ANNUAL REPORT
FRAUNHOFER INSTITUTE
FOR LASER TECHNOLOGY
2010

25 YEARS FRAUNHOFER ILT
25 Years Partner for Innovations
FOREWORD
The last International Laser Congress AKL’10 provided us with the opportunity to look back on our successes to date, within the overall context of our 25th anniversary. Apart from scientific insights and technical innovations, the around 30 spin-offs created over this period are undeniably important. Congress delegates also had the opportunity to get a feel for the wealth of topics that we promote here in Aachen, as part of over 80 live presentations: from laser sources and optics through laser material processing and laser measurement technology, to laser applications in medical engineering and biophotonics. We endeavor to make an impact in all these areas, day in day out. And it is something our customers want us to do. For that reason they talk to us in the spirit of a true partnership. Whether it’s green technology, healthcare, in production, in the field of mobility or energy, laser technology solutions are everywhere. In this respect we work together with our partners to come up with a solution to the topical issues facing society. If the general public hears about one of these solutions through an award, then that is fantastic. And with that in mind, we are going to keep working on innovative technologies designed to benefit man and machine - in accord with the Federal President’s sentiments. And along the same lines, we hope you garner some inspiration as you read through this annual report. That inspiration might well be the start of a new success story.

Yours

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

ILT - this abbreviation has stood for combined know-how in the sector of laser technology for 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 over 300 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« we develop processes and systems for our customers which conduct inline measurement of physical and chemical parameters in a process line. In addition to production measurement technology and material analysis, environment and safety as well as recycling and raw materials lie in the focus of our contract research. With EUV technology, we are entering the submicron world of semiconductors and biology.

Under one roof, the Fraunhofer Institute for Laser Technology ILT offers research and development, system design and quality assurance, consultation and education. To process the research and development contracts, we have numerous industrial laser systems from various manufacturers as well as an extensive infrastructure. In the user center of the Fraunhofer ILT, guest companies work in their own separate laboratories and offices. This special form of technology transfer is based in a long-term cooperation contract with the institute in the sector of research and development. As an additional benefit, the companies can use the technical infrastructure and exchange information with experts of the Fraunhofer ILT. Around ten companies use the advantages of the user center. Alongside established laser manufacturers and innovative laser users, new founders from the sectors of custom plant construction, laser manufacturing engineering and laser metrology find appropriate surroundings to implement their ideas industrially.

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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.
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 broadband 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 MATERIALS PROCESSING

Among the many manufacturing processes in the technology field Laser Materials 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 materials 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 on-line 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.
The focus of the technology field Laser Measurement 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.

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.

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# PRODUCTS AND SERVICES

## LASERS AND OPTICS

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<td><a href="mailto:dirk.wortmann@ilt.fraunhofer.de">dirk.wortmann@ilt.fraunhofer.de</a></td>
<td>-276</td>
</tr>
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<td></td>
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<td>-311</td>
</tr>
<tr>
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<td>-273</td>
</tr>
<tr>
<td></td>
<td>Dr. A. Gillner</td>
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<td>-148</td>
</tr>
<tr>
<td><strong>Nano Structuring</strong></td>
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</tr>
<tr>
<td></td>
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<tr>
<td><strong>Simulation</strong></td>
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<td>-680</td>
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<td></td>
<td>Prof. Dr. W. Schulz</td>
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<table>
<thead>
<tr>
<th>Medical Technology and Biophotonics</th>
<th>Contact 1</th>
<th>Contact 2</th>
<th>Tel.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bioanalytics</strong></td>
<td>Dr. C. Janzen</td>
<td><a href="mailto:christoph.janzen@ilt.fraunhofer.de">christoph.janzen@ilt.fraunhofer.de</a></td>
<td>-124</td>
</tr>
<tr>
<td></td>
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</tr>
<tr>
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</tr>
<tr>
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<td>Dr. A. Lenenbach</td>
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</tr>
<tr>
<td><strong>Microsurgical Systems</strong></td>
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</tr>
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<tr>
<td><strong>Microfluidic Systems</strong></td>
<td>Dipl.-Ing. A. L. Boglea</td>
<td><a href="mailto:andrei.boglea@ilt.fraunhofer.de">andrei.boglea@ilt.fraunhofer.de</a></td>
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<tr>
<td></td>
<td>Dr. A. Gillner</td>
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<td>-148</td>
</tr>
</tbody>
</table>
## Biofunctionalization

<table>
<thead>
<tr>
<th>Dr. E. Bremus-Koebberling</th>
<th><a href="mailto:elke.bremus@ilt.fraunhofer.de">elke.bremus@ilt.fraunhofer.de</a></th>
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<tbody>
<tr>
<td>Dr. A. Gillner</td>
<td><a href="mailto:arnold.gillner@ilt.fraunhofer.de">arnold.gillner@ilt.fraunhofer.de</a></td>
<td>Tel. -148</td>
</tr>
</tbody>
</table>

## Biofabrication

<table>
<thead>
<tr>
<th>Dipl.-Biologe D. Riester</th>
<th><a href="mailto:dominik.riester@ilt.fraunhofer.de">dominik.riester@ilt.fraunhofer.de</a></th>
<th>Tel. -529</th>
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</thead>
<tbody>
<tr>
<td>Dr. A. Gillner</td>
<td><a href="mailto:arnold.gillner@ilt.fraunhofer.de">arnold.gillner@ilt.fraunhofer.de</a></td>
<td>Tel. -148</td>
</tr>
</tbody>
</table>

## Laser Therapy

<table>
<thead>
<tr>
<th>Dr. M. Wehner</th>
<th><a href="mailto:martin.wehner@ilt.fraunhofer.de">martin.wehner@ilt.fraunhofer.de</a></th>
<th>Tel. -202</th>
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<tr>
<td>Dr. A. Gillner</td>
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<td>Tel. -148</td>
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</table>

## Implants

<table>
<thead>
<tr>
<th>Dipl.-Phys. L. Jauer</th>
<th><a href="mailto:lucas.jauer@ilt.fraunhofer.de">lucas.jauer@ilt.fraunhofer.de</a></th>
<th>Tel. -360</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dr. W. Meiners</td>
<td><a href="mailto:wilhelm.meiners@ilt.fraunhofer.de">wilhelm.meiners@ilt.fraunhofer.de</a></td>
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### LASER MEASUREMENT TECHNOLOGY

## Production Measurement Technology

<table>
<thead>
<tr>
<th>Dr. V. Sturm</th>
<th><a href="mailto:volker.sturm@ilt.fraunhofer.de">volker.sturm@ilt.fraunhofer.de</a></th>
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<tbody>
<tr>
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<td>Tel. -138</td>
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</table>

## Materials Analysis

<table>
<thead>
<tr>
<th>Dr. C. Fricke-Begemann</th>
<th><a href="mailto:cord.fricke-begemann@ilt.fraunhofer.de">cord.fricke-begemann@ilt.fraunhofer.de</a></th>
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<tbody>
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<td>Tel. -138</td>
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## Recycling and Raw Materials

<table>
<thead>
<tr>
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</thead>
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<td>Tel. -138</td>
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## Environment and Safety

<table>
<thead>
<tr>
<th>Dr. C. Fricke-Begemann</th>
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<td>Tel. -138</td>
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</table>

## EUV Technology

<table>
<thead>
<tr>
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<tr>
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<td>Tel. -138</td>
</tr>
</tbody>
</table>
FACTS AND FIGURES

STRUCTURE OF THE INSTITUTE

BOARD OF DIRECTORS

Prof. Dr. Reinhart Poprawe M.A.
Director

Prof. Dr. Peter Loosen
Vice Director

ADMINISTRATION AND CENTRAL FUNCTIONS

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Administration and Infrastructure

Dipl.-Phys. Axel Bauer
Marketing and Communications

Dr. Alexander Drenker
QM Management

Dr. Bruno Weikl
IT Management

COMPETENCE AREAS

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

Dr. Arnold Gillner
Ablation and Joining

Dr. Konrad Wissenbach
Additive Manufacturing and Functional Layers

Dr. Reinhard Noll
Measurement Technology
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:

- C. Baasel (Chairman), Carl Baasel Lasertechnik GmbH
- Dr. Thomas Fehn, Jenoptik AG
- Dr. Ulrich Hefter, Rofin-Sinar Laser GmbH
- Dr. U. Jaroni, ThyssenKrupp Stahl AG
- RD Andreas Kletschke, Bundesministerium für Bildung und Forschung BMBF
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- Prof. Dr. G. Marowsky, Laserlaboratorium Göttingen e. V.
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- Dr. Rüdiger Müller, Osram Opto Semiconductors GmbH & Co. OHG (until 15.09.2010)
- Manfred Nettekoven, Kanzler der RWTH Aachen
- Dr. Joseph Pankert, Philips Lighting B.V.
- Prof. R. Salathé, Ecole Polytechnique Fédéral de Lausanne
- Dr. Dieter Steegmüller, Daimler AG
- Dr. Ulrich Steegmüller, Osram Opto Semiconductors GmbH & Co. OHG (since 15.09.2010)
- Dr. Klaus Wallmeroth, TRUMPF Laser GmbH & Co. KG

The 25th Board of Trustees meeting was held on September 15, 2010 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.

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: Dipl.-Betrw. (FH) Vasvija Alagic MBA, Dipl.-Phys. A. Bauer, Dr. A. Gillner, Dipl.-Ing. H.-D. Hoffmann, Dr. S. Kaierle, Dr. I. Kelbassa, Prof. Dr. P. Loosen, Dr. W. Neff (until 31.07.2010), Dr. R. Noll, Dr. D. Petring, Prof. Dr. R. Poprawe, Prof. Dr. W. Schulz, B. Theisen, Dr. B. Weikl, Dr. K. Wissenbach.

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. Dr. R. Poprawe, B. Theisen, Dr. C. Janzen.

Staff Association

In March 2003 the staff association was elected by the employees of the Fraunhofer ILT and the Department of Laser Technology. Members are:

### EMPLOYEES

**Employees at the Fraunhofer ILT 2010**

<table>
<thead>
<tr>
<th>Personnel</th>
<th>Number</th>
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<tbody>
<tr>
<td>Scientists and engineers</td>
<td>124</td>
</tr>
<tr>
<td>Technical staff</td>
<td>41</td>
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<tr>
<td>Administrative staff</td>
<td>22</td>
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<tr>
<td><strong>Total Personnel</strong></td>
<td><strong>187</strong></td>
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</table>

<table>
<thead>
<tr>
<th>Other employees</th>
<th>Number</th>
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</thead>
<tbody>
<tr>
<td>Undergraduate assistants</td>
<td>130</td>
</tr>
<tr>
<td>External employees</td>
<td>6</td>
</tr>
<tr>
<td>Trainees</td>
<td>4</td>
</tr>
<tr>
<td><strong>Total Other employees</strong></td>
<td><strong>140</strong></td>
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</table>

**Total number of employees at the Fraunhofer ILT**: 327

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

### FACTS AND FIGURES

- 40% Undergraduate assistants
- 7% Administrative staff
- 12% Technical staff
- 3% External employees, trainees
- 38% Scientists/engineers
### REVENUES AND EXPENSES

#### Expenses 2010

<table>
<thead>
<tr>
<th>Item</th>
<th>Mill €</th>
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<tbody>
<tr>
<td>Staff costs</td>
<td>12,2</td>
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<tr>
<td>Material costs</td>
<td>11,7</td>
</tr>
<tr>
<td><strong>Expenses operating budget</strong></td>
<td><strong>23,9</strong></td>
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<td>Investments</td>
<td>7,9</td>
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#### Revenues 2010

<table>
<thead>
<tr>
<th>Item</th>
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<tr>
<td>Industrial revenues</td>
<td>10,7</td>
</tr>
<tr>
<td>Additional financing from Federal Government, States and the EU</td>
<td>9,4</td>
</tr>
<tr>
<td>Basic financing from the Fraunhofer-Gesellschaft</td>
<td>3,8</td>
</tr>
<tr>
<td><strong>Revenues operating budget</strong></td>
<td><strong>23,9</strong></td>
</tr>
<tr>
<td>Revenues from projects abroad (already included in total)</td>
<td>1,9</td>
</tr>
</tbody>
</table>

**Investment revenues from industry** | 0,4

**Fraunhofer industry $\rho_{ind}$** | 46,1 %

---

![Pie chart for expenses]

37 % Material costs  
25 % Investments  
38 % Staff costs  

(100 % Operating budget und Investments)

![Pie chart for revenues]

39 % Additional financing from Federal Government, States and  
16 % Basic financing from the Fraunhofer-Gesellschaft  
45 % Industrial revenues (without investments)  

(100 % Operating budget)
The following graph illustrates the budget trend over the last 11 years.

- Project revenues - public funding
- Project revenues - industrial funding
- Basic financing by Fraunhofer
REFERENCES

March 2010. Printed with the kind permission of our partners.
The companies listed here represent a selection of the Fraunhofer ILT’s many clients.
COOPERATIONS

RANGE OF SERVICES

The services of the Fraunhofer Institute for Laser Technology ILT are continually being adapted to the practical requirements of industry and include the solution of manufacturing problems as well as the realization of test series. In detail this means:

• development of laser beam sources
• components and systems for beam guiding and forming
• packaging of optical high power components
• modeling and simulation of optical components as well as laser processes
• process development for laser materials processing, laser measurement technology, medical technology and biophotonics
• process monitoring and control
• model and test series
• development, set-up and testing of pilot plants
• integration of laser technology into already existing production plants
• development of X-ray, EUV and plasma systems

• 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 »Photonics in 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

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)
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 pro- grammes 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 20 kW
- lamps and diode pumped solid state lasers up to 8 kW
- disc lasers up to 10 kW
- fiber lasers up to 4 kW
- diode laser systems up to 3 kW
- SLAB laser
- excimer lasers
- ultra short pulse laser
- broadband tunable laser
- 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

**FACILITIES**

The usable floor space at the Fraunhofer Institute for Laser Technology ILT amounts to more than 11,000 m².
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

The Fraunhofer CLT develops powerful, high-brilliance fiber lasers 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. In 2007 Arbor Photonics was founded in collaboration with the University of Michigan in order to commercialize the developments in the field of flexible fiber lasers with diffraction limited beam quality and high pulse power.

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. Lasers are also being used for economic surface structuring of silicon and to structure the covering glass. They increase absorption in the cell by several percent.

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 which offer an outstanding combination of scientific innovation and high market potential. The fields of innovative energy and power-storage devices, the associated cost-effective manufacturing, redox batteries and dynamic 3-D diagnostics of combustion processes are also covered. Multiple publications, two international patent applications and the »Inmatech« spin-off are the result of the first 18 months.
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, construction industry, ship building 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, CO₂, and excimer lasers as well as diode lasers are available for process developments involving micro technology.

Operating budget 2010

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>Operating budget</td>
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<tr>
<td>- Staff costs</td>
<td>1.1</td>
</tr>
<tr>
<td>- Material costs</td>
<td>0.6</td>
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</table>

References

Public support:
- DARPA
- Department of Energy
- U.S. Air Force Research Laboratories
- Office of Naval Research
- Michigan Life Science Corridor

Industry:
- Dow
- Ford
- General Motors
- Magna
- Medtronic
- Praxair
- Procter & Gamble
- Roche

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Plymouth, Michigan 48170, USA
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 CAROT Mines in Paris, the École Nationale Supérieure de Mécanique et des Microtechniques ENSMM in Besancon, 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.

The goals of the CLFA are:

- Integration into scientific and industrial development in France
- Growth in know-how by faster recognition of trends in the field of European laser and production technology
- Strengthening the position in the R&D market
- Assembly of a European competence center for laser technology
- Increase of mobility and qualification level of employees

The CLFA is actively participating in the realization of European research and is a result of increasing link of application oriented research and development in the field of laser technology in Europe.

The cooperation of the Fraunhofer ILT with the French partners also contributes to the improvement of the presence of the Fraunhofer Gesellschaft in Europe with the advantages for the French and German sides equally taken into consideration. On an international scale this cooperation further strengthens the leading position of European industry in the laser supported manufacturing process.

The French partners’ interests concentrate on:

- Using the competence of the Fraunhofer ILT for French companies
- Using the experience of the Fraunhofer ILT in the introduction of new technologies
- Providing the connection between industry and university with practical training for students and graduate students

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


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

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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 technologies
- Beam sources
- Micro- and nanotechnology
- Materials treating
- Opto-mechanical precision systems
- Optical measuring systems

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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, pulse magnetron sputtering and plasma activated high-rate deposition are the core areas of expertise of Fraunhofer FEP. Our 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 larger areas at high productivity. Our technologies and processes are applied in the fields of mechanical engineering, solar energy, biomedical engineering, environment and energy, for architecture and preservation purposes, in the packaging industry, for optics, sensor technology and electronics as well as in agriculture.

www.fep.fraunhofer.de
Fraunhofer Institute for Laser Technology ILT
With over 350 patents to its name since 1985, the Fraunhofer Institute for Laser Technology ILT is a sought-after industry R&D partner that specializes in developing innovative laser sources, laser techniques and laser systems. Our technology areas cover the following topics: laser and optics, medical technology and biophotonics, laser measurement technology and laser materials 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
Fraunhofer IWS is synonymous with innovations in the field of laser and surface engineering. It provides customized solutions for joining, separation, deposition, ablation, surface layer treatment and coating using laser and PVD/CVD techniques. Comprehensive materials and nanotechnology know-how forms the basis for a wide range of research and development work. System technology and process simulation complement the core competences in the fields of laser material processing, and plasma coating techniques. Fraunhofer IWS provides solutions from a single source, ranging from research and development on new processes and systems and their integration in the manufacturing environment to troubleshooting and the resolution of problems of all types. www.iws.fraunhofer.de
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 more than 80 research units in Germany, including 60 Fraunhofer Institutes. The majority of the more than 18,000 staff are qualified scientists and engineers, who work with an annual research budget of €1.65 billion. Of this sum, more than €1.40 billion is generated through contract research. Two thirds of the Fraunhofer-Gesellschaft’s contract research revenue is derived from contracts with industry and from publicly financed research projects. Only one third 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 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
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 LLT has been engaged in application-oriented research and development in the fields of integrated optics, integrative production, ablation - modification - diagnosis (AMD), drilling and generative processes since 1985. Its activities in integrated optics focus on investigating the integration of high-power diode lasers with waveguide lasers and beam-shaping optical components, as well as the development of novel integrated power lasers. The Cluster of Excellence »Integrative Production Technology for High-Wage Countries«, in which the LLT is involved, is working largely on the integration of optical technologies into production 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.

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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»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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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 in the first instance will run until the end of 2011.

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.

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**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 from 2010 through 2012. And the final stage will focus on the growth and consolidation of 19 clusters in Melaten and the Westbahnhof from 2013 to 2014, 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.

On February 18, 2010, RWTH Rector Prof. Ernst M. Schmachtenberg and NRW Minister President Dr. Jürgen Rüttgers took part in the groundbreaking ceremony for the RWTH Aachen Campus. 92 companies, including 18 international key players, together with 31 chairs at the RWTH and a study department at Aachen University of Applied Sciences, signed up to long-term collaboration and to relocating to 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 from 2010 through 2012:

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

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

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

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1 RWTH Aachen Campus I - Westbahnhof,
Sketch: RKW Rhode Kellermann Wawrowsky,
Düsseldorf.

2 RWTH Aachen Campus II - Melaten,
Sketch: rha reicher haase + associerte, Aachen.
Selected Research Results
of the Fraunhofer ILT

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- Medical Technology and Biophotonics 107 - 116
- Laser Measurement Technology 117 - 127

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 broadband 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
Passive assembly of optical components using the reflow soldering process.
ALGORITHMS FOR THE DESIGN OF HIGHLY EFFICIENT FREEFORM OPTICS

Task

Refractive and reflective surfaces which differ significantly/substantially from spherical and aspherical geometries have established themselves as ‘freeform optics’ in research and development. Design principles for these lenses and mirrors do not necessarily follow the concepts of imaging optics but aim to redistribute energy by light refraction and reflection. The optimization goal is usually to tailor the irradiance distribution while at the same time maximizing the usable light output. This goal should be achieved with a minimal number of optically effective surfaces. Light-emitting diodes or laser diode arrays serve as the radiation source. Although these exhibit a considerably higher brilliance in most cases than incandescent and discharge lamps, the emission can with good approximation be assumed to be incoherent.

Method

A key aim of the research is to efficiently describe/represent the refractive surface, so that an optimum optical surface can be described with a low number of parameters. Principles of differential geometry and computer graphics are therefore combined with optical design algorithms.

Result

The use of tailored freeform optics can considerably reduce the energy consumed in street and general illumination, while also increasing the flexibility of the lighting. Initial prototype modules have been designed and are being tested in cooperation with the Aachen public utility company in real application scenarios.

Applications

The algorithms developed at Fraunhofer ILT can be generalized for other applications, e.g. automotive lighting, process monitoring/lighting and laser materials processing.

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1 Prototype of a module for architectural lighting.
2 Highly efficient street lamp.
ANAMORPHIC PROCESSING OPTICS FOR HIGH-POWER DIODE LASER SYSTEMS

Task

Optics with low output losses are required for beam shaping in high-power diode lasers. At the same time, the requirements for the output intensity distribution must be precisely fulfilled in the focus of the optical system. The optic described here focuses laser radiation from a square fiber core (400 x 400 μm²) in a rectangular spot (1000 x 200 μm²). The power distribution should be as homogeneous as possible.

Method

The optical system consists of three elements: a collimation unit consisting of spherical lenses, a cylinder telescope to adjust the aspect ratio and a likewise spherical focusing unit. The optic uses catalog lenses exclusively throughout. A dichroic mirror is located between the cylinder telescope and focusing unit, which permits process observation with a camera or pyrometric measurements to be conducted. An LED lamp can be attached to the optic for process observation.

Result

The optic achieves a total transmission of 88.4 percent (through 14 optical elements). As can be seen in Fig. 4, the power distribution meets the requirements for the rectangular 1000 x 200 μm² focus with homogeneous distribution.

Applications

A processing optic with rectangular focus is suitable for use in many types of surface treatment. Examples include laser systems for cleaning surfaces and locally limited hardening of metals.

