systems are being designed for the control of specific processes in order to implement these exposure strategies. Selected systems are being implemented in commercial SLM systems in collaboration with equipment manufacturers, taking into account specific framework conditions such as required scan field size and focus diameter. When selecting

the optical components their suitability in terms of destruction thresholds and thermal load for the power class of 1 kW and the associated intensities, especially with the use of single-mode beam sources, are prime considerations.

Result

In collaboration with various equipment manufacturers, two different optical systems have been implemented in commercial plant which for the first time supports SLM systems with a laser output power of 1 kW. One version involves the use of variable focusing optics for the continuously variable adjustment of the beam diameter when using a 1 kW single-mode beam source. The other employs a dual-beam concept that facilitates switching between two sources: one that provides a small beam diameter with a Gaussian-shaped intensity distribution and one that provides a large beam diameter with a top-hat-shaped intensity distribution. These optical systems enable components to be manufactured with a higher build-up rate while maintaining detailed resolution and surface quality.

Applications

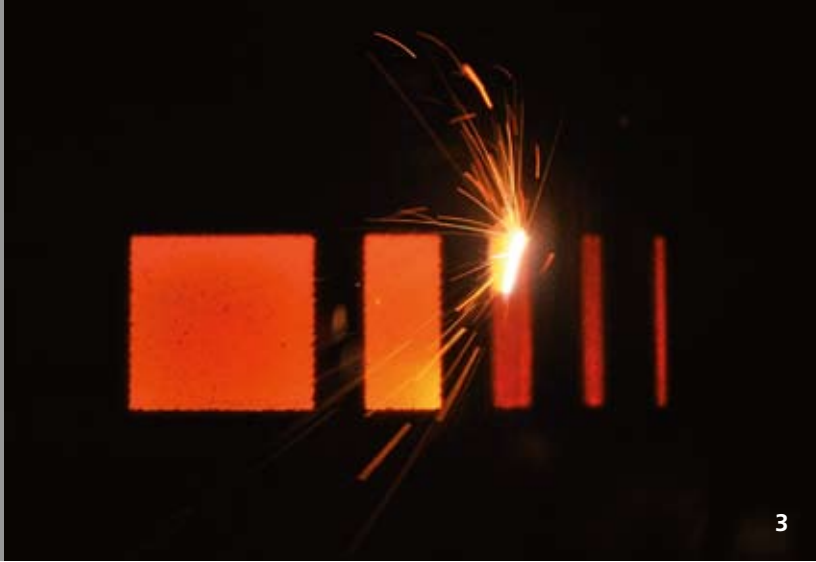
The 1 kW SLM systems are being used for additive manufacturing of components in various industries such as automotive, turbomachinery, or toolmaking.

Contacts

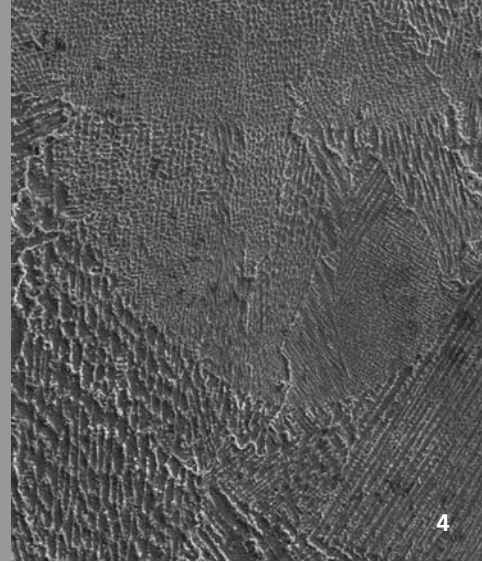
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1 SLM V8 engine block (model 1:3).

2 Beam path of an optical system for HP SLM.



3



4

PROCESSING IN738LC USING SLM

Task

Nickel-based superalloys such as Inconel 738LC have been developed for components exposed to high temperatures and represent the state of the art in turbine manufacture. Conventional manufacturing of components using precision casting is time-consuming, costly and limited in terms of geometrical freedom. Designed as cast alloys, the complex materials are difficult if not impossible to weld owing to the formation of hot cracks. Up to now it has not been possible to process IN738LC using SLM without crack formation.

Method

The processibility of IN738LC using SLM is being investigated at Fraunhofer ILT in association with partners from research institutions and turbine manufacturers as part of the EU's »MERLIN« project. Process control for manufacturing defect-free test specimens at preheating temperatures up to approx. 900 °C has been developed using a specially modified laboratory test system. On this basis the thermomechanical properties are determined once a suitable heat treatment process has been established. Finally, functional prototypes are manufactured using SLM and tested under real conditions.

Result

An SLM laboratory test system developed at Fraunhofer ILT allows test specimens with a density of almost 100 percent to be manufactured without crack formation at preheating temperatures between 800 and 900 °C. The smaller temperature difference between the weld pool and solid microstructure reduces process-induced stresses, resulting in a defect-free microstructure. Further research will investigate whether the preheating temperature can be reduced by suitably modifying the other process parameters.

Applications

IN738LC is primarily used in turbine manufacture, e.g. for turbine blades; this means the aerospace and energy industries represent the main applications. The rapid manufacture of complex functional prototypes, in particular, paves the way for much shorter and hence more cost-effective development processes. Basically, the results can also be applied to other alloys susceptible to cracking and make processing using SLM possible.

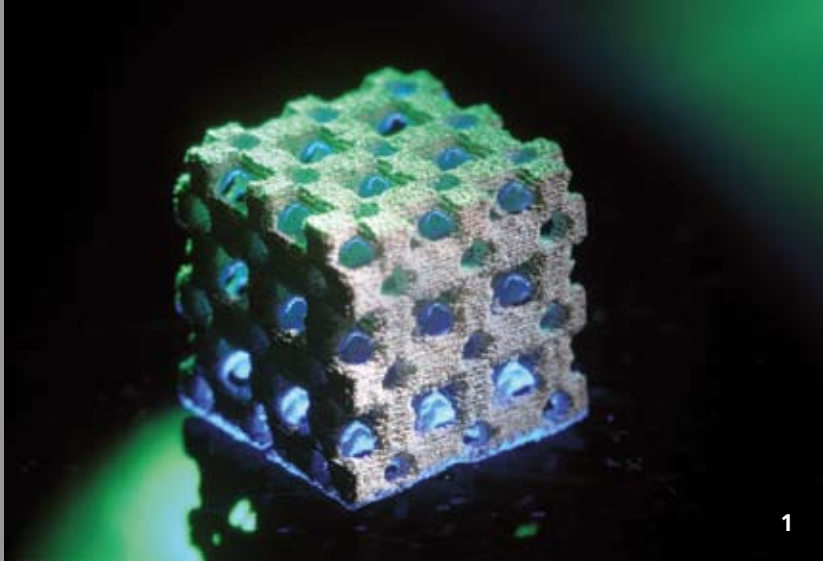
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3 SLM process at a preheating temperature of 900 °C.

4 Microstructure of test specimens made from Inconel 738LC without post heat treatment.



SELECTIVE LASER MELTING OF MAGNESIUM ALLOYS

Task

Magnesium and magnesium alloys are used primarily in lightweight construction due to their low density. At the same time, magnesium is biocompatible as an essential part of the human metabolism and offers huge potential for use as a bioresorbable material for degradable bone replacement implants even in load-bearing areas, thanks to its corrosion and mechanical properties. In combination with the geometrical freedom offered by additive manufacturing, components and implants with unique functional properties can be manufactured particularly in lightweight construction and medical technology applications. Selective laser melting (SLM) enables the manufacture of topology-optimized components that are tailored to the actual loading case as well as implants with defined, interconnected pore structures that can substantially improve bone ingrowth. These material and process advantages should be combined by developing SLM for processing magnesium alloys.

Method

The magnesium alloy AZ91 has been chosen for the initial studies to develop a suitable SLM process. The SLM system technology has been modified in accordance with the high oxygen affinity of magnesium and magnesium alloys, especially in the powder form used. The minimal difference between melt and vaporization temperatures poses another challenge when it comes to developing a suitable process window.

*1 Test geometry manufactured using SLM (edge length 6 mm)
with interconnected pore structure made out of AZ91.*

Result

The modification of the system technology supports reliable processing of magnesium powders by reducing the oxygen content of the inert gas atmosphere used to 10 ppm. Under these process conditions, simple test specimens made from AZ91 can be manufactured with a density greater than 99 percent by modifying the process parameters. Initial complex geometries with interconnected pore structures have also been manufactured.

Applications

The additive manufacturing of light metals such as magnesium and magnesium alloys is ideal for lightweight applications as it enables extremely complex geometries to be manufactured. At the same time, the possibility of using magnesium alloys as bioresorbable materials paves the way for a new application field for SLM in the area of resorbable load-bearing bone-replacement implants.

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PROCESS CHAINS FOR MANUFACTURING AND REPAIR

Task

Laser-based processes such as Selective Laser Melting (SLM) or Laser Metal Deposition (LMD) are already being used in industry for the additive manufacture and repair of turbomachinery components. Depending on the application, SLM or LMD may require conventional processes such as milling, grinding and polishing for initial or final machining of the components. To link the various process steps, the processes should be combined by setting up a joint platform – the CAx Framework – to create a single process chain. As part of Fraunhofer's »TurPro« Innovation Cluster, end-to-end process chains have been developed for three different components in collaboration with Fraunhofer IPT.

Method

To implement an end-to-end process chain, interfaces have been created in order to transfer CAD data from process to process without any losses. To this end, a clamping system for the various technologies is used in order to minimize the work involved in calibrating the component in the machine coordinate system. The offline planning of the tool paths and implementation of the process strategy are conducted for each technology by means of a separate CAx module. Commercial CAD/CAM programs for data processing and path planning can be used for the SLM process. Separate CAx modules have been developed in cooperation with Fraunhofer IPT for offline path planning of the additive manufacturing of new components and for repairing components using LMD. In the case of

additive manufacturing, tool paths are generated on the basis of the target CAD model. In the case of repair, the prepared component is scanned using a laser scanner, an actual CAD model generated and compared with the target CAD model. Tool paths for the LMD are then generated by using a best fit of the CAD models.

Result

The process chains have been implemented for the additive manufacturing of a micro gas turbine using the SLM process, for the additive manufacturing of a compressor blade using a BLISK design, and for the tip repair of a gas turbine blade using the LMD process.

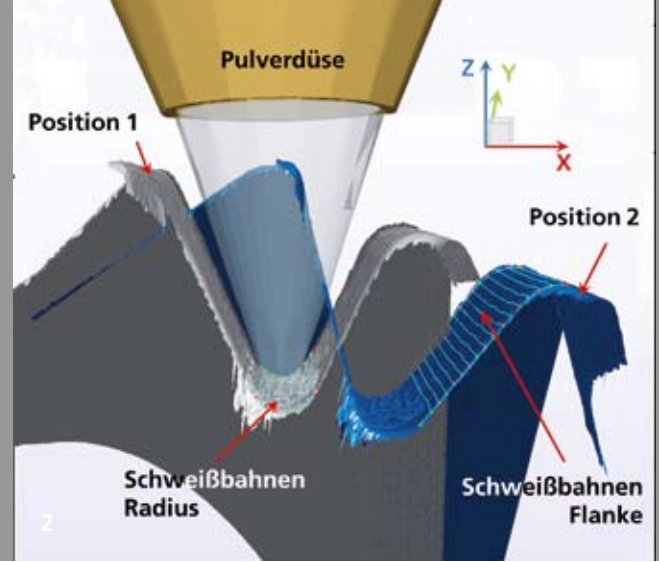
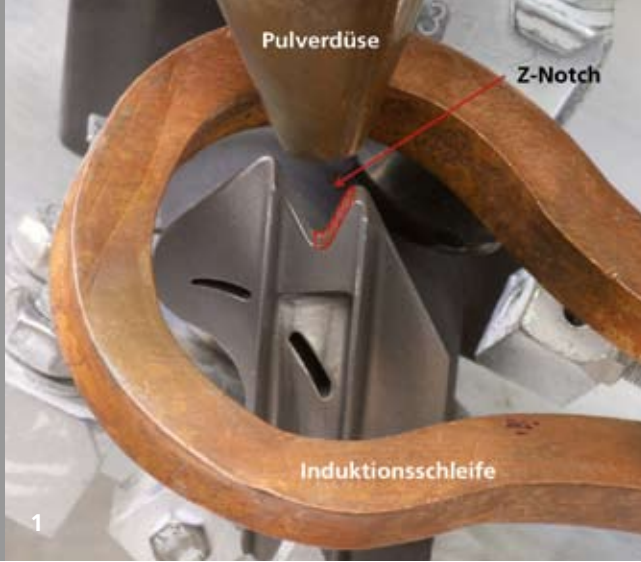
Applications

The process chains developed within »TurPro« are primarily aimed at turbomachinery components in the energy and aerospace industries. The method can, however, be applied to components and applications in other industries.

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2 Left: compressor blades additively manufactured using LMD in various finishing states. Right: tip of a gas turbine blade repaired using LMD before and after final processing. Front: micro gas turbine components additively manufactured using SLM.



LASER MATERIAL DEPOSITION ON COMPLEX GEOMETRIES OF TURBINE BLADES

Task

Wear protection coatings shall be deposited on Z notches of turbine blades in the bottom radius and on one flank using laser material deposition (Fig. 1 area marked in red). The turbine blades are manufactured from a crack-susceptible nickel-based superalloy containing γ' . It must be ensured, that cracks are prevented from forming during laser material deposition. A cobalt-based alloy with a hardness of ≥ 650 HV will be deposited as a wear protection coating. The angle of aperture of the area to be deposited is approx. 50° , accessibility is largely restricted, thus posing challenges for laser material deposition and programming.

Method

In order to prevent cracks in the blades, a buffer layer made of Inconel 625 is initially deposited using laser material deposition. Process parameters that reduce energy input into the blades are used for the buffer layer as well as for the wear protection coating made of the cobalt-based alloy. The cobalt-based alloy cannot be deposited at room temperature to the required thickness without cracks forming, so the Z notch is

preheated locally using induction (Fig. 1). To produce the tool paths, the relevant area of the Z notch is optically scanned and the resulting point cloud is converted into an stl model. In-house CAM software is used to produce tool paths on the stl model, and to create the CNC programs. Owing to the small angle of aperture of the Z notch, the turbine blades have to be turned once the coating is deposited on the radius area (Fig. 2) in order to deposit on the flank; this factor is taken into account during the creation of the CNC programs.

Result

Crack-free wear protection coatings with high hardness can be deposited on the radius and the flank of Z notches using laser material deposition.

Applications

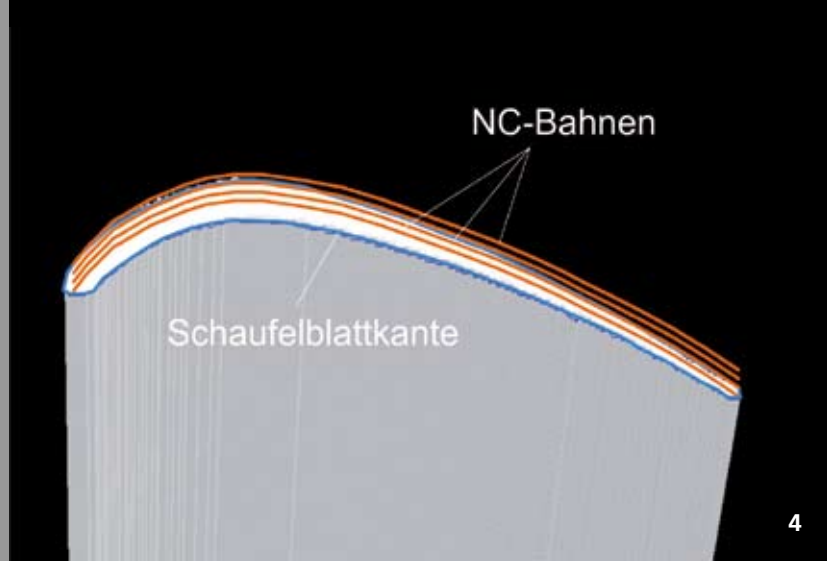
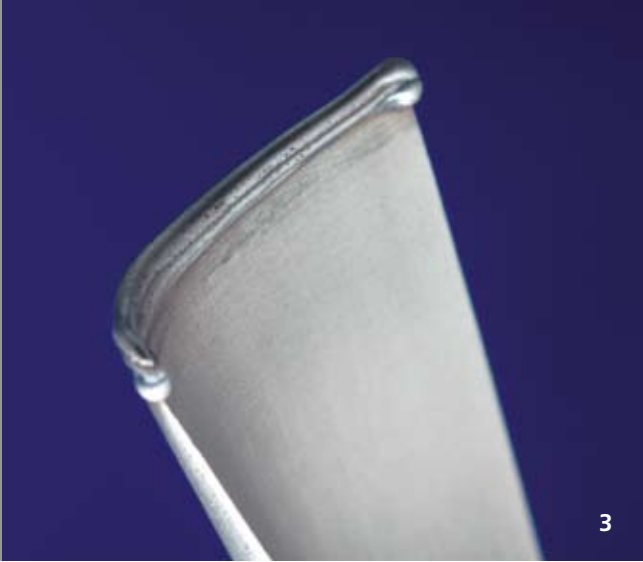
This process is particularly suited to working with components made out of crack-susceptible materials and/or with freeform surfaces, such as repairing turbomachinery components or tools, molds and dies.

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- 1 Test setup (left) for deposition position 1 with powder nozzle and induction loop, the area to be deposited is hatched in red.
- 2 Programming (right) for two deposition positions using in-house CAM software.



AUTOMATIC LASER CLADDING FOR TURBINE TIPS

Task

Wear occurs at the tip of turbine and compressor blades during operation. This reduces the blade length and increases the flow losses. If the length undershoots a certain threshold, the blade must be taken out of service.

The missing volume on the helicopter engine blade tip processed in this project would previously have been restored by manually depositing material using TIG deposition welding. The welding and the necessary finishing are very time-consuming and hence costly.

Laser cladding represents an alternative process that facilitates automatic near-net shaped material deposition and hence reduces finishing time. Since the geometry of the blades varies, this repair process needs to be automated to efficiently utilize the laser cladding process and to ensure a high level of reproducibility.

Method

The development of an automatic process chain tailored to the geometry of the turbine blade was broken down into the following working points: since the blade geometry varies, the actual geometry of each blade tip is recorded using a laser scanner. The scanned dataset is then analyzed and a center-point path on the blade tip calculated using a software module developed at Fraunhofer ILT. The points are fed into

the NC program for control purposes. During the process development of the technique, the course of the blade cladding and the process parameters are determined; the NC programs for automated control of the cladding process are generated based on this data.

Result

The technique was implemented on a blade tip made out of a nickel-based material; near-net shaped laser deposition in line with specifications was achieved with an excess of 0.2 mm. The process parameters were successfully adapted to the blade width that varies along the turbine blade profile.

Applications

This process is suitable for the automatic repair of blade tips on a host of blade types, e.g. from aerospace and power generation.

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3 Blade tip manufactured using laser cladding.

4 Digitized blade dataset with NC paths.



COAXIAL POWDER NOZZLES FOR HIGHER LASER OUTPUT POWERS

Task

One key objective of laser material deposition is to increase the deposition rate. Laser output powers in the multi-kW region are used to this end. These high laser output powers call for the development of new robust powder feed nozzles. Existing coaxial powder nozzles (angular gap nozzles) at Fraunhofer ILT with high powder efficiency (> 90 percent) were designed for a laser output power of up to 2.5 kW. A coaxial powder nozzle is being developed for laser material deposition that is designed for laser output powers of up to 5 kW, can handle higher powder mass streams > 1.5 kg/h and achieves powder efficiency of > 90 percent.

Method

As part of developing powder nozzles for laser material deposition, the distance between the powder nozzle and workpiece surface (stand-off) has been increased from 8 to 13 mm in order to reduce heating caused by reflected laser radiation. The nozzle cooling has also been improved by means of design measures.

Result

Tests have been conducted over 8 hours at 5 kW laser output power and 2.8 kg/h powder mass stream. The newly developed powder nozzle is being used successfully for cladding large hydraulic cylinders. Cladding speeds of 6 - 8 m/min have been achieved as part of these tests. Processing rates per unit area are 132 cm²/min at a feed rate of 6 m/min and a beam diameter of 2.2 mm; deposition rates at 50 percent overlap are therefore around 2 cm³/min with an achieved powder efficiency of > 90 percent and a layer thickness of 0.3 mm.

Applications

Potential applications include material deposition for large components that require a combination of robust equipment and high powder efficiency. Examples include material deposition of wear and anti-corrosion layers on cylindrical components such as hydraulic and oilfield components requiring cladding times of several hours.

Contacts

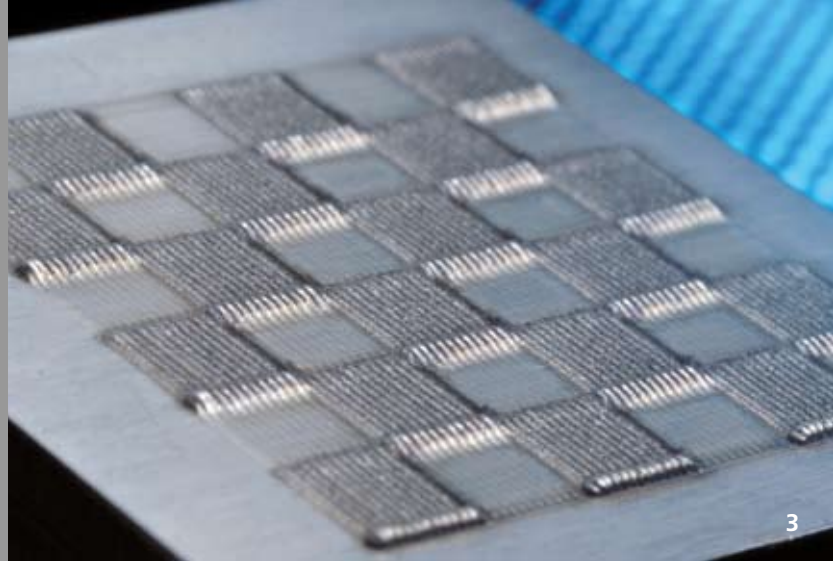
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1 Coaxial powder nozzle for higher laser output powers.



