Performance and Results
Annual Report 2003
Another exhibit that generated great interest at the trade show in Munich featured high-power diode laser systems for cutting and welding, the result of a government-sponsored collaborative research project on »Modular diode laser systems«. The growing use of lasers in material processing offers considerable scope for innovation. This year’s Fraunhofer Prize was awarded to three ILT researchers for their work on the use of selective laser melting in the manufacture of dental prostheses. This Annual Report features many other examples that illustrate the rich variety of areas in which you might consider establishing a collaborative project with the Fraunhofer ILT.

To create a sustainable basis for the consolidation of Germany’s resources in optical technologies, there is a need for concerted efforts at all levels of the innovation process – research centers, universities, industry associations and private enterprise. To encourage the younger generation to take up an interest in the field, we actively support activities organized by RWTH Aachen University in the form of action days for schoolchildren in the 10 - 12 age group, where groups of engineers and research scientists give live demonstrations of their work at various institutes of the university. The Fraunhofer ILT and the RWTH Department of Laser Technology focus on optical technologies and hold workshops tailored to the school curriculum. Schools in the Aachen region are also being targeted through visits by the traveling exhibition on laser technology sponsored by the German research ministry, staged in conjunction with the laser-technology colloquium AKL’04. The interactive exhibits are put together by the Ludwig Forum for modern art and are specifically designed to appeal to students and teachers. By collaborating with the museum’s educational department, we hope to awake curiosity in the many physical phenomena and creative aspects associated with the subject of »light«.

In an increasingly complex economic environment, we need to focus our efforts on making the overall system more transparent and on designing and applying the appropriate instruments – not only for schools and universities, and for public- and private-sector customers, but also with respect to the general significance of optical technologies in modern society. Bearing this objective in mind, we would be more than happy to receive your support in sowing the seeds that will allow us to harvest together the long-term benefits of our activities.

Sincerely,
Prof. Dr. rer. nat. Reinhart Poprawe M.A.
Contents

Profile of the Institute 6  Patents 102
Declaration of Principles 7  Dissertations 103
Business Areas 8  Diploma Theses 104
Board and Committees 10  Scientific Publications 105
Contacts 11  Lectures 107
Core Areas 12  Trade Fairs 112
Services 14  Conventions and Conferences 113
Facts and Figures 16  Publications 115
References 19  Video Films and Multimedia Software 118
Fraunhofer USA Center for Laser Technology CLT 20  Information Service 120
Coopération Laser Franco-Allemande CLFA 22  Imprint 121
The Fraunhofer-Gesellschaft at a Glance 24

Some Special Research Results from the Business Areas of Fraunhofer ILT

Laser and Plasma Sources 26 - 43
Laser Material Processing 44 - 78
Laser Plant and System Technology 79 - 89
Laser Measurement and Testing Technology 90 - 101
Short Profile

ILT - for the last nineteen 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 240 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 Centre 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 Centre. Besides subsidiaries of leading laser manufacturers and innovative laser users, new 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«

This business area encompasses the development of diode laser modules and systems as well as diode-pumped solid-state lasers, the design of new diode laser structures, the microassembly of diode lasers and optical components, and the development of plasma systems. Outstanding project results, which have been successfully transferred to practical applications in close cooperation with industrial partners, include the transversally diode-pumped 5 kW solid-state laser and diode laser modules for joining plastic components. In cooperation with the Fraunhofer IAF new structures are being designed which permit the manufacture of diode lasers demonstrating higher beam quality. The business area continues to enjoy a unique reputation in the assembly of high-power diode lasers and in particular the installation of partially automated assembly facilities. Work in the plasma technology sphere focuses on the development of EUV beam sources for semiconductor lithography. The main target markets for the business area as a whole are laser machining, medical engineering and metrology, along with the component market for information and communications technology.

»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 materials, identification testing of high-alloy steels, rapid recognition of plastics and analysis of process waste gases. Special electronic components are developed for the parallel processing of detector signals of high bandwidth. The business area has recently become involved in the new subject area of biophotonics. Projects are being conducted jointly with other institutes to systematically gather expertise in highly sensitive fluorescence detection for protein chips. 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 topology of bar and strip products, devices for the 1D to 2D scanning of unit goods, and electronic components for laser triangulation and laser split-beam sensors. Target markets include all sectors of production industry which conduct measurement and testing requiring high reliability.
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:

Ch. Schneider Dr.-Ing. Chairman
C. Baasel Carl Baasel Lasertechnik GmbH
D. Basting Dr. Lambda Physik GmbH
H. Hornig Dipl.-Ing. BMW AG
G. Marowsky Prof. Dr. Laserlaboratorium Göttingen e. V.
H. Martinen Dipl.-Phys. Rofin Sinar Laser GmbH
T. Monsau MinRat Dipl.-Phys. Ministerium für Arbeit und Soziales, Qualifikation und Technologie des Landes NRW
G. Müller Prof. Dr.-Ing. Laser-Medizin-Technologie GmbH
R. Müller Dr. Osram Opto Semiconductors GmbH & Co. OHG
J. von Schaewen MinR Dr. Bundesministerium für Bildung und Forschung (BMBF)
M. Stückradt Dr. Kanzler der RWTH Aachen
R. Wollermann-Windgasse Dr. rer. nat. Trumpf Lasertechnik GmbH

The nineteenth Board of Trustees meeting was held on September 17, 2003 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.-Phys. A. Bauer, Dr. K. Boucke, Dr. A. Gillner, Dr. J. Gottmann, B.-O. Großmann, Dipl.-Ing. H.-D. Hoffmann, Dr. S. Kaierle, Dr. E.-W. Kreutz, Dr. P. Loosen, Dr. W. Neff, Dr. R. Noll, Dr. D. Petring, Prof. Dr. R. Poprawe, Priv.-Doz. Dr. W. Schulz, B. Theisen, Dipl.-Phys. G. Vitr, Dr. B. Weikl, Dr. K. Wissenbach.

Health & Safety Committee

The Health & Safety Committee is responsible for all aspects of safety and laser safety at the Fraunhofer ILT. Members of this committee are: E. Bongard, M. Brankers, B.-O. Großmann, Dr. E.-W. Kreutz, A. Lennertz, Dr. W. Neff, E. Neuroth, B. Theisen, K.-H. Ulfig, Dipl.-Ing. F. Voigt, Dipl.-Ing. N. Wolf, Dr. G. Kotitschke (Berufsgenossenschaftlicher Arbeitsmedizinischer Dienst BAD).

Science & Technology Council

The Fraunhofer-Gesellschaft’s Science & Technology Council supports and advises the various bodies of the Fraunhofer-Gesellschaft on scientific and technical issues. The members are the institutes’directors and one representative elected from the science/technology staff per institute.

Members of the Council from the ILT are: Prof. Dr. R. Poprawe, B. Theisen, Dipl.-Phys. G. Vitr.

Department of Laser Technology LLT

at the RWTH Aachen

The Fraunhofer ILT is home to most of the Department of Laser Technology. This means that a close scientific relationship between the Fraunhofer ILT and the Department of Laser Technology has been built up, based on a contract of cooperation. Prof. Dr. rer. nat. Reinhart Poprawe M.A. is Director of the Department of Laser Technology, Dr. E. W. Kreutz is Academic Director.

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, M. Brankers, Dr. A. Gillner (until October 03), M. Janßen (since November 03), A. Lennertz (until June 03), Dipl.-Phys. G. Otto, I. Stein, B. Theisen (chair), F. Voigt, Dr. A. Weisheit, Dipl.-Ing. N. Wolf (since July 03).
Core areas

Laser Components
Dr. Konstantin Boucke (-132)
- active and passive cooling of diode lasers
- mounting of diode laser bars
- electro-optical characterization of diode lasers
- simulation of new diode laser structures
- micromachining techniques
- automation of micromachining techniques

Solid State and Diode Lasers
Dipl.-Ing. Dieter Hoffmann (-206)
- development of solid state and diode lasers
- methods and components for frequency doubling
- forming of diode laser beams
- development of diode laser modules and systems
- design and characterization of micro-optical components
- development of components for solid state and diode lasers

Laser Measurement and Testing Technology
Dr. Reinhard Noll (-138)
- development, construction and testing of laser measurement and testing equipment
- chemical analysis of solid, liquid and gaseous substances with laser spectroscopy
- surface sensitive fluorescence analysis
- quantification of protein interactions using label-free laser scattering methods
- measurement of distances, profiles and shapes with laser triangulation
- inspection of surfaces
- real time operation and automation

Cutting and Joining
Dr. Dirk Petring (-210)
- 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
- design and implementation of processing heads
- sensor-based process control
- computer-supported process control and optimization
- multimedia training and information systems

Plasma Technology
Dr. Willi Neff (-142)
- excitation systems for plasma technology
- low and high pressure plasmas for cleaning processes and sterilisation
- plasma based EUV and soft X-ray sources as well as X-ray technology
- short time measurement techniques
- photo and plasma chemistry

Surface Treatment
Dr. Konrad Wissenbach (-147)
- transformation hardening, remelting, cladding, alloying and dispersing for the production of load orientated layers
- development of powder feeding systems
- heat treatment of coated and uncoated surfaces
- cleaning and modification of surfaces such as burr removing, activation and structuring
- rapid prototyping and rapid manufacturing for production of metallic parts and tools
- polishing of metals and glass
Micro Technology
Dr. Arnold Gillner (-148)

- laser micro soldering and micro welding
- laser supported bending and adjustment
- precision cutting and drilling of metals, ceramics, semiconductors and diamonds
- micro structuring with excimer and Nd:YAG-lasers
- micro punching and stamping
- marking and lettering
- laser CVD and PVD, laser-galvanizing
- cutting and perforating of paper, plastics and composite materials
- welding of thermoplasts and thermoplastic elastomers

Modelling and Simulation
Priv.-Doz. Dr. W. Schulz (-132)

- Design of hollow cathode discharge for generation of EUV-radiation
- Design of optical resonators for gas, solid state, and high power diode lasers
- Optimisation of beam guidance in optical systems
- Analysis of radiation transfer in process gases during processing
- Sub- and supersonic gas flow of assist and process gases
- Analysis of melt flow, heat transport, and movement of phase boundaries
- Dynamical models of cutting, welding and drilling
- Data evaluation algorithms
- Programming of graphical user surfaces for simulation of the models and visualisation of data using commercial graphic-servers like OpenGL®
- Numerical methods and codes, such as Cluster-In-Cell Code (CIC), adaptive meshing domains with moving boundaries (Hierarchical Basis), finite elements and finite volume methods on time dependent domains (Level-Set Method)
- Process monitoring using spatial and temporal resolved detectors like commercial CCD- and CMOS-camera systems
- Control of processing

System Technology
Dr. Stefan Kaierle (-212)

- pilot plants
- integration of laser technology into manufacturing systems
- development of sensors and control systems
- development of power supply for diode lasers, of generators for EDM equipment and of high-voltage-pulse-generators
- small-lot applications
- concept and design of plants
- control technique for laser plants
- education and training
Services

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

• development of laser beam sources
• 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. The Fraunhofer ILT also has a video conference room and a computer network.

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
- Nd:YAG-lasers up to 5 kW
- diode laser systems up to 3 kW
- diode-pumped solid state lasers up to 8 kW
- excimer lasers
- fibre lasers
- five-axis gantry systems
- three-axis processing stations
- beam guiding systems
- robot systems
- sensors for process control in laser material processing
- direct-writing and laser-PVD stations
- clean rooms for assembly of diode lasers, diode laser systems and diode pumped solid state lasers
- devices for process diagnostics and high speed video analysis
- laser spectroscopic systems for the chemical analysis of materials
- laser triangulation sensors for distance and contour measurement
- laser coordinate measuring machine
- devices for holographic vibration analysis and Speckle interferometry

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

© AVIA-Luftbild, Aachen
Dipl.-Ing. Martin Jochum
Employees

Employees at the Fraunhofer ILT 2003

<table>
<thead>
<tr>
<th>Personnel</th>
<th>number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scientists and engineers</td>
<td>101</td>
</tr>
<tr>
<td>Technical staff</td>
<td>36</td>
</tr>
<tr>
<td>Administrative staff</td>
<td>21</td>
</tr>
<tr>
<td><strong>Total Personnel</strong></td>
<td><strong>158</strong></td>
</tr>
<tr>
<td><strong>Other employees</strong></td>
<td><strong>101</strong></td>
</tr>
<tr>
<td>Undergraduate assistants</td>
<td>90</td>
</tr>
<tr>
<td>External employees</td>
<td>8</td>
</tr>
<tr>
<td>Trainees</td>
<td>3</td>
</tr>
<tr>
<td><strong>Total number of employees at the Fraunhofer ILT</strong></td>
<td><strong>259</strong></td>
</tr>
</tbody>
</table>

- 16 members of staff completed their doctorates
- 21 undergraduates carried out their final year projects at the Fraunhofer ILT
Revenues and Expenses (Provisional)

Expenses 2003

<table>
<thead>
<tr>
<th>Expense</th>
<th>Mill. EUR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating budget</td>
<td>16.4</td>
</tr>
<tr>
<td>- Staff costs</td>
<td>8.8</td>
</tr>
<tr>
<td>- Material costs</td>
<td>7.6</td>
</tr>
<tr>
<td>Investments</td>
<td>1.8</td>
</tr>
</tbody>
</table>

Revenues 2003

<table>
<thead>
<tr>
<th>Revenue</th>
<th>Mill. EUR</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Industrial revenues</td>
<td>9.3</td>
</tr>
<tr>
<td>- Additional financing from Federal Government, States and the EU</td>
<td>5.5</td>
</tr>
<tr>
<td>- Basic financing from the Fraunhofer-Gesellschaft</td>
<td>1.6</td>
</tr>
<tr>
<td>Total revenues</td>
<td>16.4</td>
</tr>
<tr>
<td>- Revenues from projects abroad (already included in total)</td>
<td>2.0</td>
</tr>
</tbody>
</table>

Expenses 2003 (100 %)

- 42 % Material costs
- 10 % Investments
- 48 % Staff costs

Revenues 2003 (100 %)

- 33 % Additional financing from Federal Government, States and EU
- 57 % Industrial revenues
- 10 % Basic financing from the Fraunhofer-Gesellschaft
Budget Growth

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

Facts and Figures

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

Mio EUR
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 new 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
• Growth in know-how by faster recognition of trends in the field of laser and production technology
• Accelerated use of R&D and work methods, in which the USA is the leader
• Know-how growth through close cooperation with the Wayne State University and the University of Michigan.
• Strengthening position in the R&D market
• Increase of industrial return from the USA
• Increase of motivation and qualification level of employees

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.

In collaboration with the University of Michigan, the CLT develops high-power fiber lasers capable of delivering excellent beam quality both in continuous mode at outputs of several kilowatts and in ultra-short pulsed mode. In collaboration with the Wayne State University, durably stable implants for neurostimulation of the human brain are being developed. The CLT is also the main sponsor of the »Laserspot« organization, founded in 2000, and meanwhile supported by over 20 members. The purpose of Laserspot is to promote applications of laser technology in various branches of industry by bringing together suppliers of technologies and components with users in a wide variety of industrial sectors.

A spin-off company, Visotek, was created in 2001 by former members of the CLT, with the objective of rapidly commercializing Fraunhofer technology and collaborating on joint research projects. The first product to be launched on the market was a fiber-coupled diode-laser system with output in the kilowatt range. Present development projects include special optics for use in the welding of deck structures in shipbuilding.

The American partners’ interest concentrates on:
• Using the competence of the Fraunhofer Institutes for American companies
• Using the experience in the introduction of new technologies
• Providing the connection between industry and university
• Providing practical training for students and graduate students
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 at the CLT consists of CO₂ lasers with 6 kW power, pulsed Nd:YAG lasers from 1 kW to 4.4 kW, diode lasers from 300 W to 4 kW, a number of special and hybrid optics as well as a series of 3.5 and 6 axes systems.

References

- Alcan
- Borg Warner
- Coherent Semiconductor Group
- DaimlerChrysler
- Dana Corporation
- Ford Motor Company
- General Motors
- JMC Technology Group
- Johnson Controls
- Kuka
- LASAG
- Nuvonyx
- Parker Hannifin
- Praxair Surface Technologies, Inc.
- PRC Lasers
- Rofin Sinar
- Soudronic
- Spectra Physics
- Trumpf
- Tailor Steel
- T&H Lemont
- Valeo
- Visteon

Contact

Dr. Stefan Heinemann
Director
46025 Port Street
Plymouth
Michigan 48170
USA
Telephone: ++1 / 734 / 354 -6300
Extension: -210
Fax: ++1 / 734 / 354 -3335
sheinemann@clt.fraunhofer.com
www.clt.fraunhofer.com

Operating Budget 2003*

<table>
<thead>
<tr>
<th>Mio. US$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating budget</td>
</tr>
<tr>
<td>- Staff costs</td>
</tr>
<tr>
<td>- Material costs</td>
</tr>
</tbody>
</table>

*Post-calculation has not occurred yet
Short Profile

At the CLFA in Paris, the Fraunhofer Institute for Laser Technology ILT has been cooperating since 1997 with leading French research organizations, including ARMINES, the École Nationale Supérieure des Mines de Paris ENSMP, the Institut de Soudure, the Institut Universitaire de Technologie du Creusot, the École Nationale Supérieure de Mécanique et des Microtechniques ENSMM in Besançon and other major laser application centers in France (such as IREPA in Strasbourg, PALA in Bordeaux). Multidisciplinary teams of specialists from Germany and France work together on the transfer of laser-assisted manufacturing processes to European industry. The Coopération Laser Franco-Allemande is a member of the Club Laser et Procédés, the French association of laser manufacturers and users.

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 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
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 mid-sized 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.

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 analysis laboratories. The technical infrastructure of other French partners can also be shared on a project- or customer-specific basis.

Locations


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

Contact

Dr. Wolfgang Knapp
Director
CLFA c/o Armines
60 Boulevard Saint Michel
75272 PARIS Cedex 6
France

Telephone: +33 1 4051 9476
Fax: +33 1 4051 0094
wolfgang.knapp@ilt.fraunhofer.de
www.ilt.fraunhofer.de/clfa.html
The Fraunhofer-Gesellschaft

The Fraunhofer-Gesellschaft undertakes applied research of direct utility to private and public enterprise and of wide benefit to society. Its services are solicited by customers and contractual partners in industry, the service sector and public administration. The organization also accepts commissions and funding from German federal and Länder ministries and government departments to participate in future-oriented research projects with the aim of finding innovative solutions to issues concerning the industrial economy and society in general.

By developing technological innovations and novel systems solutions for their customers, the Fraunhofer Institutes help to reinforce the competitive strength of the economy in their local region, and throughout Germany and Europe. Through their work, they aim to promote the successful economic development of our industrial society, with particular regard for social welfare and environmental compatibility.

