Performance and Results
Annual Report 2008
Economic policy assimilated some time ago that innovation was the key to growth in high-wage countries. The fact that policy-makers not only actively seek public support for this truth, but have also firmly committed themselves to acting upon it, may perhaps be considered a positive core aspect of difficult economic times. In this environment, informed politicians and open-minded entrepreneurs will hopefully see strong national networks, as well as topic-focused and regionally-based clusters, as drivers of innovation. The networking of companies, research institutions, universities and service providers, which complement each other in terms of their performance capabilities, while sharing common interests in defined technology topics, may add genuine momentum to the innovation-led trend. Those taking part will, however, need to appreciate the inherent added value in national cooperation and the attraction it exerts across borders.

The greater the commitment of those involved, and the more targeted the joint initiatives become, the more convincingly the technological cluster can assert its position. There are a wide range of expectations, covering everything from collaborative research and development through collective purchasing power and training, to the internationalization of sales and marketing activities. Unlike national and international networks, the appeal of regional clusters lies in the rapid sharing of information, hardware and personnel along short paths. Naturally, the national impact on international markets is also paramount in this respect.

This recognition led some of Aachen-based institutes, each with proven excellence in their respective fields, to set up the RWTH Aachen Campus project. The aim is to set up one of the largest European technology platforms with offices and research institutions for companies in close proximity to a university. Over the next eight years the intention is to invest over one billion euros in premises, equipment and offices for some 10,000 people. The initial construction phase will start in Melen in 2009 on a site measuring some 270,000 square meters. One of the 15 envisaged clusters relating to optical technologies will be based right next to the Fraunhofer ILT. The Fraunhofer ILT has assumed responsibility for coordinating this cluster and is inviting interested parties to learn more about the benefits and prospects at the Aachen site.

Collaboration with the excellent teams of researchers at RWTH Aachen and the Fraunhofer Institutes will open up new market opportunities for your business. Take this opportunity to become a first mover by getting in touch with us. Take a look at the numerous reviews of R&D projects in the Annual Report to get an idea of what we do. Irrespective of whether you are also interested in our cluster activities, we would of course be delighted to receive challenging assignments from your company. I hope you are inspired by what you read and look forward to your feedback.

Yours sincerely,

Professor Reinhart Poprawe M.A.
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ILT - for more than twenty years, this abbreviation has stood for extensive know-how in laser technology. Innovative solutions for manufacturing and production problems, development of new technical components, competent advice and training, highly-qualified personnel, the latest technologies and an international reputation: these are the guarantors for long-term business relations. The numerous customers of the Fraunhofer Institute for Laser Technology ILT belong to various sectors like automobile industry, mechanical engineering, chemical and electrical engineering, steel construction, precision mechanics and optics.

With more than 250 employees and 10,000 m² of usable floor space the Fraunhofer Institute for Laser Technology is world-wide one of the most important development and contract research institutes of its specific field. The four business areas cover a wide range of actual and vertical integrated topics. In the business area »laser and plasma sources« development activities are concentrated on innovative diode and solid state lasers for industrial use as well as compact EUV-sources for lithographic use in semiconductor production. The business area »laser material processing« offers solutions in cutting, ablation, drilling, welding, soldering, surface treatment and micro processing. The activities cover a wide range of applications from macro processing via nano structuring to biophotonics.

In the business area »laser plant and system technology« prototypes are developed, built up and installed on site. Process monitoring and control as well as system components and control software are part of the activities. In the business area »laser measurement and testing technology« processes and systems for inspection of surfaces, for chemical analysis, for testing the accuracy of dimensions and geometry of workpieces as well as for analysis of static and dynamic deformations are developed.

The comprehensive offer of services of the Fraunhofer Institute for Laser Technology ranges from research and development as well as system construction and quality assurance to advice and training. Industrial laser systems from various manufacturers as well as an extensive infrastructure are available for the work on research and development projects.

In the Laser User Center of the Fraunhofer Institute for Laser Technology guest companies work in their own separated laboratories and offices. The basis of this special form of technology transfer is a long-term cooperation agreement with the institute in the field of research and development. The surplus value lies in the use of the technical infrastructure and in the information exchange with ILT’s experts. Already 10 companies profit from the advantages of the Laser User Center. Besides laser manufacturers and laser users, entrepreneurs from the areas of special machine production, laser processing and laser measurement find a suitable frame to realize their ideas on an industrial scale.
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.

Fascination 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.
Laser and Plasma Sources

The business area includes the development of diode lasers, rod, slab and fiber-based solid-state lasers as well as non-linear optical arrangements for frequency conversion, optical design for beam control and beam forming systems, microassembly of diode lasers, solid-state lasers and optical components, as well as the development of plasma systems.

In cooperation with leading partners from the field of semiconductor technology, such as the Fraunhofer IAF, the Fraunhofer HHI and the Ferdinand Braun Institut für Höchstfrequenztechnik, new structures and configurations are being designed which facilitate the production of diode lasers with a higher beam quality.

Unique experience demonstrated by the business area includes the implementation of automated assembly and test equipment, along with the assembly of high-power, diode and solid-state lasers. In the field of plasma technology the focus is on developing EUV beam sources for semiconductor lithography. The business area’s key target markets are laser material processing, medical engineering, metrology, lighting technology and the component market for ICT technology.

For over 10 years this business area has generated numerous spin-offs from the Fraunhofer ILT.

Laser Material Processing

Production processes addressed by this business area include cutting and joining techniques applying micro- and macro-technology, as well as surface engineering. The services provided extend from process development for the manufacture of sector-specific products and the integration of these processes in production lines, through simulation services for laser applications, to the production of samples in support of series production start-up. The strength of the business area is rooted in its extensive process know-how, which is tailored to specific customer requirements in each case. In addition to process development, the business area offers complete system solutions which utilize selected technology networks. Customers are offered laser-specific solutions that encompass design engineering, material specification, product design, production equipment and quality assurance. In addition to the target market of material processing, the business area also addresses customers in the medical engineering, biotechnology and chemical sectors.
Laser Plant and System Technology

This business area focuses on the development of prototype equipment for laser and plasma-technology applications, as well as on laser systems engineering, particularly in the fields of automation and quality assurance. Areas of application embrace welding, cutting, hardening, repair coating, drilling and micro-joining. The system technology offered provides complete solutions for process monitoring, components and control systems for precision machining, laser-specific CAD/CAM technology modules, as well as software for measurement, open- and closed-loop control and testing. For its work in process monitoring in particular the business area can draw on extensive and, where required, patent-protected know-how. In this sector numerous systems have already been licensed for companies. Target markets include laser equipment and component manufacture as well as all sectors of production industry which deploy lasers in their manufacturing activity or intend to do so.

Laser Measurement and Testing Technology

The services provided by this business area include the development of measurement and testing processes and related equipment for material analysis and for geometric testing and surface inspection. The requisite measurement and testing software is tailored to customer-specific problem areas. Material analysis is based on the deployment of laser-spectroscopic processes, focusing on the analysis of metallic and oxidic materials, identification testing of high-alloy steels, rapid recognition of materials for recycling tasks and analysis of gases and dust. Special electronic components are developed for the parallel processing of detector signals of high bandwidth.

In biophotonics joint projects are carried out in the field of highly sensitive fluorescence detection for protein chips and laser scattered light measurements in sub-µl test volumes for protein crystallization. As part of the area’s work on geometric testing and surface inspection components, devices and equipment are being developed for obtaining 1 to 3D information about the geometry or surface properties of workpieces. These include processes and special systems for testing the stability of bar and strip products and devices for the 1D to 3D scanning of unit goods. Target markets include the production and the recycling industry which conduct measurement and testing fast and close to the process.
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

Dipl.-Ing. H. Hornig
BMW AG

Dr. U. Jaroni
ThyssenKrupp Stahl AG

RD Andreas Kletschke
Bundesministerium für Bildung und Forschung BMBF

Prof. Dr. G. Marowsky
Laserlaboratorium Göttingen e. V.

MinRat Dipl.-Phys. T. Monsau
Ministerium für Arbeit und Soziales, Qualifikation und Technologie des Landes NRW

Dr. Rüdiger Müller
Osram Opto Semiconductors GmbH & Co. OHG

Dr. Joseph Pankert
Philips Lighting B.V.

Prof. R. Salathé
Ecole Polytechnique Fédéral de Lausanne

Dr. Dieter Steegmüller
DaimlerChrysler AG

Dr. Klaus Wallmeroth
TRUMPF Laser GmbH & Co. KG

The 24th Board of Trustees meeting was held on September 17, 2008 at the Fraunhofer ILT in Aachen.

Directors’ Committee

The Directors’ Committee advises the Institute’s managers and is involved in deciding on research and business policy. The members of this committee are: Dipl.-Betw. (FH) Vasvija Alagic MBA, Dipl.-Phys. A. Bauer, Dr. K. Boucke (until 31.01.2008), Dr. A. Gilner, Dr. J. Gottmann, Dipl.-Ing. H.-D. Hoffmann, Dr. S. Kaierle, Dr. I. Kelbassa, Prof. Dr. P. Loosen, Dr. W. Neff, 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 ILT are: Prof. Dr. R. Poprawe, B. Theisen, Prof. 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: Dipl.-Ing. P. Abels, Dipl.-Ing. G. Backes, M. Brankers, Dipl.-Phys. J. Geiger, M. JanBen, Dipl.-Phys. G. Otto, B. Theisen (chair), Dr. A. Weisheit, Dipl.-Ing. N. Wolf.

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.-Betw. (FH) Vasvija Alagic MBA, K. Bongard, M. Brankers, A. Hilgers, A. Lennertz, Dr. W. Neff, E. Neuroth, Dipl.-Ing. H.-D. Plum, Prof. Dr. R. Poprawe, B. Theisen, F. Voigt, Dipl.-Ing. N. Wolf, Dr. R. Keul (Berufsgenossenschaftlicher Arbeits-medizinischer Dienst BAD).
Contacts

Prof. Dr. Reinhart Poprawe M.A. (-110)
Director

Prof. Dr. Peter Loosen (-162)
Vice Director

Dr. Dirk Petring (-210)
Cutting and Joining

Dipl.-Phys. Axel Bauer (-194)
Marketing and Communication

Dipl.-Ing. Dieter Hoffmann (-206)
Laser and Laser Optics

Dr. Konrad Wissenbach (-147)
Surface Treatment

Dipl.-Betrw. Vasvija Alagic MBA (-181)
Administration

Dr. Reinhard Noll (-138)
Laser Measurement and Testing Technology

Dr. Arnold Gillner (-148)
Micro Technology

Dr. Bruno Weikl (-134)
IT-Management

Dr. Willi Neff (-142)
Plasma Technology

Dr. Stefan Kaierle (-212)
System Technology

Dr. Alexander Drenker (-223)
Quality Management

Prof. Dr. W. Schulz (-204)
Modelling and Simulation
Laser and Laser Optics
Dipl.-Ing. Dieter Hoffmann
- Active and passive cooling of diode lasers
- Matched thermal expansion coolers and mounting techniques for the diode laser assembly of laser diode bars with Indium and AuSn solder
- Characterization and testing of diode lasers in the wavelength regime between 630 nm and 2.1 μm
- Micro-optical systems for fiber coupling, for singlemode and multimode fibers
- Automation of high-precision assembly processes for laser and optical systems
- Development of components and production processes for fiber lasers as well as solid-state and diode lasers
- Design, analysis and optimization of solid-state and diode lasers, fiber lasers and ultra-short pulse lasers, as well as systems and components for frequency conversion
- Analytical and numerical modeling of the relevant mechanical, thermal and optical effects in lasers and non-linear crystals
- Optical arrangements to control and form laser radiation
- Design and characterization of optical components

Laser Measurement and Testing Technology
Dr. Reinhard Noll
- Laser measurement processes for online inspection tasks
- Development, construction, integration and testing of laser measurement and testing equipment
- Chemical analysis of solid, liquid and gaseous substances with laser spectroscopy
- Spectroscopic monitoring of welding processes
- Fluorescence analysis
- Quantification of protein interactions using label-free laser scattering methods
- In vivo diagnostics for online monitoring of minimal invasive surgery
- Measurement of distances, profiles and shapes with laser triangulation
- Real time operation and automation

Cutting and Joining
Dr. Dirk Petring
- Cutting, perforating, drilling, deep-engraving
- Welding, brazing, soldering
- High-speed processing
- Thick section processing
- Cutting and joining of special materials
- Welding with filler material
- Laser-arc hybrid technologies
- Product-oriented process optimization
- Multi-functional manufacturing processes
- Design and implementation of processing heads
- Sensor-based process control
- Computer-supported simulation and optimization
- Multimedia training and information systems

Plasma Technology
Dr. Willi Neff
- Development of plasma based EUV/XUV-sources
- Development, construction and integration of components for EUV/XUV-measuring systems (microscopy, surface characterization, measurement of reflectivity …)
- Power generators for pulsed plasma formation
- Process control and monitoring systems for spatially arranged systems based on micro seconds
- Atmospheric pressure plasma for surface modification (sterilization of packaging material, functionalization …)

Surface Treatment
Dr. Konrad Wissenbach
- Fabrication of load orientated layers by means of heat treatment, transformation hardening, remelting, alloying, dispersing and laser cladding
- Development of maintenance and repair processes for tools and components
- Development of powder feeding nozzles and inside processing heads
- Rapid prototyping and rapid manufacturing for production of metallic and ceramic parts and tools
- Polishing, structuring, smoothing and roughening by remelting metals, glass and plastics
- Functionalising of thin layers
- Generation of structured layers by remelting
- Cleaning of surfaces
Core Areas

Micro Technology
Dr. Arnold Gillner

- Laser micro welding of metals and combinations of dissimilar classes of material
- Laser welding of thermoplastics and thermoplastic elastomers with diode and fiber lasers
- Laser micro soldering of metals and glasses
- Micro bonding of glass, semiconductors and ceramics
- Laser-assisted punching, bending and embossing processes
- Precision cutting and drilling of metals, ceramics, semiconductors and diamonds
- Micro structuring with Excimer and Nd:YAG lasers
- Micro drilling with solid-state lasers
- Ablation and structuring processes using picosecond and femtosecond lasers
- Nano structuring by interference-based processes and multi-photon excitation
- Micro tool engineering in hard metals, ceramics and diamonds
- Surface structuring for functional component design
- Marking and labeling
- Cutting and perforating of paper, plastics and composites
- Laser medicine for tissue therapy
- Laser applications for biotechnology
- Cell manipulation and biophotonic analysis techniques
- Photochemical processes
- Consulting, feasibility studies, and development of processes for laser-based manufacturing
- Process qualification under close-to-real production conditions

Modelling and Simulation
Prof. Dr. Wolfgang Schulz

- Generation of EUV-radiation
- Design of optical resonators for high power diode lasers
- Beam guiding, beam shaping
- Flow and heat transport in gases and melt
- Movement of phase boundaries
- Dynamical models of removing, cutting, welding and drilling
- Evaluation and visualization of data from measurement and simulation
- Computational steering of simulations
- Numerical methods and codes, finite elements and finite volumes in domains with free boundaries, adaptive cross linking
- Diagnostics of laser radiation and laser manufacturing processes

System Technology
Dr. Stefan Kainerle

- Process monitoring and control for quality assurance
- Process analysis and process development tools
- Development of online sensors and control systems (e.g. seam tracking, velocity measurement, positioning, distance measurement and control, multi-sensor technology and networks)
- Automated testing of processing results (e.g. systems for seam evaluation)
- Process trials and testing
- Feasibility studies
- Pilot-run series
- Integration of laser technology into existing production facilities
- Remote and scanner applications
- Integrated processing heads
- CAD/CAM-supported laser processing
- Offline path planning and simulation
- Conception and design of plants
- Pilot plants
- Control techniques for laser plants
- Consulting, education and training
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
- manufacturing and assembling technology
- pulsed power supplies and control technology
- beam guiding and forming
- development, set-up and testing of pilot plants
- process development
- process monitoring and control
- model and test series
- integration of laser technology into already existing production plants
- X-ray and plasma systems

Cooperations with R&D-Partners

The Fraunhofer Institute for Laser Technology ILT is cooperating with R&D-partners in different ways:

- realization of bilateral, company specific R&D-projects with and without public support (contract for work and services)
- participation of companies in public-funded cooperative projects (cofinancing contract)
- production of test, pilot and prototype series by Fraunhofer ILT to determine the reliability of the process and minimize the starting risk (contract for work and services)
- companies with guest status at Fraunhofer ILT (special cooperation contracts)

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.
Facilities

The usable floor space at the Fraunhofer Institute for Laser Technology ILT amounts to more than 10,000 m².

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

Scientific Infrastructure
The scientific infrastructure includes a library with international literature, patent and literature data bases as well as programmes for calculation of scientific problems and data bases for process documentation.

Equipment
The equipment of the Fraunhofer Institute for Laser Technology ILT is permanently being adapted to the state-of-the-art. At present, essential components are:
- CO₂-lasers up to 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

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

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Dipl.-Ing. Martin Jochum
Employees

Employees at the Fraunhofer ILT 2008

Personnel 152
- Scientists and engineers 93
- Technical staff 37
- Administrative staff 22

Other employees 124
- Undergraduate assistants 114
- External employees 7
- Trainees 3

Total number of employees at the Fraunhofer ILT 276

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

Employees 2008

- 41 % Undergraduate assistants
- 8 % Administrative staff
- 13 % Technical staff
- 4 % External employees, trainees
- 34 % Scientists/engineers
## Revenues and Expenses

### Expenses 2008

<table>
<thead>
<tr>
<th>Item</th>
<th>Amount (Mill. EUR)</th>
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<tbody>
<tr>
<td>- Staff costs</td>
<td>9,0</td>
</tr>
<tr>
<td>- Material costs</td>
<td>10,4</td>
</tr>
<tr>
<td><strong>Expenses operating budget</strong></td>
<td><strong>19,4</strong></td>
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### Investments

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<th>Amount (Mill. EUR)</th>
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<td>2,5</td>
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### Revenues 2008

<table>
<thead>
<tr>
<th>Item</th>
<th>Amount (Mill. EUR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Industrial revenues</td>
<td>9,6</td>
</tr>
<tr>
<td>- Additional financing from Federal Government, States and the EU</td>
<td>6,4</td>
</tr>
<tr>
<td>- Basic financing from the Fraunhofer-Gesellschaft</td>
<td>3,4</td>
</tr>
<tr>
<td><strong>Revenues operating budget</strong></td>
<td><strong>19,4</strong></td>
</tr>
<tr>
<td>- Revenues from projects abroad (already included in total)</td>
<td>2,8</td>
</tr>
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</table>

### Investment revenues from industry

<table>
<thead>
<tr>
<th>Amount (Mill. EUR)</th>
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<tr>
<td>0,4</td>
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### Fraunhofer industry $p_{ind}$

<table>
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<th>Percentage</th>
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<tr>
<td>51,5 %</td>
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</table>

### Expenses 2008 (100 %)

- 47 % Material costs
- 11 % Investments
- 42 % Staff costs

### Revenues 2008 (100 %)

- 33% Additional financing from Federal Government, States and EU
- 18 % Basic financing from the Fraunhofer-Gesellschaft
- 49 % Industrial revenues (without investments)
Budget Growth

The following graph illustrates the budget trend over the last 9 years.

[Bar chart showing budget growth from 2000 to 2008 with labels for Mio EUR and years.]
March 2009
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The companies listed here represent a selection of the Fraunhofer ILT’s many clients.
Short Profile

The Fraunhofer Center for Laser Technology CLT, located in Plymouth, Michigan, has a 1250 m² development center housing $9 million worth of the most varied, leading edge laser equipment in North America. This area has established itself as the center for laser production, system integration and industrial users in the USA.

The on-going goals are:
• Integration in scientific and industrial development in the USA
• Accumulation of know-how at the German parent institute through student exchange programs and early recognition of trends led by the USA
• Know-how growth at CLT through close cooperation with the University of Michigan and the Wayne State University as well as other leading US universities
• Local provision of services to international companies on both continents
• Strengthening position in the R&D market

The central philosophy of Fraunhofer USA is the creation of a German-American joint venture where give and take occur in harmony. The win-win situation is an essential prerequisite for both sides. The Fraunhofer Gesellschaft is always interested in considering and trying to develop relationships on the American side that strengthen mutually.

The American partner universities’ interest concentrates on:
• Using the competence of the Fraunhofer Institutes
• Using the experience in the introduction of new technologies into the market
• Providing the connection between industry and university
• Providing practical training for students and graduate students

The CLT develops powerful, high-brilliance fiber lasers in collaboration with the University of Michigan. The basic research is carried out 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 that make diode lasers comparable to solid-state lasers in terms of their performance. The two establishments are currently working together on a number of research projects in this area.

The CLT is also collaborating with Wayne State University to develop cost-efficient manufacturing processes for alternative energy production and storage. The focus is on solar cells and lithium-ion batteries, which are currently going through a huge development spurt due to the trend towards hybrid vehicles. Laser-induced separation and joining of similar, but also dissimilar, classes of material such as metal and plastic form the technological basis for these processes.
In 2001, the Visotek company was spun off from the Fraunhofer CLT in order to market the center’s results in the field of fiber-coupled high-power lasers and specialized lens systems. 2007 saw the launch of Arbor Photonics with the support of the University of Michigan to market developments in the area of flexible fiber lasers with diffraction-limited beam quality and high pulse outputs.

Services

The CLT offers services in the field of laser processing, the development of optical components and special laser systems. This covers the entire spectrum from feasibility studies, process development to pre-series development as well as prototype production of laser beam sources and laser systems which are ready to use. As an independent institution small and mid-sized companies are given the opportunity to develop and test their processes on Fraunhofer machines with the help of Fraunhofer personnel. It is also possible to develop and test complete systems at the CLT. Our customers come from the automobile industry, construction industry, ship building and medical engineering.

Employees

Both Germans and Americans are employed at the CLT. The goal is to rotate German employees so that the collected experience can be brought over to the parent institutes and to offer German employees the opportunity to become further qualified during their stay in the USA. Furthermore, students from the Technical University in Aachen write their diploma thesis in the USA.

Equipment

Current equipment in the CLT lab consists of: CO₂ lasers with up to 8 kW power, Nd:YAG laser from 250 W to 4.4 kW, diode lasers from 30 W to 3 kW, frequency trebled Nd:YAG laser and excimer laser, a number of special and hybrid optics, a series of 3, 5 and 6 axes systems, as well as several robots.

References

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- Office of Naval Research
- Michigan Lifescience Corridor
- Alcan
- Borg Warner Automotive
- Dana Corporation
- DaimlerChrysler
- Ford Motor Company
- General Motors
- Hemlock Semiconductors
- Nuvonyx
- LASAG
- PRC
- Rofin Sinar
- Spectra Physics
- Siemens VDO
- Trumpf
- Visteon

Operating Budget 2008*

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<th>Mio. US$</th>
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<tr>
<td>Operating budget</td>
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<tr>
<td>- Staff costs</td>
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<td>- Material costs</td>
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*Post-calulation has not occurred yet

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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 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 Louis de Broglie in Rennes 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 on-going goals of the CLFA are:
- Integration into scientific and industrial development in France
- Growth in know-how by faster recognition of trends in the fields 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


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

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Competence by Networking

Six Fraunhofer Institutes cooperate in the Group for Surface Technology and Photonics VOP. Complementary competencies allow to adapt the research activities to the rapid technological progress in all industrial application fields in a permanent, apace and flexible way. Coordinated strategies, in line with the current needs of the market, create synergy effects and provide a larger service for the benefit of the customers.

Fraunhofer Institute for Physical Measurement Techniques IPM

The Fraunhofer IPM develops optical systems for applications in spectroscopy and light exposure technology. A major focus is the realisation of highly dynamical systems. Besides a rapid activation, they require special competencies in signal processing as realised through robust and low maintenance measurement systems for the infrastructure monitoring of high speed roads.

Fraunhofer Institute for Laser Technology ILT

In the area of laser technology, the interactive relationship between laser development and laser applications is of prime importance. New lasers allow new applications, and new applications set the stage for new laser systems. This is why the Fraunhofer ILT is continually expanding its core competencies through close cooperation with leading laser manufacturers and innovative laser consumers.

Above: Fraunhofer FEP
Middle: Fraunhofer IPM
Below: Fraunhofer ILT
Fraunhofer Institute for Surface Engineering and Thin Films IST

As an industry oriented R&D service centre, the Fraunhofer Institute for Surface Engineering and Thin Films IST is pooling competencies in the areas film deposition, coating application and film characterization. Presently, the institute is operating in the following business fields: mechanical and automotive engineering; tools; energy; glass and facade; optics; information and communication; life science and ecology.

Fraunhofer Institute for Applied Optics and Precision Engineering IOF

The core of the research activity of Fraunhofer IOF is optical systems engineering aimed at a steady improvement of light control. The institute’s focus is on multifunctional optical coatings, optical measurement systems, micro-optical systems, systems for the characterisation of optics and components for precision mechanics assemblies and systems.

Fraunhofer Institute for Material and Beam Technology IWS

The Fraunhofer IWS is conducting research in the areas of laser technology (e.g. laser beam welding, cutting, hardening), surface technology (e.g. build-up welding), micro machining as well as thin film and nano technology. The integration of material testing and characterisation into research and development constitutes and upgrades the IWS spectrum.

Contact und Coordination

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Above: Fraunhofer IST
Middle: Fraunhofer IOF
Below: Fraunhofer IWS
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 57 Fraunhofer Institutes. The majority of the 15,000 staff are qualified scientists and engineers, who work with an annual research budget of 1.4 billion euro. Of this sum, more than 1.2 billion euro 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 research centers and representative offices in Europe, the USA and Asia 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:

- Process engineering
- Energy and construction engineering, environmental and health research
- Technical/economic studies, information transfer

Target Groups

The Fraunhofer-Gesellschaft is committed to working for the economy as a whole, for individual businesses and for society. The targets and beneficiaries of our research activities are:

- The Economy: Small, medium-sized and large companies from industry and service sectors can all benefit from contract research. The Fraunhofer-Gesellschaft develops concrete, practical and innovative solutions and furthers the application of new technologies. The Fraunhofer-Gesellschaft is an important ‘supplier’ of innovative know-how to small and medium-sized companies (SMEs) not equipped with their own R&D department.
- Country and society: Strategic research projects are carried out at federal and state level, promoting key technologies or innovations in fields of particular public interest, e.g. environmental protection, energy technologies and preventative health care. The Fraunhofer-Gesellschaft also participates in technology programs initiated by the European Union.
Range of Services

The Fraunhofer-Gesellschaft develops products and services to full maturity. We work closely with our clients to create individual solutions, combining the efforts of several Fraunhofer institutes if necessary, in order to develop more complex system solutions. The services provided by the Fraunhofer-Gesellschaft are:

- Product optimization and development through to prototype manufacture
- Optimization and development of technologies and production processes
- Support for the introduction of new technologies via:
  - Testing in demonstration centers using highly advanced equipment
  - In-house training for the staff involved
  - On-going support, also subsequent to the introduction of new processes and products
- Assistance in assessing new technologies via:
  - Feasibility studies
  - Market analyses
  - Trend analyses
  - Life cycle analyses
  - Evaluation of cost-effectiveness
- Supplementary services, e.g.:
  - Advice on funding, especially for SMEs
  - Testing services and quality validation

The Advantages of Contract Research

Cooperation between all the Fraunhofer institutes means that our clients have access to a large number of experts covering a wide range of competencies. Thanks to common quality standards and professional project management, the Fraunhofer institutes ensure that research projects achieve results that can be relied on. Our institutes are equipped with up-to-date laboratory technology, making them attractive to companies of all sizes and from all industrial sectors. As a strong community, we can provide our partners with reliability and economic benefits: the Fraunhofer-Gesellschaft can bring the knowledge already gained from cost-intensive preliminary research into joint projects.
Jointly shaping the future

The RWTH Aachen University Chairs for Laser Technology LLT and the Technology of Optical Systems TOS, along with the study and research department for the non-linear dynamics of laser production methods 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 department of laser technology at RWTH Aachen University 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. Waveguide structures for frequency conversion 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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Study and research department for the non linear dynamics of laser production methods NLD

Founded in 2005, the study and research department for the non linear dynamics of laser production methods 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 inter-relationships 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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Cluster of Excellence

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.