2



3

HIGH-SPEED POWDER SWITCH – SYSTEM TECHNOLOGY FOR LASER MATERIAL DEPOSITION

Task

Laser material deposition often requires the coating process to be interrupted so that the component can cool down or the coating head can be repositioned. During these interruptions the powder feed system must either be switched off, which substantially increases processing time, or the powder gas stream allowed to continue during the interruption. The powder supplied during these downtimes can be reused only to a limited extent owing to contamination; it also soils the laser system and the components being processed. Depending on the application, up to 30 percent of the filler material can be wasted. For these reasons a high-speed powder switch that can switch the powder gas stream on and off in fractions of a second provides a compelling solution. The powder not used for the process can be collected in a separate container and reused.

Method

In collaboration with HD, a company based at Fraunhofer ILT, a high-speed powder switch (Fig. 2) was developed that enables the powder gas stream to be switched on and off and can toggle between two powder gas streams. This enables a coating process lasting several hours to be completed with no interruptions.

Result

Initial tests using the high-speed powder switch demonstrate switch-on and switch-off times for the powder gas stream of approx. 300 ms. The powder switch has been designed to ensure that no powder trickles out once it has been switched off. The developed design also allows two powder storage vessels to be linked so the system can seamlessly toggle between the powder storage vessels. The powder switch has been fitted with a pneumatic switch for automated processing; this switch drives the powder switch via the plant control system. Fig. 3 shows a chessboard pattern where the powder gas stream was switched on and off during the process without switching off the laser beam. Consequently, the processing time for this kind of geometry was reduced by a factor of 10. Apart from reducing processing time, the high-speed powder switch also saves substantial amounts of filler material.

Applications

Laser material deposition and thermal spraying are potential applications for the high-speed powder switch.

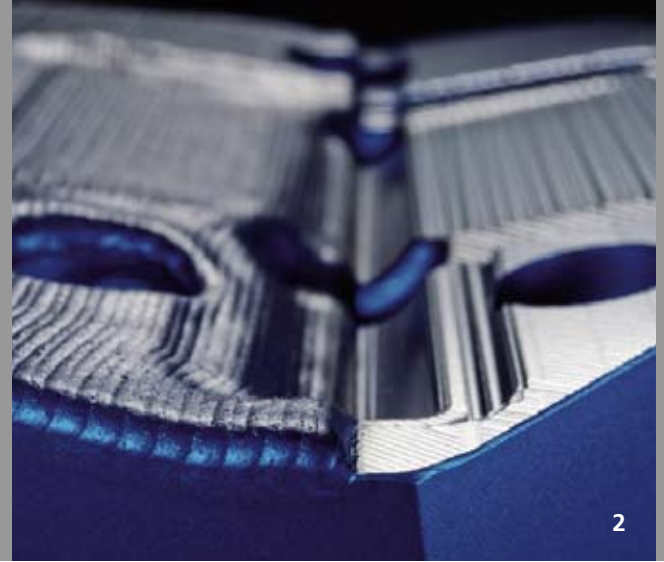
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2 High-speed powder switch.

3 Chessboard pattern, manufactured by high-speed switching of the powder gas stream.



WEAR PROTECTION LAYERS WITH NANOPARTICULATE ADDITIVES FOR TOOLS

Task

The wear protection of molds and tools is becoming increasingly important in manufacturing industry given increasing materials costs and greater demands placed on the manufactured components. In addition to wear protection of new tools, the repair of worn components is playing an ever more significant role. In both cases, wear protection must be tailored to the specific application. In this respect, a compromise between high strength, sufficient toughness and good wear resistance (hardness) must be found.

Method

In order to optimize the thermophysical fit between substrate and layer, a similar material is used as the coating material. The characteristics are modified by means of minimal additions (< 2.5 weight percent) of nanoparticles. Coatings are manufactured from the hot-work steels 1.2365 and 1.2714 with additives made of aluminum and yttrium oxide (20 - 40 nm) as well as titanium carbide, vanadium carbide and tungsten carbide (grain size 80 - 250 nm). The coatings are investigated metallographically in terms of microstructure, porosity and crack formation. Tensile tests and hardness measurements are conducted on test specimens to assess the mechanical properties.

Result

Analysis of the layers shows that nanoparticulate additives of titanium carbide have the greatest effect on the weld quality structure in terms of reducing the grain size. The best mechanical properties can be achieved by adding tungsten carbide. The tensile strength is more than 1700 MPa, with an elongation at rupture of 12 percent and a hardness of 946 HV0.3. This is equivalent to an increase in hardness of approx. 60 percent by adding 2.5 weight percent of tungsten carbide particles. Thus strength and hardness can be increased by adding nanoparticles, while largely maintaining toughness.

Applications

These kinds of layers are particularly suited to areas where thermal or mechanical fatigue develops (forging dies, die-casting molds), as well as areas subject to wear. Field tests with coated forging dies are currently being prepared.

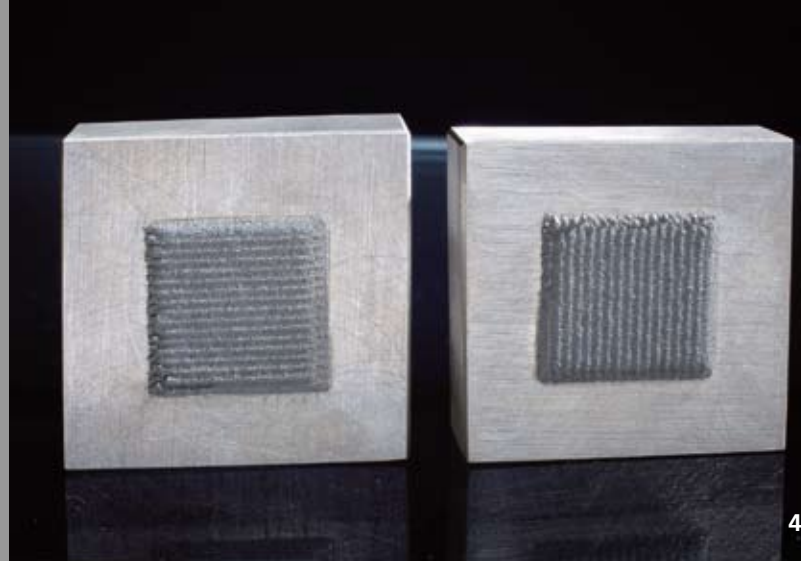
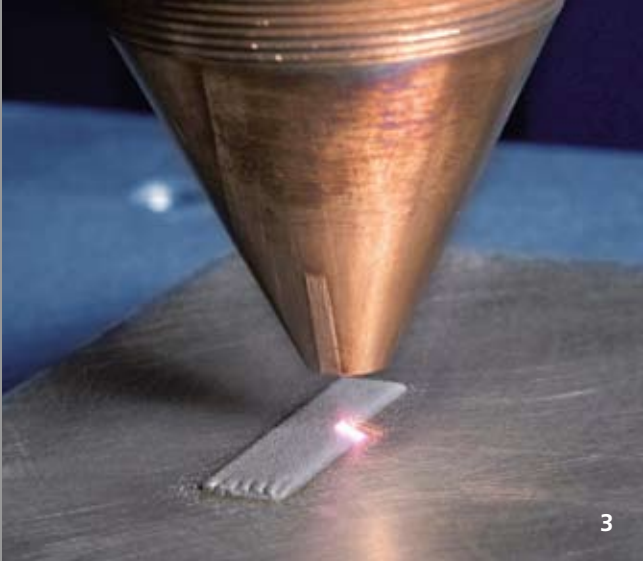
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1 Laser cladding of a tool insert.

2 Coated tool insert.



WEAR PROTECTION FOR MAGNESIUM ALLOYS USING LASER CLADDING

Task

Magnesium is used in a wide range of applications, particularly in the automotive and aerospace industries. Demand is constantly growing due to its low density, good damping characteristics and very good machinability compared with aluminum or steel. One drawback of magnesium alloys is, however, their low wear resistance. To address this issue, various layers are deposited on magnesium substrates using laser cladding.

Method

During the laser cladding process, powder fed via a nozzle is melted together with a thin layer of the substrate. A metallurgical bond is created once solidification takes place. The alloy AZ31B is used as a substrate. Layers are manufactured with the aluminum alloy AlSi20, an iron-based alloy (Metco42C) and a composite made of titanium carbide (TiC) and AlSi20. The cladding process is adjusted so that the dilution zone in which brittle intermetallic phases may occur is as small as possible (max. 100 μm).

Result

The laser-clad layers have no cracks or pores. The layer thickness is approx. 1 mm in single-layer configurations. To investigate the wear protection, the various layers were subjected to a pin-on-disc test. The abrasion rate for the substrate AZ31B is $1.23 \cdot 10^{-03} \text{ mm}^3/\text{Nm}$. With an AlSi20 layer the abrasion rate can be reduced by a factor of 2.6 to $4.76 \cdot 10^{-04} \text{ mm}^3/\text{Nm}$, with an AlSi20+TiC layer by a factor 2.9 to $4.16 \cdot 10^{-04} \text{ mm}^3/\text{Nm}$. The largest effect is obtained with an iron-based layer with $1.69 \cdot 10^{-04} \text{ mm}^3/\text{Nm}$ (factor 7.3), which cannot be applied directly on magnesium due to its high melting point, but requires an interlayer made of AlSi20.

Applications

Magnesium alloys are used as materials for gear and engine housings. Here the laser cladding process either can be used on wear-affected areas preventively or retrospectively as a repair process.

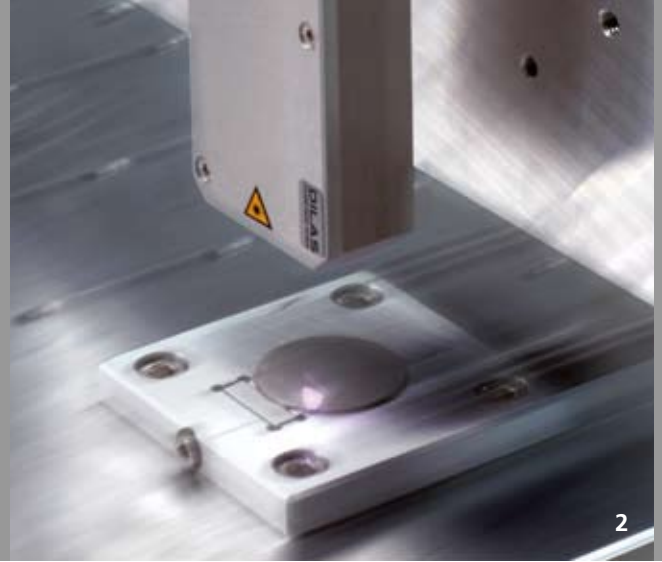
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3 Laser cladding on AZ31B.

4 AlSi20 coating on AZ31B.



PRODUCTION OF CERAMIC DECORATIVE LAYERS USING LASER PROCESSES

Task

Apart from the annealing and glaze firing process required to manufacture the base ceramics, decorated tableware and sanitary ceramic products require an additional firing to apply the decorative finish. The decorative finish is fired at temperatures $> 700\text{ °C}$ in continuous furnaces with a high thermal mass and is therefore extremely energy-intensive. In order to drive down the high costs in the industry and make a substantial contribution to climate protection, the aim is to develop an energy-efficient laser process that limits the area to be heated to a thin edge zone by precisely controlling the spatial and temporal characteristics of the laser radiation.

Method

Close collaboration with coating material manufacturers for the decorative industry enables the laser process and the coating material to be coordinated. This material is applied, for instance, by means of spraying or pad printing. Fraunhofer ILT's remit is to tailor specifically the characteristics of the laser-induced temperature distributions (e.g. heating/cooling rates, temperature hold times, temperature penetration depths, etc.) so that the firing temperatures required for the particular coating material are achieved in an energy-efficient manner without damaging the glazing components and pigments involved.

1 Black decoration fired using laser process on a glazed porcelain plate (Ø 15 cm).

2 Laser treatment with linear intensity profile.

Result

By implementing a quasi-linear processing strategy, the researchers have managed to convert the applied particulate coating materials into a homogeneous, superficially sealed coating and thus generate black decorations on glazed porcelain.

Applications

The direct application area relates to decorating tableware and sanitary ceramic products. However, the developed laser process can also be used to generate ceramic wear protection layers, thus opening up an additional application wherever surfaces need to be protected against wear.

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LASER-BASED MANUFACTURE OF SILVER CONDUCTIVE PATHS

Task

Printed conductive paths on flexible substrates boast a great deal of potential in electronic applications. Printing techniques enable structures to be manufactured from nanoparticulate metallic inks (e.g. copper, silver). Compared with conventional techniques, such as mask or lithographic processes, this process is flexible, inline-capable and saves resources, time and money. The necessary thermal post-treatment for drying, sintering and partially melting the particulate layer is completed by means of laser processes in order to facilitate the use of temperature-sensitive substrates.

Method

Nanoparticulate silver ink is deposited onto temperature-sensitive PET film using ink-jet printing. Using laser radiation with a wavelength of 532 nm, the printed layer is heated in order to obtain a conductive layer by means of drying, sintering and partial melting. Despite high temperatures in the layer, the high attained temperature gradients and the locally selective input of energy during laser treatment enables temperature-sensitive substrates to be used without damaging these.

Result

Silver conductive paths with a width of $< 100 \mu\text{m}$ can be manufactured on temperature-sensitive PET film and other substrates. By replacing conventional furnace processes with thermal laser post-treatment, a conductivity of over 50 percent of the bulk material can be achieved without damaging the substrate. Very good adhesive and bending strength is achieved on the PET film as part of this process. No cracks appear in the layer with a bend radius of up to 5 mm.

Applications

This process boasts numerous applications in electronics, particularly in the field of flexible electronics owing to the high conductivity despite temperature sensitivity of the substrates. Possible applications include sensors, RFID or displays.

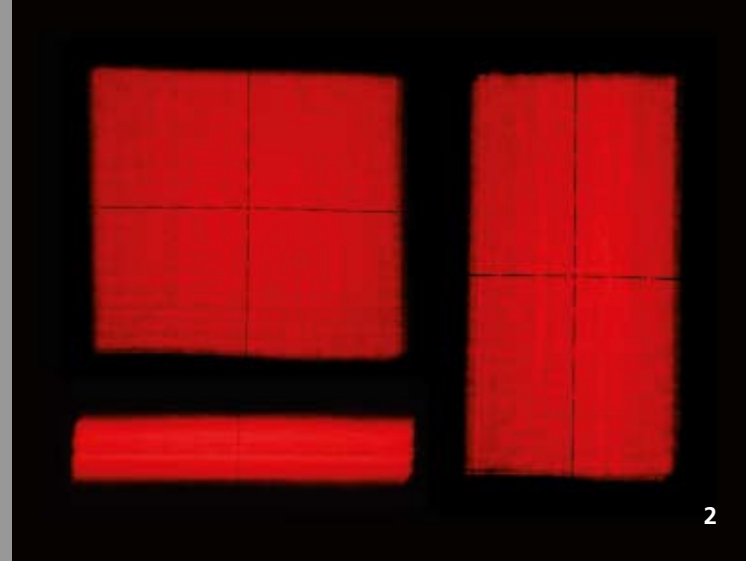
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3 Ink-jet printer.

4 Demonstrator with silver conductive path.



ZOOM HOMOGENIZER OPTICS FOR PROCESS-TAILORED CO₂ LASER MATERIAL PROCESSING

Task

The spread of efforts to increase flexibility in production environments for laser material processing calls for optical systems to generate flexible focal spot geometries with a homogeneous intensity profile. When using commercially available systems for CO₂ laser material processing the following problems can be identified at present:

- Predominantly static system behavior (fixed focal spot geometries)
- Use of crystal optics (ZnSe)
- Wavelength dependency

Method

By using cylindrically faceted optics, the input distribution is integrated with a highly homogeneous rectangularly symmetrical intensity profile. The exclusive use of metallic optics means crystal optics (e.g. ZnSe) do not need to be used and also provides virtual independence of the beam source wavelength. By integrating piezoelectric inertial drives, the optics can be adjusted in the folded beam path. This allows for continuous, two-dimensional scaling of the focal spot geometry during the machining process.

Result

The function for homogenizing the input distribution is successfully verified in the visible wavelength region and by burning tests using CO₂ laser radiation. The use of piezoelectric actuators enables the focal spot geometry to be adjusted precisely. At present, a multi-kW processing head is being implemented on the basis of the developed concept.

Applications

Owing to its better degree of absorption, CO₂ laser radiation is used to process continuous fiberglass reinforced thermoplastics in particular. The use of the developed optics concept provides optimized energy coupling and hence improved energy efficiency in the machining process.

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1 Zoom homogenizer optics.

2 Modified intensity distributions.



LOCAL HEAT TREATMENT OF HOT-STAMPED COMPONENTS USING LASER RADIATION

Task

Lightweight construction is an effective method of reducing fuel consumption and CO₂ emissions in the automotive industry. At the same time, however, crash safety specifications for vehicles are constantly being tightened. High-strength steels meet both requirements. Hot stamping allows complex components to be hot-formed, and these exhibit high strength through subsequent hardening in the cooled tool. In the case of the widely used steel 22MnB5, the tensile strength of the hot-stamped components is up to 1600 MPa. The brittleness associated with this high strength is, however, not advantageous or acceptable in the entire component. Achieving good crash behavior or joints with no crack formation in deformation zones and joining areas requires ductile material behavior.

As part of the »LOKWAB« project (reference number 02PU2020) for Germany's Federal Ministry of Education and Research (BMBF), local softening using laser radiation on hot-stamped components was investigated to improve crash behavior and subsequent joining operations.

Method

A temperature-controlled, fiber-coupled 12 kW diode laser and zoom optics with a rectangular laser spot size up to 52 x 52 mm² are being used for laser heat treatment.

Result

In the heat-treated area, the martensitic microstructure is modified (annealing or complete transformation); the elongation at rupture increases from 4 percent to up to 19 percent as strength decreases. In order to minimize distortion, a suitable heat-treatment strategy (sequence, position and dimension of the paths) was developed. In this way the maximum distortion of a heat-treated B-pillar was reduced from 10 to 1.7 mm. The AlSi protective coating of the components is not affected by the laser heat treatment. With maximum laser output power, processing rates of up to 15 cm²/s are achieved.

Applications

The process can be used inline in automotive manufacturing to locally soften hot-stamped components.

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- 3 Laser heat treatment of a hot-stamped component.
4 B-pillar with softening areas marked in color.



1

LASER MICRO POLISHING OF IMPELLERS MADE OF TITANIUM

Task

Many three-dimensional freeform surfaces are at present polished manually owing to the lack of automated manufacturing processes. In the case of titanium materials, mechanical polishing also causes smearing, making the surface finish even more difficult to achieve. Manual polishing times here are often over 10 min/cm².

For this reason, automated laser polishing for precision milled impellers from MediKomp made out of Grade 2 titanium is being investigated. Pulsed laser radiation can be used, in particular, to remove microroughness from surfaces and to increase the degree of gloss. Apart from the high machining speed, the main advantages relate to process automation and high geometrical accuracy.

Method

Suitable processing parameters for laser polishing are initially determined on flat specimens. The processing of a 3D impeller in a commercially available CAM system is then planned. Data are processed further using a technology module developed at Fraunhofer ILT for the laser polishing process. The NC data generated in this way can be used to process the impellers using a laser polishing machine.

Result

The impellers were polished using a rod laser ($\lambda = 1064 \text{ nm}$) with pulse durations in the region of approx. 150 ns at a processing rate of 3.3 s/cm². In this way a homogeneous surface was achieved across the component and its micro-roughness was reduced from Ra = 0.15 μm to Ra = 0.04 μm through polishing.

Applications

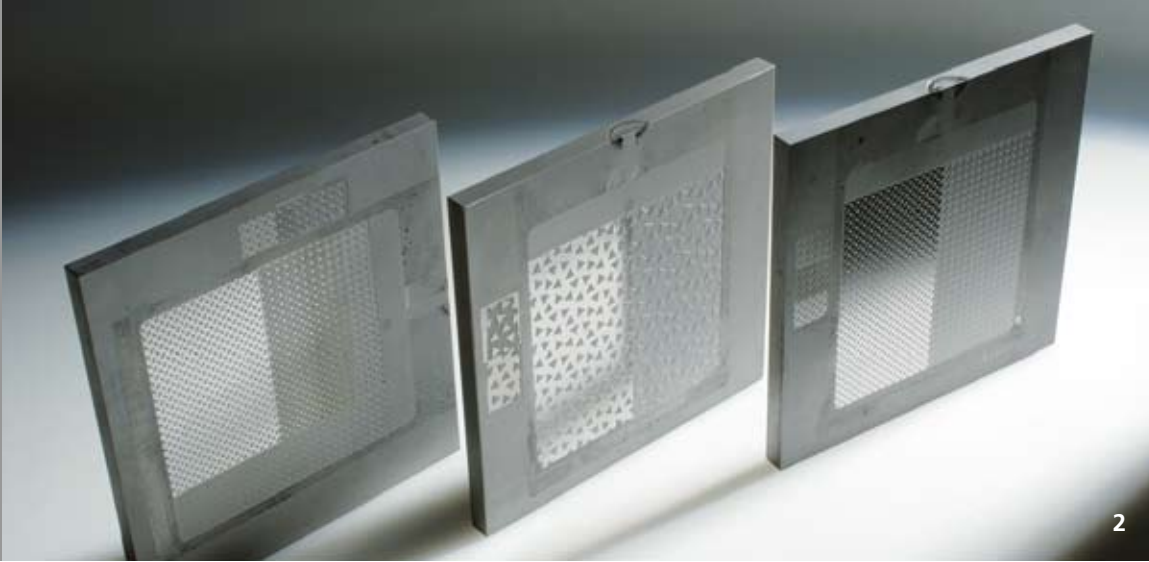
In addition to polishing titanium materials, the laser micro polishing process is suitable for many other materials and applications. In particular, the process can automate and substantially speed up the polishing of three-dimensional freeform surfaces.