As an employer, the Fraunhofer-Gesellschaft offers a platform that enables its staff to develop the professional and personal skills that will allow them to take up positions of responsibility within their institute, in other scientific domains, in industry and in society.

At present, the Fraunhofer-Gesellschaft maintains roughly 80 research units, including 58 Fraunhofer Institutes, at over 40 different locations in Germany. A staff of some 12,700, predominantly qualified scientists and engineers, work with an annual research budget of over 1 billion euros. Of this sum, more than 900 million euros is generated through contract research. Roughly two thirds of the Fraunhofer-Gesellschaft’s contract research revenue is derived from contracts with industry and from publicly financed research projects. The remaining one third is contributed by the German federal and Länder governments, as a means of enabling the institutes to pursue more fundamental research in areas that are likely to become relevant to industry and society in five or ten years’ time.

Affiliated research centers and representative offices in Europe, the USA and Asia provide contact with the regions of greatest importance to future scientific progress and economic development.

The Fraunhofer-Gesellschaft was founded in 1949 and is a recognized non-profit organization. Its members include well-known companies and private patrons who help to shape the Fraunhofer-Gesellschaft’s research policy and strategic development.

The organization takes its name from Joseph von Fraunhofer (1787-1826), the illustrious Munich researcher, inventor and entrepreneur.

Fields of Research

The Fraunhofer-Gesellschaft concentrates on research in the following fields:
- Materials technology, component behavior
- Production and manufacturing technology
- Information and communication technology
- Microelectronics, microsystems engineering
- Sensor systems, testing technology
- Process engineering
- Energy and construction engineering, environmental and health research
- Technical/economic studies, information transfer

Target Groups

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

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

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

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.
<table>
<thead>
<tr>
<th>Business Area</th>
<th>Laser and Plasma Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Semi-Automated Micro Lens Assembly</td>
</tr>
<tr>
<td></td>
<td>Burn-in System for High-Power Diode Lasers</td>
</tr>
<tr>
<td></td>
<td>Customer-Specific Diode Laser Pump Modules</td>
</tr>
<tr>
<td></td>
<td>Miniaturized Slab Laser – MicroSlab</td>
</tr>
<tr>
<td></td>
<td>Diode-Pumped Slab Laser – INNOSLAB1000</td>
</tr>
<tr>
<td></td>
<td>Scaleable Power Amplifier for Slab Geometry</td>
</tr>
<tr>
<td></td>
<td>Short-Pulse High-Power MOPA with Average Output Power in the kW Range</td>
</tr>
<tr>
<td></td>
<td>UV Solid-State Laser with High Average Output</td>
</tr>
<tr>
<td></td>
<td>Process- Compatible Optics for the Simultaneous Laser Welding of Polymer Components</td>
</tr>
<tr>
<td></td>
<td>Laser Rail Cleaner</td>
</tr>
<tr>
<td></td>
<td>Processing and Cleaning of Polluted Air</td>
</tr>
<tr>
<td></td>
<td>Plasma Reactors for Exhaust After-Treatment</td>
</tr>
<tr>
<td></td>
<td>Continuous Online Atmospheric Plasma Process</td>
</tr>
<tr>
<td></td>
<td>Fast Sterilization of Packaging Material</td>
</tr>
<tr>
<td></td>
<td>Gas Discharge Source for Extreme Ultraviolet Lithography</td>
</tr>
<tr>
<td></td>
<td>Micro- and Nanostructure Investigations with EUV Transmission Microscopy</td>
</tr>
</tbody>
</table>

**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.
**Task**

For the fiber coupling or direct application of high-power diode laser bars, the sometimes highly divergent and astigmatic beam must be collimated and focused. For collimating high-power diode laser bars, microoptics are used. For example, the beam of the so-called fast axis, with a divergence angle greater than 30° (half angle), is collimated with the help of micro-cylinder lenses. These micro lenses have a numerical aperture greater than 0.6 and a focal length of less than 1 mm. The typical dimensions are 1.5 x 1.5 x 12.0 mm. The required positioning accuracy when assembling these lenses lies in the sub-μm range.

The assembly and calibration of micro lenses is still a predominately manual process. The quality of the process thus depends on the skills of the individual operator. To ensure a high degree of accuracy and reproducibility as well as consistent long-term quality, semi-automation of the individual process steps is needed.

**Results and Applications**

The lens magazine securely houses 30 micro lenses in positive-contact slots. The equipment automatically grasps a micro lens, dispenses a layer of UV-hardening adhesive on the surface and roughly positions the lens in front of the high-power diode laser bar. For the time being, the operator must continue to perform the fine adjustment. After the fine adjustment is successfully completed, the bonding surface is automatically hardened with UV light. During the entire process, the computer controls and monitors the power supply and the flow of cooling liquid, compressed air and vacuum.

**Contact**

Dipl.-Ing. M. Haverkamp, Tel.: -531 mark.haverkamp@ilt.fraunhofer.de
Dipl.-Ing. M. Röhner, Tel.: -195 markus.roehner@ilt.fraunhofer.de
Dr. K. Boucke, Tel.: -132 konstantin.boucke@ilt.fraunhofer.de

**Method**

As a first step towards semi-automation, a magazine for the micro lenses was developed to eliminate the cumbersome procedure of removing the lenses from the cuvette, manually placing them onto the assembly gripper and in general to avoid handling mistakes.

At the same time, the various components needed to mount the micro lenses – e.g. dispensers, ultra-violet light sources and diode laser power supplies – were integrated in a commercially available multi-axis gripper system and controlled by a computer.
**Task**

The maximum optical output power of diode lasers has risen steadily over the past years and will no doubt continue to do so. In the field of diode packaging, the use of passive heat sinks is becoming more widespread, for they allow laser modules to be constructed reliably and cost-effectively without active cooling. The aim of the project is to develop a test bed designed to handle the output power and cooling geometries of the next generation of high-power diode lasers.

**Method**

The system encompasses five individual test stations each consisting of a mechanical clamping device to hold the diode laser and sensors to measure the test variables. The absolute optical output power is measured using commercially available OEM sensors. Each test station is equipped with its own high-current power supply developed by the Fraunhofer ILT and a spectrometer operating at wavelengths of 650-1100 nm with a resolution of 0.5 nm.

Other measured variables include diode voltage, coolant flow rate and coolant temperature. A cooler with integrated heating element allows the operating temperature to be set to up to 70°C.

The host computer has a user interface that allows the operator to individually set the parameters of each test station and graphically view the measurement results.

**Results and Applications**

The system can be used for the lifecycle testing and characterization of actively and passively cooled high-power diode lasers with an optical output power of up to 240 watts. The ability to precisely adjust the temperature of the diodes allows an accelerated simulation of the aging process and enables high-temperature diodes to be tested under realistic operating conditions.

**Contact**

Dipl.-Ing. W. Brandenburg, Tel.: -192 wolfgang.brandenburg@ilt.fraunhofer.de
Dr. K. Boucke, Tel.: -132 konstantin.boucke@ilt.fraunhofer.de
Customer-Specific Diode Laser Pump Modules

Task

For the pumping of solid-state lasers, customer-specific diode laser modules with fiber coupling are required. The units must be designed to compact dimensions that allow them to be inserted in 19-inch standard racks. The specifications call for a power output of 300 watts through a 800-µm fiber or 150 watts through a 600-µm fiber.

Method

The beam-shaping and fiber-coupling optical concept was designed on the basis of commercially available diode laser stacks with a defined pumping wavelength using ray-tracing simulation. Besides the polarization coupling, a newly developed beam transformer for the symmetrization of both beam dimensions (slow and fast axis) was employed. The beam forming optics folds the beam by use of a deflective prism and focuses the symmetrical beam on a rear-cooled pinhole which serves to protect the subsequent fiber coupling.

Results and Applications

At around 60% efficiency, the 800-µm fiber achieves an output power of 300 watts with a numerical aperture (NA) of 0.22. The 150-watt module is built without polarization coupling to ensure compatibility between the two pumps. By increasing the fill factor in the fast axis with compression optics and by employing wavelength multiplexing, the module is capable to deliver up to 1 kW with a NA of 0.22 at 800 µm fiber core diameter.

The module is being deployed in materials processing and in pumping optics for disc and fiber lasers.

Contact

Dipl.-Phys. A. Knitsch, Tel.: -414 alexander.knitsch@ilt.fraunhofer.de
Dipl.-Ing. M. Traub, Tel.: -342 martin.traub@ilt.fraunhofer.de
Dipl.-Ing. H.-D. Hoffmann, Tel.: -206 hansdieter.hoffmann@ilt.fraunhofer.de
Task

Diode-pumped solid-state lasers are well-established tools in the fields of marking and microstructuring. The output of commercially available end-pumped rod lasers is limited to 10 W. Scaling up the output to the 100-W range while maintaining high beam quality can be achieved with the INNOSLAB technology developed by the Fraunhofer ILT.

The rectangular-shaped slab laser components allow for simple assembly on a common baseplate and thus make it possible to automate the manufacture of the device.

Dramatically reducing the cost and dimensions of the assembly opens up new fields of application, particularly in the marking industry where to date ink-jet or conventional laser printing have been the only alternatives.

The goal is to design and develop a miniaturized, Q-switched and passively cooled slab laser that can be manufactured with automated processes and provides an output power in the vicinity of 20 watts with diffraction-limited beam quality.

Method

The INNOSLAB design was modified to allow the use of a stable folded resonator instead of a stable/unstable hybrid resonator.

The buildup of parasitic oscillations is prevented by applying a special coating to the folding mirror. Besides the bi-directional Gaussian beam profile, the advantage of the design is the small beam cross-section that makes it easier to use proven and tested components for Q-switching and frequency conversion.

The structural dimensions required to homogenize the diode lasers and compensate for their failure can be significantly reduced by using micro-optical components in the pump assembly.

Results and Applications

Using a test setup, the angular selectivity of the folding mirror, limited by the available pump capacity, was verified at power outputs of up to 40 watts. Pulse lengths in A/O Q-switched TEM00 mode between 50 and 150 ns are achieved.

The illustration shows the miniaturized version of the MicroSlab laser, which measures 170 x 70 x 50 mm³. The individual components are attached to alignment pins and fixed to the baseplate. The only adjustable element is the output coupling mirror.

Contact

Dipl.-Phys. M. Hoefer, Tel.: -128 marco.hoefer@ilt.fraunhofer.de
Dipl.-Phys. J. Luttmann, Tel.: -128 joerg.luttmann@ilt.fraunhofer.de
Dipl.-Ing. H.-D. Hoffmann, Tel.: -206 hansdieter.hoffmann@ilt.fraunhofer.de
Task

Commercially available diode-pumped slab lasers deliver an output of up to 8 kW with a beam parameter product of 12.5 to 25 mm x mrad. Optical waveguides with core diameters of 300-600 µm are employed for beam delivery. These lasers generate an approximately 4-16-times lower focusing capacity than diffraction-limited CO₂ lasers.

For laser applications such as remote welding, selective laser melting or high-speed cutting, significantly higher beam quality is required. The enhanced beam quality can alternatively be used for improved focusing, enlarging the depth of field or reducing the diameter of the machine optics.

The aim of ongoing research on the diode-pumped INNOSLAB slab laser is to increase output power to the 1000-watt range with M² < 10, thus achieving a beam quality that is at least equal to diffraction-limited CO₂ lasers.

Method

The INNOSLAB slab laser concept developed by the Fraunhofer ILT is based on a rectangular-shaped laser crystal end-pumped by diode laser stacks. The diode laser beam characteristics reduce focusing to a homogenous line with a high aspect ratio.

The rectangular cross-section of the end-pumped crystal creates an amplifying volume that can be efficiently exploited to enhance beam quality through the use of a stable/unstable hybrid resonator. To reduce thermally induced stress, crystals with undoped areas are used. The impact of these undoped end pieces on thermal induction effects was investigated theoretically and verified experimentally.

Results and Applications

In cw mode, the use of bonded crystals enabled the output power to be increased to 1050 watts while at the same time improving the diffraction index to M² < 4 over the entire output range.

A Q-switched laser based on the same technology achieved an output power of 80 watts with M² < 1.5. At a repetition rate of 1 kHz, the pulse energy amounted to 6 mJ and the pulse length 15 ns.

The photo shows an industry-compatible prototype of the laser that can be integrated in a 19" rack together with the control and power supply units.

Contact

Dipl.-Phys. M. Hoefer, Tel.: -128 marco.hoefer@ilt.fraunhofer.de
Dipl.-Phys. J. Luttmann, Tel.: -128 joerg.luttmann@ilt.fraunhofer.de
Dipl.-Ing. H.-D. Hoffmann, Tel.: -206 hansdieter.hoffmann@ilt.fraunhofer.de
Task

Laser oscillators operating with pulse durations in the nanosecond or picosecond range are typically limited to an output power of between a few watts and a few dozen watts. The generation of laser radiation at higher output levels requires the use of an optical amplifier. The aim is to develop an efficient technology for amplifying output power without significantly impacting beam quality and pulse shape and without the use of active switching elements such as Pockel’s cells or modulators.

Method

The amplifier stage consists of a rectangular-shaped laser crystal (slab) with a diode-pumped line focus. The high aspect ratio of the slab end face offers the scope for power scaling along the broad axis. The incoming beam is adapted to the pumping volume along the narrow axis. The beam passes through the crystal several times in the scaling direction, forming a folded single-pass amplifier. This allows the system to be optimized either for high output power or for high amplification. A suitable folding design ensures that the beam intensity remains within the vicinity of the saturation value, and thus well below the level that would destroy the optical components, even at high output power.

Results and Applications

The following MOPA systems have been implemented in concrete applications, such as ultra-high-speed laser deposition of thin films or resonator-external frequency conversion:

- MHz Nd:YVO₄-Amplifier
  f = 1.5 - 4 MHz, \( \tau = 13 \) ps,
  Oscillator: 4 W, \( M^2 = 1 \)
  Amplifier: 50 W, \( M^2 < 1.4 \)
- MHz Nd:YVO₄-Amplifier
  f = 80 MHz, \( \tau = 7 \) ps,
  Oscillator: 3.5 W, \( M^2 = 1 \)
  Amplifier: 48 W, \( M^2 < 1.1 \)
- kHz Nd:YAG-Amplifier
  f = 0 - 10 kHz, \( \tau < 10 \) ns,
  Oscillator: max. 4 W, \( M^2 < 1.7 \)
  Amplifier: max. 42 W, \( M^2 < 1.5 \)
- kHz Nd:YAG-Amplifier
  f = 0 - 50 kHz, \( \tau > 20 \) ns,
  Oscillator: max. 75 W, \( M^2 < 1.6 \)
  Amplifier: max. 135 W, \( M^2 < 1.9 \)

In the course of future work, it is hoped to scale up the output power to a level of several hundred watts.

Contact

Dipl.-Phys. J. Luttmann, Tel.: -128
joerg.luttmann@ilt.fraunhofer.de

Dipl.-Phys. M. Hoefer, Tel.: -128
marco.hoefer@ilt.fraunhofer.de

Dipl.-Ing. H.-D. Hoffmann, Tel.: -206
hansdieter.hoffmann@ilt.fraunhofer.de
Short-Pulse High-Power MOPA  
with Average Output Power in the kW Range

Task

The continuous increase in the packing density of lithographically created structures in microchips demands novel methods in the area of lithographic beam sources. For laser-based EUV lithography at a wavelength of $\lambda = 13.4$ nm, high-power laser systems must be developed that exhibit pulse outputs in the MW range, average outputs in the kW range at high beam quality.

On behalf of XTREME technologies, an Nd:YAG oscillator-amplifier system will be developed with pulse durations under 15 ns, repetition rates of several kHz and an average output in the kW range with $M^2 < 10$.

Method

The amplifier system is based on a commercially available diode-pumped Nd:YAG laser module that was recently developed in collaboration with Rofin Sinar for use in high-power CW lasers. The rod based modules are pumped transversally.

To achieve the required beam quality, an optical system is developed to compensate for the typical loss in quality that occurs when Nd:YAG rods are operated at the higher end of the average output range.

Results and Applications

The oscillator-amplifier arrangement currently operates at up to 10 kHz with a pulse length between 5 and 15 ns.

A system is developed and built on the basis of an industrial laser consisting of four laser modules. The system is routinely operated at 0 - 10 kHz with an average output of up to 500 watts, achieving a diffraction index of $M^2 < 2$.

An optimized version with eight laser modules achieves an average output of 1.3 kW at a repetition rate of 10 kHz and $M^2 < 12$.

Besides EUV lithography, the system also has potential for use in high-speed materials processing applications such as percussion drilling, surface structuring or pulsed laser deposition (PLD).

Contact

Dipl.-Phys. K. Nicklaus, Tel.: -224  
kolja.nicklaus@ilt.fraunhofer.de
Dipl.-Ing. H.-D. Hoffmann, Tel.: -206  
hansdieter.hoffmann@ilt.fraunhofer.de
UV Solid-State Laser with High Average Output

Task

Innovative manufacturing processes such as the direct exposure of circuit boards or electronic circuit board drilling applications require a stable UV solid-state laser with an average output of about 10 watts. For direct circuit board exposure, UV argon lasers are currently employed. For the drilling of electronic circuit boards, CO₂ lasers are used. While argon lasers are characterized by high power consumption and low operational reliability, CO₂ lasers are theoretically unable to achieve diameters as small as 25 µm. To resolve this problem, a low-cost all-solid-state UV laser system will be developed together with Jenoptik Laser Optik Systeme GmbH that will exhibit an output power of greater than 10 watts and increased operational reliability.

Method

A Q-switched slab MOPA arrangement, consisting of a diode-pumped slab oscillator and a downstream slab amplifier, delivers a near-diffraction-limited beam at 1064 nm with high average output at pulse repetition rates between 5 and 50 kHz. With non-linear crystals, the laser is first frequency-doubled (532 nm) and then quadrupled (266 nm).

Results and Applications

At a pulse repetition frequency of 10 kHz, the slab MOPA arrangement delivers an output power of over 120 watts at 1064 nm with a diffraction index of $M^2 \leq 2$ and a pulse length of less than 30 ns.

After doubling the frequency with an LBO crystal, an output power of greater than 65 watts at 532 nm with a diffraction index of $M^2 \leq 1.3$ is available for frequency quadrupling.

The first attempts at frequency quadrupling with a CLBO crystal produced an output power of more than 10 watts at 266 nm. Further work should eventually enable output power to be raised to a consistently stable 15 watts or more at 266 nm.