Integrative production

The Cluster of Excellence »Integrative Production Technology for High-Wage Countries« is aiming for the long-term goal of increasing the competitiveness of German production technology. The overarching hypothetical solution lies in achieving the next higher level of production integration.
Individualized production

Individualized production involves allowing for a high degree of product variability and dynamics at costs equivalent to those of mass production. Concepts are being developed that will enable the optimum combination and configuration of the different elements in a production system to be identified. At the same time, advanced manufacturing technologies such as selective laser melting (SLM) are being further refined, and will eventually enable one-piece-flow concepts to be implemented at the same costs as mass production.

Virtual production

The introduction of greater flexibility in production processes necessarily results in an increased volume of preparatory and planning activities. In the cluster domain Virtual Production Systems, the aim is therefore to improve planning quality while simultaneously reducing the quantity of work involved. This is being done by developing discrete models representing, for instance, laser welding processes and materials, linking them together and integrating them in a virtual supply chain.

Hybrid production

By integrating a number of discrete processes in a single hybrid process, it is possible to reduce the length of supply chains and hence organize them more efficiently. In the cluster domain Hybrid Production, methods are being investigated that will enable supply chains to be systematically hybridized, and hybrid technologies such as laser-assisted incremental sheet forming are being developed.

Self-optimizing production

Self-optimization is a way of optimizing production processes without increasing the volume of upstream planning activities. In the cluster domain Self-optimizing Production, methods and technologies are being developed to increase the cognitive capabilities of production systems such as a laser cutting plant or an assembly system for optical components.

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The official opening of the Cluster of Excellence in October 2006, source: WZL Aachen.
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.

Development and timetable

The RWTH Aachen Campus will be created in three stages. The first stage starts in 2009 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 15 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 15 clusters – focusing on production technology, power technology, automotive technology, ICT technology as well as materials technology.

Materials Technology is subdivided into the clusters Aluminum Engineering, Advanced Metals, Chipless Forming, Surface Engineering, Plastics Technology and Fiber-based Materials. Power Technology/Automotive Technology includes the clusters Sustainable Energy, Heavy Duty & Off Highway Powertrain, Future Fuels, Tailor-made Chemical Products and Future Internal Combustion Engines. Automotive Technology/ICT Technology covers the clusters Car Communication and High-Speed Mobile Communication and Information. Automotive Technology/Production Technology is divided up into the clusters On Highway Powertrain, Integrative Production Technology, Production Logistics, Bio-Medical Engineering and Photonics. Prof. Dr. rer. nat. Reinhart Poprawe and Prof. Dr. rer. nat. Peter Loosen, respectively from the Fraunhofer ILT, and from the Chair for Laser Technology LLT and Chair for Technology of Optical Systems TOS, will head up the Photonics cluster.
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.

Source:
Machine tool lab at the RWTH Aachen, Project planning RWTH Aachen Campus.
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 more than 20 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, summer schools etc. In the future, 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) already 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
- Abdelkrim Chehaibou, Institut de Soudure, France
- Dr. François De Schutter, Lasercentrum Vlaanderen, Belgium
- Dr. Paul Hilton, TWI, Great Britain
- Dr. Wolfgang Knapp, CLFA, France
- Prof. Dr. Veli Kujanpää, Lappeenranta University of Technology, Finland
- Prof. Dr. José Luis Ocaña, Centro Láser U.P.M., Spain

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Short Profile

PhotonAix, the Competence Network for Optical Technologies and Systems, was founded in 2002 by the Fraunhofer Institute for Laser Technology ILT, the Fraunhofer Institute for Production Technology IPT and the Laboratory of Machine Tools and Production Engineering WZL of the RWTH Aachen. Aachen-based PhotonAix and eight other regional competence networks in the field of optical technologies made up of more than 400 members from research and industry are concentrating their skills with the mutual goal of promoting optical technologies in their respective regions.

These networks represent the full range of »Made in Germany« optical technologies, from laser-based materials processing and biophotonics to transportation and aerospace applications. The competence networks are primarily engaged in providing services such as technology management, start-up consulting, regional technology and industry marketing, quality training and education initiatives, and fostering communications within the network. The regional concentration of expertise leads to practical, real-time problem resolution and an accelerated transfer of research results into market-ready products.

Highlights 2008

Besides participating in Photonics West 2008 in San Jose, USA, and Optatec 2008 in Frankfurt as a joint exhibitor with the other German competence networks for optical technologies, the major events of 2008 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 in December 2008 to set up cluster management for the »Nano-Micro+Materials« technology field.

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### Some Special Research Results from the Business Areas of Fraunhofer ILT

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### Note from Institute Director

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

The business area includes the development of diode lasers, rod, slab and fiber-based solid-state lasers as well as non-linear optical arrangements for frequency conversion, optical design for beam control and beam forming systems, microassembly of diode lasers, solid-state lasers and optical components, as well as the development of plasma systems.

In cooperation with leading partners from the field of semiconductor technology, such as the Fraunhofer IAF, the Fraunhofer HHI and the Ferdinand Braun Institut für Höchstfrequenztechnik, new structures and configurations are being designed which facilitate the production of diode lasers with a higher beam quality.

Unique experience demonstrated by the business area includes the implementation of automated assembly and test equipment, along with the assembly of high-power, diode and solid-state lasers. In the field of plasma technology the focus is on developing EUV beam sources for semiconductor lithography. The business area’s key target markets are laser material processing, medical engineering, metrology, lighting technology and the component market for ICT technology.

For over 10 years this business area has generated numerous spin-offs from the Fraunhofer ILT.
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Task

The latest generation of compact, low-cost RGB laser beam sources for use in display applications has the potential to capture a large mass market. Laser-based display systems make it possible to build projectors with a significantly higher resolution and screen size than the flat displays used at present in mobile devices, capable of handling the high data bandwidths required for mobile TV reception, Internet access, and wireless video transmission/streaming.

Laser diodes are particularly suitable candidates for the implementation of very compact systems that can be incorporated directly in appropriately designed handsets or realized in the form of standalone micro-projectors. They have the added advantage of delivering high-brilliance colors, high contrast, and enhanced efficiency. Another advantage of laser-based projectors is that they are capable of producing sharply defined images even on rough projection surfaces.

Method

Whereas existing semiconductor materials permit the manufacture of laser diodes that emit light in the red and blue areas of the spectrum, today there is no direct means of producing diodes for display applications that provide the third essential color, green. One promising approach to accessing the wavelength range of approximately 532 nm involves the frequency doubling of laser diode emission with a set frequency of 1064 nm.

A tapered DFB laser was employed as the laser source. This ensures the generation of a laser beam with high output power, good beam quality and a low spectral bandwidth. This beam is focused on a periodically-poled MgO-doped Lithium niobate crystal. Periodically poled crystals present the advantage of a significantly higher non-linear coefficient, enabling them to achieve acceptable conversion efficiencies even at low intensities.

Results and Applications

In a first step the conversion process was simulated using numerical simulation. This enabled the optimum parameters to be established for crystal length and focusing, taking into account the spectral bandwidth, beam quality and thermal effects. On the basis of these data, a prototype was built, using a DFB diode laser from FBH as laser source. At an input power of 3.8 W, this demonstrator was capable to produce an average output power of more than 500 mW at 532 nm. Fluctuations of the output power of less than 1 % and a nearly diffraction limited beam quality were achieved.

This project was funded by the European Comission (www.brighter.eu, Contract no.: IST-2005-035266).

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Task

Consumer demand in the market for digital projectors has boosted manufacturing output to millions of units per year. Until now, ultra-high-pressure discharge lamps have served as the light source in digital projectors, and this component has considerably determined the design and production costs of such products. These projector lamps could be replaced by laser-based RGB modules, which offer the advantage of being more compact, efficient and brilliant. Moreover, the smaller dimensions and higher energy efficiency of the laser modules could open the way to entirely new areas of application, such as highly integrated, portable micro-projectors, thus significantly increasing market volume. The key component in such an RGB laser module is an integrated laser capable of efficiently producing green light. Whereas laser diodes emitting light in the blue and red areas of the spectrum are readily available, there is no such equivalent for green.

Method

The proposed solution involves implementing the green component of the RGB module by means of a special optically pumped laser crystal. An off-the-shelf, blue-emitting laser diode is used as the pump source, and a Praseodymium-doped YLF-crystal as the active laser medium.

This concept to generate green laser light at a frequency of 523 nm is based on a conversion process that guarantees high efficiency and low temperature dependency. This in turn allows products to be built with a high degree of integration.

Results and Applications

The first step was to determine the alignment tolerance of the planned setup by means of a performance analysis based on numerical simulation.

A laboratory setup was then designed and built, using an extremely short resonator with a length of 10 mm, with which it was possible to produce a cw output of 136 mW from a pump input of 410 mW. The measured beam quality of the laser is $M^2 < 1.05$.

More powerful pump diodes permit the power output to be scaled up and provide scope for improved efficiency. As part of the project, it is now planned to integrate the beam-forming element, which will lead to an even more compact assembly.

The project is funded by the BMBF under reference number 13N9353.

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Task

Solid-state UV lasers with a high average output are needed for a variety of production tasks including drilling, scribing and cutting Si or Sapphire wafers, drilling µ-scale vias in printed circuit boards, cutting flex circuits, and edge insulation of solar cells. Lasers operating in the 20-30 W range are state of the art. To obtain higher production rates, there is a need for beam sources with higher brilliance, repetition rates and pulse energies.

Method

The frequency of the optical output of a Q-switched InnoSlab laser, based on an oscillator-amplifier arrangement (Nd:YVO₄, 1064 nm) developed by the company EdgeWave, is tripled to 355 nm in two conversion stages using LBO crystals. At a pulse repetition rate of 40 kHz and a pulse duration of 11.4 ns, it delivers an average output of 300 W at a beam quality of $M^2 = 1.8/5.2$ in the stable/unstable direction to the converter. To maximize the efficiency of the system, a numerical simulation method was employed to optimize the frequency tripling process on the basis of the measured beam parameters of the laser. In particular, finite-element calculations were applied in respect of the inhomogeneous heating of the nonlinear crystals, employing a software package developed for this specific purpose by the Fraunhofer ILT.

Results and Applications

An average power of 66 W @ 355 nm, pulse duration of 8.9 ns and pulse energy of 1.65 mJ were obtained at the output of the conversion stage. This corresponds to a pulse output of over 180 kW @ 355 nm. The resulting beam quality of $M^2 = 1.7/2.4$ in the stable/unstable direction represents a significant improvement over the parameters measured in the infrared range. The conversion efficiency amounted to 35 percent of the input power measured at the converter. The experimental results exhibited a strong concordance with those obtained by simulation.

The specific geometry of the hybrid resonator in the InnoSlab laser enables the beam to be imaged in a top-hat shape by means of simple cylindrical lens telescopes. Numerical simulation of the conversion process based on this top-hat intensity distribution indicates that it is possible to obtain a conversion efficiency of 47 percent without increasing the load on the optical surfaces.

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**Task**

Future satellite-based differential absorption lidar (DIAL) systems, designed to measure concentrations of water vapor in the atmosphere with unprecedented lateral horizontal resolution, require robust and efficient Q-switched laser sources operating at a wavelength of 935 nm. Requirements include pulse energies of several 10 mJ at a repetition rate of 100 Hz in single-frequency mode, a spectral width of less than 100 MHz at high transversal high beam quality. The institute’s partners in this collaborative project, the University of Hamburg and the crystallography department of the Research Institute for Mineral and Metallic Materials in Idar-Oberstein (FEE) have for the first time succeeded in growing Nd:YGG crystals with the necessary mechanical and optical quality for use in Q-switched lasers. Experiments have already demonstrated that it is possible to obtain an optical efficiency of 9 percent (ratio of laser light to absorbed pump light) with pulse energies in the order of 4 mJ at 100 Hz.

**Method**

To meet the spectral requirements, the existing oscillator was modified using a twisted-mode technique, seeded with a cw single-frequency laser. The resonator length was controlled using the ramp-fire method. This method offers the benefit of a highly stable central wavelength even in vibrational environment.

Pulse energy scaling was implemented by means of an InnoSlab-based amplifier with a bidirectional, longitudinal pump arrangement. 44 passively cooled diode bars deliver a pulse energy of 870 mJ at a pump duration of 200 µs.

The arrangement consists of 4 optical stacks, each containing 11 diode bars, in which each pair of stacks was polarization coupled.

**Results and Applications**

An output of 4.3 mJ was achieved operating the resonator in single-frequency mode with a beam quality of $M^2 < 1.12$. The spectral width of the oscillator was determined to be 8 MHz (fwhm) using a heterodyne-unit. The pulse energy could be scaled up to 30 mJ by the amplifier stage. This corresponds to an efficiency of 3 percent optical efficiency (ratio of energy extracted by the amplifier to pump energy). The amplification is achieved by 13 passes through the slab crystal. A beam quality of $M^2 < 1.3$ was demonstrated.

The system will be used to perform ground-based atmospheric water-vapor measurements, in order to demonstrate its fitness for use (proof of principle) in sensing applications. Its future deployment aboard climate research aircraft operated by the German Aerospace Center (DLR) or research satellites depends on the successful results of these tests.

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Task

The aim of this study was to investigate the amplification of pulsed laser light ($\tau < 1$ ps) with an average power output in the region of several hundred watts using an INNOSLAB laser. Ytterbium-doped ($\text{Yb}^+$) laser materials are the only solid-state medium combining an amplification bandwidth that is sufficiently broad to support ultra-short pulses with a wide absorption band covering the range of wavelengths delivered by today’s high-power diode lasers. The pump source must fulfill very demanding requirements due to the quasi-level-3 behavior of the laser-active $\text{Yb}^{3+}$-ions. Unpumped zones must be avoided because this leads to internal absorption.

Method

$\text{Yb:YAG}$ was selected as the lasing medium due to its good thermal conductivity and relatively high gain. The slab-shaped $\text{Yb:YAG}$ crystal (1x10x10 mm$^3$) was pumped from both ends using the output of two horizontally arranged stacks, each consisting of four diode laser bars. The light emitted by the diode laser bars was shaped into a homogenous line measuring 10 mm in width and several hundred $\mu$m in height by the pump optics. The transmitted pump light was folded back again in the laser crystal, making use of the polarization. Approximately 800 W of pump power ($\lambda_{\text{pump}} = 940$ nm) is deposited in the laser crystal, which is located inside a hybrid resonator. The latter folds the seed beam nine times through the crystal, widening the diameter of the beam by a gain factor of $M$ during each transit. The advantage of this method is that the intensity of the laser beam remains more or less constant and the gain medium is evenly saturated, thus amplifying the beam efficiently. It also prevents the risk of peaks in intensity that could cause damage to optical components.

Results and Applications

The $\text{Yb}$ slab amplifier delivers an output of 400 W using a $\text{Yb:KGW}$ fs-oscillator ($\tau = 277$ fs, $\nu_{\text{rep}} = 76$ MHz) with an average power of 2 W as a seed source. The oscillator bandwidth of 3.7 nm is reduced to 1.8 nm by gain narrowing. The measured output pulse length of $\tau = 682$ fs is effectively bandwidth-limited, without using any chirped pulse amplification (CPA) arrangement to temporally stretch or compress the pulses. The beam quality was measured to be $M_x^2 = 1.44$ and $M_y^2 = 1.28$. No signs of intrinsic phase modulation, background emission or parasitic oscillation were observed at the maximum pulse energy of 5.3 µJ achieved so far and the corresponding peak pulse output of 7.7 MW.

This work was partially funded by the BMBF as part of the »Lasertron« research project (reference code: 13N8720).

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Task

The use of soldering techniques to join optical components when assembling laser systems presents numerous aspects worthy of further investigation. On the one hand, components affected by heat lost during the laser process require an effective and steady thermal contact for cooling. On the other hand, in comparison with adhesive bonding or crimp connections, soldered joints have superior mechanical properties and are less sensitive to environmental factors, such as humidity or temperature fluctuations. The wide variety of laser components and their specific requirements during assembly call for the development of application-specific joining methods. To realize this, several decisive factors have to be investigated, including precision of alignment and positioning stability, as well as the mechanical, thermal and electrical behavior of the joints.

Method

The manufacture of laser systems requires an assembly process in which the components can be mounted successively to ensure optimal manufacture. The developed soldering techniques have to ensure a local application of heat to enable a successive mounting of the components on a common base plate. The two options for soldering optical components such as lenses or mirrors involve either passive alignment, which means using a fixed reference surface for soldering the components, or active alignment, where the component is aligned in a melted solder pool. Interferometric measurements are employed to determine the effects of the soldering process and of external factors such as temperature fluctuations or mechanical stress on the alignment of the components.

Results and Applications

A resistance soldering method has been developed which enables optical components to be successively soldered onto a ceramic base plate. The electrical resistance of the soldering material is exploited to apply the thermal energy required to melt the solder. To do so, a thin layer of solder is deposited on the surface of a pre-metallized ceramic substrate by using a high-vacuum PVD process. A structure is imprinted into the applied layer of solder, resulting in two distinct contact zones, to which electrical current could be applied, and one joining zone, in which the optical components are to be soldered in place. The method is employed to assemble the beam-shaping optics for a miniaturized slab laser.

Another method is currently being developed to allow optical components to be aligned while the solder pool is still melted (Pick & Align). The ultimate goal is to develop a complete process for e.g. assembling a resonator mirror.

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Task

Laser systems are widely used in a variety of labeling, marking and engraving applications, and have meanwhile captured a significant share of the global market for labeling systems. The precision assembly processes currently employed to manufacture laser systems involve a considerable number of manual or semi-automated process steps, resulting in significant competitive disadvantages for companies based in high-wage countries. As part of the Cluster of Excellence »Integrative Production Technology for High-Wage Countries«, a miniaturized slab laser (MicroSlab) has been developed at the ILT, which meets the requirements for an automated, self-optimizing assembly process.

Method

Despite the ability of assembly robots to position components with high accuracy and the feedback provided by the visual control systems of the assembly cell, resonators still have to be aligned during laser operation. In order to automate this process, the assembly robot is provided with access to the sensors integrated in the product and to the laser control system.

The laser control system consists of a power board that provides functions to regulate the pump current and the temperature of the pump diode as well as cooling and safety functions. A second, superimposed signal board is used to process the output of the online monitoring sensors that are surface-mounted on the conductive coating of the ceramic substrate. The assembly robot is connected to the sensors and laser control system via a USB interface and a microcontroller, which are also placed on the signal board. The microcontroller enables the laser to operate independently by supplying algorithms to regulate the temperature and pump current.

Results and Applications

The use of integrated sensors eliminates the influence that variations in component and assembly-process parameters have, and opens the way to online process monitoring. All adjustments including sensor calibration, identification of the optimum operating parameters, laser characteristics and, if necessary, fault diagnosis, can then be carried out during the assembly process. The electronic control unit is based on a modular design that permits additional functions to be integrated at a later date. The use of a microcontroller provides a standardized, flexible and infinitely scalable communication platform between the product and the assembly robot, replacing thereby a fixed interface in the form of an analog docking station. The electronics concept chosen thus enables the integrated system - consisting of assembly cell and product - to optimize itself. Indeed, this characteristic will form a key concept contributing towards the competitive manufacturing of hybrid products in high-wage countries.

The presented work was funded by the German Research Foundation DFG as part of the Cluster of Excellence »Integrative Production Technology for High-Wage Countries«.

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Task

On account of their excellent beam quality, even at high output power, fiber lasers offer unique opportunities in various areas of laser materials processing, most particularly for cutting and welding. As the laser can be built fully all-fiber, it is possible to design compact, robust, alignment-free systems for industrial applications. One of the tasks of the HELIOS collaborative research project was to develop a prototype of an all-fiber laser with a cw output power in the 1 kW range.

Method

The fiber laser was designed as an high power oscillator without any additional amplifier stages. The fiber was pumped from both ends by two pump couplers. Twelve fiber-coupled diode laser modules, each with an output power of approximately 125 W were employed as the pump source, resulting in a total available pump power of 1.5 kW. The resonator was formed by two fiber Bragg gratings, the first designed to operate as a reflector and the second as an output coupling grating. The gratings had a center wavelength of 1080 nm. An ytterbium-doped LMA fiber with a core diameter of 20 μm and a cladding diameter of 400 μm was employed as the active medium.

Results and Applications

An output power of 1.1 kW was demonstrated using the prototype setup. This corresponds to an optical-to-optical conversion efficiency of about 73 percent. The thermal load on the spliced fiber connections between the separate components was reduced to such an extent that it was possible to operate the system continuously at maximum output. Power leakage on the high-reflection side was less than 2 percent, and the back-scattering of power into the pump modules amounted to less than 9 percent.

This work was funded by the BMBF (reference code 13N8691).

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Above: Prototype of the 1 kW fundamental-mode fiber laser, which contains the optical engine, the diode-laser-based pump modules, the power supply unit and the cooling system.
Below: Fiber laser in operation. The active fiber is coiled on a copper spool with water flowing through it to cool the fiber.
**Task**

Volume markets in micro materials processing such as laser marking, ablation and drilling require cost-efficient, pulsed beam sources with fundamental mode beam quality. Pulsed fiber lasers perfectly match these demands due to their high efficiency, simple construction and excellent beam quality. In the recent years, Q-switched fiber lasers have proven appropriate for high average outputs and high repetition rates. However, some components such as fiber-coupled optical modulators are significantly pushing up costs for average outputs beyond 5 W. Gain-switched fiber lasers offer a new approach, promising considerable cost savings. This concept has the advantage, in comparison to pulsed fiber laser amplifiers and Q-switched fiber lasers, that the fiber laser is built as an all-fiber oscillator and only consists of one active fiber and two fiber Bragg gratings. The pulse is generated by temporal modulation of the pump diodes. This means that, in contrast to other designs, the pulse repetition rate can be extended from approximately 100 kHz right down to single-shot operation.

**Results and Applications**

In order to show the feasibility of the concept, a 12.5 m long, ytterbium-doped fiber was pumped with a diode laser pump module. The pump energy coupled into the fiber was approximately 30 µJ for a pulse width of 200 ns. Pulse energies in the range of 8 µJ were achieved at repetition rates of approximately 50 kHz and a laser wavelength of 1080 nm ± 0.25 nm. The recorded pulse width was approximately 1.4 µs. In order to shorten the pulses and to further increase efficiency, a pulsed diode laser is currently being constructed which will make it possible to approximately double the pump peak output, and also to more than double the output power of the gain-switched fiber laser thanks to an increased extraction efficiency.

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

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Task

As part of an internal research program of the Fraunhofer-Gesellschaft, Ytterbium-based fiber amplifiers of various power classes were studied. The target was to generate pulse durations of about one nanosecond at a repetition rate in the high kHz to MHz range. The aim was to investigate both the highly amplifying, unsaturated regime and power scaling. The main focus of the work was on amplifier characteristics and the amplified spontaneous emission (ASE). Non-linear effects such as stimulated Raman scattering (SRS) and self-phase modulation (SPM) were also investigated.

Method

The input signal for the amplifier is delivered by a pulsed laser diode, which defines the temporal and spectral characteristics of the pulses and that has a high degree of polarization. The first amplifier stage consists of a core-pumped single-mode fiber. This is followed by the main amplifier, which is based on a large-mode-area fiber with a core diameter of 20 µm. This stage is pumped by a single-emitter-based diode laser module with up to 45 W at 976 nm. It is operated in double-pass mode and achieves a maximum output power of 17 W at a repetition rate of 500 kHz. Over 70 percent of the power is within a spectral bandwidth of 2.4 nm. The degree of polarization is 99 percent. The active fiber of the third stage is a micro-structured large-mode-area fiber with a core diameter of 40 µm and an air-clad structure. It is pumped with up to 150 W at 976 nm in a counter-pumped configuration. Using a half-wave plate in the signal beam the fiber can be operated either with linearly polarized or unpolarized light.

Results and Applications

The following parameters were achieved:

- Average output of up to 100 W
- Pulse peak of 100 kW polarized and 200 kW unpolarized
- Repetition rate between 50 kHz and 4 MHz
- Pulse energy of up to 100 µJ
- Pulse duration of approx. 1 ns
- Degree of polarization better than 95 percent
- Total amplification 56 dB

The system is being used for pilot applications in materials processing and for frequency-conversion tests.

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Above: Laboratory setup including the pre-amplifier (back left), the main amplifier (front) and the power booster (back right).
Below: Pulse energy of the polarized beam.
Task

The accurate preparation of fibers is a crucial factor in the assembly of fiber lasers with high average output power, in order to ensure long-term stable operation. Splicing, as a connection technique, is one of the most difficult steps in the process and the thermal load resulting from suboptimal splice connections is often the limiting factor in scaling the output power.

Method

Fiber splices can achieve a quality very similar to that of a drawn fiber piece. However, all four preparation steps - stripping, cleaving, splicing and recoating - must be carried out in the best possible way.

The first step involves removal of the coating in the area of the fiber end. An inappropriate stripping technique can result in major thermal problems, particularly in the case of cladding-pumped fibers, which are used for fiber lasers. The fiber facet is prepared by cleaving. In this process, the quality of the fiber facet depends substantially on the tensile stress selected, as can be seen in the adjacent pictures. During the actual splicing process, the quartz cores of both fiber ends are fused. If the fiber only guides one mode, the cores must be centered to one another with sub-micrometer accuracy. Finally, the splice is surrounded with a new coating. In the case of double clad (DC) fibers, even a minimal absorption of the pump light results in thermal destruction due to the small spatial expansion. If the fibers used have different core radiiuses, the mode field must additionally be adapted. In order to do this, the core diameter can be changed by diffusion or tapering. This either enlarges or reduces the mode field radius, minimizing losses.

Results and Applications

Attenuation of the light guided in the core can be reduced from 0.4 dB to less than 0.03 dB. The outstanding results achieved in the test bed were also verified in practice on a fiber-laser setup. The splices were constantly operated with 750 W pump light and 1.1 kW signal light. The measurement results confirm signal losses in the range of less than one per cent and low heat stress. This can significantly reduce the effort for sufficient cooling.

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Above: Fiber facet of large mode area fibers cleaved under various tensile stresses. Below: Schematic diagram of crucial points and thermographic measurement during laser operation.
Task

The use of single-emitters in fiber-coupled diode modules for pumping high-performance lasers and direct application in laser processing has become attractive due to the recently achieved increase in output power in the range of 7 and 12 W. It is envisaged that 50 W will be coupled into a 100 µm fiber at an optimum pump wavelength of 976 nm. The concept should allow the output to be scaled to 100 W. An optimized beam forming optics is necessary in order to achieve high coupling efficiency.

Method

In order to fulfill this task, a module consisting of two heatsinks – each with 5 soldered single-emitters – is designed, constructed and tested in experiments. The beams of the single-emitters of each heat sink are superimposed by means of polarization coupling and are coupled into a 100 µm fiber. A fiber connector developed especially for this is used for cladding-mode-free fiber coupling. The beam formation necessary for this is simulated and optimized. A partially automated adjustment stage is designed and constructed for the exact positioning of the optical components during assembly of the module.