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*1 Impeller made out of titanium
(\varnothing 43 mm, Grade 2) in precision milled original
state (left) and in laser-polished state (right).*



SELECTIVE LASER POLISHING

Task

Structured or grained surfaces are often required for plastic components such as automobile instrument panels. The tools used to produce these plastic components therefore have to be structured accordingly. The method most commonly used is photochemical etching. The structures are often designed to imitate natural materials such as leather or to provide a technical function. They also have to fulfill requirements in terms of touch and appearance. The new manufacturing technique of selective laser polishing (SLP) enables, for instance, only the indentations of a surface structure to be polished to create variable optical effects, meaning only the raised sections of the structure are polished on the molded component. The new method enables surfaces to be manufactured which were not possible before or which required considerable time and effort.

Method

SLP is being investigated on the basis of flat tool inserts made of tool steel 1.2343 with a wide range of different grained structures. First the complete surface is digitized using an optical sensor system with a resolution of 1040 dpi. SLP can be used with both pulsed and continuous wave laser radiation. The process involves scanning the surface in a meandering pattern while the laser beam focus is adjusted in accordance with the tool geometry. In addition, the laser power is modulated along the processing paths as a function of the existing structures (only selected areas are laser polished).

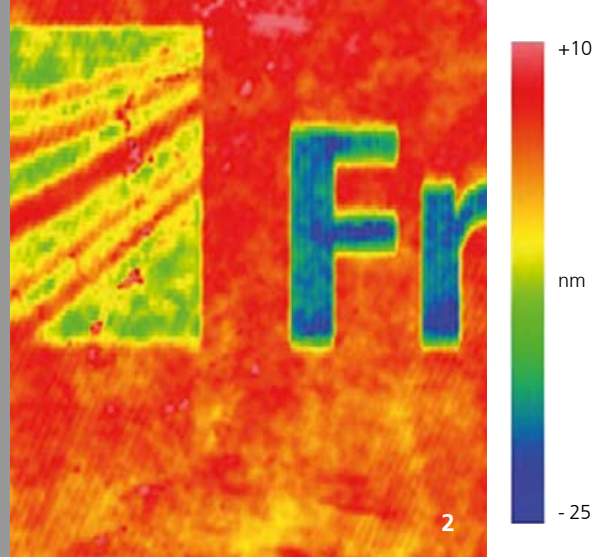
Result and Applications

By locally modulating the laser power, the gloss in selected areas of the structure is increased to create a dual-gloss effect. Depending on the selected processing parameters, the degree of gloss can be adjusted from the initial state through to very high glosses. The highest degree of gloss is achieved by means of successive processing using continuous wave and pulsed laser radiation. To demonstrate the process, a wide range of different periodic and non-periodic structures on flat tool inserts made of the material 1.2343 have been selectively laser polished, thereby providing a structure catalog for SLP. Plastic parts with dual-gloss effect were also molded from these tool inserts. At present, the processing time is approx. 30 to 60 s/cm² with a resolution of 1040 dpi. The smallest selectively laser polished structure is currently 150 µm in diameter (size of the laser beam focus). Future research work aims primarily to significantly improve the process speed (up to factor 100) and transfer the findings to 3D tools that are highly relevant in industrial applications, e.g. embossing dies or automobile instrument panels, and to test the process in an industrial environment.

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2 *Selectively laser-polished, flat tool inserts made from tool steel 1.2343 with surfaces featuring varied graining.*



POLISHING AND SHAPE CORRECTION OF OPTICAL COMPONENTS

Task

Compared with spherical lenses, aspherical or freeform optics combine higher imaging quality, smaller dimensions and lower weight, making them increasingly popular. However, the processes currently used to polish optics with these kinds of surfaces tend to be time-consuming, making manufacturing uneconomical in many instances. This is why Fraunhofer ILT is developing the two processes laser polishing and laser form correction, which are particularly suited for processing aspherical and freeform optics.

Method

The active principle of laser polishing is based on heating the glass material surface to just below its particular vaporization temperature. This reduces the viscosity and the surface is smoothed by means of surface tension. Unlike conventional polishing processes no material is removed. By modifying the process parameters, both flat and virtually any curved surface can be machined in an identical time. Laser form correction following laser polishing selectively removes smallest quantities of superfluous glass material by means of vaporization, which in turn increases the form accuracy.

Result

Laser polishing already achieves roughness levels sufficient for illumination optics; the processing rate per unit area of $1 \text{ cm}^2/\text{s}$ is at least one order of magnitude above that achievable with conventional polishing. Glass material can be selectively ablated with a vertical resolution of below 10 nm using form correction. The process is currently being adjusted to allow its use on laser-polished surfaces. By combining both processes, it should also be possible in future to process imaging optics with higher requirements in terms of surface roughness in future.

Applications

The main application is the rapid, cost-effective polishing and form correction of nonspherical optical components in small to medium production volumes. The process can also be combined with conventional machining techniques. A completely laser-based production method to manufacture optics is also being developed; the shape is generated by means of material ablation using laser radiation prior to the polishing process.

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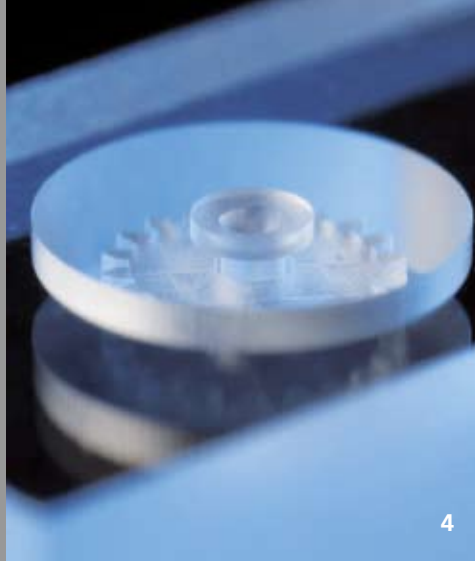
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1 Laser-polished asphere made from BK7.

2 White light interferometer image of selective material ablation for shape correction.



3



4

ASSEMBLED MICROCOMPONENTS MADE OUT OF GLASS

Task

Microcomponents are manufactured for micromechanical systems using mask-based or molding processes; these processes are often not suitable for prototypes and small production volumes. The subsequent assembly of the microcomponents to create a micromechanical system is time-consuming and costly if the components are small and complex. As such, the manufacture of preassembled micromechanical systems is advantageous, particularly for prototypes and small series. The aim is to implement customized production of complex structures by means of digital photonic production, in other words laser-based manufacturing directly from digital data (CAD). In-volume Selective Laser Etching is a process that is suitable for digital photonic production for transparent materials.

Method

In-volume Selective Laser Etching is a two-stage process: in the first stage the material that is transparent to the laser radiation is modified inside. This involves focusing ultrashort pulsed laser radiation (500 fs - 5 ps) to focal radii of $\sim 1 \mu\text{m}$. Moving the focus allows modification of a continuous volume that has contact with the outer surface of the workpiece. In the second stage, the modified material is removed selectively by means of wet-chemical etching. For the digital photonic production of complex components, the path data for the laser focus is generated from the digital CAD data and the microscanner system is synchronously controlled using CAM software. The microscanner system and the components are marketed commercially by the spin-off LightFab.

Result

A gear wheel with a diameter of 4 mm has been manufactured in silica glass; the gear wheel is assembled on its axis so it can rotate following etching (Fig. 4). Along similar lines to this demonstrator, complex micromechanical systems such as transmissions can be manufactured on the basis of CAD data. For microfluidic applications a three-dimensional micromixer with four channels and a movable glass sphere inside the mixing volume has been manufactured (Fig. 3).

Applications

Applications include micromechanics for customized and preassembled microcomponents as well as microfluidics in which hollow structures are used.

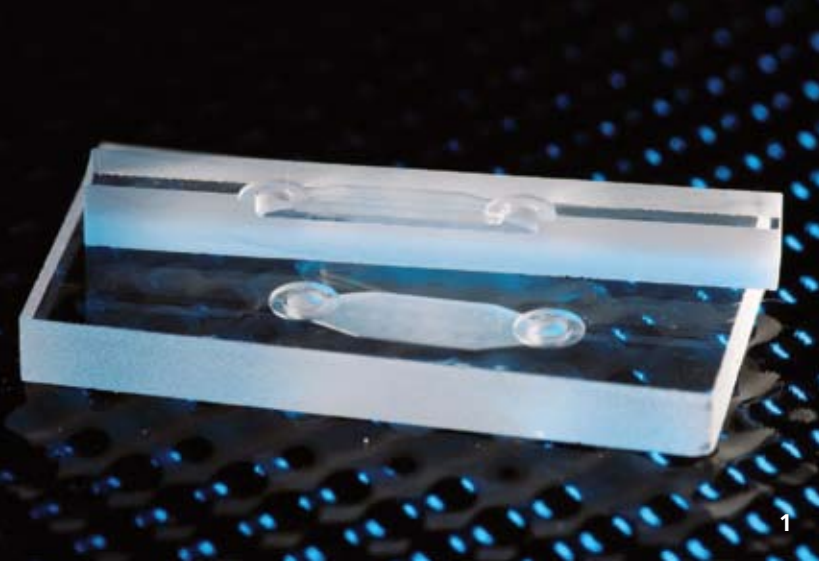
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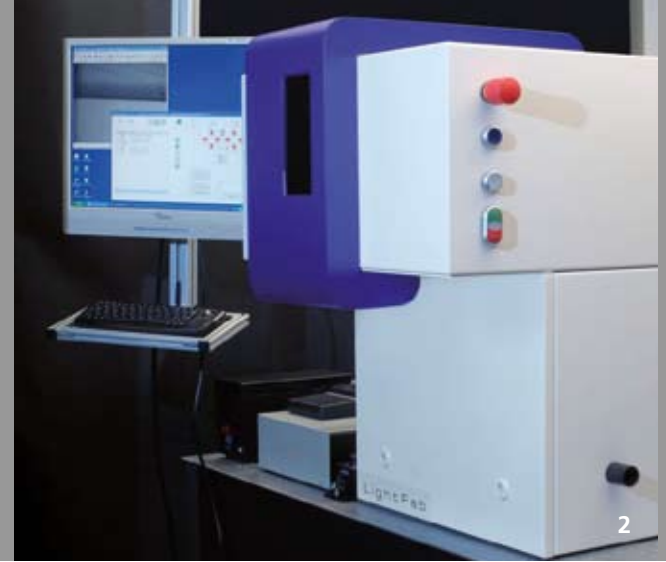
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3 Movable glass sphere in the micromixer.

4 Movable assembled gear wheel in glass.



1



2

HIGH-SPEED MICROSCANNER

Task

New high-power fs slab amplifiers with an output between 150 W and 1 kW and repetition rates > 5 MHz enable an increase in productivity for digital photonic production – the direct manufacture of parts from CAD data using laser radiation without masks or molding tools. The development of a micro-focusing system with high-speed beam deflection and CAM software is required to exploit this potential for manufacturing 3D microcomponents with 1 μm precision.

Method

A modular high-speed microscanner has been set up on the basis of acousto-optic beam deflection, galvanometer mirrors and linear axes. CAM software has also been developed to synchronously control the laser output power, the various beam deflection modules and the linear axes. The system is marketed commercially by the spin-off company LightFab. For the digital photonic production of microstructured 3D components, 3D CAD data are broken down into 2D path data; these are then successively fed by the CAM software which controls the microscanner modules and the laser (Fig. 1).

Result

The workpiece is clamped in the high-speed microscanner behind the sliding door that has a laser protection window (Fig. 2). To use an already existing 3-axis system, the high-speed microscanner is alternatively mounted on the z axis. The microscanner system contains a microscope with a camera to align the workpiece and to check the machining results. For a focus radius of 1 μm , a telecentric lens with a 10 mm focal length is used and a track speed of up to 12 m/s achieved on a track radius of 400 μm so that pulses with repetition rates of up to 5 MHz are spatially separated.

Applications

The high-speed microscanner facilitates the production of 3D microcomponents using In-volume Selective Laser Etching (ISLE) irrespective of the batch size and the product complexity. Other applications include microstructuring using material ablation, two-photon polymerization and high-speed microwelding.

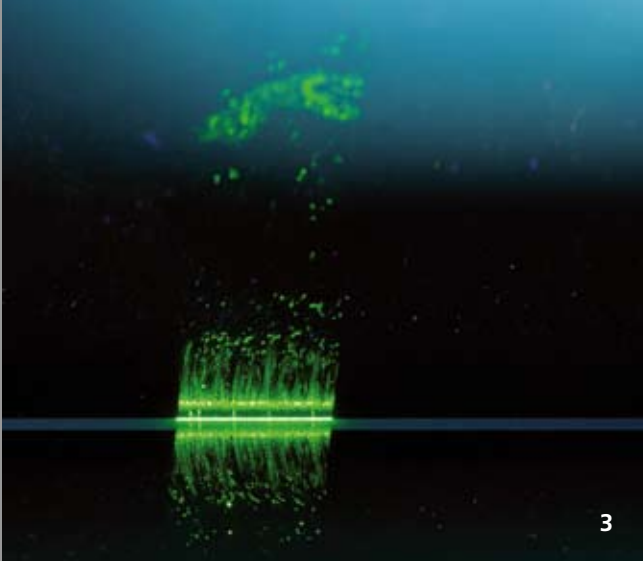
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1 3D microchannel in silica glass produced using ISLE.

2 High-speed microscanner.



LASER ABLATION FOR PATTERNING OF THIN FUNCTIONAL FILMS

Task

Many novel products are based on conducting, semiconducting or isolating thin films. In most applications film thicknesses are needed in the range of nano- to micrometers. Their primary functions are of optical and electrical nature. A competitive process technology for patterning these films requires high process speed, small structure sizes and has to be applicable to large areas. High speed printing methods enable features down to 10 μm . The combination of these high speed processes with direct laser patterning offers high resolution at high throughput.

Method

Laser ablation has been proven as a versatile tool for thin film structuring. However, debris within and in the surrounding of the irradiated areas, thermal damage, as well as bulging all have to be avoided. Due to this, process development has to consider parameters like process atmosphere, wavelength, spatial and temporal pulse shape, and a cleaning step after laser ablation. In particular, patterning of transparent conducting Indium-Tin-Oxide (ITO) leads to bulging, which is problematic for adjacent coatings. The usage of ultrashort pulse lasers or excimer lasers with wavelengths in the deep UV enables physical processes that are not achievable with other technologies.

Result

Applying adjusted wavelengths, pulse durations and ablation strategies, patterning in the range of microns with negligible bulging is possible. Extremely high patterning speeds of several hundred meters per second can be reached with polygon scanners or by parallel patterning via multi beam splitting.

Applications

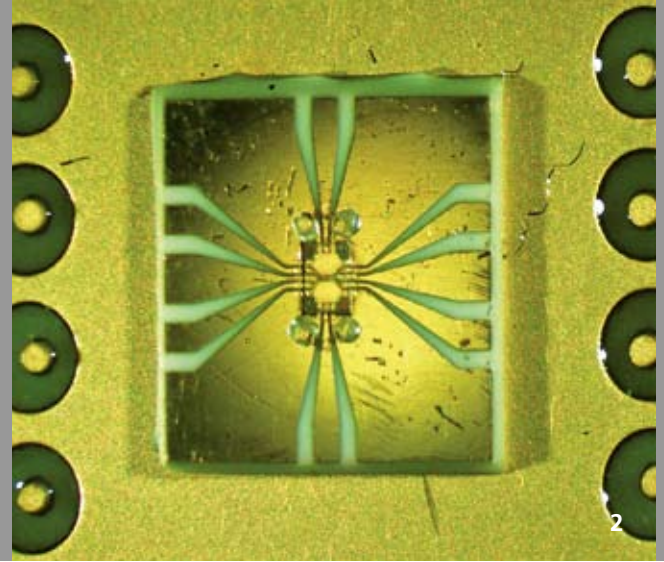
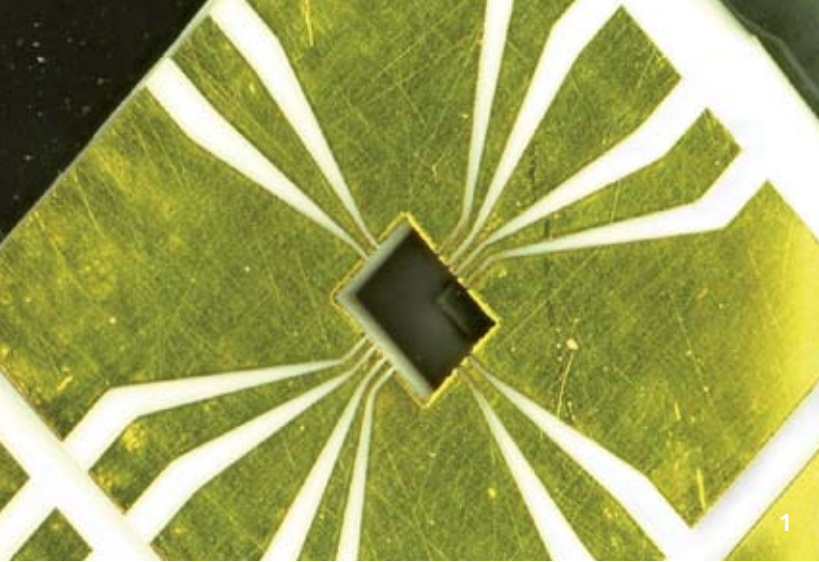
High resolution thin film patterning is of special interest for organic electronics. This technology can be used to pattern OLEDs, multi-functional RFID-tags and high resolution flexible displays. A different application is monolithic series interconnection of thin-film solar cells.

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- 3 Patterning thin metal layers with a ps laser.
4 Patterning amorphous silicon layers on glass.



STRUCTURING OF HIGH FREQUENCY CERAMIC SUBSTRATES

Task

The trend towards high-frequency components with higher bit rates up to 100 Gbit/s requires substrates and printed circuit board structures having the necessary electrical properties and, at the same time, the small waveguide structures for such high frequencies. These components operate at frequencies above 50 GHz and have to be connected to the waveguides on the substrate via strip conductors with minimal losses. To manufacture the chip carrier, one must first make grooves in the ceramic substrates where the chips fit in exactly, and, second, implement the interconnect structures with conductor track widths of 70 μm and a spacing of 30 μm .

Method

These chips have dimensions of 1 mm x 1 mm with a thickness of 0.6 mm. To reduce the length of the bonding wires or ribbon bonding, the chip must be located on a level with the substrate surface, so that the recesses can be produced with high precision. By ablating with ultra-short pulse laser radiation with pulse durations of 10 ps, engineers at the Fraunhofer ILT have been able to manufacture the chip mount and remove the conducting paths directly from the copper coating. Thereby, the gap between the chip and substrate is less than 50 μm ; this way, bond wire lengths can be reduced to about 100 μm .

Result

With ultra-short pulsed lasers, both ceramic and copper coating can be removed without leaving any residue. This ultra-short pulsed laser ablation enables the production of the hole and the conductor structures in a single setup, using one laser and only modified processing parameters. Each individual chip carrier is about 5 x 5 mm in size. On a larger substrate several chip carriers are produced in a single pass and scribed with the laser. Then, the chip carriers can simply be separated by breaking them off. Recently available laser power up to 100 W makes this method suitable not only for prototyping, but also, due to the small dimensions of the structures, for the mass production of high-frequency circuit boards.

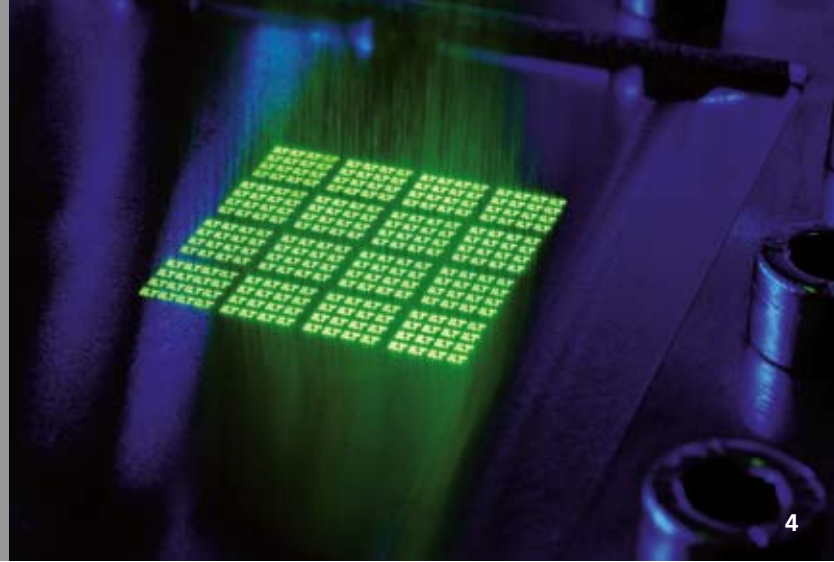
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1 Laser structured, metallized ceramic substrate with chip cavity.

2 Substrate carrier with inserted chip.



PROCESS ACCELERATION IN ULTRASHORT PULSED MICROMACHINING USING MULTI-BEAM OPTICS

Task

As ultrashort pulsed laser sources continue to be developed, the available laser power for laser micromachining is increasing constantly. For industrial use ultrashort pulsed laser systems with output powers in the range of 50 - 100 W are already commercially available, while laser systems with average powers of 1000 W and more will conquer the market in the next few years.

Many applications using these laser systems demand small spot sizes to achieve high precision or small structure sizes. However, when the average power of the laser systems increases at the same spot size, thermal or material dependent factors limit the potential for enhancing the process velocity at constant machining quality considerably. In order to raise the process velocity, new technologies are needed that allow a fast distribution of the laser power on large areas.

Method

In addition to the possibility of a fast beam deflection with, for example, polygon scanners, the available laser power can also be split into a number of partial laser beams. To accomplish this, a multi-beam scanning system on the basis of diffractive optical elements and a galvanometric scanning head has been developed and built.

Result

The new system allows the available pulse energy to be split into up to 196 partial beams, in order to generate a pattern of laser spots with fixed spot period in the machining plane. Using this system, researchers at the Fraunhofer ILT have been able to boost the process velocity by a factor of 196 and more. Thanks to the availability of ultrashort pulsed laser systems with pulse energies in the range of 1 mJ, this technology will enable users to machine large work pieces with periodic structures precisely and allow high power USP lasers to be used efficiently.