Contact

Dipl.-Phys. Marco Hoefer, Tel.: -128 marco.hoefer@ilt.fraunhofer.de
Dipl.-Ing. H.-D. Hoffmann, Tel.: -206 hansdieter.hoffmann@ilt.fraunhofer.de
Process-Compatible Optics for the Simultaneous Laser Welding of Polymer Components

Task

Due to their smaller dimensions and lower capital and operating costs, diode lasers offer significant advantages over gas and solid-state lasers for polymer laser welding applications. To further increase the flexibility of diode lasers, fiber-coupled systems are employed. Compared to contour welding, simultaneous welding processes in which the joints are created with a single-shot process without any moving parts allow cycle times to be reduced while lowering equipment costs. Consequently, the Fraunhofer ILT, together with the CLFA, designed and assembled suitable processing optics for a defined welding contour.

Method

For the given component, two circular, concentric weld seams must be created. For this purpose and with the help of a ray-tracing program, a suitable fiber-coupled diode laser system was designed in which the power density distribution of the individual rings exhibits a radial top-hat shape and is angle-independent. This allows continuous variation of the power ratio of the two rings, permitting the optics to be set to the specific far field distribution of the laser in use.

Results and Applications

After designing the optics, the Fraunhofer ILT developed a prototype for simultaneous welding of the aforementioned geometry and successfully tested it at the CLFA. The optics generate two concentric rings with diameters of 10 and 25 mm at a processing distance of 150 mm. The optics have an efficiency of 95%. Using the same concept, optics with process-compatible power density distributions are being developed for other geometries such as squares and rectangles.

Contact

Dipl.-Ing. M. Traub, Tel.: -342 martin.traub@ilt.fraunhofer.de
Dipl.-Ing. H.-D. Hoffmann, Tel.: -206 hansdieter.hoffmann@ilt.fraunhofer.de
Laser Rail Cleaner

Task

In wet weather, autumn foliage, grease and oil and thin layers of rust form a sticky film that adheres to rail tracks, causing loss of traction during acceleration and prolonging braking distances, and creating an increased electrical resistance between the wheels and the track. Conventional cleaning methods such as high pressure water jets and sand dispensers do not entirely satisfy requirements in terms of operating speed and the need to limit wear and tear on the tracks. In addition, the cleaning material must be transported in a container and periodically refilled.

One solution is to employ high-power lasers as part of a non-contact cleaning system. Lasers and machine optics that meet all of the requirements are not commercially available. Because of its extensive expertise in the field of high-power pulsed lasers, the Fraunhofer ILT was contracted by the British firm LASERTHOR to develop a diode-pumped laser with fiber-coupled machine optics.

Method

A diode-pumped solid-state laser with an average output of 1000 watts is Q-switched to achieve the power density required for an efficient cleaning process. The laser beam is delivered via fiber-optic cable to the machine optics installed on the chassis of the rail vehicle close to the surface of the rails. The machine optics generate a line-shaped focus, and contain no moving parts. The resulting assembly is easily accommodated in the limited space available, and is capable of withstanding the extreme stress of vibrations, dirt and grease.

Results and Applications

The prototype delivered to LASERTHOR supplies a pulsed output of 500 kW with a pulse duration of 60 ns and a pulse frequency of 25 kHz via glass fiber. The gap between the optics and the rail is more than 200 mm. A speed of 64 km/h was achieved during tests. The system is currently being tested on the British rail network.

The system will initially be installed on maintenance vehicles, but the longer-term goal is to integrate it in regular passenger and freight trains.

Contact

Dipl.-Ing. R. Meyer, Tel.: -197 rudolf.meyer@ilt.fraunhofer.de
Dipl.-Ing. M. Traub, Tel.: -342 martin.traub@ilt.fraunhofer.de
Dipl.-Ing. H.-D. Hoffmann, Tel.: -206 hansdieter.hoffmann@ilt.fraunhofer.de

Fiber-coupled beam shaping optics
Task

Many everyday activities contribute to or are affected by air pollution, which is subject to strict concentration limits. A typical example is the exhaust emissions from road vehicles and industrial plant, which often contain volatile organic compounds (VOCs). Most of the available treatment technologies are complex to install and maintain. One low-maintenance, easy-to-install alternative is the generation of atmospheric-pressure plasmas through processes such as barrier discharge.

Method

The test gas mix is composed at a special setup which also allows liquids to be vaporized and added to the gas flow. The gas mix can be treated by different kinds of plasma reactor. The gas analysis is performed by mass spectrometry, FT-IR analysis (variable path length up to 10 m) and gas chromatography.

Results and Applications

When treating VOC-polluted air, high removal efficiencies are achieved, e.g. 95% of formaldehyde in air was removed. Also the toxic carbon monoxide was converted to carbon dioxide with 85% efficiency. It was observed that temperature and humidity as well as the oxygen concentration have a strong influence on the removal efficiency.

In automobile exhaust after-treatment, the plasma is used to condition the exhaust gas for subsequent processes. In order to assess the viability of plasma processes, the Fraunhofer ILT has the facilities to perform in-house feasibility studies.

The work on VOC removal is funded by the EC under contract no. G1ST-CT-2001-50138.

Contact

Dipl.-Ing. O. Franken, Tel.: -415 oliver.franken@ilt.fraunhofer.de
Dr. W. Neff, Tel.: -142 willi.neff@ilt.fraunhofer.de
Plasma Reactors for Exhaust After-Treatment

**Task**

High temperatures and gas flows such as those in the exhaust system of an automobile make great demands on the performance of a plasma treatment unit. The plasma treatment unit (reactor) should not only be capable of operating efficiently at high temperatures but also be cheap and compact.

**Method**

The choice of a suitable electrode material and electrode geometry (slab-built or pipe reactor) is important as well as contacting the high voltage to the reactor at high temperatures. The overall dimensions need to be kept as low as possible to allow the reactor to be integrated in the exhaust system.

**Results and Applications**

Slab-built reactors at the Fraunhofer ILT in the past were made of quartz. It has now become possible to construct such reactors from ceramic materials; a first step toward cheap mass production. By further decreasing the overall size, they can be installed in the exhaust system of an automobile. Failure-free operation up to 300° C in the exhaust system was achieved. The maximum coupled plasma power at the moment is 700 W. The efficiency of the plasma treatment can be further increased by use of a downstream catalyst or additives.

The plasma reactors are supplemented by matched high voltage generators to achieve maximum power coupling into the plasma. The real plasma power can be measured by an external power measurement unit.

In order to assess the viability of plasma processes, the Fraunhofer ILT has the facilities to perform in-house feasibility studies. Customer-specific reactor designs are available on request as well as process and technical support during testing. In addition, the Fraunhofer ILT can supply electrical controls, electrical measuring instruments and PC-based controls for the entire system.

**Contact**

Dipl.-Ing. O. Franken, Tel.: -415 oliver.franken@ilt.fraunhofer.de
Dr. W. Neff, Tel.: -142 willi.neff@ilt.fraunhofer.de
Continuous Online Atmospheric Plasma Process

Task

The aim of the project is to develop a continuous online atmospheric plasma process (speed 600 m/min; processing width up to 2 m) for the surface treatment of various materials (paper, fibers, plastics, textiles). The objectives are to improve product characteristics (adhesion, wettability, printability), to improve process yield, consume less energy and toxic chemicals, reduce contamination of the final products and environmental burden, and reduce output of waste.

Method

The consortium is composed of eleven partners from six European countries. Six research centers (three specialized in plasma, one in paper, one in composite fibers, one in material sterilization) and five industrial firms (one manufacturer of plasma equipment, one paper manufacturer, one glass-fiber producer, two textile manufacturers) participate. The ILT focuses on the development and characterization of new types of electrode.

Results and Applications

After evaluation of the plasma process at lab scale, it is planned to gradually scale it up to industrial level. High plasma power densities were tested successfully to achieve short treatment times. Certain types of electrode combine emission of UV light and direct impact of reactive plasma on the treated surface. This leads e.g. to more homogeneous plasma appearance and may result in a more uniform surface treatment.

The project is currently funded by the European Commission (project no. G1RD-CT-2002-00747).

Contact

Dipl.-Phys. M. Heise, Tel.: -137
michael.heise@ilt.fraunhofer.de
Dr. W. Neff, Tel.: -142
willi.neff@ilt.fraunhofer.de

Above: System for plasma treatment of samples with high speed
Below: Set-up to investigate the plasma homogeneity
Fast Sterilization of Packaging Material

**Task**

Sterility is an essential property of the materials used to package food or medical products – often plastic films made of PET, PE or PP. Plasmas at atmospheric pressure – such as those produced by dielectric barrier discharge – can be used to sterilize packaging material. Such plasmas emit UV light and produce oxidative radicals which lead to the destruction of germs.

**Method**

In collaboration with the Fraunhofer Institute for Process Engineering and Packaging IVV, it was shown that so-called cascaded dielectric barrier discharges (CDBDs) are very efficient in spore inactivation. The combination of UV light and direct plasma impact on the packaging material reduces the spore count by 5 decades after 2 seconds of treatment. But count reduction is not a suitable method for verifying the sterility of samples. This only can be done with special plasma reactors which can be used for end-point tests.

**Results and Applications**

An appropriate device was developed for use in microbiology laboratories. The compact dimensions allow it to be integrated in a laminar flow bench. First end-point tests were successfully carried out. Further development allows pre-sterilization of the reactor chamber and the treatment of moving samples.

**Contact**

Dipl.-Phys. M. Heise, Tel.: -137
michael.heise@ilt.fraunhofer.de
Dr. W. Neff, Tel.: -142
willi.neff@ilt.fraunhofer.de

Above: Cascaded dielectric barrier discharges (CDBDs) with UV-flat excimer source
Below: Plasma reactor for end-point tests
**Task**

Next-generation semiconductor chips with typical feature dimensions of below 30 nm will offer significantly higher storage capacity and processing speeds than those currently available. The technology considered most likely to replace the current process for exposing wafers with UV light is extreme ultraviolet (EUV) lithography.

This process images a mask onto a wafer at a wavelength of 13.5 nm, using a system consisting of molybdenum-silicon multilayer mirrors.

Supplying a suitable light source requires further development work to fulfill the demands of the semiconductor industry with respect to average power, repetition rate and life cycle of the source itself and the associated optical system.

**Method**

In a joint venture between Philips and the Fraunhofer-Gesellschaft, a gas-discharge source for EUV lithography will be developed. A pulsed current of over 10,000 amperes generates a xenon plasma that emits thermal radiation in the EUV range.

Operating such high currents presents a new technological challenge for the development of the electrode system. Electrode erosion leads to modification of its geometry and therefore degradation of the plasma emission characteristics as well as creating debris that reduces the life cycle of the associated optical system.

**Results and Applications**

By improving the electrode geometry, it was possible to prevent the negative effect on emission characteristics associated with the physical deformation of the cathode in particular. Together with a new cathode material concept, the source's life cycle was increased by at least one order of magnitude. The light source therefore fulfills the required specifications for use in an alpha-version exposure station being produced by market leader ASML.

The project was financed by Philips EUV and the German research ministry under contract number 13N8132.

**Contact**

Dr. K. Bergmann, Tel.: -302
klaus.bergmann@ilt.fraunhofer.de

Dr. W. Neff, Tel.: -142
willi.neff@ilt.fraunhofer.de
Micro- and Nanostructure Investigations with EUV Transmission Microscopy

Task

As miniaturization continues its march of progress in the semiconductor industry, the introduction of EUV lithography (Extreme Ultra Violet) will soon lead to greater interest in nanoscale manufacturing technologies and analytical methods for pattern recognition in the nanometer range. Once such object resolutions have been attained, a variety of alternative EUV applications outside lithography will be possible as well. As the resolving power of an optical instrument is dependent on the wavelength used, conventional devices already work at their resolution limit. This limit can be shifted to below 100 nm by the use of light with wavelengths from about 5 to 50 nm.

Since May 2001, the Fraunhofer ILT has been in charge of the strategic Fraunhofer cooperation project KOSAR (Optical Components and Radiation Sources for Future Applications in the X-Ray Range), which also involves the Fraunhofer Institutes IWS and IOF. The ILT's role in this project is to investigate and adapt plasma radiation sources to different analytical applications in the EUV and soft X-ray range, of which transmission microscopy will be realized as a demonstrator. The optical system is specified for 13.5 nm central wavelength, 21-fold magnification and 100 nm spatial resolution.

Method

The structure of the EUV microscope resembles that of a conventional light microscope and consists of a ring collector, a Schwarzschild lens and a CCD detector. The microscope is illuminated by a pulsed EUV-gas-discharge plasma source from AIXUV GmbH. The EUV source emits line or broadband radiation, which is guided in vacuum, because of the high absorbance. Imaging requires precise mirror optics with sophisticated single- or multi-layer coatings. The transmission of the probe delivers a contrast image, which is projected onto the detector plane. The EUV microscope is currently being set up and placed in operation. First images of test structures show that the EUV radiation can be well focused and the achieved intensities allow exposure times in the ns range.

Results and Applications

The EUV microscope is especially suitable for investigations with high spatial and temporal resolution. Through the combination with spectroscopic methods, a broad spectrum of applications is possible in the fields of material and life sciences. Besides applications in structural biology, future activities will focus on pattern recognition of thin films and semiconductors.

Contact

Dipl.-Ing. K. Walter, Tel.: -313
konstantin.walter@ilt.fraunhofer.de
Dr. W. Neff, Tel.: -142
willi.neff@ilt.fraunhofer.de
### Business Area

#### Laser Material Processing

<table>
<thead>
<tr>
<th>Application</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Application of SHADOW® Technique for Welding of Copper Parts</td>
<td>46</td>
</tr>
<tr>
<td>Application of SHADOW® Technique in Watch Industry</td>
<td>47</td>
</tr>
<tr>
<td>SHADOW® Rotating Optics</td>
<td>48</td>
</tr>
<tr>
<td>Laser-Beam Microwelding of Stainless Steel to Copper Alloys</td>
<td>49</td>
</tr>
<tr>
<td>Laser-Assisted Deep Drawing</td>
<td>50</td>
</tr>
<tr>
<td>Micromachining of Tools and Injection Molds by Laser Ablation</td>
<td>51</td>
</tr>
<tr>
<td>Microstructuring of Polymer Surfaces</td>
<td>52</td>
</tr>
<tr>
<td>Laser-Beam Welding of Thermoplastic Medical Products</td>
<td>53</td>
</tr>
<tr>
<td>Ear Surgery by UV Nanosecond Laser</td>
<td>54</td>
</tr>
<tr>
<td>Excimer-Laser Structuring of Bioactive Thin Films</td>
<td>55</td>
</tr>
<tr>
<td>Joint Fraunhofer Development: Modular Microreaction Systems</td>
<td>56</td>
</tr>
<tr>
<td>Laser Anastomosis of Small Vessels</td>
<td>57</td>
</tr>
<tr>
<td>Welding with Trapezoidal High-Power Diode Laser</td>
<td>58</td>
</tr>
<tr>
<td>Optimization of Welding Result by Customization of Shielding Gas Guidance</td>
<td>59</td>
</tr>
<tr>
<td>Customized Hybrid Welding Heads for Industrial Application</td>
<td>60</td>
</tr>
<tr>
<td>HybSy – The Next Generation of Laser-Arc Hybrid Welding</td>
<td>61</td>
</tr>
<tr>
<td>Laser Welding of Extraction Devices for Geological Sediment Samples</td>
<td>62</td>
</tr>
<tr>
<td>Laser Welding of High-Carbon Steel</td>
<td>63</td>
</tr>
<tr>
<td>Welding of High-Strength Stainless Steel in the Construction of Railway Vehicles</td>
<td>64</td>
</tr>
<tr>
<td>Cutting with an 8-kW Diode-Pumped Solid-State Laser</td>
<td>65</td>
</tr>
<tr>
<td>Welding with an 8-kW Diode-Pumped Solid-State Laser</td>
<td>66</td>
</tr>
<tr>
<td>Crack-Free Cutting of Ceramics</td>
<td>67</td>
</tr>
<tr>
<td>Cutting and Welding with the »Autonomous Nozzle«</td>
<td>68</td>
</tr>
<tr>
<td>Autogenous and Burnoff-Stabilized Laser Beam Oxygen Cutting with the Annular Diode Laser Beam Device</td>
<td>69</td>
</tr>
<tr>
<td>Manufacturing of Dental Prostheses by Laser Melting</td>
<td>70</td>
</tr>
<tr>
<td>Polishing of Fused Silica</td>
<td>71</td>
</tr>
<tr>
<td>Laser-Beam Polishing of Injection-Molded Tools</td>
<td>72</td>
</tr>
<tr>
<td>Laser Cladding of Titanium Base Alloys without Processing Gas Chamber</td>
<td>73</td>
</tr>
<tr>
<td>FEM Simulation of Laser Cladding</td>
<td>74</td>
</tr>
<tr>
<td>Modeling the Formation of Pores in Deep-Penetration Welding</td>
<td>75</td>
</tr>
<tr>
<td>Simulation of Material Transfer during Laser-Induced Ablation in Vacuum</td>
<td>76</td>
</tr>
<tr>
<td>Trepanning Simulation: The Effect of Beam Profile</td>
<td>77</td>
</tr>
<tr>
<td>Trepanning Simulation: Supersonic Gas Flow</td>
<td>78</td>
</tr>
</tbody>
</table>

**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.
Application of SHADOW® Technique for Welding of Copper Parts

Task

The welding of copper parts that are partly coated with an insulating varnish on the underside requires a joining technique that is able to guarantee the reliability to meet the requirements of the automotive industry for 100 to 300 joints per part. In automotive engineering, welding with Nd:YAG laser radiation is increasingly employed as a non-contact, reliable and low-maintenance joining technique and needs to be characterized for the above-mentioned joining task.

Method

The copper parts are designed for an overlap joint. When welding highly reflective copper materials, the SHADOW® technique presents crucial advantages over conventional laser beam welding techniques. A wide process window is provided by the low sensitivity against the dispersion of reflectance. Robust and reliable joints are the result. The weld depth thus remains constant, and the insulating varnish on the underside of the underlying part is not damaged.

A semi-automated manufacturing plant for low-scale production was designed and set up. It includes processing optics that were specifically designed and adapted for the required welding task. The processing optics sweep the laser beam across the part and are equipped with a vision system for position control and a process monitoring system for quality control.

Results and Applications

In-depth parameter studies served as the basis for the process that has been implemented by Rohwedder AG at the low-volume production line of Continental Temic. The plant has been producing electric machines for General Motors since late 2003. High-volume production is planned for 2007.

With courtesy Continental ISAD Electronic Systems GmbH & Co. oHG.