Results and Applications

The special feature of the module is a high wall plug efficiency of greater than 40 percent. An optical output power of more than 60 W is achieved. It is possible that, with progressive development of the emitters, an output power of 100 W can be reached with the same optical design. The partially automated adjustment system enables an exact and time-efficient positioning of the optical components.

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Task

As a laser radiation source for marking, micromaterials processing and in other applications that require a high pulse peak output but a low heat input, super-pulsed diode lasers could be ideal due to their compact construction and simple manageability, provided the required focused intensity can be achieved. In order to achieve maximum power density, a super-pulsed diode laser is to be developed. Optionally the diode laser is suitable for direct application or as the pump source of a gain-switched fiber laser which allows for tighter focusing because of 1 - 2 order of magnitude improvement of beam quality.

Method

The laboratory model created is based on four short bars with an aperture of 800 µm x 1 µm. Two bars are superimposed geometrically and the two beam paths are then polarization-coupled. Microstep mirrors are used to symmetrize the beam. The microstep mirror is imaged to the entrance surface of a transport fiber with a diameter of 105 µm and a numerical aperture of 0.2, using anamorphic imaging optics. A PICOLAS pulse driver is used for temporal modulation. To achieve intensities as high as possible, the pump current of the four laser bars is increased by a factor of 10 in comparison to the nominal CW rating. The extremely short current pulses of a maximum of 300 ns make this possible without damage of the diode facet.

Results and Applications

The peak pulse power coupled into the fiber is in the range of over 500 W at variable pulse lengths of approx. 50 to 300 ns. This corresponds to a power density of approx. 6 MW/cm² at a pulse energy of 150 µJ. A gain-switched fiber laser was successfully pumped with the super-pulsed diode laser module.

This project was funded by the BMBF under the reference number 13N9671.

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**Task**

Interstitial photodynamic therapy (iPDT) is a promising method of treatment for curing deep-lying tumors. It requires systems with several fiber-coupled, individually controllable red laser emitters in the wavelength range of 635 nm to 652 nm and an optical power output of 2 W to 16 W. Appropriate inexpensive systems with the stated performance data are currently not available worldwide. The aim is to produce a demonstrator module with individually addressable emitters which can be combined into 8 individual ports, each with a 2-W power output, and which are suitable for use in iPDT.

**Method**

A laser bar is soldered p-side down onto an extremely thermoconductive ceramic plate structured with conductor paths. A water cooled micro-channel heat sink is used to cool the bottom side of the ceramic. A specially developed power supply controls the 20 individual emitters on the anode side and connects them via a joint cathode. This layout guarantees that any emitter can be allocated to a port and that any arising effects like thermal crosstalk can be reduced or at least equally distributed. All parameters are set via a terminal program from a PC.

**Results and Applications**

The demonstrator module enables diode laser bars to be switched with different emission patterns. The current source delivers currents of up to 2 A per emitter, at pulse lengths from 20 µs to cw and a pulse-pause ratio of 10:1 to 1:10. Typically, the mounted bars have a smile of approx. 3 µm across their total width, making it possible to couple in a 200-µm fiber array at high efficiency. The semi-conductor material available (652 nm) achieves a maximum output of 1400 mW at 1.8 A for individually operated emitters. If several adjacent emitters are activated simultaneously, the average output per emitter falls, as bar material in the red spectral range shows a significantly higher sensitivity under thermal loads than material in the NIR range.

The sub-project described here was funded by the German Federal Ministry of Education and Research (BMBF) under the reference number 13N8961 and is part of the ROLAS project.

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**Task**

High-power diode lasers require a heat sink technology capable of handling a specific power density of more than 500 W/cm². The laser bar is usually mounted by its p-side on the heat sink using a suitable soldering process. In connection with creep-resistant, temperature-stable AuSn solder expansion-matched heat sinks need to be used. A second, additional, heat sink on the n-side of the laser bar can greatly improve the cooling effect. Similar packages are currently set up with two-stage soldering processes using two solders with different melting points.

**Method**

In order to achieve a good cooling effect, the laser bar is soldered by both its p-side and its n-side onto an expansion-matched gold-plated CuW heat sink using AuSn solder. First, the laser bar is mounted on the heat sink. After melting the solder, a eutectic AuSn alloy is created. Its melting point is around 280 °C. During the further course of the process, the solder becomes enriched with gold, which diffuses from the galvanic coating of the heat sink into the solder layer. This causes the solder's melting point to rise. In the second step, a heat sink is soldered onto the n-side of the laser bar with the same AuSn alloy. The previously soldered bond on the p-side must not melt again in the process.

**Results and Applications**

By suitably controlling the process, the desired diffusion of gold from the coating of the heat sink into the first soldered connection on the p-side of the laser bar is achieved. This results in a higher-melting AuSn alloy on that side, which does not melt again during the second soldering process. The critical position of the laser bar facet in relation to the front edge of the heat sink, which is set in the first soldering process, thus remains unaffected by the second soldering process. The connections produced are strong, smooth and virtually free of tension. This method makes it possible to implement more powerful new package concepts cooled on both sides, and to simultaneously solder several laser bars and submounts to form a diode-laser stack.

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**Task**

Assembling diode laser modules is a complex task due to the numerous degrees of freedom of many of the optical components. In industrial manufacturing, the adjustment of complete modules is performed partly or entirely by hand. There is a growing need for automated manufacturing processes in order to be able to produce larger batches without compromising quality.

A pilot plant for the automated manufacture of complete diode laser modules is to be set up as part of the BMBF project PrOpSys under the coordination of Lissotschenko Mikrooptik GmbH. The task of the Fraunhofer ILT is to develop and test an algorithm that will enable the critical optical elements to be adjusted automatically.

**Method**

The main focus is on the automated adjustment of the beam-transformation micro-optics, which is mounted in front of a high-power diode laser bar, allowing for five degrees of freedom. For pre-adjustment, the near field is mapped onto a camera behind the micro-optics and analyzed with an image processing system. Different degrees of freedom are systematically adjusted, and the related position of the micro-optics is analyzed using a variety of processed camera signals. The position is ideal when the near-field image appears sharp.

The subsequent fine adjustment process is carried out by means of far-field imaging. Just as in near-field adjustment, the various degrees of freedom are systematically readjusted until the far-field divergence is at its lowest.

**Results and Applications**

The developed adjustment algorithm has been integrated into the software environment of a micro-assembly system at the Fraunhofer ILT and successfully tested. The test showed that the system is highly reliable and insensitive to variations of starting conditions and component tolerances.

The work was funded by the BMBF under the reference number 13N9360.

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Above: Adjusted beam-transformation micro-optics.
Below: Camera signal of a sharp near-field image.
Method

High-power diode lasers are expected to be in high demand in the coming years (> 1 million lasers per year) for use in various applications in consumer and other markets. In view of this prospect, the Fraunhofer ILT is developing systems that will meet the new requirements involved. Especially the time-intensive long-term tests carried out in burn-in systems will be adapted to the new requirements. It is necessary to achieve a high throughput of diode lasers under uniform, reproducible conditions. In order to satisfy the requirements, package changes need to be quick, and the recorded measurement results need to provide direct information on quality.

Method

The large number of possible types of diode laser package is compensated by just a few adapters in the burn-in system. Optical measuring heads and a cooled base plate form the basis of each level in the system. All the test places on a level have a uniform cooling temperature. The temperature can differ from level to level. The cooling process and temperature regulation are carried out using Peltier elements. This obviates the need for DI water to cool the packages. The entire burn-in system is cooled by conventional service water. The packages can also optionally be cooled with DI water for use under very high currents (> 150 A).

Results and Applications

The system that has been set up constitutes one level with 10 test places. Up to 80 test places can fit inside a cabinet. They are operated via a touch screen monitor, which can be used to inspect the current state of the test places and activate pre-defined test parameters. These are entered by computer. Up to 120 A/2.5 V of electric current is available for each test place. The system can be operated either in cw or in »hard pulse« mode (0.1 to 10 Hz), and is designed for cooling-water temperatures of up to 70 °C. Each measurement place is monitored individually by a thermal sensor and switched off if a pre-defined maximum temperature is exceeded. A measuring head determines the relative optical power and saves the data. All data are stored at freely defined time intervals and can subsequently be analyzed.

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Task

Laser brazing has been established as a joining technology in the automotive and electronics industry due to its process-specific advantages. Until now only laser brazing heads with lateral wire feeding have been deployed for industrial manufacturing. In general the brazing wire is fed from the forward direction. During the process this direction has to be maintained through constant reorientation of the brazing head. As a result disadvantages of the lateral wire feeding are: radii of less than 10 mm are difficult or impossible to realize, a need for extensive programming of the controlling axes, loss of productivity as well as variations in seam width and lack of fusion due to variations of process speed. For those reasons a brazing head with coaxial wire feeding in combination with a ring shaped laser beam would be of great advantage. The brazing process could be fully independent of the orientation of the brazing head.

Method

An optical system is being developed, which produces a ring-shaped laser beam that enables a coaxial wire feed without crossing of brazing wire and laser beam (lower figure). The optics transforms the collimated beam into a ring-shaped beam. This ring-shaped beam is split into two halves so that the brazing wire can be fed into the joining zone coaxially to the laser beam without crossing of brazing wire and laser beam. Subsequently, the two halves of the beam are recombined to form again a ring-shaped laser beam, which is finally focused onto the processing zone.

Results and Applications

Based on the innovative optics concept a machining head (upper figure) for laser brazing has been developed and successfully tested. The processing optics features a coaxially integrated wire feed. This together with a ring-shaped laser beam intensity distribution, which surrounds the wire, enables the brazing process to be carried out in any direction without the need to re-orient the machining head each time the direction is changed. In combination with a coaxially integrated seam tracking system the brazing head can be deployed independent of direction.

The project was sponsored by the industrial research foundation »Stiftung Industrieforschung«.

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Task

Anti-personnel mines pose a major threat to the civilian population in many parts of the world. Several areas contain huge quantities of mines, which makes it difficult to clear them reliably by conventional means. The mines are usually deactivated manually or with the help of special mine-clearing vehicles, but this is not very efficient and also poses a great risk for the people doing it, as they have to get very close to the mines. For these reasons, the LBBZ laser center is currently developing a laser system that can deactivate mines from a safe distance and is very efficient at clearing them. Suitable laser optics will be developed for this purpose.

Method

The mobile mine-clearing system, which will be mounted on a vehicle, is equipped with a diffraction-limited multi-kW fiber laser. With the aid of the newly developed optics, the output beam of the laser will deactivate mines from a distance of up to 200 m. The optics is diffraction-limited so as to ensure a sufficient power density even at the maximum possible distance to the mine. The system’s design needs to factor in thermal effects which occur in the optical components due to the absorption of the laser radiation and which lead to aberrations and a shift in the focal position. The design also needs to take into account atmospheric influences, which cause aberrations and unwanted movements of the laser beam.

Results and Applications

For clearing mines, a laser optics was developed which enables a variable processing distance between 50 m and 200 m. When used in combination with a diffraction-limited fiber laser, the achievable spot size is 3 mm. With the aid of an FEM thermal analysis it was possible to calculate the transient temperature profile of the optical components and the steady state temperature distribution and, from this, the thermal lens of the overall system was determined. The next step is for the LBBZ to implement the developed optics and to test its suitability for the intended application.

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Above: Steady-state temperature distribution of the optics ($\Delta T_{\text{max}} = 1.7$ K).
Below: Wavefront map for the maximum field, taking the thermal lens into consideration (peak-to-valley 0.11 waves).
### Task

Optical systems are designed using concepts based on non-imaging optics. The procedure aims to map the light density distribution of any source onto the required spatial distribution of intensity on a target surface. A reflective optical surface is sought, with which the required mapping can be achieved given a predefined distribution of incident radiation. The mathematical task consists in solving a system of elliptical partial differential equations. The solution is not unique. The solution becomes unique by posing an additional condition, namely the geometric shape of the edge of the freeform surface is predefined.

### Method

Various methods for calculating optical freeform surfaces were examined: direct solution of the elliptical differential equation on the grid by multigrid methods, least square methods, and transformation to traditional differential equations.

### Results and Applications

In order to control the error in the calculation method used, different intensity distributions with radial distribution are mapped (picture above). The commercial Raytracing program ZEMAX is used to test how well the calculated surface actually reproduces the stated intensity distribution. Optical freeform surfaces can be a replacement for mask methods, for example in lithography. Their advantage in comparison to mask-based methods lies in the more efficient utilization of the radiation that is to be made available for exposure to light.

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Above: Calculated freeform surface.  
Below: Intensity distribution resulting from the freeform surface pictured above.
Task

Soft X-ray microscopy in the water window spectral range is a high-resolution method for examining dense aqueous solutions containing biological samples. Tomographic imaging makes it possible to fully utilize the potential of X-ray microscopy. Generating the necessary photon flux on microscopic samples is currently only possible using synchrotron X-ray sources. By developing high-output compact light sources, it will be possible to construct X-ray microscopes on a laboratory scale.

Method

Pulsed high-current gas discharge sources were tested as a light source for extreme ultraviolet lithography. The hollow-cathode-triggered pinch plasma concept originally developed for this application was subsequently scaled up to permit the efficient emission of line radiation at a wavelength of 2.88 nanometers, thus creating a high-performance source for soft X-ray microscopy. To generate light at this frequency, the gas is repeatedly ionized by a series of current pulses and briefly heated to temperatures of several hundred thousand degrees Celsius. Part of the coupled energy is emitted in the form of characteristic X-rays.

Results and Applications

The source can reach a radiant intensity of $4 \times 10^{13}$ photons/(sr x pulse) at the $1s^2-1s2p$ transitions of helium-like nitrogen. Using a suitably adapted collector optic and a pulse repetition rate of 1000 Hz, a photon flux of $1 \times 10^7$/(µm² x s) can be generated on the sample. This flux enables microscopic images of optically dense aqueous samples to be obtained with an exposure time of approximately ten seconds.

A demonstrator model of the microscope has been built in collaboration with the Institute for X-Ray Optics at the University of Applied Sciences in Koblenz. A resolution of under 40 nanometers was achieved with an exposure time in the region of a few seconds. The objective is to produce a light source for a commercial X-ray microscope suitable for tomography applications by integrating an appropriately adapted collector optic and by further improving the brilliance.

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Fibroblast of a rat embryo (X-ray microscope image).
Task

If extreme ultraviolet (EUV) radiation is generated with an electrical discharge (vacuum arc), a current of several k-ampere flows into the plasma. The electromagnetic fields resulting from this and the plasma of the vacuum arc interact. If the magnetic field is sufficiently large, the electricity distribution is determined by the Hall effect. In the following, a model plasma shows the influence of electron density on the Hall effect and consequently on electricity distribution.

Method

A charge carrier with a capacity ($C = 200 \text{ nF}$), an inductivity ($L = 20 \text{ nH}$) and a charging potential ($U = 2 \text{ kV}$) is discharged across a plasma. The plasma is issued through a spatially varying conductivity (picture above) and a constant electron density. The discharge begins at the time $t = 0$ and the current flows through the plasma (middle picture). The chronological course of the electricity strength is calculated using the equation of the electrical circuit. The spatial distribution of the electrical current is determined by the magnetic field. The magnetic field is obtained upon solving the magnetic diffusion equation, which is non-linear due to the Hall effect. The equation of the electrical circuit and the diffusion equation are solved numerically.

Results and Applications

The temporal evolution of the current has been calculated for the electron densities of $10^{22}$ and $10^{25} \text{ [1/m}^3]\text{]}$ (middle picture). When the density is less, the Hall effect obstructs the current flow. The current density at the time of 40 ns is shown. When the density is higher, the progression of the current follows the conductivity distribution (picture below). The Hall effect does not play a part in this. When the density is lower, the course of the current is moved to the symmetry axis and the current is driven through a smaller transverse section (picture very below).

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Task

The Mach-Zehnder interferometer makes it possible to measure the phase difference between light waves very precisely. Use of a white-light source ensures large spatial resolution, as well as large phase resolution. This enables precision measurements of the refractive index and of the thickness of transparent materials. In addition, the white light interference is also a strong contrast form for the microscopy. These measurement options are available in automated form for a large number of applications in the area of cell biology, medicine and materials research.

Method

The special features of Mach-Zehnder interference microscopy are due to lenses with identical wave optics and the alignment precision of the fractions of a wavelength. The alignment and measurement were automatized using the interferometer, in order to improve the user-friendliness of the technology and to enable efficient use with a larger number of samples. The system can therefore be used for a large variety of requirements in terms of sample sizes and measurement precision.

Results and Applications

Extensive measurements were made on a wide range of objects from the areas of life science and materials research. In the area of ecology, measurements of the cell dry mass and of the carbon content of individual cells under variable growth conditions were taken from a selection of different blue algae species, with the aim of introducing new standard values for ecological model calculations. For pharmacological tests, interference microscopy showed that reactions of the cell membrane could be detected by changes in the optical density. Within the scope of the quality control of optical glasses, interferometric measurements can be supplemented by polarization-optical measurements. This serves as a basis for automatized inspection systems in materials research and analysis.

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Above: Green algae in comparison: microscopic light-field (left) and phase measurement (right).

Middle: Diatom in the interference contrast.

Below: Neuron in comparison: light-field (left) and interference contrast (right).

Very below: Crystal growth in the interference contrast.
Laserfertigungsverfahren
Laser Material Processing

Production processes addressed by this business area include cutting and joining techniques applying micro- and macro-technology, as well as surface engineering. The services provided extend from process development for the manufacture of sector-specific products and the integration of these processes in production lines, through simulation services for laser applications, to the production of samples in support of series production start-up. The strength of the business area is rooted in its extensive process know-how, which is tailored to specific customer requirements in each case. In addition to process development, the business area offers complete system solutions which utilize selected technology networks. Customers are offered laser-specific solutions that encompass design engineering, material specification, product design, production equipment and quality assurance. In addition to the target market of material processing, the business area also addresses customers in the medical engineering, biotechnology and chemical sectors.
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High-speed cutting of sheet metal using solid state lasers can achieve cutting speeds over 100 m/min with metal thicknesses of up to 1 mm. Compared with CO₂ lasers, brilliant solid state lasers such as fiber or disc lasers deliver improved process efficiency particularly with low metal thicknesses. An experimental and theoretical comparison between CO₂ and solid state lasers is designed to provide quantitative results.

Results and Applications

The focus of the fiber laser is chosen so that the Rayleigh length $z_R$ of 0.7 mm is more than 3 times the comparable figure from a CO₂ laser, thus ensuring a much more robust, more distance-tolerant process. Due to the higher absorption at the 1-µm wavelength, the fiber laser achieves even slightly higher maximum cutting speeds despite the selected larger focus diameter $d_f$ (see figure). The results coincide in good approximation with the CALCut simulation calculations.

The demonstrated ability to increase process tolerances without reducing speed opens up new optimization potential for the configuration of more robust (more tolerant) and, at the same time, even more productive (faster) processes for applications involving linear motion, e.g. trimming or longitudinal slitting, in which the high speeds can be fully exploited. In the case of 2-D or 3-D applications, the necessary laser power output can be reduced using robust, efficient processes in accordance with the dynamic systems available.

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Task

Lasertechnology faces new challenges in the field of cutting. One of these is to consistently translate the high focusability of fiber lasers in the multi-kilowatt range into higher cutting speeds for processing sheet metal. Here the key is to ascertain the physical process limits by means of simulation calculations and implement these in practice.

Method

In a series of feasibility studies conducted on behalf of industrial users, a range of uncoated, galvanized and aluminized steel materials of varying strengths, including ultra-high-strength materials with thicknesses between 0.7 mm and 2.5 mm, were investigated with respect to the achievable cutting speeds and quality of the cut. A 4-kW YLR4000 fiber laser manufactured by IPG with a fiber diameter of 50 µm was used. Simulation calculations using the CALCut program were used as the basis for ascertaining major parameter dependencies and the physical process limits governing the cutting speed.

Results and Applications

Following systematic, simulation-based parameter optimization, cutting speeds were obtained that were hitherto inconceivable. These speeds are several times greater than those achieved using CO₂ lasers with the same output power. The maximum speeds achieved in practice in the investigations were at least 80 percent and frequently over 90 percent of the physical limit speeds calculated using CALCut. Quality cuts with adherent dross heights under 100 µm, maximum roughness values Rₜ of 10 to 20 µm and a process window size appropriate to the given application were typically obtained at around 10 - 15 percent below the maximum speed. Currently the process limits are being extended through further optimization of optics and nozzle parameters.

As well as applications used in automotive manufacture, other sectors can also benefit from flexible, highly productive sheet metal processing. With applications that do not require high cutting speeds or cannot be implemented due to the machine’s kinematic limits, the industrial user benefits from the much lower laser output power requirements, flexible fiber coupling and the lower operating costs, all of which are characteristic of the new developments.

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Above: Light emitted by the process and expulsion of the molten metal with high-speed cutting.
Below: Theoretically calculated (CALCut) and maximum cutting speeds v_max achieved in practice as a function of sheet thickness s.
Task

The uses of aluminum are varied, ranging from vehicle manufacturing through electrical engineering, container construction and lighting systems to facade construction. The present study aims to put together initial findings on cutting the aluminum alloy AlMg3 using a multi-kW disc laser and a combi-head.

Method

A TruDisk 8002 disc laser manufactured by Trumpf with a maximum output power of 8 kW was used together with an F2-Y combi-head from Laserfact with an optical magnification of 1:1.5 for these tasks. Cut tests on sheet metal with thicknesses between 1 mm and 6 mm were carried out with a constant nozzle distance of 1 mm, with nitrogen and oxygen used as cutting gases; the cutting gas pressure was varied between 5 and 20 bar. In the course of these investigations, the maximum cutting speeds were determined for different outputs up to 8 kW.

Results and Applications

6-mm-thick sheet metal was cut at maximum cutting speeds of 8 m/min for nitrogen and 14 m/min for oxygen. The oxygen helps to increase speed. As far as aluminum is concerned, this effect is increased substantially as a function of laser power. The use of nitrogen with sheet thicknesses of 2 mm produced the maximum cutting speed for this gas as well as minimal bonding of adherent dross with cutting gas pressures under 10 bar. Comparative analysis using the CALCutsimulation program provided important insights into various process regimes when cutting aluminum using a laser operating at a wavelength of 1 µm.

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Above: Maximum cutting speed.
Middle: Cut edge AlMg3, 6 mm, P_l = 8 kW, above: N_2, v_i = 6.4 m/min, below: O_2, v_i = 11 m/min.
Below: Cut edge AlMg3, 3 mm, P_l = 4 kW, above: N_2, v_i = 8 m/min, below: O_2, v_i = 16 m/min.
Task

The challenges and opportunities arising from the new fiber-coupled laser sources in the multi-kilowatt range over the past few years have prompted researchers to revisit the principles of the manufacturing process based on laser cutting. Practical experience derived from cutting applications using conventional CO₂ lasers is not necessarily transferable to disc or fiber lasers with their 10-times shorter wavelength. It is now clear that purely empirical parameter variations will not provide the answers to questions regarding actual physical possibilities and limits.

Method

The Fraunhofer ILT can look back on over 20 years’ experience in the field of laser cutting, including a wealth of scientific and application-specific research and development. The CALCUT simulation software, which has been tried and tested in a wide range of industrial development projects, along with the know-how gleaned in optimizing laser-beam and gas-jet parameters and associated system components, provide a sound base for analyzing the factors that influence the laser cutting process when using the new laser sources.

Result and Applications

The results of theoretical and practical analyses indicate that certain common assumptions concerning the interaction between 1-µm-wavelength lasers and steel materials need to be qualified. For instance, the blanket assertion that laser light emitted at a wavelength of 1 µm is absorbed more effectively fails to take account of the physical mechanism of Fresnel absorption. This phenomenon depends on the angle of incidence and can in fact result in lower absorption at shorter wavelengths, especially in deep and narrow kerfs. On the other hand, it has been demonstrated that the widespread speculative belief that light at a wavelength of 1 µm cannot propagate into the deeper regions of kerfs, and is therefore impractical - unlike the 10 µm wavelength used by CO₂ lasers - is unfounded. On the contrary, simulations with CALCUT show that multiple reflection and consequently wave guiding play a significant role in applications of 1 µm lasers. A comparison of theoretical and practical cutting results backs this up. This work has also demonstrated the kind of conditions where improved beam quality pays off and the range of sheet thicknesses where the shorter wavelength of 1 µm already lowers costs. Other simulation calculations and practical cutting investigations will extend the potential uses of the new laser sources, but also highlight their limits compared with CO₂ lasers.

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Above: Comparison of the maximum cutting speeds \( v_{\text{max}} \) (calculated with CALCUT and achieved in practice) in 4-mm stainless steel as a function of laser output \( P_L \) for different wavelengths and focus or fiber diameters (optical magnification 1:1).

Below: Maximum cutting speeds \( v_{\text{max}} \) calculated with CALCUT as a function of the sheet thickness \( s \) for different beam qualities (structural steel, laser wavelength 1 µm).
**Task**

The technical task is to establish the scientific basis for a »self-optimizing« operation of the cutting machine in laser cutting of metallic materials. The basis for »self-optimization« requires that the cutting process is sufficiently well understood. The technical requirements include diagnosis of the current system state and implementation of understanding into the machine that will determine how the settings for the variable cutting parameters can be optimized. For detailed investigation, methods need to be devised for diagnosing and simulating the physical process, monitoring the cutting process and implementing the resulting intelligence in the machine.

**Method**

The computation of a metamodel enables the acquired knowledge to be implemented in the machine. The metamodel contains a mathematical representation of the correlation between the cutting quality, the measured variables and the set process parameters. The results of simulation and diagnosis are combined to create a metamodel. The diagnosis and simulation of the physical process provide a better understanding of the impact of algorithms based on the metamodel. A detailed knowledge of the hierarchy of dominant parameters in the process domain of interest forms the basis for devising a suitable algorithm for setting up the cutting machine.

**Results and Applications**

A comparison of the commercially available metamodeling software shows that research is currently focusing on the treatment of dynamic systems and the inclusion of scattered data for the parameter and criteria. The comparison of diagnosis and simulation with the metamodel (figure above) provides an indication of how the diagnosis and simulation methods can be extended or refined. The simulation of the compressible flow of cutting gas and the induced friction shows the effects of the process parameters or associated variations that can be visualized in the schlieren photographs (figure below).

The presented work is funded by the German Research Foundation DFG as part of the Cluster of Excellence »Integrative Production Technology for High-Wage Countries«.

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**Task**

The uses of aluminum are varied, ranging from vehicle manufacturing through electrical engineering, container construction and lighting systems to facade construction. The present study aims to put together initial findings on welding the aluminum alloy AlMg3 using a multi-kW disc laser and a combi-head.

**Method**

A TruDisk 8002 disc laser manufactured by Trumpf with a maximum output power of 8 kW together with an F2-Y combi-head from Laserfact with an optical magnification of 1:1.5 was used for the weld tests. Welding was carried out in the form of bead-on-plate welds and butt welds (edges laser-cut using the combi-head) with a nozzle distance of 6 mm. Different laser outputs, weld speeds, focus positions and the influence of argon and helium shielding gas at different flow rates were investigated.

**Results and Applications**

The focus position in particular has a significant impact on the welding depth and the quality of the seam surface. Defocusing reduces the welding depth but produces a far more regular seam surface. By contrast, the type of gas and flow rate affect the welding depth and seam surface to a much lesser extent. Quality was further improved in the case of butt-weld joints through the use of a root protection and double-focus optics. Future development work will be based on these results.