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3 Anamorphic optical system.
4 Power density distribution in the focus.
**OPTICAL WAVEGUIDE FOR BEAM SHAPING AND GUIDANCE**

**Task**

Compact components for beam shaping and beam guidance can be produced using waveguiding structures in transparent dielectrics. The design of the waveguide can tailor the laser radiation for specific tasks. Elaborate lens systems and frequency filters can be replaced by an integrated solution. Waveguides can be combined with microfluidic components and gratings to create integrated systems.

**Method**

A local refractive index change is induced in the volume of a transparent material with focused femtosecond laser radiation. These modifications can be generated in three dimensions with resolution in the micrometer range. In such structures light can be guided and shaped with minimal losses. Non-linear absorption processes enable the waveguides to be produced in virtually all transparent materials, such as glass, plastic and crystalline media.

**Result**

Curved waveguides with diameters of a few μm and curvature radii of 0.5 to 2 mm, which deflect light through angles of up to 90°, have been written in borosilicate glass. The far field of such a waveguide exhibits a numerical aperture of about 0.1. Straight waveguides with diameters of up to 40 μm have been produced. Elliptical laser diode radiation has been converted into a round beam profile by waveguides with a circular cross-section.

**Applications**

Waveguides with a round cross-section can be used for beam shaping of laser diodes, making optical systems more compact and flexible. In combination with microfluidic components, biomedical applications are possible. To this end, we are currently working on ways of reducing the losses in the waveguides.

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THERMO-OPTIC SIMULATION FOR OPTICAL SYSTEMS

Task

Current commercially available raytracing software only enables thermal and mechanical influences to be taken into account to a limited extent in the design and optimization of optical systems. Especially in laser applications, the inhomogeneous heating of the optical components leads to a thermal lens effect and thus to a shift in focus during operation. To counter this, a configuration for an operating point or an operating range is conceivable which can be achieved by taking thermal effects into account in the simulation.

Method

For the coupled modeling of thermal and optical systems it is necessary to prepare a suitable interface between two different simulation tools. This was accomplished between the FEM software Ansys Workbench and the raytracing software Zemax, with a method that comprises several steps. The first configuration using raytracing software does not take thermal influences into account. The absorption values calculated by it are used as the starting condition for the thermal FEM simulation. The resulting temperature distribution is processed and interpolated to provide a refractive index profile for the raytracing program. An iterative process takes the interaction of the effects into account and optimizes the result.

Result

With the interface developed at Fraunhofer ILT the thermal effects in optical components can be simulated and transferred to a format that is understandable for raytracing. This interface has already been used for a laser crystal in slab geometry and calibrated using analytical solutions.

Applications

This interface can be used in the configuration of a zoom optic in order to compensate the thermal lens effect. Other applications can also benefit from this calculation method. In particular in multi-kW laser systems with high temperature and refractive index gradients at the operating point, coupled thermo-optic simulations can optimize the configuration.

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3 Slab laser with thermal lens compensation unit.
OPTICAL PARAMETRIC GENERATION OF INFRARED LASER RADIATION

Task

An optical parametric generator (OPG) was developed and built to generate laser radiation in the infrared spectral range. This tunable system produces wavelengths between 1.7 μm and 2.8 μm at an average power of up to 20 W and can therefore be used as a pump source for further conversion stages or amplifiers.

Method

A ps laser at 1064 nm is used as the pump source. At a repetition rate of 20 MHz an average power of 25 W is available. The pump beam is focused into a 50-mm periodically poled lithium-niobate crystal (PPLN) by means of a suitable optical system. The poling period of the crystal is selected such that the quasi-phase-matching for the optical parametric generation of the signal and idler wave is fulfilled in the MIR (mid infrared). The output wavelengths of the radiation produced can be tuned with the temperature of the PPLN crystal, in this case between 1.7 μm and 2.0 μm (signal) and 2.3 μm and 2.8 μm (idler), respectively. Particular attention has to be paid to homogeneous temperature distribution in the crystal as this is essential for achieving high conversion efficiency.

Result

Depending on the output wavelengths, more than 77 percent of the pump power was converted into the infrared. The signal and idler waves reach average powers of 12.5 W and 6.8 W, respectively, with output fluctuations of less than 1 percent. The efficiency achieved and the output stability depend considerably on the design of the crystal oven. The spatial pump beam parameters and the pump beam stability are also key factors.

Applications

The developed laser beam source delivers the input waves for further non-linear conversion stages to generate broadband tunable laser radiation in the MIR. The spectral range in the mid infrared between 5 μm and 12 μm represents the fingerprint region in material analysis. Absorption bands are present in this region which make it possible to differentiate materials.

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CHARACTERIZATION OF PPSLT CRYSTALS FOR EFFICIENT FREQUENCY DOUBLING OF INFRARED LASER RADIATION

Task

Periodically poled crystals are used for frequency doubling of pulsed infrared radiation. Through the principle of quasi-phase-matching, very high effective non-linearities can be used for this purpose. What’s more, the radiation is not subject to walk-off and as a result long crystals can be used without negatively affecting the beam quality. The conversion efficiency, however, depends considerably on the quality of the poling structure produced. Periodically poled stoichiometric lithium tantalate (ppSLT) exhibits a higher resistance to photorefractive damage than lithium niobate. In this study ppSLT crystals from four different manufacturers are compared under reproducible conditions.

Method

All the crystals used have a length of 10 mm and a poling period of 8 μm for frequency doubling from 1064 nm to 532 nm and are operated in a thermostat for the tests. An adjustment mechanism permits high-resolution translation of the sample along the transversal and the longitudinal axis and detuning of the angle of incidence in polar and azimuthal direction. A microchip laser with an average output power of 40 mW and a pulse peak output of 6 kW is used as the pulsed radiation source. For the case of optimal phase matching and central positioning of the laser beam with respect to the crystal aperture the conversion efficiency for various focus radii is measured. In addition, the temperature and angle acceptances as well as the transversal homogeneity of the crystals are examined.

Result

The maximum conversion efficiencies achieved are, depending on the crystal, between 60 percent and 80 percent. Additionally, distinct differences in the homogeneity of the poling structure were found. The variances in conversion efficiency along both transversal coordinates are between 1 percent and 30 percent. The temperature and angle acceptances exhibit deviations of 1 percent and 10 percent from the theoretical reference values.

Applications

Converters based on ppSLT can be used up to an average output power of a few watts for doubling the frequency of laser radiation of low pulse power in the visible wavelength range.

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2 Periodically poled stoichiometric lithium tantalate.
COMPACT SHG STAGE FOR PULSED FIBER LASERS

Task

The aim of the study presented is to develop a compact module for converting infrared fiber laser radiation with moderate pulse power to the green wavelength range.

Method

A commercially available fiber laser with a wavelength of 1064 nm, a pulse output power of 25 kW and an average power of about one watt is used as infrared radiation source. At these laser parameters periodically poled crystals can be advantageously used for frequency doubling. To develop an optimum design of the converter module the spectral, spatial, temporal and energetic properties of the laser are determined experimentally and serve as input variables for simulating the non-linear process. On the basis of the modeling, a suitable working point exhibiting high conversion efficiency and low loading of the components is identified for operation. This is used to configure a compact optical system for imaging the fiber laser radiation in the non-linear crystal. The converter module can be used without optical isolation of the fiber laser. The non-linear crystal is mounted in a compact thermostat, ensuring that the temperature stability is distinctly better than 0.1 °C.

Result

The fiber laser is operated at a repetition rate of 50 kHz. In the infrared, up to 1.2 W of output power is produced with close to diffraction-limited beam quality and a spectral bandwidth of less than 140 pm. The pulse duration is about one nanosecond. The SHG stage delivers more than 500 mW of output power at 532 nm with a conversion efficiency of 50 percent and diffraction-limited beam quality.

Applications

The development presented here expands the applications range of pulsed fiber lasers to meet requirements in remote sensing, medical engineering and marking. The results can also be applied to the frequency conversion of innovative solid-state lasers with similar pulse parameters.

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**ND:YLUGG-BASED LASERS FOR H₂O DIAL SYSTEMS**

**Task**

Knowledge of the global distribution of water vapor densities in the atmosphere is an important basis for climate research and numerical weather forecasting. With the aid of satellite-based DIAL systems (Differential Absorption LIDAR), gas densities can in principle be determined with high lateral resolution. The requirements for a water vapor DIAL instrument have been investigated in an ESA study bearing the name WALES. Results indicate that for low error measurement in the entire troposphere spectrally narrowband laser pulses with a line width of less than 160 MHz, a pulse energy of about 70 mJ and a pulse duration of less than 200 ns have to be generated at four different vacuum wavelengths in the range from 935.561 nm to 935.906 nm. Tunable beam sources based on Ti:sapphire or OPO technology exhibit comparatively low efficiency and high complexity. As an alternative, various mixed garnets Nd:YₓLu₃₋ₓGa₅O₁₂ (0 ≤ x ≤ 3) are to be studied for the direct generation of these wavelengths.

**Method**

Crystals with different mixing ratios x were examined spectrally and deployed in a Q-switched resonator. Experiments were then performed in longitudinal single-mode operation. The laser crystals used were grown for the first time by the crystal research institute FEE in collaboration with Fraunhofer ILT.

**Result**

With the mixed garnet Nd:YₓLu₃₋ₓGa₅O₁₂, a tuning range (vacuum wavelength) of 935.4 nm to 936.0 nm was demonstrated in longitudinal single-mode operation. Using a Q-switched resonator pulses with a pulse energy of 6.6 mJ were generated in transversal fundamental mode with a repetition rate of 100 Hz. The optical efficiency (pump output to laser output) was 10% in longitudinal multi-mode operation. These results provide the basis for further energy scaling in the 70 mJ range using INNOSLAB amplifier stages.

**Applications**

In addition to using an Nd:YLuGG-based system within the WALES project, application-specific wavelengths can be generally addressed by adapted laser crystals. This, however, requires precise analysis of the crystal properties and an adapted design of the laser system.

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Task
Laser ablation techniques used to produce three-dimensional microstructures by area scanning and sublimation or melting of the material exhibit a very high degree of flexibility in terms of the structures that can be produced and the materials that can be processed. Owing to the limited average power of industrial ps lasers, however, these techniques have so far only become established for small ablation volumes, e.g. in microtool technology or in printing with plastic rollers or special coatings. The aim of the PICOFLAT project is to make it possible to use laser ablation for structuring large components made of virtually any material by developing a high-power picosecond laser with an average output power of up to 400 W.

Method
In cooperation with LUMERA LASER GmbH a MOPA laser system consisting of a master oscillator developed by LUMERA and an INNOSLAB power amplifier developed by Fraunhofer ILT is built. The power amplifier is of compact design and offers a parameter combination of pulse repetition rate, pulse energy and average output power which can be selected over wide ranges. The use of Nd:YVO₄ as amplifying medium enables the output power of a broad range of ps and ns lasers available on the market to be amplified in the range above 100 W.

Result
Using a double-side pumped INNOLAB amplifier stage and starting from an input power of less than 3.6 W the following consistently stable values (f = pulse repetition rate, P = average output power, E = pulse energy) are achieved:
- f = 500 kHz, P = 160 W, E = 320 μJ
- f = 1 MHz, P = 225, E = 225 μJ
- f = 10.7 MHz, P = 250 W, E = 25 μJ
A beam quality of M² < 1.5 is measured over the entire range of parameters.

Applications
- Structuring of injection molding tools for producing decorative and haptic surfaces
- Structuring of large-area three-dimensional molding tools e.g. for plastic parts
- Structuring of embossing rollers
- Volume ablation of glass

The work was funded by the German Ministry of Education and Research (BMBF) under reference number 13N9571.

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MONOLITHIC, CONTRA-DIRECTIONALLY PUMPED LINEAR FIBER AMPLIFIER WITH VARIABLE PULSE DURATION AND REPETITION RATE

Task

The development of pulsed fiber amplifier systems in various pulse duration ranges from a few picoseconds up to microseconds and repetition rates ranging from single kilohertz to megahertz is funded by the German Ministry of Education and Research (BMBF) as part of the FAZIT research project. Within this framework a single-stage linearly polarized fiber-integrated linear amplifier with a small form factor in single mode beam quality is to be developed.

Method

The temporally modulated signal with a wavelength of 1064 nm is generated and controlled using a diode driver circuit and a single mode laser diode. For the purpose of amplification, the 5-meter active fiber is pumped contra-directionally, i.e. in the opposite direction to the signal, via a pump combiner with a wavelength of about 915 nm.

Result

A single stage, completely fiber-integrated demonstrator was built. Within the freely adjustable pulse duration of 10 ns to 1 μs and repetition rate of 20 kHz to 500 kHz it can be operated at duty cycles of 1:1000 to 1:25. An average power of up to 2 W and a pulse peak output in the kilowatt regime are attained. A degree of polarization of over 30 dB and a signal-to-noise ratio of more than 20 dB round off the required specification profile.

Applications

The fiber amplifier primarily serves as a seed source for further high-power amplifier stages, but can also be used as an independent beam source for material processing tasks such as marking and microstructuring as well as in metrology and medical technology.

This development work was funded by the German Ministry of Education and Research (BMBF) under reference number 13N9671.

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GAIN-SWITCHED FIBER LASER IN SINGLE SHOT OPERATION

Task

Pulsed fiber laser systems usually consist of linear fiber amplifiers in which the radiation from pulsed laser diodes is amplified in several stages or Q-switched fiber lasers. A new and simple concept for generating pulses in the range of a few 100 ns, in particular at low repetition rates down to single shot operation, is embodied in the gain-switched fiber laser, in which the signal pulses are generated by pulsed operation of the pump sources.

Method

In addition to analytical and numerical modeling, this innovative approach was studied by building monolithic, gain-switched fiber lasers which are pumped by pulsed diode laser modules. To achieve single shot operation, an adequately powerful and brilliant pump source is needed which delivers with one pump pulse the required energy for taking the fiber laser so far over the threshold that the individual pulses are not affected e.g. by a residual inversion in the fiber.

Result

A gain-switched single mode fiber laser was built based on a pulsed and fiber-coupled module developed at Fraunhofer ILT and consisting of four geometrically superimposed and polarization-coupled broad stripe emitters. The fiber-integrated resonator consists of an active ytterbium-doped fiber with a core diameter of 6 μm and two fiber Bragg gratings. Single shot operation was verified with a pump energy of approx. 170 μJ and repetition rates of below 200 Hz. A pump power limited signal energy of 28 μJ was attained with a pulse duration of 250 ns and a slope efficiency of 44 percent. Thanks to the pulsed pump resonator, no amplified spontaneous emission (ASE) occurs, as a result of which the signal-to-noise ratio is over 50 dB and the spectral width of the signal at 1080 nm is less than 1 nm. Along with the low repetition rates of a few Hz, repetition rates of up to 50 kHz were also demonstrated with this concept.

Applications

By virtue of their simple and completely fiber-integrated design and their good beam quality at peak powers of a few hundred watts up to the kW range, gain-switched fiber lasers can be used in direct applications such as microdrilling and marking and also as seed sources for subsequent fiber laser amplifiers. This work was funded by the German Ministry of Education and Research (BMBF) under reference number 13N9671.

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1.1 KW YB:INNOSLAB FEMTOSECOND AMPLIFIER

Task

The advantages of ultra-short pulses for precision ablation are recognized in many areas of laser material processing. Wide industrial use, however, is impeded by economic factors, such as costs per watt, maintenance requirements and process speed. These impediments can be overcome by scaling the mean output into the range of a few 100 W without increasing system complexity.

Method

Pulse energies in the μJ range required for most applications can be attained with Yb:INNOSLAB amplifiers without chirped-pulse amplification. A pulse energy of 5.2 μJ has been demonstrated at a repetition rate of 76 MHz. A greater pump power density and therefore amplification not only increases the output power and efficiency of INNOSLAB amplifiers but also reduces the number of beam passes through the crystal and leads to larger beam cross-sections. The pump power density is limited by the power and brilliance of commercially available laser diodes and by thermal management in the amplifier. A further increase in power and pulse energy can be achieved either by increasing the width of the laser crystal or by cascading several amplifiers.

Result

The maximum pump output of the Yb:INNOSLAB amplifiers was increased by 50 percent to 1250 W by new laser diodes. The radiation of a Yb:KGW fs oscillator with a repetition rate of 20 MHz and an average output of 2 W is amplified in a Yb:YAG INNOSLAB amplifier with seven transits to an output of 620 W and a pulse energy of 31 μJ. The pulse duration is 636 fs and the beam quality M² < 1.5. By means of an additional transit in a second amplifier an average output power of 1.1 kW is attained with a pulse duration of 615 fs and a beam quality of M² < 3 in a linearly polarized beam. At a pulse energy of 55 μJ and a pulse peak output of 80 MW there were no signs of self-phase modulation.

Applications

Ultra-short-pulse lasers of high average output power and with a pulse energy of a few 10 μJ open up new applications in material processing, increase the throughput rate and make industrial use economically viable. In scientific applications they also increase the efficiency and power of non-linear processes, such as frequency conversion, optically parametric amplification and the generation of high harmonics, and thus improve the signal-to-noise ratio of measurements.

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PASSIVE ASSEMBLY OF OPTICAL COMPONENTS USING THE REFLOW SOLDERING PROCESS

Task

Mechanically and thermally stable joining techniques are required for satellite-based atmospheric research. The concepts used at present are conditionally suited for the implementation of satellite-based LIDAR (Light Detection and Ranging) systems. The stable, high-precision assembly of optical components such as lenses and mirrors by means of soldering creates the basis for the development of higher-power, robust laser systems. The active alignment needed during assembly is the biggest cost factor. Passive alignment can significantly reduce the costs for tolerance-insensitive optical components (less than 20 arc seconds angular tolerance).

Method

Where passive assembly techniques are applied, materials with low coefficients of thermal expansion must be used. An invar alloy is deployed in a soldering furnace specially designed for the reflow process. The components to be soldered are aligned by pneumatic positioning cylinders on adjustable stops and then soldered. Alongside furnace design, the soldering strategy also plays an important role. Solders with high melting points are unsuitable because both the accuracy of the soldering and the stress behavior of the optical components are negatively affected. BiSn-based solders exhibit a low melting point and low coefficient of thermal expansion, permitting reproducible soldering of glass components on metal substrates.

Result

With the assembly concept developed at Fraunhofer ILT, mechanically and thermally stable joints can be produced using BiSn solder. The reproducibility with regard to angular tolerance is 20 arc seconds. The results of environmental and shear tests highlight the potential of passive assembly using the reflow soldering process.

Applications

The applications spectrum for passive assembly extends far beyond space application. Especially in the manufacturing of medium size and large series, this technology offers advantages in terms of robustness, reliability and production cost.

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1 Components in the soldering furnace.
2 Optical component on an Al submount.
Among the many manufacturing processes in the technology field Laser Materials 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 materials 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 on-line 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.
## Invisible weld seams for joining transparent polymers

- Laser material deposition with variable track widths
- Process monitoring of laser metal deposition
- Process diagrams for high-deposition-rate laser metal deposition
- Resistance to thermal shock of protective coatings applied to magnesium alloys by laser cladding
- Surface digitization as a means of geometry data acquisition for the laser cladding processes
- Additive manufacturing of high-strength aluminum components
- Additive manufacturing of high strength oxide ceramics
- Inline quality assurance for large-scale additive manufacturing
- Processing optics for hybrid incremental sheet forming
- Laser polishing in tool and mold making
- Laser-based manufacturing chain for optics
- Structuring of functional surfaces using ultra-short-pulse lasers
- Three-beam interference structuring of glass
- Modification of metal surfaces
- Superhydrophobic surfaces
- Laser treatment of nanocoatings
- Optical system for multibeam laser structuring
- In-volume-marking of transparent materials
- Microstructured electrodes for lithium-ion batteries
- Synthetic microfilaments for use as sensors
- Laser drilling of PEEK for hypersonic tests
- High-speed laser drilling of silicon wafers for photovoltaics
- Laser soldering in photovoltaic cell manufacturing
- Electrical contacting of lithium-ion cells
- Laser-based hermetic packaging of LTCC ceramic housings

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- Laser welding of ice speed skates
- Laser production of vacuum insulation panels
- System for the remote laser cutting of metal sheet
- Highly dynamic 2D handling system
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- Flame cutting
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- Laser hybrid welding with high-power disk lasers
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- Corrosion protection by laser cladding of pure titanium
- Laser material deposition of internal contours

Invisible weld seams for joining transparent polymers
CUTTING POLYMER FIBER MESHES

Task

Many applications in the textile industry require the highly accurate and flexible production of polymer fiber meshes. A mesh consisting of polymer fibers, in which three individual threads each with a diameter of 0.22 mm form one fiber (whereby these fibers cross below an angle of 45°), is to be cut to a given contour. To achieve high shape stability the individual fibers along the contour line are to be connected with each other, which is not the case when mechanical separation techniques are used.

Method

(Far) infrared laser radiation is suitable for separating polymer materials because plastics exhibit a high degree of absorption in this spectral range. For this reason, the cutting technology was developed using a CO₂ laser emitting at a wavelength of 10.6 μm. Because the individual fibers are required to melt, the cut is performed with a defocused laser beam and a double pass so that enough melt volume is produced at the fiber ends cut by the laser.

Result

The result from the process tests clearly shows that the three polymer fibers arranged in parallel have melted and a small ball has formed at the fiber ends. Multiple irradiation along the cutting contour melts the fibers and keeps the cut edge stable in shape. Owing to the high degree of absorption and the resultant low penetration depth of the laser radiation in commercial polymers - spectrometer measurements indicate approx. 20 μm - underlying fiber layers cannot be bonded, which would have additionally increased the shape stability. The ball of melted material cannot be completely avoided as the stresses introduced in the fibers by stretching and cooling during melt spinning are removed after reheating and the fiber end solidifies to form a ball.

Applications

Polymer fiber meshes are often used in textiles and technical applications. As the fibers are specially made, their shape, thickness and length can be adapted to specific requirements.

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1 Detail: Fused polyester fibers during laser cutting.
2 Straight laser cuts in a woven mesh of polymer fibers 
   \( (v = 10 \text{ mm/s}, P = 10 \text{ W}) \).
LASER WELDING OF ICE SPEED SKATES

Task

Skates for long track race events have to meet particular requirements in terms of weight, rigidity and strength. Weight can be reduced by replacing the conventional brazed, clamped or bonded joints by welding. To ensure a strong weld on narrow joint cross-sections, the thickness and notch effect of the weld must be adapted precisely to the structure of the blade. Also, care must be taken not to restrict the scope for individual adjustments by the skater, such as by grinding and bending.