Contact

Dr. A. Olowinsky, Tel.: +49 1
alexander.olowinsky@ilt.fraunhofer.de
Dr. A. Gillner, Tel.: +48
arnold.gillner@ilt.fraunhofer.de
Application of SHADOW®-Technique in Watch Industry

Task

Nd:YAG laser radiation has recently become established as a joining technique in the manufacture of so-called balance wheels (French: balancier). Up to four set screws are inserted in the balance wheels. Afterwards the two parts are joined from one side of the wheel in a single spot weld. Wheel and set screw are both made of a copper-beryllium alloy, and the high degree of reflection that is typical of copper materials leads to a high variance of the weld quality. This results in a high rejection rate. To reduce manufacturing costs, the welding technique had to be fundamentally reviewed and modified. Obtaining a welding process that is more robust against variation of the degree of reflection ensures a reproducible weld depth.

Method

The SHADOW® technique is a proven method of joining highly reflective materials, on account of its continuous process management. Performing the weld as a circular seam, the laser beam turns several times during a single laser pulse. The quality of the weld is therefore independent of the starting point of the weld seam and the variation in the degree of reflection and can be maintained at a consistently high level. To apply seam welding on the balance wheel and the set screw, the weld is performed around the set screw on the contact surface of the wheel. FEM simulations have been run for process optimization with the aim of generating a roughly rotational-symmetric temperature distribution at the end of the laser pulse. When the part cools down after the end of the laser pulse, the compressive and tensile stresses are rotational-symmetric as well and the distortion is minimized.

Results and Applications

The laser beam is moved by a two-axis galvanometer-scanner. During the pulse duration of 6.5 ms, the laser beam turns nine times in a circle around the set screw. The circular weld seam increases the virtual weld width as compared to a single spot weld. Consequently a higher torque is required to destroy the weld. The robust continuous process management of the SHADOW® technique leads to a noticeable reduction in the rejection rate.

Contact

Dr. A. Olowinsky, Tel.: -491 alexander.olowinsky@ilt.fraunhofer.de
Dr. A. Gillner Tel.: -148 arnold.gillner@ilt.fraunhofer.de

Above: Balancier wheels welded by the SHADOW® technique
Middle: FEM simulation of temperature distribution at the end of the laser pulse
Below: FEM simulation of compressive and tensile stresses at the end of the laser pulse (distortion magnified by 100)
**Task**

The SHADOW® technique, developed at the Fraunhofer ILT, offers significant advantages for laser beam microwelding especially for rotation-symmetric parts.

To benefit from these advantages, the rotating optics have to fit certain requirements. In particular, in the case of a typical arbor-wheel joint, the laser radiation must revolve around the arbor from the outside. An angle of incidence of 45° has proven effective even for material combinations such as steel-brass. The revolution speed is up to 60,000 U/min and, depending on the diameter of the arbor, the feed rate is up to 150 m/min.

Nd:YAG lasers are employed as the beam source in almost all industrial manufacturing applications. The beam diameter in the focal plane must not exceed 70 µm to guarantee weld widths below 100 µm.

**Results and Applications**

Lead-managed by Lasag AG, the Fraunhofer ILT developed rotating optics to apply the SHADOW® technique to arbor-wheel joints. Thus, the laser beam turns up to ten times around the arbor within the typical processing time of 10 ms of a single laser pulse to generate a microweld. Specific fields of application include microengineering, electronics and automotive parts. Any rotation-symmetric welding task can be tackled quickly, precisely and reliably using the SHADOW® rotating optics.

**Contact**

Dr. A. Olowsky, Tel.: -491 alexander.olowsky@ilt.fraunhofer.de
Dr. A. Gillner, Tel.: -148 arnold.gillner@ilt.fraunhofer.de

**Method**

The rotating optics to be developed should comprise as few rotating parts as possible, to ensure high reliability and precision for the whole lifetime as well as to minimize the amount of maintenance. The optical setup should be easily adjustable, but nevertheless offer great flexibility with respect to the diameter of the processing geometry.

Moreover, the processing optics require a compact and handy mounting system that allows worn parts to be replaced easily.
Laser-Beam Microwelding of Stainless Steel to Copper Alloys

Task

Only very few applications have been optimized for laser beam microwelding with respect to accessibility and combination of materials. The design of the joint geometry is usually adapted to other manufacturing techniques such as crimping or resistance welding. The aim of the project was therefore to investigate and compare the laser-weldability of selected material combinations, in different T-joint geometries.

Method

The laser beam microwelding of stainless steel (X5CrNi1810) with copper (CuNi3SiMg) or brass (CuZn37) was examined in the T-joint configuration. The material thickness in each case was 250 µm. The arrangement within the joint was varied. Both fillet weld and overlap weld have been produced. Thus, altogether eight different T-joint configurations have been examined. In this application, SHADOW® was used as welding technique. Therefore, one single laser pulse of 20 ms length delivered by a fiber-guided Nd:YAG laser is used in combination with a high feed rate of 10 m/min. This leads to a weld seam of 3.3 mm length. The mechanical and aesthetic characteristics of the joints were analyzed, taking into account such factors as splashes and holes, as well as smoke development and cracking.

Results and Applications

The eight T-joint configurations could be separated into weldable and non-weldable joint configurations. In general, the weldability of stainless steel and copper is better than the combination of stainless steel and brass. Hot cracking only occurs in welds between stainless steel and copper if the temperature gradient is too high.

Using suitable processing parameters, the count of splatters could be minimized when welding stainless steel and brass. The splatters are caused by the fumigation of zinc in the brass material. This also leads to a degradation of the appearance and a reduction of the strength at stainless steel and brass joints.

Contact

Dipl.-Ing. K. Klages, Tel.: -490 kilian.klages@ilt.fraunhofer.de
Dr. A. Olowinsky, Tel.: -491 alexander.olowinsky@ilt.fraunhofer.de
Dr. A. Gillner, Tel.: -148 arnold.gillner@ilt.fraunhofer.de
Task

The increasingly demanding specifications to be met in the manufacture of small metallic parts for microengineering applications calls for new technologies capable of fulfilling higher requirements in terms of complexity and precision. Sheet metal working processes provide an economical solution, but are restricted with respect to the attainable degree of deformation. By locally heating the workpiece, the degree of deformation can be augmented.

The workpiece is heated by a laser beam which is guided through a transparent tool part directly onto the workpiece during the process. Short-pulse heating generates a temperature profile in the workpiece which shifts the drawing limit ratio up to higher values.

Method

The use of transparent tool materials such as sapphire or diamond allows the laser beam to heat the workpiece during the forming process. The laser beam is shaped to match the contours of the workpiece, allowing the temperature to be raised in areas of material flow and ensuring that areas of force application are kept cool so as to preserve tensile strength.

Fiber-coupled solid-state lasers or diode lasers are used, because this facilitates the integration of the laser beam optics in the material forming tool. The use of special optics allows the laser beam shape to be adapted to the areas of the workpiece which need to be heated. The advantage of in-process heating is that the heating phase is very short, allowing the process to be implemented in mass production with very short cycle times.

Results and Applications

The process of laser-assisted sheet metal working was realized on the basis of a deep drawing process of a rotation-symmetrical cup. A drawing matrix made of sapphire allows the collar area to be heated by means of a circular laser beam. A drawing punch of 4-mm diameter was used to draw a steel sheet of 1.4301 with a thickness of 150 µm in the first draw without and with heating by 150 J laser pulse energy. The drawing limit ratio $\beta$ could be increased by 15% from 2.0 to 2.3 by heating. Rising drawing forces can be reduced by nearly 40%, depending on the applied heat energy.

Possible applications are envisaged particularly in the production of small metallic parts, where shaping is required in the first draw without intermittent heat treatment in order to meet the requirements of mass production.

Contact

Dipl.-Ing. A. Bayer, Tel.: -273 alexander.bayer@ilt.fraunhofer.de
Dr. A. Gillner, Tel.: -148 arnold.gillner@ilt.fraunhofer.de
Task
The cost-efficient mass production of microparts with part geometries < 100 µm requires the use of replication processes such as injection-molding and die-casting. In many cases, the higher demands on the tool manufacturing process cannot be met by conventional machining technologies.

Laser ablation overcomes these limitations to some extent, but existing laser ablation systems present deficiencies in terms of contour accuracy and surface quality.

Method
To manufacture a 3D mold, the pulsed laser beam is guided over the molding blank line by line. At each pulse, a volume of about 20 µm in diameter and 2 µm in depth is removed by a combined sublimation and melting process. The relation between these two ablating-processes is determined by the pulse duration and affects the quality and efficiency of the manufacturing process. In experiments with laser beam sources of different pulse duration and characteristics in combination with several materials like steel, copper, PCD and graphite, we were able to determine the specific requirements with which the lasers have to comply in terms of beam quality, stability, wavelength and pulse duration.

Results and Applications
Positive results were achieved in tool steel with a Q-switched Nd:YAG laser source of very high beam quality and a pulse duration of 200 ns. Experiments have shown that it is possible to achieve higher quality with shorter pulses, but with an accompanying loss of ablation efficiency.

Materials like PCD or sapphire can be machined in good quality with UV lasers (355 nm) at shorter pulses of about 40 ns.

Contact
Dipl.-Ing. A. Dohrn, Tel.: -220
andreas.dohrn@ilt.fraunhofer.de
Dr. A. Gillner, Tel.: -148
arnold.gillner@ilt.fraunhofer.de
Microstructuring of Polymer Surfaces

Task

The surface composition of polymers is of vital importance when used in contact with biological systems. This is of relevance to applications in medical technology and biotechnology.

Especially for cell-based assays (e.g. biochips) and components designed to support cell growth (e.g. implants), tailoring of surface properties is crucial. Our investigations therefore focused on topographical and chemical changes after laser microstructuring and their influence on wetting properties and cell adhesion.

Method

Excimer laser radiation is absorbed very well by most polymers. Using an ArF laser, we created four different surface topographies: wells, pillars, ripples and scales with geometries varying from 250 nm to 50 µm. These microstructures were topographically characterized by WIM and REM and chemical changes in the surface composition were detected by XPS. The effect of laser treatment on the wetting properties was examined by water contact angle measurement. Seeding of L929 cells on these polymer surfaces was used to show the influence of topographic and chemical changes on cell adhesion and growth.

Results and Applications

The laser-generated microstructures had a marked effect on wetting properties. Hydrophobic surfaces such as polydimethyl siloxane (PDMS) become super hydrophobic, whereas polymers with aromatic groups and/or polar functional groups such as polyetheretherketone (PEEK) become strongly hydrophilic. The water contact angle of PDMS for example can be increased from 110° to approx. 150° so that the surface exhibits the so-called lotus effect. PEEK shows an »anti«-lotus effect with a drop of contact angle from approx. 70° below 5° that is fully wettable. The increased roughness of the surfaces is crucial for contact angle change because the surface area is enhanced. On the other hand, it gives rise to chemical reactions such as cross-linking and photo-oxidation which also affect surface properties. Both effects are active on laser-treated surfaces. The nature of the polymer determines whether their consequences amplify or attenuate each other.

The laser-generated micro patterns reveal influence on cells. The cell density on laser treated areas is enhanced due to the increased roughness. There is also a noticeable effect on cell distribution, which can be utilized to guide cells along laser-generated microstructures such as grooves or pillars.

Contact

Dipl.-Chem. E. Bremus-Köbberling,
Tel.: -202
elke.bremus@ilt.fraunhofer.de
Dr. A. Gillner, Tel.: -148
arnold.gillner@ilt.fraunhofer.de
Laser-Beam Welding of Thermoplastic Medical Products

Task

Colostomy bags are disposable medical products which are made up of different components. Mechanical coupling may cause discomfort due to rigid rings and extensive mounting aids. When an adhesive ring is welded to a colostomy bag, the plastic materials are heated using a hot tool, which joins the parts under mechanical pressure. Therefore, this method places restrictions on the shape and size of colostomy bags.

Method

The manufacture of colostomy bags involves joining injection-molded parts and thin films. The alternative to conventional joining techniques is laser-beam welding as a non-contact welding technique offering defined energy input in space and time while avoiding mechanical or thermal load on the components to be joined. Crucial aspects are the optical properties of the joined components which have to be adapted to both the product and the joining process in terms of the appropriate choice of dyes, additives and the manufacturing process.

Results and Applications

Systematic and basic investigations have been performed, such as spectroscopy to determine the optical properties, welding experiments and tensile testing to discover the optimal pre-processing of the joined components. The results of these experiments were used to determine the optimum materials and laser processing parameters. Furthermore, laser welding gives the designers more scope to optimize the shape and design of colostomy bags to specific applications. The laser tool may, for instance, weld two middle layers without welding other layers in the process. The laser beam passes through most plastics unimpeded, to stop only when a layer contains color pigment. The pigment absorbs the energy from the laser beam and the material is welded. Experimental research and product-to-process adaptation has led to industrial implementation of a laser welding plant.

With courtesy Coloplast A/S, Humlebaek, Denmark

Contact

Dipl.-Phys., Dipl.-Ing. U.-A. Russek, Tel.: -158
ulrich.russek@ilt.fraunhofer.de
Dr. A. Gillner Tel.: -148
arnold.gillner@ilt.fraunhofer.de
Task

Microsurgery of middle-ear structures demands minute attention to the risk of traumatizing surrounding tissue, in order to preserve hearing and avoid damage to the vestibular organ and the facial nerve. Especially when auditory ossicles have to be replaced by implants (e.g. in otosclerosis), the stapes footplate has to be fenestrated. This requires precise perforation of the footplate which is best accomplished by a non-contact technique. Thus, various types of laser such as Nd:YAG-, argon, KTP, holmium-YAG and erbium-YAG have been used in-vitro and in-vivo, but none of the present systems allows for optimum treatment in middle-ear applications.

In particular, concerns have been raised regarding the thermal load to the perilymphe when argon, KTP or CO₂ lasers are used. On the other hand, Er:YAG lasers cause few thermal effects but create pressure transients which could result in acoustic trauma. Thus, the dilemma between thermal load and mechanical stress remains yet unsolved.

Method

Short pulses of low energy are expected to deliver minute amounts of heat and to induce very weak acoustic pressure waves. Therefore we used a nano-second-pulsed, frequency-tripled Nd:YAG laser operating at 355 nm wavelength with spot sizes < 100 µm and pulse energies < 0.5 mJ. In-vitro tests were performed on ossicles (malleus) in cooperation with the Ear, Nose and Throat Department of the University Clinic in Aachen.

Results and Applications

Initial results showed the feasibility of the laser process when rapid scanning is applied. The ablation sites show no serious thermal effects and carbonization of tissue can be avoided when the irradiation site is kept wet. Since the applied pulse energy is reduced by a factor of about 100 compared to Er:YAG laser treatment, acoustic trauma should be ruled out.

In Cooperation with Dr. Illgner, Ear, Nose, and Throat Department of the University Clinic in Aachen.

Contact

Dr. M. Wehner, Tel.: -202
martin.wehner@ilt.fraunhofer.de
Dr. A. Gillner, Tel.: -148
arnold.gillner@ilt.fraunhofer.de
Excimer-Laser Structuring of Bioactive Thin Films

Task

Biotechnological and pharmaceutical applications require platforms for high-throughput screening of protein-protein interactions.

This generally involves structuring a thin film of a bioactive substance, such as biotin, on an approximately 70-nm-thick substrate, in such a way that individual proteins can be immobilized at defined positions on the biochip. The required size of the individual features, e.g. round spots, is in the order of just a few nanometers up to micrometers.

Method

An excimer laser ablation technique was used to structure the biochips. We selected two different wavelengths: 248 nm produced by a KrF excimer laser and 193 nm produced by an ArF excimer laser. The energy density needed to generate the structures illustrated here by means of a single laser pulse amounted to 1.5 and 0.7 J/cm² respectively at the site of the probe.

Results and Applications

Figure 1 shows a biotin structure on a quartz glass substrate. The raised features have a diameter of 30 µm. The ability to detect protein binding activity on this biotin film was proven by fluorescence analysis (see Figure 2). Phycoerythrin was used as the fluorescent dye. For a bioactive layer of biotin structured by mask projection, the resolution limit lies at around 3 µm (see Figure 3).

Contact

Dipl.-Phys. S. Beckemper, Tel.: -325 stefan.beckemper@ilt.fraunhofer.de
Dr. A. Gillner, Tel.: -148 arnold.gillner@ilt.fraunhofer.de

Above: 30-µm structure on a biotin-coated glass substrate
Middle: 30-µm nub structure seen under a fluorescence microscope
Below: Structure generated in biotin by an excimer laser through mask projection
Task

Microreaction technology uses miniaturized microfluidic components (e.g. mixers, reactors, heat exchangers) with volumes in the microliter range for chemical conversions. Advantages of microreaction technology are safer handling, increased heat and mass transfer, defined reaction pathways and higher product selectivity. Despite these emerging areas of application, there is currently a highly insufficient availability and utilizability of microreaction components. The Fraunhofer Network for Modular Microreaction Systems consists of six Fraunhofer Institutes working together on a modular and software-supported microreaction system. The microreaction components are to be manufactured in appropriate quantities and made available to industrial users for the investigation, evaluation and design of new chemical reactions.

Method

The realization of microfluidic structures in a wide variety of materials (stainless steel, glass, ceramics, PC, PTFE) by laser ablation and laser packaging, starting from 3D CAD models, allows for a fast and flexible production of microreaction components. To make the components impervious to fluids and gas-tight, a laser welding technique is used that is specially developed at the ILT for such applications.

Results and Applications

The layout and fabrication of microfluidic units composed of polycarbonate, alumina, glass and Teflon is carried out with laser processing systems available at the Fraunhofer Institute for Laser Technology ILT. The processing of stainless steel is carried out with Nd:YAG laser radiation, the processing of ceramics (Al₂O₃) with frequency-tripled Nd:YAG-lasers, the processing of glass and Teflon with F₂ laser radiation at 157 nm and other polymers are processed using excimer lasers. The accurate tailoring of porous ceramic foams for use in microreactors with tolerances of ± 50 microns is carried out using a Nd:YAG laser as well. The processing time for ceramic components could be reduced by structuring ceramic green components (8 h → 30 min). The processed components were subsequently sintered and showed reduced surface roughness. The joining of polymeric parts using a mask technique leads to weld seams with minimal dimensions of less than 100 microns. The employed chrome fused silica mask can be aligned to the component with an accuracy of better than 50 microns using the welding systems available at the ILT.

Further information in the Internet: www.mikroreaktionstechnik.info.

Contact

Dipl.-Chem. E. Bremus-Köbberling
Tel.: -202
elke.bremus@ilt.fraunhofer.de

Dipl.-Chem. P. Jacobs, Tel.: -135
philipp.jacobs@ilt.fraunhofer.de

Dr. A. Gillner, Tel.: -148
arnold.gillner@ilt.fraunhofer.de
Task

Connecting of small vessels (anastomosis) is a laborious task in vascular surgery. Tubular structures are usually joined by sutures and in the case of small vessels magnifying glasses or microscopes are used by the surgeon. For example, re-anastomosis of sperm duct will require up to 20 stitches which could take up to two hours operation time, even for a skilled person.