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Above: Seam surface and root, butt joint AlMg3, 3 mm, $P_l = 4$ kW, $v_s = 3$ m/min, double-focus with Ar root shield.  
Below: Cross-section.
Task

The task consists in identifying a process window for gas-tight welding in connection with the precision welding of tubular components consisting of multiple layers of metallic and non-metallic materials. One of the requirements was to establish the effect of tolerances governing component and process parameters on temperature. A further requirement was a detailed analysis of the effect of the various parameters on gas-tightness, porosity and gap-bridging ability, and an assessment of their suitability for use in process control.

Method

Simulation was performed in order to obtain a better understanding of the effect of component and process parameters on local and temporal variations in temperature, porosity and gas-tightness, and to provide a basis for comparison with experimental results.

Results and Applications

As results it is possible to identify the sought process window and permissible parameter tolerances with which a minimum temperature loading of the component and a reliable weld could be achieved. The key phenomena recorded by the simulation were the combined effect of the laser beam’s spatial distribution, propagation and absorption, the formation of weld capillaries, and the temperature distribution in the layered component. The simulation illustrates the effect of gaps on the welding depth. Thermomechanical calculations can be used to estimate the breaking stress limit. The tendency toward porosity can be deduced from the weld shape and the beam propagation in the weld capillary.

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Task

Computer simulation of distortion caused by welding is not standard in industrial practice because the quality of the results is poor. To reduce the calculation time, for instance, simplified versions of the models are applied although their actual properties have not been adequately investigated. A systematic examination of the structural stability of the underlying physical model is intended to highlight the sensitive dependence of the numerical solution on a model structure which has been reduced in stages.

Method

The examination focuses on three industry-relevant components (gear wheel, microcomponent, car body component) and three steel materials. The numerical and analytical solutions for distortion and internal stresses are initially compared for components of reduced geometrical complexity (figure above). The sensitivity of the simulation results to the parameters and structure of the model is examined. To obtain a heat source for the FEM thermomechanical simulations, an efficient hybrid simulation of the weld capillary and the temperature in the component has been developed.

Results and Applications

The existing simulation of the process model for welding has been extended to include the properties of the heat source as a function of the geometric shape of the component and the shape of the weld track. The proximity of the molten pool to the component boundaries is described by a thermal feedback effect in which the temperature in the component affects the shape of the weld capillary. As a result, the solution of a hybrid model is calculated. The hybrid model consists of a reduced model to calculate the weld capillary and an FEM calculation of the temperature. The surface of the weld capillary is embedded in a three-dimensional mesh to calculate the temperature outside the capillary (figure below).

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Above: Hybrid simulation of the welding of a gear wheel.
Below: Meshed representation of the component, weld shape and weld capillary.
**Task**

The properties of a product after welding reflect both the history of different processing steps and finally its transformation during welding. The task consists of incorporating the change in the material from a micro-structure formation model into the simulation of the welding process. The additional properties of the larger model resulting from coupling micro- and macrosimulations are to be investigated. Multiscale thermophysical modeling enables relevant phenomena with emphasis on material properties to be taken into account at any point in the process chain.

**Method**

To enhance the quality of the welding simulation, the models for calculating the weld capillary, the temperature and stress during solidification and micro-structure formation are combined. The interaction takes place on different scales of time and space, whereby the microstructure scale is related to nucleation and the welding process scale is determined by the length of thermal penetration depth. In the first instance, the dynamic model of the welding process and the thermomechanical stress model are examined to ascertain the sensitive dependence of the resulting values on spatially varying material properties. Once identified, the areas presenting qualitatively different solution characteristics (process domains) in the respective models are investigated in greater detail with regard to their sensitivity with respect to coupling.

**Results and Applications**

The existing »LaserWeld3D« hybrid model describes the shape of the weld capillary and the temperature in the surrounding component depending on the process parameters and component shape. As a free surface or the absorption and reflection front for the laser light, the capillary is part of the solution and is not a priori given.

LaserWeld3D enables the parameterized, algorithmic creation of a calculation grid for various classes of rotation-symmetrical workpieces. The dimensions of these geometric shapes are stored in an input file. LaserWeld3D calculates the three-dimensional shape of the weld capillary. The volume enclosed by the surfaces of the component and the weld capillary is meshed within the overall volume to a locally specifiable accuracy using an automatic tetrahedron mesher. This automatically generated mesh is then passed over to an FE solver which solves the thermal conduction equation in the volume of the workpiece.

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Task

For laser welding of flat components consisting of two dissimilar classes of materials, namely aluminum (99.5) and stainless steel (1.4301), a suitable process window was sought to create high-strength welds. The properties for the laser welded joint are compared with the results obtained using conventional resistance welding. Diagnosis and simulation of the process were employed to obtain a better estimate of the feasibility of laser welding. The application requires the use and refinement of advanced laser microwelding techniques.

Method

Simulations are performed to provide a better understanding of the impact of process parameters on the local and temporal variations in temperature that can be achieved with fundamental-mode fiber lasers, and provide a basis for comparison with experimental results.

The simulation is refined by analysis of offline diagnostics. Diagnosis of the weld shape, blending and hardness in the weld zone highlights those parameters that lead to crack-free welding with minimal thermal expansion of the phase seam in the intermetallic phases.

Results and Applications

Compared with state-of-the-art joining techniques for aluminum and steel, laser microwelding concepts using fundamental-mode fiber lasers and scanning optics provide a suitable solution that enables the weld depth and the introduction of heat to be adjusted precisely. The simulation supplies data showing the effect of the process parameters and the permissible deviation from the nominal values (figure above). The result correlates the laser output and velocity of the laser beam axis relative to the workpiece with the welding depth and the ratio of dissimilar classes of materials in the melt zone (figure below). The time required for the formation of intermetallic phases during the cooling phase is reduced by introducing less heat. The feed rate influences the blending of the steel and its distribution in the weld zone.

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Task

Magnesium-alloy components are known for their low density, good machinability and good damping properties. They are widely used in lightweight design concepts by the aerospace (e.g. casing components, see figure above) and automotive industry (e.g. transmission casing, engine block). Usually a protective anticorrosion coating is applied by means of painting, anodizing or thermal spraying. Often, however, these coatings do not provide the necessary mechanical strength, hardness or adhesive strength to ensure adequate wear resistance. One possible solution is laser cladding. The challenge is to deposit material with a higher melting temperature on a substrate with a lower melting and evaporation temperature. The mixing zone between the two materials must be small since the formation of brittle intermetallic phases is likely to weaken the composite.

Method

The fundamental research undertaken to manufacture the wear and corrosion protective layers involves various additive materials being deposited using powder-based laser cladding on various magnesium alloy substrates (AZ31B, AZ91D, AE42, ZE41). These coatings are cladded as single or multi composite layer and then examined regarding microstructure formation as well as corrosion and wear properties.

Results and Applications

The selection of suitable process parameters enabled layers made out of AlSi alloys to be cladded with no defects. These layers provide good corrosion protection and sufficient wear protection in response to moderate stress. If greater wear resistance is required, the AlSi layer is used as a buffer zone on which hard Ni- or Fe-based alloys are deposited (figure below). The buffer zone prevents galvanic corrosion between the magnesium substrate and the Ni- or Fe-based layers. One particular challenge is to reduce the dilution zone between the Mg-Al and Al-Fe(Ni) systems. These zones give rise to areas of brittle intermetallic phases where microcracks occur that may lead to premature failure of the layer during subsequent operation. By using suitable process parameters the thickness of the dilution zone can be reduced (approximately 20 µm) to the extent that cracks no longer occur. Initial samples are undergoing corrosion and wear testing at present.

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Task

The most common causes of failure of die-casting molds include heat cracks, stress cracks and erosion, caused by cyclic thermomechanical stresses acting on the mold during the casting process. This damage ultimately leads to the failure of the molds. Tool resetting and replacement incurs high costs, which could be reduced by extending the mold lifetime. This problem cannot be solved by modifying the material properties of standard hot-work steels because the high thermal strength needed to prevent erosion and the high toughness needed to minimize heat and stress cracks can only be combined to a limited extent in a homogenous compound. The use of graduated materials that combine the characteristics of different materials gives rise to new property profiles that can be customized to specific patterns of wear.

Method

Graduated materials have a multilayer structure manufactured using a powder based laser deposition welding technique in which successive layers are laid down on a substrate, each of a different composition. To build up multi-dimensional gradients as required for tool inserts with complex geometry, the powder mass flows are also varied within a layer (figure above). The combinations of materials are selected in cooperation with the Institute of Joining and Welding Technique at TU Braunschweig. Simple 3-D solids are built up to determine the microstructure and mechanical properties.

Results and Applications

To reduce the formation of heat and stress cracks in the surface region of the gradient, tough materials resistant to thermal changes such as Marlok 1650C are used. Ultrahard, corrosion-resistant materials such as CPM 420 V with hardnesses over 60 HRC are used to reduce erosion (figure below). In addition to gradients based on iron, graduated combinations of Fe- and Ni-based or Co-based alloys have been successfully built up by adjusting the process parameters. Current investigations are focused on microstructure analysis and determination of mechanical properties. Subsequently, a mock-up mold will be manufactured using selected graduated materials and tested in a die-cast molding machine to assess the quality of the gradient under operating conditions.

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Above: Complex geometry manufactured as a graduated structure consisting of a core of tough 1.2709, multiple transition layers, and a corrosion-resistant surface layer made of Metco 42 C (Sulzer Metco).

Below: Cross-section through a one-dimensional gradient of Metco 42 C (Sulzer Metco) and ultrahard CPM 420 V in the surface region. Linear increase in hardness from 550 HV to over 800 HV in the surface region.
The additive process of Selective Laser Melting (SLM) is being used to an increasing extent in the direct industrial manufacturing of metallic functional components. The Fraunhofer ILT is currently qualifying SLM for the aluminum die-casting alloys AlSi10Mg and AlSi9Cu3 as part of the BMBF-funded »AluGenerativ« collaborative research project, with the aim of employing this additive process to manufacture functional prototypes and volume-production components. Dimensional accuracy and accuracy of shape are key quality factors in this type of application.

Because the components are built up layer by layer, internal stresses are induced in the component as a result of thermal shrinkage in each layer. These internal stresses cause distortion of the component, impairing dimensional accuracy and accuracy of shape. It is known from other materials that preheating can reduce the thermal induced stress and as a consequence reduce also distortion. In order to investigate the influence of preheating on distortion for AlSi10Mg a thin-walled component (figure above) was built with and without preheating. The component is measured using an optical system in cooperation with the BMW Group’s experimental vehicle facility. The actual geometry is compared with the specified CAD geometry.

3-D measurements reveal that the demonstrator built without preheating contains distortions ranging between - 0.5 and + 0.7 mm (middle figure). Small cracks also arise at critical points in the component. By contrast, the component manufactured with a preheating temperature of 300 °C demonstrates a significantly greater dimensional accuracy (figure below), with distortion lying within a range of ± 0.1 mm. The reduction of internal stresses completely eliminates the formation of cracks. It is thus demonstrated that preheating significantly increases dimensional accuracy and accuracy of shape when manufacturing components made of AlSi10Mg using SLM.

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**Task**

Selective Laser Melting (SLM) is an additive manufacturing process used to make complex three-dimensional components layer by layer from a powder starting material that is melted by a laser beam. SLM is already used in industry for metallic materials. There is still no comparable process for ceramic materials. The EU-funded project »Custom-IMD« aims to manufacture high-strength components from zirconia (ZrO₂) using SLM.

**Method**

The approach involves the direct, complete melting of a purely ceramic powder. One particular challenge is to avoid crack formation when processing the ceramic. Special high-temperature preheating is used to heat the ceramic before and during processing to over 1100 °C.

**Results and Applications**

Complex shaped demonstration components were manufactured with a high density (> 98 percent). The components shown in the top and middle figures were produced without preheating and therefore still exhibit fine microcracks. High-temperature preheating in conjunction with a specially developed ZrO₂-based ceramic can prevent crack formation. Manufactured samples (figure below) have a flexural strength of over 500 MPa.

The most important application of this process development involves the manufacture of individual all-ceramic dental restorations. Reduced costs are possible since this process dispenses with geometry-specific molds or tools. Other applications are the manufacture of functional prototypes and, more generally, the production of one-off pieces or limited runs of components presenting the same geometry.

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Task

In the DFG project «Reaction laser sintering of spinel ceramic» the additive manufacture of components from spinel ceramic (MgAl₂O₄) is investigated. The aim is to manufacture components whose mechanical properties correspond to those of spinel components manufactured by conventional means. The final purpose is to qualify SLM as a forming process for the additive manufacture of components made out of spinel.

Method

Previous investigations demonstrated that microcracks occur throughout the microstructure of the remelted ceramic when pure MgAl₂O₄ is processed using SLM.

Therefore a new approach was applied to the process design, aiming to prevent crack formation. This approach is based on a two-stage method. In the first stage, a powder mix comprising AlMg₃ and MgO is processed in the absence of oxygen using SLM which creates a porous component. In a second stage, the component is placed in a sintering furnace at a temperature of over 1300 °C, where it reacts with the oxygen present in the air to create a 100-percent spinel ceramic. The approach prevents stress-induced microcracks in the component.

Results and Applications

The process parameters, which allow the fabrication of crack-free components (figure above) can be varied through a wide range. The components manufactured in this way show open porosity, which enables the oxygen to penetrate the entire component during reaction sintering. The density after this initial process step is approximately 75 percent.

EDX analyses show that after the reaction sintering process in the furnace the components consist of 100-percent spinel (figure below). The increase in volume during the reaction with the oxygen increases the density. The density achievable with this process is currently over 98 percent.

Thanks to the virtually unlimited geometry options available with the SLM process, complex components made out of spinel ceramic can be made without molds and tools, for applications such as dentistry.

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Selective Laser Melting (SLM) has been qualified at the Fraunhofer ILT as a manufacturing process for individual titanium implants. A medical application in which the SLM process was used to manufacture a hip-cup implant demonstrated its suitability for manufacturing of bone substitute implants. Surgical applications are currently moving away from conventional materials (titanium alloys, cobalt-chrome, implant steel) used to manufacture implants toward the use of new innovative materials. Biocompatible materials are increasingly being used: materials that are gradually accepted and degraded by the body as it generates new bone. This trend is being taken into account in additive implant manufacturing.

Method

Selective laser melting is being qualified for the processing of various biocompatible materials as part of the “Resobone” project funded by the German federal ministry of education and research. A composite material made out of calcium phosphate ceramic (TCP) and the biocompatible polymer polylactide (PLA) is used as the bone substitute material. TCP comes closest to the chemical structure of bone but cannot be directly processed using SLM. PLA leaves behind an undesirable acidic environment during degradation, but can be processed using SLM. For this reason, granules made out of the composite TCP and PLA have been used to combine the advantages of both materials. The focus of the work undertaken is on the creation of fully dense parts (density > 98 percent) and the implementation of hollow and mesh structures. To ensure the complete resorption of an implant, it must have an interconnective pore structure allowing cell tissue to fully penetrate the implant. A suitable pore structure is integrated in the CAD model of the implant, which is reproduced in the implant by the additive manufacturing process.

Results and Applications

The starting material for the SLM process is a composite material consisting of variable ratios of PLA and TCP. During processing, the polymer is completely melted and the TCP is embedded homogenously in the polymer matrix. The selection of suitable process parameters enables the manufacturing of demonstrators with a density approaching 100 percent using SLM. Possible applications include customized implants with an interconnective pore structure e.g. for maxillofacial surgery. There are plans to develop an application for manufacturing biocompatible stents using pure PLA.

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Task

Resistances arising at contact points within a stack can reduce the power output of direct methanol fuel cells (DMFCs). To reduce the contact resistance between the bipolar plates and the membrane electrode assemblies (MEAs), the bipolar plates are coated with a conductive gold layer. Electro-plated coatings, however, tend to detach from the substrate under operating conditions and nickel (used as an adhesion promoter) may be washed out and damage the electrodes. An alternative is to coat the bipolar plates using a sputtering process, but this has the disadvantage of coating the entire surface of the bipolar plate when in fact, due to the channel structure, the MEAs only contact selected points on the cell surface, located on the ribs. To reduce the amount of precious metal used and to improve the metallurgical bonding to the substrate, contact points are selectively manufactured using micro-laser cladding (figure above).

Results and Applications

By adapting the manufacturing equipment, it has been possible to create gold contact points with diameters of around 70 µm and heights of around 30 µm (figure below). The contact points exhibit a good adherence to the substrate. Measurements of the contact point resistance show a significant reduction of ohmic losses in fully assembled fuel cells. Selective laser deposition of the contact points reduces the consumption of precious metals for the selected contact point diameter by a factor of more than 100 compared with electroplating techniques. Further investigations aim to reduce the contact point diameter to 20 - 50 µm and to qualify the process for other combinations of materials of interest to the electrical and electronics industry.

Method

The required amount of filler material is determined by the number of contact points on a given cell surface area and the dimensions of the contact points. The development objective for the micro-laser cladding process is therefore to minimize the contact point geometry by using high-brilliance laser beam sources, to adapt the manufacturing setup to accommodate feeding and focusing of fine-grain powder fractions (middle figure) and to develop suitable process windows. The contact points are deposited on embossed metal sheets with a thickness of 100 µm. The electrical properties of the gold material should be retained as far as possible after solidification. The contact resistance of test plates and complete fuel cell stacks is investigated by the Jülich research center.

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Task

Indium tin oxide (ITO) is used in the manufacture of transparent anodes for OLEDs (organic light emitting diodes) because it provides the best compromise between high conductivity and high transparency. Yet the rare metal indium is becoming increasingly expensive, making it all the more important to minimize wastage of the material during the coating process. The standard method of manufacturing structured anodes involves the use of conventional sputter techniques in conjunction with lithography or masking. A large proportion of the ITO used in these processes cannot be recovered (middle figure). The aim is to develop an additive process in which the requisite structure is applied without wasting material. The deposition of structured nanoparticle ITO coatings on glass or PET substrates, e.g. using an ink-jet printing process, represents a challenge in that the thermal post-treatment process - which is needed to reduce the surface resistance of the dried layers - requires temperatures that exceed the temperature stability point of the substrate. Laser treatment overcomes this drawback by virtue of its rapid heating and cooling rates that allow the required temperatures to be reached in the coating layer without affecting the substrate material.

The laser post-treatment of nanoparticle-based ITO films represents the key to the efficient use of materials when manufacturing structured films with defined functions such as low sheet resistance and high transparency.

Method

The first stage of the process involves creating a dispersion of ITO nanoparticles (figure below). Additives are employed to modify the properties of the dispersion so that it can subsequently be deposited on the substrate to form the required defect-free structure using an ink-jet printing process. In the final stage, the deposited film undergoes thermal post-treatment through exposure to laser radiation, which results in the specified sheet resistance through a combination of thermal compression and sintering.

Results and Applications

Thermal laser post-treatment reduces the sheet resistance of 800 nm thick films on glass by several MΩ/sq to less than 150 Ω/sq with a speed rate of 14 cm²/s. The layer transparency remains more than 98 % (at 550 nm). Such films can be employed in the manufacture of electroluminescent light sources (figure above) or displays with low information content, such as pricing displays.

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Task

Photochemical etching is widely used as a manufacturing technique for structuring tools and other metallic surfaces. But the process is time-consuming and costly, and also requires large quantities of environmentally hazardous acids. Laser ablation is another established technique for structuring metallic surfaces. Its shortcomings are the often low processing rates (approximately 3 mm²/min for 150-µm-high structures) and the frequent extensive need for post-treatment. To address these drawbacks, a novel process for structuring metallic surfaces has been developed in which a thin (~100 µm) surface layer is remelted by continuous laser radiation.

Method

In contrast to laser ablation, where material is removed, laser remelting generates structures by reallocating material in the molten state as a result of modulating the volume of the melt pool. The laser power is periodically modulated to specifically influence the melt pool volume and hence produce surface structures. The laser power is modulated around the average laser power $P_M$ within an amplitude range $P_A$ over the wavelength $\lambda$, while the focus of the laser beam with the diameter $d_i$ and the velocity $v_S$ is moved unidirectionally over the metallic surface (figure above). By systematically varying these parameters, it is possible to investigate the effect of process parameters on the symmetry and structural dimensions of the generated surface topographies based on the analysis of single tracks. To enable large-area surfaces to be processed, the spacing $d_y$ between single overlapping processing tracks is set to an appropriately low value (figure above). The structure solidifies (smoothed/polished) from the melt and does not require any further post-treatment.

Results and Applications

At a processing rate of approximately 50 mm²/min, it was possible to reproducibly create profile heights in the range of 150 µm. The standard deviation from this profile height is less than 4 percent. At a significantly lower processing rate of approximately 1 mm²/min, structure heights greater than 2 millimeters were achieved, with a gradient angle of the structures close to 90°. The largest area to date was produced on a tool insert made of 1.2343 steel. The structured surface measures 120 x 150 mm² (middle figure) with a structure height of 150 µm, generated with a wavelength of 3 mm. The processing time for this area is six hours, which corresponds to a processing rate of 50 mm²/min. The tool insert was then used to mold accurately detailed structures on plastic parts (figure below).

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Task

High-power LEDs are increasingly being used as the basis for low-cost backlit displays and lighting panels. Single LEDs are now beginning to replace LED arrays, but they require appropriate lightguide structures to distribute the light homogeneously. To evenly illuminate the often circular or rectangular displays, the transparent plastic lightguide element must be provided with suitable outcoupling structures in its volume or on the surface to ensure even outcoupling regardless of the LED’s position in the display. To meet the requirements of low-cost production for these lightguide elements, the transparent plastic components are manufactured using an injection-molding process in which the tools have to be engraved with microscopically small structures.

Method

Injection-molding tool inserts containing up to 100,000 individual structures were used to manufacture the necessary outcoupling structures in the form of hemispheres with a diameter of 100 µm and a depth of 25 µm. The structures were generated by ultra-short pulsed laser ablation followed by laser polishing to produce a high optical surface quality. The precise ablation with ultra-short laser pulses enables the microlenses to be shaped to an accuracy of 100 nm. The distribution of the lightguide structures - determined previously by means of simulation - can be replicated via low-cost micro injection molding.

Results and Applications

Splitting up the light decoupling structures into a limited number of tiles - each with a different quantity and distribution of hemispheres - reduced the necessary data and computing overhead. On average, two hemispheres were ablated per second. Lightguide elements for automotive applications manufactured using the tools have already entered series production.

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Above: Steel mold for a 7-inch backlit display containing more than 500,000 structures. Below: Close-up of a mold surface with various structure densities.
**Task**

Products with functional surfaces based on micro- or nanostructures offer considerable market potential through the ability to incorporate new functionality in terms of flow characteristics, tribology, haptics and optics. Various processes such as lithography, micromilling and laser ablation are available to produce these surfaces, but are not yet widely used due to the high investment costs involved.

To resolve this problem, a new process chain is being developed that combines precise micro- and nanostructuring by means of laser ablation with replicable mass-production processes. As a result, the functional micro- and nanostructured 3-D surfaces can be manufactured directly and quickly in the same primary forming process together with the macro component.

**Method**

As part of the Cluster of Excellence at RWTH Aachen »Integrative Production Technology for High-Wage Countries«, a process chain suitable for mass production is being developed that comprises the following steps:

- Manufacture of a micro- or nanostructured tool with wear-resistant, anti-adhesive coating;
- Use of the tool in a laser-assisted injection molding or extrusion process or in connection with investment casting.

The main focus as far as laser structuring is concerned lies on the development of a process capable of producing seamless, large-area micro- and nanostructures on 3-D tool surfaces, and the structuring of wear-resistant, anti-adhesive hard material layers.

**Results and Applications**

Negative functional structures with dimensions in the micrometer range were generated in tool steel and hard metal for use in the subsequent replication process. The corresponding positive functional surface of the plastic product exhibited superhydrophobic characteristics.

In cooperation with the Institute of Plastics Processing IKV, the use of auxiliary laser heating during the production process enabled structures smaller than 1 µm to be achieved and microstructures smaller than 100 µm to be molded with an aspect ratio of greater than 1:1.

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Task

To generate a functional surface topography for products or components with freeform surfaces, these are usually hand-polished in industrial practice. The quality of the manual polishing depends on the skill of the polisher, and the surface rate is low. There is therefore a growing need for an automated polishing process for freeform surfaces. Laser polishing is a remelting production technique in which the roughness is reduced during the molten phase owing to surface tension. The focus of the laser beam is guided in meanders over the surface to be polished along contour-aligned processing paths. Until now, research has shown that laser polishing is in principle suited for processing freeform surfaces. In order to make the process useful for industrial applications, an end-to-end CAM-NC process chain needs to be developed for laser polishing of freeform surfaces.

Method

The beginning of the data chain is a 3-D CAD model of the component to be polished. In the first step, the CAD model is used as a basis to compute the path data with a conventional computer-aided manufacturing (CAM) program for CNC milling. The geometrical information of these milling paths is passed on as x, y and z coordinates to a post-processor software developed by the Fraunhofer ILT (figure above). The process parameters for the laser polishing of freeform surfaces have to be chosen on a case-by-case basis depending on the material, the initial roughness and the required roughness. The post-processor software has a technology database from which a suitable set of process parameters can be chosen for the respective application. The software calculates the geometry-dependent process parameters according to the user’s specification for the process parameter set to be used and the laser polishing machine to be used. The last step in the process chain involves transferring the machine-dependent NC code to the 3-D laser polishing machine and processing the surface.

Results and Applications

The development of the post-processor software has closed the CAM-NC process chain for the laser polishing of freeform surfaces. The figure below shows a mould half processed with the developed process chain in its initial condition (figure below, left) and in the processed condition (figure below, right). The mould half made from GGG40 has a roughness of $Ra = 1.7 \, \mu m$ in its initial state. The aspired roughness of $Ra = 0.4 \, \mu m$ attained on flat test pieces was successfully achieved on the freeform surface. The surface processing rate for this application case was about $1 \, cm^2/min$.

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Task

The demands for better imaging quality and precision made on lenses and optical systems for high-volume markets, such as eyeglasses, or for special applications, such as UV microlithography, are growing continuously. Using lenses with aspherical surfaces is a way to avoid imaging errors. Because they reduce the number of lenses needed, aspherical or freeform surfaces in optical systems still offer the great advantage of lower weight and miniaturization. Due to the deviation from the spherical form, polishing these kinds of lenses is extremely difficult and costly. The aim is to develop and qualify a laser-based polishing process for optical precision surfaces of fused silica and polymers. In this process, locally heating up a thin surface layer to just below the vaporization temperature creates an »outflowing« of the roughness due to the surface tension.

Method

Within the framework of the process development, the optimal process parameters are to be established as well, such as laser output power, feed speed and scanning speed. Suitable processing strategies and preheating technologies as well as different beam shaping optics are also to be tested on a laboratory system. The process will then be developed for various types of glasses and plastics by adapting the process parameters to the material.

Results and Applications

Basic investigations for laser polishing of fused silica and polycarbonate have been carried out. This technique can reduce the roughness from an initial roughness $R_a = 150 \text{ nm}$ for fused silica and $R_a = 100 \text{ nm}$ for polycarbonate to $R_a < 10 \text{ nm}$. The polishing process can also be applied to spherical and aspherical lenses. Potential applications are eyeglasses, aspherical lenses for high-volume markets, and even laser optics, for example with increased destruction thresholds.

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Task

In the manufacturing of photovoltaic modules, the individual solar cells are contacted with an electrical contact of tin-plated copper ribbon to form a string. The electrical contacting between silicon cell and ribbon is usually done by soldering. The demand for continuously increasing productivity and efficiency is calling for new joining processes that are quick, efficient and contact-free. Contact-free joining can be done with a laser-supported joining process. This involves both laser beam soldering as well as laser beam welding. These two joining methods enable efficient and locally limited energy input, so that the thermal stress on the silicon can be kept low. The advantage of laser beam micro-welding over laser beam soldering is that the process times are about ten times shorter and do not need fluxing agents or leaded solder.