Method

Starting from the calculation of dynamic strength, various materials and their combinations were examined with regard to their suitability for laser welding. Because martensitic Cr-V steels lose their strength in the HAZ during welding, a combination of martensitic hardening steel as the tube (Reynolds 953) and a tungsten-alloyed, hardened chromium steel as the blade was used to make the skates. A number of prototypes were produced which after grinding and final assembly were given to professional long-track skaters for testing. The findings from the tests were applied to optimize geometry, equipment and production.

Result

The required high strength of the welded connection was ensured by optimized pairing of the materials constituting the tube and blade. The reports from the test skaters indicated that there was a problem with regard to residual waviness (weld distortion). As a result, the clamping concept and finishing process were improved. The blades are currently being produced by a Dutch firm. After final assembly they are distributed by an American company as the Record LT long track skate.

Applications

Although originally planned as a product in the mid-range price segment for amateurs, the new generation of skates is popular with professionals. In 2009 Dutch skater Bob de Jong set a new track record over 3,000 m of 3:44 in Berlin on Record LT skates. He also came second in the 5,000 and 10,000 m events.

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3 Macrosection of a weld seam.
LASER PRODUCTION OF VACUUM INSULATION PANELS

Task

Vacuum insulation panels (VIPs) represent an economic and effective solution for reducing energy consumption in large industrial, commercial and sports buildings of lightweight steel construction. In this connection Fraunhofer ILT has developed a laser technique for producing VIPs.

Method and Result

For the development of an economically viable production process, the deep drawing method was compared with the folding technique. Owing to the thinness of the stainless steel foil it was not possible to produce a fault-free rectangular shape by deep drawing. While the pleated structures made it difficult to achieve a faultless seam, cracks also formed in the corners of the material. As an alternative, a folding method was developed which meets the technical requirements that exist for VIPs, such as vacuum-tightness. At the same time, this technique is less expensive to implement than the deep drawing method. The cutting and welding process was optimized and prototype VIPs were made using the multifunctional cutting and welding head from the company Laserfact. Thanks to the innovative combination of laser cutting and welding, the VIPs exhibited excellent technical characteristics as a cost-effective production technique. A 4-kW fiber laser from the company IPG was employed as the beam source.

The VIPs were produced using silicic acid as filler material. With evacuated insulation panels thermal conductivities can be attained which are one to five times lower than those of conventional insulation materials. To this end, a thick-walled panel material (1 mm) is produced as the carrier structure (outer panel). This carrier structure is completed with thin stainless-steel foils (0.1 mm) to encapsulate the element for introduction of the filler material. The panels are evacuated at a pressure of $10^{-2}$ mbar. The welding speed was $4 - 10$ m/min at a maximum laser output of 2.5 kW.

Applications

The production technique covers a wide range of applications. The VIPs can be used wherever insufficient space is available for conventional insulation materials, for example in refrigerators, buildings requiring renovation, large gates and doors on commercial buildings and halls for sports events.

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1 Laser-welded vacuum insulation panel.
2 Microsection.
SYSTEM FOR THE REMOTE LASER CUTTING OF METAL SHEET

Task

Die Complex metal components such as interconnection grids, lead frames and chip carriers are produced today largely by punching, etching or galvanoforming. All these technologies require complex and expensive preparation and tool systems, and as a result cost-efficient component production is possible only in large volumes.

By contrast, laser cutting reduces delivery times to just a few days. As the laser is a low-wear tool, the parameters for the path contour, once defined, do not have to be reset. What’s more, customer-specific design changes can be easily implemented without having to make new tools.

Compared with punching, however, laser cutting is not at present able to achieve the cycle times required for series production. The main speed-limiting factor is not the cutting process itself but the inadequate dynamics of the drive system used.

Result

In remote laser cutting mechanical movement axes are not needed. The beam is deflected by a galvanometer scanner. With suitable optical systems kerfs of 25 μm are achieved, enabling precision parts to be produced. The material is removed without cutting gas support. At present, the production cell is equipped with a 1 kW fiber laser and a scanner for deflection speeds of up to 10 m/s.

Applications

The modularity of the system permits its use in various machining processes. Apart from cutting, these include drilling and welding. Depending on the handling equipment deployed, applications range from single part production to small series manufacture.

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Die Complex metal components such as interconnection grids, lead frames and chip carriers are produced today largely by punching, etching or galvanoforming. All these technologies require complex and expensive preparation and tool systems, and as a result cost-efficient component production is possible only in large volumes.

By contrast, laser cutting reduces delivery times to just a few days. As the laser is a low-wear tool, the parameters for the path contour, once defined, do not have to be reset. What’s more, customer-specific design changes can be easily implemented without having to make new tools.

Compared with punching, however, laser cutting is not at present able to achieve the cycle times required for series production. The main speed-limiting factor is not the cutting process itself but the inadequate dynamics of the drive system used.

In remote laser cutting mechanical movement axes are not needed. The beam is deflected by a galvanometer scanner. With suitable optical systems kerfs of 25 μm are achieved, enabling precision parts to be produced. The material is removed without cutting gas support. At present, the production cell is equipped with a 1 kW fiber laser and a scanner for deflection speeds of up to 10 m/s.

The modularity of the system permits its use in various machining processes. Apart from cutting, these include drilling and welding. Depending on the handling equipment deployed, applications range from single part production to small series manufacture.

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HIGHLY DYNAMIC 
2D HANDLING SYSTEM

Task

Highly brilliant solid-state lasers make it possible to perform laser machining operations at very high speed. At 4 kW laser power output 1 mm steel plates can be cut at a speed of 100 m/min and aluminum plates at over 150 m/min. To utilize the potential of fast speeds for complex contours, highly dynamic systems are required. Typically the cutting head is moved in at least one axis relative to the workpiece because this accelerates lower masses than with a moving workpiece. This arrangement is, however, unsuitable for process developments where observation of the process is desirable.

Method

In order to be able to observe highly dynamic processes, a system with a stationary optic is set up which offers optimal accessibility above and below the observation zone for sensor equipment such as high-speed cameras. The workpiece is moved in both axial directions by double axes with linear motors.

Result

The system is designed for a maximum speed of 300 m/min with an acceleration of 4 g. The processing field measures 500 x 500 mm². For precise processing at high speeds the path accuracy is +/- 15 μm. Position-dependent activation of the laser has a delay of less than 10 μs.

Applications

The system can be used to develop improvements in cutting, welding and surface engineering, e.g. structuring. Apart from the applications in high-speed processing, development work in the machining of heavier-gauge plate thicknesses at reduced speed can also benefit from its diagnostic potential.

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**ANALYZING THE THERMAL BEHAVIOR OF LASER PROCESSING OPTICS**

**Task**

When used with multi-kilowatt lasers, laser processing optics exhibit a transient, thermally induced shift in focus position, which disrupts the stability of processes or requires additional reserves of processing speed. The causes of the shift in focus position are the temperature dependency of the refractive index, refractive index gradients and thermally induced expansions and stresses in the optical materials and housings. For the development of thermally stabilized optics the main factors of influence are to be identified by analyzing the thermal behavior.

**Method**

By means of a detailed diagnosis of the focused laser beam on a fiber laser with up to 4 kW laser output and temperature measurements taken on the optics and housings, the temperature behavior of various processing heads is analyzed.

**Result**

With the measurements conducted it was possible to determine the time characteristic of the focus position for various optics as a function of the laser output. Depending on the configuration, type and condition of the components, focus shifts of up to one Rayleigh length were measured at 4 kW laser output. Knowledge of the focus shift and temperature fields of the optics provides the input variables for detailed analysis of the influences exerted by the optical material, cooling and optical parameters such as the size of the laser beam, the output and the focal length using ray-tracing calculations. These provide the basis for the development of thermally stabilized processing optics.

**Applications**

Processing optics need to achieve highest possible thermal stability. This applies wherever they are used, because uncontrolled transient thermal influences take up some of the tolerances within a process window and thus lead to a loss of performance. Thermal stability acquires particular significance in high-performance processes such as high-speed cutting at high laser output and when using lasers of very good beam quality such as single-mode fiber lasers.

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2 Temperature field on a protective glass cover.
Task

Process gases are used in many areas of production to protect optical devices from contamination. They are also used as primary processing tools, e.g. in flame cutting. Many of these applications involve a flow of reactive gases which either react with atmospheric oxygen or with the material being processed. For this reason, numerous inquiries are received for the representation of this reaction chemistry within the gas flow and how the two influence each other.

Method

The gas flow itself is simulated by numerically solving Navier-Stokes equations, which for a reactive gas flow are supplemented by reaction equations based on an Arrhenius law for the reaction rate. In the case of flame cutting, a block nozzle consisting of three concentric parts is modeled as the source for the reactive gas flow. A jet of high-purity oxygen is introduced in the inside channel at a comparatively high pressure, while combustible gas and oxygen are added at much lower pressures in the two outside channels.

Result

It was shown that the jet of cutting gas was lengthened by combustion in the enclosing jet of heating gas. The length of the entire jet of gas observed in the simulation thus matches very well with the experimentally observed length, especially if the turbulence of the gas flow is also taken into account (by means of turbulence modeling ). The distributions of the reaction product CO2 and of the absolute flow speed are shown here by way of example.

Applications

The reactive gas flow simulation can be applied to all processes which use e.g. oxygen as process gas. It provides information about the distributions of flow speed, pressure, density (jet shape), the proportion of individual species, burnoff, and the thermal energy released by combustion.

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FLAME CUTTING

Task

Flame cutting is a method used to cut large pieces of metal (up to several meters) which has been prevalent in steel processing (especially in steel mills) for many years. The increase in casting speeds in steel plants over recent years, however, calls for higher cutting speeds while maintaining the current level of cutting quality. Using process simulation techniques the potential of conventional flame cutting technology and conceivable improvements in cutting speed are identified in advance of technical implementation.

Method

The flame cutting simulation is performed by using a model of global balanced equations and has been successfully applied to local balances. This ultimately enables the geometrical shape of the kerf and the distribution of physical process variables over the kerf to be calculated (see Fig. 3). Because these models can be quickly evaluated they also enable representation in the form of a metamodel, which can represent the flame cutting process in its highly dimensional parameter space.

Result

The key dependencies for the maximum cutting speed, i.e. the nozzle diameter, nozzle pressure, oxygen purity and sheet thickness can be visualized, as can the physical limits, e.g. the separation limit (blue volume in Fig. 2). In addition to presenting the relationship between parameters and results, the simulation also indicates the significance of key process variables (e.g. burnoff). Potential is thus provided for designing new flame cutting technologies and is currently being studied.

Applications

The simulation of flame cutting can be used to analyze both oxyacetylene flame cutting as well as laser flame cutting. The method presented as an example showing the potential of flame cutting is widely applicable, for example to welding and drilling.

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2 Maximum cutting speed in the parameter space.
3 Calculated flame kerf.
SURFACE ROUGHNESS
IN LASER CUTTING

Task

Minimal roughness and the visual appearance of the cut edge are key quality requirements in laser cutting of 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 aim is 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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SELF-OPTIMIZING PRODUCTION SYSTEMS

Task

With every generation production systems offer improved characteristics. The demand for higher production rates and increased precision takes the production processes closer and closer to their physical limits. In such an environment even small deviations from the set parameters or material properties can lead to significant changes in the process outcome. The aim of the research work is to ensure reliable control of processes at the limits of their stability by using self-optimizing production systems.

Method

In the cluster of excellence at RWTH Aachen University research scientists are using various processes to find a generally valid solution for this task. Methods for describing production processes are being studied so that a quality-oriented closed-loop control system can be implemented at machine level.

Result

The work shows that the combination of process knowledge from experiments, simulations and physical descriptions can be used as a basis for self-optimizing systems. The approach of model-based self-optimization for production systems essentially comprises a component for optimization and a component for controlling process variables.

The connection between control variables and process outcome is non-linear and highly dynamic in most cases. This makes it difficult to prepare and use comprehensive models which cover all parameters and data points. Metamodels permit the combination of existing process knowledge in the form of derived, reduced models which provide machine-readable knowledge for self-optimization.

In process control the use of optimization results requires a modular system structure consisting of reconfigurable, information-processing sensor/actuator systems. They enable the production system to be adapted to the process status and production task in real time.

Applications

Model-based self-optimization addresses the control of production processes which are operating at their technical limit. Integration in a system network yields optimization potential for the entire production procedure.

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SELF-OPTIMIZING LASER CUTTING MACHINE

Task

As part of the Integrative Production Technology for High-Wage Countries cluster of excellence at RWTH Aachen University, Fraunhofer ILT is involved in the Integration of Self-Optimizing Setup, Monitoring and Control Systems in Production Processes project. The aim of the project is to develop a process-independent methodology that provides a better understanding of the laser machining processes used and to pave the way technologically for the self-optimization of production systems.

Method

The basis for the developments is provided by a detailed process analysis, a definition of the most sensitive process parameters and the identification of a suitable concept for the process sensor system. In self-optimization the metamodel is the central, methodically integrative tool for storing and processing available theoretical and experimental knowledge and for issuing optimized parameters to the process control system. The focus position, which is one of the most relevant process parameters, is subject to thermal changes in the optical elements. Despite the challenge posed by a stationary setting, the focus position opens up the possibility of exerting strong influence on the cutting quality, process robustness and cutting efficiency. A high-speed camera integrated coaxially to the laser beam provides the necessary process data for this.

Result

Various stages of self-optimization were developed on a TRUMPF TruLaser 5030 laser cutting machine as a function of the complexity of the closed-loop control system. In the first stage, external control of the focus position was implemented, enabling the position to be changed without affecting the functionality of the system. To achieve automated referencing of the focus position a concept for a set-up assistance function was developed and largely implemented. Using a high-speed camera the reference value belonging to the position of the minimal gap width is determined from numerous cuts at different focus positions.

Applications

The methodology developed in this project for laser cutting can be applied to a broad range of production processes, for example, injection molding, welding, weaving and milling.

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1 TruLaser 5030 laser cutting machine.
2 Close-up of a cut edge in stainless steel t = 6 mm.
METAMODELING

Task

The practical use of scientific results from computer simulation and experiments requires the combination of the individual simulations and experiments to create a complete entity in which the knowledge gained is made available for use and answering questions in the particular application concerned.

Method

For this purpose the technique of metamodeling is developed with the aim of presenting the results of simulation clearly in a way that allows them to be searched. The knowledge encapsulated in the model can be retrieved directly on a production machine and used for control purposes. The technique is demonstrated on the example of a laser cutting machine as part of the Integrative Production Technology for High-Wage Countries cluster of excellence at RWTH Aachen University. In addition to multidimensional function approximation methods, symbolic regression techniques are now also being used for metamodeling.

Result

Tools for visualizing response surfaces (MeMoViewer) were developed. Algorithms for the local inversion of the functional connection between parameters and criteria (inverse problem) have been implemented and can be retrieved on the laser cutting machine used by way of example in the project. On this basis a set-up assistance function will be added to the system.

Applications

The procedure described can be applied to any type of modeling for analyzing and optimizing a static or dynamic system.

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SENSORS FOR LASER CUTTING

Task

Lasers are an established tool for cutting stainless steel sheet and plate. Production systems with CO₂ laser beam sources have particular strengths for cutting heavier-gauge plate and rapidly producing contours on flatbed machines. Reliable process control for the necessary product quality, however, requires information about the current working point of the process. A process sensor system therefore has to provide relevant measured variables for active closed-loop control.

Method

In the cluster of excellence at RWTH Aachen University research scientists from Fraunhofer ILT are working on the development of a sensor system which observes the laser cutting process coaxially through the cutting head. From the signals measured, variables are extracted which make it possible to determine the working point of the process. This information is subsequently used for self-optimization of the cutting process.

Result

The sensor setup for CO₂ laser cutting consists of two components: an optical system with an area sensor and a system for image processing. The optical system couples process observation coaxially into the beam path of the laser and projects the zone of interaction through the focusing optic onto the sensor. By subsequent signal processing variables are extracted which enable a conclusion to be drawn as to the working point of the process. One of these variables is the gap width, which as a function of further parameters permits a conclusion to be drawn about the focus position.

For the purpose of self-optimization the signal processing function is extended to extract numerous variables using multiple algorithms. In combination with process modeling, a method has thereby been established to comprehensively determine the working point, enabling self-optimization of the process.

Applications

The process sensor equipment has been installed in an industrial production system. Together with model-based analysis of the measured variables, quality-relevant information is extracted which is used to control the process. The system is being transferred to other production processes on the basis of corresponding process models.

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1 Beam control component for integration with process monitoring.
2 Coaxially imaged cut gap.
ONLINE PATH MEASUREMENT OF THE TOOL CENTER POINT

Task

In laser materials processing, process parameters are of crucial importance. Only by adhering to tight parameter fields can high quality be ensured. Parameters such as output, focus position and kinematic variables play an important role.

Owing to the influence of mass inertia and the often large working distance between the processing optic and the workpiece, fluctuations in position and speed occur at the processing point. Up to now it has not been possible to directly measure the actual speed of the processing point relative to the workpiece so that this can be used as a control variable.

Method

A technique is being developed to measure the laser processing speed on the workpiece directly through the processing optic. The workpiece surface is visualized in the direct vicinity of the processing point by means of a camera system with connected image processing. Consecutive images are compared with each other. The shift between two consecutive images is determined. Together with the image rate of the camera and the imaging data this delivers the speed of the observed workpiece surface relative to the processing point.

Result

With the technique developed at Fraunhofer ILT the user receives precise feedback about compliance with the kinematic process parameters of the previously programmed NC path. This makes it much easier to optimally set and program the machine. In some processes, with little secondary radiation, the path contour can be measured during operation.

Applications

The technique can be used wherever direct measurement of a path trajectory is required, including processes where lasers are not used. In laser materials processing this covers all handling systems, scanner systems and combination machines.

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3 Speed measurement on workpiece surface before processing (hot-galvanized steel).
4 Online speed measurement during micro-ring welding.
**8-AXES SIMULTANEOUS PROCESSING WITH 5 MECHANICAL AND 3 OPTICAL AXES**

**Task**

In laser materials processing, the use of optical axes (laser scanner) in combination with mechanical axes (handling systems) is constantly growing. Solutions already exist for line-based processes with comparatively low feed speeds, such as cutting and welding. The situation is more difficult, however, in surface processing and at feed speeds of several meters per second, such as in laser polishing, cleaning, marking and structuring. Sometimes 5+3-axes processing is already used, in which the surfaces are “tiled”. But this approach has not yet been completely mastered. The quality of the work tends to be affected by joins which are visible between the separate areas. One way to avoid these joins is 8-axes simultaneous processing, in which the 5 mechanical and 3 optical axes work simultaneously.

**Method**

To make it easier for users to apply 5+3-axes processing as well as 8-axes simultaneous processing, a CAM-NC data chain was developed. Users can plan the laser path using their usual CAM system, e.g. for milling. A technology processor, which also incorporates the functionality of a postprocessor, transforms the laser paths into the moving coordinate system of the mechanical axes and generates the NC programs for mechanical and optical axes. These NC programs can then be transferred directly to a suitable machine.

**Result and Applications**

The CAM-NC data chain was successfully tested with the CAM systems PowerMill and CATIA V5 for 5+3-axes processing as well as 8-axes simultaneous processing. The import function for NX is in preparation. Testing is currently focused on the synchronized control of the superimposed axes systems. Initially, 5+3-axes processing and 8-axes simultaneous processing are used for laser polishing. Further possible applications include laser cleaning, marking and structuring.

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1 5+3-axes processing with 3 separate areas, black arrows indicate center and orientation of the areas.  
2 8-axes processing without separate areas; main path of the machine marked black.
LASER HYBRID WELDING WITH HIGH-POWER DISK LASERS

Task

Now that laser MAG hybrid welding using CO₂ lasers and off-axis torches has become established in industrial production, the next step is to transfer this technology to fiber-coupled laser systems. As with the use of CO₂ lasers, the focus here is on a stable, robust machining process, which with a wavelength of 1 μm exhibits a much narrower process window. Owing to limited accessibility, compact laser hybrid welding units are increasingly required. Comparative tests have been conducted on off-axis torches in steel plate welding using a compact hybrid welding head developed at Fraunhofer ILT.

Method

The tests were performed using a 10 kW disk laser to make butt welds in welding position PA with optimized parameters, and a hybrid welding head developed at Fraunhofer ILT.

Result

The weld seams produced by the Fraunhofer ILT hybrid head exhibited a smooth upper bead without any undercuts and a flowing gentle transition from the bead to the base material, along with a regular seam cross-section of acceptable convexity. By contrast, welds produced using off-axis torches exhibit an upper bead that is increasingly drawn upwards and of hemispherical shape, which increases the risk of notch effect. Owing to the high laser power and speed, a slim weld seam forms. The consumption of filler material is, however, about the same as in the lower speed range.

Applications

The results can be transferred to hybrid welding applications in shipbuilding, container manufacture, heavy vehicle production (yellow goods), pipeline construction, the manufacture of tubular products and steel sections. This welding technique can also be used on thin metal sheets, e.g. to make tailored blanks.

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3 Welding using Fraunhofer ILT head, 
vₜ = 2 m/min.
4 Welding using off-axis torch, 
vₜ = 2 m/min.
AUTOMATION AND ACCELERATION OF HEAT SOURCE CALIBRATION IN LASER WELDING

Task

Commercially available software for simulating laser welding does not always incorporate all the relevant physical phenomena. Energy coupling, for instance, is in most cases described by a parameterized volume source. The parameter values are determined iteratively (i.e. in several steps) and are adjusted on the basis of trial and error until the calculated and experimental temperature values agree sufficiently. In each step a partial differential equation (PDE) is solved in three spatial dimensions, and using conventional finite element (FE) methods this entails considerable calculation effort. What’s more, the adjustment of the parameters in each iteration step requires a long phase of evaluation and sound expert knowledge.

Method

The aims of the project are to automate and accelerate this calibration process while achieving the same reliability as the established method. Optimization techniques are used to adjust the parameter values as well to assess adequate accuracy between the simulation and the experiment. Numerical model reduction methods such as reduced bases (RB) and proper orthogonal decomposition (POD) are used to solve the PDE.