Applications

This optical system can be used to solve current issues in the field of tool technology for the production of light guiding and scattering structures or other functional structures. This scan approach can also be used in other fields of laser material processing such as laser cutting, laser annealing or rapid laser manufacturing.

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3 Parallel machining of piston rings for wear reduction.

4 Multi-spot beam distribution generated with a diffractive optical element.



CHARACTERISATION OF SCANNER BASED MANUFACTURING SYSTEMS

Task

Manufacturing processes for laser-based micro material processing rely on a high degree of precision in the positioning of the laser beam. Especially in laser ablation processes, the required contour is repetitively irradiated by the laser beam in order to remove the volume layer by layer. Errors in positioning of the laser beam, however, accumulate through the large number of ablation layers, leading to significant processing errors. Such errors can result from thermal drift of the focusing optics, false positioning of the beam or insufficient calibration of the imaging plane.

Method

To detect system errors, engineers at the Fraunhofer ILT have developed a camera-based measurement system which allows them to identify the relative displacement of the laser beam relative to the work piece. A camera system is coupled coaxially to the optical path of the processing laser and, thus, observes the work piece through the complete beam delivery chain. Algorithms for image processing determine the displacement of the observation position relative to a fixed reference plane. The programmed setting parameters of the beam deflection system are recorded synchronously to allow a comparison with results from the analysis.

Result

The analysis of the programmed path against measured motion yields a description of the dynamic behavior of the complete beam guidance and delivery chain. Based on these results, the engineers at Fraunhofer ILT are able to derive corrective measures for the generation of processing strategies or information for optimization of the overall system performance.

Applications

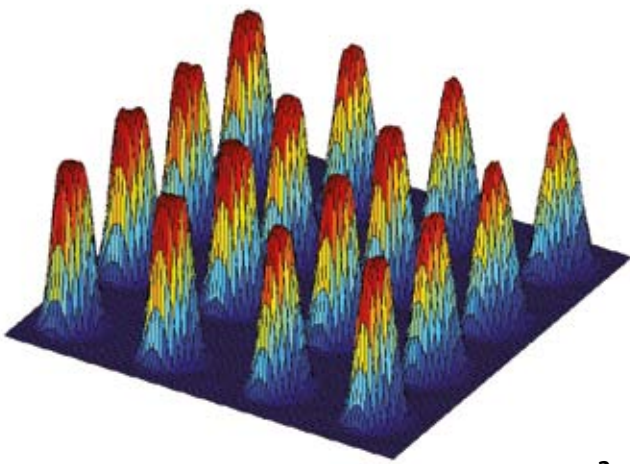
The system can be used to characterize scanner-based manufacturing systems and allows dynamic properties, such as path and contour precision, to be clearly determined. When the system is combined with a suitable laser source, users will be able to safeguard production relevant properties from the laser source itself to the coupling of the energy into the work piece.

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1 Camera based scanner measuring system.



2



3

MEASUREMENT AND CHARACTERISATION OF MULTI-BEAM OPTICS

Task

Micro material processing with ultra-short pulsed (USP) lasers enables a multitude of innovative manufacturing processes based on short interaction times. The small spatial extent of the laser focus of some microns, however, contradicts high productivity. One approach to increase production rate is by using diffractive optical elements to split the laser beam into a multitude of beams. The achievement of required beam properties, though, is a prerequisite for successful manufacturing with high reproducibility at requested quality. Current beam analysis tools are only capable of analysing single beams with high accuracy.

Method

To process materials with USP laser radiation and spot geometries below 10 μm in multi spot configuration, the researchers at the Fraunhofer ILT have implemented an analysis system capable of determining the absolute position of each beam as well as the geometry of the beams themselves. A flat panel sensor with 2 μm pixels is positioned under the focusing optics and measures process-relevant properties of each beam. Image and signal processing algorithms especially developed for the analysis of multiple laser foci extract relevant information about the laser beams from the measurement signals.

Result

The visualisation of the processed measurement data allows a direct inference on positioning errors in the plane and on deviations in intensity distribution in the field. This information enables an efficient and precise adjustment of optical components in the beam path and aids in achieving increased performance of the overall system.

Applications

The multi spot measurement system enables users to determine properties of multiple beams in manufacturing systems for micro material processing. Its use for adjustment and inspection of the optical system facilitates fast set up of manufacturing systems and regular examination of boundary conditions in the manufacturing environment.

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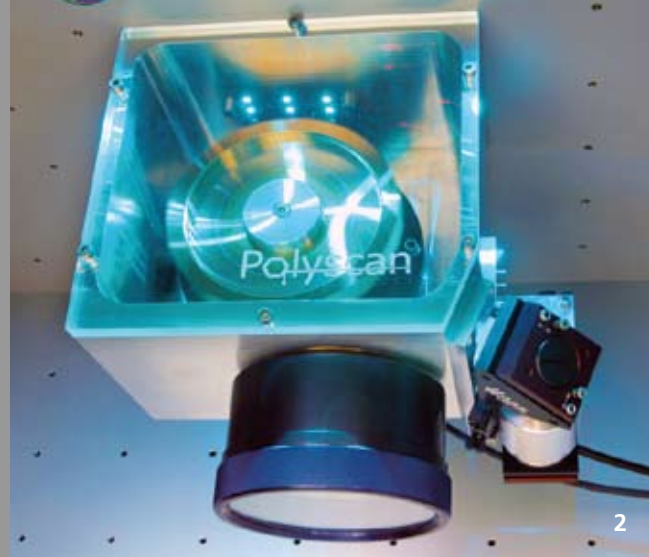
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2 Visualisation of multiple beams.

3 Sensor system with attenuator.



1



2

LASER MATERIAL PROCESSING AT THE SPEED OF SOUND

Task

Current developments of ultra-fast lasers have reached new records regarding average laser power and pulse rate. To produce high-quality processing results, the individual laser pulses have to be separated from each other, which prevents the material from overheating and the individual pulses from interacting with each other. At pulse frequencies in the multi-MHz range, the scanning speed of galvanometric scanners is, however, no longer sufficient since scanning speeds of more than 100 m/s are required. Using this high scanning speed, researchers at the Fraunhofer ILT have been able to utilize high power and high repetition rate ultrafast lasers, thereby achieving high process efficiencies.

Method

To make a high scan rate possible in the range of > 100 m/s and to structure with ultra-fast lasers, the Fraunhofer ILT has developed a processing system with a polygon scanner rotating at extremely high speeds and fast laser beam modulation. The polygon mirror of a polygon scanner rotates at a high, constant speed, thus increasing the maximum scanning speed considerably. This allows a low pulse overlap

for optimum processing results and the utilization of the full laser power. An incident laser beam hitting the polygon mirror is deflected along a line. This line is shifted by moving the working piece on a linear axis to allow two-dimensional processing. The laser beam modulation occurs synchronized to the laser pulse and the position of the polygon and the axis.

Result

The Fraunhofer ILT has developed a polygon scanner system for 2.5 dimensional machining. Scan speeds of up to 360 m/s can be achieved, whereby even pulses with a diameter of 20 µm at pulse rates of 18 MHz remain separated. The processing area is restricted to 100 x 200 mm² by the focusing lens and the travel range of the axis.

Applications

Areas of application include the large-scale structuring or laser treatment of different materials with high power ultrashort pulse lasers. In addition to current applications of the system with these lasers, high-speed processes with cw lasers, such as the quasi-simultaneous soldering of solar cells or dicing of semiconductor wafers are also possible.

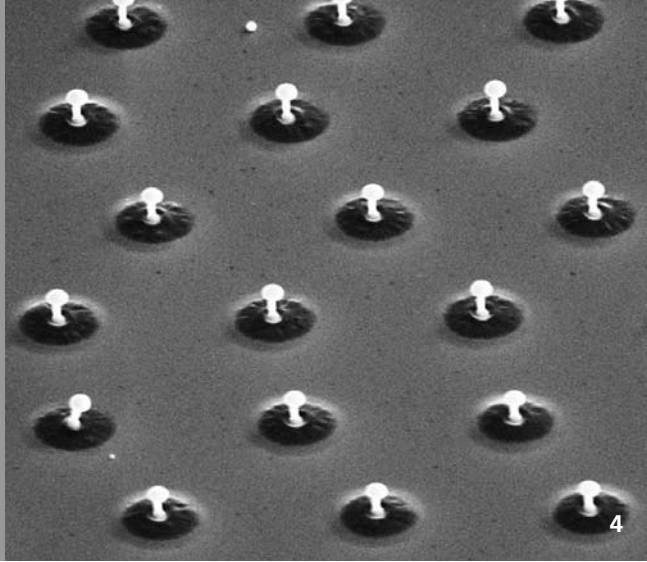
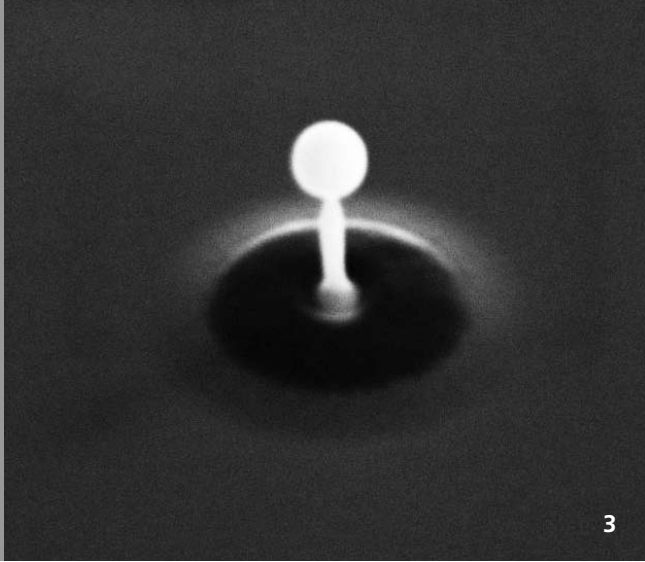
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1 Projection of one processing layer.

2 Polygonal processing optics.



NANOANTENNAS

Task

The amplification of evanescent nearfields through the use of optical antennas is utilized, for instance, in the scanning near-field optical microscope (s-SNOM) and in surface enhanced infrared absorption (SEIRA) spectroscopy. SEIRA is an optical measuring process for detecting the absorption bands that are characteristic of a certain molecule. In order to detect signals from individual molecules or molecules in low concentration, such as in thin films, the light backscattered into the farfield by these molecules must be amplified. Using the s-SNOM measuring process, the chemical and structural properties of a test sample can be optically resolved with a sensitivity of below 20 nm, which is fundamental for analytical applications in biology and chemistry.

Method

Ultrashort laser pulses are focused using a microscope objective onto 30 nm thin gold films. The high intensities, which are achieved even at pulse energies of a few 10 nJ owing to the short pulse duration of 100 fs, induce ultrafast melting of the gold film across its entire thickness. The melt dynamics cause the material to be transported upwards from the center of the irradiated area (jet). Given the very small quantity of energy input, the gold jet solidifies as it moves upwards, forming a stable antenna (Fig. 3).

Result

Nanojets as optical antennas, for instance for SEIRA or s-SNOM applications, can be manufactured with a diameter of less than 100 nm. By suitably selecting the focusing, the pulse energy and the gold film thickness, the size of the nanoantennas can be controlled very precisely. As a result, the system can be adjusted, for instance, to the characteristic absorption bands of certain molecules in SEIRA spectroscopy.

Applications

Nanojets as optical antennas can be used in analytical areas of chemistry, biology and mechanical engineering. The amplification of evanescent nearfields enables optical detection with a spatial resolution in the region of 10 nm and the detection of minute concentrations down to individual molecules.

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3 Individual nanojet.

4 Nanojet field.



1



2

LASER BEAM DRILLING OF HIGH-PRESSURE JET NOZZLES

Task

At present, mobile automotive air conditioning systems contain refrigerants with certain properties that are harmful to the environment and health. The natural refrigerant CO₂ provides one long-term alternative; it is available cost-effectively in virtually unlimited quantities as a technical byproduct. Owing to the large pressure ratios required of up to 300 bar, the control unit needs to be redesigned. The nozzle hole with a diameter of 300 µm cannot be manufactured mechanically because of the inhomogeneous microstructure of the lightweight material used, AlSi17Cu4Mg, and the technical requirements placed on the hole geometry. The laser beam drilling process has the potential to become a suitable alternative.

Method

In order to meet the requisite specifications in terms of geometrical and metallurgical quality, tests with short- and ultrashort-pulsed laser radiation are being conducted (pulse durations in the µs to ps region). The experimental testing is based on the design of experiments (DOE), ensuring a minimal testing overhead.

Result

The use of ultrashort-pulsed laser radiation allows the following geometrical and metallurgical properties of the nozzle holes to be achieved:

- Diameter tolerance $\pm 5 \mu\text{m}$
- Conicity < 10 percent
- Recast layer thickness < 10 µm
- Surface roughness $R_a < 5 \mu\text{m}$
- Prevention of molten adherent dross at the hole entry and exit

Applications

In light of the expected legal ban on currently used refrigerants, some of which are hazardous, in mobile air conditioning systems, the newly developed control unit for CO₂-operated air conditioning systems provides a suitable alternative. The laser drilling process step can be integrated in an automated production facility.

This research was funded as part of the EFRE cofinanced operational program for North Rhine-Westphalia as part of the »Regional Competitiveness and Employment« objective.

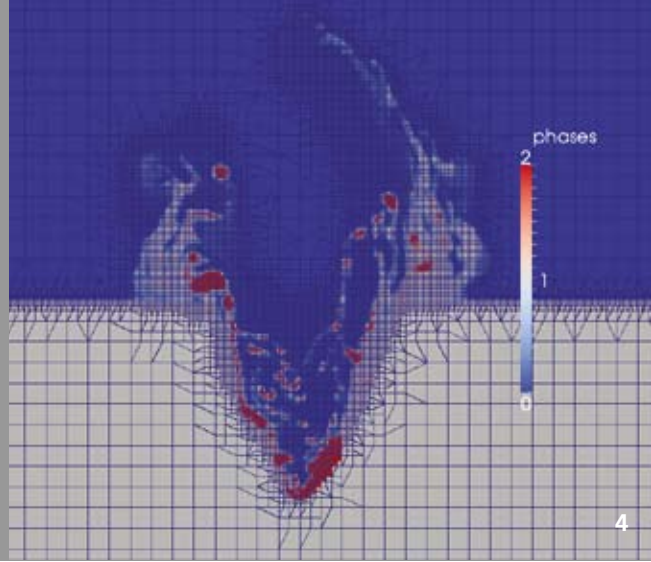
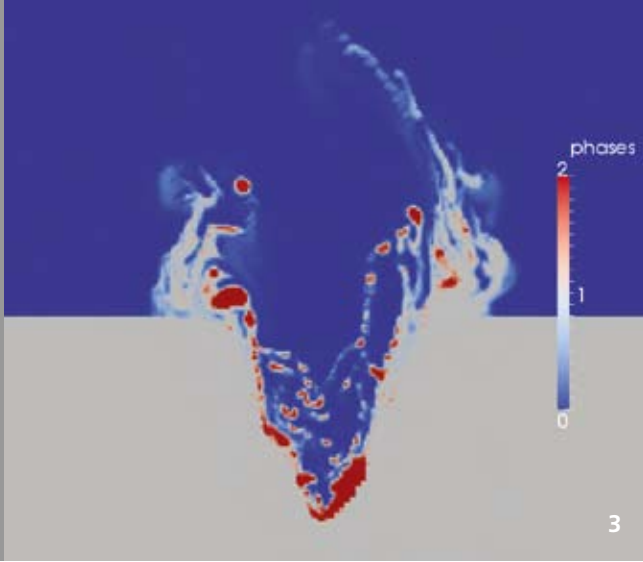
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1 Laser beam drilling.

2 Longitudinal section of a nozzle hole.



MODELING AND SIMULATION OF MELT ABLATION

Task

Drilling/ablation by melt ejection is the most efficient process for manufacturing holes with a large aspect ratio in materials with a molten phase. The complex behavior of the melt and the influences of vaporization, surface tension and process gases still remain an object of research.

Method

An operational model is required to optimize productivity and quality. This model should describe the key physical phenomena responsible for the ablation and the melt flow.

Result

A finite-volume CFD code with volume-of-fluid (VoF) processes for calculating the free surfaces was implemented. An enthalpy model was created for the phase transitions (melt, vaporization). The beam propagation within the hole is at the moment based on an advection scheme (geometrical optics) but is about to be extended to a beam propagation scheme (wave optics). A Continuous-Surface-Force (CSF) model is used to model the recoil pressure of the vaporization and other surface forces such as the surface tension.

Particular attention was paid to adaptive meshing, which is required in particular at the phase boundaries in order to resolve the resulting fine structures, which are based on the mechanisms of thin film flow with surface tension and vaporization.

Applications

The presented simulation describes the absorption of laser radiation on workpiece surfaces, the thermal diffusion and convection, and the melt flow driven by vaporization. The simulation has no restrictions in terms of the geometrical form of the ablation area produced and can, for instance, describe disconnected molten areas. It can therefore be used wherever materials are melted using laser radiation and whose melts are driven to a certain extent through vaporization. It has initially been developed for use in drilling using laser radiation.

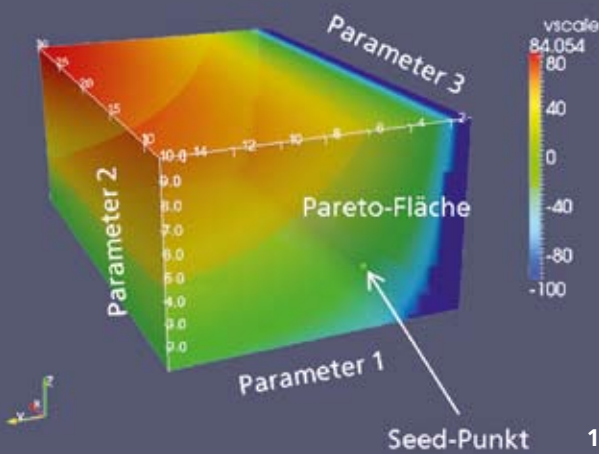
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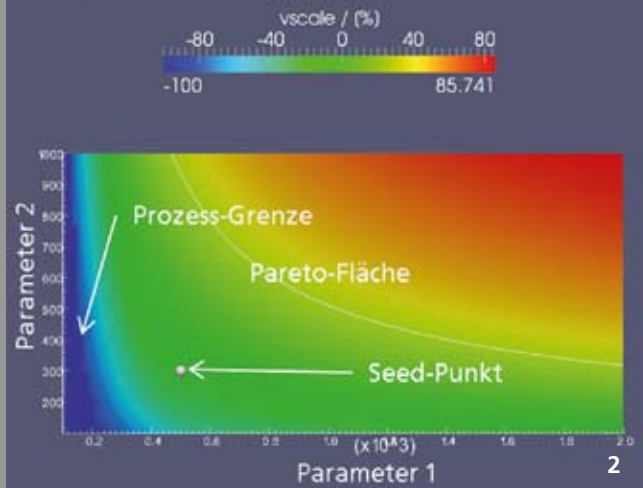
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- 3 Simulation of the phases: solid (gray), liquid (red) and gaseous (blue).
4 Simulation result with illustration of the adaptive meshing.

Kriterium 1



Kriterium 1



METAMODELING

Task

The practical use of scientific results from computer simulation and experimentation requires the results from simulations and experiments to be assembled in such a way that the data become fully explorable.

Method

The metamodeling technique enables individual simulation results to be combined to create a single process model within which experimental data can be stored and the results can be subsequently presented clearly in a way that allows them to be explored. The metamodel data can also be retrieved directly on a production machine and used for control purposes. This principle is currently being illustrated as part of the Integrative Production Technology for High-Wage Countries cluster of excellence at RWTH Aachen University using a laser cutting machine as an example. In addition to multidimensional function approximation techniques, metamodeling also uses Design of Experiment (DOE) methods and multidimensional optimization techniques.

Illustration of an exemplary high-dimensional process model:

- 1 In a three-dimensional slice of the parameter space.
- 2 In a two-dimensional slice of the parameter space.

Result

Proprietary tools for visualizing response surfaces (MeMoViewer) and plugins for the familiar VTK (Visualization Toolkit graphics standard) have been developed. Algorithms for locally inverting the functional relationship between parameters and criteria (inverse problem) have been implemented and can be accessed for the exemplary process models chosen so far. As the next stage the Virtual Production Intelligence (VPI) concept devised in the cluster of excellence will be implemented.

Applications

The procedure described can be applied to any type of modeling for analyzing and optimizing a static or dynamic system. It provides users with a process map that they can use to find their way around in the high-dimensional parameter space in order to locate specific points of interest that would be more difficult to pinpoint without this kind of assistance.