Results and Applications

Essentially, a fiber laser does enable the contacting on solar cells to be welded. The good beam quality and the small focus geometries of the laser enable welding of the contact ribbon onto the screen-printing paste of the solar cell without mechanical pressure. The joint connections show little damage to the silicon. They can withstand tensile forces of up to 5 N. A joint connection can only be done without pressure if the distance between the contact ribbon and the screen-printing paste is minimal.

For the production of photovoltaic modules, laser beam micro-welding generates new assembly methods that can further reduce the thermal energy input in comparison with laser beam soldering and thereby cope with the thermal management brought about by the materials. In upcoming studies, welded modules will have to be characterized with regard to their specifications.

Method

In order to prove the general feasibility of this task, various beam sources were compared: a fiber guided Nd:YAG laser with a focus diameter of 180 µm, a free-beam guided Nd:YAG laser with a focus diameter of 70 µm and a fiber laser with a focus diameter of 30 µm.

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Above: Cross-section of a welded contact ribbon to a solar cell.
Below: Spot-welded ribbon.
Task

Contacting on electronic components and micro-mechanical connections is frequently implemented using laser beam spot welding. Quality demands with rejection rates in the range of 2 ppm require techniques that generate reproducible results even in the case of fluctuating starting conditions. As a rule, a pulsed Nd:YAG laser with a static beam and a focus diameter ranging from 100 to 500 µm is used for laser beam spot welding. The spot welding diameter is determined by the focus diameter. The melting zone is tapered in a cone shape towards the seam root.

The typical conical profile of spot welds is especially disadvantageous for lap welded joints because the weld cross section is very dependent on the welding penetration depth. In order to achieve a secure joint, the penetration depth must go well beyond the level of the separation plane. Problems are mostly due to fluctuating coupling conditions, for example, owing to various surface conditions and the size of the keyhole in relation to the volume of molten material. The consequences are often uncontrolled fluctuations of the weld penetration depth as well as irregularities in the melting zone due to overheating of the melt bath.

Method

Fiber lasers with a focus diameter of < 30 µm combined with fast beam scanners offer the possibility of substituting spot welding by ring welds with desired diameter. To do this, the beam is guided along a circular path. Numerous passes over the circle create a cylindrical melting zone in the middle of the circle due to a controlled accumulation of heat.

Results and Applications

The ring welding technique provides three additional parameters to influence the geometry of the melting zone, feed speed, circle diameter and the number of passes. If the process parameters are properly set, a perfectly cylindrical welded layer can be obtained, whose diameter remains almost constant throughout the entire profile. This means that the weld cross section can be adjusted independently of the welding penetration depth. The auspicious relationship between the keyhole diameter and the weld pool diameter on the one hand, and the beam movement on the other hand, prevents weld pool overheating and related errors such as the formation of pores or spatter.

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**Task**

Laser beam brazing today is already an industrially established technique for the manufacturing of high-performance tools that combine carbide cutting tools with steel substrates. The joint connections exhibit the necessary strength for this, but they are not always sufficiently reproducible owing to the uneven amount of brazing solder and the varying thermal conditions. A self-regulating joining technology for a bronze sinter segment with a steel component is therefore required for high quality mass production. Implementing process control based on pyrometric sensors the process window for a reproducible joining process should be defined.

**Method**

The laser used is an LDL40-300 diode laser built by Laserline. The entire unit consists of four individual lasers that emit continuously and have a maximum output of 300 W. To avoid stressing the sinter bronze by high joining temperatures, a low-melting brazing solder is used. This brazing solder is used for the soldering of hard metals and difficult-to-wet materials. Furthermore, a suitable fluxing agent is used for the soldering of hard metals and CrNi steels. An SE 200 series pyrometer from Amtron was selected to carry out the tests and integrated in the plant. The pyrometer sensor can detect the processing temperature and thereby allows the laser output to be controlled in terms of material and speed. The pyrometer is integrated in the optical focusing unit coaxially to the beam path of the processing laser. The processing optics focus the laser onto the workpiece using a dichroic mirror. The pyrometer observes the processing zone through the dichroic mirror and the processing optics. The coaxial arrangement of the pyrometer ensures that the process zone is always displayed on the sensor during processing.

**Results and Applications**

As part of the research, the significant parameters, such as laser output, processing speed and fluxing agent, were ascertained. This demonstrated the need to control the process, in order to avoid overheating and the development of pores. In addition, a minimal temperature has to be attained in order to melt the solder completely and ensure that the two joining partners are wetted along their entire length. A stabilization of the joining results was achieved through the deployment of the pyrometer-based process control, which allowed adjustment of the laser focus and hence the related area of interaction with the assistance of the right control parameters.

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Above: Cross section of brazing joint.  
Below: Bronze-steel bond with silver brazing solder.
Task

The need to conserve energy and resources has increased the trend towards manufacturing components from different functional materials which are well adapted to the specific use. For lightweight construction, this means that metal and plastic components increasingly have to be merged. Thanks to this hybrid technology, the advantages of both materials can be combined. Higher functionality can be obtained even at a lighter weight. In order to optimally combine the two different materials, the plastic-metal components have to be joined together stably and durably.

Method

In order to fulfill the task, a variety of approaches are being implemented within the framework of the RWTH Aachen’s Cluster of Excellence »Integrative Production Technology for High-Wage Countries.« A novel method creates a very strong bond by combining adhesive joining and form fitting joining of metals in a transparent polymer. To achieve this, a surface structure consisting of a point, line and checkered pattern is carved into the metal component using Nd:YAG laser radiation. The structured stainless steel sample is then joined with the transparent plastic sample in a contour or quasi-simultaneous joining process using diode laser light.

Results and Applications

For the plastic-metal joint, various material pairings were examined, as well as different types of irradiation. Tensile tests showed very promising results with good robustness values for all plastics used.

Thanks to the micro-structuring of the metal surface and the resulting undercuts, plastics can be durably bonded with metal. Since over 50% of the material strength is achieved, the mechanical strength for industrial applications in the field of hybrid components is attainable. A new approach with a special structuring geometry aims at further increasing strength and even achieving impermeability to media.

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Above: Cross section of a laser welded metal polymer joint.
Below: Hybrid sample (steel-polycarbonate)
**Task**

Process reliability and robustness are important basic conditions for the successful use of laser techniques in industry. This also applies to the laser beam welding of plastics where processing quality depends strongly on the workpiece and geometry. In real-life production situations, frequent variations in component features, such as changes in the absorber concentration or design deviations, can have a decisive effect on weld quality. In order to guarantee uniform processing quality, techniques must be made available that react autonomously to process variances.

The TWIST® method for laser beam welding of plastics, which was developed at the Fraunhofer ILT, permits optimized and controllable energy input. This, in turn, enhances the robustness of the welding process and increases speed at the same time.

**Method**

The TWIST® method superimposes a highly dynamic movement of the laser beam on the feeding movement along the joining contour. In one variant of the process, the laser beam is moved on a circular path along the welding contour during the feeding movement. This results in heat being homogeneously inserted into the material and a reduction in the heat influence zone. The welding experiments are performed using a fiber laser built by IPG with a maximal output of 20 W. The feed and the superimposed highly dynamic circular movement are implemented with a ScanCube 7 galvanometer scanner from Scanlab.

**Results and Applications**

Due to the superimposed movement, the TWIST® method makes additional parameters available (e.g., frequency or amplitude) to influence the heat penetration in the zone of interaction. The correct choice of process parameters can result in better gap bridgeability in comparison with normal contour techniques. Furthermore, the high speed on the path within the contour increments leads to a homogeneous energy input in the material and to a significantly reduced depth of the heat influence zone with a very shallow effected zone, in contrast to conventional welding using diode lasers.

Deployment of a fiber laser beam with a fine focus allows the material to be heated up quickly and hence to achieve a high processing speed.

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Above: TWIST® welding of high-performance polymers (PEEK) at intervals of a second.
Below: Improved gap bridgeability for the welding of micro-titer plates.
Task

Owing to continual miniaturization in the semiconductor industry and in microsystems technology, the significance of temperature load on sensitive, multifunctional chips in packaging is gaining ever greater significance. In the case of silicon-based microsystems and conventional bonding technologies used in the industry, the temperature load can lead to damage in the chips’ functional area. In contrast, laser transmission bonding (LTB) with selective heat input enables a restricted heat influence zone along the packaging frame. So the chips can be bonded at wafer level or chip layer without, or only with slight, temperature load in the functional areas.

Method

The principle of laser transmission bonding is based on transmission joining, whereby the laser beam passes through the upper joining member and the temperature needed for bonding is then developed at the interface with the lower bonding partner. When bonding silicon with silicon, absorbing metallic interlayers are used at the interface that can also be used as functional conducting layers on the chip. For the silicon-silicon material pairing, a fiber laser with a wavelength of over 1.5 µm is used. The energy of the laser beam is turned into heat at the interface and a joint bond is obtained by thermo-chemical reactions.

Results and Applications

Melt-free, selective bond contours and superficial bonding can be done with a laser output between 20 and 30 W and process speeds of \( v = 100 \) mm/min.

The work on implementing large area bonding shows that energy input through simple contour scanning can produce thermal tensions and hence fissuring due to the high energy input. Inputting energy through multiple scans with lower laser output can, for example, result in bonding without fissures. This requires laser outputs of 12 - 16 W twice with a process speed of up to \( v = 200 \) mm/min.

Focus of future work will be on the microstructural characterization of the bonding areas. The qualification of the mechanical strength and the transfer of the results to wafer-level bonding are being planned.

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Task

In microsystems technology and sensor systems, functional components such as micro-mechanical movement sensors must be durably protected from environmental influences. Moreover there are high demands on the mechanical and thermal stability of the joint connection. Glass frit bonding has prevailed in industry over other techniques. When using temperature-sensitive functional layers and individual elements in these components, glass frit bonding, which is done at high temperatures in an oven, can no longer be used.

Method

Laser beam glass frit bonding represents a possibility of joining glass-silicon components at lower temperatures for the components and with a spatially limited joining zone. The local energy input with selective laser radiation through one of the joining members generates temporally and geometrically limited heat and hence the flowing and wetting of the glass solder. This can prevent the evaporation of elements of the glass solder.

A significant precondition for a successful soldering process is sufficient absorption of the laser light in the glass solder used. The radiation energy is turned into heat and melts the glass solder. The contact between the solder and the joining member, which is ensured by slight pressure, results in the wetting of the solder-free joint member. In this manner, the silicon part is joined with the covering glass preglazed with solder.

Results and Applications

Heating up the glass solder is done quasi-simultaneously by a multiple scan of the joint contour at high laser beam scanning speeds (> 800 mm/s). This produces uniform heat in the joining zone, melting and bonding of the glass solder, which in turn generates an even »sinking in« of the second joining partner. The »joining path« can be down to 50 µm, given a soldering height of 75 µm. Simultaneous heating and sinking in of the entire contour minimizes the occurrence of thermal tensions. Solder seams created in this way are notable for their form-fit and their bubble- and fissure-free soldering.

The potential applications for this joining technique include, for instance, the encapsulation and manufacturing of microsensors and microactuators.

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Task

In order to increase the thermodynamic efficiency of stationary gas turbines as well as aero engines, new materials are being analyzed with regard to their usability in high temperatures. Ceramic matrix composites (CMC) are a materials group that can be considered for use in gas turbines owing to their mechanical, thermal and chemical properties. CMCs boast a great degree of breaking elongation vis-à-vis non-fiber-reinforced ceramics and they achieve values that are comparable with those of cast iron. What is crucial for the material properties of CMCs is that the ceramic fibers are able to move within the ceramic matrix in order to dissipate energy in the event of distortions and reduce load transmission from the matrix to the fiber to the point of preventing the spread of fissures.

CMCs are difficult to process mechanically. At the present time, tools with diamond coatings are used for the machining. The aim of the research is to use laser drilling as a manufacturing technique for CMCs (e.g., for cooling-air holes), without destroying the matrix structure of the materials.

Method

Two CMC materials, C/SiC (figure above) and SiC/SiC are investigated regarding their processibility by drilling a series of holes using Nd:YAG laser radiation. The varying processing parameters are pulse energy, number of pulses and focus position. The drill holes are assessed on the basis of longitudinal polishing. The fibers, in particular, are checked for damage such as swelling or burn-out.

Results and Applications

The C/SiC exhibits clearly defined bore walls after drilling with laser radiation. The fiber ends are intact (middle figure). Thin recast layers about 3 - 20 µm thick have been formed on the bore wall. With the SiC/SiC, first the fibers are abraded by the laser light, since they have a lower degradation temperature than the matrix (figure below) owing to impurities (e.g., oxygen and titanium).

The two ceramic fiber-reinforced composites can be drilled using Nd:YAG laser radiation. An uncontrolled burn-out or a swelling of the fiber ends is not observed. In spite of the fiber structure, the bore walls are clearly defined with recast layers of < 20 µm. The bore depth can be adjusted by the number of pulses and the pulse energy. Therefore, drilling with laser radiation offers an alternative to mechanical processing techniques with diamond-coated tools.

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Task

Waterjet deburring is used to debur workpieces which push alternative processes such as grinding to their technical or economic limits. Waterjet deburring generates a pressure of up to 1100 bar, with the result that the waterjet’s large amount of kinetic energy not only removes burrs on machining edges and difficult-to-access deburring points in cutting and drilling processes, but also removes machining swarms and other adherent impurities in the workpiece. The materials are not subject to any thermal impact during waterjet deburring. In order to guide the waterjet directly to the deburring point, component specific high-pressure jet nozzles are required. The high-pressure jet nozzles with individual geometries are manufactured in one production step by laser drilling.

Method

The geometry of the high-pressure jet nozzle is dependent on the form and position of the deburring point and on the required cross-section of current. Sometimes high-pressure jet nozzles with complex three-dimensional geometries are necessary. A CAD program is used to design the high-pressure jet nozzles. A postprocessor breaks down the drilling geometries into meshes and generates tool paths. The tool paths are shown in a dataset for numerical control of the laser drilling unit. The high-pressure jet nozzles are manufactured according to the specifications of the feed rate and processing parameters (pulse duration, repetition rate, pulse energy, process gas type and pressure). The high-pressure jet nozzles are nitrified after laser drilling, in order to reduce abrasive wear and to increase the lifetime.

Results and Applications

5-axis drilling (trepanning) is used to manufacture high-pressure jet nozzles with various complex geometries for water-jet deburring. This eliminates the use of special tools such as those required for EDM (Electro Discharge Machining) or counter-boring, so that individual jet nozzle geometries can be manufactured without changing or wearing of tools. The aim is to achieve preset geometries of high-pressure jet nozzles with a tolerance of ± 15 µm. The lifetime of the high-pressure jet nozzles depends on the operating pressure of the water jet, but is usually several hundred hours.

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Task

Laser beam drilling has already established itself in many areas of application in the manufacturing of micro holes with diameters of less than 100 µm. Problems are caused by materials with a molten phase which result in a molten mass flowing laterally out of the hole during processing. This affects the quality of the hole wall and entry. The aim of many system tests for laser beam drilling is therefore to reduce the recast area. One option is helical drilling, in which the laser radiation is moved in rotation, relative to the workpiece, resulting in a considerable reduction in the recast area. Extensive knowledge of the physical processes taking place is essential for a further increase in drilling quality. The parameters of the helical drilling process which specifically affect quality must also be ascertained.

Method

In order to test the helical drilling process, different beam sources are used to introduce percussion- and helical drilled holes into metals. Q-switched solid-state lasers with an effective pulse duration of several hundred ns up to a few ps are used for this. The helical drilled holes are introduced using helical drilling optics developed at the Fraunhofer ILT; the rotation speed is varied from zero (percussion drilling) to 16,000 rpm. Scanning electron microscopy (SEM) images of the hole entry and of transverse and longitudinal sections are made in order to test precision.

Temporal progression is also considered during the manufacturing of a helical drilled hole in dependence on the helix diameter and the angle of incidence of laser radiation.

Results and Applications

On the basis of the test results, we developed a model for helical drilling process that shows the predicted formation of molten mass and the influence of a rotating laser beam on the melt dynamics. It was identified that a rotating movement of the molten mass along the hole wall is a vital component for increasing precision. This process enables the molten mass to adhere evenly to the whole wall surface. It is then vaporized by the rotating laser radiation. This process was monitored for both ps and ns pulses. Overall, the results show that drill-holes manufactured with pulse durations in the area of several nano-seconds are comparable with drill-holes manufactured with ultra-short pulses. Due to the much larger ablation rates of short-pulsed lasers in comparison to ultra-short pulsed lasers, their areas of use include applications in which efficiency is as important as precision.

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Task

Laser-drilled holes are produced using various drilling techniques, such as single-pulse drilling, percussion drilling and trepanning. Until now, there have been a few investigations of the use of double pulses for laser drilling. The main purpose of double pulses is to increase the ablation rate or plasma emissivity. This enables, for example, a more precise diagnosis of plasma in laser-induced breakdown spectroscopy (LIBS).

Method

Blind drill holes are manufactured with nano-second double pulses into stainless steel with a material thickness of 1 mm. The beam source used consists of two cavities which can be controlled independently with a repetition rate of 1 kHz. The Δt pulse spacing from pulse to pulse is varied from 5 to 800 ns, the pulse number from 5 to 10,000. The pulse energy is 1.4 mJ for the first pulse and 1.8 mJ for the second pulse for a wavelength of emitted laser radiation of 1064 nm and a pulse duration of 5 ns each. The focus of the laser beam with a diameter of 35 µm is positioned on the material surface. When the longitudinal sections have been manufactured, the microstructure of the drill-holes is metallurgically investigated and geometrically measured (figure above).

Results and Applications

The depth of the drill holes depends significantly on the pulse spacing when drilling with a constant pulse number of 5000 pulses (middle figure). The depth of the drill hole reaches a maximum to a pulse spacing of 100 - 200 ns and decreases at smaller and larger Δt pulse spacing.

The dependence of the drill hole depth on the pulse number when drilling with single and double pulses shows that the drill hole depth is comparable for the first 20 pulses (about 30 µm). Up to a pulse number of approx. 2,000 drilling with double pulses results in a significantly increased drilling depth (approx. 650 µm) in comparison to drilling with single pulses (approx. 130 µm). A further increase in the pulse number causes a reduction in the drilling speed, resulting in a drilling depth of approx. 200 µm when drilling with single pulses or 780 µm when drilling with double pulses after 10,000 pulses (figure below).

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Above: Longitudinal sections of the drill holes for different Δt pulse spacing. 
Middle: Drill hole depth depending on the Δt pulse spacing for a pulse number of 5,000 pulses when drilling in stainless steel with a thickness of 1 mm. 
Below: Drill hole depth depending on the pulse number for a Δt pulse spacing of 100 ns.
Task

A large part of the material is ablated in melted form during laser drilling with pulse durations in the nanosecond or microsecond range. When femtosecond laser radiation is used, ablation is very accurate, as the majority of the material is ablated as vapour. In comparison to laser radiation with pulse durations in the nanosecond or microsecond range, this results in greater reproducibility and precision of the drill holes with reduced productivity due to the small amount of material ablated per pulse. The aim is to produce the smallest drill holes possible in metal foil with foil thicknesses of approx. 50 µm.

Method

Drill holes are manufactured by femtosecond laser radiation into stainless steel foils with a material thickness of 50 µm. The IMRA µJewel beam source used emits laser radiation with a wavelength of 1045 nm, pulse durations < 500 fs and pulse energies of up to 10 µJ. The focus of the laser beam with a diameter of approx. 35 µm is positioned on the surface of the material. The repetition rate is varied from 100 kHz to 5 MHz.

Results and Applications

Foils with a thickness of 50 µm can be drilled through with repetition rates of 100 - 500 kHz. The drill holes produced are investigated by using scanning electron microscopy (SEM). The drill hole diameters attained depend significantly on the repetition rate used. The drill holes are conically shaped. At 100 kHz, entrance diameters of approx. 25 - 30 µm and exit diameters of approx. 10 µm are achieved. An increase in the repetition rate to 500 kHz results in a reduction of the entrance diameter to approx. 20 µm and the exit diameter to approx. 3 µm.

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**Task**

During percussion drilling with laser radiation, processing parameters such as the process gas used, the repetition rate, the pulse duration and the pulse energy have a significant influence on the drilling speed and on the attainable geometric and metallurgical quality of the drill holes. Closures emerging during drilling and the resulting reduction in productivity and quality are usually diagnosed by metallographic tests using lateral thermography. During drilling close to the edge of the sample material, emerging closures and temperature distribution should be investigated in dependence of the processing parameters such as the type of process gas or the repetition rate.

**Method**

Drill holes are inserted at a distance of approx. 150 µm to the sample edge in stainless steel with material thicknesses of up to 15 mm. Thermography is used to monitor the sample’s temperature distribution laterally to the direction of the drill hole. This enables emerging closures to be diagnosed online during drilling - the advancing base of the drill hole is visible in the thermographic images due to the increased temperature resulting from the absorption of laser radiation at the hole front. During drilling, emerging closures form a new drill hole front, which is heated by the energy introduced by the laser radiation. The closure is visible due to a changed heat image, as the heated point is situated in a different position in the drill hole.

**Results and Applications**

The monitoring results suggest a significant dependence of closure formation on the process gases used. When oxygen is used, hardly any closures can be detected. The use of argon or nitrogen results in an increased closure formation, which results in a longer drilling time, as drilling progress is disrupted during ablation of the closures by laser radiation.

Lateral thermography during percussion drilling with laser radiation enables online diagnosis of drilling progress, detection of closures without complex ex-situ diagnosis using metallographic tests, and identification of temperature distribution of the sample during drilling. The results can be used to optimize the type and pressure of process gas.

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Thermographic images taken during percussion drilling (above: 60 s, middle: 100 s, below: 300 s).
Task

The formation of the ablation profile and melt flow within a drill hole produced by laser light is determined essentially by the distribution of inserted laser light power. The task consists of specifying laser light transport within a drill hole and using it in the process simulation to couple laser light energy into the workpiece. The emerging interference structures are an additional effect on the melt flow and are relevant, for example, for the formation of melt closures and recast formation.

Method

In order to improve quality when simulating drilling, the models for calculating the ablation profile, the temperature, the melt flow and the laser light transport are combined. Light transport is calculated using a ray tracer developed at the Fraunhofer ILT. The ray tracer has now been improved to cover transport of the optical phase, allowing phase-correct superposition of the individual beamlets. This allows any complex wavefield to be composed of beamlets, which are defined by the transported output and phase, and by the propagation directions of the characterizing peripheral beams.

Results and Applications

The existing ray tracer, »Laser ray«, is an extension of the »Laser drill« simulation of drilling. Beams are tracked and outputs are transported along the beams. A gradual expansion of geometric optics is possible by simultaneous transport of the phases along the calculated beams and the phase-correct superposition of light in the propagation area or on the surfaces of the objects considered. This expansion makes it possible to retain the advantages in calculation time of ray tracing over wave-optical processes (Fourier optics, FDTD, etc.), and at the same time to analyze interference structures (see figures), which emerge during the superposition of primary incident and reflected laser radiation.

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**Task**

Functionalizing medical products requires a high-resolution coating technology for proteins and other biomolecules. In the context of the InnoNet project PROTOPRINT, a new system has been developed with which virtually any pattern made up of biomolecules, proteins or cells can be selectively applied to a surface. This can improve the biocompatibility of medical devices and opens the door to novel chip-based in-vitro test systems. In bioanalytics, medical engineering and regenerative medicine, in particular, it will be possible to create new products with improved properties.

The aim of the project is to develop a process technique capable of applying complex patterns made up of sensitive material - such as agents, proteins and cells - to a surface.

**Method**

Complex structures can be printed using the innovative laser-printing technique LIFT (laser-induced forward transfer). This enables to deposit a bioactive film (cells, proteins, etc.) from a target with an absorber layer to be transferred to a substrate through targeted laser ablation (figure below). The transfer takes place via a laser-active absorber layer, which evaporates when irradiated with laser light. The resulting pressure wave transports the bioactive film across short distances onto a substrate.

**Results and Applications**

Using a fast optical scanner it is possible to generate array patterns between 20 µm and 300 µm in size with up to 1000 spots/s. Any grid patterns can be processed using this technique. It was also demonstrated that vital cells can be specifically transferred. The parameters need to be adapted for each cell type.

Unlike in conventional processes, small quantities of highly viscous liquid were reliably transferred. This opens up a new spectrum of possible formulations for bioactive substances, which can help to improve transfer - especially of protein and DNA solutions, which tend to pose problems in bioanalytics.

The possibility of printing films that have already dried likewise opens up new areas of application in the coating of medical devices and implants. Selecting suitable additives when composing the substances can significantly influence the material’s adhesive properties.

The partners in this project are Arthro Kinetics, Aurentum, BioCat, Boston Scientific TZ, CryLaS, GeSim and the IGVT of the University of Stuttgart.

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**Task**

A diode-pumped waveguide laser has been produced by structuring a deposited laser-active amorphous Nd:Ga₃Gd₅O₁₂ film. It is now being investigated whether such a waveguide laser can be integrated with a semiconductor laser by depositing the film directly in front of it.

**Method**

Neodymium-doped phosphate glass (LG 760) is being investigated as a potentially suitable material for integration with a semiconductor laser.

Nd:phosphate glass films are produced in a vacuum (P < 0.02 Pa) by PLD using excimer laser radiation (wavelength $\lambda = 193 \text{ nm}$) and by varying the substrate temperature. Femtosecond laser light is used to produce planar ridge waveguides. The laser-active films are characterized by means of optical spectroscopy. Nd:phosphate glass films are deposited directly in front of a semiconductor laser to test the possibility of seamless integration.

**Results and Applications**

Films with few droplets (number of droplets < 10 in $1 \times 100 \times 100 \mu m^3$) are produced at a substrate temperature of 120 °C. A damping of the signal light by 15.4 dB/cm, which is due to resonant absorption of the Nd³⁺-ions and a non-resonant scattering loss caused by droplets or surface roughness, is detected in the film. The non-resonant measurement of the scattering losses revealed a resonant absorption of Nd³⁺-ions of approx. 6 dB/cm. Owing to the additional scattering at the edges of the waveguide, the extinction in the structured layer was 19.1 dB/cm.

Deposition and structuring of the active film directly in front of the semiconductor laser makes it possible to cost-efficiently mass-produce compact, highly integrated laser beam sources for use in lighting systems or as pulsed beam sources (processing lasers) in medical engineering and inscription.

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Task

Selective laser-induced etching is a new manufacturing process for producing microstructured components made of transparent materials. The use of a newly developed high-speed scanning system with a large numerical aperture (NA = 0.4 - 0.9) and laser beam sources with a large repetition rate (f > 1 MHz) enables great productivity (v = 100 mm/s) and a high degree of precision (Δx < 1 µm).

Method

By focusing femtosecond laser radiation in the volume of sapphire, the structure is locally modified and its etchability thus selectively increased by a factor of 10,000. With a large pulse overlap (> 90 percent), connected volumes with a cross-section of approx. 1 µm are modified and then removed by chemical etching in aqueous solution of KOH or hydrofluoric acid.

The use of a newly developed rapid deflection system enables the laser light to be focused with a large numerical aperture (NA = 0.4 - 0.9) in the volume of transparent materials. Scanning speeds of several 100 mm/s are achieved with a focus diameter of < 1 µm. Novel laser beam sources with pulse frequencies > 1 MHz and pulse energies of several µJ can thus be used very productively for selective laser-induced etching.