To overcome this difficulty, a laser technique for suture-less joining of small vessels was investigated in cooperation with experts from medical science, materials science and laser technology. The high initial strength of suturing (defining the «gold standard») has to be met but easier handling and therefore reduced operation time has to be obtained.

Method

The experimental procedure has been investigated on the sperm ducts of rats. Essential for high initial strength and low leakage is the perfect apposition of the adjoining ends of the vessel. Therefore a small, bioresorbable stent (tubing) made of poly(lactid-co-glycolid) (PLGA) is inserted. After it has been attached, a drop of albumin solder is applied and subsequently polymerized by laser radiation. The laser radiation is used as a locally and temporarily exactly controlled heat source which solidifies the protein solder but exerts minimum thermal load on the surrounding tissue.

Results and Applications

In the framework of the project »Microsurgical anastomosis by laser tissue fusion soldering«, the preparation of stents, the consistency and doping of solder, a prototype instrument and the irradiation conditions were worked out. The tensile strength measured in-vitro was revealed to be as high as in the case of sutures, but the time taken to perform anastomosis was substantially less. The extension of this technique to blood vessels and its use in general surgery will represent a significant advancement in surgical operation techniques.

In Cooperation with Dr. Brkovic, Urological Clinic of the University Clinic in Aachen, and funded by the Aachen Competence Centre for Medical Technology AKM.

Contact

Dr. M. Wehner, Tel.: -202
martin.wehner@ilt.fraunhofer.de
Dr. A. Gillner, Tel.: -148
arnold.gillner@ilt.fraunhofer.de

Above: The two ends of a vessel attached to a stent
Below: Laser anastomosis of the sperm duct of a rat
Welding with Trapezoidal High-Power Diode Laser

**Task**

As part of the BMBF lead project »Modular Diode Laser Systems«, the Fraunhofer ILT sub-project »Joining Light Gage Sheet Metal« dealt with the system and process engineering principles fundamental to heat conduction welding and deep penetration welding by means of diode lasers. Investigations covered conventional system configurations with compact beam spots as well as diode laser tools involving special beam geometries (ring, line) that were built at the ILT. The purpose is to enable new, particularly efficient welding applications both with and without relative motion between the laser and workpiece.

**Method**

Inter alia a Rofin Dilas high-power diode laser (HPDL) of the latest generation that utilizes novel so-called trapezoidal diodes to generate laser radiation has been applied for welding tasks. This device for the first time provided a diode laser beam that is comparable to present commercially available solid-state lasers with respect to power density and focal spot dimensions. The HPDL provides laser power of 3 kW and can be applied directly as well as in fiber-coupled mode with a maximum power output at the workpiece of 2.1 kW and 2.8 kW, respectively.

**Results and Applications**

When applied directly, the boundary feeding rates for 2-mm thick mild steel and stainless steel sheets could be increased to 3.9 m/min and 4.4 m/min respectively. These welding speeds are about three times higher than the speeds achieved with a 3 years older HPDL model.

Fully penetrating welds at butt joints in stainless steel could be realized up to 20 m/min at 0.5 mm thick sheets and with 10 m/min at a thickness of 1 mm. 1 mm thick AlMg3 aluminum alloy sheets were welded with 8 m/min at butt joints and with 5 m/min at overlap fillet welds.

Fully penetrating butt joints in 5 mm and 6 mm thick stainless steel sheets were achieved at 0.5 m/min and 0.25 m/min, respectively. The aspect ratio (ratio of depth to width of weld) of these welds is about 2.

**Contact**

Dipl.-Ing. C. Benter, Tel.: -219 christian.benter@ilt.fraunhofer.de
Dr. Dirk Petring, Tel.: -210 dirk.petting@ilt.fraunhofer.de

Graph: Boundary feeding rates (BFR) of 2-mm thick stainless steel for HPDLs at different stages of development

Butt joints on stainless steel
**Above:** 0.5 mm: 20 m/min
**Middle:** 1 mm: 10 m/min
**Below:** 5 mm: 0.5 m/min
Optimization of Welding Result by Customization of Shielding Gas Guidance

**Task**

In laser welding, shielding gases are commonly fed to the welding zone to stabilize the welding process, to increase welding depth and to protect the weld seam against oxidization. Besides the type of shielding gas used, such as argon, helium or »custom-made welding gas mixtures« with proportions of active gases, the nozzle parameters play an essential role. Shielding gas guidance can be customized by adjusting the nozzle’s orientation (trailing or leading) and the gas flow’s impingement point (ahead of, central to or after the laser spot) and can thus be optimized according to the desired welding result.

**Method**

Welding tests on 6-mm thick stainless steel were performed with a fiber-coupled high-power diode laser of the latest generation that provides a maximum power of 2 kW at the workpiece. Nozzle parameters were varied at a constant welding speed of 150 mm/min and a constant shielding gas flow (argon) of 60 l/min. The shielding gas was directed to the welding zone by a tubular nozzle with an internal diameter of 8 mm.

Welding depths and aspect ratios of the seam’s cross-section as well as the metallic brightness and smoothness of the weld bead were assessed.

**Results and Applications**

The influence of the gas foot point’s alignment becomes eminently clear with a leading gas nozzle setup. When the gas foot point runs 2 mm after the laser spot, the weld does not penetrate the sheet and its cross-section is defined by a cup-shaped geometry. The wide, shiny and smoothly scaled weld seam gives evidence of the good protective effect of the gas flow.

When the gas foot point is moved away another 2 mm from the laser spot, deep penetration welding is initiated in this setup. A decidedly narrower, fully penetrating weld with parallel flanks and a dead, oxidized weld seam is the result. By adjusting the shielding gas guidance the result of diode laser welding applications can be directly influenced. The impact might even be more distinctive as in solid state or CO₂ laser welding.

**Contact**

Dipl.-Ing. C. Benter, Tel.: -219 christian.benter@ilt.fraunhofer.de
Dr. D. Petring, Tel.: -210 dirk.petring@ilt.fraunhofer.de

Above: Gas foot point of a leading gas nozzle follows the laser spot at a distance of 2 mm
Below: Gas foot point of a leading gas nozzle follows the laser spot at a distance of 4 mm
Customized Hybrid Welding Heads for Industrial Application

**Task**

Regardless of whether you want to benefit from laser-arc hybrid welding with an Nd:YAG or a CO₂ laser, the modular performance of the hybrid welding heads developed by the Fraunhofer ILT provides an appropriate solution for each laser system. The patented key component is the »Integrated Nozzle«, which combines laser and arc. Solutions for various fields of application have been developed on the basis of a standard hybrid head which has been in industrial use since the year 2000.

**Method**

To meet industrial demands for increased durability on the one hand and better accessibility for 3-dimensional applications on the other hand, three different hybrid welding heads have been developed, all based on the patented »Integrated Nozzle«. Only this configuration permits a steep inclination of the arc process at the nearest possible approach to the laser beam. The variable distance between the two processes enables the most efficient utilization of synergy effects, which can be directly translated into welding speed and penetration depth. The coaxial flow of process gas out of the water-cooled nozzle ensures a homogeneous stream to the welding zone and thus a maximum of quality. All hybrid heads are equipped with a newly developed integrated cross-jet.

**Results and Applications**

Customized to the welding application, the hybrid heads are combined from the existing program and adapted for special requirements if necessary. The presented hybrid solutions are suitable for laser-MIG and laser-TIG welding as well as for laser-MIG brazing.

**Contact**

Dipl.-Ing. C. Fuhrmann, Tel.: -221
carsten.fuhrmann@ilt.fraunhofer.de
Dr. D. Petring, Tel.: -210
dirk.petting@ilt.fraunhofer.de

Above: Heavy duty version
- Very robust design
- Best durability
- Industry-tested

Below: Superslim version
- Best accessibility
- Short focal length possible
- Good durability
- Light weight
- Particularly suitable for 3D
HybSy – The Next Generation of Laser-Arc Hybrid Welding

Task

The synchronization of the pulsed arc process with a modulated laser beam constitutes another milestone in the development of laser-arc hybrid welding. The new technology promises an improvement of the whole process with regard to its stability and efficiency. The two processes are combined with a programmable synchronization unit to form a so-called HybSy process.

Results and Applications

The series of preliminary tests conducted so far already show promising results. In comparison to non-modulated hybrid welding, an increase of 40% of the welding depth could be achieved when a synchronously modulated MAG-laser-process was applied. Future basic and application-oriented investigations will be conducted to further tap the potential of the Hybsy technology.

Method

To obtain an adequate synchronization of the modulated laser with the arc process, the synchronization unit (HybSy Manager) is supplied with a master pulse from the welding source. The synchronization unit is freely programmable and allows all of the parameters necessary for the control of the laser for the pulse shaping to be set individually. For example, the laser (driven as »slave«) is modulated synchronously or asynchronously to the pulse of the arc source. The various pulse and synchronization parameters offer a wide spectrum of possibilities to influence the type and degree of laser and arc coupling in the welding zone.

Contact

Dipl.-Ing. C. Fuhrmann, Tel.: -221 christian.fuhrmann@ilt.fraunhofer.de
Dr. D. Petring, Tel.: -210 dirk.petring@ilt.fraunhofer.de

Example:
Asynchronous phase relation between laser beam and MAG-arc
Task

As part of its involvement in global climate research programs, the GeoforschungsZentrum Potsdam (Potsdam center for geological research) analyzes sediment profiles taken from drill cores up to 100 meters long. Samples are taken from these drill cores using a screw extractor.

The stainless-steel sides of the body of the extractor, until now fastened with screws, are instead to be welded by an Nd:YAG laser beam. The task demands a parallel, planar and distortion-free joining of the metal. In addition, a fine, non-elevated welding seam is required and only a small heat-affected zone is allowed near the seam. An I-seam at the butt joint is used.

Method

Welding was accomplished with a diode-pumped Nd:YAG laser with enhanced beam quality (12 mm mrad). Stainless steel sheets with a thickness of 0.2 mm were used. The decisive factor was optimizing the weld seam by adjusting the focusing parameters.

Results and Applications

The joint was welded at a feed rate of 6 meters per minute and with an output of 0.7 kW and met all specifications.

Using the new device with welded sides, the GZF succeeded in extracting scientifically reliable samples from the drill cores. The new extractor is currently being used to examine sediment profiles from the Huguangyan maar lake in northeastern China. This allows research into climatic conditions reaching back as far as 40,000 years.

Contact

V. Nazery Goneghany, Tel.: -159 vahid.nazery@ilt.fraunhofer.de
Dr. D. Petring, Tel.: -210 dirk.petring@ilt.fraunhofer.de
Task

The GKN company uses laser welding to manufacture power train components out of high-carbon steel. To reduce arising expenses (manufacturing costs per shaft), all process gas parameters are put to test.

The robust laser welding process currently used for production must not be negatively influenced by application of a different process gas guidance, i.e. welded joints have to at least comply with the presently valid quality standards.

Method

Preliminary test series using various process gases have been conducted with a CO₂ laser to assess plasma formation, weld seam quality at different laser powers, alignment of the gas nozzle and gas flow volumes. The welds’ microstructures and hardness have been metallographically analyzed and X-ray and WDX analyses have been carried out on planar specimen sheets as well as on axial and radial circular seams. At the premises of industrial partner GKN, actual components have been welded with the appraised parameters to assess the achievable product quality. The components were subject to product-specific tests such as dynamic endurance testing to evaluate the components’ durability.

Results and Applications

Significant reductions in manufacturing costs without forfeiting quality aspects could be achieved by changing over to a different process gas. This result was reinforced by product-specific verification of the operational stability of the welds. Additionally, improved measures in process gas guidance have been developed to further increase the weld quality and process efficiency. These measures allowed manufacturing of welds of the same quality as in the original setup. The welding suitability and stability of the process could be proven through product-specific analyses. Thus it is possible to reduce manufacturing costs by significantly cutting the process gas costs.

This research was conducted as part of a project with GKN Driveline International GmbH, Lohmar.

Contact

Dipl.-Ing. N. Wolf, Tel.: -448 norbert.wolf@ilt.fraunhofer.de
Dr. D. Petring, Tel.: -210 dirk.petrings@ilt.fraunhofer.de
Welding of High-Strength Stainless Steel in the Construction of Railway Vehicles

Task

As in the automotive sector, high-strength stainless steels are increasingly used in the construction of rail vehicles. In order to use these steels for structural parts in rail vehicle construction, a laser welding process that allows for precision assembly and low distortion was to be optimized and qualified. The semi-finished parts that have to be joined are pre-fabricated through laser cutting.

Method

To qualify the laser welding process on high-strength stainless steel H400 with sheet thickness between 1.5 mm and 10 mm, l-seams at butt joints and corner joints as well as fully penetrating fillet welds at T-joints and cross joints have been generated. The welds were performed without filler material and were tested regarding tensile strength and fatigue. To assess the feasibility of a manufacturing procedure that allows for precision assembly, i.e. accurate manufacturing of vehicle components low on distortion, sample parts as well as the mock-up of the complex front section of a rail vehicle (dimensions 4490 x 2665 x 337 mm) were welded with a CO₂ laser.

Results and Applications

No increased hardness was found in the seam sections of the test welds. Together with a transition geometry that is low on notch effects, this proves the good ductility and fatigue strength of the welds. Results of the dynamic endurance tests show the excellent load capacity of the laser welds. Crash tests impressively confirm the good deformation capacity of the base material and the laser welded joints.

This research was conducted as part of the eSIE.CAR project, lead managed by Siemens AG Transportation Systems, business unit Trains (TS TR), and funded by the BMBF and Forschungsvereinigung Stahlanwendung e.V.

Contact

Dipl.-Ing. N. Wolf, Tel.: -448 norbert.wolf@ilt.fraunhofer.de
Dr. D. Petring, Tel.: -210 dirk.petring@ilt.fraunhofer.de
Cutting with an 8-kW Diode-Pumped Solid-State Laser

**Task**

New diode-pumped solid state lasers and fiber lasers reach output powers in the range of 10 kW. Although the primary use of these lasers is in welding applications, their flexible and combined use is of interest to cutting applications. Appropriate cutting processes have to be qualified. Up to now, hardly any experience exists for this high power range. Suitable process parameters should be found in cutting tests with a 8 kW system (Rofin DY 088 HP). The system components have to be qualified for the high laser power.

**Method**

The focal lengths of the collimation and focusing optics are 200 mm, used with a fiber of 600 µm diameter. 7.2 kW laser power at the workpiece was used. The sheet thickness was between 4 and 10 mm. For fusion cutting in stainless steel, the cutting speed, focal position, gas pressure and nozzle diameter were varied.

**Results and Applications**

The maximum speed was 2.5 m/min for oxide-free cuts in 10-mm-thick sheets. To reach similar speeds with CO₂ lasers, in spite of the better beam quality, at least 20 % more power and the use of mirror optics would be necessary.

The work will be continued with oxygen cutting of mild steel and a wider range of material thicknesses under adapted focusing conditions.

**Contact**

Dipl.-Ing. F. Schneider, Tel.: -426  
frank.schneider@ilt.fraunhofer.de  
Dr. D. Petring, Tel.: -210  
dirk.petr@ilt.fraunhofer.de
Welding with an 8-kW Diode-Pumped Solid-State Laser

Task

The advance of the new diode-pumped solid-state laser into the high power range, which was formerly the exclusive reserve of the CO₂ laser, also widens the range of possible applications for this type of laser. The new lasers feature high power at simultaneous good beam quality. The essential advantage of the solid-state laser is the ability to deliver the laser beam to the workplace over an ordinary fiber. Thus the complexity for welding thick plated, three-dimensional components is significantly reduced since technically demanding and expensive mirror beam guiding optics can be dispensed with.

Method

Welding experiments were carried out with a diode-pumped Nd:YAG laser from ROFIN-SINAR labeled DY 080 HP. The laser power at the workpiece was 7.2 kW. Collimation and focusing lenses with focal lengths of 200 mm each and a fiber with a core diameter of 600 µm were employed.

Results and Applications

The welding tests were performed on 6-mm to 10-mm thick stainless steel and mild steel plates. Typically achieved welding speeds were 1.2 m/min for 10-mm and 3 m/min for 6-mm mild steel. To reach these figures, one of the main tasks was to suppress the emerging vapor plume of the process by means of new, effective nozzle concepts. Conventional tubular nozzles are only able to suppress the vapor plume at the cost of accepting a negative influence on the melt pool.

Further investigations will be carried out to study the formation and suppression respectively of the vapor plume, to enable utilization of the full potential of the diode-pumped Nd:YAG lasers.

Contact

Dipl.-Ing. C. Fuhrmann, Tel.: -221 christian.fuhrmann@ilt.fraunhofer.de
Dr. D. Petring, Tel.: -210 dirk.petring@ilt.fraunhofer.de

First result of a bead on plate welding of 10-mm mild steel at 7.2 kW laser power and a welding speed of v_s = 1.2 m/min
Crack-Free Cutting of Ceramics

Task

The conventional technique for cutting ceramics is comparable to the processing of glass. Scribing followed by controlled breaking allows the parts to be separated along a straight line or a wide-radius curve. The established method for contoured cuts is water-jet cutting.

The thermal processing of ceramics by laser radiation runs the risk of crack formation due to high temperature gradients during the cutting process. If a critical crack growth is reached, it can result in partial or total destruction of the workpiece.

The goal of the investigations, which focused on quality aspects, were low roughness of the cut edge, no dross and in particular crack-free edges.

Method

The experiments were carried out on aluminum-oxide ceramics. The laser source was a CO₂ laser with high beam quality (K = 0.9) and 2500 W maximum pulse power. Various types of cutting gas were used.

Results and Applications

Clean and crack-free cut edges were obtained in the treated material thickness range of up to 5 mm. The cutting speed was 40 mm/min with the laser in pulse mode. This exceeds the speeds in water-jet cutting, but is still relatively slow. The use of a higher average laser power with optimized pulse parameters seems possible and thus higher differences in speed between laser and water-jet cutting are expected for the future.

Contact

Dipl.-Ing. F. Schneider, Tel.: -426
frank.schneider@ilt.fraunhofer.de
Dr. D. Petring, Tel.: -210
dirk.petring@ilt.fraunhofer.de
Cutting and Welding with the »Autonomous Nozzle«

Task

Mirror optics are generally used for welding with CO₂ lasers. The two essential reasons are the higher thermal and mechanical robustness of mirror optics compared to lens optics and the possibility of applying high laser powers.

In laser cutting, mirror optics are used only for special applications at laser powers above 4 kW. With standard nozzles the pressure chamber in the cutting head is sealed towards the beam guidance by the lens to build up the cutting gas pressure. Open mirror optics require pressure to be built up inside the gas nozzle. The »Autonomous Nozzle«, developed at the ILT, solves the problem. It allows the use of mirror optics also for cutting and has been established in industry for 10 years.