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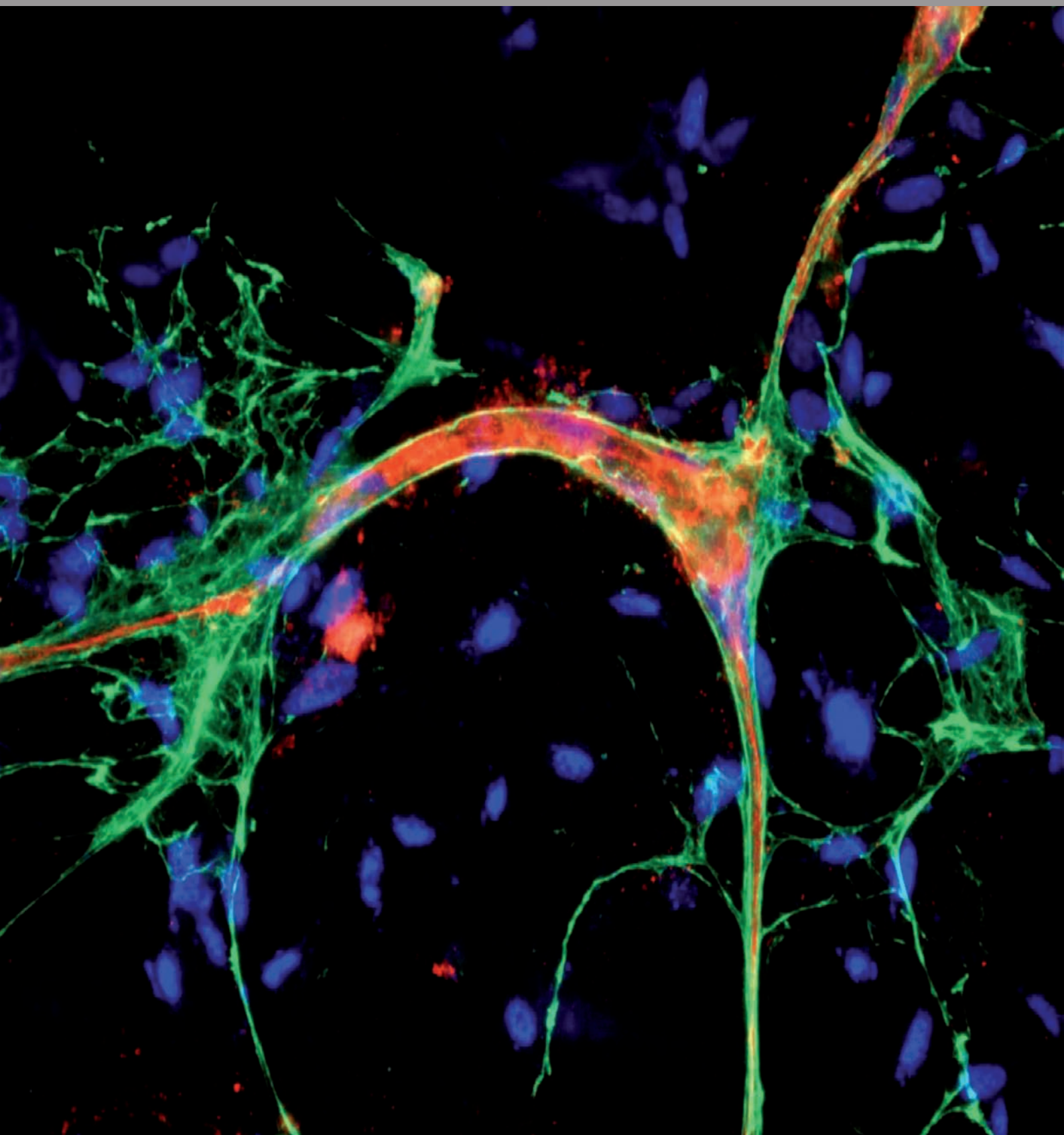
TECHNOLOGY FOCUS MEDICAL TECHNOLOGY AND BIOPHOTONICS

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 patient 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

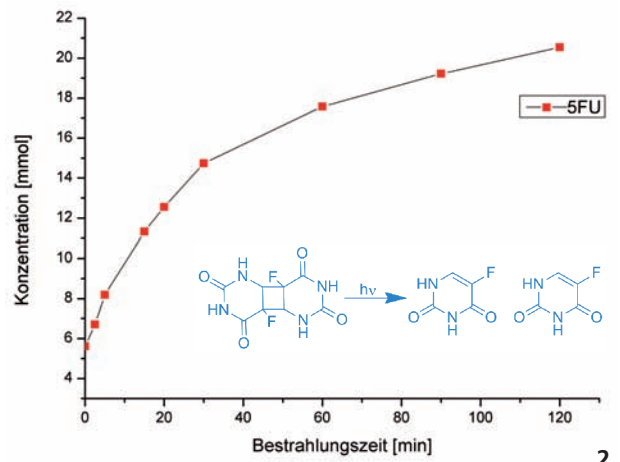


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2

LASER-INDUCED DRUG RELEASE FOR TUMOR TREATMENT

Task

Controlled drug release from implants is currently being intensely studied in the fields of drug delivery and tissue engineering. The development of innovative medical devices equipped with an intelligent release system for temporal and spatial drug delivery is a new therapeutic approach in numerous medicinal fields. With help of such intelligent medical devices, therapies with adapted medication could become available, thereby minimizing negative side effects for the patients.

Method

To implement this approach, a research project within the Excellence Initiative of RWTH Aachen University investigated controlled drug release based on special photo chemically addressable micro gels; these gels were triggered via laser light to control drug release temporally and spatially. Proof of concept and feasibility of this therapeutic approach could be demonstrated for tumor reduction in the gastrointestinal tract. The light-controlled drug supply is based on a scaffold made from polymer fibers containing drug-loaded micro gel capsules. The chemotherapeutic agent 5-Fluorouracil (5FU) is selectively released by means of laser irradiation.

1+2 Photo cleavage for 5FU drug release.

Result

The drug 5FU was converted into the corresponding dimer via [2+2] cycloaddition reaction and coupled onto a cyclodextrin (CD-) micro gel. This CD-micro gel was mixed with a polymer solution and spun into drug-loaded polymeric fibers. Photo chemical cleavage of 5FU from the micro gel support is performed with UV radiation of 254 -266 nm in wavelength. The targeted photo cleavage products were detected by high pressure liquid chromatography (HPLC). The polymeric drug release system developed here was tested in cell culture experiment and proved to be non-cytotoxic. Further investigations are ongoing to prove that activity and concentration of the released drug is sufficient to prevent tumor cell lines from growing.

Applications

In biomedical engineering there is a trend for coaction of medical devices and pharmaceutical agents. In established products, active control mechanisms for drug release are missing; our approach promises to fill this gap. Besides being a more effective and gentler treatment of tumors, such local therapies can be applied for wound treatment via controlled release of anti-inflammatory drugs as well as in regenerative medicine for triggered release of growth factors to selectively induce tissue formation.

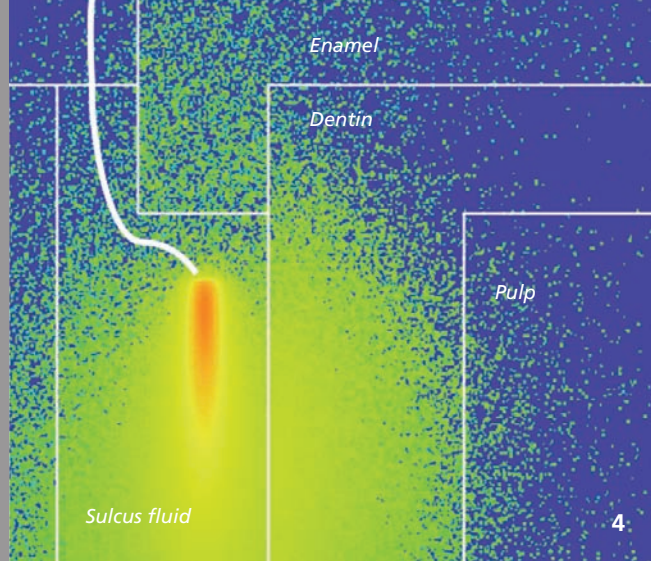
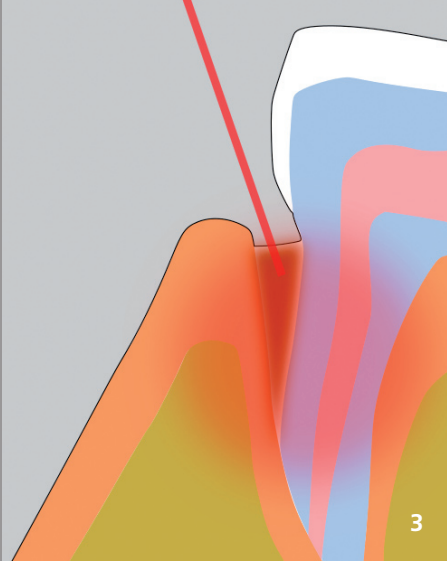
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MODELING ANTIMICROBIAL PHOTODYNAMIC THERAPY

Task

Antimicrobial photodynamic therapy (aPDT) is used in minor cases of periodontitis and as a supplement to conventional mechanical or anti-infective treatment methods. Its full potential is not currently being exploited due to a lack of knowledge of the physical and chemical processes involved in aPDT. This work aims to extend empirical clinical research methods to cover mathematical-physical modeling, which will augment the understanding of aPDT.

Method

A phenomenology of the active principle of laser-induced aPDT is set out in the literature: the organisms responsible for disease progression are destroyed as a consequence of a biochemical reaction when a photoactive agent is inserted into the inflected area and irradiated by laser radiation with a low output power in the mW region. The concentrations of the substances involved in the aPDT are described in rate equations in a spatially homogeneous model familiar from tumor therapy. The success of the therapy is calculated by resolving these equations and predicted as a function of the treatment parameters and initial concentrations. The local intensity of the laser radiation in the periodontium is one of the input variables for the rate equations and is simulated beforehand as a spatial distributed variable.

Result

Early results allow conclusions to be drawn about the initial concentrations of the substances involved. These initial concentrations have to be present at the start of treatment so that the therapy can be completed successfully. The structure of the rate equations also motivates a separation of the time scales on which the therapy processes run. This separation of time scales provides a method for controlling and observing the ongoing processes during the therapy.

Applications

The long-term goal of model-based therapy is being pursued with the aid of the aforementioned investigations. In addition to periodontal treatment, tumor therapy and dermatological treatments constitute other compelling applications.

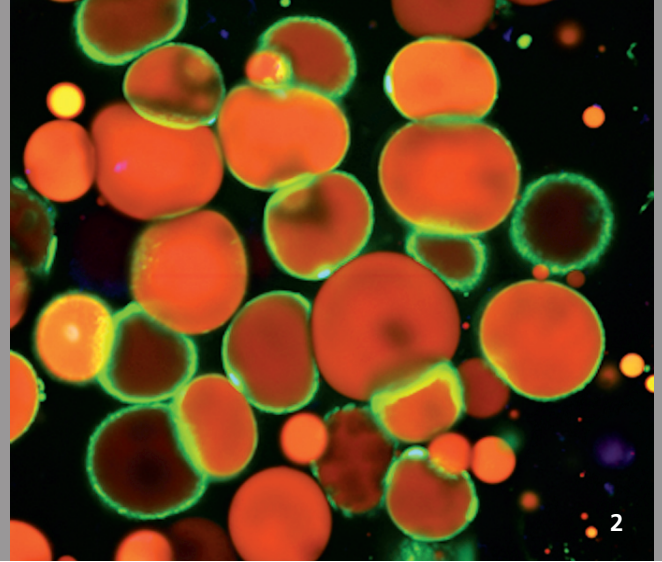
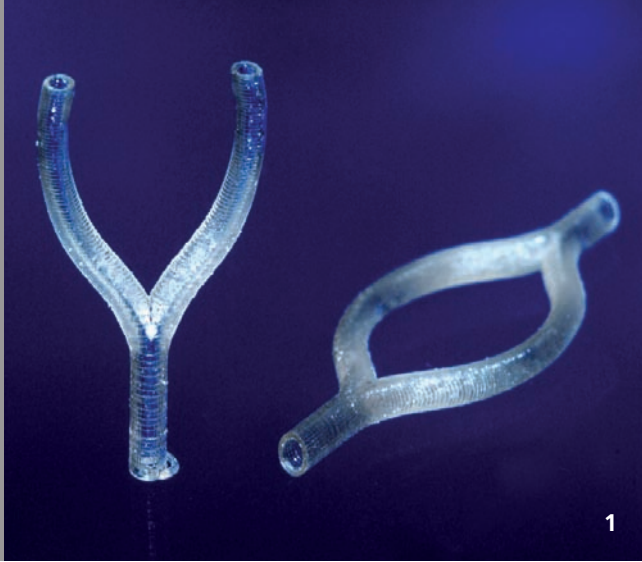
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3 Schematic of the periodontium.

4 Simulated intensity distribution in the periodontal model.



DEVELOPMENT OF ARTIFICIAL TISSUE

Task

To develop artificial soft tissue for medical tissue replacement or pharmaceutical testing, artificial scaffolds – which can be cultivated with tissue specific cells – have to be developed. Such scaffolds, which provide long-term stability and biological activity need a vascularization system for nutrition supply and waste removal within the several cell layers. Researchers in the multidisciplinary consortium of the EU project ArtiVasc 3D are developing such an artificial soft tissue replacement, which allows nutrition supply within a several millimeter thick tissue.

Method

For the development of such an artificial tissue, the combination of several disciplines is essential. Therefore, biological project partners are working on characterizing and isolating tissue specific cells like adipocytes, endothelial cells and pericytes so that they can cultivate them on the newly developed biopolymers. Adipocytes will be cultivated on electrospun fibers and hydrogels to mimic fatty tissue. For vascularization endothelial cells and pericytes will be cultivated on special branched vascular tubes produced by a combination of inkjet printing and laser based stereolithography and multiphoton polymerization.

1 *Laser-structured branched vessel, inner diameter 5 mm.*

2 *Primary human subcutaneous adipocytes*
(source: Fraunhofer IGB).

Result

Currently, different cell cultures have been established. Adipocytes can be cultivated on electrospun fleeces and in hydrogels. By using laser based polymerization processes, researchers in ArtiVasc 3D have been able to produce branched vascular structures consisting of vessels and capillaries from flexible biopolymer. In future experiments cell cultivation will be tested.

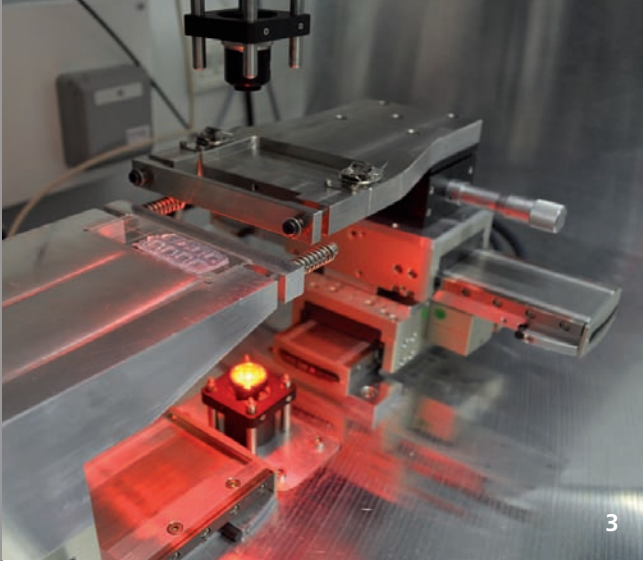
Applications

The artificial tissue planned within the ArtiVasc 3D project will be employed in pharmaceutical research and will, therefore, help to reduce the amount of animal testing. Later on the scaffold will be used for the development of medical tissue such as skin and vessel replacement.

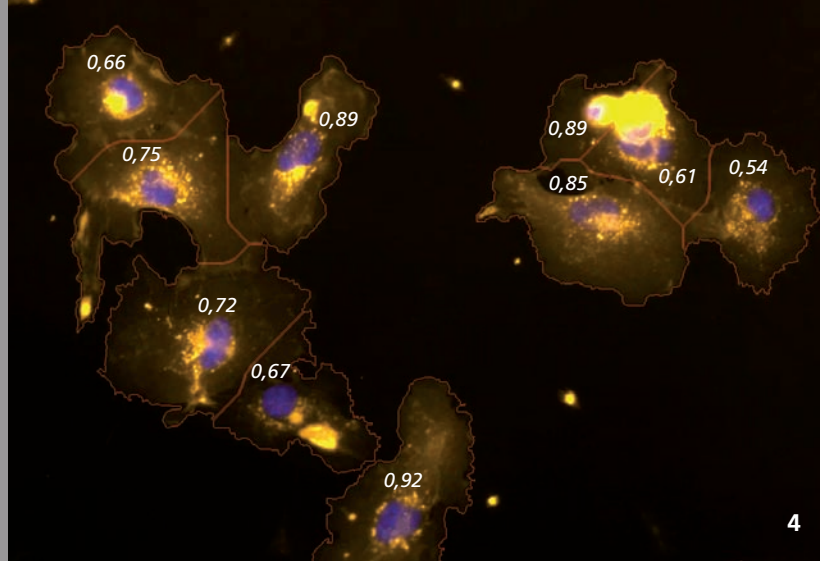
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3



4

CELL PRINTING AND AUTOMATED CELL IMAGING

Task

The use of stem cells is becoming increasingly important in medicine. Researchers are looking for ways of generating skin cells, hematopoietic cells and, in the future, entire organs from stem cells. As part of a cooperation project between the Max Planck Society and Fraunhofer, research is being done into the necessary conditions for differentiating hematopoietic stem cells on the basis of multilayer three-dimensional stem cell systems. For the realization of such artificial stem cell niches a building technology is necessary, one which enables a highly defined and reproducible printing of the cell types of interest. In addition to precise cell positioning, Fraunhofer ILT's task also includes the automated analysis of cell ensembles. In particular, the tracking of the cell boundaries is one of the most required pieces of information for the biologists.

Method

Laser Induced Forward Transfer (LIFT) is a versatile technology that can fulfill the above challenges. During LIFT, cells can be transferred from a transfer slide onto a receiver slide. Highly resolved microscopic images will be taken from the stem cell assays built up artificially by the LIFT technology. These images are then analyzed automatically with the help of dedicated image processing algorithms. The combined analysis of fluorescent images as well as bright field images will enhance the detection result of the designed algorithms.

Result

The Fraunhofer ILT has developed a LIFT-Tool (LIFTSYS) that enables scientists to select cells using a camera based system and thereafter to transfer them onto a receiver. These cells can be transferred into a 3D matrix and used for cell-based in vitro assays. Initial experiments show that HEK 293 cells can be positioned by LIFTSYS. For the automated detection of cell boundaries, first results could be achieved using bright field images as well as fluorescent images. One challenge still remains in distinguishing adjacent cells. Only with the help of fluorescently labelled cell nuclei could the cell differentiation be completed.

Applications

With the help of high precision cell positioning in 3D cell assays and the automated tracking of the cell boundaries, in-vitro test systems can be built and analysed. The insights gained will help to explain the processes that play an important role within the stem cell niches and, thus, promote the use of in-vitro stem cell niches in developing drugs over the long term, e.g. the development of new leukaemia drugs.

Contacts

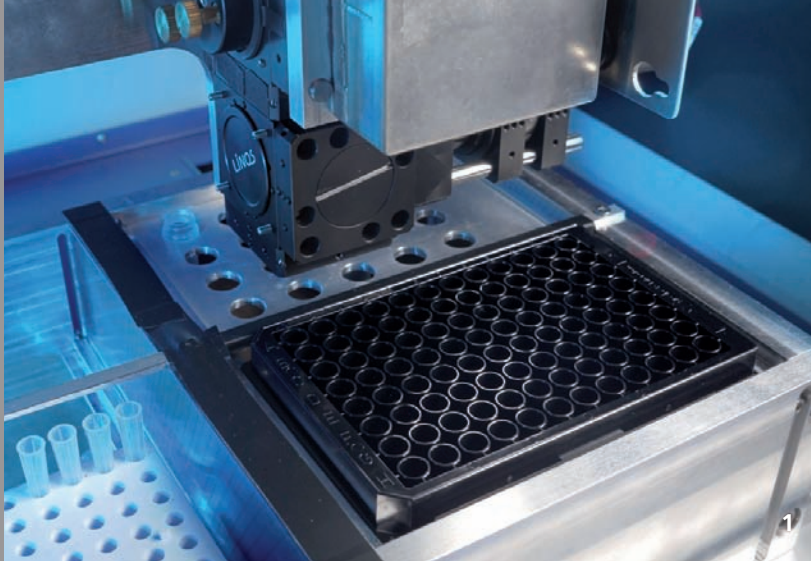
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3 Handling system of the LIFT Tool.

4 Detection of cell boundaries.

(source: Max-Planck-Institut für molekulare Biomedizin, Münster).



BIOCHEMICAL ANALYSIS IN MICROTITER PLATES

Task

A wide range of analytes, including hormones, toxins, active drug ingredients, etc., can be detected and quantified highly specifically on the basis of antibody-based biochemical assays. Minute quantities of liquid must be applied and mixed with each other for automated assay analysis in microtiter plates. Depending on the assay, an optical readout is then made, for instance in the form of a fluorescent measurement. Thorough mixing of the liquids is an important factor since inhomogeneities can cause false measurement results.

Method

The project aims to develop a demonstrator for quantitative and highly sensitive assay analysis in microtiter plates. The system should allow liquids to be pipetted, homogenized and optically measured in an automatic process. The homogenization takes place using a piezo ultrasonic transducer, which vibrates the microtiter plate and sets the liquids contained in the wells in motion. Inhomogeneities and bleaching effects during the optical measurement can thus be avoided.

Result

Working together with project partners from industry and the research community, a demonstrator was built at Fraunhofer ILT for automated multitoxin analysis. Both the pipetting of the assay components using an electronic pipette and the optical measurement of the fluorescence polarization take place automatically. The assay components assembled in a microtiter plate – sample extract, fluorescence dye and antibodies – are mixed using ultrasound and homogenized.

Applications

The primary area of application is food analysis, in particular mycotoxin analysis of cereal products. In principle, the demonstrator that has been developed is capable of detecting any analyte for which a specific binding antibody is available.

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TECHNOLOGY FOCUS LASER MEASUREMENT TECHNOLOGY AND EUV TECHNOLOGY

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

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

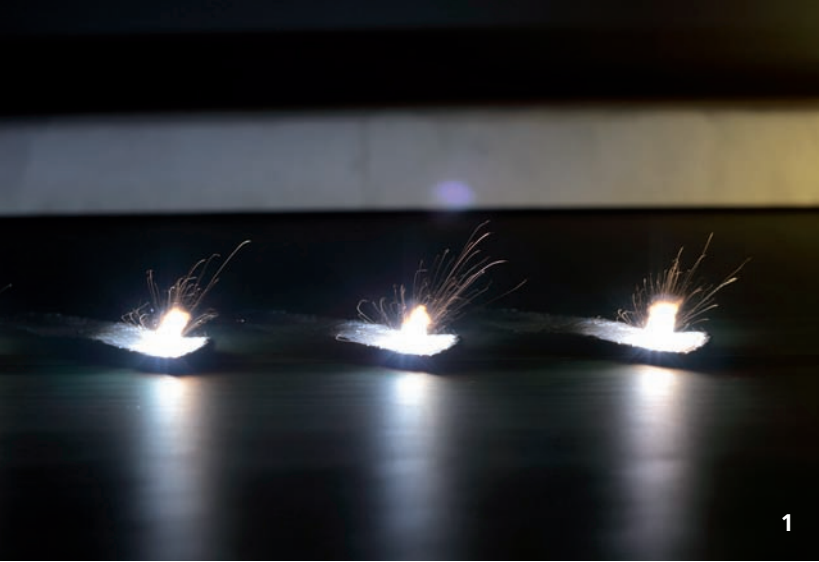
In EUV technology, Fraunhofer's experts develop beam sources for lithography, microscopy, nanostructuring or x-ray microscopy. Optical systems for applications in EUV engineering are calculated, constructed and manufactured as well.