Result

Rapid, automated and reliable determination of the new parameter values in each iteration step removes the need for an extended phase of evaluation by an expert. Also, both model reduction methods yield a considerable time-saving compared with conventional FE methods. The RB method delivers an estimate of the reduction error, but compared with the POD technique requires more effort in the initialization phase.

Applications

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

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1 Simulation of workpiece temperature.
2 Workpiece cross-section after welding.
LASER WELDING OF ELECTRICAL CONNECTIONS ON DAB SUBSTRATES

Task

In power electronics, high-performance semiconductor elements are mounted on the copper layer of direct copper bonded (DCB) substrates and connected up to create e.g. DC/AC converters in power modules. For external contacting, load connections are joined to the metallization of the ceramic by thick wire bonding, soldering or welding. As an alternative to the copper used up to now, the intention in future is to use direct aluminum bonded (DAB) substrates with Al metallization. The substrates consist of a 300 μm aluminum layer overlying an AlNi layer, with an additional aluminum layer on the reverse side, to which the Al load connections have to be joined. The load connections can be up to 500 μm thick. The cross-section of the load connection geometry has to be attained by the joint in order to ensure adequate current carrying capacity. The ceramic must not be damaged by welding.

Method

DAB substrates with an additional nickel and gold layer were used for the process development. To obtain a suitable weld cross-section without excessive weld penetration, the load connection is fillet-welded to the aluminum layer. Rapid melting of the gold layer and the aluminum is achieved by using a disk laser of high beam quality. In addition, the seam and the weld cross-section are widened by rapid local power modulation.

Result

By using a disk laser and local power modulation the load connections can be welded reproducibly and reliably. Weld penetration into the aluminum layer of the substrate is low and an adequate cross-section is achieved.

Applications

The main area of application is the electronics industry, which produces power modules in large quantities. The technique can also be generally used for joining metal-coated ceramics.

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3 DAB substrate with welded lead frame.
4 DAB substrate with welded load connection.
WELDING COPPER PLATE

Task

Copper materials present a major challenge for any welding process owing to their high thermal conductivity. Laser welding encounters a further difficulty because of copper’s comparatively low degree of absorption in the IR wavelength range. The return reflections this causes are a potential source of damage to the optical system, beam guidance and laser source. For this reason, only a few systematic tests have been conducted and hardly any industrial applications exist – in particular beyond 1 mm penetration depth. In view of the growing industrial demand for cost-efficient joining techniques for copper applications in energy, electrical, solar and automotive engineering, Fraunhofer ILT is developing laser methods to facilitate the reliable welding of copper materials.

Method

With their high power outputs and excellent beam qualities, disk and fiber lasers open up previously unobtainable process regimes. Their use for copper welding in industrial applications is to be brought closer to reality by determining the fundamental scaling laws, using models to acquire an understanding of the process and developing the process rules for welded connections.

Result

New findings were gained about the real launch efficiencies and temperature-dependent material variables by comparing the empirically determined scaling laws with model calculations. At suitable parameter settings the tests indicate a typical launch efficiency of approx. 50 percent, even for a laser wavelength in the range of 1 μm, i.e. without frequency doubling to the green. In addition, analytical correlations were determined on the influence of laser power and intensity, as well as feed and material, on the penetration depth and seam width. Finally, numerous practical welding operations were demonstrated on similar and dissimilar copper materials (deoxidized copper, CuNi, CuSn and CuZn alloys).

Applications

For applications in electrical engineering and power electronics the process developed provides a high-performance technology that delivers welds offering long-term stability and resistance to high current. This will make it possible to dispense with screwed and clamped connections.

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1 4-mm CuNi3Si1Mg, welding speed 4 m/min.
2 9.5-mm-deep lap welding through CuNi3Si1Mg sheets.
3 4-mm CuSn6 on 2-mm CuZn37, welding speed 2.5 m/min.
SYNCHRONIZED QUALITY ASSURANCE IN LASER BRAZING

Task

Signals from the laser process must be as robust as possible when used for the online quality assurance of laser processing techniques. A single measuring method is often not enough, as the number of relevant characteristics provided by one signal is usually limited. The pseudo-error rate can, at the same time, be improved by a combined analysis of two signals. A synchronized observation of the laser process in different spectral ranges therefore represents a robust method of online quality assurance. This is demonstrated here using the example of laser brazing.

Method

The laser brazing process is recorded in the visible spectral range (VIS) using monochromatic external illumination. A real image of the process zone is obtained (Fig. 4). At the same time a second camera records the thermal radiation of the process as a broadband image in the near-infrared spectral range (NIR) (Fig. 5). The cameras are synchronized by an external clock.

Result

While the VIS image indicates the feed speed, wire position and geometrical dimensions of the seam, the NIR image provides information on the heat distribution of the two joining partners, the occurrence of pores (Fig. 5), wetting on one side and the position of the laser spot. Quality-relevant conclusions can be drawn by comparing NIR and VIS features. For example, the position of the laser spot (symmetry in the NIR image) relative to the position of the wire (VIS) has a decisive influence on the wetting behavior of the joining partners and thus on the occurrence of seam defects.

Furthermore, the algorithms for quality assurance gain a higher level of robustness through the combined analysis of both camera images.

Applications

The system makes it possible to conduct online quality assurance during laser brazing of two-part auto tailgates. Future applications include laser metal deposition and the SLM process. The heat distribution provides information about the geometry of the molten pool as well as about the quality of the microstructure.

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**ABSORBER-FREE LASER WELDING OF TRANSPARENT POLYMERS**

**Task**

In conventional laser welding of polymers, it is usual for one of the two components to be joined to contain an additive that absorbs electromagnetic radiation at specific frequencies. In most cases, the intrinsic color of the absorber has a noticeable effect on the appearance of the welded part and of the weld seam, which restricts the range of applications. By using a laser wavelength adapted to the properties of the material in conjunction with innovative laser-exposure strategies, it is now possible for the first time to join polymers without absorbers and still benefit from the advantages of a laser weld seam.

**Method**

Until now, it has been usual to join polymers using a diode laser emitting at a wavelength of between 800 and 980 nm. Instead, the new method for the laser welding of transparent thermoplastics uses novel laser sources emitting at wavelengths of 1400 nm or higher. By using high-numerical-aperture optics to focus the beam, it can be ensured that its intensity only exceeds the threshold required to melt and join the polymer materials inside the joining layer. The beam intensity on the surface of the part is so low that it causes no damage to the welded part. The thermal characteristics of the process can be optimized by employing the TWIST® method to locally modulate the timing and amplitude of the laser output.

**Result**

With the use of new laser sources operating at wavelengths of 1400 nm or higher in combination with innovative laser-exposure strategies such as TWIST®, laser welding can now be used to join transparent polymers without having to modify the properties of the material or add absorbers. Medical device technology thus has access to a new manufacturing process that allows the specific advantages of laser welding to be used without restriction for joining thermoplastic materials.

**Applications**

The availability of a laser joining technique that requires no additives and creates no contamination opens the way to new production engineering solutions for medical devices and bioanalytical systems in which the transparency of the integrated microfluidic components is essential to their function of constantly monitoring blood flow, drug dosage, etc. The new technique is also suitable for use in the assembly of plastic optical components, because the properties of the polymer materials are not altered by the addition of absorbers.

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1 Uninvisible weld seams for joining transparent polymers.
Result

The radiation field is divided into bundles of rays, and a so-called beam tracing method is used to calculate the intensity at each point within the internal volume of a bundle from the divergence of its outer rays. This provides the balance between available and required power and allows the geometrical shape of the welding keyhole to be predicted.

Applications

In addition to its use in the simulation of laser welding processes, this model can also be used to simulate other types of material processing. The described beam tracing method can be used to calculate radiation fields in all areas of laser material processing. It provides a means of calculating continuous radiation fields which is much faster than comparable wave-optical methods.

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Task

The way in which the geometrical shape of a weld seam is formed during laser welding is determined to a large extent by the distribution of absorbed laser power at the surface of the workpiece. The task of this project, thus, consists of creating a beam propagation model for the laser welding process and integrating it in the simulation of the process.

Method

A stationary model is used to predict the geometrical shape of the welding capillary formed during laser welding, where the materials exist in vapor phase, thereby allowing penetration of the laser beam. In this model, correlations are established between the local absorption of power by the medium and the local laser power required by the process (for heating, melting and vaporization). The distribution of the available laser power is a priori unknown and depends on reflections from the walls of the welding capillary, which in turn depend on the geometrical shape of the welding capillary. Geometrical optical equations are, therefore, used to determine the extent to which the absorbed power increased due to focusing and defocusing of reflected radiation at the curved surface of the welding capillary.
COMPUTER CLUSTER FOR HIGH-RESOLUTION SIMULATION CALCULATIONS

Task

The numerical simulation of complex problems in laser material processing requires the use of cluster systems with very high computation power.

Method

With funding provided by the Land of North Rhine-Westphalia, the new »Center for Nanophotonics « in Aachen was equipped with a heterogeneous computer architecture consisting of multi-core processors and special systems that allow massively parallel processing applications to be executed on graphics processor units (GPUs), together with redundant storage systems for large quantities of simulation data.

Result

The installed cluster system has 376 CPUs and 8 graphics processor systems with a total of 1920 GPUs. It has 1.86 terabytes of main memory and 67 terabytes of hard disk storage, including 20 terabytes on redundant arrays of independent disks (RAIDs). A high-speed InfiniBand network is used for data transfer within the cluster.

Applications

The new high-performance computer system enables complex problems in laser material processing to be simulated at high resolution in a short processing time. Typical applications include the simulation of gas flows in gas-cutting nozzles using the discontinuous Galerkin method, the simulation of laser propagation using finite-difference time-domain (FDTD), Fourier and beam tracing methods, linear stability analysis of the melt dynamics during laser cutting operations, and molecular dynamics simulation of laser ablation with ultra-short pulses.

The heterogeneous architecture of the computer cluster, with its multi-core systems based on different architectures and special systems equipped with graphics processor units, enables the most efficient processor configuration to be used for each specific type of simulation.

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1 High-performance computer system.
2 High-resolution simulation of cutting gas flow.
Task

Due to operational wear of gas turbine components - e.g. blade tips - repairs may become necessary. Laser cladding is frequently chosen as the method for such repairs, due to its specific advantages such as low heat input and near-net shape material deposition. Within the Innovation Cluster »Integrative Production Technology for Energy-Efficient Turbo Machinery - TurPro« process chains for different repair tasks of turbo machine components are being developed in collaboration with Fraunhofer IPT. As an example an automated process chain for repairs of blade tips by laser cladding is being demonstrated with Fraunhofer IPT.

Method

Within the repair process chain several consecutive steps are necessary: measurement of geometrical data by laser scanning of the worn blades and digitization of the whole blade, milling of the blade tip as a preparation for laser cladding, laser cladding of the blade tip, followed by a scanning and digitization of the cladded blade tip in order to mill the tip to the final geometry. Throughout all process steps a uniform designed clamping device is used as reference system (see Fig. 3). In order to integrate the single process steps into a process chain a uniform clamping device as well as integrated data management and tool path generation (CAx module) are used.

Result

In collaboration with Fraunhofer IPT, the repair process for blade tips of gas turbine blades was integrated into a demonstration process chain. The necessary process parameters and laser cladding strategies were incorporated in the CAx module for laser cladding (see Fig. 4).

Applications

The demonstrated process chain can be used for a wide variety of different components and repair tasks. It can also be adapted for additive manufacturing. Through the integration of all process steps into a process chain all software modules for automated repairs involving laser cladding operations are at hand.

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3 Repaired gas turbine blade tip in clamping device.
4 Recontoured gas turbine blade tip.
**CORROSION PROTECTION BY LASER CLADDING OF PURE TITANIUM**

**Task**

The corrosion resistance of materials is of particular interest to the chemical engineering industry, where highly corrosive media are processed and stored. The most demanding applications often require the use of metals such as tantalum or titanium in their pure form. The high price of these commodities on the world market often prohibits their use in the manufacture of large components such as heat exchangers. The aim of this project is to provide the required corrosion resistance by coating low-cost steel materials with a protective layer of these more resistant metals.

**Method**

The laser cladding process used to deposit a titanium layer on a steel substrate results in the formation of brittle intermetallic phases in the dilution zone. By adapting the process parameters, the size of this zone can be minimized. It is also important to limit iron dilution in the layer, so as to ensure a sufficiently pure coating with high corrosion resistance properties. Another essential requirement is that the melt pool must be adequately shielded against oxygen in the surrounding air, to avoid oxidation reactions with the titanium.

**Result**

Dense layers of grade-2 titanium with a thickness of 350 μm were deposited on a CK45 steel substrate without crack formation. The zone containing intermetallic phases was reduced to a thickness of only a few micrometers. No significant oxidation of the titanium coating occurred. The purity of a single-layer titanium coating was 99.8 percent which can be increased by multilayer cladding.

**Applications**

The chemical engineering sector represents the largest market for coating applications based on this technique, because it allows corrosion-proof components to be manufactured that would not otherwise be economically viable. Medical technology is another area in which titanium coatings could be of interest, given the material’s high biocompatibility.

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1 Cross-section through a single-layer coating of grade-2 titanium on CK45 steel.  
2 Cladding process.
LASER MATERIAL DEPOSITION OF INTERNAL CONTOURS

Task

In recent years, various concepts have been developed for the laser cladding of internal contours in which powder and gas feed, cooling, and laser beam guiding and shaping functions are integrated in a single, compact unit. A new design approach is needed to enable such units to meet new requirements, including the ability to process additive materials such as titanium alloys and to produce uniform results in all processing directions in parts with increasingly small internal diameters. The aim is therefore to develop a compact internal cladding unit that benefits from the advantages of a continuous coaxial powder feed system, as opposed to lateral powder feed, such as high powder efficiency, uniform processing results in all directions and improved gas shielding of the melt pool. Another requirement is the ability to vary the diameter of the laser beam by means of an integrated, movable lens system, to enable laser cladding with different track widths. And finally, process monitoring is to be provided for each position of the sliding focusing lens.

Method

The internal coating unit was designed, the individual modules were manufactured and assembled, and a series of functional tests were carried out with the complete internal cladding unit.

Result

In an initial test phase, it was demonstrated that the internal cladding unit is suitable for laser cladding operations using a Nd:YAG laser with an output of up to 1000 W in pipes with a minimum internal diameter of 105 mm. The maximum depth inside the pipe to which the whole internal cladding unit was able to penetrate was 900 mm. The first experimental cladding tests on the internal surface of a pipe with track widths set to between 1.1 mm and 2.1 mm resulted in powder efficiencies of between 69 and 81 percent. The use of a coaxial powder feed system also allows oxidation-free deposition of structured layers, such as lattices, inside the pipe without changing the travel direction. Process monitoring is provided by a flexible lens system for each position of the sliding focusing lens.

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3 Internal cladding unit of length \( l = 1 \) m.
4 Cladding unit in use inside a compressor outlet with an internal diameter \( d = 110 \) mm.
LASER MATERIAL DEPOSITION WITH VARIABLE TRACK WIDTHS

Task

Laser material deposition is commonly used in many applications including the repair of surfaces and components and the improvement of their resistance to wear and corrosion. To obtain a near-net-shape coating, variable track widths are necessary. The track width can be varied by adjusting the position of the optics relative to the surface, but this adjustment must be accompanied by manual adaptation of the powder supply nozzle to the new working position. In industrial applications, it is preferable if such manual readjustments can be avoided. A project was therefore set up to develop a processing head containing a modular optical system with interchangeable lens units and a powder feed nozzle capable of generating tracks of variable widths.

Method

A modular optical system for metal deposition applications was developed in collaboration with Reis Lasertec. It consists of a basic module and interchangeable lens units for fiber-guided lasers. The basic module, which is inserted behind the collimator, is equipped with integrated medium channels for cooling water, process gas and compressed air, and wire through-connections for sensor and camera signals. By using different lens units, the beam diameter on the workpiece surface can be varied between 0.9 and 2.0 mm. An adapter for different types of powder nozzles (coaxial, three beam) is mounted on the processing head.

Result

A compact, modular processing head was developed for material deposition applications which enables the laser beam to be set to three defined diameters (0.9 mm, 1.5 mm and 2 mm) in successive steps without modifying the working position (constant tool center point). The only intervention required is to swap lens units. Different types of powder feed nozzles can be mounted on the processing head. A powder efficiency in excess of 85 percent was achieved using a coaxial nozzle when generating track widths of 0.9, 1.5 and 2 mm.

Applications

The new processing head is suitable for all applications involving laser material deposition (repairs, wear and corrosion protection). It enables the track width to be varied without having to reconfigure the machine (TCP readjustment).

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1 Basic unit of the modular processing head (Reis Lasertec) fitted with a coaxial powder nozzle from Fraunhofer ILT.
2 An interchangeable lens unit.
PROCESS MONITORING
OF LASER METAL DEPOSITION

Task
Laser metal deposition is an established process for surface functionalization, the repair and modification of components, and the manufacture of new parts. The geometric expansion and dynamics of the melt pool are important parameters for the monitoring of process quality.

Method
In order to monitor the melt pool geometry, it first has to be made visible to the camera using a suitable light source. A narrowband light source is superimposed on the light generated by the process and the reflected light is recorded selectively by the camera. To obtain sufficiently bright images, it is usual to capture the direct reflections of a diode laser coupled into the circuit in the coaxial plane of the processing laser. This technique cannot be used to monitor laser metal deposition processes because the illumination laser beam lies in the same plane as the powder gas stream delivered by the coaxial nozzle, and its light is therefore smothered. To solve this problem, a lateral process lighting arrangement consisting of high-power LEDs was developed. The advantage of this design is that it provides an even level of lighting in all directions. The incoherent light emitted by the LEDs is an additional advantage, because it produces images of very good quality without any speckle effect. To obtain the necessary brightness to overpower the light generated by the process, the LEDs are focused using aspheric lenses and pulsed in synchronism with the camera’s frame rate. Different algorithms are being developed to measure the length, width and surface area of the melt pool on the basis of the achieved image quality. Different algorithms are compared and qualified on the basis of parameter variations (power/feed rate).

Result
The new illumination system and the associated melt pool measuring algorithms developed specifically for laser metal deposition applications represent the necessary groundwork for developing an application-specific process monitoring system.

Applications
Applications can be found in all areas of laser deposition welding where process monitoring is of interest. The main industrial sectors where this applies are mechanical engineering, tool and die making, engine manufacturing, and automotive engineering.

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3 Process lighting with high-power LEDs.
4 Melt pool during laser metal deposition.
**Task**

One of the goals of the Fraunhofer Cluster of Innovation »Integrative Production Technology for Energy-Efficient Turbo Machinery - TurPro« is to qualify laser metal deposition as a certified manufacturing technique for the additive manufacturing of blades on existing conventionally manufactured disks to form what are known as blisks (blade integrated disks). First, coating diagrams were developed to visualize the achievable deposition rates, porosities and powder efficiencies as a function of the process parameters. Blade geometries were then built up using increased rates of laser deposition.

**Method**

Starting with known and tested combinations of parameters for the laser metal deposition of Inconel 718 on a similar substrate material, the feed rate for track widths of 2 mm and 4 mm was increased in increments of 500 mm/min. The powder mass flow was adjusted to obtain a constant ratio of track width to track height of approximately 4:1. A suitable laser output range was determined for each feed rate. The experiments were repeated numerous times, and the mean values and standard deviations of the porosities obtained were documented in the coating diagrams.

**Result**

Coating diagrams were developed for the laser metal deposition of tracks with a width of 2 mm and 4 mm. These indicate that it is possible to increase the deposition rate from 200 mm³/min to up to 9000 mm³/min for 4-mm wide tracks. An initial model blisk with 20 blades and a core diameter of 100 mm was built up completely within a time $t < 10$ min.

**Applications**

The process has applications in the aerospace industry, the tool and die making industry, and in the field of wear and corrosion protection.

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1 Model blisk with laser-deposited blades.
2 Near-net-shape, airfoil-like specimen produced from IN 718 by laser metal deposition, completion time approx. 2 min.
RESISTANCE TO THERMAL SHOCK OF PROTECTIVE COATINGS APPLIED TO MAGNESIUM ALLOYS BY LASER CLADDING

Task

BComponents made of magnesium alloys (e.g. engine casings in the aircraft industry) are highly susceptible to corrosion and abrasive wear. It has been conclusively shown that coatings applied by laser cladding can provide superior protection. But under operating conditions these components are frequently exposed to high temperatures (up to 250 °C) and cyclic temperature fluctuations. This gives rise to thermal stresses that can lead to premature failure of the component. As part of a DFG-funded project, the resistance of these coatings to thermal shock was therefore investigated and compared with that of other coatings.

Method

Test specimens made of the magnesium alloy AZ31B were coated using different methods (laser cladding (LC): AlSi20, thermal spraying (TS): AlSi20, Al2O3, FeCr30Ni13B3C0.5, Interfill®: epoxy-based coating, HAE: anodized coating) and subjected to cyclic thermal stress. The coatings (thickness: 0.5 mm, anodized layer: approx. 70 μm) were subsequently analyzed and evaluated by means of dye penetrant testing and structure analysis.

Result

AlSi20 laser cladding tends to produce coatings with better resistance to temperature fluctuations than the thermal spraying or Interfill® methods. HAE coatings produce the best results of all, due to the low thickness of the anodized layers.

<table>
<thead>
<tr>
<th>Coating</th>
<th>RT-200°C 100 cycles</th>
<th>RT-200°C 400 cycles</th>
<th>RT-400°C 100 cycles</th>
<th>RT-400°C 400 cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td>LA - AlSi20</td>
<td>OK cracks</td>
<td>OK cracks</td>
<td>OK cracks</td>
<td>OK cracks</td>
</tr>
<tr>
<td>TS - AlSi20</td>
<td>destroyed</td>
<td>destroyed</td>
<td>destroyed</td>
<td>destroyed</td>
</tr>
<tr>
<td>TS - Al2O3</td>
<td>OK cracks</td>
<td>cracks</td>
<td>cracks</td>
<td>delaminated</td>
</tr>
<tr>
<td>TS - Fe-based</td>
<td>cracks</td>
<td>destroyed</td>
<td>destroyed</td>
<td>destroyed</td>
</tr>
<tr>
<td>Interfill®</td>
<td>OK cracks</td>
<td>cracks</td>
<td>cracks</td>
<td>delaminated</td>
</tr>
<tr>
<td>HAE</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
</tr>
</tbody>
</table>

Applications

The main applications are local wear and corrosion protection of magnesium parts used in the automotive and aerospace industries.