So mirror optics can be used for both cutting and welding. Goal of this investigation is to study the possibility of cutting and welding alternately with one processing head without retooling.

Method

Reference experiments were carried out with stainless steel 1.4301 in 6 mm thickness and a 12-kW CO₂ laser. This laser has a beam quality of K = 0.22 and is therefore more suitable for welding than for cutting applications. The sheets were processed with a mirror optic with an F-number of 10 and 5 kW laser power. The key component of the processing head is the »Autonomous Nozzle«. The process gas for cutting was nitrogen, for welding helium.

Results and Applications

The sheets were cut oxide-free in good quality at a cutting speed of 1.7 m/min.

Subsequently, the laser-cut sheets were welded in a butt joint and a corner joint simply by modifying the NC parameters, such as the settings for focal position, type of gas, gas flow rate, and a slight adaptation of the speed. Thus laser cutting and welding applications are feasible in one machine without changing the processing head.

Contact

Dipl.-Ing. F. Schneider, Tel.: -426
frank.schneider@ilt.fraunhofer.de
Dipl.-Ing. N. Wolf, Tel.: -448
norbert.wolf@ilt.fraunhofer.de
Dr. D. Petring, Tel.: -210
dirk.petring@ilt.fraunhofer.de
Task

As part of the BMBF-funded project »Modular Diode Laser Systems (MDS)«, a diode laser device that generates an annular focus with a median diameter of 5 mm and a width of about 1 mm has been developed at the Fraunhofer ILT. The modular design of the diode lasers enabled a construction featuring a central passage aperture. This assembly is ideally suited for autogenous cutting with the annular beam only and burnoff-stabilised laser beam oxygen cutting with an additional central CO₂ laser beam.

Method

During oxygen cutting the central passage aperture of the diode laser device is used to feed oxygen towards the cutting process via a Laval nozzle. The material surrounding the nozzle is heated to ignition temperature by the annular laser beam. To enhance the speed of the autogenous cutting process, an additional CO₂ laser beam was directed through the central passage aperture and the cutting nozzle.

Results

Using a diode laser power of 700 W, autogenous oxygen cuts in 10-, 20- and 30-mm thick mild steel plates could be accomplished with a speed of 0.4 to 0.75 m/min. Compared to the autogenous process, the additional application of central CO₂ laser radiation with a power of 4.7 kW at the workpiece allows for 50 % higher cutting speeds in 30-mm thick mild steel plates. Thereby the annular diode laser beam acts as a process-stabilizing module that enables a steadier-going burn-up and hence smoother cutting edges (RZ<40 mm) than laser-beam oxygen cutting with the CO₂ laser only. The cutting kerf widths and heat affected zones (HAZ) that are achieved during burnoff-stabilised laser-beam oxygen cutting are narrower than for autogenous oxygen cutting.

Besides oxygen cutting, the annular diode laser beam device allows for numerous applications in the field of welding technology, for example overlap spot welding, welding of annular seams and dual-laser hybrid welding.

Contact

Dipl.-Phys. B. Seme, Tel.: -426
bernd.seme@ilt.fraunhofer.de
Dr. D. Petring, Tel.: -210
dirk.petrting@ilt.fraunhofer.de

Above: Autogenous cutting of a 10-mm thick mild steel plate with the annular diode laser beam device
Below: Burnoff-stabilized laser-beam oxygen cut in mild steel St52-3
diode laser power: 700 W
CO₂ laser power: 4700 W
cutting speed: 0.65 m/min
Task

Laser melting has been developed as a new manufacturing process for the generation of metal parts with a complex shape. The parts are built up in layers by melting a powder material with laser radiation.

In cooperation with Bego Medical AG, the laser melting process had to be enhanced in order to enable the direct manufacturing of dental prostheses (crowns, bridges) out of the materials CoCr dental alloy, titanium and gold.

Results and Applications

The laser melting process has been qualified for the direct manufacturing of dental prostheses out of CoCr dental alloy, titanium and gold. Density, dimensional accuracy, mechanical properties and biocompatibility correspond to cast (conventional manufacturing technique) parts. Project partner Bego Medical AG has implemented a process chain for the automated manufacture of dental prostheses on the basis of the ILT prototype plant. For the first time a rapid manufacturing process is being applied to customized mass production in industrial practice.

Contact

Dr. W. Meiners, Tel.: -301
wilhelm.meiners@ilt.fraunhofer.de

Dr. K. Wissenbach, Tel.: -147
konrad.wissenbach@ilt.fraunhofer.de
Polishing of Fused Silica

Task

Due to its outstanding optical, mechanical and chemical properties, fused silica is used in many applications in industry and research. For example all reactors for high-temperature processes in mass production of semiconductors are made out of fused silica. State-of-the-art is to polish ground surfaces and edges by manual flame polishing. Roughnesses of $R_a < 50$ nm and feed rates of 1 cm$^2$/s can be reached.

Laser polishing is being investigated as a possible means of automating the manual process and improving the quality of the polished surfaces. The aim is to find out whether laser polishing is a viable alternative to flame polishing in terms of quality and costs.

Method

Because of the strong absorptivity, CO$_2$-laser radiation is suited for the polishing of fused silica. The thermal energy melts a very thin surface layer that flows under the action of surface tension. Surface imperfections that remain after grinding are smoothed and micro cracks are closed by the remelting process.

Preheating reduces the generation of thermal stresses and therefore the generation of cracks. Process disturbances like non-uniform temperatures of the workpiece due to non-uniform heat conduction or heating up of the workpiece can be compensated for by closed-loop temperature control of the laser power.

Results and Applications

Laser polishing of fused silica has been demonstrated and the basics of the process were investigated. From an initial surface roughness of $R_a = 150$ nm, a final surface roughness of $R_a < 10$ nm can be achieved. Flat parts as well as edges and axially symmetrical parts can be polished.

Possible applications for the polishing of fused silica by laser radiation are parts for the chemical and the semiconductor industries as well as micro and aspherical optics.

Contact

Dipl.-Ing. E. Willenborg, Tel.: -213 edgar.willenborg@ilt.fraunhofer.de
Dr. K. Wissenbach, Tel.: -147 konrad.wissenbach@ilt.fraunhofer.de

Above: Laser-beam polishing of fused silica
Below: Grinded component
The machine-tool industry has urgent need of automated processes for the polishing of complex 3D metal surfaces. At present, it is not possible to automate the polishing process for many tools and molds, which therefore have to be polished manually. Typical processing times for manual polishing lie in the region of 10 - 30 min/cm².

Our objective was to test a laser-beam polished tool under real-life conditions, as a means of determining whether the resulting quality and characteristics of the surface layer comply with the requirements for injection-molded machine tools.

In collaboration with Braun, Markt-heidenfeld, we tested the laser polishing process on part of an injection-molded machine tool with a simple geometry in 1.2343 steel, which initially had an eroded surface. The laser polishing was carried out in a multiple remelting process.

In several passes at a polishing rate of between 1 and 5 min/cm², the initial roughness was reduced from $R_a \approx 3 \, \mu m$ to $R_a \approx 0.3 \, \mu m$. The resulting surface layer was free of cracks, had a more homogenous structure and slightly higher hardness. The laser-polished tool was then buffed by means of a manual finishing process. Initial laser polishing shortens the final polishing time, and there was no distinguishable difference between the laser-polished surfaces and those that had not been laser-polished, neither on the tool nor on the manufactured plastic parts.

The tool has been tested in practice, without any perceptible negative effects of laser polishing on the surface of any of the over 60,000 plastic parts manufactured to date.

Dipl.-Ing. T. Kiedrowski, Tel.: -282 thomas.kiedrowski@ilt.fraunhofer.de
Dr. K. Wissenbach, Tel.: -147 konrad.wissenbach@ilt.fraunhofer.de
Task

The most commonly used materials in aero engines are titanium base alloys. Laser cladding using a powder additive of the same material represents an alternative repair method for aero engine components. The process layout has to be developed for the titanium base alloy Ti-17 to meet the following specifications:

- Local gas shielding enabling laser cladding without a processing gas chamber
- Avoidance of embrittlement of the clad material by contamination with O₂, N₂, C
- Clad material free of pores, cracks and bonding defects
- Compact powder nozzle to ensure ease of access to the BLISK under repair

Method

In a first step, suitable processing parameters and strategies for 3D laser cladding are determined on the basis of simple test geometries. In a second step, tensile test samples are processed on the basis of the processing parameters and strategies determined in step 1, heat-treated and tested. In a third step, the process layout is transferred to a real BLISK.

Results and Applications

The use of a compact, coaxial powder nozzle and a special component-adapted shielding gas nozzle guarantees the required accessibility and helps to avoid the embrittlement of the clad material.

The static mechanical properties of the heat-treated, defect-free clad titanium base alloy Ti-17 are equivalent to or even better than those of a heat-treated raw material (Figures 1 and 2).

Figure 3 shows the results transferred to a BLISK (repaired leading edge).

Contact

Dipl.-Ing. I. Kelbassa, Tel.: -411 ingomar.kelbassa@ilt.fraunhofer.de
Dr. K. Wissenbach, Tel.: -147 konrad.wissenbach@ilt.fraunhofer.de

Above: Ultimate tensile strength Rₘₚ and yield strength Rₑₘₚ of the heat-treated titanium base alloy Ti-17
Middle: Elongation at break Aₜ and contraction at break Z of the heat-treated titanium base alloy Ti-17

Leading edge of a BLISK (BLade Integrated DiSK) made of titanium base alloy Ti-17 after repair by laser cladding.
FEM Simulation of Laser Cladding

Task

Deposition welding for the generation of wear and corrosion protective layers on highly loaded parts and tools is increasingly performed with the so-called laser cladding technique (LC). LC is applied even for the repair of wear-damaged parts for applications in rapid prototyping and rapid tooling.

In order to reduce the experimental effort for process optimization for different part geometries and materials, a 3D finite element program was developed for the computed prediction of temperature field, track geometry and solidification conditions as a function of process parameters.

Method

In LC, the additive powder material is applied by a carrier gas and coaxial or off-axial powder feeding systems. Depending on the process parameters, the particles heat up due to interaction with the primary and reflected laser radiation before impingement onto the melt surface. This thermalized optical energy represents an important contribution to the heat needed for the process. Because the reflected laser radiation depends on the track geometry, which depends on the powder particle distribution and the heat energy supplied to the process, a strong interrelation exists between the subprocesses of LC. The developed finite element program calculates the self-consistent stationary solution for the particle temperature, the temperature field and track geometry in an iterative approach.

Results and Applications

From the calculated temperature field (Fig. 1) the solid/liquid interface is determined (Fig. 2) and discretized in triangles. The program allows the computation of local solidification conditions such as for example the temperature gradient in the direction of a given crystal orientation (DTZ, Fig. 2). The computed and experimentally determined shape of the track geometry shows a satisfactory agreement (Fig. 3).

The program is currently being applied within an EU project for the assistance of process optimization by computation.

Contact

Dr. N. Pirch, Tel.: -403
norbert.pirch@ilt.fraunhofer.de

Dr. K. Wissenbach, Tel.: -147
konrad.wissenbach@ilt.fraunhofer.de
Task

An important basic research activity at the Fraunhofer ILT consists in identifying process windows and their adjoining process domains on the basis of different quality characteristics. Pores within a weld seam represent a decreased seam quality. The formation of pores has to be detected on-line in welding and avoided by suitable process control.

Our task was to specify the mechanisms of pore formation and to identify the process domains involved.

Method

The model describes the melt flow and the dynamic phenomena within the gaseous phase, e.g. evaporation, recondensation, and flow within the plasma capillary. The mass flow (model of Aoki and Sone) of evaporating melt and the vapor flow (Euler equations) are evaluated numerically.

The boundary layer flow of the melt and the propagation of perturbations are analyzed.

The motion of the melt film thickness (wave amplitude, wavelength) during relaxation of perturbations within the vapor is analyzed.

Results and Applications

Because of the different time-scales of phenomena within the capillary (evaporation/recondensation, compressible flow), relaxation oscillations occur. The melt flow is accelerated in advance of the laser beam and de-accelerated in its wake. Initial amplitudes of the melt film thickness may be amplified in the wake. As a consequence, a part of the capillary is blocked and a pore is formed. The almost periodic behavior is related to inner time-scales at which the formation of pores is triggered or arrested by modulation/fluctuation of external parameters.

Contact

Dipl.-Phys. J. Michel, Tel.: -163 jan.michel@ilt.fraunhofer.de
Dipl.-Phys. M. Nießen, Tel.: -307 markus.niessen@ilt.fraunhofer.de
Priv.-Doz. Dr. W. Schulz, Tel.: -204 wolfgang.schulz@ilt.fraunhofer.de
Simulation of Material Transfer during Laser-Induced Ablation in Vacuum

Task

A vacuum discharge could be initiated with pulsed laser radiation. The laser beam is focused onto the cathode to induce local evaporation. The laser-induced plasma is used to bypass the distance between cathode and anode.

The resulting ignition time has to be calculated as a function of the laser parameters. The state of the laser-induced plasma should be characterized.

Method

The dynamic behavior of the plasma is described using the continuum laws for mass, momentum and energy. At the ablation front, the plasma and the condensed state (cathode) are linked by jump conditions. The temperature of the cathode is calculated. The ionization state of the plasma is determined by the Saha equations. The propagation of the laser radiation depending on the absorption coefficient of the plasma is calculated by use of the radiation transport equation. The set of equations is solved numerically.

Results and Applications

An increase in pulse energy also causes an increase in the proportion of laser radiation absorbed by the plasma. This leads to different ionization states of the plasma and has an impact on the ignition time. For the design of an efficient ignition process, the interrelations between ignition time, the proportion of absorbed laser radiation and the ablated volume are presented to the customer.

Contact

Dr. M. Aden, Tel.: -469
mirko.aden@ilt.fraunhofer.de

Priv.-Doz. Dr. W. Schulz, Tel.: -204
wolfgang.schulz@ilt.fraunhofer.de
**Task**

Pulsed laser beam sources are used for trepanning micro holes (effusion cooling) in turbine blades. The velocity of the ablation front and the spatial distribution of the solidified melt are determined to improve the productivity and the quality.

The motion of the ablation front has to be determined in relation to the real beam profile. The analysis of the front motion serves as preparation for investigations of the melt flow, its separation and solidification.

**Method**

The motion of the spatial 3-dimensional ablation front is modeled by a free boundary problem that is defined by a system of partial differential equations. The solution properties are reproduced qualitatively with an approximate model that has a reduced complexity. The approximation accuracy is determined by comparison with the numerical solution and asymptotic analysis. The solution of the approximate model is evaluated and visualized by an interactive PC simulation.

The effect of the spatial distribution of the laser beam and temperature-dependent material parameters were analyzed by comparison with experimental results from beam diagnostics and ablation results at the Department of Laser Technology at RWTH Aachen University.

**Results and Applications**

The ablation rate depends significantly on the beam profile: a laser beam with an intensity of a Gaussian distribution ($M^2 = 2$) shows a 70% higher ablation rate than the experimental results. The experimental results are comparable to values of the simulation that takes into account the real beam profile. The ablation rate varies by up to 20% due to the influence of temperature-dependent material parameters.

**Contact**

Dipl.-Phys. J. Michel, Tel.: -163
jan.michel@ilt.fraunhofer.de

Dipl.-Ing. J. Willach, Tel.: -409
jens.willach@ilt.fraunhofer.de

Priv.-Doz. Dr. W. Schulz, Tel.: -204
wolfgang.schulz@ilt.fraunhofer.de

Above: PC simulation
Below: Ablation rate
Task

Pulsed laser beam sources are used for trepanning micro holes (effusion cooling) in turbine blades. The spatial distribution of the solidified melt is a characteristic of the hole quality.

To eject the formed melt, improvements to the injection of a supersonic gas flow into an inclined hole (length 2-5 mm, diameter 60-200 µm) are required.

Method

The gas inflow is analyzed up to a depth equivalent to the diameter of the hole. Here, the typical values of the Reynolds number are high compared to unity and the thickness of the viscous boundary layer remains low compared to the diameter of the hole. The gas flow is calculated by solving the Euler equations (finite volume method of Godunov type, modified Harten-Lax-Leer method as Riemann solver).

The numerical solution of the approximate model is evaluated by an interactive PC simulation. Mass density, pressure, velocity components, Mach number, and temperature of the gas are visualized. Boiler pressure, diameter, distance, position, and alignment of the nozzle are varied. The velocity of the gas flow and the spatial variation of the gas pressure along the hole wall are compared to experimental results (Department of Laser Technology, RWTH Aachen) relating to the thickness of the solidified melt.

Results and Application

The position of the nozzle relative to the laser beam axis is a crucial parameter. When in coaxial alignment, the gas flow creates multiple reflections at the walls. The gas pressure and the thickness of the solidified melt vary periodically along the wall of the hole. The lateral displacement of nozzle and laser-beam axis enables the gas to expand into the hole without reflections; the gas pressure decreases monotonically with the depth and the melt is almost completely ejected.

Contact

Dipl.-Phys. M. Nießen, Tel.: -307  
markus.niessen@ilt.fraunhofer.de

Dipl.-Ing. J. Willach, Tel.: -409  
jens.willach@ilt.fraunhofer.de

Priv.-Doz. Dr. W. Schulz, Tel.: -204  
wolfgang.schulz@ilt.fraunhofer.de
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.
Production Cell for Laser Beam Soldering of Ceramic Substrates

Task

Electronic modules for the automotive environment are required to meet highly specific specifications. On the one hand there are requirements in terms of performance, functionality and miniaturization and on the other hand of reliability and durability. Thick-film or hybrid circuits have a high level of integration and an excellent performance in harsh environments. This special kind of circuit consists of screen-printed layers of conductive, dielectric or resistive materials on an alumina (Al₂O₃) substrate. The interconnection of the substrate to the next packaging level, which is usually a plastic housing, is achieved by either a thick wire, ribbon bonding or soldered leads.

The purpose of this investigation was to demonstrate the technical feasibility of laser soldering as well as to build up a production cell for this kind of interconnection.

Method

Based on an extensive feasibility and qualification study, a process window for the laser beam soldering process was qualified. By means of the product specifications and the requirements of the customer, an appropriate production cell was realized and integrated into the existing production line.

Results and Applications

The main part of the fully automated production cell is a compact laser processing head, consisting of a galvanometer scanner system with an integrated pyrometric sensor. As beam source, a fiber-coupled diode laser with a maximum optical power output of 250 watts (continuous wave) is used.

The powerful combination of rapidly adjustable laser power and closed-loop temperature control enables the stability of the laser beam soldering process to be improved. The correlation of laser power and pyrometric signal is used to compensate for deviations in process-relevant values of the products. It is thus possible to produce hybrid circuits with consistently high-quality solder joints.