Results and Applications

After etching, the micro components and cut-outs are produced (figures above, middle and below). The interfaces feature a typical roughness of Rz = 1 µm and a process-typical periodic nanostructure with a period of ~ 300 nm. Sapphire with a thickness of 500 µm is separated with a kerf width of ~ 1 µm (figure below) to achieve a minimized cut.

The systems engineering and process management involved are being further developed for future high-power femtosecond lasers in order to be able to manufacture microcomponents cost-efficiently and productively. Tests are being carried out on the use of complex three-dimensional components in micro-optics, microfluidics, medical engineering and microsystems engineering.

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Above: SEM image of the resulting hole in sapphire, thickness 460 µm.
Middle: SEM image of the cut-out cylinder made of sapphire.
Below: SEM image of a detail of the kerf on a cube with edges approx. 500 µm long.
Bottom: SEM image of the cut surface of the cut-out sapphire cube.
Micro-channels in transparent materials are of great importance for future applications in the field of micro-fluidics, medical engineering and micro-systems engineering. The channels can be produced in three dimensions in the volume of transparent materials by selective laser-induced etching.

Method

By focusing femtosecond laser radiation in the volume of transparent materials (sapphire, glass), the structure and thus also its etchability can be locally modified. Micro-channels can then be produced inside the material by etching with aqueous solution of KOH or hydrofluoric acid.

Results and Applications

In sapphire, differences in etchability of up to 10,000:1 are achieved between modified and unmodified sections. This makes it possible to produce micro-channels with cross-sections of between 1 and 10 µm and lengths of approx. 1 cm (figure above).

In quartz glass, differences in etchability of 30:1 to 100:1 are achieved between modified and unmodified sections. The processing results include conical micro-channels with diameters of between 5 and 100 µm and lengths of several mm (figures middle and below).

Potential applications include micro-fluidic systems for use in diagnostics, medical engineering and micro-systems engineering.

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Above: SEM image of the cross-section of a micro-channel in sapphire at a depth of 1 mm.

Middle: Reflected-light microscopy image of the cross-section of micro-channels in quartz glass at a depth of 200 µm.

Below: Reflected-light microscopy image of micro-channels in quartz glass.
Task

Waveguides and waveguide lasers for guiding and emitting electromagnetic radiation are of significant importance for future applications in the field of optics. Waveguides can be used as optical elements for such tasks as three-dimensional shaping of diode laser beams. Waveguide lasers can be used, for instance, as light sources in display technology.

Method

In transparent materials such as phosphate glass and fluoride glass, the index of refraction is locally modified by focusing femtosecond laser radiation in the volume of the material (figure above). By irradiating the material with ultra-short pulses, it is possible to deposit energy inside it through non-linear absorption processes and thus to achieve a local, temporally stable refraction index modification.

Results and Applications

In phosphate glass, structuring by femtosecond laser light makes it possible to achieve refractive index changes of up to $\Delta n = 1.7 \times 10^{-3}$ compared to unmodified material. Interference microscopy can be used to observe phase differences which develop in the material after irradiation due to the differing refractive indices. In this way, the refractive index distribution in cross-sections of the structures produced can be determined in spatial resolution (figure below).

Fluoride glass materials doped with rare earth ions and nano-crystalline glass ceramics are being tested as waveguide lasers for emitting laser light in the visible range. Fluorescence is detected at a wavelength of $\lambda = 525$ nm in the green spectral range.

Three-dimensional refractive index control is used to manufacture optical elements in the field of integrated optics. One important application is the integration of solid-state lasers in the form of waveguide lasers with high-power diode lasers serving as pump sources. This enables compact, inexpensive beam sources to be produced. Waveguide lasers open up new possibilities in markets such as lighting and medical engineering with a view to applications in diagnostics, cosmetics and therapy.

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**Task**

In the trend towards miniaturizing of optical components and systems, processes such as writing waveguide structures or joining glass materials in the µm range by ultra-short pulsed laser radiation (pulse duration \( t_p < 1 \text{ ps} \)) represent a major challenge. Time- and space-resolved measurements of phase changes and transient refraction index modifications in dielectrics by means of white-light interference microscopy help to gain a deeper understanding of the physical processes taking place during modification, and thus to optimize and monitor the process.

**Method**

A modified Mach-Zehnder interferometer set-up serves as the basis for the measurement process. When using this system, the difference between the optical density of a reference sample and that of a laser-modified area results in a phase difference. Transient changes in the index of refraction can then be derived from the recorded data.

The novel combination of well-known optical measurement techniques such as white-light interference microscopy with pump-probe techniques requires an ultra-short pulsed white-light source. The wide-band spectrum required for color imaging is generated by self-phase modulating of ultra-short laser pulses (\( t_p < 100 \text{ fs} \)). The generated pulses have a pulse energy of just a few µJ, a pulse duration of \( \tau < 10 \text{ ps} \) and a usable spectrum in the range of approx. 450 nm to 750 nm.

**Results and Applications**

The observed phase changes are a combination of different transient effects (tension, temperature, color centers, etc.) and their influence on the local index of refraction. The measuring process enables time-resolved measurements of transient refraction index modifications with a temporal resolution in the pico-second range. The influence of the processing parameters on the processing result can therefore be observed in situ, and the data can then be used to control the process. In the case of volume modifications of transparent dielectrics, for example, the accumulation of heat occurring at high repetition rates (> 500 Hz) is detected around the focal area. Refraction index modifications are observed, for instance, when structuring waveguides, micro-welding glass or selectively etching sapphire. The developed diagnostic technique enables these processes to be diagnosed in temporal resolution and controlled.

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This business area focuses on the development of prototype equipment for laser and plasma-technology applications, as well as on laser systems engineering, particularly in the fields of automation and quality assurance. Areas of application embrace welding, cutting, hardening, repair coating, drilling and micro-joining. The system technology offered provides complete solutions for process monitoring, components and control systems for precision machining, laser-specific CAD/CAM technology modules, as well as software for measurement, open- and closed-loop control and testing. For its work in process monitoring in particular the business area can draw on extensive and, where required, patent-protected know-how. In this sector numerous systems have already been licensed for companies. Target markets include laser equipment and component manufacture as well as all sectors of production industry which deploy lasers in their manufacturing activity or intend to do so.
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Task

The Fraunhofer ILT is strongly engaged in a project called »Integration of self-optimizing setup, monitoring and control systems in production processes« within the framework of the Cluster of Excellence »Integrative Production Technology for High-Wage Countries« of RWTH Aachen University. The aim of the project is to elaborate a process-independent method that will enable improved process understanding and to pave the way technologically to integrated cognition and self-optimizing of production systems. A very wide variety of processes were considered, such as injection molding, milling and weaving. In this project, the Fraunhofer ILT is focusing on laser beam cutting.

Method

After a detailed process analysis based on experimentation and theory, after defining the process parameters that need to be treated as top priorities - owing, for example, to their sensitivity and proneness to error - and after identifying suitable process sensors, the setup, monitoring and/or control systems are to be gradually integrated in a TruLaser 5030 laser cutting machine made by the company TRUMPF. Meta-models, which are central, methodically integrative tools, will make dependencies on process and quality parameters rapidly available at the machine.

Results and Applications

Owing to complex metrological accessibility, time-dependent thermal behavior and dependency on the state of deterioration of the focusing lens, etc., the focal position is a somewhat difficult parameter to control. By the same token, it is one that seriously influences cutting quality and the maximum cutting speed. Therefore, the influence of the laser beam output and the raw beam diameter on the focus position was first documented with relation to time using extensive beam diagnoses, and the fields of tolerance of the focus position were ascertained in cutting trials.

On the way to designing a self-optimizing machine, the first step will be to develop a set-up assistant that will help the user suitably adjust the focus position. In the next step, adjustment of the focus position is to be replaced by a process parameter that is dependent on the focus position and ascertainable with a sensor, and which will lead the process to an optimal parameter area without the focus position having to be explicitly known.

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Task

The Cluster of Excellence “Integrative Production Technology for High-Wage Countries”, of which the Fraunhofer ILT is a member, is pursuing the long-term objective of increasing the competitiveness of German production technology. One of the core research questions concerns the creation of new value-added structures for the production of individual parts at costs matching those of serial parts while maintaining the individuality demanded by the market. From a technological point of view, additive manufacturing techniques with their almost infinite geometrical variability represent one of the areas of the greatest potential. A major cost factor in the SLM process developed by the Fraunhofer ILT for the processing of metallic materials is the manufacturing cycle time, which depends mostly on the volume of material that has to be built up to produce the components. In order to produce at least small batches economically, increasing the build-up rate is necessary. One of the main boundary conditions for the increase of the build-up rate is the maintenance or improvement of the detail resolution that has been attainable so far.

Method

The increase of the build-up rate is to be achieved by a major increase in the laser power to 1 kW. Increasing the laser output power while maintaining a constant beam diameter increases the intensity at the point of processing. This, in turn, leads to a higher incidence of spattering, so the beam diameter must be adjusted. At this point it is advantageous to strive for maintaining the most uniform intensity distribution possible (“top-hat”). The prototype machine developed at the Fraunhofer ILT can generate focus diameters up to 1 mm. But as the beam diameter increases, the attainable detail resolution of the exterior contours of additively manufactured components decreases. In order to resolve this dilemma, a multi-beam concept was designed and implemented that allows processing different materials with various laser power outputs and focus diameters depending on the component specifications required. So, as with conventional roughing and finishing operations, component cores can be built up at high build-up rates (wide focus), while in the skin area (small focus), the necessary detail resolution and surface finish can be guaranteed.

Results and Applications

The integration of a fiber-coupled disc laser in combination with a variable beam switch allows the build-up rate to be increased and a component-adapted skin-core strategy to be implemented. Because of the automated change of the processing fiber, it is possible to work on both, the covering as well as the core areas with a sharp image of the fiber end. This has the advantage of uniform intensity distribution (“top-hat”) in all processing situations, which in turn almost completely prevents process instability due to local intensity peaks.

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Above: Schematic representation of the skin-core principle.
Below: 3-D CAD volume model of the beam switch, a) upper fiber active, b) lower fiber active, beam deflector cubes visible.
Task

The necessity of combining materials with various functionalities raises the issue of a suitable joining technique that can generate durable material composites quickly and reproducibly. For plastic-metal bonds, in particular, adhesive joining was the only method that was up to the task in the past.

Method

A new process technique that requires no additional bonding materials like adhesives is now available: the LIFTEC® method developed at the Fraunhofer ILT. It involves warming up the joining partner (metal, for example) through a plastic component and then pressing it into the plastic. The plastic, now heated by heat conduction, flows around the joining partner creating a solid, form fitting bond once it cools.

A flexible machine technology that allows components with different geometries to be joined in short cycles is required to implement the process on an industrial scale. As a flexible deployable machine technology, a servo-electric press was equipped with a high vertical positioning precision and a maximum pressing capacity of 5 kN, with form-flexible scanning optics and a high-power diode laser.

The joining partner is seized by the gripper affixed to the press and pressed into the plastic. The loading system guarantees reproducible positioning with a great deal of geometrical flexibility. The diode laser ($\lambda = 810 \text{ nm}$; $P_{\text{max}} = 50 \text{ W}$) used to heat the joining partner is fully integrated in the plant. A scanner enables simple adaptation of the irradiated surface to the respective component geometry. The individual process parameters are ascertained through the integrated power output, positioning and temperature sensors. A camera facilitates alignment of the two components to one another. An integrated process control system regulates all the relevant parameters. Preset functional elements, such as positioning or power-controlled joining, are arranged into process sequences and enable a high level of flexibility in the processes.

Results and Applications

The developed machine was tested for a variety of different joining tasks and also for processes that are related, such as laser-assisted hot-stamping. Typical cycle times are in the region of 30 seconds.

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Task

Extensive automation of assembly and manufacturing processes is necessary to deliver reproducible production results at low cost for small batches as well. To solve this task and to provide a flexible machine technology the innovative INTAKT processing cell was set up in cooperation with the Chair for Image Processing at RWTH Aachen University and various industrial partners. Thanks to its modular structure, the cell enables fast and flexible integration of various laser processing tasks in a partially automated setup. By including methods that use image processing to identify components, the system can be adapted to various component geometries without requiring too much retooling.

Method

The processing head for laser joining and structuring was designed as a combination of a galvanometer scanner and a Cartesian axis system. This permits components to be processed within a field 240 x 240 mm² in size with accuracies of some micrometers. In order to recognize the component's position, the processing field is observed by a CMOS camera coaxially to the laser through the scanner system. Optically-related observation errors are compensated by an automatic calibration cycle. This allows for a precision of < 20 µm in pinpointing a position.

Results and Applications

The controlling software, which can be operated intuitively for the most part, lets even inexperienced users prepare the machine for new components. Thanks to the automatic matching of the camera image with the CAD data of the component being observed, identified features such as edges and corners are automatically assigned the right contour. On the basis of this information, suggestions for processing are made that can be confirmed or rejected by the user. Another possibility is direct processing of the component by introducing any welding contour into the live camera image (»click & weld»).

When the system is on automatic, position recognition and processing are carried out according to the set pattern without the need for any further action by the user. Alternating processing of several different types of components is also possible by indexing the work piece holders accordingly. The process monitoring system, which is also based on the coaxially installed CMOS camera, offers the possibility of identifying welding errors in real time, depending on the particular application.

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Task

Combi-processing allows for a very flexible, highly productive use of laser systems for cutting and welding sheetmetal products. In order to fully exploit the potential of a rapid change of process without having to retool, the system should be optimally adapted as a whole to the efficient process chain and high level of precision of combi-processing, including handling and clamping technology.

Method

A combi-head with a connection flange arranged coaxially to the optical machine axis and with a compact additional axis is being developed in cooperation with the companies Reis Robotics, as the machine manufacturer, and Laserfact, as the manufacturer of the combi-head. The mirror beam guidance system being integrated in the robot arm makes it possible to move in two rotatory axes without the laser fiber moving. This reduces the strain on the fiber and considerably increases the permissible dynamics during rapid reorientations of the head and sharp accelerations.

Results and Applications

The overall length of the combi-head was reduced to allow for more dynamic re-orientations in the 3-D paths. The nozzle design was further improved for good access to the components thanks to a reduction in the angle of taper of the autonomous nozzle from 60° to 40°. The functional scope of the controls was extended for the dynamic additional axis integrated in the head for distance control. For example, not only can the true measured distance be conveyed to the superordinated control, but the distance control system also includes monitoring whether a pre-defined tolerance band is being complied with. As with the combi-head for direct fiber coupling, the version for integrated beam guidance also offers the possibility of a swift change of focusing optics and protective glass for convenient and rapid servicing. The improved features of the head have been applied to the processing of 3-D automobile components, for example.

The work is being funded by the German Federal Ministry of Economics and Technology (BMWi) as well as by the companies Reis Robotics, Laserfact and LBBZ as part of the InnoNet project »Flexible Production Cell for Combined Laser Processing with Adaptive Gripper Technology (koLas)«.

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Task

When using deep-drawn components made of high-strength steel, the mechanical processing for trimming the parts, drilling holes and making cut-outs reaches its limits owing to the material’s extreme hardness. The alternative is cutting with a laser, a solution that has already been applied industrially. The process is frequently followed by welding, for example, of reinforcement plates or bolts. This is done using conventional welding techniques such as resistance welding or arc welding.

Using lasers to both cut and weld as a combined process can shorten the process chain. The integration of laser cutting and welding processes in one machine is to be demonstrated using work on an automotive B-pillar as an example.

Method

The B-pillars are trimmed with a cut, and all hole cutting work is done as well. Cutting is done in the large contours at a speed of 15 m/min at a maximum laser beam output of 2.5 kW. The holes are processed at 3-9 m/min to match the system’s dynamics. Immediately following the trimming, the same head welds a reinforcement plate in a lap seam at a speed of 3 m/min. Another change in process then takes place for cutting, in order to cut custom-fit holes through the composite of the reinforcement plate and the base material. The processing takes place on a laser gantry robot (Reis Robotics) with a fiber laser (from IPG) and a combi-head (from Laserfact) with a design adapted and optimized to the coaxial beam guidance of the gantry system.

Results and Applications

The processing time for cutting and welding tasks on the workpiece is about 1 minute. The welding part only takes about five seconds. The combi-head avoids the need to switch to another processing station and hence saves all operational and investment costs that this entails.

For these types of applications, the laser can be deployed efficiently for technological and economical reasons already when carrying out a single process. Combi-processing opens up even more efficient manufacturing possibilities as well as technological advantages thanks to improved precision because reloading and reclamping are no longer necessary and the process sequence can be chosen flexibly.

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Above: Processing a B-pillar with a combi-head: cutting …
Below: … and welding.
Task

An increasingly acute problem in medical care is the treatment of chronic wounds, especially in light of an aging population. One form of treatment that is already in use today is placing a leak-proof dressing on the entire area of the wound. The dressing needs to be held in place securely even in the damp wound environment. Using a new laser-based concept, a dressing made of collagen is to be broadly fixed onto the wound area using a protein glue. The protein glue is applied in liquid form and can then be cross-linked with a laser beam. For the cross-linking to take place without damage to the tissue, a temperature of around 50 - 60 °C must be held steady to within 5 °C for a few seconds. Because of the many variables in the wound situation (including tissue morphology, wetting, contact between the dressing and the tissue), the desired temperature cannot be set reliably just by inputting the laser parameters.

Method

A new type of applicator with an integrated temperature control system was implemented for laser bonding of collagen to skin. This makes a reproducible protein adhesive bond possible. The ideal time-temperature sequence was determined in preliminary studies using skin models and animal preparations, and a suitable infrared sensor for measuring the temperature was selected. The sensor and the laser optics have been combined in an applicator in such a way that the sensor’s measurement spot corresponds to the size of the laser spot. The temperature signal of the sensor was integrated in the laser’s power output control, and limits for maximum temperatures and duration of exposure were preset.

Results and Applications

The system depicted can achieve reproducible, highly cohesive tissue bonds without overheating or damaging tissue. Once the prescribed temperature has been reached, the laser output is reduced and the temperature is held constant for the rest of the treatment. The metered time period of the closed loop is about 20 ms, fast enough to avoid overheating the tissue at laser outputs of up to 50 W. It was the temperature control that enabled reliable coagulation of the glue in changing conditions.

The work is being funded by the German Federal Ministry of Economics and Technology (BMWi) in the context of the InnoNet project »Laserfix«.

Project partner: Berufsgenossenschaftliches Universitätsklinikum Bergmannsheil in Bochum

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Above: Closed loop for temperature control.
Middle: Outline of the applicator with laser focusing system and temperature sensor.
Below: Typical signal curve for laser output (blue) and temperature (yellow).
Task

During longitudinal seam welding of pipes in industrial manufacturing plants, lacks of fusion often lead to production downtimes and returns. In particular, lack of fusion in the weld seam that has not been identified by an eddy-current test or an extra visual check can lead to a failure of the seam in further processing. The reason for the defect is a lateral shifting of the groove in relation to the laser beam, which can be caused by the pipe twisting, the joining edges being out of alignment, poor initial setting of the plant or of the seam-tracking sensor, and shifting of the laser beam owing, for example, to thermal influence.

While the first two effects can be controlled and corrected using conventional seam-tracking sensors and proper tracking, thermal effects result in a shifting of the beam within the beam guiding system. The principle suggests that this can be neither identified nor corrected by conventional seam tracking. And so the aim is to ascertain the beam’s position relative to the seam, in order to have the seam tracking correspond to the operating point of the laser. The task of the research is to examine the feasibility of simultaneous visualization of the capillary and the seam during welding, using camera imaging from the coaxial process control (CPC) method developed by the Fraunhofer ILT.

Method

As part of the activity, coaxial and lateral observation strategies were first theoretically examined in terms of performance, for example regarding the possible optical resolution potential. Subsequently, the selected lateral observation methods and the respective illumination scenarios were tested in experimental studies at an industrial pipe welding plant.

Results and Applications

The experimental work demonstrates that it is possible to visualize both the point of interaction zone and the groove that is to be welded, given the right lighting and employing the appropriate optical band-pass filters in front of the camera. The local resolution achieved is better than 15 µm and hence precise enough. The exposure time is 10 µs and hence brief enough to reliably prevent blurring due to movement during the process visualization.

The results are promising, so the next step will be to build up a seam-tracking system on this basis.

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Task

In shipbuilding today, panels 12 x 4 m² in size are welded in production lines using CO₂ laser radiation in a butt-joint configuration. The main advantage is the low energy input per unit length, which avoids the need for complicated truing and refinishing that make up almost one-third of the total manufacturing work in conventional welding. For the seam tracking, conventional sensors are deployed using the light-section method.

The aim is to improve a system for seam tracking with integrated optical speed measurement and to compare it with a conventional forerun sensor. In addition, process visualization for automated quality assurance during processing is to be examined.

Method

The camera-based system for coaxial process control (CPC) with external illumination developed at the Fraunhofer ILT was used as the sensor system. The CPC system was integrated in the beam path of the processing laser by means of a transmissive beam combiner made of zinc selenite. The wavelength and power of the laser light used (CO₂ laser with up to 8 kW of beam power) makes the optical set-up particularly challenging.

The process zone is illuminated coaxially by a separate monochromatic laser. The coaxially arranged camera permits visualization of the weld pool by recording the reflected radiation from the processing area.

Results and Applications

The significant advantage of autonomous seam tracking is that the actual position of the capillaries (keyhole) relative to the joint can be read in the images. Thanks to real-time image processing, reading can be automated. By feeding the information gained back to the plant control, the welding process can be automatically centered on the joint. Systematic errors, like the lateral shift of the focus point owing to erroneous adjustment or temperature drift of the optics, can thereby be identified and corrected. Furthermore, the visualization of the processing zone forms the basis for the detection of imperfections in welding applications using CO₂ laser radiation.

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Above: Diagram of a beam path.

Middle: Camera image of the BOP (bead on plate) welding of D36 sheet steel for shipbuilding with a primer coating at $P_\text{l} = 6$ kW, $v_\text{s} = 2.4$ m/min, $s = 5.5$ mm.

Below: Camera image of the welding of D36 sheet steel for shipbuilding with a primer coating at $P_\text{l} = 6$ kW, $v_\text{s} = 2.4$ m/min, $s = 5.5$ mm.
The potentials of coaxial process observation using external illumination for automated optical quality monitoring and control of industrial solid-state laser welding processes have been demonstrated in a series of preliminary studies. In the EDePha project, this idea has been stringently refined for the real-time detection of imperfections and transferred to welding with high-power CO₂ lasers, which is important in industrial applications. Using coaxial process observation and real-time image processing, imperfections are to be identified immediately, for example through changes in the geometry of the solid-liquid phase limits, and - if possible - suppressed by the automatic modification of process parameters.

A CMOS high-speed camera is used for the process visualization. The zone of interaction is monochromatically illuminated with such intensity that the process radiation in the area of the illumination wavelength (808 nm) is actually outshone. First of all, films are made with the camera placed laterally (image above). In this case, the camera is tilted by 15° relative to the observation laser in the forerun. For the coaxial observation, the coaxial process control (CPC) system developed at the Fraunhofer ILT is coupled into the beam path of the high-output CO₂ laser via a ZnSe beam splitter. The imaging of the interaction zone on the camera's CMOS chip in the CPC system is carried out through the welding optics. A comparable imaging quality as with the lateral placement can be attained with precisely manufactured copper mirrors, whose surface roughness is specified in such a way that visible light (about 1/20th of the laser wavelength) can also be depicted without error. Prepared welding samples are used to simulate welding imperfections. Their influence on the dynamics of the welding process is analyzed using the recorded film material.

The phase boundaries can be identified and measured in the recorded images of the interaction zone. The automated real-time evaluation of the film material is the subject of ongoing work and it also provides the cornerstone for the real-time detection of imperfections when welding with laser radiation. In the medium term, this should reduce costs for subsequent component testing.

The studies are supported by the German Federation of Industrial Research Associations (AIF).
Task

The transmission laser welding of plastics using laser radiation has become an established technique in industrial production. Component-, material- or environment-related conditions that elude controls can lead to deviations from the »optimal processing point« and hence to processing errors. The aim is to identify the problems in plastics welding and to develop a suitable process monitoring strategy relevant for industrial needs.

Method

The work has been carried out jointly with the industrial partners Amtron GmbH, Huf Tools GmbH and LIMO-Lissotschenko Mikrooptik GmbH under a project funded by the ‘Stiftung Industrieforschung’ industrial research foundation. This involves comparing the specific informative capabilities of the coaxial spatially integrated and the spatially resolved coaxial process observation, as well as the measurement of secondary radiation and the observation with external illumination.

Results and Applications

Thanks to the optical module developed at the Fraunhofer ILT, a processing head was built up that enables spatially integrated monitoring using the Amtron pyrometer and spatially resolved monitoring using a CMOS camera, while at the same time applying external illumination via high-power LEDs. This makes it possible to evaluate the various monitoring strategies and to correlate the sensor signals. Welding tests for polycarbonate, polypropylene and polyamide have been carried out.

The main reasons for processing errors can be cracks between the joining partners and fluctuations in the absorbed power. The results show that, with the help of the pyrometer, deviations from the desired process temperature caused by changes in the absorption or by cracking can be well identified, but the respective causes cannot, however, be distinguished from one another. The camera system helps clearly identify the cracking. However, deviations in the quality of the seam resulting from thermal influences can only be proved after completed processing.

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Above: PA - good connection.
Middle: PA - decomposition.
Below: PA - no connection.
Task

Process monitoring is already being used in laser welding of plastics. To monitor the process, three detector systems were used in three different wavelength ranges: a CMOS camera for the visible spectrum integrated in the beam guiding system, a pyrometer for the near-infrared spectrum integrated in the optics and an off-axis infrared camera for the range extending to the middle infrared wavelengths. For the further control of the welding process, the following questions should be answered with the ultimate aim of optimizing the existing process monitoring set up (see figure above):

• Can laser output differences be detected?
• Can pressure differences be detected?
• How can the process be controlled through temperature measurement?

Method

The contour method is used for the welding tests. A diode laser with a wavelength of 940 nm and a maximum power output of 70 W was used in the process. The relative movement between laser and workpiece is implemented via a three-axis system. Varying the laser output and the processing speed creates different weld seam strengths, measured by a tensile-shear test. In order to correlate the measured weld seam strengths with the data taken from process monitoring, the measurement data of the monitoring systems are averaged over the joining path for each parameter combination of infeed and laser output.

Results and Applications

The results show that a prediction of the weld seam strength is possible by way of the process monitoring system used. By using a closed loop system and the pyrometer, it is also possible to adjust for a desired weld seam strength and hence to balance out an inhomogeneous IR absorber coating (figure below).

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Above: Test system for polymer welding
Below: Controlled (above) and uncontrolled weld seam (below).
Task

The usability of three monitoring methods for deployment when welding transparent plastic films was investigated within the framework of an industrial study. Imaging methods in the visible and the IR spectral range were analyzed comparatively with a pyrometer in the near-IR range. During welding, an IR absorber is installed between the two transparent joining partners in overlap configuration for the absorption of the laser radiation. The low process temperature and the material's low thermal emission, in particular, pose special challenges when monitoring the machining process.

Method

The coaxial process control (CPC) system developed at the Fraunhofer ILT observes the zone of interaction through the beam path of the processing laser with a high-speed digital camera for the visible spectral range and with a pyrometer in the near-IR spectral range. The processing zone and the surrounding area are lit up with high-performance diodes. The IR thermography camera observes the lateral joint zone. With this experimental setup, comprehensive tests were carried out. The welding quality was destructively determined using shear force measurements on the seam.