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3 Bonding zone between AlSi20 coating and AZ31B magnesium substrate.
4 Specimens after thermal shock testing, from left: TS - Fe-based, TS - AlSi20, LC - AlSi40, LC - AlSi20, TS - Al2O3, HAE, Interfill®.
Task

Precise knowledge of the surface geometry is of major importance to the reliability of laser cladding processes. When applying repair coatings to worn or damaged parts, the actual geometry differs from the CAD data for the new part, and may also have suffered distortion. When applying multilayer coatings and in additive manufacturing, measurements of the thickness of each successive layer permit the processing head to be adjusted accordingly and precisely if the measured thickness deviates from the required thickness. The task therefore involved implementing an optical sensor for geometry data acquisition.

Method

To obtain the digitized surface data, an optical profile sensor was integrated in the handling system. It has a scanning width of 50 mm, which enables the surface to be digitized in one or more passes, depending on the size of the part. Shadows cast by steep-sided features can be avoided by tilting the sensor away from the vertical axis. The scanning rate is 500 mm/min, which enables the scanning process to be completed in only a few seconds. The data recorded by the scanner are stored in STL format. The file is input to a CAD program and processed to create a surface model.

Result

Digitization was successful for polished metal and coated test specimens. A resolution of 5-10 μm was achieved, depending on the nature of the scanned surface. This is sufficient for laser cladding. Programming of the laser paths, which is often still done today by manual teaching, can be performed offline by a CAD/CAM software using the digitized component data. When applying multilayer coatings, the positioning of the processing head can be adapted to the desired thickness. In the present version, this is done manually, but in future it will be performed automatically by a feedback control circuit.

Applications

The main areas of application are repair coatings, where it will be possible to significantly reduce the time and effort required to program the cladding paths, and the monitoring and control of additive manufacturing processes.

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1 Digitization of a tool insert. 
2 CAD image of the tool insert based on digitized surface data.
ADDITIVE MANUFACTURING OF HIGH-STRENGTH ALUMINUM COMPONENTS

Task

Two die-casting alloys, AlSi10Mg and AlSi9Cu3, have already been qualified at Fraunhofer ILT for the additive manufacturing of aluminum components by Selective Laser Melting (SLM). The aerospace industry has a need for high-strength aluminum components that are suitable for lightweight construction and at the same time meet the requirements for structural durability and corrosion resistance. An innovative alloy (Scalmalloy®) was investigated as a possible solution. AlMgScZr is a material that combines the good corrosion resistance and welding properties of AlMg alloys with the increased strength offered by precipitation hardening (Al3Sc(+Zr) phase). The higher strength of this material is the result of rapid cooling from the molten state. Previous studies demonstrate the viability of melt spinning in this context (cooling rate 104 to 106 K/s). It has been typically applied to extruded parts.

Using SLM with the same range of cooling rates will enable the manufacture of complex 3-D parts with increased strength, a task that was previously not possible.

Result and Applications

The primary objective when qualifying a material for SLM is to obtain a component density approaching 100 percent without any cracks, fusion defects or pores. This involves evaluating the process parameters, especially scanning velocity and laser output power, required to produce components with a density approaching 100 percent. The next step is to study the mechanical properties. Initial results indicate that very high strengths can be achieved (Rm and Rp 0.2 approx. 500 MPa), accompanied by high elongations at rupture (A approx. 20 percent). Compared with SLM components made of AlSi10Mg, the yield strength Rp 0.2 is approx. 200 percent higher and the elongation at rupture approx. 400 percent higher. Aerospace components are frequently subjected to dynamic loads, which are currently being tested in an exhaustive series of fatigue tests. Initial results indicate that test specimens made of AlMgScZr possess greater dynamic strength than components made of AlSi10Mg.

In future studies, we aim to determine whether it is possible to increase component strength still further by increasing the Sc or Mg content of the alloy and by increasing the SLM process cooling rate. Other potential means of reducing component weight include optimizing component topology and its manufacture by SLM.

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ADDITIVE MANUFACTURING OF HIGH STRENGTH OXIDE CERAMICS

Task

At the Fraunhofer ILT complex, net-shape parts made of structural Al₂O₃/ZrO₂ ceramics have been successfully built by means of Selective Laser Melting (SLM). The specimens reach densities of > 99% and crack formation is fully suppressed by means of high temperature preheating. Still, limitations to the surface finish persist. Accordingly, a surface roughness of Rₜ 150 µm - 200 µm is achieved. Therefore, a reduction of the surface roughness is subject to present research.

Method

To prevent crack formation, a homogenized CO₂-laser beam is applied for high-temperature preheating of the powder bed, reaching preheating temperatures of just below the melting point of the applied powder mixture (~1830°C). Due to this high preheating temperature a large low-viscous melt evolves during selective melting. This melt pool exceeds the specimen’s boundaries, causing poor surface qualities. Online process monitoring by means of high speed videography allows for analyzing the dynamics of the melt pool. Based on this analysis appropriate process parameters and scanning strategies are identified. Accordingly, the surface finish is improved by using a multi contour scan at elevated scanning velocities where the clearly defined contour scans serve as a barrier against spilling of the melt pool.

Result

The above mentioned strategy allows for generating structural oxide ceramics consisting of 58.5 wt.-% Al₂O₃ and 41.5 wt.-% ZrO₂ at a surface roughness of Rₜ < 70 µm at densities of > 99% without any formation of cracks.

Applications

Main application for additive manufacturing of structural ceramics is the individual fabrication of dental restorations. This new approach aims at reducing manufacturing costs due to high material efficiency and absence of any tool wear, thus, securing competitiveness of German manufacturers of dental restorations.

Further applications can be found as high temperature and high wear appliance in the aerospace and automotive sector.

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1 Process monitoring: selective melting of ceramic material.
INLINE QUALITY ASSURANCE FOR LARGE-SCALE ADDITIVE MANUFACTURING

Task

In recent years increasing globalization has led to severe competitive pressure on the manufacturing sector. To survive in this competitive environment, companies in high-wage countries often adopt a marketing policy based on a portfolio of customized and high-quality products. Yet at the same time, costs have to be kept down. One of the new technologies that offer the greatest potential for overcoming this dilemma is additive manufacturing with its virtually infinite geometrical variability. But there is still room for improvement, especially with respect to quality and reproducibility, which are often regarded as the Achilles heel of additive manufacturing. The resulting products often have to be scrapped due to a wide variety of problems associated with the manufacturing process, such as insufficient powder feed, pore formation and fusion defects.

Method

Monitoring systems for industrial laser processes are much more difficult to implement than similar systems in a conventional manufacturing environment, due to the greater number of parameters and failure factors as well as the non-deterministic nature of the processes. By monitoring the behavior of the melt pool during Selective Laser Melting (SLM), the principal aim is to gain a better understanding of the process variables that determine product quality, especially in function-critical regions. By measuring the dimensions of the melt pool and by feedback control of the laser output and scan speed accordingly, it will also be possible to avoid structural defects due to discontinuity of the melt pool or pore formation. Thus, the first step is the design of a process monitoring system.

Result and Applications

As the first step toward implementing the inline quality assurance system, ray tracing was used for the design of the optical system, which is subsequently subjected to a tolerance analysis. To enable a flexible response to different process conditions, the optical system incorporates variable settings allowing different magnifications to be implemented. The mechanical design was based on the input variables to be delivered by the optical system. Due to the restrictions imposed on the positioning and orientation tolerance by the superposition of different ray paths, an error budget was defined to eliminate manufacturing inaccuracies from the outset. The integration of monitoring components for an inline quality assurance system will significantly improve the reproducibility of components made using additive manufacturing techniques, making it economically viable to use such techniques for (low-volume) series production in a wide range of new applications.

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2 Image of Selective Laser Melting (SLM) process.
3 Schematic of the process monitoring setup.
Task

Incremental sheet forming (ISF) is a method used to manufacture complex sheet-metal parts. The metal is formed using a simple CNC-controlled, round-tipped tool, without the need for complex forming tools. The aim of the project is to improve component accuracy and allow the process to be applied to a wider range of applications and components (involving, for example, the forming of titanium and magnesium alloys) by combining ISF with local preheating of the process zone using laser radiation.

Method

The envisaged processing optics is designed to provide continuous, localized heating of the process zone, without shadow effects and independently of the travel direction of the forming tool. To achieve this, the processing optics is fixed in a stationary position with respect to the forming tool. The positioning of the laser beam on the sheet surface is set by manipulating the beam path within the optics. Another requirement was that the laser beam should have a (variable) elliptical intensity distribution and always be focused on the area in front of the forming tool.

Result

A processing optics was developed that projects an elliptical beam onto a concentric path that rotates around a common axis with that of the processing tool. The laser beam geometry can be adapted by inserting different optical modules. The position of the laser beam is synchronized with movement of the tool by the ISF control system, to ensure that the beam is always focused on the area in front of the forming tool.

Applications

The concept allowing a laser beam to rotate freely on a coaxial path around the processing tool or the device for additive material offers a means of designing processing optics for a wide variety of applications. It is particularly suitable for use in hybrid processes in which the laser beam needs to be moved around the tool in an environment that restricts the laser’s mobility. This research was conducted with the financial support of the DFG as part of the Cluster of Excellence »Integrative Production Technology for High-Wage Countries«.

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1 Processing optics and ISF plant.
2 Testing of the optical system.
LASER POLISHING IN TOOL AND MOLD MAKING

Task

In tool and mold making polishing is often the last manufacturing step. Due to the complex geometries resulting in limited accessibility state-of-the-art is manual polishing with processing times of 10 to 30 min/cm². High costs due to long processing times and the growing shortage of specialized workers lead to an increasing demand for automated polishing processes for complex shaped workpieces.

Method

Laser polishing is a remelting process. In the molten state the roughness is reduced due to the surface tension. The innovative aspect of laser polishing is that it is based on a fundamentally different active principle (remelting) compared to conventional grinding and polishing, which are based on removal of material.

In order to establish laser polishing in industry, two public funded projects were launched involving more than 10 industrial partners. The BMBF-funded ALPINE project aims to develop a machine tool for laser polishing and test it for the polishing of molds used in glass manufacturing. The machine will be capable of processing workpieces with dimensions of up to 350 x 350 x 300 mm³. In the EU-funded polIMATIC project, laser processes are being developed and tested for the polishing of injection molds and extrusion dies, and undergoing extensive technical and cost evaluation in comparison with manual polishing techniques.

Result and Applications

Milled and eroded surfaces of tool steels 1.2343, 1.2344 and 1.3207 with an initial roughness of Ra = 1 - 4 μm were laser polished to a roughness of Ra = 0.05 – 0.1 μm. The processing time is ≈ 1 min/cm². The method can be used to polish also other types of steel and casting alloys, but the attainable roughness strongly depends on the material and especially its homogeneity.

An end-to-end CAM-NC data chain was implemented for the processing of 3-D surfaces. It is now available for use in further process development, and for component-specific and customer-specific testing.

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3 Mold for manufacturing glass bottles with partially laser-polished freeform surface and glass bottle manufactured with laser-polished mold.
LASER-BASED MANUFACTURING CHAIN FOR OPTICS

Task

The manufacturing of optics, for both mass products such as eyeglass lenses and for specialized products such as laser optics, calls for high standards of quality and functionality. Aspheric lenses or freeform surfaces can substitute a series of spherical lenses, resulting in lower weight, smaller dimensions and even enhanced imaging performance. However, the use of conventional grinding and polishing processes to manufacture these types of optics is time-consuming and cost-intensive due to the non-spherical shape of the surface. On the other hand, molding processes involve high tooling costs which make them viable only when manufacturing high volumes of identical optics.

The aim of the new laser-based manufacturing chain currently under development is to enable optical elements with almost any surface geometry to be manufactured rapidly and at low cost, by decoupling the tool from the workpiece by using laser radiation.

Method

In a first step, material is ablated by evaporation from a glass blank using cw-CO₂ laser radiation. In the subsequent polishing step, again using CO₂ laser radiation, the surface roughness is reduced by remelting, without any further ablation. The actual surface shape is then compared with the desired geometry and, if necessary, the shape accuracy can be optimized still further in a final, high precision laser ablation step.

Result

The ablation rate on quartz glass using CO₂ laser radiation currently lies above 20 mm³/s and results in a surface roughness of Ra < 5 μm, and is thus suitable for the first rough ablation step. Using an adapted processing strategy, it is already possible to produce shaped lenses and subsequently reduce their surface roughness with the following polishing step. A surface roughness of Ra < 0.05 μm can be attained in a final high precision laser ablation step at a slower ablation rate. The use of a femtosecond laser operating at a wavelength of λ = 1 μm is also being investigated as an alternative to the CO₂ laser for the high precision laser ablation step. Initial experiments demonstrate that the results obtained in this way are of a high precision.

Applications

Potential applications are the manufacturing of optical elements made of (quartz) glass with a virtually unlimited range of surface geometries.

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1 Laser ablated test sample.
2 Laser-polished and unpolished glass lens.
STRUCTURING OF FUNCTIONAL SURFACES USING ULTRA-SHORT-PULSE LASERS

Task

Microstructuring techniques can be used to create surfaces with specific functional properties. Alongside the better-known examples such as the water-repellent LotusEffect® and the antireflective moth eye effect, which mimic natural phenomena, engineers are increasingly inventing new ways of structuring surfaces to create new functions. For instance, an array of micro-dents in a transparent medium can serve as a light diffraction structure. Micro-dent arrays in internal combustion engine components subject to high frictional loads can significantly reduce friction and thereby increase the engine’s mechanical efficiency and minimize fuel consumption.

Method

New products based on functional surfaces are being developed in cooperation with partners in a number of different industrial research projects. These include laser-microstructured injection-molding tool inserts made of tool-grade steel for the manufacture of optical diffraction structures. To enhance the frictional properties of piston rings and cylinder sleeves, their surface was modified by laser ablation to create a structure consisting of micro-dents in an arrangement that had been optimized by simulation. Ultra-short-pulse lasers are ideally suited to the task of structuring tool inserts, piston rings and cylinder sleeves because they permit almost burr-free machining. The structured components have no need of time-consuming and cost-intensive post-processing.

Result

The injection-molded parts made using the tool inserts can be used as diffraction structures for background lighting. The pattern of micro-dents permits a homogenous distribution of light over the entire surface. Initial wear tests of the laser-structured piston rings confirm that the micro-dents significantly reduce component wear.

Applications

Injection-molded parts with optical diffraction structures are meanwhile being used throughout the world for instrument backlighting in new automobile models.

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3 Injection-molded part with a diffraction structure made up of microlenses.
4 Fully assembled module for homogenous surface lighting.
THREE-BEAM INTERFERENCE STRUCTURING OF GLASS

Task

For direct structuring processes, the minimum feature size that can be produced by mask-based laser structuring or in scanning mode with a focused laser beam lies in the region of a few millimeters. However, applications in lighting technology and medical engineering require feature sizes below 1 μm, e.g. in order to fabricate components with functional surfaces.

Method

To create micro- and nanostructures with geometries ranging from 200 nm to a few millimeters, a modified three-beam interference technique was developed that also allows large areas to be structured. A laser beam is split into three coherent beamlets, which are spatially aligned and superimposed at a predefined angle. Different periods can be obtained by varying the angle of superposition. Different intensity distributions and thus different structures can be obtained by adjusting the direction of polarization of the beamlets relative to one another. A frequency-tripled Nd:YAG laser is used as the beam source.

Result

The newly developed technology was used to produce micro- and nanostructures directly in polymer materials and also in different types of photo resist. Using a modified technique, it was possible to create periodic structures in the μm range even in materials that are less amenable to laser processing.

For example, nanostructures were produced in glass using a combination of interference structuring and etching. This is done in two steps: First a thin polymer film is applied to the surface of the glass and structured by laser. Then this structure is transferred to the glass using a reactive ion etching technique. Fig. 1 shows a SEM image of a micro-relief structure in glass with a feature height of 1.5 μm. The tips of the conical features are approximately 200 nm wide.

Fig. 2 shows a micro-dent pattern with a feature depth of approx. 2.3 μm and a feature diameter of 1.5 μm. The technique employed is capable of producing structures with a feature diameter of less than 200 nm.

Applications

Laser micro- and nanostructuring enables new functions to be incorporated in technical surfaces. The structure can provide the surface with hydrophilic or hydrophobic properties, or reduce friction, or serve as a security marking. In the latter case, nanostructures of different periods can be applied to a product, rather like a barcode, reflecting light in a specific sequence of colors that serves as a unique, forgery-proof identification.

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1 SEM image of a micro-relief structure in glass.
2 SEM image of a micro-dent pattern in glass.
MODIFICATION OF METAL SURFACES

Task

The surface properties of solid objects, such as light absorption and wettability, play a very important role in many analytical and technical processes. As well as being dependent on the intrinsic chemical and physical properties of the material, they also depend to a large extent on the surface morphology, which can be deliberately modified and optimized for specific applications by patterning the surface with microscale and nanoscale structures.

Method

The surface properties of copper and copper alloys were modified using a high-power femtosecond laser source developed at Fraunhofer ILT and commercialized by the spinoff company AMPHOS. The laser beam, which has a pulse duration of less than 1 picosecond and an average output power of up to 400 watts, is focused on the surface of the workpiece via a plane-field lens and moved over the surface using a galvano-meter or polygon scanner and a linear axis. Scanning rates of up to 100 m/s can be achieved in this way. The pulse repetition rate of the laser beam source can be variably adjusted over a range extending to 27 MHz. This enables the process to be scaled up to the high processing speeds required in industrial structuring applications based on ultra-short-pulse lasers.

Result

Through the combination of directly fabricated microstructures, whose area and orientation are determined by the movement of the scanner, and self-organizing nanostructures, it is possible to significantly modify the optical and mechanical properties of the processed surface. For instance, by varying the process parameters it is possible to minimize or define the reflectivity of a copper surface within a wide range of wavelengths. It is similarly possible to modify the surface's wettability to the extent that it becomes hydrophobic instead of hydrophilic.

Applications

The use of high-power femtosecond lasers to modify surfaces by means of micro- and nanostructuring opens up a broad spectrum of potential applications, including improving the efficiency of solar thermal collectors and photovoltaic cells by increasing their absorption capacity, facilitating analytical and catalytic processes in chemistry and the life sciences by increasing surface area, and reducing frictional wear in engine and motor vehicle components.

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3 A hydrophobic surface.
4 Black copper selective surface.
SUPERHYDROPHOBIC SURFACES

Task

Superhydrophobic surfaces are needed above all in products designed to deliver precisely measured doses of liquid substances or where it is important that they can be emptied without leaving behind the slightest film of liquid. For such products to be manufactured at minimum cost, a process is required that is capable of generating the necessary superhydrophobic properties with simple resources and preferably without the need for additional process steps. The ideal solution is an integrated process that produces the component and the functional surface in a single step, e.g. by integrating the structure in the injection-molding die.

Method

A process chain capable of being scaled up to industrial standards was developed by RWTH Aachen as part of the Cluster of Excellence “Integrative Production Technology for High-Wage Countries” in collaboration with the Institute of Plastics Processing (IKV). Functional microstructures were created in injection-molding tools by means of precision ablation using a picosecond laser. Sample components were then manufactured using these tools in an adapted variothermic injection-molding process.

The elements required to create the LotusEffect® are a topographical microstructure and an adapted surface energy of the material. This combination was achieved by fabricating an injection-molding tool with a micro-dent structure consisting of a multitude of indentations, each measuring a few millimeters in diameter, overlaid with a ripple structure with a feature size of a few hundred nanometers.

Result

The method was successfully used to produce components with a superhydrophobic surface using the injection-molding tool with its combined micro- and nanostructures and the adapted variothermic injection-molding process. The polymer curls around the nanostructures during the injection-molding process and is pulled into filaments when the product is removed from the mold. The resulting hair-like structure demonstrates superhydrophobic properties at contact angles greater than 160°.

Applications

Plastic components with superhydrophobic surfaces have applications in many areas of medical engineering. Laboratory equipment designed to deliver precise doses of liquids or be emptied without leaving behind any residues represents one of the main applications. But other applications are also conceivable in consumer products and polymer optics, where superhydrophobic surfaces can be used to provide a self-cleaning effect.

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LASER TREATMENT OF NANOCOATINGS

Task

Wet-chemical coating processes based on nanoparticle materials hold great potential as a low-cost production process for functional coatings. Such processes are easy to implement and give access to a wide range of possible functionalities. One application with significant market potential is the fabrication of wear protection coatings used in the automobile industry in order to optimize wear protection performance of engine components subjected to high mechanical loads. The main challenge of wet-chemical coating processes lies in the necessary thermal post treatment. Due to its exact local and temporal controllability, a laser process is very well suited for generating temperature-time-profiles that enable the coating to be functionalized without any negative impact on the substrate material, which in many cases may be highly heat-sensitive.

Method

In collaboration with partners in the BMBF-funded FunLas project, ILT researchers developed a laser-based process for the fabrication of wear-resistant coatings on 100Cr6 steel substrates. Coatings with a thickness between 0.1 and 1 μm based on nanoparticle materials developed by Merck KGaA Darmstadt were functionalized using a continuous-wave diode laser. The results of Fe8 wear tests conducted by Schaeffler KG have already demonstrated very good wear protection performances. A future objective is to minimize the heat affected zone in the substrate material.

Result

Tests of laser-treated coatings on 100Cr6 steel demonstrated that it is possible to reduce the depth of the heat affected zone to ≤ 10 μm by using a pulsed diode laser with pulse durations in the μs range as opposed to ≥ 50 μm when using a continuous-wave laser. A Fe8 test procedure for coatings treated with a pulsed laser is in preparation.

Applications

This technology is suitable for applications where functional surface coatings are to be produced on heat-sensitive substrate materials.

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4 SEM image of the area of fracture on a coated 100Cr6 steel sample (coating thickness approx. 230 nm).
5 Wear protection coatings on components of diverse geometries (internal diameter of Fe8 ring: 62 mm).
OPTICAL SYSTEM FOR MULTI-BEAM LASER STRUCTURING

Task

The FluidStruc collaborative research project funded by the Volkswagen Foundation aims to investigate process and machine technology for structuring of design surfaces by laser remelting. The process involves superposing the beams from a continuous-wave and a pulsed laser source. The cw laser melts a thin surface layer, while the pulsed laser selectively evaporates small amounts of material and shapes the surface of the melt pool by steam pressure. The design of an optical system for the combined process constitutes one of the project’s main objectives, alongside the process engineering aspects.