Contact

Dipl.-Ing.(FH) A. Koglin, Tel.: -145 andreas.koglin@ilt.fraunhofer.de
Dipl.-Ing. L. Bosse, Tel.: -305 luedger.bosse@ilt.fraunhofer.de
Dr. A. Gillner, Tel.: -148 arnold.gillner@ilt.fraunhofer.de
Concept and Setup of a Laser-Based Cutting Facility for Rubber Belts

Task

For a new type of textile spinning machine, a specially perforated rubber belt is needed. During the pre-production phase, several short-run batches of perforated elastomeric belts were produced at ILT facilities. The production rate of these belts has since been increased to 100,000 pieces/year, necessitating a new type of laser drilling machine.

Method

The basic machine concept consists of three separate units: a machining unit, a control unit, and a filter unit.

A CO₂ laser with 60 W maximum output power, two linear drives, and a rotational drive are the main components of the 1 x 1 x 1 m enclosed machining unit. Using two-beam-cutting optics developed at the ILT, two belts (diameter 40 mm, width 20 mm, thickness 1 mm) can be perforated simultaneously with millimeter-scale holes.

The control unit contains all electrical supply devices for laser and drives. By using a CNC control, different hole geometries can be produced with a high degree of flexibility.

The exhaust unit, equipped with active carbon filter units, filters the fumes emitted by the cutting process and eliminates the rubber smell.

Results and Applications

Depending on the perforation pattern, the laser cutting machine has a capacity of up to 100 belts per hour. The belts are fed in and out of the machine semi-automatically by means of replaceable belt holders, which can be inserted and removed while the machine is in operation.

Contact

Dipl.-Phys. A. Koeppe, Tel.: -217 alexander.koeppe@ilt.fraunhofer.de
Dipl.-Phys. G. Otto, Tel.: -165 gerhard.otto@ilt.fraunhofer.de
Dr. A. Gillner, Tel.: -148 arnold.gillner@ilt.fraunhofer.de
Task

Laser cladding and alloying of internal surfaces cannot be performed with standard optics and standard powder feed nozzles. At the ILT, an optics for the treatment of bores with a minimum diameter of 50 mm was developed and successfully tested. The optics is fixed, therefore the workpiece has to rotate. Components with eccentric or non rotationally symmetric bores are difficult to process. A solution is offered by a rotating optics. This requires a rotating feed system for cooling water, shielding gas and powder.

Method

The challenge is to implement a homogeneous powder feeding system which is independent of the rotational movement. In a first step this module was developed separately, followed by the development of the complete optics based on the existing concept.

Results and Applications

The optics was tested successfully. A continuous operation for 20 minutes at 3 kW was verified. Figure 3 shows an application involving repair to the eccentric bore of an injection mold.

A new optical system for laser cladding of bores with a minimum diameter of 30 mm is currently being developed and tested. This optics is designed for a maximum output power of 500 W, and will be equipped with a light source and a camera for accurate positioning of the laser beam.

Contact

K. Karimov, Tel.: -282
khudaverdi.karimov@ilt.fraunhofer.de
Dr. A. Weisheit, Tel.: -403
andreas.weisheit@ilt.fraunhofer.de
Dr. K. Wissenbach, Tel.: -147
konrad.wissenbach@ilt.fraunhofer.de
Diode Laser Network with Distributed Temperature Control

Task

Diode lasers, low-cost alternatives to CO₂ or solid-state lasers, enable cost-effective and efficient machine processes using multi-beam technology. To capitalize on this potential, a diode laser network will be developed that allows synchronized and flexible control or regulation of simultaneously running distributed processes.

Using an actual application as the basis, the temperature in various processing areas of a workpiece will be simultaneously and locally controlled or the specific laser output being emitted will be adjusted and controlled to conform to the specific geometry of the workpiece.

Method

Under the framework of the German research ministry (BMBF) lead project related to modular diode laser beam tools, a diode laser network with integrated process controller was developed within the sub-project »hardening«. The network consists of up to ten diode laser devices linked together via commercially available field bus technology to form a coordinated system. A single graphical user interface provides the means to configure and operate each individual diode laser device via the network structure.

Each device consists of a diode laser module with integrated beam thermometer (pyrometer) and an intelligent power supply. The power supply contains algorithms for measuring and controlling the process temperature and regulating the laser.

Results and Applications

Because the process controls are decentralized and performed by each diode laser device, multiple process steps can be conducted simultaneously. During the process of hardening precision guide rails for instance, the hardening and straightening lines are created simultaneously which minimizes the amount of reworking required by reducing the number of defects.

Diode laser networks make sense when the desired result can be achieved more efficiently than by a single beam source. The use of diode laser networks is also appropriate in connection with complex finite component geometries, where there is a need for automatic adjustment of segmented power density distributions, in order to avoid unwanted melting or overheating.

Contact

Dipl.-Ing. J. Sommer, Tel.: -390 jan.sommer@ilt.fraunhofer.de
Dr. A. Drenker, Tel.: -223 alexander.drenker@ilt.fraunhofer
Dr. S. Kaierle, Tel.: -212 stefan.kaierle@ilt.fraunhofer.de
Remote Laser Welding Process Control

Task

A remote welding system is a highly dynamic beam motion system that rapidly and precisely deflects the laser beam by means of mirrors. The system has been well received by the automobile industry. In remote welding, like other machine processes, coaxial monitoring of the processing result has become increasingly important.

A collaborative research project involving several Fraunhofer Institutes was therefore initiated in order to develop a prototype remote welding system with integrated process control.

Method

The remote welding system for high-power Nd:YAG lasers, a concept developed by the Fraunhofer Institute for Material and Beam Technology IWS, consists of an optical beam deflector with three highly dynamic positioning axes and an industrial robot. The system provides extremely accurate positioning and tracking.

The coaxial process control (CPC) for laser beam materials processing was developed by the Fraunhofer Institute for Laser Technology ILT. The interaction zone between the laser beam and workpiece is monitored during the process with an image detector (high-speed camera). Conclusions regarding the quality of the laser process can be drawn by analyzing the camera images.

The two individual systems were integrated to form a single system, thus providing the following characteristics:

- Coaxial process control integrated in the optical beam deflector
- Extremely high frame rate which allows monitoring of the highly dynamic motion of the beam spot
- Compact, robust construction

Results and Applications

During test welding using a diode-pumped Nd:YAG laser at an output of more than 4 kW, through-welds on the workpiece were clearly identified and located.

Contact

Dipl.-Ing. J. Sommer, Tel.: -390 jan.sommer@ilt.fraunhofer.de
Dr. S. Kaierle, Tel.: -212 stefan.caierle@ilt.fraunhofer.de

Snapshot of welding on a 30° corner (v = 6 m/mm):
Above: beginning of the welding process
Middle: through-weld in the corner area
Below: continuation of the through-weld
Planning and Tools Diagnosis for Autonomous Laser Materials Processing

**Task**

The autonomous production cell (APC) manufacturing concept offers the opportunity to perform stand-alone and reliable complex machine processes with limited interruptions over extended periods of operation.

In the same-named special research area 368, the Fraunhofer ILT is working together with the Chair for Laser Technology at RWTH Aachen University to implement the process and machine functionalities needed for autonomous laser materials processing.

The autonomous process is preceded by the automated diagnosis of the laser beam in combination with a 3D offline planning system.

**Method**

The diagnosis system records data from a variety of sources such as a beam diagnosis device, calorimeter and laser system control. The measuring and data management software, developed specially for this purpose, acquires and administers this information in a database.

The planning system uses so-called features to describe the production task. These features link geometric data (CAD) with technical information in the form of process parameters and strategies.

For the process, the planning system generates a control program that also takes into account diagnosis data representing the current status of the laser equipment.

**Results and Applications**

Integrating the diagnosis in the features-based planning system provides a production-quality description of the production task before the process actually begins by analyzing the additional input on the status of the equipment.

This additional preparatory step plays a significant role in augmenting the autonomy of laser materials processing.

**Contact**

Dipl.-Ing. L. Böske, Tel.: -427
lars.boeske@ilt.fraunhofer.de

Dipl.-Ing. J. Kittel, Tel.: -136
jochen.kittel@ilt.fraunhofer.de

Dr. S. Kaierle, Tel.: -212
stefan.kaierle@ilt.fraunhofer.de

3D offline planning system
Laser Experiment Database

Task

For the purpose of coordinating experiments in the ongoing EU project IPcim (integrated processing and control for improved large section and sheet metal steel welding), a database was required to allow each participant to make the details and results of their experiments available to the other project partners. Also required was a means for participants to gain access to the information of the other partners to adequately plan their own experiments, avoid unnecessary duplication of experiments and to conduct necessary comparative tests.

Method

With the ubiquitous availability of the Internet and based on experience with the EU project VELI (Virtual European Laser Institute), the World Wide Web was selected as the communications platform for the project partners.

The mySQL database platform and the PHP programming language were selected to meet the need for flexible data storage and retrieval and dynamic database expansion. First, an extensive database structure was created to dynamically record the equipment, sensors, workpieces and materials used in the experiments. Importance was placed on the ability to record the specific parameters of individual pieces of equipment in a flexible manner.

Due to the pan-European nature of the project, not only the user interface but also the database information was localized (translated). After the preliminary conclusion of the design phase, the user interface was implemented using PHP to enable support for as many Internet browser configurations as possible.

Results and Applications

The database is currently in use by the IPcim project partners, and is being tested and continuously adapted to the needs of the users.

The database has equal potential as a knowledge base application for corporate intranets or for public domain access via the Internet. In addition, with a suitable front-end, the database could be used as an electronic laboratory notebook or experiment-planning tool.

Contact

Dipl.-Phys., Dipl.-Inf. J. Petereit, Tel.: -326 jochen.petereit@ilt.fraunhofer.de
Dr. S. Kaierle, Tel.: -212 stefan.kaierle@ilt.fraunhofer.de
Initial Situation

Europe has a world-wide leading position in laser research. But industry in general and small and medium sized enterprises (SMEs) in particular experience significant difficulties to exploit the enormous body of knowledge already existing in Europe and to transfer it into new laser applications and products. Objective of ELI is the improvement of the accessibility and use of the available European expertise and experience in laser technology.

Furthermore, it is the objective of ELI to make the significance and the perspectives of European laser research open to a broader public.

Method

The European Laser Institute builds a European network providing local access to the knowledge dispersed in Europe. Main tasks of ELI are:

- set-up of a database, containing know-how formerly dispersed at various laser research institutions
- operation of a virtual environment where supply and demand on knowledge can meet
- development of a framework for knowledge and technology transfer between research institutions and enterprises as well as between research institutions among each other.

Actual Situation

Led by Fraunhofer ILT, 15 leading European laser research institutions have founded the European Laser Institute ELI in 2003. The network is open to additional partners. Objective is to integrate into ELI all relevant European keyplayers in the field of laser technology.

Further information on the web site: www.europeanlaserinstitute.org.

This work is funded by the European Union.

Contact

Dipl.-Phys. C. Hinke, Tel.: -352
E-mail: hinke@ilt.fraunhofer.de
Dr. S. Kaierle, Tel.: -212
E-mail: kaierle@ilt.fraunhofer.de
Laser Light Section Exhibition

Task

Through the campaign »Faszination Licht« (www.faszination-licht.de), the German research ministry is partnering the VDI Technology Center to promote the training and education of skilled professionals for the emerging field of optical technologies. A traveling exhibition by the same name features a varied selection of exhibits, all related to optical technologies, presented in an educational format designed specifically for school classes.

As its contribution to this exhibition, the Fraunhofer Institute for Laser Technology ILT supplied a demonstration model illustrating the principles of laser light section.

Method

The ILT exhibit features an industrial light section sensor that has been modified to allow visitors to look inside the casing. The test objects are placed on a turntable which can be rotated using a hand-wheel to bring individual objects into the line of sight of the measuring sensor. The VDI and its partners worked together to integrate the components in the exhibit.

Results and Applications

The measurement results are displayed on a touch screen by software designed specifically for the exhibit. Besides viewing measurement results, visitors can also retrieve supplemental information and videos related to industrial applications of the technology.

Contact

Dipl.-Ing. (FH) O. Klein, Tel.: -133
oliver.klein@ilt.fraunhofer.de
Dr. R. Noll, Tel.: -138
reinhard.noll@ilt.fraunhofer.de
**Task**

The laser light-section technique is a non-contact, high-frequency method for measuring the geometric profile of objects. It is thus particularly suited for use in industrial online measurement and inspection applications.

One example of its use is 3D deformation analysis with hydraulic bulge testing to determine the deformation and strain-hardening behavior of sheet metals. The bulge test is a rapid, comprehensive way to characterize materials and as a result is employed in the development of new metallic materials, which have increasingly sophisticated properties, as well as in the quality assurance testing of sheet metals.

**Method**

As part of an ongoing collaborative R&D project, a 3D laser sensor demonstrator was developed and integrated with a sheet metal testing machine. During the bulge test, the deformation of the metal sheet is recorded by laser light-section sensors on two planes in perpendicular alignment with one another. An additional online camera sensor tracks the trajectory of individual points on the surface of the metal sheet. The measurement results are used to calculate material characteristics such as flow and strain-hardening behavior.

**Results and Applications**

Since the individual sensors operate at different wavelengths, it is possible to measure sheet-metal deformation by the three sensors simultaneously, without interference by ambient or scattered light.

The deformation of sheet metal was simulated by means of a patterned balloon skin. The trajectory of defined points could be determined with sub-pixel accuracy. The next stage of the project is to test and optimize the demonstrator on a sheet-metal testing machine.

The project is being financed by several SMEs and the German research ministry under project number 13N8111.

**Contact**

Dipl.-Phys. J. Vrenegor, Tel.: -308  
jens.vrenegor@ilt.fraunhofer.de  
Dr. R. Noll, Tel.: -138  
reinhard.noll@ilt.fraunhofer.de
### Task

During the production of galvanised sheet steel, a key monitoring parameter is the thickness and chemical composition of the zinc coating. To ensure a consistent quality for further processing of the sheet metal, the thickness and composition of the zinc layer must remain as constant as possible over the entire kilometer-long steel strip. The aim of the project is to develop an online process to measure the thickness and chemically analyze the depth profile of the zinc layer. The process is to be evaluated as a potential alternative to conventional methods such as X-ray fluorescence.

### Method

The process is based on laser-induced breakdown spectrometry (LIBS), a method in which a plasma is generated on the metal by a pulsed Nd:YAG laser and the chemical composition is determined by detecting the element-specific line radiation. The ablation depth and thus the measuring depth can be adjusted by optimizing the laser parameters.

### Results and Applications

Tests on static metal sheets showed that a single laser pulse is capable of penetrating the approximately 10-µm-thick zinc layer, thus fulfilling one of the key requirements for application on a moving sheet metal. By continuously varying the ablation depth, it was possible to locate the transition between the galvanized coating and the sheet metal.

The project is being carried out with financial support from the European Coal and Steel Community ECSC and the Fraunhofer-Gesellschaft.

### Contact

Dr. H. Balzer, Tel.:-196
erbert.balzer@ilt.fraunhofer.de
Dr. V. Sturm, Tel.:-154
volker.sturm@ilt.fraunhofer.de
Dr. R. Noll, Tel.:-138
reinhard.noll@ilt.fraunhofer.de
Laser-Based Elemental Analysis of Production Control Samples with Scale Layers

Task

The rapid elemental analysis of production control samples is an important aspect of metallurgical process control in steel manufacturing. Currently employed methods such as spark emission spectrometry, combustion analysis and X-ray fluorescence analysis necessitate time-consuming preparation of the samples using mechanical processes such as grinding and polishing. As part of an R&D project, a single laser-based analysis system was developed as an alternative to the conventional two-step process involving mechanical sample preparation followed by elemental analysis by spark emission spectrometry. By eliminating various intermediate stages, the new method can significantly improve the productivity of the steel manufacturing process.

Method

The laser performs both tasks – preparation and analysis. The scale layer is first removed locally by laser ablation, and then the bulk material is analyzed with the laser. The laser method is non-contact and relatively maintenance-free by comparison with automated milling and grinding.

Results and Applications

The accuracy and precision of the test data obtained through analysis of the scaled side of the samples was greatly improved when using the new method. Comparison of the analysis values of prepared and non-prepared samples showed a very close correlation for most elements.

The work is being conducted with the financial support of the European Coal and Steel Community ECSC and the Fraunhofer-Gesellschaft.

Contact

Dr. V. Sturm, Tel.: -154
volker.sturm@ilt.fraunhofer.de
Dipl.-Phys. Jens Vrenegor, Tel.: -308
jens.vrenegor@ilt.fraunhofer.de
Dr. R. Noll, Tel.: -138
reinhard.noll@ilt.fraunhofer.de

Above: Correlation between the analytical values obtained from measurements on the front, ground face of a sample and the rear, scaled side of the same sample. The values lie very close to the plotted bisectrix representing the ideal curve.

Below: Example of a low-alloy steel production control sample, showing (left) a sample whose surface has been prepared for conventional analysis and (right) an equivalent unprepared scaled sample.
Task

Inclusions by non-metallic compounds within the steel matrix have a detrimental effect on the material properties of steel. The conventional methods used to identify and quantify these inclusions are cost- and time-intensive. One alternative is multi-element analysis based on emission spectrometry in which microscopic amounts of material are vaporized and excited with a laser beam or spark discharge. But the data obtained from these different methods of analysis are incompatible, and do not provide a conclusive evaluation of the cleanness of the steel. The aim of the project is to define a uniform data evaluation method in collaboration with European steel industry partners in order to be able to compare the results of the different types of test systems.

Method

In a joint project with European steel industry partners, a multi-element analysis using spark and laser emission spectrometry with a defined sample set will be conducted on-site at the location of the participating partners. The resulting data are sent to the Fraunhofer ILT, where they are converted into a common format, if this has not already been done by the partner. The various mathematical analysis methods developed by the partners will then be evaluated and improved with respect to accuracy and their compatibility with different types of equipment. The results of the analysis process will be placed on a Fraunhofer ILT Web server and made available to all of the partners. This allows the partners to quickly compare and evaluate each other’s characteristic data for steel cleanness and thus allows them to directly coordinate their analysis techniques.

Results and Applications

To enable the various sets of measurement data to be analyzed using the same programs, a standard data format and process parameters were defined. Conversion programs convert each partner’s measurement data into a standard format and then analyze the data using algorithms developed by each of the partners on the basis of the same format. These algorithms are implemented in C++. The measurement data, a description of the measurement parameters and the results are all stored in a database. The database resides on a Web server accessible by all of the partners.

The project is being carried out with financial support from the European Coal and Steel Community ECSC.