Results and Applications

A significant finding of the studies is that the strength of the weld joint can be determined with IR thermography and the pyrometer via heat radiation. Changes in strength, caused by variations in the laser power, the welding speed and wetting through the IR absorber, are quantitatively determined. Faulty weld spots, such as cracks between and within the joining partners or in the IR absorber, can also be recognized, as can variations in the clamping force. All in all, observation in the visible spectral range is inferior to observation in the near and IR spectral range. The better local resolution of the IR thermography is compensated for by the greater temporal resolution of the pyrometer and the lower investment it requires. A process control system for welding plastic foils with an IR absorber was implemented on the basis of the dependency demonstrated between joint strength and the pyrometer’s signal. Temperature control produces a high and reproducible strength of weld joints, especially in the case of different welding speeds. Control was also able to counterbalance particularly problematical variations in layer thickness of the IR absorber.

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The services provided by this business area include the development of measurement and testing processes and related equipment for material analysis and for geometric testing and surface inspection. The requisite measurement and testing software is tailored to customer-specific problem areas. Material analysis is based on the deployment of laser-spectroscopic processes, focusing on the analysis of metallic and oxidic materials, identification testing of high-alloy steels, rapid recognition of materials for recycling tasks and analysis of gases and dust. Special electronic components are developed for the parallel processing of detector signals of high bandwidth.

In biophotonics joint projects are carried out in the field of highly sensitive fluorescence detection for protein chips and laser scattered light measurements in sub-µl test volumes for protein crystallization. As part of the area’s work on geometric testing and surface inspection components, devices and equipment are being developed for obtaining 1 to 3D information about the geometry or surface properties of workpieces. These include processes and special systems for testing the stability of bar and strip products and devices for the 1D to 3D scanning of unit goods. Target markets include the production and the recycling industry which conduct measurement and testing fast and close to the process.
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Task

Modern manufacturing lines require highly sophisticated systems of automated process and quality control. These systems require a means of checking geometric dimensions, and this task is increasingly being performed by laser triangulation. Future applications will require sensors that are even more flexible and accurate. As part of a collaborative research project funded by the German ministry of economics, novel technologies are being tested in collaboration with industrial partners for use in triangulation sensors.

Method

It is anticipated that fundamental improvements can be made to the sensors by selecting a laser beam source with shorter wavelengths and improved beam quality. The aim is to increase accuracy and enable high-temperature measurements. Use of a spatial modulator transforms the sensor into a flexible tool, which can easily be adapted to the various measuring requirements of triangulation that apply to the measurement of distances and profiles.

Results and Applications

A blue-violet laser diode is employed as the laser beam source, with its beam being coupled into a single-mode optical fiber. This enables levels of accuracy to be achieved in the region of 1 µm on reflective surfaces. This beam source can also be used to perform measurements on the surfaces of objects at temperatures > 1200 °C. Thanks to the use of a glass optical substrate for the sensor, the design is extremely lightweight and stable. Depending on the measurement task in each case, the spatial modulator can generate a variety of beam patterns, for example multiple points, lines or gridlines. At 60 Hz, this enables geometries to be measured to an accuracy of 50 µm with a measurement range of 90 mm.

The aim of the development work is to achieve levels of accuracy of < 1 µm using the new sensors. A further goal of the project is to test out a passively temperature-stabilized thickness measurement system with a jaw length > 800 mm on products with a bright metal surface.

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Task

In recent years, studies by market research companies have repeatedly concluded that demand across Europe for plastic packaging is increasing by roughly 5.5% per annum and have predicted that this trend will continue. At the same time, requirements are becoming ever more sophisticated, especially in the field of food packaging. For example, consumers expect packaging to keep products fresh for increasingly longer periods of time or to offer enhanced functionality such as indicating product freshness. The high levels of manufacturing expertise amassed by German companies enable them to derive particular benefit from this growing demand for high-tech packaging. The fact that packaging films are being expected to perform increasingly sophisticated functions is reflected in technologies that are capable of producing plastic films featuring ever more complex layer structures and an increasing number of functional layers. Even today, it is not unusual to find transparent films that consist of five or more individual layers, which have different functions. Due to the comparatively high material costs of functional plastics, however, plastics processors are striving to keep the proportion of these raw materials in the product to an absolute minimum while maintaining its full functionality.

Method

Guaranteeing an optimum barrier effect at all times requires constant checks to be made to ensure that the functional layers are fully present and sufficiently thick. Application of measuring systems to determine total film thickness for quality control and process control purposes are already standard in the manufacture of plastic films. However, there are currently no suitable film inspection systems available that are capable of measuring the layer structure of multilayer films. Optical coherence tomography (OCT) is an imaging technique that enables the creation of high-resolution 3-D tomography images. Based on interferometric measurements, this technology permits individual layer thicknesses to be detected in plastic films with a depth resolution of just a few micrometers.

Results and Applications

Part of the IRIS research project involves filling this gap in the available technologies through the development of a »Interferometric control and in-line monitoring system for the production of multilayer plastic films«, thereby making it possible to measure thin individual layers in the micrometer range during the production process. As well as ensuring top-notch process reliability, IRIS also allows for implementation of a control concept for film manufacturing plants, which is capable of cutting the resources required and thereby saving up to around 100,000 Euro per year in the case of a medium-capacity machine.

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### Task

Air pollution in the form of fine and ultrafine particulate matter has recently been identified as a major public health risk. Significant sources of anthropogenic particles are vehicular traffic and industry. Extremely small nanoscale particulate matter represent an elevated health risk because their size allows them to penetrate deeply into the human organism. At the same time, these aerosol particles are most challenging to analyze, hence there is a pressing need for further development of measuring instruments. In this case not only the chemical composition of particulate matter is in the focus of interest but also the size-dependence of the composition. The aim of this project is to develop a method for determining the composition of particulate matter in correlation with their size, with particular emphasis on the concentration of heavy metals.

### Method

To perform chemical analysis of the particles, two methods of measurement are under development on the basis of laser-induced breakdown spectroscopy. In the first method, the particles are collected according to size on filters and then analyzed in the laboratory. In the alternative method particles can be analyzed directly in the airstream. This latter method additionally permits rapid online characterization. To obtain reliable measurement results, it is necessary to produce samples and aerosols that enable instruments to be calibrated for all relevant elements over a range of concentrations covering several orders of magnitude.

### Results and Applications

Results of analyses conducted on emissions from steel factories indicate, for example, elevated contents of lead, cadmium and copper in particles of about 200 nm in diameter. The particle composition varies widely as a function of their size, and is characteristic of the specific process giving rise to their emission. This finding permits the identification of “process-fingerprints” enabling a classification of different emission sources. The correlation between particle size and composition also allows for a more accurate estimation of the health risk associated with the different types of emission. Measurements based on particle size can also be obtained when analyzing particles directly in the air stream. The short time required for such measurements allows them to be used directly for process control. The response time in this case is less than one second.

The method can also be universally employed in other branches of industry, as well as in engine development and nanotechnology.

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**Task**

The threat of terrorist attacks has increased significantly over the last few years, particularly in the form of car and suitcase bombs. Currently, there is no system available that can detect such «improvised explosive devices» (IEDs) from a safe distance. Furthermore, there is a great demand in the civil and environmental protection sectors for systems capable of remote chemical analysis. These could help to monitor emissions or provide assistance when dealing with accidents involving hazardous chemicals, for example in the petrochemical industry.

**Method**

Four Fraunhofer Institutes have joined forces to develop a system for the stand-off detection of hazardous and explosive materials using several optical methods that complement one another. The Fraunhofer ILT has been investigating the suitability of Raman spectroscopy as a method of standoff detection. Raman spectroscopy enables substances with similar atomic compositions to be differentiated on the basis of frequency measurements of the molecules’ characteristic natural vibration.

One of the challenges is the low strength of the Raman signals. To increase the signal strength, the Raman scattering is excited by an ultraviolet laser. This reduces the detection limit by several orders of magnitude as compared to conventional infrared lasers.

A key aspect is the development of automated data reduction methods that are capable of making a yes/no decision without requiring a specially trained user.

**Results and Applications**

In conjunction with the Fraunhofer ICT, a blind test was carried out which required 15 samples of ANFO (ammonium nitrate fuel oil) and 15 samples of TNT to be detected in a group of 111 samples. The surface concentrations were in the region of typical fingerprint traces, i.e. roughly 100 µg/cm².

At short distances, all the ANFO samples with a surface concentration greater than 80 µg/cm² were successfully identified in a 10-second measuring period. There were no false-positive results. In the case of TNT, all the samples with surface concentrations greater than 100 µg/cm² were identified.

Further applications for this technology include security technology and industrial process control in environments such as food and fine chemicals.

The project is being carried out with the financial support of the Fraunhofer-Gesellschaft.

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Automatic detection of ANFO explosives. All samples with a signal amplitude greater than 3 are correctly categorized as ANFO.
**Task**

The use of online measurement systems for chemical analysis in the extraction of minerals can achieve significant cost savings by creating more accurate models of mineral deposits. This helps to minimize the extraction of any unwanted waste rock.

Two sample applications are being examined as part of the project. For underground coal extraction, an analysis module is being developed for integration in a shearer loader, which automatically measures the proportion of waste rock that is cut. In the case of surface mining, a drilling rig is equipped with an online analysis module that enables a model of mineral deposits to be created at the same time as carrying out exploratory drilling or drill and blast tunneling.

**Method**

The rock dust produced during drilling or cutting is drawn off and a chemical analysis is performed by laser-induced breakdown spectroscopy directly in the airstream. The results of the analysis are incorporated into a model of mineral deposits and can therefore be used to guide the mining operations.

Investigations of the application for underground mining focus on the differentiation between hard coal and clay slate. In the case of surface mining, the analysis system is initially intended for deployment in limestone quarries. The same technique can also be transferred to other types of exploitable minerals and waste rock.

Use of the analysis module in such harsh environments imposes special demands on the module with respect to vibration, dust and water resistance. Deployment of the analysis module in underground workings means that explosion protection issues have to be taken into account.

**Results and Applications**

In a laboratory setup, measurements of the dust particles in the air stream demonstrated how minerals of economic value could be distinguished from waste rock. The analysis can be performed on both dry and wet dust.

With regard to explosion protection, a comprehensive series of tests was conducted in conjunction with the Physikalisch-Technische Bundesanstalt (PTB), the German national metrology institute.

Once a demonstrator had been set up, tests to demonstrate the suitability of the measuring process under the intended operating conditions were initially carried out in quarries and subsequently in underground workings.

The project is being conducted with the financial support of the German ministry of economics, various small and medium-sized enterprises and industrial partners, and the Fraunhofer-Gesellschaft.

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Task

In order to efficiently exploit primary raw materials such as limestone or other minerals and ores, the materials of economic value have to be separated from any inter-grown accessory rock before processing. Owing to the comparatively low price at which these raw materials are sold, separation must take place in the immediate vicinity of the extraction site, transportation of the extracted material being uneconomical in many cases. At present, there is no cost-efficient automated process capable of sorting primary raw materials on the basis of single particles. A collaborative research project has therefore been launched, which initially aims to develop a laser-assisted sorting process for the separation of limestone and dolomite. Its scope may conceivably be widened to include other ores and minerals.

Method

The process employed to rapidly identify and sort the raw materials is based on a combination of image processing, laser geometry measurement and laser-induced breakdown spectroscopy (LIBS). After separation of the particles, the geometrical and optical characteristics of the material are determined and then analyzed using image-processing algorithms. In the next step, laser spectroscopy is used to determine the chemical composition of the single particles. Finally the sorted material is discharged as two or more fractions in accordance with the sorting decisions that are made online.

The aim of the project is to build a pilot-scale demonstrator capable of testing the functionality of the sorting process under close-to-real-life conditions.

Results and Applications

Initially, the sorting process is being developed and tested for use with limestone and dolomite. In this process, relatively pure calcium carbonate rocks are separated from rocks that contain undesirably high proportions of magnesium. A series of tests using samples from various quarries demonstrated that the LIBS measurements are able to determine the MgO content regardless of which deposit the samples originate from. For each class of materials examined, the level of correct identification exceeded 90 percent with a recovery of 100 percent. Moreover, it emerged that the quality of the analysis can be improved if the laser beam is first used to clean the minerals and subsequently to analyze them.

In sorting experiments with production samples at a conveyor belt speed of 3 m/s, the materials were successfully separated into two fractions with 10 percent and 2 percent MgO contents, respectively, thereby achieving an efficient increase/decrease in the mineral concentration as compared to the source rock (5 percent MgO). These results were achieved by exposing each individual particle to only one laser pulse group, thereby enabling high material throughput rates. The requirements for industrial application are that the system should achieve a mass throughput of 150 t/h with a recovery of 90 - 95 percent and a product purity of > 95 percent.

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Task

Environmental factors including vehicle exhaust fumes and road salt can provoke corrosive changes in concrete structures and buildings such as bridges and multistory car parks. The infiltration of elements such as nitrogen, sulfur and most particularly chlorine can permanently damage the soundness of these structures. To optimize the cost of remedial maintenance, the concentration and depth of penetration of these elements must be determined as accurately as possible. An analysis system is being developed that will enable engineers to determine the content of these elements in building materials on-site, allowing them to assess damage on the basis of "element maps" and repair the structure in a manner that reflects the degree to which the structure has been affected.

Method

Laser-induced breakdown spectroscopy is a non-contact method used to analyze the chemical composition of solids, liquids and gases. It allows the concentration of different elements to be determined simultaneously and very rapidly.

Drilling cores extracted from a structure are split, and the fractured surface is scanned using a focused Nd:YAG laser beam. At the points where the laser pulses hit the surface, minute quantities of the drilled core are vaporized and ionized, creating a plasma. The element-specific line emissions from this plasma enable the elemental composition of the material at the respective points to be determined.

Results and Applications

A demonstrator has been designed and built that enables the automated creation of 2-dimensional element maps.

Over 20 elements are detected simultaneously within a single measuring process. The concentrations of elements (Ca, Si, etc.) can be used as a basis for distinguishing the aggregates and cement contained in the concrete.

The research team has meanwhile achieved a detection limit for chlorine in cement of 0.1% by mass, as per DIN 32 645.

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**Task**

The number, distribution and composition of metallic and non-metallic inclusions are important quality criteria in steel manufacturing. These inclusions, which typically range in size from 0.1 µm to 100 µm, affect the properties of the material, potentially reducing its fatigue strength and even resulting in fracture. Inclusions frequently consist of a combination of different elements, for instance MnS or TiN. A means of detecting the presence of so-called light elements such as C, N, O, P and S is therefore required. As far as possible, the analysis is to be performed without the need for elaborate preparation of the sample. In addition to the inclusion analysis, another goal is a simultaneous quantitative analysis of the base material (bulk analysis).

**Method**

A ground or milled sample is all that is needed to analyze the purity of the steel. The sample is placed in a measuring chamber filled with a shielding gas, where its surface is scanned by the beam of a focused diode-pumped solid-state laser at low pulse energies (in the region of 1 - 3 mJ). A small quantity of the sample material is vaporized at the focal point of the laser beam to form a plasma. The emissions from the plasma are resolved spectrally, converted into electrical signals, and analyzed.

The high measuring frequency of e.g. 1 kHz employed in this method (a scanning LIBS process) enables a sample surface area of 10 mm x 10 mm² to be analyzed in 10 minutes. During this period, element maps for up to 48 different chemical elements (depending on the spectrometer configuration) are produced simultaneously, with a spatial resolution of 20 µm. The parameters of the measuring process, from the definition of the zones of interest through to the purging of the shielding gas, are set using the Sirius-C software interface. The measuring process is fully automated.

**Results and Applications**

Comparisons have shown that the measurement results from the inclusion analysis largely coincide with the results of more time-consuming conventional methods. Algorithms were developed and implemented to process and evaluate the large volumes of data. The development of calibration methods for the scanning measurement process enables quantitative bulk analysis of steel samples, even with the small pulse energies used in this case.

The work is being supported financially by the Research Fund for Coal and Steel (RFCS) and the Fraunhofer-Gesellschaft.

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Task

As well as responding to environmental concerns, the recycling of steel scrap for reuse in steel production has taken on a new, economic significance due to the growing scarcity of natural resources and the rising cost of raw materials. The better we are able to characterize the chemical composition of steel scrap, the greater the value of the recovered fraction. Conventional fractionation processes (magnet extraction, density analysis, etc.) only cover a limited number of characteristics, and are generally not sufficiently selective with respect to the elements that can play a critical role in recycling. The defined task is to develop and verify the suitability of a measuring technique for the on-site characterization of steel scrap streams on conveyor belts with belt speeds of up to 3 m/s.

Method

Laser-induced breakdown spectroscopy (LIBS) was chosen as the method for element-selective characterization. A short laser pulse forms a plasma on the surface of the scrap steel. The light emitted by this plasma contains information on the elemental content and is analyzed by a spectrometer. The geometry of the pieces of scrap is determined using a laser light section sensor and the analysis laser is quickly deflected by a scanner. Further development of this laser process is required to enable a reliable average elemental content of a scrap fraction to be determined.

Results and Applications

In the first phase of the project, the researchers identified laser parameters that also permit the laser to remove coatings and layers of dirt in order to allow elemental analysis of the bulk material. A demonstrator setup featuring an optics module, a spectrometer module and a control module was designed and constructed. The optics module contains various components including the laser light section sensor for geometry measurement, the LIBS laser and the scanner. In an on-site field campaign at a recycling plant, the demonstrator setup was put into action in a shredder facility with a belt speed of roughly 1 m/s.

The work is being supported financially by the European Commission’s Research Fund for Coal and Steel (RFCS) and the Fraunhofer-Gesellschaft.

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Task

In neurosurgical procedures, precision and surgical safety are essential to the successful therapeutic outcome. The Fraunhofer ILT is therefore developing a neuroendoscope that can be used to ablate brain tissue with sub-millimeter precision and without causing any thermal damage to surrounding tissue thanks to the use of picosecond laser light.

Method

The rigid-type neuroendoscope is designed for use with high-energy short-pulse laser light. The laser beam is guided through the endoscope via a micro-optical channel of 23 cm in length and 2.8 mm in width and is decoupled by a deflection mirror mounted on the tip of the endoscope at 90° to its longitudinal axis. The tip of the endoscope with the deflection mirror can execute a rotational movement around the endoscope’s longitudinal axis, which enables it to move the focus of the laser beam in a circular path. In combination with functions that allow the depth of the endoscope to be altered and the focusing lens to be axially displaced, the laser focus can be set to any point within a cylindrical volume measuring 5 cm in diameter and 12 cm in height. To carry out tissue ablation, high-power picosecond laser light is coupled into the endoscope, while an active beam position control system ensures the undisturbed passage of the laser beam through the micro-optical channel of the endoscope. The ablation laser comprises an amplifier chain consisting of regenerative and high-power amplifiers used to produce a laser beam with a wavelength of $\lambda = 532$ nm, a pulse duration of $\tau = 25$ ps and a pulse energy of $E_p = 1$ mJ at a repetition rate of $f = 10$ kHz.

Results and Applications

To determine the ablation efficiency, ablation experiments were performed on myocardial tissue extracts from pigs’ hearts as a function of the energy of the ablating laser pulses of between $E_p = 50$ µJ and $E_p = 500$ µJ. This involved carrying out in-plane scanning of the tissue samples under the focused laser beam using a motorized microscope stage. The samples were placed in a flow cell through which a salt solution was pumped in order to wash the ablated fragments of tissue out of the ablation zone. Systematic investigations yielded a maximum ablation rate per pulse of $V_p = 80,000$ µm³ at a pulse energy of $E_p = 500$ µJ.

The research project was funded by the German ministry of economics and technology (BMWi) and carried out in collaboration with partners in industry and clinical research.

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Above: The endoscope is composed of three coaxial tubes. On the inside is the lens tube with the micro-optical channel (Ø 2.8 mm), in the middle the axially displaceable and rotating mirror tube and, on the outside, the sheath tube (Ø 5.5 mm).  
Below: Non-thermal ablation using a high-power picosecond laser beam. No thermal damage to tissue is visible at the edges of the ablated zones. The ablation geometries feature sharp resection edges.
A laser endoscope procedure has been developed for the cauterization of blood vessels during microneurosurgical procedures. The goal is to deploy this procedure in hard-to-access areas of the brain or to provide support for laser neurosurgical techniques. To monitor and control the laser coagulation process, the Fraunhofer ILT is developing an online optical measuring technique on the basis of optical coherence tomography (OCT).

Laser coagulation is carried out using an ytterbium fiber laser ($\lambda = 1070$ nm, $P_{\text{max}} = 120$ W). The laser beam is coupled into an endoscope for laser neurosurgery and a convex lens is used to focus the beam on the blood vessel to be coagulated at the end of a 23-cm-long micro-optical channel. During coagulation, the measuring beam of the integrated OCT measuring system scans the cross-section of the irradiated vessel at a frame repetition rate of 10 Hz. The cross-section images produced at a lateral resolution of 60 µm and an axial resolution of 25 µm allow monitoring of the changes in the diameter of the vessel as a function of time. The aim of monitoring the process in this manner is to enable the laser power to be controlled during vessel coagulation in order to prevent destruction of the irradiated vessel or the surrounding tissue through an excessive dose of irradiation.

The endoscopic laser coagulation of blood vessels was investigated systematically, with initial ex vivo investigations on the vascular system of a porcine heart on 435 vessels and subsequent in vivo investigations on 176 vessels of Sprague-Dawley rats. All the vessels were irradiated for more than 5 s and had a diameter of between 150 µm and 1300 µm. In the in vitro experiments, the vessels were perfused with a native BSA solution under a hydrostatic pressure of $p = 120$ mm Hg. The researchers ascertained a power range for successful and reproducible vessel cauterization both for the in vitro and the in vivo models.

In addition, vessel occlusion was observed online using the OCT measuring system in a further 100 coagulation experiments. Based on the OCT data, the time to occlusion could be determined for vessels of various diameters between 0.2 mm and 1.1 mm. Previous investigations into the monitoring of laser coagulation processes had shown that optical coherence tomography is suitable in principle for monitoring endoscopic laser coagulation in real time.

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Blood vessel of a Sprague-Dawley rat after laser coagulation. The thermal interaction at the coagulated site is clearly visible from the brownish coloring of the vessel (see arrow). The blood vessel was transected with a scalpel after coagulation in order to verify that it had been successfully occluded.
Task

Confocal laser-scanning microscopy has established itself as a versatile measuring technique for the optical analysis of fluorescence-tagged or reflective samples in high spatial resolution. Applications are primarily focused on experiments involving scattering tissue and the identification of reaction kinetics in process engineering.

Method

The high spatial resolution capabilities are obtained by using objectives with a high numerical aperture (NA = 1.4) and imaging the measuring signal on a pinhole aperture with a diameter of just a few micrometers in the image plane. High-speed galvanometric scanner mirrors redirect the laser beam with a 2 kHz line frequency to generate two-dimensional microscopic images. High-resolution three-dimensional images can be produced with the aid of a z-scanner that axially displaces the position of the scanning laser focus. Coupling a tunable femtosecond laser into one of the new-generation laser scanning microscopes makes it possible to excite dyes in the UV range with multiphoton processes. In this way, microscopic insights can be obtained even in deep tissue layers or strongly scattering tissue.

Results and Applications

The Fraunhofer ILT primarily employs confocal microscopy in situations where there is a need to detect weak signals with a high signal-to-noise ratio. Penetration into deeper organic layers is limited due to scattering and reabsorption of the emitted fluorescence. Ultrashort pulses in the femtosecond range and the associated high photon densities permit the excitation of multiphoton processes in the laser focus, so that fluorescence can only occur at those points. A purpose-built prism compressor ensures short pulse durations following propagation of the laser beam through optical media. Since infrared radiation is not so widely scattered, this method allows tissue layers at a depth of up to 1 mm to be examined.

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Above: Multiphoton image of a Convallaria colony; excitation wavelength 860 nm, pulse duration 20 fs.
Below: Prism compressor developed by the Fraunhofer ILT.
Task

As part of the IMIKRID R&D project, researchers are aiming to develop a technology platform enabling highly sensitive diagnosis of tumor and cardiovascular markers in blood serum. The goal is to reduce the detection limit to a concentration range of $10^{-12}$ to $10^{-13}$ mol/l, which would facilitate early diagnosis.

Method

Sensitive detection of marker molecules is carried out using nanoprobes coated with an antigen that specifically binds to the target marker molecule. To obtain a high interaction efficiency between the marker molecules and the specific binding receptor molecules, the biological probes are positioned in the middle of the channel of a microfluidic cell. The flow velocity is at its maximum in the middle of the channel, as a result of which a large proportion of the markers contained in the serum come into contact with the surface of the probes. In comparison to diffusion-controlled antigen binding tests, this results in a significant increase in the probability of detection. A further advantage of this technique lies in the small surface area of nanoparticles ($\Phi$ 100 nm); this significantly reduces the non-specific adsorption events of serum proteins as compared to standard tests on planar substrates, thereby improving the signal-to-noise ratio. Through combining high interaction efficiency with an increased signal-to-noise ratio, the goal is to achieve an increase in sensitivity from $10^{-11}$ mol/l to up to $10^{-13}$ mol/l.

In the diagnostics platform developed at the Fraunhofer ILT, the specific binding events to the nanoprobes are detected optically using a confocal single-molecule detector. In this process, the focus of the optical tweezers is superimposed on the laser focus of the single-molecule detector in order to ensure optimum illumination of the sensor surface of the nanoparticle.

Results and Applications

The single-molecule detector with integrated optical tweezers was assembled and its sensitivity determined as $10^{-12}$ mol/l using pure dye solutions in a microfluidic cell. Capture experiments in a microfluidic cell have demonstrated that particles with a diameter of 200 nm can be reproducibly captured and immobilized using the optical tweezers at flow velocities of up to $v > 10$ mm/s.

The R&D activities of the IMIKRID project are supported by the BMBF and are being implemented in conjunction with partner institutes of the Fraunhofer-Gesellschaft and the Institute for Micro Sensors in Erfurt.

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Task

The detailed analysis of biochemical interactions, especially specific interactions between proteins and their binding partners, is one of the fundamental tasks of pharmacological research. To perform detailed studies on the mechanism of action of a potential drug candidate, scientists currently employ X-ray diffraction analysis of crystalline protein-ligand complexes. This method makes it possible to determine the molecular structure of the protein together with the position of a specifically bound ligand at atomic resolution. In so-called »soaking experiments«, protein crystals are brought into contact with ligands, which diffuse into the open crystal structure of the protein, thus enabling specific binding to occur. Raman spectroscopy can then be employed to rapidly locate the crystals in which specific binding has occurred, without the need for elaborate preparation of the sample. Only the crystals pre-selected by means of Raman spectroscopy are subsequently subjected to more detailed study in an X-ray diffraction experiment.

Method

Soaking experiments can be performed in microtiter plates using a screening approach. Using Raman difference spectroscopy, it is then possible to analyze binding events between proteins and their ligands within the crystal. A specific ligand binding event alters the vibrational spectrum of the investigated protein. By computing the difference between the measured spectra of the bound and the free proteins, these band shifts can be obtained in a sensitive manner. The high concentrations of the substances in the crystal facilitate the spectroscopic analysis.

The experiments were conducted with a confocal Raman microscope assembled at the Fraunhofer ILT incorporating a diode laser (785 nm) as an excitation source and a spectrometer featuring a highly sensitive CCD detector.

Results and Applications

The excitation laser is focused in a diffraction-limited mode and the Raman signals from the focal point of the laser are collected by a microscope objective. The fact that the protein crystals are so small (typically 50 - 100 µm) means that the laser focus must be positioned with great precision. A camera is therefore integrated in the setup to monitor the position during the experiment. The laboratory setup recorded the first Raman spectra of protein crystals with a signal-to-noise ratio that was typically greater than 250 for a measuring period of 60 seconds (based on the most intensive Raman peak in each case).