Method and Result

Two industrial lasers emitting in the near infrared spectral range at wavelengths of 1064 and 1030 nm respectively were selected to implement the combined laser process. To increase the process-specific parameter range, the beam from the cw laser is split into two beams polarized perpendicular to each other using a polarization splitter. The relative position of the two beams to one another can be adjusted in two dimensions using a motorized tilting mirror. The output power and beam diameter can set independently for each of the two beams. Motorized zoom telescopes, developed in-house, are used to vary the spot size. At a constant focal length, the image can be zoomed through a magnification factor of 0.25x to 2x. In addition to the ability to modify the spot size, the pulsed laser beam is deflected by a tilting mirror driven by two piezoelectric actuators. This enables the pulsed laser beam to be deflected transversally at high frequencies (up to 2 kHz). The beams from the pulsed and the continuous-wave laser source are combined by a wavelength coupler and focused on the surface of the workpiece using a 3-D laser scanner. All necessary process parameters (spot size, output power, relative beam position, etc.) can be set via a graphical user interface. The optical system for simultaneous processing with a continuous-wave and a pulsed laser was successfully implemented. Its flexibility enabled a wide range of process parameters to be made available for the subsequent process testing stage of the project.

Applications

The optical system is particularly well suited to structuring applications in the tool- and die-making and jewelry industries, and to all other applications requiring the use of multiple, dynamically superposed laser beams, for instance to implement process parallelization.

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1 Tool insert made of 1.2343 steel, showing the surface structured by laser remelting.
IN-VOLUME-MARKING OF TRANSPARENT MATERIALS

Task

Marking and identification numbers in transparent materials are required to clearly and permanently mark products in industrial applications as well as in marketing and advertising. To achieve such goals, ultrashort pulsed laser radiation is focused in the volume of the material according to individual requirements. The challenge is to process glass, crystals, polymers and other transparent materials for industrial applications crack free and at sufficiently high processing speeds.

Method

In the volume and on the surface of transparent materials, modifications are created in seconds using focused femto-second laser radiation. A scanner system allows the production of individual structures in three dimensions. The micro-structure and, thus, the refractive index of the material are changed locally. Depending on the choice of the focusing optical components, structures are fabricated up to a material depth of 2 mm. The processing speed reaches up to 350 mm/s with nanometer resolution at the same time.

Result

Light-fast and colorful markings arise from diffraction and interference effects at the generated refractive index changes. In borosilicate glass, grating structures with distances of a few micrometers produce angle-dependent color effects by light incidence. Crack-free labels are induced in the volume of sapphire with a scanner system.

Applications

In-volume markings are useful, for example, as alignment aids in the production of ophthalmic lenses, for tamper-proof identification in food and pharmaceutical industries as well as in advertising for logos and decoration. In industrial production and logistics the generated markings can be applied for the identification and labeling of numerous components and products.

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2 Logo in the volume of sapphire.
3 Diffraction and interference effects at a grating in glass.
MICROSTRUCTURED ELECTRODES FOR LITHIUM-ION BATTERIES

Task

Modern lithium-ion batteries are based on a design in which the anodes and cathodes are made up of active masses consisting of a paste applied to a metal film. The film serves as an electrical conductor and mechanical support, and also helps to dissipate heat from the battery. The insertion compounds employed as the active mass have a tendency to swell or contract during charging and discharging, as a result of the insertion or expulsion of lithium ions. The mechanical load induced by these changes in volume significantly reduces the battery’s life, especially in the case of full cycling. The aim of this project is to introduce a pattern of perforations in the metal film as a means of improving the mechanical contact between the active mass and the film and preventing mechanical rupture of the electrical contact.

Method

A frequency-tripled Nd:YAG laser is used to drill the holes. The short wavelength and the use of very short focal distances enable a focal diameter of less than 5 μm to be achieved. A galvanometer scanner is used to position the laser beam. A software program is used to define the position of the holes and the order in which they are drilled within the scanning process. The hole-drilling sequence is adapted to the material in question, with the aim of improving the removal of material by melt expulsion and reducing the thermal load on the film.

Result

The new drilling technique enables holes to be pierced in a variety of materials at a rate of 1000 holes per second. The minimum hole diameter achieved using this technique lies in the region of 2 μm. A transparency of 30 percent was obtained in an aluminum film pierced with holes with a diameter of 20 μm.

Applications

In addition to applications in the field of lithium-ion batteries, the technique also has potential uses in microfiltration and nanofiltration membranes for mechanical water purification, the production of back contacts for photovoltaic cells, and anti-clogging devices to remove particles with a diameter > 50 μm during the filtration of biofuels.

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1 Drilling process using a random drilling sequence to minimize film distortion.
2 Perforated brass film (thickness 50 μm).
3 Perforated brass film (thickness 50 μm).
SYNTHETIC MICROFILAMENTS FOR USE AS SENSORS

Task

Microfilaments are commonly found in nature. Many animals use them as sensors to obtain information on their environment. Grasshoppers, for example, have microscopic hairs on their backs measuring up to 1 mm in length, which they use to sense the direction of low-frequency noises. In order to develop technical applications that mimic this highly efficient sensor concept, there is a need for a method of fabricating microfilaments with a diameter of between 20 and 100 μm and a length of up to 1 mm.

Method

The microfilaments are cast in polycarbonate molds in which microscopic holes have been drilled using an excimer laser. The use of a mask-projection laser ablation technique enables a wide variety of hole geometries, and hence filament geometries, to be produced by selecting appropriate mask layouts. To fabricate the microfilaments, polydimethylsiloxane (PDMS, a silicone compound) is poured into the mold, hardened, and peeled off. Since the mold is not destroyed by this process, it can be reused.

Result

Arrays of filaments of different geometries and lengths were produced using the method described. Two examples are illustrated above. Fig. 5 shows radially symmetrical microfilament arrays in which the individual filaments have a diameter of 100 μm and a length of 1 mm. Fig. 4 shows filaments with a U-shaped cross-section. The different geometries result in microfilaments with different bending and breaking strengths.

Applications

Synthetic microfilaments can be used in combination with suitable piezoelectric devices as tactile sensors. Radially symmetrical microfilament arrays, for instance, can be used in medical devices to detect and diagnose stenosis and arterial insufficiency. Another area of application for microfilaments is flow testing, where flow characteristics can be established by measuring the deflection of the filaments.

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4 U-shaped microfilaments.
5 Illuminated, radially symmetrical microfilament arrays.
LASER DRILLING OF PEEK FOR HYPersonic TESTS

Task

For investigations of the stabilizing effect of porous walls on the transition from laminar to turbulent flow, it is necessary to drill 660,000 blind holes with a diameter of 100 µm and a depth of 1 mm in the high-performance synthetic material PEEK.

Method

The aim of the project is to drill blind-holes in a cone shaped workpiece made of PEEK with a length of 475 mm and a diameter of 31 - 79 mm. The blind-holes are drilled perpendicular to the surface over a peripheral angle of 120°. The holes are manufactured with a ns-pulsed laser source with a wavelength of 532 nm. A five-axis positioning system is used in combination with a scanner that scans arrays of 20 x 20 holes.

Result

By using a laser source with a pulse duration in the ns-range and a wavelength of 532 nm it is possible to drill holes with almost no recast. The surface is not cleaned after drilling.

Applications

The drilled workpiece is used in experiments to analyze the stabilizing effect of porous walls on the transition from laminar to turbulent flow and for the systematic study of the Reynolds' and Mach number in dependency of the transition. Therefore the workpiece is placed inside a hypersonic wind tunnel with wind speeds up to Mach 11.2. IR thermography identifies transition boundaries and the turbulence is directly measured by pressure sensors.

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1 Cone shaped workpiece made of PEEK inside a hypersonic wind tunnel with a transition from laminar to turbulent flow.
2 Cone shaped workpiece with 660,000 blind holes.
3 Enlargement of the drilled blind holes.
HIGH-SPEED LASER DRILLING OF SILICON WAFERS FOR PHOTOVOLTAIC CELLS

Task

High-speed laser drilling is an important processing step in the production of high-efficiency solar cells, especially in the case of emitter-wrap-through (EWT) solar cells which require ten thousand and more vias to be drilled in each cell. Given that the typical duration of a single process step on a production line for solar cells is in the order of one or two seconds, a drilling rate of 10,000 vias per second is the minimum requirement for industrial-scale production.

Method

The maximum drilling rate currently achievable with commercially available laser sources and galvanometer scanners is 4,000 vias per second. New optical concepts such as the combined use of high-performance galvanometer scanners and optical beam dividers offer a potential means of attaining the required drilling rate. This calls for laser sources with an average power output of several hundred watts and a pulse duration in the microsecond range. A number of different system solutions were set up and compared in order to assess their suitability.

Result

Parameter studies indicate that the chosen pulse duration and pulse energy are decisive factors in the efficiency of the drilling process. On the basis of experimental results, a numerical simulation of the ablation process was used to evaluate a number of different laser sources and optical concepts. The simulation will make it possible to identify the most suitable laser source and design the appropriate system technology for the drilling process. A system is currently under construction that has the potential to achieve a drilling rate of at least 9,000 vias per second.

Applications

The high-speed drilling process developed in this project relates specifically to a processing step in the manufacture of EWT solar cells in which the back contacts are connected to the emitter layer through electrical feedthrough structures in the silicon. This increases the active surface area of the solar cell and hence its efficiency. The ability to drill holes of a similarly small diameter has other potential applications beyond that of photovoltaic cells, for instance in filter technology.

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LASER SOLDERING IN PHOTOVOLTAIC CELL MANUFACTURING

Task

Photovoltaics is a key technology destined to play a major role in future energy supply concepts. To reduce the cost of PV modules, their efficiency needs to be increased, production rates need to be accelerated, and the volume of rejects also needs to be reduced. To produce a solar module, the individual solar cells are connected in series by means of tin-plated copper ribbon connectors to form a string. The electrical contacts are usually established by soldering.

Method

The proof of principle of laser soldering has been demonstrated in numerous studies. Fraunhofer ILT is now equipped with an automated assembly machine that allows the laser soldering process to be evaluated under production conditions.

Result

The assembly machine is a Stringer TT 900 from Teamtechnik, which has the capacity to link together up to 900 cells per hour. The modular design of the soldering station enables different laser sources and beam-shaping concepts to be tested for viability in a production environment. As part of the current technological research project, innovative methods of process monitoring based on IR thermography, pyrometric temperature measurement, and high-speed video imaging of the melt pool are being tested.

Applications

The fully automated assembly system enables laser-based joining and process monitoring processes to be investigated using industry-standard machines operating at typical industrial throughput rates. This enables manufacturers of PV modules to study process parameters without intervention in the actual production process but nevertheless under real production conditions. The system also offers a means of studying laser-based joining processes for innovative cell and interconnection designs, such as back-contact solar cells or solar cells with a layer thickness of < 150 μm.

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1 Teamtechnik Stringer TT900 machine for automated assembly of solar cell strings.
2 Laser soldering of a tin-plated cell connector on a solar cell.
ELECTRICAL CONTACTING OF LITHIUM-ION CELLS

Task

The high energy density of rechargeable lithium-ion batteries has prompted an increasing number of car manufacturers to use them as energy storage systems in electric vehicles. Vehicle battery packs consist of multiple cells, which have to be interconnected via electrical contacts. Cells in flexible casings known as pouch cells are frequently used in such applications. They have strips of copper and aluminum respectively leading from the electrode layers and extending from the envelope to form positive and negative terminals.

To build a battery pack, the terminals of the individual cells have to be connected in series by linking the anode of one cell to the cathode of the next cell, and so on. This is normally done using screw connections, because aluminum and copper are dissimilar metals and thus difficult to bond reliably. Conventional welding and soldering techniques are not a practical alternative because the flexible cells risk being damaged by the heat.

Method

The use of a bonding method to connect the terminals, instead of screw connections, offers the advantage of a much lower electrical resistance and hence increased battery efficiency. Laser welding is well suited as a joining method because it allows the process to be automated and can be performed with a relatively low energy input if the process parameters are set appropriately. As part of the Fraunhofer “System Research for Electromobility” project, laser welding is therefore being qualified as a joining technique for the described task.

Result

In experimental tests, a process parameter window was identified within which it is possible to produce reproducible welded connections between the terminals with an adequate current carrying capacity. Current research is focused on qualifying the long-term stability of the connections.

Applications

Rechargeable lithium-ion batteries are at present the most promising energy-storage technology for electromobility applications. The availability of efficient energy-storage systems that can be manufactured at low cost is a vital enabling factor for this fast-growing branch of industry. Laser welding can help manufacturers to produce the high-performance batteries needed for mobile applications more cost-effectively.

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3 Welded connection between terminals of lithium-ion battery cells.
LASER-BASED HERMETIC PACKAGING OF LTCC CERAMIC HOUSINGS

Task

The trend toward even greater packing densities of highly sensitive functional components has resulted in the wider use of combinations of dissimilar materials with different thermal physical properties. A typical example is the joining of LTCC ceramics and glass.

High-temperature joining processes involving the use of a furnace are often a source of problems, because the component that is the most sensitive to heat determines the maximum temperature that can be applied to the whole system. This prohibits the use of such processes for gas-tight packaging, along with all existing adhesive joining techniques, because adhesive joints do not meet the requirements for the durability of gas-tight seals. There is an evident need for a joining technique with a limited, local energy input.

Method

A selective laser glass soldering technique was developed in view of this technology's suitability as a means of hermetically packaging glass-and-ceramic components with a minimum energy input. The energy required to join the parts comes from the absorption of the incident laser beam by the glass solder employed. The choice of glass solder material was based not only on absorption and wettability criteria but also on its coefficient of thermal expansion, to provide the best match to both the LTCC ceramic and the glass. The actual soldering was performed in a quasi-simultaneous process. At a beam scanning rate of 1000 mm/s and with multiple overlaying of the scanned contours, a homogenous seal was created between the ceramic housing and the glass cover.

Result

Laser welding with glass solder provides a means of concentrating the energy needed to create the seal within the limited area of the joining zone. The quasi-simultaneous heating of the entire contour minimizes the risk of thermally induced stress. The solder weld seams provide a tightly sealed joint that is free of trapped air bubbles and cracks.

Applications

The main application for the new packaging process is the hermetic encapsulation of sensors and other precision components, such as those integrated in optical systems and medical devices.

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Together with partners from the Life Sciences, the technology field Medical Technology and Biophotonics opens up new areas of applications for lasers in therapy and diagnostics as well as in microscopy and analytics. The process Selective Laser Melting, developed at the ILT, allows implants to be generated, tailored to the individual patent on the basis of data from computer tomography. The material variety ranges from titanium through polyactide all the way to resorbable man-made bone based on calcium phosphate.

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

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

Task

285,000 craniotomies - a cut that opens the skull - are performed in neurosurgical procedures throughout Europe every year. During this procedure, the operating neurosurgeon manually applies a craniotomy cutter under high pressure onto the bone that will be ablated. In 10 percent of cases, the surgeon damages the meninges situated under the skull bone, which can lead to infections and impaired wound healing.

A laser craniotomy is designed to allow the skull bone to be opened using a high-power picosecond laser and to substantially reduce the rate of injury thanks to an integrated residual thickness measurement function.

Method

Laser craniotomy allows the surgeon to carry out the ablation process manually using the familiar procedure. The surgeon traces the required cut line using a handpiece. Microoptics and a microscanner system in the handpiece move the laser focus through the ablation volume. The ablated tissue fragments are removed from the operating area by means of a rinse and suction system built into the handpiece. An optical 3-D measurement system monitors the ablation process, which records and analyzes in real time the progress of the laser cut on the bone surface and the depth profile of the bone ablation. Metrology and an analysis algorithm are built into an assistance system which ensures the exact positioning of the laser focus in the cut gap, thus guaranteeing steady manual execution of the laser process.

Result

A high-power picosecond laser was developed for the efficient, non-thermal tissue ablation. The laser system has the following specifications: Pulse duration $t = 25$ ps, repetition frequency $f = 25$ kHz, pulse energy $E_p = 0.8$ mJ, wavelength $\lambda = 532$ nm. Using the ps laser, non-thermal tissue ablation on bone samples was demonstrated with pulse energies of $E_p = 1.2$ mJ and repetition frequencies of $f = 10$ kHz.

Applications

The laser craniotomy can be used as a microsurgical tool for bone ablation with all complicated surgical procedures involving the ultraprecise removal of hard tissue. Suitable applications therefore include spinal cord surgery, oral and jaw surgery, as well as operations on the muscoskeletal system.

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1 Bone ablation using the ps laser.
2 Curved laser cut in a cow’s scapula.
MANUFACTURING INDIVIDUAL TITANIUM IMPLANTS USING SELECTIVE LASER MELTING

Task

Selective Laser Melting (SLM) is an additive manufacturing process used to manufacture complex and small-batch components. Unlike comparable manufacturing processes, SLM involves direct processing of standard metallic materials in powdered form by laser radiation. At present, SLM is increasingly being used for the direct manufacturing of medical bone replacement implants made from titanium materials.

Method

Standard requirements relating to biocompatibility and mechanical properties must be met to use tailor-made implants for joint replacement or osteosynthesis. Benchmarking against conventional manufacturing processes (milling, precision casting, metal injection molding MIM) is conducted by comparing the mechanical, dynamic and static properties of the material TiAl6V4.

Result

The microstructure of the SLM test geometries is homogenized using post heat treatment and converted into an α-β titanium microstructure. The samples are loaded until breaking (static) and subjected to repeated loading (dynamic) until material fatigue causes a fracture. In cooperation with aap Implantate AG, the mechanical properties have been compared with conventionally manufactured components. The results demonstrate that the SLM components can at least match the limits of conventionally manufactured components under static and dynamic load. In combination with successful biocompatibility testing, SLM implants can now be used in clinical applications. A clinical application has been realized in cooperation with OS Orthopedic Services and the Catholic Clinic of Duisburg, involving the use of a tailor-made acetabulum with an integrated lattice structure in the region of the implant bone interaction zone.

Applications

Following the feasibility demonstration, OS Orthopedic Services is already designing and distributing titanium hip-replacement implants manufactured by C.F.K. CNC Fertigungstechnik Kriftel using SLM. Further applications include osteosynthesis to temporarily stabilize bone fractures, or large-scale implants to reconstruct skull defects.

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3 X-ray of the implanted acetabulum.
4 SLM acetabulum made out of titanium.
BIORESORBABLE IMPLANTS USING SELECTIVE LASER MELTING

Aufgabenstellung

Usage of a resorbable bone replacement material instead of the current standard procedure to insert autologous into the defect may in many cases provide a better solution for the treatment of bone defects resulting e.g. from accidents, a tumor resection or congenital disorders. While only experienced specialists are able to reconstruct large-scale defects (>10 cm²) during an operation, the removal of the bone also exposes the patient to additional trauma.

Method

Selective Laser Melting (SLM) is an additive rapid manufacturing process which enables the production of parts with complex shapes on the basis of CAD data within a very short time. This process allows for the manufacturing of custom bone replacement implants fitted to the specific patient using the bioresorbable ceramic material tricalcium phosphate (TCP) and the polymer polylactide (PLA). These materials are subsequently degraded by the body and replaced by autologous bone.

Result

In collaboration with the Department of Dental Materials and Biomaterials Research, and the Clinic for Oral Maxillofacial and Plastic Facial Surgery at university hospital Aachen, the properties of the implants manufactured using SLM have been analyzed in the lab and on the animal model. The results demonstrate that a pore structure integrated (through the additive manufacturing process) into the implant with a pore size of approx. 600 µm promotes the ingrowth of new bone structure into large implants. In a rabbit animal model it can be demonstrated that the percentage of new bone formation after 3 months is virtually the same as the bone formation using the current standard procedure to reconstruct similar bone defects. Thus, the implants can be designed without any loss of function before the operation, individually adjusted and provided to the surgeon.

Applications

The main application area is bone replacement in the field of cranio-maxillofacial surgery. Modifying the materials (increasing the strength) would enable applications in the load bearing area of the jaw or at extremities, too.

In future, bioresorbable stents could also be manufactured out of pure PLA materials using SLM.

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1 Skull implant made of the resorbable composite material TCP/PLA.
2 Cross-section of a sample from the animal model with newly formed bone (asterisk).
   Source: University Hospital Aachen.
MULTI-PHOTON POLYMERIZATION TO MANUFACTURE MICROSTRUCTURES

Task

Multi-photon polymerization (MPP) is a high-resolution stereo lithographic process that can be used to produce complex nano- to microscale three-dimensional structures. The materials used include a wide range of photosensitive polymers, such as acrylate resins or biomolecules. These materials should pave the way for implementing processes that allow the further development of technology in the field of tissue engineering applications, and the production of micro- and nanostructures tailored to specific cell growth.

Method

Today’s systems for multi-photon polymerization deliver very high resolutions, yet are limited by high plant costs and low process speed. The aim is to develop a compact, cost-effective, rapid alternative to conventional technology by combining different rapid prototyping processes with beam guidance tailored to the process. The process design supports a wide range of materials that are relevant for tissue engineering. Special polyblends with modified mechanical properties, such as elasticity, are used, along with biomolecules that promote cell growth.

Result

To fulfill these aims, a flexible, modular test plant with two different laser beam sources (femtosecond and picosecond system) has been implemented. Three-dimensional structures can be manufactured from different materials with resolutions < 1 μm using this test plant.

Applications

A compact MPP module is used in the field of rapid prototyping of micro- and nanostructures made out of synthetic polymers and natural proteins. A key area relates to tissue engineering, with the high resolution supporting the production of cell-specific structures. However, the technology is also relevant for non-medical applications on account of its high resolution.

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3 Electron-microscope image of a μ-knight with a height of approx. 80 μm.
4 Electron-microscope image of a polymer tube with an internal diameter of 20 μm.
COMPACT SYSTEM FOR LASER INDUCED FORWARD TRANSFER

Task

Medical engineering applications used to manufacture microarrays or polymer electronics applications used for polymer electronic components involve the transfer of costly high-viscosity or solid materials. Conventional processes such as inkjet printing cannot handle these materials. Dead volumes also result in substantial material wastage. The laser induced forward transfer (LIFT) process enables high-viscosity and solid materials to be deposited without damage, achieving a spot size of up to 10 μm and with minimal material loss. Even sensitive objects such as cells can be accurately placed on any given surface.