LASER MEASUREMENT TECHNOLOGY AND EUV TECHNOLOGY



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1



2

SORTING ALUMINUM ALLOYS WITH LASER ANALYSIS

Task

Manufacturing aluminum from primary raw materials uses several times more energy than melting scrap metal. This makes recycling a compelling option for both economic and environmental reasons. Aluminum is used in a wide range of alloys. If an undefined mixture of these alloys is melted, heavy »dilution« with pure primary aluminum tends to be then required in order to meet the specifications for manufacturing a certain material. Extracting low-alloy aluminum directly from secondary raw materials, however, requires efficient material sorting.

Method

In collaboration with Tomra Sorting Solutions a transportable demonstrator was developed that addresses the entire process chain, right from depositing the pieces of scrap to be recycled through to discharge, see Fig. 1. Individual pieces of scrap are transported on a conveyor belt at a speed of 3 m/s. 3D object recognition determines the position of each piece on the belt. A pulsed laser beam is focused on the pieces, vaporizes a small quantity of the material and transforms this into a plasma. The light emitted by the plasma is routed by an optical waveguide to a spectrometer, see Fig. 2. Laser-induced breakdown spectroscopy (LIBS) classifies the pieces of scrap into up to four fractions in real time. Depending on the size of the individual pieces, the throughput rate is up to 4 t/h.

1 Time exposure over 3 measurements.

2 PARILAS demonstrator.

Result

Quantitative laser analysis of each individual piece is possible with production scrap. Test batches including production samples from eight commercially available aluminum wrought alloys are identified with a high degree of accuracy. A processing technique for a mixed set of samples including approx. 200 pieces of shredder scrap made of various aluminum wrought alloys was also studied. The aim was to determine how high-grade 3xxx and 6xxx compatible fractions can be extracted from a single mixed set of samples.

Applications

Sorting by laser analysis classifies various metals on the basis of multi-element analysis. This enables various metals such as steel, brass, zinc and titanium to be separated and individual alloys to be precisely differentiated.

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RAPID ISOTOPE ANALYSIS OF SWIPE SAMPLES

Task

International organizations carry out routine inspections to check and monitor nuclear facilities. As part of a frequently used process, swipe samples are taken in the facilities in order to analyze the collected particles in the laboratory. Minute quantities of material in these samples can provide inspectors with important clues to the processes being used. A rapid testing process for pre-screening of the collected sample material is required to analyze the test samples efficiently.

Method

As part of a study for the German Support Program for the International Atomic Energy Agency IAEA, Fraunhofer ILT is developing a measurement process for an isotope-sensitive test of low quantities of material on swipe samples. The process uses scanning microanalysis with laser-induced breakdown spectroscopy. A laser beam is guided over the swipe sample and provides spatially resolved analysis of the material contained in the sample. The induced emissions are analyzed spectroscopically at high resolution, thus providing sensitive detection coupled with isotope separation of minute traces of uranium.

Result

The developed process enables the material distribution on a swipe sample to be analyzed rapidly without any prior preparation. Traces of a few micrograms per square centimeter are sufficient to determine the level of enrichment of uranium particles.

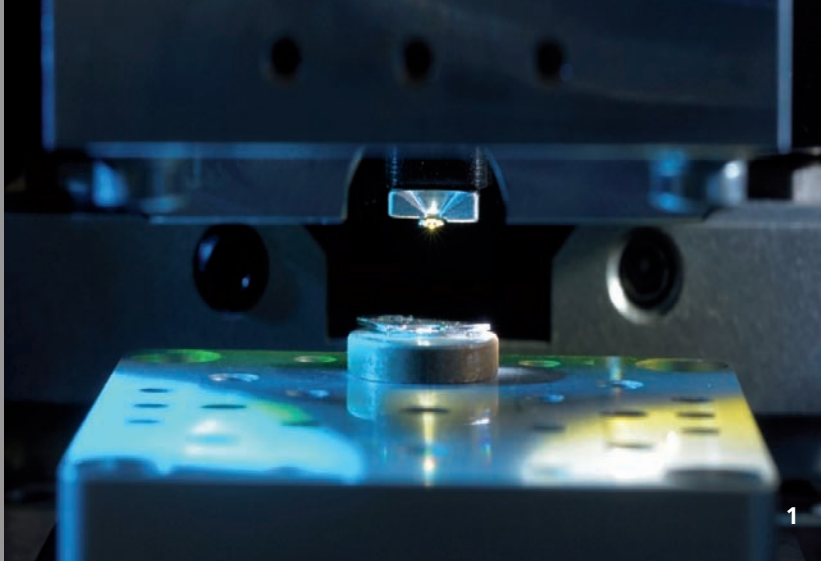
Applications

The speed of the laser process allows subsequent further analysis methods to be used more efficiently, so inspectors can respond faster to any anomalies found. The process has been designed to rule out cross-contamination between individual samples, with minimal work involved in handling the samples. It also allows for a flexible response to the varying quality of the test samples.

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BROADBAND NEAR-FIELD MICROSCOPY FOR MATERIAL CHARACTERIZATION

Task

The semiconductor material gallium nitride is used in the field of high-power and high-frequency electronics. The properties of the components depend on the strain induced in the crystal structure. The ability to characterize this strain with a spatial resolution below the optical diffraction limit would be useful.

Method

A scanning near-field optical microscope (SNOM) can be used to record infrared spectra with a spatial resolution of a few 10 nm. In addition to distinguishing individual materials, crystal properties such as polytypes and strain can also be investigated using nondestructive techniques. A broadband tunable laser system developed at Fraunhofer ILT is used for the scattered light near-field microscope. Overview images at a fixed center wavelength as well as spectra at individual measurement points can be recorded from a test sample.

The tuning range of the broadband laser was extended to around 8.9 μm to 14.5 μm . This large spectral range enables various materials to be characterized, such as silicon carbide and gallium nitride.

Result

Initial measurements on gallium nitride were made using the broadband near-field microscope. The aim is to investigate strained gallium nitride test samples.

Applications

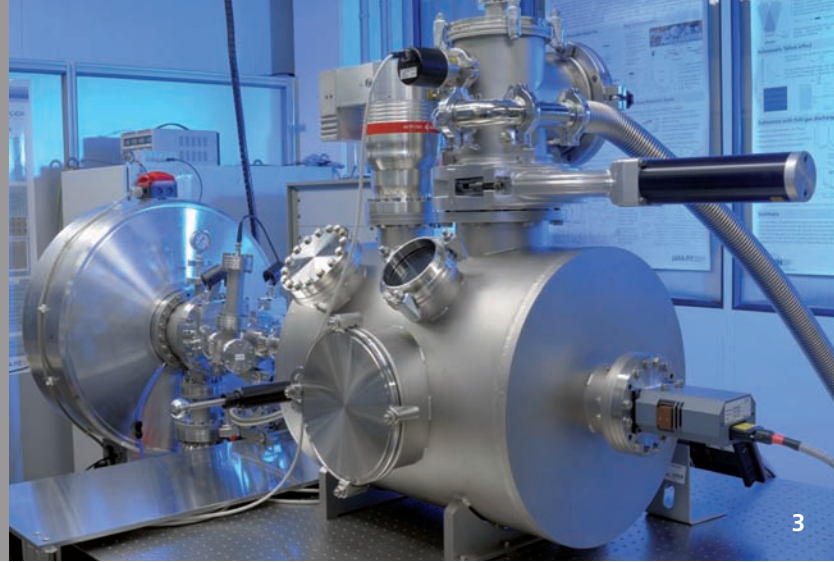
Near-field microscopy has numerous applications in the field of characterizing optoelectronic components, e.g. LEDs, transistors made out of gallium nitride and silicon carbide as well as nanocomposite materials, such as textile fibers, and nanoscopic inclusions. A SNOM application laboratory is being set up at Fraunhofer ILT where these issues will be investigated.

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1 View of near-field microscope showing the holder of the illuminated tip and the underlying test sample.



NANOSTRUCTURING WITH EUV LABORATORY EXPOSURE TOOL (EUV-LET)

Task

Many industrial applications in nanotechnology require a production method that enables the implementation of nanoscale, periodic structures across large areas quickly and cost-efficiently. The development of short-wave radiation sources opens up new solutions in this area.

Method

Gas-discharge based radiation sources for extreme ultraviolet radiation (EUV, $\lambda = 5 \text{ nm} - 15 \text{ nm}$) are used to illuminate transmission masks with nanoscale periodic structures. The fabrication technology for such high-resolution masks is developed in the institute as well. At defined intervals behind the transmission mask self-images are generated. These images are recorded in a photosensitive medium and become visible after a development procedure, comparable to traditional photography. Due to the unique radiation characteristics of the EUV source, it is not only possible to reproduce the mask structure but also to reduce the period of the pattern by a factor of two.

Result

Based on previous investigations at the Fraunhofer ILT an EUV Laboratory Exposure Tool (EUV-LET) was constructed for test-sample sizes up to 100 mm. With the assistance of high-precision positioning and alignment systems, it is possible to monitor the distance between the mask and the surface of test sample with an accuracy of 10 nm. Within an exposure time of approximately one minute, periodic nanostructures are generated over an area of up to 4 mm² on the sample. The demonstrated resolution of the EUV-LET reaches 10 nm. First results validate the potential of the EUV-LET in terms of pattern resolution, flexibility and industrial implementation.

Applications

For a variety of research institutions active in the field of nanotechnology the EUV-LET offers a possibility to generate periodic structures over large areas. This kind of nanostructuring tool also provides an effective solution for the growing nanotechnology market, which is particularly relevant for small and medium-sized enterprises.

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2 EUV-LET station.

3 Cleanroom processing bench.

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Behrens, Michael

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Britten, Simon

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Gretzki, Patrick

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Güdükurt, Okan

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Kaempgen, Silvia

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Kamps, Tobias

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Experimentelle Untersuchungen zum gepulsten Laserpolieren mittels Zweistrahltechnik

Schmitz, Patrick

Untersuchung der Oberflächenstrukturbildung beim Abtragen von Quarzglas mit CO₂-Laserstrahlung

Vogel, Mario

Reparatur von Spritzgießwerkzeugen mittels Mikro-Laserstrahl-Auftragsschweißen

Winzer, Sebastian

Selective Laser Melting SLM Bearbeitung von Inconel 718 nach dem Hülle-Kern Prinzip

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LECTURES

22.01.2012 – A. Temmler: Laser polishing. SPIE LASE 2012, San Francisco, CA, USA

23.01.2012 – R. Poprawe: Digital photonic production – »from bits to photons to atoms«. LLNL, LAM, Livermore, CA, USA

24.01.2012 – B. Gronloh: High average power sub-picosecond pulse generation at 515 nm by extracavity frequency doubling of a mode-locked Innoslab MOPA. LASE 2012, San Francisco, CA, USA

25.01.2012 – M. Leers: Highly precise and robust packaging of optical components. Photonics West 2012, San Francisco, CA, USA

25.01.2012 – H. Faidel: Passive alignment and soldering technique for optical components. Photonics West 2012, San Francisco, CA, USA

25.01.2012 – M. Hermans: In situ diagnostics on fs-laser induced modification of glasses for selective etching. Photonics West 2012, San Francisco, CA, USA

02.02.2012 – W. Meiners: Neue Möglichkeiten der Implantatfertigung durch innovative Laserverfahren: Generative Fertigung und Laserpolieren. Workshop »Innovative Fertigungstechnologien für medizinische Instrumente und Implantate«, Bremen

06.02.2012 – D. Ivanov: MD modeling of laser ablation processes. 32nd International Workshop on Physics of High Energy Density in Matter, Hirschegg, Österreich

08.02.2012 – W. Meiners: Selective Laser Melting and Laser Metal Deposition: An overview of recent applications and R&D activities in aerospace. EUCOMAS 2012, Hamburg

01.03.2012 – I. Kelbassa: High-speed laser additive manufacturing LAM. LAM 2012, Houston, TX, USA

06.03.2012 – R. Poprawe: The future of tailored light – perspectives of ultrashort lasers, applications and strategies. Innovationsforum »MikroLas«, Rostock

08.03.2012 – A. Roesner: Lasermaterialbearbeitung von Faserverbundkunststoffen. Workshop »Leichtbau für Elektromobilität«, Berlin

13.03.2012 – A. Temmler: Designing surfaces by laser remelting. ICOMM 2012, Chicago, IL, USA

13.03.2012 – P. Loosen: Automatisierungsgerechte Aufbaukonzepte für Laserbaugruppen. Workshop »Automatisierte Montage von Laserkomponenten und -baugruppen«, Aachen

14.03.2012 – R. Noll: Fraunhofer Institute for Laser Technology – Measurement technology and EUV sources. University Gainesville, FL, USA

15.03.2012 – S. Bremen: Selective Laser Melting - a manufacturing method for series production. DDMC 2012, Berlin

15.03.2012 – R. Noll: LIBS in industrial applications – inline analysis for efficient process control. Pittcon 2012, Orlando, FL, USA

15.03.2012 – J. Ryll: Scannerbasierte Laser- Schneidprozesse für die Feinbearbeitung - neue Trends in der Lasermaterialbearbeitung. Optence e. V., Kaiserslautern

15.03.2012 – N. Hambach: Stability limits of laser drilled hole arrays on large areas. DPG Frühjahrstagung 2012, Kurzzeitphysik, Stuttgart

21.03.2012 - W. Meiners: Selective Laser Melting: Generative Fertigung für die Produktion der Zukunft. Seminar »Optische Technologien in der Produktionstechnik«, Dortmund

- 22.03.2012 – W. Meiners:** *Rapid Manufacturing - Selective Laser Melting als neues Verfahren zur Herstellung von Bauteilen aus Titan. DGM Fortbildung, Köln*
- 25.03.2012 – R. Poprawe:** *Bedeutung der Lasertechnik für die Märkte in Deutschland und der Welt. Photonic-Akademie, Aachen*
- 27.03.2012 – A. Olowinsky:** *Welchen Einfluss hat das Streuverhalten von Kunststoffen auf die Fügequalität - Simulation und experimentelle Ergebnisse. Diodenlaserworkshop IWS Dresden, Dresden*
- 28.03.2012 – K. Wissenbach:** *Generative Laserverfahren für die Produktion der Zukunft. MST Kooperationsforum »Lasertechnik Heute und Morgen«, Köln*
- 28.03.2012 – R. Noll:** *Einführung in die Lasertechnik für die Inline Prozessdiagnostik. Antrittsvorlesung zur Habilitation, Fraunhofer ILT, Aachen*
- 29.03.2012 – L. Bürgermeister:** *Antimikrobielle Photodynamische Therapie - Analyse des Ablaufs der chemischen Prozesse. 10. Workshop »Automatisierungstechnische Verfahren für die Medizin«, Aachen*
- 16.04.2012 – O. Pütsch:** *Electro-optically actuated liquid-lens zoom. SPIE Photonics Europe, Brüssel, Belgien*
- 17.04.2012 – A. Gatej:** *Thermo-optical (TOP) analysis by coupling FEM and ray tracing. SPIE Photonics Europe, Brüssel, Belgien*
- 18.04.2012 – S. Heidrich:** *Development of a laser based process chain for manufacturing freeform optics. SPIE Photonics Europe, Brüssel, Belgien*
- 19.04.2012 – P. Werheit:** *Automated LIBS sorting system for single particle analysis in metal recycling. Sensor Based Sorting 2012, Aachen*
- 20.04.2012 – S. Bremen:** *Build up increase with high power SLM. Materialise World Conference, Leuven, Belgien*
- 23.04.2012 – P. Loosen:** *The INNOSLAB-laser - a versatile solid-state laser concept. Third Annual SU2P Symposium, Edinburgh, Schottland, UK*
- 24.04.2012 – R. Poprawe:** *A paradigm shift in production technology: Laser additive manufacturing. Optics & Photonics International Congress 2012, Yokohama, Japan*
- 24.04.2012 – J. Ryll:** *System and process for laser drilling and trimming of micro-tubes. Hannover Messe 2012, Hannover*
- 25.04.2012 – A. Olowinsky:** *Laser based manufacturing processes for battery technology. Hannover Messe 2012, Hannover*
- 25.04.2012 – R. Poprawe:** *Innovations and trends in European laser technology – sources, applications and strategy. Optics & Photonics International Congress 2012, Yokohama, Japan*
- 30.04.2012 – R. Noll:** *Neueste Entwicklungen in der Medizintechnik und klinischen Diagnostik – mit Lasern messen, steuern und operieren. Habilitationskolloquium, Fraunhofer ILT, Aachen*
- 04.05.2012 – D. Riestler:** *Laser induced forward transfer - Options and challenges for stem cell research. Interne Klausurtagung des Kompetenznetzwerks NRW, Mont Cenis Akademie Herne*
- 08.05.2012 – D. Petring:** *Fundamental and practical aspects of fiber laser cutting sheet metal. IIW Commission I Meeting, Aachen*
- 09.05.2012 – G. Backes:** *Ressourceneinsparung im Triebwerksbau durch Generieren von Bauteilen und Segmenten durch Laserauftragsschweißen. Rapid Tech, Erfurt*

09.05.2012 – W. Meiners: Additive manufacturing of turbine engine parts by Selective Laser Melting. International Laser Technology Congress AKL'12, Aachen

09.05.2012 – A. Gasser: Innovative impact of LAM, additive manufacturing in turbo-engine applications. International Laser Technology Congress AKL'12, Aachen

09.05.2012 – A. Olowinsky: Extending the process limits of laser polymer welding with London high-brilliance beam sources. International Laser Technology Congress AKL'12, Aachen

09.05.2012 – S. Eifel: Verfahrensentwicklung zum Hochgeschwindigkeits-Abtrag. International Laser Technology Congress AKL'12, Aachen

10.05.2012 – E. Willenborg: Overview on laser polishing and thin film processing. International Laser Technology Congress AKL'12, Aachen

10.05.2012 – R. Poprawe: Die Gesellschaftsrelevanz der Lasertechnik: Trends und Perspektiven. International Laser Technology Congress AKL'12, Aachen

11.05.2012 – W. Meiners: Generative Fertigung für die Produktion der Zukunft? International Laser Technology Congress AKL'12, Aachen

11.05.2012 – F. Schmitt: Lasermikrofügen – Prozesse und Anwendungen in Forschung und Entwicklung. International Laser Technology Congress AKL'12, Aachen

11.05.2012 – U. Eppelt: Modellbildung und Simulation zum Bohren. International Laser Technology Congress AKL'12, Aachen

16.05.2012 – S. Engelhardt: 3D-Lasertechnologie für die Herstellung hochaufgelöster dreidimensionaler Scaffolds. Workshop »Biorap – 3D-strukturierte Biomaterialien mittels Rapid Prototyping«, Stuttgart

23.05.2012 – R. Poprawe: Die Zukunft der Fertigung – vom Design direkt zum Bauteil via generativer Fertigungsverfahren. InnoMateria Kongressmesse, Köln

23.05.2012 – C. Engelmann: Integrative Prozesskette zur verschnitt-optimierten Serienfertigung von TPI/FVK-Leichtbauteilen auf Basis von Hybridgarnen. IKV Fachtagung, Aachen

30.05.2012 – A. Bruneton: Efficient freeform optics for street lighting applications. 113th DGaO, Eindhoven, Niederlande

30.05.2012 – M. Leers: Pick and align - High precision active alignment of optical components. IEEE – ECTC 2012, San Diego, CA, USA

31.05.2012 – O. Pütsch: Active, multi-aperture beam integrator for application adapted laser materials processing. 113th DGaO, Eindhoven, Niederlande

31.05.2012 – A. Richmann: Polishing of illumination optics with CO₂ laser radiation. 113th DGaO, Eindhoven, Niederlande

12.06.2012 – J. Gottmann: Microcutting and hollow 3D microstructures in glasses by in-volume selective laser-induced etching (ISLE). LPM2012, Washington, DC, USA

12.06.2012 – R. Noll: Inline elemental characterization of scrap charging for improved EAF charging control and internal scrap recycling. RFCS TGS9 Meeting, Düsseldorf

12.06.2012 – H. Hoffmann: Average power scaling of ultrafast lasers based on the INNOSLAB Platform. LASYS 2012, Stuttgart

- 12.06.2012 – H. Hoffmann:** Hochbrillante Strahlquellen. WLT Short Course »Basiswissen Laser und Lasermaterialbearbeitung« LASYS 2012, Stuttgart
- 13.06.2012 – D. Petring:** Cutting with 1 micron wavelength lasers: An intermediate assessment of speculations, simulations, diagnostics and facts. Stuttgarter Lasertage 2012, Stuttgart
- 14.06.2012 – E. Willenborg:** Entwicklung einer Prozesskette für die individualisierte Fertigung von Freiformlinsen. Optence, Wetzlar
- 20.06.2012 – M. Schaefer:** Comparison of laser ablation of transparent conductive materials on flexible and rigid substrates. LOPE-C 2012, München
- 25.06.2012 – A. Richmann:** Laser polishing of lenses of fused silica and BK7. OF&T, Monterey, CA, USA
- 26.06.2012 – A. Gillner:** High power ultra-short pulse laser processing – a new approach for high precision manufacturing. Innovative Manufacturing Research Centre Conference, Edinburgh, Schottland, UK
- 27.06.2012 – S. Heidrich:** Optics fabrication with a laser based process chain. OF&T, Monterey, CA, USA
- 03.07.2012 – A. Bäuerle:** Auslegung abbildender und nicht-abbildender optischer Systeme. Seminar »Optische Kunststoff-Formteile in Design und Praxis«, Süddeutsches Kunststoff-Zentrum, Würzburg
- 04.07.2012 – R. Poprawe:** Mit Lasertechnik in eine neue Ära unserer Gesellschaft. Seniorenstudium, RWTH Aachen University, Aachen
- 09.07.2012 – H. Hoffmann:** Brilliance improvement of high power diode laser systems: Status and Prospects. IEEE Summer Topical Meeting, Seattle, WA, USA
- 09.07.2012 – G. Rolink:** Impact of different coating systems on corrosion and wear resistance generated by laser cladding. International Conference of Magnesium and Magnesium Alloys ICMMMA 2012, Vancouver, Kanada
- 11.07.2012 – S. Bremen:** Selective Laser Melting – Further steps towards series production. Additive manufacturing conference Loughborough 2012, Loughborough, Leicestershire, UK
- 26.07.2012 – J. Witzel:** LACAM3D, CAM solution for tool path generation for build up of complex aerospace components by laser powder deposition. 37th International MATADOR Conference, Manchester, England
- 26.07.2012 – J. Witzel:** High speed LAM. 37th International MATADOR Conference, Manchester, England
- 12.08.12 – A. Gatej:** Thermo-optical (TOP) analysis of transmissive elements for laser-systems. SPIE Optics + Photonics, San Diego, CA, USA
- 12.08.12 – A. Bruneton:** Irradiance tailoring with two-sided Fresnel-type freeform optics. SPIE Optics + Photonics, San Diego, CA, USA
- 13.08.2012 – M. Schaefer:** Investigation of the influence of laser radiation on material properties of transparent conductive layers. SPIE Optics + Photonics, San Diego, CA, USA
- 16.08.2012 – M. Schulz-Ruhtenberg:** Novel approach to short-pulse and ultra-short pulse laser ablation of silicon nitride passivation layers. SPIE Optics + Photonics, San Diego, CA, USA
- 31.08.2012 – A. Meissner:** Resonantly-pumped single-frequency Er:YLuAG-laser with pulsed emission at 1645.2 nm (air). Europhoton 2012, Stockholm, Schweden