The project is being conducted with the financial support of the German ministry of economics, various small and medium-sized enterprises, and the Fraunhofer-Gesellschaft.

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at RWTH Aachen
Lecture in association with
the RWTH Colloquium on Laser Technology
Prof. Dr. M. Kneissl, Technische Universität Berlin, Berlin
»Von ultraviolettten Leuchtdioden bis zu grünen Laser - Herausforderungen und Fortschritte bei der Entwicklung GaN-basierter Lichtemitter«

22.02.2008, Aachen
Unihits for Kids
Forum organized by the Chair for Laser Technology LLT and the Fraunhofer I LT to give advice on scientific careers to students at the Geschwister-Scholl-Gymnasium in Fulheim.

28.02.2008, Aachen
Unihits for Kids
Forum organized by the Chair for Laser Technology LLT and the Fraunhofer I LT to give advice on scientific careers to students at the Bischöfliche Maria-Montessori Gesamtschule in Krefeld.

11.04.2008, Aachen
Launch of the Fraunhofer Innovation Cluster »TurPro«
A gala followed by a press conference was held at the Fraunhofer I PT on Friday, April 11, 2008 to mark the launch of the Fraunhofer Innovation Cluster »Turbine Production Technologies - TurPro«. This Innovation Cluster is coordinated by the Fraunhofer I LT and IPT Institutes. Prof. Fritz Klocke, director of the Fraunhofer Institute for Production Technology I PT, first welcomed guests before handing over to Prof. Andreas Pinkwart, Minister for Innovation, Science, Research and Technology NRW, who spoke on the subject of »NRW - The Place for Innovative Production«. Prof. Hans-Jörg Bullinger, President of the Fraunhofer-Gesellschaft, presented the concept of Fraunhofer Innovation Clusters.
This was followed by presentations from Prof. Reinhart Poprawe, Pro-Rector of the RWTH Aachen and director of the Fraunhofer Institute for Laser Technology ILT, Dr. Hans-Otto Jeske, Board member of MAN Turbo AG and Dr. Norbert Arndt, Managing Director Engineering, Purchasing & Logistics of Rolls-Royce Deutschland Ltd & Co KG. To round off events the delegates were treated to a tour of the machine halls and laboratories at Fraunhofer ITP and ILT.

07. - 09.05.2008, Aachen International Laser Technology Congress AKL’08

Featuring 57 talks, more than 30 exhibitors and 80 live presentations on the use of lasers in materials processing, the International Laser Technology Congress AKL’08 provided laser manufacturers and users from a wide variety of sectors with a central platform on which to exchange information and experiences.

AKL’08 enjoyed the moral support of the industrial associations EUROM, SPECTARIS, VDA, VDI and VDMA, as well as the Arbeitskreis Lasertechnik e.V., the European Laser Institute ELI and the European Commission. The Fraunhofer Institute for Laser Technology ILT, which hosted the event, had a turnout of about 500 participants at the Eurogress conference center in Aachen.

In order to cater for the needs of all the different target groups, AKL’08 was subdivided into several event modules. The technological program section on May 8 and 9, 2008 was directed at suppliers and customers of laser systems and processes for use in production. It addressed laser manufacturers, systems providers and users from different areas of the manufacturing industry.

The ‘Laser Technology ABCs’ seminar on May 7, 2008 gave a first practical overview to companies that had not previously worked in the field of laser technology, neither as suppliers nor as users.

The Technology Business Day, also on May 7, 2008, was directed at business managers, marketing directors, sales managers and other executive managers wishing to find out specifically about the status and prospects of today’s laser markets.

At the EU Innovation Forum ‘Laser material processing in aeronautics’ (May 7, 2008), members of collaborative EU projects reported on the results of their R&D work.

07.05.2008, Aachen Technology Business Day TBT’08

At the Technology Business Day, experts provided an overview of the status and development of the laser markets in Europe (Dr. Arnold Mayer, Optech Consulting), America (David Belforte, Belforte Associates) and Japan (Prof. Dr. Isamu Miyamoto, Osaka). In addition, experienced laser users explained the production-related challenges to be met by laser technology in Europe, on the basis of selected industry-specific examples. Dr. Michael Zürn (Daimler AG), Dipl.-Ing. Stefan Wischmann (Thyssen Steel) and Dr. Arnold Gilling (Fraunhofer ILT) addressed aspects of the automotive, metal-working and microtechnology industries.

07.05.2008, Aachen EU Innovation Forum »Laser material processing in aeronautics«

At the EU Innovation Forum, members of collaborative EU projects reported on the results of their R&D work. The forum focused on the topic of laser production technology in the aircraft industry. Introductory lectures were given by Dr. Andrzej Podsadowski, Aeronautics Unit of Directorate-General XII of the European Commission, and Prof. Stewart Williams of Cranfield University.

In the three subsequent parallel sessions, participants discussed the technological aspects of generative, joining and surface pre-treatment laser processes and their application in the production of aircraft components and the provision of MRO services. The objective of the three roundtables was to develop concepts for new collaborative projects designed to tackle hitherto unsolved technological challenges in this field.

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

07.05.2008, Aachen Laser Technology ABCs Seminar

In this seminar, novices to the laser world learned in a clearly structured format how laser machining processes work, what type of laser is employed for different applications, which optics are used for laser materials processing, how laser manufacturing processes are monitored and controlled online, which areas of industry employ laser technology, and what development trends have been identified for various aspects of laser technology.

08. - 09.05.2008, Aachen AKL’08 Laser Technology Conference

The following speakers were confirmed for the Geir Herzig session on May 8, 2008: Dr. Michael Mertin, Chairman of the board of Jenoptik AG (Lasers and Optics in Systems), Dr. Joseph Pankert, CTO of the Special Lighting Applications business unit at Philips Lighting B.V. (Laser-Based EUV Technology for Next-Generation Microchips), Dr. Eberhard Kroth, Technical Director of Reis Robotics (Status and Prospects of Robot-Assisted Laser Systems Technology), Dr. Tony Hoult, Applications Manager at SPI Lasers (Fiber Lasers: Sources and Applications) and Prof. Dr.-Ing. Robert Schmitt (RWTH Aachen University Cluster of Excellence: »Integrative Production Technology for High-Wage Countries»).

These talks were followed by parallel sessions spread over two days, with talks on innovative laser-based developments in both micro and macro processing. The topics covered during these sessions ranged from laser cutting, welding, polishing, structuring and generating to precision joining and separation, functionalization, drilling and ablation.

At the end of the Laser Technology Conference, participants were able to continue their exchange of information and experiences at the »Laser Technology Live« session in the applications laboratories of the Fraunhofer ILT, where ILT engineers displayed the results of their R&D activities in 80 presentations.
08.05.2008, Aachen
Innovation Award Laser Technology 2008
The Innovation Award Laser Technology 2008, initiated by the associations Arbeitskreis Laserotechnik e.V. and the European Laser Institute ELI and provided with 10 000 Euros prize money, was conferred to Dipl.-Ing. Bertold Hopf, Daimler AG, Sindelfingen, Germany on May 8, 2008 in Aachen’s town hall. Bertold Hopf had applied to the open call for proposals as representative of the RobScan project team. In the historical ambience of the »Coronation Hall« more than 300 participants of the International Laser Technology Congress AKL’08 attended the awarding ceremony.

Prof. Reinhart Poprawe, vice-president of the association Arbeitskreis Laserotechnik AKL e.V. and director of the Fraunhofer Institute for Laser Technology ILT, pointed out the dedicated work of the RobScan project team and the outstanding innovation in the field of laser technology. RobScan - Robot-guided remote Scanner for laser beam welding - is a new laser beam welding process, which has been developed for vehicle body construction by Dipl.-Ing. Bertold Hopf and Dr. Klaus Debschütz and their project team within the Daimler AG. Dipl.-Ing. Bertold Hopf is Head of Material and Production at the Technology Department of Daimler AG in Sindelfingen. Dr. Klaus Debschütz is Head of Materials, Manufacturing, Concepts - Body of Daimler’s Group Research in Ulm.

The international jury consisting of 10 members that are recruited from industry and the research community selected on a basis of merit and according to the published assessment criteria (see www.innovation-award-laser.org) 3 innovation teams out of 15 applications as finalists:

- RobScan - Robot-guided Remote Scanner for Laser Beam Welding (team representative: Dipl.-Ing. Bertold Hopf, Head of Material and Production, Daimler AG, Technology Department, Sindelfingen)
- RAPID: High-power, high-repetition-rate picosecond (ps) laser for industrial high-end micro-machining (team representative: Dr. Achim Nebel, Managing director, LUMERA LASER GmbH, Kaiserslautern)
- Ultrafast Laser for Efficient Industrial Micromachining (team representative: Dr. Dirk Sutter, Senior Scientist, Advanced R&D and Product Development Manager, TRUMPF Laser GmbH + Co. KG, Schramberg)

All 3 applications have led to an outstanding innovation in the field of laser technology and are presented in detail on www.innovation-award-laser.org. The 3 finalists were nominees for the Innovation Award Laser Technology 2008. The trophy for the prize winner and the certificates for all finalists were handed over by Dipl.-Ing. Ulrich Berners, president of the Arbeitskreis Lasertechnik AKL e.V.; Dr. Stefan Kairele, president of the European Laser Institute ELI and by Ric Parker, Director Research and Technology of Rolls-Royce plc and guest speaker of the awarding ceremony. The prize winner Bertold Hopf has been furthermore awarded the title of »AKL Fellow« and »ELI Fellow«.

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.

09.05.2008, Aachen
31st seminar of the »Aix Laser People«
the alumni club of the Fraunhofer ILT and the Chair for Laser Technology ILT, including an opportunity to watch 80 live demonstrations in the ILT Laser Applications Center in connection with the International Laser Technology Congress AKL’08.

29.05.2008
Chair for Laser Technology LLT at RWTH Aachen
Lecture in association with the RWTH Colloquium on Laser Technology
Prof. Dr. E. P. Ippen, Massachusetts Institute of Technology, Boston, USA »Femtosecond Lasers: More than just really fast«

05.06.2008, 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 at the Katholische Grundschule Zeppelinstraße in Mönchengladbach.

23.06.2008, 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 at the Gymnasi-um Baesweiler in Baesweiler.

26.06.2008
Chair for Laser Technology LLT at RWTH Aachen
Lecture in association with the RWTH Colloquium on Laser Technology
Prof. Dr. Peter R. Herman, Dept. of Electrical and Computer Engineering, University of Toronto, Canada »Femtosecond laser proceeding of 3D photonic and optofluiddic microsystems«

03.07.2008
Chair for Laser Technology LLT at RWTH Aachen
Lecture in association with the RWTH Colloquium on Laser Technology
Prof. Dr. Friedrich Dausinger, Institut für Strahlerwerkzeuge (IFSW) der Universität Stuttgart, Stuttgart »Hochgeschwindigkeitsphotographie Schweißen mit Laserstrahlung«
10.07.2008
Chair for Laser Technology LLT at RWTH Aachen
Lecture in association with the RWTH Colloquium on Laser Technology
Prof. Dr. Aravinda Kar, University of Central Florida CREOL, Florida, USA
»Laser doping of silicon carbide for white light-emitting diodes«

21.08.2008
Chair for Laser Technology LLT at RWTH Aachen
Lecture in association with the RWTH Colloquium on Laser Technology
Dr. Andreas Ostendorf, LZH Laser Zentrum Hannover e. V., Hannover
»Stereolithographie - von Mikrobauteilen zu Nanostrukturen«

11.09.2008, 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 at the Franz-Meyer-Gymnasium in Mönchengladbach.

23.09.2008
Laser Zentrum Hannover
2nd HANNOVER MESSE Fall Forum: Lasers in Production - New Opportunities for Micro and Nano Precision Processing
Following the inauguration of the »Lasers in Micro- and Nanotechnology« series of events at Fraunhofer ILT in fall last year, the 2nd HANNOVER MESSE Fall Forum was held in the Laser Zentrum Hannover on September 23, 2008. The one-day conference was devoted to »Lasers in Production - New Opportunities for Micro and Nano Precision Processing«.

Experts provided insights into the key areas of photovoltaics and solar thermal systems, the semiconductor industry and microelectronics, as well as rapid prototyping. Presentations looked at the very latest developments, applications and success stories.

The Fall Forum was organized by the IVM Fachverband für Mikrotechnik - an international association of companies and institutes in the field of microtechnology, nanotechnology and advanced materials - and by trade fair organiser Deutsche Messe. The Laser Zentrum Hannover e.V., the Fraunhofer Institute for Laser Technology LLT and LIMO Lissotschenko Mikrooptik GmbH contributed to the content of the event. Companies such as Rofin Baasel Lasetech, LPKF Laser & Electronics, Polytec, Lumera Laser and Ingenerc attended the Fall Forum.

The HANNOVER MESSE Laser Fall Forum provides a preview of the laser topics covered in the Micro Technology show that forms part of the HANNOVER MESSE. IVAM organized a second installment of the special exhibition on »Lasers for Micromaterial Processing and Microproduction«, held at the trade fair between April 20 and 24, 2009.

16.10.2008
Chair for Laser Technology LLT at RWTH Aachen
Lecture in association with the RWTH Colloquium on Laser Technology
Prof. Dr.-Ing. Michael Rethmeier, Bundesanstalt für Materialforschung und -prüfung BAM, Berlin
»Anwendung von Hochleistungsfaseroptik für das Schweifen von Rohren«

04.11.2008, Aachen
Aachen Laser Seminar »Laser sensors and laser measuring systems for the automotive and steel industry«
Seminar organized by Carl Hansen Publishers, Munich in association with the Fraunhofer Institute for Laser Technology ILT, Aachen. Additional information: www.aachenerlaserseminare.de

04.11.2008, Aachen
Aachen Laser Seminar »Laser welding of plastics«
Seminar organized by Carl Hansen Publishers, Munich in association with the Fraunhofer Institute for Laser Technology ILT, Aachen. Additional information: www.aachenerlaserseminare.de

05.11.2008, Aachen
Aachen Laser Seminar »Micro drilling with laser radiation«
Seminar organized by Carl Hansen Publishers, Munich in association with the Fraunhofer Institute for Laser Technology ILT, Aachen. Additional information: www.aachenerlaserseminare.de

20.11.2008, 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 at the Geschwister-Scholl-Gymnasium in Aachen.

20.11.2008
Chair for Laser Technology LLT at RWTH Aachen
Lecture in association with the RWTH Colloquium on Laser Technology
Prof. Dr. Karsten Danzmann, Max-Planck-Institut für Gravitationsphysik, Hannover
»Gravitationswellenexperiment mit Laserstrahlung«

27.11.2008
Chair for Laser Technology LLT at RWTH Aachen
Lecture in association with the RWTH Colloquium on Laser Technology
Dr. Jens Rauschenberger, Max-Planck-Institut für Quantenoptik, München
»Generation of coherent intense XUV-radiation«

04.12.2008
Chair for Laser Technology LLT at RWTH Aachen
Lecture in association with the RWTH Colloquium on Laser Technology
Prof. Dr. Alan Caldwell, Max-Planck-Institut für Physik, München
»HERA and the wee partons«

15.12.2008, 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 at the Otto-Hahn-Gymnasium in Monheim at the Rhine.

18.12.2008, Aachen
32nd seminar of the »Aix Laser People«
the alumni club of the Fraunhofer ILT and the Chair for Laser Technology LLT, including a visit to Solland Solar Cells GmbH in AVANTIS, the business park on the German/Dutch border. This was followed at the Fraunhofer ILT by presentations from Dipl.-Ing. Hans-Dieter Hoffmann on »New developments in the field of diode and solid-state lasers at the Fraunhofer ILT«, and by Dr. Alexander Knitsch, TRUMPF Laser GmbH & Co. KG, Schramberg, who talked about »New developments and applications of disc and fiber lasers at TRUMPF«.
19.01.-24.01.2008
San Jose, USA
Photonics West 2008
International trade fair for optics and photonics
Participation of the Fraunhofer ILT on the German Pavilion stand.
ILT/LLT topics: Diode laser packaging, characterization of diode laser bars (e.g. LIV, wavelength, polarization, emitter resolution), laser systems based on laser bars (e.g. fiber-coupled, wavelength-stabilized), high-power diode laser modules for space-based applications.

Hanover
Hannover Messe 2008
International industry fair
The Fraunhofer ILT Micro Technology department was present on the IVAM joint stand. ILT topics: Microdrilling at high drilling density involving drilling diameters of 5 µm - 15 µm, precision tool engineering with picosecond lasers for applications in micromachining, laser microwelding of films and wires with geometries < 50 micrometers for applications in photovoltaics and microfluidics. Highlight: Remote micro laser cutting using fiber lasers and high cycle rates for the flexible manufacture of small-scale series in precision engineering and micro technology. In addition, the entire portfolio of Fraunhofer ILT including micro technology applications was illustrated on the basis of selected examples.

25.08.-29.08.2009
Joinville, Brazil
INTERPLAST
Plastics trade fair
In 2008, the Fraunhofer ILT made its debut at the Brazilian plastics trade fair INTERPLAST. This is one of the most important events of its kind in Brazil in the field of plastics applications and processing. The trade fair was held in Joinville, State of Santa Catarina, a highly developed industrial region in Brazil. Numerous German companies are represented in this region. The Fraunhofer ILT was present on a joint stand with the Brazilian cooperation partners Precision Engineering Laboratory (LMP) from the Universidade Federal de Santa Catarina (UFSC, Florianopolis, Brazil) and the spin-off from this laboratory, Welle Laser (Florianopolis, Brazil).

04.11.-07.11.2008
Paris
MIDEST
International trade fair for industrial subcontracting
Attendance of CLFA together with Poly-Shape at the MIDEST in Paris. CLFA topics: Generative methods (Selective Laser Melting - SLM) and joining of plastics.

19.11.-21.11.2008
Düsseldorf
COMPAMED
International trade fair for components, pre-products + raw materials for medical production
Participation by the Fraunhofer ILT Micro Technology department on the IVAM joint stand. ILT topics: Laser transmission beam welding of plastics without adding absorbers, as well as microstructuring of tool surfaces to functionalize molded polymer components.

03.12.-06.12.2008
Frankfurt
EuroMold
International trade fair for tooling and moldmaking, design and product development
Participation by the Fraunhofer ILT Surface Treatment department on the joint Fraunhofer stand. ILT topics: Laser-beam deposition welding to modify and repair mold inserts, as well as the production of gradient layers on tool inserts. The generative production process Selective Laser Melting (SLM) allows tool inserts with integrated contour-tracing cooling channels to be produced from the standard materials 1.2343 or 1.2083. Structuring and automatic polishing of surfaces of mold inserts using a laser beam. Highlight: Analysis of mechanical properties of generatively produced aluminum components for series production through Selective Laser Melting.

To present the findings the Fraunhofer ILT produced a video for EuroMold on the topic of surface treatment in collaboration with Rolls-Royce, Braun and Stork Gears and Services. The following topics were covered: SLM, surface welding, ablation and cleaning, production of microscale printed circuits and nanoparticle layers, and polishing.

Above: IVAM joint stand at COMPAMED 2008 in Düsseldorf.
Middle: Dr. Arnold Gillnert talking with the North Rhine-Westphalian Minister of Economic Affairs Christa Thoben.
Below: Joint Fraunhofer stand at EUROMOLD 2008 in Frankfurt.
»Your Partner for Innovation«
(German/English)
This brochure provides a concise overview of the Fraunhofer ILT. In addition to presenting a summary of European R&D projects conducted by the ILT, the brochure also contains a short profile of the institute as well as a list of reference customers.

Annual Report 2008
(German/English)
The annual report presents a comprehensive look at the R&D activities of the Fraunhofer ILT for the respective business year. Lists of scientific publications and lectures as well as patents, dissertations, conferences and trade fairs are also included. The English version can only be found on our website at: www.ilt.fraunhofer.de.

Proceedings - AKL’08 International Laser Technology Congress
The English proceedings consist of the summaries of all speeches including CD-ROM with the slides of the AKL’08 speakers. This CD-ROM includes the 4 modules of the congress: AKL’08 Laser Technology Conference, Laser Technology ABCs Seminar, Technology Business Day TBT and EU Innovation Forum »Laser Applications in Aeronautics«.

»Networks of Competence«
»Networks of Competence« was set up on the initiative of the BMBF and serves as an international marketing instrument and presentation showcase for the most highly skilled networks of competence in Germany. Its Internet portal, at: www.kompetenznetze.de, with its efficient search engine and many useful links, provides an ideal information source and communication platform for individuals and organizations in Germany and elsewhere looking for information and potential working partners.

»European Laser Institute E LI«
This brochure provides information on the European network of recognized centers of R&D in laser technology coordinated by the Fraunhofer ILT. The members of this network have set themselves the goal of making existing laser know-how in Europe accessible to all interested parties in industry and science. The project is sponsored by the European Commission. Further information can also be found at: www.europeanlaserinstitute.org.

Product and Project Data
Descriptions of projects from the Fraunhofer ILT annual reports and specific product information can be downloaded from our website at: www.ilt.fraunhofer.de.
»High-Power Diode Lasers«
This technical brochure outlines the various development activities of the Fraunhofer ILT in the area of high-power diode lasers. Included are developments such as the design of special components for laser cooling, diode laser bar packaging, diode laser burn-in characterization and the optical design and development of complete diode laser modules.

»Design of Diode Laser Heat Sinks«
This brochure describes the structure of diode laser heat sinks, illustrated by prototypes.

»Customized Services for Diode Lasers«
This technical brochure provides an insight into research and development activities and customer-specific solutions in the field of high-power diode lasers.

»Laser Microscopy«
A brochure offering insights into advanced techniques of laser scanning microscopy developed at the Fraunhofer ILT.

»Material Analysis and Process Monitoring with Laser«
This technical brochure provides an overview of materials analysis systems and their possible applications.

»Heat Treatment with Laser Radiation«
This brochure provides an insight into laser-assisted hardening, softening, annealing and forming.

»Laser Technology for Surface Modification and Forming«
This technical brochure provides an overview of how lasers are employed in the area of surface modification and forming. Included are processes such as deburring, melting and forming, polishing, roughening, structuring and activation, re-crystallization, annealing and fine pearlitizing.

»Laser Technology for Wear and Corrosion Protection«
Wear and corrosion protection can be created by various laser processes. This technical brochure provides insights into processes such as martensitic surface hardening, remelting, deposition welding, alloying and dispersion.

»Laser Beam Deposition Welding«
This technical brochure provides an introduction to the processes and systems used in laser beam deposition welding. It also elucidates the differences between conventional powder feed nozzles and those used in laser beam deposition welding.

»Rapid Prototyping and Rapid Manufacturing«
This brochure describes the selective laser melting process developed at the Fraunhofer ILT which enables complex metal parts to be manufactured directly from 3D CAD data. It also provides examples of applications of the laser beam generation technique.

»Polishing with Laser Radiation«
This technical brochure describes the process of laser polishing and its possible applications.

»Laser Ablation, Cleaning and Marking«
This technical brochure outlines the advantages of the different laser processes and the wealth of potential applications.
Lasers in Plastics Technology
This technical brochure describes the use of lasers in the processing of plastics, composite materials, paper, and glass.

Lasers in Microstructuring
This technical brochure describes processes such as laser ablation, precision cutting, drilling, and laser-assisted microforming.

Lasers in Mounting and Connecting Techniques
This technical brochure gives an overview of the use of laser technology in mounting and connecting techniques. Micro joining processes such as laser beam bonding and laser beam soldering are demonstrated.

Lasers in Life Science
This technical brochure deals with applications of laser technology in medical engineering. It also describes the use of lasers as tools in microreaction processes and biotechnology.

Systems and Plant for Laser Materials Processing
This technical brochure highlights the systems engineering solutions available to Fraunhofer ILT customers. They encompass the planning, development and installation of complete laser facilities and process monitoring and control systems, complemented by feasibility studies, training and education seminars and consulting services.

Quality Assurance in Laser Materials Processing
This technical brochure explains the potential for process monitoring and control in laser materials processing. It also outlines the services available from the Fraunhofer ILT for the development of such monitoring systems.

Modeling and Simulation
Written by experts, this brochure provides an overview of the activities and core competencies of the project group on modeling and simulation. ILT specialists and researchers at the Chair for Laser Technology LLT of RWTH Aachen University devise models to simulate resonator design concepts and beam-guiding and focusing systems, and a variety of machining processes including cutting, welding and drilling.

Mach-Zehnder Interference Microscopy
This technical brochure provides an insight into Mach-Zehnder interference microscopy. Applications of microinterferometry include dye-free observation of living cells as well as materials research and analysis.

Laser Drilling
This technical brochure explains the laser drilling process and its potential applications. Applications include the production of cooling holes in turbine components such as combustion chambers and blades, holes for fuel filters, plus nozzle and ventilation holes in injection molds for toolmaking and plant manufacturing.

X-Ray Systems
This technical brochure outlines X-ray system technology and its applications in metrology and for the optical simulation and design of collector optics.

X-Ray Microscopy
This technical brochure provides an insight into the technology behind X-ray microscopy and its applications.

XUV Sources
This technical brochure explains the technology behind XUV sources and their potential applications in the soft X-ray range and for EUV lithography.
Arbeitskreis Lasertechnik AKL e.V.
The Forum for Industrial Laser Applications

AKL e.V. was founded in 1990 to ensure that the fascinating opportunities opened up by the laser as a tool in terms of precision, speed and cost-effectiveness could be leveraged for industrial applications by improving the exchange of information and training.

A host of potential applications are now known, and the processes involved have been tried and tested. The use of lasers has become commonplace in many areas. Yet new laser sources and laser processes are constantly being developed that open up innovative, new opportunities in industrial production. A network like AKL e.V. effectively helps support innovation processes in this rapidly changing discipline.

The AKL e.V.’s activities focus on scientific work in the field of laser technology and the uptake of laser technology to improve the quality and cost-effectiveness of production processes. AKL e.V. sees itself as the mediator between suppliers and users as well as between the relevant economic, scientific and political institutions.

A continual exchange of information and development of a shared knowledge base, as well as the sustained improvement in training available, are key to achieving the association’s aims. AKL e.V. has 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

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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 Department 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 OS R 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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Principles, prospects and examples for the innovative engineer.

Applied laser technology is too wide-ranging a topic to be covered in a single volume. For this reason, the book places special emphasis on laser technology as used in manufacturing applications, particularly present-day machining processes used in production technology. The phenomena occurring in laser-based materials processing are quantified by formulae and illustrated with corresponding models that are readily understood by the trained engineer or physicist.

These basic principles enable the different types of machining operations to be systematically characterized, permitting the various applications to be illustrated using a common scientific basis. Of more practical significance are the processes described for various machining operations, which explain in simple terms the basic principles and key quantitative interrelationships between the process parameters. The numerous examples are intended to spark the reader’s creativity and help to inspire new applications.

Contents
Introduction, behavior of electromagnetic radiation at interfaces, absorption of laser radiation, energy transfer and thermal conduction, thermomechanics, phase transformation, melting pool flows, laser-induced ablation, plasma physics, laser radiation sources, surface technologies, forming, rapid prototyping, rapid tooling, joining, ablation and drilling, cutting, systems engineering, laser measuring technologies.

Appendices: A: optics, B: continuum mechanics, C: laser-induced ablation, D: plasma physics, E: explanation of symbols and constants, F: color images, index


The book can be ordered from:
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  - German
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- Proceedings of the International Laser Technology Congress AKL'08

- Program of the International Laser Technology Congress AKL'10 from May 5 - 7, 2010 in Aachen

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  - Innovation Award Laser Technology 2010

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- Information Flyer: Arbeitskreis Lasertechnik AKL e.V.

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  (Laser Technology) (only German)

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