Method

The LIFT processing system involves a converted GeSiM Nanoplotter™ which has been designed to ensure broad compatibility with existing systems. Optimum system features include:

- Compact, easily transportable design
- Automatic feeding of donor film
- Automatic relative positioning of donor film and receiving substrate

Result

In collaboration with GeSiM, a scanner and a miniaturized solid-state laser were added to a compact positioning system. This setup supports end-to-end processing of carriers for transfer materials. Meanwhile, the donor film and the substrate to be coated can be positioned relative to one another, thus allowing freely configurable contours to be printed.

Applications

The developed compact LIFT printing system for high-viscosity and solid materials supports rapid printing of proteins or DNA used in the manufacture of analytical microarrays under sterile conditions. Flexible component holder and interchangeable material carriers also pave the way for transferring solid materials and new formulations of bioactive materials onto medical engineering components. Other applications include polymer electronics since the laser printing process does not damage the material and utilizes minimal quantities of the material in question. Consequently the LIFT process also adds up to an economic solution for small-scale applications.

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1 Table-top system for LIFT.
2 Protein microarray produced using LIFT.
GLASS-MICRO FLUIDICS FOR MEDICAL APPLICATIONS

Task
Micro fluidics made out of plastics with micro channels (approx. 100 µm in diameter) are used for rapid tests in medical research. Since substances from the plastic can diffuse into the test fluid, the test results may be distorted. Furthermore, plastic micro fluidics cannot be reused because they cannot be cleaned sufficiently. The objective is to manufacture micro fluidics made of a chemical inert material like glass using a laser assisted etching process (In-volume Selective Laser Etching, short ISLE).

Method
For the ISLE process the device is first irradiated with tightly focused ultra short pulsed laser radiation. Using a scanner system with various focusing options 3D structures are manufactured in the volume of the transparent material. The material is locally modified by the laser radiation, which results in a better etchability of the irradiated areas. In the subsequent etching step the irradiated material is removed creating the required geometries.

Result
In addition to manufacturing simple micro channels in the volume of different glasses, channel systems and hollow volumes have been realized. ISLE is also the appropriate tool to manufacture micro devices like cog wheels and thin-walled glass tubes.

Applications
Glass-micro fluidics manufactured using ISLE have a wide range of application in medical research. Also the amount of toxic substances in the chemical industry and research can be substantially reduced using glass-micro fluidics.

In the near future, glass-micro fluidics will be used wherever test tubes are used at present.

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3 Coupler system made out of micro channels with a length of approx. 800 µm in 1 mm thick fused silica, manufactured with ISLE.
4 Scanning electron microscope image of the cross-section of a 1 cm long micro channel in sapphire. The channel is about 1 µm wide and 125 µm high.
TWIN-BEAM RAMAN DIFFERENCE SPECTROSCOPY

Task

The detailed analysis of biochemical interactions, especially of specific interactions between proteins and their binding partners, is one of the basic tasks performed in pharmacological research.

Raman difference spectroscopy is a process that enables detailed conclusions to be drawn about the interaction between molecules. Changes in the vibration spectrum of a molecule, which already occur as a result of non-covalent interactions with binding partners, can be detected accurately using Raman difference spectroscopy. On the basis of the difference of the Raman spectra of a protein as well as a protein-ligand complex, quantitative and qualitative assertions about the existence and type of interactions can be made.

Ideally, both spectra are recorded simultaneously, so that minute changes to the measurement parameters, such as laser power, sample temperature, calibration, have an identical effect on both measurements, thus providing exact differentiation.

Method

A demonstrator that uses twin-beam Raman difference spectroscopy has been set up at the Fraunhofer ILT. Optics are used to split the laser beam into two partial rays; each sample - protein and protein-ligand complex - is excited using a focused partial ray and the Raman signal imaged using a confocal optical arrangement in one fiber respectively. Both fibers are connected to an imaging Czerny-Turner spectrometer which allows the two Raman spectra to be recorded simultaneously.

Result

A Wollaston prism splits the laser beam at an included angle of approx. 8.1° in order to generate two focal points at a distance of 1.25 mm using a microscope lens. The distance of the focal points is decisively influenced by the choice of lens. To couple the broadband Raman signal, a lens has been developed which consists of an achromatic lens and a magnesium fluoride lens, and boasts high coupling efficiency. A prototype demonstrator is already up and running.

Applications

This process could provide a faster, more cost-effective alternative to conventional fluorescence-based measuring techniques for research into new pharmaceuticals.

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The focus of the technology field Laser Measurement 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 direct analysis of high-throughput metallic material flows.
PROCESS FOR IMPROVING THE EFFICIENCY OF AIRBORNE PARTICULATES ANALYSIS

Task

An analysis process based on laser-induced breakdown spectroscopy has been designed to determine directly the chemical composition of airborne particulates with sizes ranging from 10 nm to 1 μm in a gas stream. The aim is to increase the sensitivity of this process in order to detect minute traces of analyte material and individual particulates.

Method

In order to increase the sensitivity of the process, a new particulate inlet has been developed which transfers the particulates to a measuring chamber where the measurement process takes place. The inlet enables radial concentration of the particulates where they react with the laser beam. This increases the intensity of the analysis signal, as well as the sensitivity and stability of the measurement process. Various methods for concentrating the particulates are being tested and their impact on the analysis investigated.

Result

A modular particulate inlet has been developed that allows particulates measuring between 10 nm and 1 μm to be introduced into the interaction zone with the laser beam. The design enables the inlet to be utilized in various configurations, including nozzles and aperture arrangements in various sizes, as well as a ducted flow system to concentrate the aerosol stream. By using an arrangement consisting of several apertures with different internal diameters, the analyte signal was increased on average by 10 percent. The detection limit for the analysis of particulates based on size has been reduced in relation to mass by a factor of 5. By improving localization in the interaction zone of the particulate stream and the laser beam, individual particulates down to a size of 120 nm in diameter were detected.

Applications

The process can be used in all industrial areas in which process dust plays a role. Due to its rapid response, the process can be used with in-line analysis of process dust. The size-resolved analysis of the chemical composition makes it possible to locate the source of emissions from different processes once these have been identified against a background aerosol.

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1 Accumulated CaCl₂ particulates on an impact-sensor plate; in the background the analysis process using the laser.
2 Aerosol inlet components that provide radial concentration of particulates of varying sizes.
DIRECT ANALYSIS OF MINERAL RAW MATERIALS WITH A LASER

Task

Mineral raw materials are subject to natural variations. The composition of the material differs between individual natural deposits and may also vary widely within the same natural deposit site. Knowledge of the material’s composition is indispensable to its targeted extraction and commercially effective usage. Composition analysis often relies solely on measurement methods that provide analysis results with a considerable time lag and at high cost. These methods may also pinpoint parameters that are only indirectly linked to the material’s composition and thus prone to error.

Method

Direct laser analysis using laser-induced breakdown spectroscopy (LIBS) directly determines the content of all the required elements. The measurements are conducted inline on the material flows during industrial processing. The measurement devices are purpose-built to work with existing powdered or solid materials. The results are analyzed in real time and transferred to the process control function; in many cases, it is now possible for the first time to directly adjust processes to variations in the material composition.

Result

A demonstrator to measure the composition of borings while conducting blasthole drilling has been tested in field trials and can be used in future to draw up an inline natural deposit model in support of the flexible adjustment of the hole matrix. In cooperation with industry partners, a system has been set up which continually determines the ash content of coal, thus providing data on the coal’s calorific value.

Applications

Direct laser analysis can be used to analyze the content of all mineral raw materials. Economic benefits can be derived from specifically targeting the usable rock in extraction and processing of the raw materials. As a result, natural deposits can be extracted more precisely and exploited for longer. This method saves raw materials and energy, helping to conserve natural resources.

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3 Inline analysis system for coal.
4 Demonstrator for direct laser analysis on a drilling rig.
LASER DIRECT ANALYSIS OF HIGH-THROUGHPUT METALLIC MATERIAL FLOWS

Task

Limited resources and increasing energy prices are helping promote the usage of secondary raw materials. In the field of material recycling in particular, there is a need to characterize secondary raw material streams in terms of their basic elements prior to the melt process, and particularly to sort these various materials. Laser-induced breakdown spectroscopy (LIBS) offers a flexible, viable process for this application that provides contactless multi-element analysis of various metallic materials, such as stainless steel, aluminum or titanium.

Method

The laser direct analysis uses a pulsed Nd:YAG laser, which exposes moving objects on a conveyor belt (3 m/s) to a laser pulse using a galvanometric scanner mirror system. The laser-induced plasma of each individual object is analyzed spectroscopically and a sorting decision taken. In conjunction with a sorting and recycling plant manufacturer, the LIBS system developed at the Fraunhofer ILT has been integrated into a sorting system, see figure 2. The entire system will be tested in terms of its robustness for industrial usage with high mass throughputs of > 4 t/h.

Result

Initial measurements with defined sample rates demonstrate that aluminum cast and wrought alloys can be correctly identified and separated with up to 95 percent accuracy. To this end, silicon - the characteristic element for both analyzed alloys - was used as a sorting criterion.

Applications

Applications of this technology can be found especially in the recycling industry to identify individual particles, as well as to characterize material flows. Laser excitation of the measuring radiation means this method of optical LIBS is not limited to metallic materials, but can also be used for minerals, such as limestone, dolomite, coal, etc.

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1 Discharge unit for sorting individual particles.
2 Sorting plant for laser direct analysis.
X-RAY MICROSCOPY ANALYSIS OF NANOPARTICLES

Task

Nanoparticles are the subject of research in material science, colloid chemistry and medicine. They are increasingly being used in everyday products. Analysis of the self-organization of nanoparticles in fluid media calls for microscopic processes with resolutions in the region of 50 nm. Conventional light-microscopy processes cannot deliver such fine resolution. High-resolution transmission electron microscopy cannot be used either on account of the limited penetration depth of the electrons.

Method

A laboratory x-ray microscope developed in conjunction with the Institute for X-Optics at the Koblenz University of Applied Sciences and Bruker ASC is being operated at the Fraunhofer ILT. The device is fitted with a gas-discharge source developed at the Fraunhofer ILT. It enables samples up to 10 μm thick to be analyzed with a resolution of 60 nm at a working wavelength of 2.88 nm.

The University of Michigan is conducting research into the creation of multiple-branched nanocrystals and nanotubes by means of the self-organization of cadmium-telluride nanocrystals and lead-sulfide nanocrystals. The structures are being used for innovative semiconductor materials, which will help boost the efficiency of organic solar cells.

Result

These particles are being analyzed by means of x-ray microscopy at the Fraunhofer ILT. Resolution and contrast of the images demonstrate the suitability of the process for analyzing these nanostructures. In a follow-up experiment, the self-organization of nanoparticles, which is completed over a period of hours, can be tracked directly in the fluid medium.

Applications

Self-organization of nanoparticles is an interesting proposition for various applications:

- Nanoelectronics, e.g. innovative organic semiconductor materials
- Colloid chemistry, e.g. structure formation when setting concrete
- Environmental sciences, e.g. analysis of the morphology of soils

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3 X-ray microscope images of PbS nanocrystals (left) and CdTe nanotubes (right).
MODULATED FLUORESCENCE POLARIZATION

Task

Fluorescence polarization is an antibody-based analytical process which facilitates the highly specific quantitative detection of various analytes. Together with partners from industry and research, the Fraunhofer ILT is working on the further development of this process for the accurate detection of mycotoxins in cereal products.

Method

Modulated fluorescence polarization is being developed to achieve the highest possible sensitivity. The analytical signal of a fluorescence polarization experiment is generated from the difference between two polarization components of the sample fluorescence. The two fluorescence components (horizontal and vertical) alternately hitting the detector at rapid intervals give rise to a modulated signal. The modulation depth (amplitude) corresponds to the sought analytical signal. High signal quality and high analytical accuracy are achieved thanks to a phase-correct averaging of numerous signal periods.

Result

A demonstrator for the modulated fluorescence polarization has been set up. The signal modulation is generated by rotating a polarization analyzer.

Initial validation measurements have been taken using the system; polarization values (P values) of fluorescein as a standard dye in a concentration range of up to 0.1 nmol have been recorded.

Applications

The work is being integrated into a system for food analysis, which should allow cereals and cereal samples to be analyzed. Modification of the biochemical assays will also allow other food toxins to be detected.

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1 Polarization modulation device.
DISCHARGE-BASED COMPACT SOURCES OF EXTREME ULTRAVIOLET RADIATION

Task

The spectral range of extreme ultraviolet radiation (EUV) offers a wide range of innovative applications in materials analysis, metrology, life sciences and microscopy. The requirements placed on compact radiation sources differ widely within these applications. The spectral/spatial emissions characteristics and the radiance of the source constitute the determinant parameters.

Method

Based on the concept for hollow-cathode-triggered pinch plasma developed for extreme ultraviolet radiation lithography (EUVL), a compact modular radiation source is being developed whose emissions properties can be varied across a wide range. Beam-guidance and vacuum-integration components tailored to the application complement the system.

Result

The radiation source is operated in three configurations for different spectral ranges. Typical repetition rates lie in the region of 1000 Hz to 3000 Hz. In terms of average radiation output and brilliance, the values achieved represent benchmarks in international comparison.

Applications

There are numerous applications for the compact source of extreme ultraviolet radiation:
- Soft X-ray microscopy
- Mask inspection for EUV lithography
- Technology development in the EUVL environment (e.g. resist development, optics characterization)
- EUV-based metrology for nanosciences

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1. Line radiation at 2.88 nm wavelength with a relative spectral width Δλ/λ von 1/840; radiance: 2·10⁹ photons / (µm² sr s); emission-line intensity: 15 W / (2π sr)
2. Radiation at 11 nm wavelength in 4% bandwidth
   Radiance: 100 W / (mm² sr) @ 11 nm ± 2 %
   Beam intensity: 40 W / (2π sr) @ 11 nm ± 2%
3. Radiation at 13.5 nm wavelength in 2% bandwidth
   Radiance: 13 W / (mm² sr) @ 13.5 nm ± 1 %
   Beam intensity: 45 W / (2π sr) @ 13.5 nm ± 1 %

2 Compact source of extreme ultraviolet radiation.
EUV DEFECT INSPECTION

Task

Defect-free masks and mask blanks are required to use EUV lithography as new chip-manufacturing technology. There is still no inspection device on the market, however, that can analyze EUV masks and mask blanks for defects. All defects > 20 nm need to be detected on the mask or on the mask blank. Since the masks and mask blanks are built up as multilayer mirrors and potential defects may also be located in or below the multilayer, the same wavelength must be used during inspection as used during the manufacturing of the chips.

Method

The dark-field mode is ideal for detecting defects thanks to its high contrast and ability to detect low signals produced by small defects. An EUV dark-field microscope in reflection mode is therefore used to inspect mask blanks. The radiation from a gas-discharge source is focused via an ellipsoidal ring collector and a deflection mirror onto the sample. The potential defect on the sample scatters the light; the mask blank itself reflects the light. The reflected portion of the light is blocked at the deflection mirror and only the scattered light reaches the Schwarzschild objective. The objective images the scattered light onto a CCD camera. Although the defect is not resolved, the sensitivity to small defects is fully utilized. The advantage of this option is the large image area (due to the moderate 21-times magnification of the lens) that facilitates faster scan speeds.

Result

The EUV dark-field microscope has been set up and its functionality demonstrated on various defects on multilayer mirrors. The analyzed structures have also been examined with a scanning force microscope for comparison purposes.

Applications

Mask manufacturers require a mask-blank inspection device to guarantee that the produced masks are defect-free.

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1 Optical system on the EUV microscope.
2 Plant for inspecting defects on EUV masks.
FEMTO EUV

Task

Sub-100 nm structures are increasingly being used in technology areas such as photovoltaics, biotechnology or for the design of functional photonic and plasmonic surfaces. An understanding and control of the dynamic development process is essential for reproducible results in the manufacture of tailor-made nanostructures. Numerical simulation provides one way of understanding and describing the formation of these kinds of nanostructures. The theoretical models created in the simulation and the corresponding input parameters are validated by means of ultraprecise experimental data and tailored to the actual dynamic development processes of the nanostructures.

Method

An innovative high-resolution EUV pump-probe microscope has been developed to monitor the formation dynamics of laser-induced nanostructures on metallic thin-films. This combination brings together the large temporal resolution of a pump-probe process with the large spatial resolution of an EUV microscope in a single apparatus. To generate the structures, laser radiation with pulse durations < 100 fs is coupled into the observation chamber. An oxygen plasma is used as the illumination source, combined with a zone plate as imaging optics and a microchannel plate as detector, to facilitate high spatial resolution of the nanostructure formation process of Δx < 100 nm. Thanks to the temporal coupling of fs laser, EUV illumination source and microchannel plate, high temporal resolution is achieved in the sub-ns region.

Result

A vacuum chamber with an oxygen EUV source and a 5-axis positioning system for the investigation samples has been set up. The EUV source is now in operation and has produced the first images of static test objects.

Applications

The EUV microscope provides all analytical areas of chemistry, biology, mechanical engineering, etc. with an innovative method to observe - at high temporal resolution - the dynamic processes of structures which are built up on a scale below the resolution capability of conventional microscopes.

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### FACTS AND FIGURES

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26.09.2010 - I. Kelbassa: Additive manufacturing, repair and salvage of turbo machinery components by laser metal deposition. ICALEO® 2010, Anaheim, CA, USA

27.09.2010 - D. Wortmann: EUV-pump-probe microscopy of fs-laser induced nanostructure formation. ICALEO® 2010, Anaheim, CA, USA

27.09.2010 - M. Hörstmann-Jungemann: 3D nano- and microstructures in transparent materials by in-volume femtosecond laser processing. ICALEO® 2010, Anaheim, CA, USA

28.09.2010 - J. Gedike: Laser beam welding of electrical interconnections for lithium-ion batteries. ICALEO® 2010, Anaheim, CA, USA

28.09.2010 - D. Petring: Laser cutting basics, state-of-the-art and research topics. ICALEO® 2010, Anaheim, CA, USA

28.09.2010 - J. Witzel: Increasing the deposition rate of inconel 718 for LMD. ICALEO® 2010, Anaheim, CA, USA

28.09.2010 - P. Russbueldt: Status quo and outlook of power scaling of ultrafast lasers. ICALEO® 2010, Anaheim, CA, USA


29.09.2010 - D. Petring: Learning more about laser beam welding by applying it to copper and copper alloys. ICALEO® 2010, Anaheim, CA, USA

29.09.2010 - S. Kaierle: Concept and realization of a high-rate laser drilling process reaching for ten thousand holes per second and beyond. ICALEO® 2010, Anaheim, CA, USA

29.09.2010 - M. Hörstmann-Jungemann: 3D-microstructuring of sapphire using high power fs-laser radiation and selective etching. ICALEO® 2010, Anaheim, CA, USA

29.09.2010 - R. Poprawe: New ultrafast high power KW lasers open next generation applications. IEEE Photonics Society, New Jersey, USA
30.09.2010 - R. Ostholt: Laser polishing of metallic freeform surfaces. ICALEO® 2010, Anaheim, CA, USA

30.09.2010 - D. Hawelka: Laser-based production of thin wear-protection films. ICALEO® 2010, Anaheim, CA, USA

30.09.2010 - C. Franz: Measuring welding velocity at tool center point. ICALEO® 2010, Anaheim, CA, USA

30.09.2010 - A. Roesner: Laser in der Kunststofftechnik. IVAM-Workshop, Dortmund

30.09.2010 - J. Weitenberg: Festkörperlaser und Diodenlaser für das Schweißen von Kunststoffen. Süddeutsches Kunststoffzentrum, Würzburg

03.10.2010 - R. Poprawe: High power ultra short pulse lasers - key enablers for emerging Applications, Deutsch-Chinesischer Workshop, Wuhan, Volksrepublik China

04.10.2010 - I. Kelbassa: Laser additive manufacturing. Deutsch-Chinesischer Workshop, Wuhan, Volksrepublik China


05.10.2010 - S. Engelhardt: Fabrication of 3D polymer-protein hybrid structures. 2010 International Conference of Biofabrication, Philadelphia, PA, USA

06.10.2010 - D. Riester: Polymer- alginate hybrid structures produced with laser induced forward transfer. 2010 International Conference of Biofabrication, Philadelphia, PA, USA

06.10.2010 - N. Seiler: Laserinduzierte Gradienten zur Oberflächen-funktionalisierung von Polymeren. Jahrestagung der Deutschen Gesellschaft für Biomedizinische Technik, Rostock

06.10.2010 - D. Ivanov: Present stance of molecular dynamics problems. Molecular dynamics based studies of solid targets response to a strong and localized excitation. LPPM3, Petrovac, Montenegro

06.10.2010 - V. Lipp: Atomistic-continuum modeling of short pulse laser melting of semiconductors. LPPM3, Petrovac, Montenegro


15.10.2010 - J. Holtkamp: Künftige Lasertechnologien in der Mikrobearbeitung und deren Anwendung. LaserJob Technologie Forum, Fürstenfeldbruck

18.10.2010 - L. Juschkin: Artificial and natural mirrors: comparison of dark field EUV microscope and AFM. International Symposium on Extreme Ultraviolet Lithography, Kobe, Japan

Sino-German Workshop on Simulation of Welding, Berlin

27.10.2010 - A. Gillner: Micro and nano processing with ultra short 
pulsed lasers. ISL 2010, Chemnitz

03.11.2010 - M. Traub: Novel applications for high power diode lasers 
enlighten meetings. High power diode lasers & systems. Photonex 
2010, Telford, Großbritannien

04.11.2010 - M. Nießen: Modelling and simulation for laser cutting 
- recent advances in numerics. The 6th International Conference 
of Photonics and Applications, Hanoi, Vietnam

04.11.2010 - G. Vossen: Optimization methods for laser processings - 
theory, numerics and applications. The 6th International Conference 
of Photonics and Applications, Hanoi, Vietnam

08.11.2010 - M. Nießen: Discontinuous-Galerkin method for com-
pressible flows in a laser cut kerf. The 6th International Conference 
of Photonics and Applications, Hanoi, Vietnam