05.09.2012 – **M. Wehner:** Light-weight optical sensor for standoff detection of fluorescent biosensors. Future Security 2012, Bonn

05.09.2012 – **A. Gillner:** Präzisionsbearbeitung mit Ultrakurz-pulslasern – Chancen und Herausforderungen. Primes-Workshop, Pfungstadt

11.09.2012 – **D. Hawelka:** Improving surface properties by laser based drying, gelation and densification of printed sol-gel coatings. The 17th International Coating Science and Technology Symposium (ISCST), Atlanta, GA, USA

16.09.2012 – **A. Temmler:** Structuring by remelting. VWS-Symposium, Aachen

18.09.2012 – **A. Roesner:** Verfahrensvergleich beim Laserdurchstrahl-schweißen von Kunststoffen. DVS Congress, Saarbrücken

18.09.2012 – **R. Poprawe:** High power KW-class ns- and fs-SLAB lasers and their specific applications. FLAMN 2012, St. Petersburg, Russland

19.09.2012 – **S. Bremen:** High power Selective Laser Melting – Ein Fertigungsverfahren für die Serienproduktion. IPA Anwenderforum, Stuttgart

24.09.2012 – **M. Sun:** Laser ablation mechanism of transparent dielectrics with picosecond laser pulses. SPIE Laser Damage Symposium 2012, Boulder, CO, USA

24.09.2012 – **D. Petring:** Some answers to frequently asked questions and open issues of laser beam cutting. ICALEO® 2012, Anaheim, CA, USA

25.09.2012 – **U. Eppelt:** Diagnostic and simulation of ps-laser glass cutting. ICALEO® 2012, Anaheim, CA, USA

25.09.2012 – **C. Vedder:** Process monitoring and control for laser-based thin film treatment. ICALEO® 2012, Anaheim, CA, USA

26.09.2012 – **A. Roesner:** Laser assisted joining of plastic and metal using mechanical interlocking. ICALEO® 2012, Anaheim, CA, USA

26.09.2012 – **M. Meixner:** Production of silver conductive paths by laser processing. ICALEO® 2012, Anaheim, CA, USA

27.09.2012 – **C. Fornaroli:** Laser-beam helical drilling of high quality micro holes. ICALEO® 2012, Anaheim, CA, USA

27.09.2012 – **S. Ocylok:** Effects of nano-particles on the properties of laser clad wear resistant layers of hot working tool steels. MSE-Konferenz, Darmstadt

27.09.2012 – **S. Hoelters:** Laser-Messtechnik für Geometriemessungen in der Produktion. Veranstaltung »Optische Technologien in der Produktionstechnik: Metrologie«, NanoMikro+Werkstoffe.NRW e.V., Technologie Zentrum Dortmund GmbH, Dortmund

27.09.2012 – **M. Schulz-Ruhtenberg:** Laser Processing for Organic Photovoltaics: Status and Prospects. Spectaris Forum at EU PVSEC 2012, Frankfurt

28.09.2012 – **V. Mamuschkin:** Einfluss der Streuung auf den Schweißprozess beim Laserdurchstrahl-schweißen von Kunststoffen. ALASKA Seminar, Aachen

01.10.2012 – **R. Noll:** Isotopic trace detection for environmental sample analysis by LIBS microanalysis. 7th Int. Conference on Laser-Induced Breakdown Spectroscopy, Luxor, Ägypten

04.10.2012 – R. Noll: *The challenging path to industrial LIBS applications. 7th Int. Conference on Laser-Induced Breakdown Spectroscopy, Luxor, Ägypten*

09.10.2012 – K. Bergmann: *Discharge based EUV source for metrology. EUV Source Workshop, Dublin, Irland*

09.10.2012 – A. Wissinger: *Laser transmission bonding of silicon with titanium and copper layer for wafer-level packaging. PRiME 2012, 222nd Meeting of ECS – The Electrochemical Society, Honolulu, Hawaii*

11.10.2012 – A. Roesner: *Entwicklung einer verschnittoptimierten Serienfertigung von thermoplastischen FVK-Leichtbauteilen auf der Basis von Hybridgarnen. Composites Europe, Düsseldorf*

18.10.2012 – J. Wueppen: *Ultrafast mid-IR laser source with a tuning range from 9 to 16 microns based on nonlinear frequency conversion. MIRSENS 2, Breslau, Polen*

23.10.2012 – R. Poprawe: *Fundamentals of laser additive manufacturing. LME 2012, Chicago, IL, USA*

24.10.2012 – R. Poprawe: *The basics of ultrafast laser machining. LME 2012, Chicago, IL, USA*

25.10.2012 – H. Hoffmann: *Festkörperlaser und Diodenlaser für das Schweißen von Kunststoffen. Süddeutsches Kunststoff-Zentrum, Würzburg*

31.10.2012 – M. Dahmen: *Aspects of learning and training for the application of laser enhances manufacturing. RAPDASA Conference 2012, SAMI – LAN Workshop, Kwa Maritane, Südafrika*

01.11.2012 – R. Poprawe: *Digital photonic production: high power ultrafast lasers, laser additive manufacturing and laser micro/nano fabrication. POEM 2012, Wuhan, China*

01.11.2012 – A. Gasser: *New developments in Selective Laser Melting (SLM) and Laser Metal Deposition (LMD) for Rapid Manufacturing. RAPDASA Conference 2012, Kwa Maritane, Südafrika*

02.11.2012 – H. Leonards: *Entwicklung von Thiol-En basierten Präpolymeren für den Aufbau 3-dimensionaler Hydrogelstrukturen. DGBM Jahrestagung, Hamburg*

02.11.2012 – M. Traub: *High power diode lasers and their applications: Recent developments and future trends. POEM 2012, Wuhan, China*

04.11.2012 – R. Poprawe: *The societal impact of laser technology – innovation management and laser materials processing. Ningbo Institute of Materials, Technology & Engineering, Ningbo, China*

07.11.2012 – M. Dahmen: *Laser beam welding of martensitic stainless steels as rolled and under press-hardening conditions. IWW Regional Congress 2012 Proceedings, SAIW, Johannesburg, Südafrika*

14.11.2012 – J. Gottmann: *Digital photonic production of micro structures in glass by in-volume selective laser-induced etching using a high speed micro scanner. Lane 2012, Erlangen*

15.11.2012 – D. Petring: *Diagnostics, modeling and simulation: Three keys towards mastering the cutting process with fiber, disk and diode lasers. LANE 2012, Erlangen*

19.11.2012 – E. Willenborg: *Laser polishing in tool and die making. 3rd Steel Polishing Workshop, Aachen*

22.11.2012 – E. Willenborg: Laserstrahlpolieren von metallischen Oberflächen. Jenaer Lasertage, Jena

22.11.2012 – J. Holtkamp: Die photonische Fräse – Verfahrens- und Systemtechnik zum präzisen Hochleistungsabtrag mit Ultrakurzpulslasern. Fertigungstechnisches Kolloquium, ETH, Zürich, Schweiz

23.11.2012 – J. Holtkamp: Aktuelle Trends in der Mikrobearbeitung mit ultrakurz gepulster Strahlung. Laserjob Technologieforum, Fürstfeldbruck

27.11.2012 – R. Wester: Irradiance tailoring for extended sources using a point-source freeform design algorithm. SPIE Optical Systems Design, Barcelona, Spanien

27.11.2012 – P. Loosen: From research to application – Highlights of on-going research activities at the prestigious engineering facilities in Aachen. 7. Int. Aachener Optikkolloquium, Aachen

28.11.2012 – R. Poprawe: Digital Photonic Production – Stand und Perspektiven der individualisierten Produktion mittels Lasertechnik. Euromold 2012, Frankfurt a. M.

28.11.2012 – A. Olowinsky: Innovative qualitätsoptimierte Laserverbindungs-technik für Photovoltaikmodule. BMU Wissenschaftstage Photovoltaik, Berlin

29.11.2012 – E. Willenborg: Glanz durch Licht! Automatisiertes Polieren komplexer Oberflächen. Euromold 2012, Frankfurt a. M.

29.11.2012 – W. Meiners: Individualisierung und Komplexität zum Nulltarif! Neue Horizonte für die Produktion von morgen durch SLM. Euromold 2012, Frankfurt a. M.

29.11.2012 – R. Noll: Photons yielding new insights into production processes - Laser spectroscopy enabling direct chemical analysis of ferrous, non-ferrous and oxidic materials. RATEC 2012, Tokyo, Japan

03.12.2012 – D. Wortmann: Laserinduzierte Nanostrukturierung für optische Nahfeldanwendungen. SPP 1327 Treffen, Berlin

06.12.2012 – B. Mehlmann: Laser micro joining – process and applications in research and development. Konferenz Micro-joining, CJ Eindhoven, Niederlande

11.12.2012 – A. Gatej: Thermo-optische Simulation: Realisierung und Validierung. Workshop »Fokus-Shift bei Hochleistungslasern«, Nürnberg

14.12.2012 – L. Jauer: Recent SLM R&D Activities at Fraunhofer ILT. The 154th Chinese Engineering Science & Technology Forum 2012 International Additive Manufacturing Forum and the 6th China National Additive Manufacturing Conference, Wuhan, China

15.12.2012 – L. Jauer: SLM of Biodegradable Implants. International Additive Manufacturing Forum 2012, Wuhan, China

CONVENTIONS AND CONFERENCES



AKL'12

09. - 11.05.2012, Aachen **International Laser Technology Congress AKL'12**

Experts from the field of industrial laser technology gathered in Aachen from May 9 to 11, 2012 for the International Laser Technology Congress AKL'12 for the 9th time. The outstanding technical innovations included the processing of new materials, ultrashort pulse lasers, and progress in the field of laser additive manufacturing.

The AKL'12 set a new record, attracting over 600 visitors. The biennial congress has further consolidated its position as the leading forum for applied laser technology for manufacturing applications. International participation also rose further. As always, the program in Aachen was extremely varied, including some 76 presentations that nonetheless remained tightly focused on delegates' varying interests: in addition to the beginner's seminar on Laser Technology and the Technology Business Day for executives and marketing managers, the first day was also host to two EU Innovation Forums and a seminar focused on the usage of ultrashort laser pulses in industry. The EU seminars devoted to »Laser Additive Manufacturing (LAM) in Aeronautics and Power Generation« (EU joint project MERLIN) and »Perspectives of Polymer Welding with Lasers« (EU joint project POLYBRIGHT) provided an insight into the current state of development of this compelling laser technology for the user industries.

*1 Ice sculpture of the artist Klaus Grunenberg
with cheekbone implant.*

2 Laser Technology Live at AKL'12.

3 AKL'12 participants.

»Digital Photonic Production« at the Laser Technology Conference on May 10 and 11, 2012

The Laser Technology Conference constituted the mainstay of the congress. Three separate series of presentations showcased new developments in the fields of beam sources and laser material processing in the micro and macro range. In the opening presentation of Dr. Dieter Steegmüller (Daimler AG) two trends, in particular, were shown: greater flexibility in manufacturing and new materials in vehicle manufacturing. The materials covered included high-strength steels, new Al alloys, magnesium, and fiber-reinforced plastics. Prof. Reinhart Poprawe, director of Fraunhofer ILT, focused on the issue of flexibility in his presentation afterwards. Under the heading »Digital Photonic Production« a new world of manufacturing in which virtually any complex, high-precision components can be manufactured rapidly and directly from computer-generated specifications, as part of customized or series production was outlined.

The subsequent presentations demonstrated that such applications are already a reality in many places: for instance with the extended application of LAM processes in the aero engine segment. In such applications it is clear that additive processes, in particular, offer a high level of flexibility coupled with maximum customization during manufacturing, at no additional cost.

In the field of beam sources, ultrashort pulse lasers (USP) again took center stage, alongside current developments in diode and fiber lasers. Entirely new applications are being opened up thanks to the availability of systems with average output of over 100 watts. A new generation of USP lasers with high operating reliability, long service life, and acceptable costs has finally made inroads into industrial manufacturing.



Lasertechnik Live on May 11, 2012

As highlight of the AKL'12 79 different technical installations and exhibits presented current research findings and developments in industrial laser technology in the Laser Technology Center of the Fraunhofer ILT. These covered the fields of laser material processing as well as EUV technology, or laser beam sources and optics components. The applications are wide-ranging: alongside mechanical engineering, the line-up includes medical technology and electronics, aeronautical and automotive industry as well as energy and solar technology.

The high-power short pulse laser, which defines the high-end segment at output power in excess of 1 kW, attracted a great deal of attention. In recognition of its outstanding multi-disciplinary collaboration across all locations, the Fraunhofer ILT and several cooperation partners from science and industry received the Stifterverband's Science Award 2012 for their work on scaling the output of ultrashort laser pulses.

Review of AKL'12: www.lasercongress.org

09.05.2012, Aachen Awarding ceremony of the Innovation Award Laser Technology 2012

In the historical ambience of the »Coronation Hall« around 300 guests attended the awarding ceremony of the Innovation Award Laser Technology 2012 that that was embedded in the International Laser Technology Congress AKL'12.

Prof. Reinhart Poprawe, vice-president of the association Arbeitskreis Lasertechnik AKL e.V. and director of the Fraunhofer Institute for Laser Technology ILT, welcomed in Aachen's town hall the audience and especially the teams of the 3 finalists

and the 10 members of the international jury. In his laudatio Dr. Paul Hilton from The Welding Institute TWI Cambridge and speaker of the jury members pointed out the dedicated work of all 3 finalist's and the outstanding innovations of the project teams in the field of laser technology.

The jury conferred the 1st prize of the Innovation Award Laser Technology 2012 provided with 10 000 Euro prize money to Dr. Stephan Brüning, responsible for R&D Laserapplications within Schepers GmbH&Co KG in Vreden for the innovation »3D micro-structuring of large scale metal surfaces for embossing and printing applications with high power ultrashort pulse-lasers«. The main focus of the company Schepers is based on designing, developing and manufacturing laser machines for the rotogravure and flexo industry as well for the embossing industry. The prize winner Dr. Brüning has been furthermore awarded the title of »AKL Fellow« and »ELI Fellow«. The prize was handed over by Dipl.-Ing. Ulrich Berners, president of the Arbeitskreis Lasertechnik AKL e.V. and Dr. Stefan Kaierle, president of the European Laser Institute ELI.

The members of the rewarded project team:

- Dr. Stephan Brüning, (team representative), Schepers GmbH & Co KG, Vreden
- Dr. Gerald Jenke, SAUERESSIG GmbH + Co. KG, Vreden
- Dieter Hüls, SAUERESSIG GmbH + Co. KG, Vreden
- Dr. Ralf Knappe, LUMERA LASER GmbH, Kaiserslautern
- Dr. Sergey Naumov, LUMERA LASER GmbH, Kaiserslautern
- Dr. Daijun Li, EdgeWave GmbH, Würselen
- Dipl.-Phys. Marco Höfer, Fraunhofer Institute for Laser Technology ILT, Aachen
- Dipl.-Phys. Stephan Eifel, Fraunhofer Institute for Laser Technology ILT, Aachen
- Dr. Arnold Gillner, Fraunhofer Institute for Laser Technology ILT, Aachen



The prize for the 2nd place of the Innovation Award Laser Technology 2012 has been conferred to Dipl.-Ing. Rainer Pätzelt, Director of Marketing, and his team of Coherent GmbH, Göttingen, a supplier of laser sources, laser tools and laser accessories for a broad range of commercial and scientific applications. The innovation consisted in »Excimer lasers for Active-Matrix-LCD and Active-Matrix-OLED based flat panel displays«.

The prize for the 3rd place of the Innovation Award Laser Technology 2012 has been conferred to Dr. Markus Kogel-Hollacher, head of department R&D projects within Precitec Optronik GmbH, Rodgau and his team. Precitec is a supplier of processing heads, process monitoring and system solutions for laser cutting and welding as well as measuring systems. The innovation consisted in a »3D-capable co-axial laser brazing head with integrated seam tracking«.

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

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

CONGRESSES AND SEMINARS

29.02. - 01.03.2012, Houston, USA

LAM – Laser Additive Manufacturing Workshop 2012

At the Laser Institute of America LIA's fourth LAM workshop, Dr. Ingomar Kelbassa represented Fraunhofer ILT as a keynote speaker on the topic of high-speed laser additive manufacturing. Fraunhofer ILT and Joining Technologies Inc. had a shared presence at the exhibition accompanying the conference.

27.11. - 28.11.2012, Aachen

7th International Colloquium on Optics in Aachen

With a two-day international congress devoted to optics and photonics, the Fraunhofer Institute for Production Technology IPT and the Fraunhofer Institute for Laser Technology ILT in Aachen offer a biennial information forum looking at current perspectives, technological innovations and new applications from industry and research.

The Colloquium with around 107 delegates examined in detail the three themes of »Market and Strategies«, »Products and Innovation« and »Technology and Production« as part of some 17 presentations. The program covered application-specific presentations on current developments and trends as well as tours around the machine halls and laboratories at Fraunhofer IPT and Fraunhofer ILT.

Further information on the 7th International Colloquium on Optics in Aachen can be found at: www.optik-kolloquium.de

1 The winners of the Innovation Award Laser Technology 2012.

2 The Photonic Process Chains symposium at EuroMold in Frankfurt was well attended.

3 Participants in the podium discussion at the Colloquium on Optics.



28.11. - 29.11.2012, Frankfurt

**»Photonic Process Chains – Revolution in Production?«
Symposium**

Given the relevance of the topic for research and industry, the German Federal Ministry of Education and Research BMBF hosted a symposium entitled »Photonic Process Chains – Revolution in Production?« at EuroMold 2012 in Frankfurt from November 28 - 29, 2012 in collaboration with Fraunhofer ILT, the German Engineering Federation VDMA, and DEMAT, the organizer of the trade fair. A total of 15 speakers from the mechanical engineering, toolmaking, automotive, printing, dental and science sectors discussed the possibilities and challenges in linking photonic production processes together intelligently.

The presentations and discussions were centered on the necessity of considering product manufacturing not merely as individual steps but as the totality of processes along the entire process chain. Dr. Schlie-Roosen, the BMBF's head of photonics and optical technologies, stressed the importance of photonic production for the German economy. Over 80 participants showed great interest in the intensive discussions around this topic.

**COLLOQUIUM ON LASER
TECHNOLOGY AT THE RWTH
AACHEN UNIVERSITY**

12.01.2012, Aachen

**Chair for Laser Technology LLT at RWTH Aachen
Colloquium on Laser Technology**

Prof. Andreas Tünnermann, Fraunhofer-Institut für Angewandte Optik und Feinmechanik IOF, Jena:
»Prospects and challenges of high power fiber lasers«

19.01.2012, Aachen

**Chair for Laser Technology LLT at RWTH Aachen
Colloquium on Laser Technology**

Prof. Rudolf Steiner, Institut für Lasertechnologie in der Medizin und Messtechnik ILM an der Universität Ulm:
»Trends of laser applications in medicine«

02.02.2012, Aachen

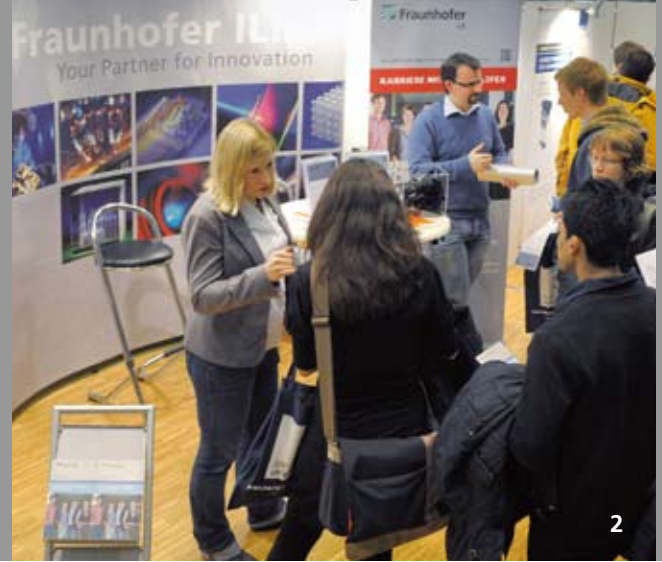
**Chair for Laser Technology LLT at RWTH Aachen
Colloquium on Laser Technology**

Prof. Georg v. Freymann, Technische Universität Kaiserslautern, Fachbereich Physik: »3D laserlithography – towards smaller feature sizes«

19.04.2012, Aachen

**Chair for Laser Technology LLT at RWTH Aachen
Colloquium on Laser Technology**

Prof. Thomas Graf, Universität Stuttgart, Institut für Strahlwerkzeuge: »CFK-Bearbeitung – Herausforderung für die Lasertechnik«



26.04.2012, Aachen

Chair for Laser Technology LLT at RWTH Aachen
Colloquium on Laser Technology

Prof. Andreas Ostendorf, Ruhr-Universität Bochum,
Lehrstuhl für Laseranwendungstechnik: »Selektiver Abtrag
dünner Schichten mit ultrakurzen Laserpulsen«

24.05.2012, Aachen

Chair for Laser Technology LLT at RWTH Aachen
Colloquium on Laser Technology

Prof. Ursula Keller, ETH Zürich, Institute of Quantum
Electronics: »Ultrafast solid-state laser technology«

31.05.2012, Aachen

Chair for Laser Technology LLT at RWTH Aachen
Colloquium on Laser Technology

Prof. Mool C. Gupta, Department of Electrical and Computer
Engineering, University of Virginia: »NSF Laser Center and its
current research in the laser processing area«

15.11.2012, Aachen

Chair for Laser Technology LLT at RWTH Aachen
Colloquium on Laser Technology

Dr. Ralph Wagner, Osram, Regensburg: »Laser in der Fertigung
von LEDs und anderen Optohalbleitern«

22.11.2012, Aachen

Chair for Laser Technology LLT at RWTH Aachen
Colloquium on Laser Technology

Dr. Stephan Falter, GE Sensing & Inspection Technologies,
Hürth: »Zerstörungsfreie Werkstoffprüfung mit Ultraschall im
Produktionsprozess von Kohlefaserverbundwerkstoffen«

1 Lecture of Prof. Kampker at the 44th Aix-Laser-People meeting.

2 Annika Richmann and Benjamin Mehlmann at the
Companies Night on November 7, 2012.

3 Participants of the Photonics Academy 2012.

4 ... in the Philips »Lumiblade Creative Lab« in Aachen.