09.11.2010 - G. Vossen: Numerical model reduction for computation 
of a heat source in laser welding. The 6th International Conference 
of Photonics and Applications, Hanoi, Vietnam

10.11.2010 - R. Poprawe: Was gibt es Neues in der Zukunft der Laser-
technik? Rotaract Club Aachen, Aachen

12.11.2010 - R. Poprawe: Faszination Lasertechnik. Wissenschafts-
nacht der RWTH Aachen, Aachen

12.11.2010 - R. Ostholt: Laser polishing. Konferenz neue Polier-
technologien, Neuchâtel, Schweiz

13.11.2010 - L. Juschkin: Interference lithography at 11 nm with 
a laboratory gas discharge source. 2010 International Workshop on 
Extreme Ultraviolet Sources, Dublin, Ireland

13.11.2010 - L. Juschkin: GIXUVR- grazing incidence extreme 
ultraviolet reflectometry: an all-optical technique for metrology 
of ultra-thin layers. 2010 International Workshop on Extreme Ultra-
violet Sources, Dublin, Ireland

13.11.2010 - L. Juschkin: EUV dark-field microscopy for actinic defect 
inspection. 2010 International Workshop on Extreme Ultraviolet 
Sources, Dublin, Ireland

14.11.2010 - K. Bergmann: Brilliance scaling of discharge based 
EUV and soft X-ray sources. 2010 International Workshop on 
Extreme Ultraviolet Sources, Dublin, Ireland

14.11.2010 - P. Loosen: Advanced INNOSLAB solid-state-lasers for 
XUV/EUV-generation. 2010 International Workshop on Extreme 
Ultraviolet Sources, Dublin, Ireland

15.11.2010 - M. Nießen: Discontinuous-Galerkin method for com-
pressible flows in a laser cut kerf. Institute of Aerodynamics and 
Gardynamics, Stuttgart

19.11.2010 - L. Juschkin: GIXUVR-Grazing incidence extreme 
ultraviolet reflectometry: an all-optical technique for metrology 
of ultra-thin layers. COST Action MP0601, Short Wavelength Laboratory 
Sources, Southampton, Großbritannien

19.11.2010 - A. Maryasov: EUV dark-field microscopy for defect 
inspection. COST Action MP0601, Short Wavelength Laboratory 
Sources, Southampton, Großbritannien

26.11.2010 - R. Poprawe: Präzision trifft Leistung - KW Ultrakurz-
pulslaser für neue Bearbeitungsverfahren. FH Jena, Jena

30.11.2010 - R. Poprawe: Innovation mit Lasertechnik - von der 
Auftragsforschung bis zum RWTH-CAMPUS. Carl Zeiss Jena, Jena
30.11.2010 - H. Kind: Glaslöten mittels Laserstrahlung für Anwendungen in der Sensorik. Zentralverband Elektrotechnik- und Elektronikindustrie e. V., Frankfurt/Main


06.12.2010 - R. Poprawe: The future of tailored light-perspectives of lasers, applications and strategies. 74th annual meeting of the Japan Laser Processing Society, Tokyo, Japan


AKL’10

05.05. - 07.05.2010, Aachen
International Laser Technology Congress AKL’10

Laser manufacturers and users from various branches were meeting for the eighth time in the imperial city at the biannual International Laser Technology Congress AKL from May 5 to 7, 2010. The AKL’10 was organized by the Fraunhofer Institute for Laser Technology ILT. Supporting organizations included the European Commission, the Association of German Engineers (VDI), the Arbeitskreis Lasertechnik e.V., the European Laser Institute ELI as well as the following industrial associations: the European Federation of Precision Mechanical and Optical Industries (EUROM), the German Industrial Association for Optical, Medical and Mechatronical Technologies Inc. (SPECTARIS), the German Association of the Automobile Industry (VDA) and the German Association of Machine and Plant Construction (VDMA).

With over 500 participants, around 60 speakers and over 30 exhibitors, the AKL has established itself as the leading forum for applied laser technology in Germany. The international public got a wide range of lectures in complete German and English simultaneous translations. From newcomers via system providers all the way to laser users, the AKL’10 offered something relevant for every target group.

The technological symposium of the AKL’10 (May 6 to 7, 2010) informed users and manufacturers about the latest developments and practical experience with laser production processes such as laser welding, cutting, drilling and removal. The conference also emphasized new laser sources, like ultra-short pulse lasers or the next generation of diode, fiber and solid-state lasers. Within the framework of the sponsor’s exhibition, around 30 companies presented practical laser-based solutions to the professional public for a whole range of branches from the manufacturing industry. On the Technology Business Day (May 5, 2010), managing directors, marketing officers as well as sales directors received an overview of the current status as well as the perspectives of the laser market world-wide.

At the seminar »Laser Technology ABC's« (May 5, 2010), experts from laser praxis offered a structured and praxis-oriented overview to companies with little experience in this area. The EU Innovation Forum »Laser Processing in Aeronautics and Power Generation« (May 5, 2010) was directed at experts from industry and science who work with laser material processing for turbine construction. Within the scope of the event Laser Technology Live (May 7, 2010), the Fraunhofer ILT and the companies of the Application Center of the Fraunhofer ILT presented in around 80 live presentations the latest results from application-oriented research and development.

05.05.2010, Aachen
Technology Business Day TBT’10

This event was directed at marketing managers, sales executives, company directors and senior managers who wished to obtain specialized information on the current status and future prospects of the laser technology markets. The information presented by industry insiders and market specialists was also of value to technology brokers, management consultants, market analysts and investors.

The European, American and Asian markets for laser products were analyzed for the around 130 participants on the basis of market studies. A breakdown of the relevant sales regions was presented. Market forecasts were drawn up on the basis of current technological developments and enduser requirements. A closer look was taken by industry experts using the example of individual branches of industry in order to meet the requirements of manufacturing applications. These were then translated into the trends that laser technology will follow in future years. The Technology Business Day is intended as a forum and platform for decision-makers tasked with devising product and business strategies, and as such forms a complement to the more technically oriented aspects of the AKL’10 Congress.
05.05.2010, Aachen
EU Innovation Forum »Laser Processing in Aeronautics and Power Generation«

At the EU Innovation Forum the around 80 members of collaborative EU projects met to discuss the results of their R&D work. There was also an intensive exchange of experiences with technology suppliers in the laser sector and technology users in the aircraft and power generation industry. The EU Innovation Forum focused on the topic of laser production technology in turbo engines. In sessions, participants discussed the technological aspects of generative and joining laser processes and their application in the production of aircraft components and power generation as well as in maintenance, repair and overhaul.

At the end of the EU Innovation Forum, participants could discuss the successful results of the R&D work in a series of live presentations at the applications center of the Fraunhofer ILT.

05.05.2010, Aachen
Awarding ceremony of the Innovation Award Laser Technology 2010

The Innovation Award Laser Technology 2010, initiated by the associations Arbeitskreis Lasertechnik e.V. and the European Laser Institute ELI and provided with 10 000 Euros prize money, has been conferred to Dr. rer. nat. Keming Du, managing director of EdgeWave GmbH, Würselen, Germany on May 5, 2010 in Aachen’s town hall. In the historical ambience of the »Coronation Hall« over 250 guests attended the awarding ceremony.

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. Prof. Dr.-Ing. habil. Prof. e. h. mult. Dr. h. c. mult. Hans-Jörg Bullinger, president of the Fraunhofer-Gesellschaft and dinner speaker of the awarding ceremony, conferred the 1st prize of the Innovation Award Laser Technology 2010 provided with 10 000 Euro prize money to Dr. Keming Du and his team of the EdgeWave GmbH, Würselen, Germany for the development of »Q-switched INNOSLAB lasers for high quality micro-processing«. The prize winner Dr. Du has been furthermore awarded the title of »AKL Fellow« and »ELI Fellow«. The trophy for the prize winner and
the certificates for Dr. Du and the other project management team members Dr. Claus-Rüdiger Haas, Dipl.-Ing. Alexander Schell and Dr. Dailjun Li were 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 international jury, consisting of 10 members that are recruited from industry and the research community, selected 2 other innovation teams as finalists, which have also been honoured in the Coronation Hall.

The prize for the 2nd place of the Innovation Award Laser Technology 2010 has been conferred to Dipl.-Ing. Jürgen Dupré and his team of Rolls-Royce Deutschland Ltd. & Co. KG, Dahlewitz and Oberursel, Germany. The innovation consisted in a »New repair technique for aero-engine components using Laser Metal Deposition«.

The members of the project management team were:
• Dipl.-Ing. Jürgen Dupré, Repair Engineering Specialist, IPT Lead, Rolls-Royce Deutschland Ltd. & Co. KG, Dahlewitz
• Certified Engineer Elke Weiss, Repair Engineer Rolls-Royce Deutschland Ltd. & Co. KG, Oberursel
• Dipl.-Ing. Gerhard Backes, Project Leader Repair Processes Lehrstuhl für Lasertechnik LLT, RWTH Aachen University
• Dr. Andres Gasser, Group Leader Laser Metal Deposition Fraunhofer-Institut für Lasertechnik ILT, Aachen

The prize for the 3rd place of the Innovation Award Laser Technology 2010 has been conferred to Dipl.-Ing. Hermann Lembeck and his team of the MEYER WERFT Laserzentrum GmbH, Papenburg, Germany. The innovation consisted in »Laser hybrid welding of thick sheet metals with disk lasers in shipbuilding industry«.

The members of the project management team were:
• Dipl.-Ing. Hermann Lembeck, Factory manager
• Dipl.-Ing. Guido Pethan, Project leader invests
• Dipl.-Ing Frank Boekhoff, Test manager, R&D MEYER WERFT Laserzentrum GmbH, Papenburg

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

06.05.2010, Aachen
25th anniversary of Fraunhofer ILT

The Fraunhofer Institute for Laser Technology ILT was founded 25 years ago by Prof. Gerd Herziger. Based in Aachen, the Institute employed five members of staff. Under the auspices of the Fraunhofer-Gesellschaft the research institute flourished and is now the largest laser center in Europe. The institute’s 300 staff develop processes, systems and beam sources for laser manufacturing and laser measurement. Its customers represent a wide range of industrial sectors, from medical engineering to the auto and aviation industry. Highlights of the past 25 years include the 40-KW CO2 laser, developed in collaboration with industrial partner Trumpf, and the 4-KW diode-pumped solid-state laser, developed together with Rofin-Sinar. Applying the results of Fraunhofer ILT’s research, the electronic switch systems manufacturer Marquardt became the first company to successfully use a diode laser to weld plastic components.
The development and qualification of selective laser melting and the combined cutting and welding method using special optics was a pioneering advance in laser-based process technology. Fraunhofer ILT filed 365 patents between 1985 and 2009. Over this period, some 30 companies were spun off by former employees. Numerous alumni bring their know-how to industrial production by working for laser manufacturers and laser users. Through the association Arbeitskreis Laser-technik e.V., the “Aix-Laser-People” alumni club organizes regular meetings that help promote specialized training and networking.

The official Fraunhofer ILT anniversary celebrations with partners, alumni and customers were held on May 05, 2010 as part of the AKL’10 in the Ludwig Forum. At the end of September 2010, the 25th anniversary was fittingly celebrated in the institute’s facilities with over 300 employees in attendance.

CONGRESSES AND SEMINARS

05.05. - 07.05.2010, Aachen
International Laser Technology Congress AKL’10

22.06. - 23.06.2010, Bonn
Conference on Multiphysics Simulation

19.10. - 20.10.2010, Aachen
6th 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 120 delegates examined in detail the three themes of »Market and Strategies«, »Products and Innovation« and »Technology and Production« as part of some 20 presentations.

1 25 years of Fraunhofer ILT - anniversary celebrations in the Ludwig Forum in Aachen.
2 Lecture sessions at the 6th International Colloquium on Optics in Aachen.
3 Dr. Reinhard Noll during his presentation at the Aachen Laser Seminar.
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 6th International Colloquium on Optics in Aachen can be found at www.optik-kolloquium.de.

21.10.2010
Plymouth, Michigan, USA
Technical Conference »Towards Carbon Neutral Vehicles«
Conference organized by Fraunhofer USA and the Michigan Memorial Phoenix Energy Institute of the University of Michigan with around 100 delegates from the automotive sector in Plymouth, Michigan, USA.

10.11.2010, Aachen
4th HANNOVER MESSE Laser Fall Convention
Topic: Lasers in Production, New Opportunities for Photovoltaics and Electromobility Focusing on Manufacturing Technology for Energy Storage Devices and Electric Vehicles. The HANNOVER MESSE Laser Fall Convention was organized jointly by Fraunhofer ILT, the Laser Zentrum Hannover, LIMO Lissotschenko Mikrooptik GmbH, the Ruhr-Universität Bochum (Faculty of Mechanical Engineering, Laser Applications Technology), the IVAM Fachverband für Mikrotechnik - an international association of companies and institutes in the field of microtechnology, nanotechnology and advanced materials - and by trade fair organizer Deutsche Messe Hannover. The Laser Fall Convention provided an insight into the special exhibition on »Lasers for Micromaterial Processing and Microproduction« at the HANNOVER MESSE. Key areas include mobile energy-storage devices, power infrastructure as well as alternative fuels.

09.12. - 10.12.2010, Aachen
Seminar organized by specialist publisher Carl Hanser Verlag Munich in cooperation with the Fraunhofer Institute for Laser Technology ILT in Aachen.

COLLOQUIUM ON LASER TECHNOLOGY AT THE RWTH AACHEN UNIVERSITY

14.01.2010, Aachen
Chair for Laser Technology LLT at RWTH Aachen
Colloquium on Laser Technology
Prof. Dr. S. Hell, Max-Planck-Institut für biophysikalische Chemie, Göttingen: »Optische Nano-Mikroskopie jenseits der Beugungsgrenze«

14.04.2010, Aachen
Chair for Laser Technology LLT at RWTH Aachen
Colloquium on Laser Technology
Prof. Dr. L. Wöste, Freie Universität Berlin, Institut für Experimentalphysik, Berlin: »Nutzung und Anwendung von Plasma-Filamenten«

22.04.2010, Aachen
Chair for Laser Technology LLT at RWTH Aachen
Colloquium on Laser Technology
Dr. H. Giessen, Universität Stuttgart, 4. Physikalisches Institut, Stuttgart: »Meta-Nano Materialien«
1 Participants of the »Conference on Multiphysics Simulation« in Bonn.
2 Presentation for pupils at the Fraunhofer ILT.
3 Fraunhofer ILT staff at the Photonics West 2010 in San Francisco.
PRESENTATIONS FOR PUPILS AND STUDENTS

29.01.2010, Aachen
Children’s University RWTH Aachen University
Presentation by Prof. Poprawe in the main auditorium of RWTH Aachen devoted to »The Laser Saber of the Future - what Next after Star Wars?«.

11.03.2010, 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 6th grade at the Bischöfliche Maria-Montessori-Gesamtschule in Krefeld.

24.03.2010, Aachen
Guided tour for pupils
Forum organized by the Chair for Laser Technology LLT and the Fraunhofer ILT for pupils of the Ernst-Barlach-Realschule.

21.04.2010, Aachen
Guided tour for students
Forum organized by the Chair for Laser Technology LLT and the Fraunhofer ILT for design students of the FH Aachen.

22.04.2010, 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.

25.05.2010, Aachen
Guided tour for students
Forum organized by the Chair for Laser Technology LLT and the Fraunhofer ILT for a student group from San Sebastian, Spain.

18.06.2010, 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 6th grade at the Gymnasium in den Felder Benden in Moers.

14.07.2010, Aachen
Guided tour for students
Forum organized by the Chair for Laser Technology LLT and the Fraunhofer ILT for a student group from Krakau.

03.08.2010, 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. On August 3, 2010, Fraunhofer ILT took part in the Mechanical Engineering A component with lectures and lab experiments on the topic of laser technology.

12.11.2010, Aachen
Guided tour for students
Forum organized by the Chair for Laser Technology LLT and the Fraunhofer ILT for students of the FH Cologne.
TRADE FAIRS

23.01. - 28.01.2010
San Francisco, USA
Photonics West 2010
International trade fair for optics and photonics
Presence of Fraunhofer ILT and the Chair for Laser Technology LLT on the German Pavilion stand.
ILT topics: Packaging and joining technology for lasers and laser components, marking lasers, fiber lasers, nonlinear optics.

13.04. - 15.04.2010
Paris, France
JEC Composites 2010
Trade fair for composites
Fraunhofer ILT and CLFA were present on the Fraunhofer stand.
Topic: Welding fiber composites.

19.04. - 23.04.2010
Hannover
HANNOVER Messe 2010
International industry fair
Fraunhofer ILT was present on the IVAM stand and on the Fraunhofer stands.
ILT topics: Laser in microtechnology, laser technology solutions for the mobility segment.

06.09. - 10.09.2010
Valencia, Spain
PV-Sec 2010
ILT topic: Laser processes in photovoltaics.

26.09. - 30.09.2010
Anaheim, California, USA
ICALEO 2010
29th International Congress on Applications of Lasers & Electro-Optics
Participation of Fraunhofer ILT and Chair for Laser Technology LLT in the presentation sessions and in the ICALEO vendor exhibition program.

28.09. - 01.10.2010
Düsseldorf
Glasstec 2010
International Trade Fair for Glass Production, Processing, Products
Fraunhofer ILT present on the Fraunhofer stand.
ILT topic: Glass - Material for Innovations.

26. - 30.10.2010
Hannover
EuroBLECH 2010
21st International Sheet Metal Working Technology Exhibition Participation of Fraunhofer ILT.
ILT topics: Combi-head, innovative measurement method to set up and monitor the actual welding line and speed on the workpiece, new technique for controlling the actual TCP position relative to the seam, high-speed cutting of thin metal sheet using fiber lasers, self-optimizing cutting machine.

1 Fraunhofer ILT at EuroBLECH 2010 in Hannover.
2 Fraunhofer stand at K 2010 in Düsseldorf.
27.10. - 03.11.2010
Düsseldorf
K 2010
International Trade Fair for Plastics and Rubber
Fraunhofer ILT present on the Fraunhofer stand.
ILT topic: Mark-free welds using plastic laser welding
with TransTWIST.

17.11. - 19.11.2010
Düsseldorf
COMPAMED 2010
International trade fair
Fraunhofer ILT present on the IVAM stand.
ILT topics: Laser transmission beam welding of plastics
without adding absorbers, microstructuring of tool surfaces
to functionalize molded polymer components.

01.12. - 04.12.2010
Frankfurt
EuroMold 2010
17th International trade fair for tooling and moldmaking,
design and product development
Fraunhofer ILT present on the Fraunhofer Alliance Additive
Manufacturing stand and on the Fraunhofer stand.
ILT topics: Additive manufacturing techniques and polishing
using lasers.

AWARDS

Dr. Ümit Aydin scoops German Study Prize
On November 23, 2010 our former colleague Dr. Ümit Aydin
was awarded the German Study Prize for his work on the
topic »Energy Savings through Automated Laser Sorting for
Aluminum Recycling«: runner-up in the natural sciences and
engineering category. »For me this award is testimony to
RWTH Aachen’s and, particularly, ILT/LLT’s ability to facilitate
first-class dissertations thanks to their subject expertise and
their leading position in the field of cutting-edge research in
Germany«, said the prizewinner, who now works for Boston
Consulting in Düsseldorf.
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 Kaierle (chairman)
  Fraunhofer ILT, Germany
- Dr. Paul Hilton
  TWI, Great Britain
- Dr. Wolfgang Knapp
  CLFA, France
- Prof. Dr. Veli Kujanpää
  Lappeenranta University of Technology, Finland
- Dr. Filip Motmans
  Lasercentrum Vlaanderen, Belgium
- Prof. Dr. José Luis Ocaña
  Centro Láser U.P.M., Spain
- Prof. Dr. Andreas Ostendorf
  Ruhr-Universität Bochum, Germany

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Highlights 2010

Besides participating in Photonics West 2010 in San Jose, USA, and Optatec 2010 in Frankfurt as a joint exhibitor with the other German competence networks for optical technologies, the major events of 2010 were the European technology platform Photonics21 and the participation in the NRW cluster strategy.

The objective of the technology platform Photonics21 is to further strengthen Europe’s leading role in the field of optical technologies and to coordinate joint research and development activities.

The North Rhine-Westphalia regional government’s cluster policy promotes cooperation between business, research institutions and the public sector along the value creation chain in a total of 16 industry and technology fields.

Together with seven other networks, the regional government commissioned PhotonAix to set up cluster management for the »NanoMicro+Materials« technology field.

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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 over 90 members.

AKL e.V.’s mission includes:
• Providing information on innovative laser-technology products and processes
• Nurturing personal networks between laser experts
• Organizing conferences and seminars
• Producing teaching material on laser technology
• Promoting junior scientific staff
• Advising industry and the scientific community on laser-technology issues
• Presenting the Innovation Award Laser Technology Board

Dipl.-Ing. Ulrich Berners (Chairman)
Prof. Dr. Reinhart Poprawe M.A. (Deputy chairman)
Prof. Rolf Schloms (Treasurer)
Dipl.-Phys. Axel Bauer (General secretary)

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CD-ROM »LASER TECHNOLOGY«

CD-ROM »Laser Technology« (German only)

This CD-ROM is a collection of graphics, pictures and videos from the lectures Laser Technology I and II by Prof. Dr. rer. nat. Reinhart Poprawe M.A. and a new revised version was produced in 2003.

It was produced by the Chair for Laser Technology LLT in the machine faculty at the RWTH Aachen University in close cooperation with the Fraunhofer Institute for Laser Technology ILT.

It contains the basics of laser technology as well as physical and technical processes for modern manufacturing processes. Furthermore, the current state of economic use of laser and industrial applications is demonstrated in numerous examples.

The program runs using Acrobat Reader 5.0 on computers with Microsoft Windows 95 OSR 2.0, Windows 98 SE, Windows Millenium Edition, Windows NT 4.0 with Service Pack, Windows 2000, Windows XP and MacOSX (64 MB Ram (random access memory) as well as 30 MB free fixed disk storage).

The printing and use of unaltered graphics and pictures is only allowed for educational purposes.

Further information and order forms for the CD-ROM »Laser Technology« are available through the laser technology association AKL e.V., Steinbachstraße 15, 52074 Aachen.

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»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.


»Tailored Light 2« by Reinhart Poprawe
Laser Application Technology

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