13.12.2012, Aachen

Chair for Laser Technology LLT at RWTH Aachen
Colloquium on Laser Technology

Prof. Gero von Plessen, I. Physikalisches Institut, RWTH Aachen
University: »Steuerung von Goldnanopartikel-Aggregaten
mit Laserlicht«

AIX-LASER-PEOPLE

11.05.2012, Aachen

43rd seminar of the »Aix-Laser-People« alumni club
of Fraunhofer ILT and the Chair for Laser Technology LLT,
including an opportunity to watch more than 70 live demon-
strations in the ILT Laser Applications Center in connection
with the International Laser Technology Congress AKL'12 in
Aachen.

20.12.2012, Aachen

44th seminar of the »Aix-Laser-People« alumni club
of Fraunhofer ILT and the Chair for Laser Technology LLT,
hosted by StreetScooter GmbH in Aachen, included the
following presentations: »Electromobility – the Aachen
business case StreetScooter« by Prof. Achim Kampker,
Chair of Production Management, WZL at RWTH Aachen
University and General Manager of StreetScooter GmbH; »The
StreetScooter as an example of laser processing in lightweight
construction« by Dipl.-Ing. Ulrich Petschke, LBBZ GmbH;
»Laser processes in battery manufacturing« by Dr. Alexander
Olowinsky, manager of the Micro Joining group at Fraunhofer
ILT. The presentations were followed by a tour of StreetScooter
GmbH and concluded with a round of on-site discussions.



PRESENTATIONS FOR PUPILS AND STUDENTS

26.01.2012, Aachen

Unihits for Kids

Forum organized by the Chair for Laser Technology LLT and the Fraunhofer ILT to give advice on scientific careers to students in 5th grade at the Anne-Frank-Gymnasium in Aachen.

24.02.2012, Aachen

Guided tour for pupils

Forum organized by the Chair for Laser Technology LLT and the Fraunhofer ILT for pupils in 10th to 13th grade in the framework of TandemSchool.

08.03.2012, Aachen

Unihits for Kids

Forum organized by the Chair for Laser Technology LLT and the Fraunhofer ILT to give advice on scientific careers to students in 7th grade at the Gesamtschule Aachen-Brand.

25. - 30.03.2012, Aachen

Photonics Academy 2012

A total of 40 students (10 women and 30 men) from across Germany spent an intensive week at Fraunhofer ILT in Aachen considering the topic of light. This Photonics Academy is part of Photonics Campus Germany, an initiative aimed at encouraging young science and engineering talent. It is organized by the German Hightech Industry Association SPECTARIS, the German Engineering Federation VDMA, the German Electrical and Electronic Manufacturers' Association ZVEI and the German Federal Ministry of Education and Research BMBWF. A number of Fraunhofer Institutes are also partners in this initiative.

These future academics got a chance to visit the laboratories at Fraunhofer ILT on the very first day, following a series of presentations. The next day was devoted to "lasers you can touch". EdgeWave, a spin-off of Fraunhofer ILT based in Würselen, offered insights into the manufacturing of high-end laser beam sources. cleanLaser in Herzogenrath, also a Fraunhofer ILT spin-off, let the budding photonics experts have a go for themselves, using manually guided optics to focus the laser beam onto a casting mold in order to clean it. At the end of this practical day, participants visited the Philips "Lumiblade Creative Lab" in Aachen, where the company gave them a look at tomorrow's lighting technology based on organic light-emitting diodes (OLEDs).

The third and fourth days of the Academy took the 40-strong group, along with their guides from Fraunhofer ILT and VDI Technologiezentrum, to Laserline in Koblenz, where participants learned about diode laser production. On the final day they visited a key player in laser technology, TRUMPF, based in Ditzingen close to Stuttgart, where the visitors gained deep insights into the work of photonics experts. An informal evening fireside gathering with representatives of the sector gave the students a chance to pick up some insider tips on how to start out on a career and what the business world expects of future academics.

26.04.2012, Aachen

Girls' Day event

The event provides girls aged 10 upwards with the opportunity to gain an insight into the world of work involving technology, skilled trades, engineering and natural sciences, or to find out about female role models in management positions in business and government. Fraunhofer ILT has teamed up with Fraunhofer IPT and IME to take part in this nationwide careers guidance day for girls aged between 10 and 15. A total of 50 girls enjoyed a tour of the institutes during the event.



The ILT team at glasstec 2012 in Düsseldorf.



Fraunhofer at EU PVSEC 2012 in Frankfurt.

27.06.2012, Aachen

Guided tour for pupils

Forum organized by the Chair for Laser Technology LLT and the Fraunhofer ILT for professional school pupils.

17.07.2012, Aachen

Student University

RWTH Aachen offers free student universities covering the MINT disciplines (math, information technology, natural sciences, technology) for students in 9th grade and older. Fraunhofer ILT took part together with the Institute of Aeronautics and Astronautics ILR and the Institute for Machine Elements and Machine Design IME in the Mechanical Engineering A component with lectures and lab experiments on the topic of laser technology.

12.10.2012, Aachen

Guided tour for students

Forum organized by the Chair for Laser Technology LLT and the Fraunhofer ILT for 30 students meeting in Aachen in the framework of the Réunion Européenne des Étudiants Luxembourgeois 2012.

07.11.2012, Aachen

Companies Night

This was the third time that Fraunhofer ILT set up a booth in the Technology Centre "am Europaplatz" (TZA) for Companies Night. Over 1800 graduates, students and specialists came along on November 7 to find out from the 90 or so companies present about how they might structure their career. Annika Richmann and Benjamin Mehlmann represented Fraunhofer ILT and the RWTH Aachen University Chairs at a dedicated booth. The next Companies Night will be held on November 6, 2013.

TRADE FAIRS

Photonics West 2012

21. - 26.01.2012, San Francisco, USA

International conference for optics and photonics
Fraunhofer ILT had a notable presence at the Photonics West international conference through the several presentations it gave on the current status of R&D developments in the field of lasers and laser optics. Together with 53 German exhibitors, Fraunhofer ILT was also present in the German Pavilion, which covered the topics of new high-powered lasers, precise assembly techniques for optical components and frequency converters.

JEC Composites

27. - 29.03.2012, Paris, France

Composites show and conferences

Fraunhofer ILT and the CLFA were both present at the joint Fraunhofer booth. Topics included the cutting and welding of fiber reinforced plastics using the example of a laser-machined rear seat backrest and a front end, as well as further exhibits on plastic-metal bonds.

HANNOVER Messe 2012

23. - 27.04.2012, Hannover

International industry trade show

Fraunhofer ILT was present at the joint IVAM booth in Hall 17 and at the ProduktionNRW cluster booth. At the joint IVAM booth, Fraunhofer ILT presented both the polygon scanner, which combines various scanning principles and multi-beam techniques, and the polytubes machine for drilling and cutting polymers. At the ProduktionNRW cluster booth, it presented the Integrative Production Technology for High-Wage Countries cluster of excellence.



Representatives of ILT and Concept Laser GmbH at EuroMold 2012.



Joint Fraunhofer booth at EuroMold 2012 in Frankfurt.

LASYS 2012

12. - 14.6.2012, Stuttgart

International trade fair for laser material processing
Fraunhofer ILT joined the Laser Zentrum Hannover (LZH), the Institute for Laser Tools IFSW at Stuttgart University, the Bayerisches Laserzentrum blz and Fraunhofer IWS for the "Meet the Experts" event at the Solution Center booth.

EU PVSEC 2012

24. - 28.09.2012 Frankfurt

27th European Photovoltaic Solar Energy Conference and Exhibition
The joint Fraunhofer booth presented Fraunhofer ILT's polygon scanner, which combines various scanning principles and multi-beam techniques.

MICRONORA

25. - 28.09.2012, Besançon, France

International microtechnology trade fair
The CLFA had a booth at MICRONORA in France. With almost 600 international exhibitors and 13,900 visitors, this is the most important event of its kind in the country. Fraunhofer ILT's exhibits on the topic of lasers ranged from micromachining and surface structuring to functional surfaces.

ICALEO 2012

23. - 27.09.2012, Anaheim, USA

31st International Congress on Applications of Lasers & Electro-Optics
Fraunhofer ILT and the Chairs of RWTH Aachen University took part in the ICALEO presentation sessions and vendor reception. Prof. Poprawe was honored for his 2012 presidency of the Laser Institute of America LIA.

glasstec 2012

23. - 26.10.2012, Düsseldorf

International Trade Fair for Glass
The topics covered by Fraunhofer ILT and the Chair for Laser Technology LLT included 3D microstructuring and internal marking using ISLE, laser cutting, welding, drilling and polishing of glass substrates, edge rounding in glass, volume waveguides in glass and crystals, and plant technology for in-volume manufacturing of structures.

EuroBLECH 2012

23. - 27.10.2012, Hannover

22nd International Sheet Metal Working Technology Exhibition
Fraunhofer ILT's topics included process monitoring, combi-head system technology for cutting and welding sheet metal assemblies, and local heat treatment of high-strength steels in the automotive industry.

COMPAMED / MEDICA 2012

14. - 17.11.2012, Düsseldorf

World forum for medicine and international trade fair
At the joint IVAM booth, Fraunhofer presented the Mini-Twister® machine for welding plastic microcomponents, laser-polished components for a cardiac support system, and laser polymerization techniques that can be used to manufacture scaffolds for colonized implants.

EuroMold 2012

27. - 30.11.2012, Frankfurt/Main

19th World Fair for Moldmaking and Tooling, Design and Application Development
Fraunhofer ILT's topics included high-power SLM and hybrid technologies, LaCam 3D software for efficient laser material deposition, and laser polishing. It exhibited various SLM components for the aviation industry, components that were coated or repaired using LMD, and laser-polished implants and optics.



Together they developed the core aspects of EUV lithography, (fltr): Dr. T. Feigl, Dr. S. Braun und Dr. K. Bergmann.



The winners of the Stifterverband Science Prize.

AWARDS AND PRIZES

Innovation Challenge 2012

Each year, the U.S. magazine Aviation Week honors outstanding solutions in the area of Aerospace and Defense (A&D). It is on the lookout for new developments that reduce production costs and allow better integration of innovative technologies. The Fraunhofer ILT team was awarded the Innovation Challenge 2012 in the Power and Propulsion category for its additive manufacturing technique for BLISKs. By achieving materials savings of up to 60 percent and shortening the overall manufacturing time by around 30 percent, this innovative manufacturing technology enables the Aachen-based researchers to significantly cut the production costs for BLISKs compared to conventional techniques. The team comprised Dr. Konrad Wissenbach, Dr. Andres Gasser, Stefanie Linnenbrink, Frank Mentzel and Patrick Albus of Fraunhofer ILT as well as Dr. Ingomar Kelbassa, Gerhard Backes, Dr. Bernd Burbaum, Johannes Witzel and Marco Goebel of the Chair for Laser Technology LLT at RWTH Aachen University.

Stifterverband Science Prize

A team of Fraunhofer ILT researchers received the Stifterverband Science Prize 2012 together with several cooperation partners from science and industry. Presented on May 8, 2012 as part of the Fraunhofer annual general assembly in Stuttgart, this award recognized outstanding multi-disciplinary collaboration across all locations on the topic of a laser platform for scaling the output of ultrashort laser pulses. For the last ten years the Fraunhofer-Gesellschaft has been able to submit nominations for the 50,000 euro prize, which honors scientific excellence in applied research projects, to Stifterverband,

the German Science Foundation founded in 1920. In order to open up new markets for laser systems with ultrashort wavelengths, the developer team had to increase the average laser output of ultrashort pulse beam sources – up to the range of several 100 watts. Higher outputs allow higher throughput in production and shorter measuring times in scientific experiments. The newly developed laser platform for overcoming this problem has an INNOSLAB amplifier at its core. The ultrashort pulse platform was developed by Fraunhofer ILT and refined together with several cooperation partners from science and industry, including the Chair for Laser Technology LLT at RWTH Aachen University and the Max Planck Institute for Quantum Optics MPQ in Munich, along with Jenoptik GmbH, EdgeWave GmbH and AMPHOS GmbH. These last two are spin-offs of Fraunhofer ILT.

Joseph von Fraunhofer Prize

Dr. Klaus Bergmann of Fraunhofer ILT, Dr. Stefan Braun of Fraunhofer IWS in Dresden and Dr. Torsten Feigl of Fraunhofer IOF in Jena worked with their teams to develop the core aspects of EUV lithography: beam sources (ILT); collector optics (IOF); and illumination and projection mirrors (IWS). For their achievements in this area of strategic collaboration, they received one of the four Joseph von Fraunhofer Prizes, each worth 20,000 euros, which were presented as part of the Fraunhofer annual general assembly in Stuttgart on May 8, 2012.

Beam source performance is one of the key aspects in driving the commercial utilization of EUV technology. Dr. Bergmann's team developed its first prototype EUV sources back in 2006. There is now a beta version that is already being employed to expose microchips in an industrial setting. The laser vaporizes a small amount of tin and excites it with a large current to induce emissions at 13.5 nm – many thousands of times a second.



Awarding ceremony of the 2012 Berthold Leibinger Innovationspreis awards for the INNOSLAB-Laser project group in Ditzingen.



Dr. Ingomar Kelbassa and Johannes Witzel at the awarding ceremony of the Innovation Challenge in Washington.

Collector mirror quality is central to ensuring that the radiation hits the exposure mask on target. Dr. Feigl and his team applied an extremely heat-resistant and highly reflective multi-layer coating system to the heavily curved collector surface. This guarantees the high quality of the EUV radiation it directs. At a diameter of 66 centimeters, this collector mirror is the world's biggest multilayer-coated EUV mirror.

Behind the mask, the EUV radiation is directed onto the chips using further illumination and projection mirrors. Dr. Braun and his team at Fraunhofer IWS developed the optimum reflective coating for these components. Through their research work, these three institutes have managed to establish themselves as important partners for system manufacturers in Germany and elsewhere. The new lithography systems are expected to make their debut in industrial manufacturing in 2015.

Berthold Leibinger Innovationspreis awards

On September 14, 2012 in Ditzingen, the INNOSLAB-Laser project group, with 13 staff members from Fraunhofer ILT and its spin-offs EdgeWave and AMPHOS, received second prize in the 2012 Berthold Leibinger Innovationspreis awards for applied laser technology. INNOSLAB is the name of a laser platform for a diode-pumped solid-state laser with a slab-shaped crystal that is approximately one millimeter thick and serves as the laser-active medium. Similar to disk and fiber lasers, which are also diode-pumped, the INNOSLAB concept offers high average power and beam quality.

The slab's geometry is nothing new. But at high powers, normal rod-shaped laser crystals came up against the thermal lens and depolarization problem. This limited their usefulness in lasers with high average output.

Prof. Peter Loosen, then head of the beam source development department at Fraunhofer ILT, and his colleague Dr. Keming Du decided to go against the mainstream and devote themselves to developing a diode-pumped slab laser. Until then, there had as yet been no commercially relevant application of this concept anywhere in the world. It was Dr. Du who had the radical insight: that the crystal itself should not, as was standard up to then, limit the laser light within the beam source; rather, the laser beam should spread out freely while passing through the crystal. With this patent in 1996, Dr. Keming Du eliminated all the problems that had occurred until then in solid-state slab lasers. A further patent in 1998 expanded the concept to amplifiers. Three years later, Dr. Du founded the start-up company EdgeWave.

Since 2001, Hans-Dieter Hoffmann has been driving forward developments with regard to short and ultrashort pulse generation and amplification. In 2010, as part of a collaborative research project funded by the German Federal Ministry of Education and Research BMBF, Marco Höfer and his working group demonstrated the first use of ps lasers with up to 400 W laser output to process embossing rollers with very high precision and processing speed. At the same time, Dr. Peter Rußbüldt and his group managed for the first time to increase the average output power of USP lasers to more than 1 kW. Dr. Torsten Mans and Johannes Weitenberg made significant contributions to this work. In 2010 the innovative concept bore further commercial fruit, when Dr. Torsten Mans and Dr. Claus Schnitzler founded the start-up company AMPHOS together with Jan Dolkemeyer.

A further R&D topic is climate research. Together with its partner EADS ASTRIUM and the German Aerospace Center DLR, Fraunhofer ILT is developing beam sources for a satellite-based LIDAR system for measuring the global distribution of climate-relevant trace gases such as methane and CO₂. The work of Jörg Luttmann and Jens Löhring succeeded in demonstrating the excellent energetic and spectral properties of INNOSLAB lasers.

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 Committee

The members of the committee representing the ELI are:

- Dr. Stefan Kaielerle (chairman)
Fraunhofer ILT, Germany
- Dr. Paul Hilton
TWI, Great Britain
- Dr. Wolfgang Knapp
CLFA, France
- Prof. Veli Kujanpää
VTT Technical Research Center of Finland,
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Lasercentrum Vlaanderen, Belgium
- Prof. Dr. José Luis Ocaña
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- Prof. Dr. Andreas Ostendorf
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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 115 members at the moment.

AKL e.V.'s mission

- Providing information on innovative laser-technology products and processes
- Nurturing personal networks between laser experts
- Organizing conferences and seminars
- Producing teaching material on laser technology
- Promoting junior scientific staff
- Advising industry and the scientific community on laser-technology issues
- Presenting the Innovation Award Laser Technology

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TECHNICAL BOOKS

»Laser Technology for Manufacturing« by Reinhart Poprawe

Principles, prospects and examples for the innovative engineer.

Contents

Introduction, behavior of electromagnetic radiation at interfaces, absorption of laser radiation, energy transfer and thermal conduction, thermomechanics, phase transformation, melting pool flows, laser-induced ablation, plasma physics, laser radiation sources, surface technologies, forming, rapid prototyping, rapid tooling, joining, ablation and drilling, cutting, systems engineering, laser measuring technologies. Appendices: A: optics, B: continuum mechanics, C: laser-induced ablation, D: plasma physics, E: explanation of symbols and constants, F: color images, index.

2005. XVII, 526 pages, 353 illustrations (VDI publication), ISBN 3-540-21406-2

»Tailored Light 2« by Reinhart Poprawe

Laser Application Technology

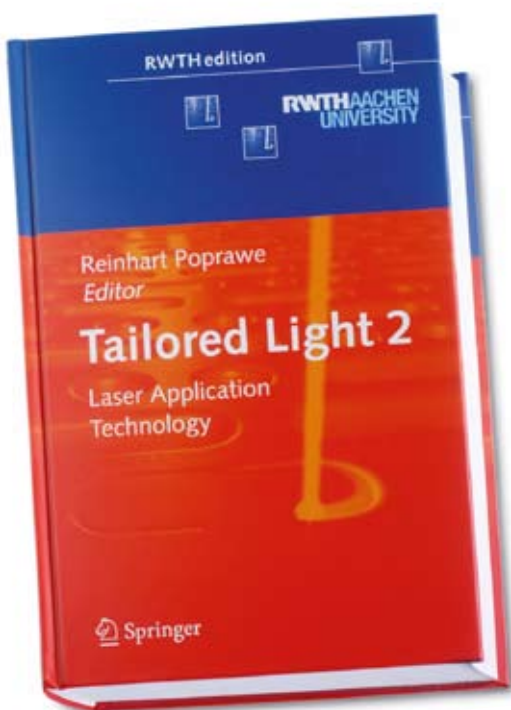
Contents

Preface.- Introduction.- Radiation at interfaces.- Absorption of Laser Radiation.- Energy Transport and Heat Conduction.- Thermo Mechanics.- Phase Transformations.- Melt Flow.- Laser Induced Vaporization.- Plasma Physics. - Laser Beam Sources. - Surface Treatment.- Forming.- Rapid Prototyping & Rapid Tooling.- Joining.- Ablation.- Drilling.- Cutting.- System Technology.- Laser Measurement Technology.- Appendix.- Subject index. 2011.

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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 2012 2011 2010
 (English versions only available online at www.ilt.fraunhofer.de)

Proceedings of the International Laser Technology Congress AKL'12
 Technical Book »Lasertechnik für die Fertigung«
 (Laser Technology for Manufacturing)

Technical Book »Tailored Light 2«

Technical Brochures

Biofabrication
 Laser Drilling German English
 Fiber Lasers German English
 Solid State Lasers German English
 Processing Glass with Laser Radiation German English
 In-Volume Micro Structuring of Transparent Materials
 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 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 Transparent Materials
 German English

Micro and Nano Structuring with Lasers German English
 Modeling and Simulation 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
 Quality Assurance in Laser Materials Processing
 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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