Contact

Dr. R. Wester, Tel.: -401
rolf.wester@ilt.fraunhofer.de
Dr. R. Noll, Tel.: -138
reinhard.noll@ilt.fraunhofer.de
Rapid Identification of Light Metal Alloys for Automated Sorting

Task

The recycling of light metals, which are increasingly used in automobile manufacturing for instance, can only be a profitable activity if the recovered waste is pre-sorted according to the type of material. Because conventional analysis and sorting processes do not allow cost-effective separation of light-metal alloys, a novel laser-based identification process will be developed under the framework of a national R&D project. The new process allows a high material throughput to be achieved while simultaneously ensuring that the separated fractions are of the highest purity.

The aim of the project is to develop a demonstrator to validate the functionality of the process under realistic operating conditions.

Method

The approach is based on a combination of image processing, laser-based determination of geometric features and laser emission spectrometry. In addition to recording the geometric and optical characteristics of the sorted material, the chemical composition of the individual particles is determined via laser spectrometry. The waste material is subsequently sorted into two or more fractions on the basis of selection criteria derived from the entire set of measured values.

Results and Applications

In order to conduct a chemical elemental analysis of moving individual particles, the beam of the laser emission spectrometer must focus on and track each sample. To obtain the planned material throughput, a 3D scanning unit positions the beam on as many as 100 different locations per second. The element-specific light emission of the laser-induced plasma is coupled to a Paschen-Runge spectrometer equipped with photomultiplier detectors. The acquired signals are then digitized and evaluated. The measuring set-up has been expanded to include a belt conveyor for measuring moving samples.

The project receives financial support from several SMEs, the German ministry of economics and labor, and the Fraunhofer-Gesellschaft.

Contact

Dr. J. Makowe, Tel.: -124
joachim.makowe@ilt.fraunhofer.de
Dipl.-Phys. Ü. Aydin, Tel.: -431
uemit.aydin@ilt.fraunhofer.de
Dr. R. Noll, Tel.: -138
reinhard.noll@ilt.fraunhofer.de
Microfluorescence Analysis Technique
for Identifying Biological Binding Activities

Task

A flexible screening system will be developed for cell and molecular diagnostics that will have the capability to detect and select protein binding activity in aqueous solutions and on biochips through a combination of microfluorescence analysis and micro-manipulation.

Method

The biochips are positioned and scanned by two linear-axis units. The biological binding activities occurring on the chip are identified via targeted markings with dye-labeled beads that are made to fluoresce excited by highly-focused laser pulses in the picosecond range.

Using a combination of confocal microscopy and time-correlated single photon counting (TCSPC), the emitted fluorescence photons are temporally and spatially separated from other interfering photons and detected by avalanche photodiodes. With the help of a second laser system, immobilized species can be selected and extracted at defined locations.

Results and Applications

The Fraunhofer ILT is currently developing a universal, laser-based micro-analysis and processing system for the light, epifluorescence and confocal laser scanning microscopy of biochips.

Modular software controls the system components and allows individual scan sequences on the chip. The scan has a maximum resolution of 100 nm, positioning accuracy of < 1 µm and reproducibility of ≤ 0.3 µm. Picosecond-laser diodes with wavelengths of 404, 658 and 758 nm excite fluorescent dyes with extinction in the blue and red spectrum and in combination with an integrated photon counting card allow localized fluorescence lifetime imaging of the chips. The diffraction-limited laser focus has a diameter of less than 1 µm. The detection volume in aqueous solutions lies between 120 and 340 femtoliters and allows single-molecule diagnostics.

In parallel to the scanning process, a second microscope optic provides the opportunity to simultaneously conduct wideband excitation and wide-area fluorescence detection via a slow-scan CCD camera. The maximum exposure time is two hours and is suitable for conducting chemical luminescence measurements.

Contact

Dipl.-Phys. A. Brysch, Tel.: -124 adriane.brysch@ilt.fraunhofer.de
Dipl.-Ing. (FH) O. Klein, Tel.: -133 oliver.klein@ilt.fraunhofer.de
Dr. R. Noll, Tel.: -138 reinhard.noll@ilt.fraunhofer.de

Fluorescence image of AF 649-marked streptavidin bound to a laser-structured biotin surface. The section measures approximately 50 x 50 µm.
Task

Understanding the molecular structure of the target protein is necessary for the rational development of active pharmaceutical substances. The protein structure is resolved by means of X-ray diffraction, which presupposes the presence of single crystals of the investigated proteins. Growing such crystals is extremely time-consuming and in many cases fails completely. Thus the need exists for a systematic method to produce protein crystals for a more efficient rational development of active substances.

Method

The direct measurement of protein interactions by means of marker-free laser light-scattering techniques provides a tool for optimizing crystallization conditions in protein solutions. Static scattered light measurements allow parameters to be identified that quantify the interaction between the proteins. This information is used as feedback to establish favorable conditions for crystallization by modifying the composition of the observed protein solution. The iteration of the described method forms the basis of a process to enable the targeted crystallization of proteins.

Results and Applications

The Fraunhofer ILT is currently developing a demonstrator that combines a light scattering module, online data analysis and a liquid handling system for pipetting nanoliter volumes. Individual solutions prepared for crystallization, whose composition has been determined from the previously obtained scattered light data, are injected by pipette into a sample carrier developed for this application. This leads to a systematic adaptation of the protein solution interaction parameters until the optimal crystallization conditions are achieved.

Contact

Dr. C. Janzen, Tel.: -196, christoph.janzen@ilt.fraunhofer.de
Dr. A. Lenenbach, Tel.: -431, achim.lenenbach@ilt.fraunhofer.de
Dr. R. Noll, Tel.: -138, reinhard.noll@ilt.fraunhofer.de
Analysis of Fine Liquid Droplets

Task

In chemical analysis, the term »hyphenated techniques« describes combination methods that link a chromatographic separation stage with the sensitive detection of isolated fractions. As part of a German collaborative research project, a novel technique is being developed for the elemental analysis of chromatographically separated fractions. One of the key applications is in the field of speciation analysis.

Method

The eluate of an HPLC-column is transformed in a regular stream of fine droplets through a piezoelectric pulsed nozzle. The droplets are irradiated, evaporated and transferred into a bright plasma by synchronized laser pulses (laser-induced breakdown spectrometry LIBS). The plasma radiation is spectrally resolved to yield information regarding the elemental composition of the sample.

Together with partners in a national collaborate research project, the Fraunhofer ILT is developing a demonstrator to evaluate the new technique. A Paschen-Runge spectrometer is coupled to a measuring chamber that is used to house the droplet generator, the light-collection optics and also for setting up a defined argon atmosphere. An electronic control circuit generates a series of voltage pulses, which are adjusted to the volume flow of the HPLC column, to generate the individual droplets.

Results and Applications

The demonstrator permits the analysis of the elemental composition of extremely small volumes of liquid. Single droplets have a volume of only 200 pl. In continuous operation, volume flows of less than one microliter per minute are feasible. Since direct laser evaporation of the analyte has no diluting effect – as is the case in an inductively coupled argon plasma – this technique is particularly well-suited for the analysis of extremely small sample volumes (micro-HPLC). Absolute detection limits in the order of less than one picogram or LOD values in the parts-per-billion range are thus achievable.

The project is being financed by several SMEs, the Fraunhofer-Gesellschaft and the German research ministry under reference number 13N8039.

Contact

Dr. C. Janzen, Tel.: -196 christoph.janzen@ilt.fraunhofer.de
Dr. R. Noll, Tel.: -138 reinhard.noll@ilt.fraunhofer.de
Task

The customer uses an optical measuring system to determine the velocity of spherical particles. The velocity of the particles is measured by a photoelectric barrier. This system is capable of determining the velocity of particles with diameters greater than 1 mm. The task consists in miniaturizing the measuring system for spherical particles with diameters down to 100 µm.

Method

To enable smaller spheres to be measured, the size and contrast of the diffraction patterns as the particles pass the barrier are calculated using an approximate model. The intensity distribution of the diffraction image on the detector chip and the resulting detector signals are analyzed as a function of the Fresnel number. The wavelength of the laser radiation, the radius of the spherical particles, and the distance between particle and detector are taken into account. The improved measuring method is tested experimentally.

In addition to the technical task, the accuracy of the approximate model is analyzed in cooperation with the Kompetenzzentrum für Prozesssimulation (SimPRO) (National Center of Excellence for Process Simulation) at RWTH Aachen. The higher-order asymptotic expansions (Keller, Rubinow, Nussenzveig, Buldyrev) of the diffraction patterns are determined with respect to the characteristic parameters (e.g. diffraction angle, impact parameters).

Results and Applications

Suitable components to realize the improved measuring method have been assigned and tested. Size and position (Fresnel number) of the detector planes affect the detector signal. The detector signals and the concept for the miniaturized measuring system are presented to the customer by means of an interactive PC simulation.

Contact

Dipl.-Phys. M. Nießen, Tel.: -307 markus.niessen@ilt.fraunhofer.de
Priv.-Doz. Dr. W. Schulz, Tel.: -204 wolfgang.schulz@ilt.fraunhofer.de
Dr. R. Noll, Tel.: -138 reinhard.noll@ilt.fraunhofer.de
### Germany

<table>
<thead>
<tr>
<th>Patent Number</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>DE 196 25 873 C 2</td>
<td>Verfahren zum Verfügen von Fügepartnern</td>
</tr>
<tr>
<td>DE 199 48 264 C 2</td>
<td>Anordnung und Verfahren zur Reflektometrie</td>
</tr>
<tr>
<td>DE 101 12 445 C 2</td>
<td>Verfahren zum Schneiden von zu fügenden Bauteilen mit Laserstrahlung</td>
</tr>
<tr>
<td>DE 199 17 433 C 2</td>
<td>Mikroreaktorsystem zum Erzeugen und Testen von Substanzen und Wirkstoffen</td>
</tr>
<tr>
<td>DE 196 43 925 C 2</td>
<td>Vorrichtung zur Erzeugung einer Gasentladung mit schnellen Spannungsanstiegen und hohen Leistungsfällen</td>
</tr>
<tr>
<td>DE 198 08 275 C 2</td>
<td>Verfahren und Vorrichtung zur Detektion von Porosität erzeugenden Gasen in Schweißverbindungen</td>
</tr>
</tbody>
</table>

### Europe

<table>
<thead>
<tr>
<th>Patent Number</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>EP 1 137 504 B 1</td>
<td>Prozesskammer für das selektive Laser-Schmelzen</td>
</tr>
<tr>
<td>EP 0 926 262 B 1</td>
<td>Verfahren zur selektiven Abscheidung einer Metallschicht</td>
</tr>
<tr>
<td>EP 0 788 673 B 1</td>
<td>Strahlführungs-Laserdiodenarrays</td>
</tr>
<tr>
<td>EP 1 181 754 B 1</td>
<td>Optische Verstärker-Anordnungen</td>
</tr>
<tr>
<td>EP 1 144 146 B 1</td>
<td>Vorrichtung für das selektive Laserschmelzen zur Herstellung eines Formkörpers</td>
</tr>
<tr>
<td>EP 1 015 165 B 1</td>
<td>Verfahren und Vorrichtung zur Materialbearbeitung mit Plasma</td>
</tr>
<tr>
<td>EP 1 119 436 B 1</td>
<td>Verfahren zur Materialbearbeitung mit Plasma induzierender Hochenergiestrahlung</td>
</tr>
<tr>
<td>EP 0 875 360 B 1</td>
<td>Verfahren zur Aufrauung von Kunststoffoberflächen</td>
</tr>
<tr>
<td>EP 1 133 377 B 1</td>
<td>Vorrichtung und Verfahren zum Abtasten einer Objektfläche mit einem Laserstrahl</td>
</tr>
<tr>
<td>EP 0 823 144 B 1</td>
<td>Transformation von Array-Strahlung</td>
</tr>
<tr>
<td>EP 1 198 341 B 1</td>
<td>Vorrichtung und Verfahren zur Herstellung von Bauteilen aus einer Werkstoffkombination</td>
</tr>
</tbody>
</table>

### USA

<table>
<thead>
<tr>
<th>Patent Number</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>US 6, 583, 379 B 1</td>
<td>Process Chamber for Selective Laser Fusion</td>
</tr>
<tr>
<td>US 6, 534, 740 B 1</td>
<td>Device and Process Using a Laser Beam to Scan an Area of an Object</td>
</tr>
</tbody>
</table>

### Patent Applications

<table>
<thead>
<tr>
<th>Patent Number</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>103 31 442.3</td>
<td>Transformationsanordnung Feld-Linie</td>
</tr>
<tr>
<td>103 36 273.8</td>
<td>Vorrichtung zur Erzeugung von EUV- und weicher Röntgenstrahlung</td>
</tr>
<tr>
<td>103 42 239.0</td>
<td>Verfahren und Vorrichtung zum Erzeugen von Extrem-Ultraviolettstrahlung oder weicher Röntgenstrahlung</td>
</tr>
<tr>
<td>103 28 086.3</td>
<td>Kompressionsoptik für Diodenlaserarrays</td>
</tr>
<tr>
<td>103 28 083.9</td>
<td>Angleichung der Strahlqualität von Diodenlaserarrays</td>
</tr>
<tr>
<td>103 28 084.7</td>
<td>Erhöhung der Brillanz von Diodenlasern</td>
</tr>
<tr>
<td>203 15 196.8</td>
<td>Anordnung/Verfahren zur Justage optischer Komponenten in Lasern oder Laseranordnungen</td>
</tr>
<tr>
<td>103 42 748.1</td>
<td>Polieren poröser Werkstoffe mit Laserstrahlung</td>
</tr>
<tr>
<td>103 42 750.3</td>
<td>Verfahren zum Glätten und Polieren oder zum Strukturieren von Oberflächen</td>
</tr>
<tr>
<td>103 27 260.7</td>
<td>Optische Verstärkeranordnung</td>
</tr>
<tr>
<td>103 28 081.2</td>
<td>Homogenisierung durch Mikrooptik</td>
</tr>
<tr>
<td>103 00 439.4</td>
<td>Verfahren und Vorrichtung zum Behandeln von Oberflächen</td>
</tr>
<tr>
<td>103 10 623.5</td>
<td>Verfahren und Vorrichtung zum Erzeugen eines Plasmas durch elektrische Entladung in einem Entladungsraum</td>
</tr>
</tbody>
</table>
Rogg, J. - 07.02.2003
Hochleistungsiodenlaser hoher Strahlqualität mit integrierten winkelselektiven Modenfiltern

Geißler, St. - 25.03.2003
Regelung der Abtragstiefe für das reaktive Abtragen mit CO₂-Laserstrahlung

Steffens, O. - 07.04.2003
Adaption numerisch gesteueter Werkzeugmaschinen an das Fertigungsumfeld bei der Materialbearbeitung mit Laserstrahlung

Kratzsch, Chr. - 30.04.2003
Realisierung eines kamerabasierten Prozessüberwachungssystems am Beispiel des Laserstrahlenschweißens

Bernges, H.-J. - 09.05.2003
Auslegung und Anwendung nichtrotationssymmetrischer Optiken für die Lasermikrobearbeitung

Over, Chr. - 18.06.2003
Generative Fertigung von Bauteilen aus Werkzeugstahl X38 CrMoV 5 1 und Titan TiAl16V4 mit Selective Laser Melting

Hobein, B. - 15.07.2003
Herstellung von dünnen Elektrolytschichten mittels Laserablation und Kathodenzerstäubung für Hochtemperatur-Brennstoffzellen

Rinner, F. - 15.07.2003
Verbesserung der Langzeitstabilität von InGaAs/AlGaAs Hochleistungsiodenlasern

Baumann, M. - 25.07.2003
Analyse und Formung von Diodenlaserstrahlung

Berden, T. - 11.09.2003
Mikroabtrag von Polymeren mit Kurzpuls-Laserstrahlquellen für optoelektronische Anwendungen

Horn, A. - 11.09.2003
Zeitaufgelöste Analyse der Wechselwirkung von ultrakurz gepulster Laserstrahlung mit Dielektrika

Beersiek, J. - 13.11.2003
Überwachung und Regelung der Einschweißtiefe beim Schweißen mit Laserstrahlung

Röhner, M. - 21.11.2003
Einzeladressierbare Diodenlaserbarren für lithographische Anwendungen

Perera Mercado, Y.-A. - 09.12.2003
Diamond-like carbon and ceramic materials as protective coatings grown by pulsed laser deposition

Slab laser hoher Brillanz für den Einsatz in der Mikro- und Makro-Materialbearbeitung

Approximatives Modell für das Tiefschweißen mit Laserstrahlung
Barthel, Juri  
Untersuchung der Wechselwirkungen von extrem ultravioletter Strahlung mit Materie für mess-technische Anwendungen

Birkner, Bernhard  
Konzeptionierung, Entwurf und Aufbau einer Kontroll- und Regeleinheit für Versorgungsnetzteile von diodengepumpten, frequenzvervielfachten Festkörperlasern

Cheng, Chia-Hung  
Vorrichtung für die laserunterstützte Mikroanastomose an Samenleitern

Fleige, Rüdiger  
Untersuchungen der Dynamik von laserinduzierten Plasmen aus Mikrotropfen

Geiger, Jens  
Konzeptionierung eines breitbandig durchstimmbaren Ti:Al₂O₃-Kurzpulslasers

Heesen-Te, Henrik  
Dynamik der Abtragsfront beim Bohren

Hoehne, Manuela  
Tiefenprofilanalyse verzinkter Bleche mit Hilfe der laserinduzierten Atomemissionsspektrometrie (LIBS)

Jansen, Stefan  
Entwicklung einer Prozesskette zur Auslegung und Herstellung einer belastungs- und fertigungsgerechten Knochenprothese mit dem SLM-Verfahren

Kiedrowski, Thomas  
Untersuchung der Prozessführung für die Verarbeitung von Metall-Keramik Pulvermischungen mit dem SLM-Verfahren

Kinnen, Werner  
Entwicklung einer stackbaren, ausdehnungsangepassten passiven Wärmesenke für Hochleistungs- diodenlaser

Lafuente Cerdá, Patricia  
Untersuchung und Charakterisierung von Laser deponierten planaren Er:BaTiO₃ Wellenleitern

Müller, Jaques  
Fertigungstechnische Studie zum Aufbau kompakter Slablaser in Planartechnik

Regaard, Boris  
Statistische Untersuchung der Korrelation von Prozessgrößen und Sensorsignalen beim Laserstrahlschweißen; Implementierung einer Online-Signalanalyse zur quantitativen Bestimmung dieser Prozessgrößen

Schell, Alexander  
Konzeptionierung, Entwurf und Aufbau einer Regeleinheit für einen diodengepumpten frequenzvervielfachten Festkörperlaser

Straesser, Alexander  
Propagation gepulster Laserstrahlung durch thermisch hochbelastete Verstärkeranordnungen

Wenk, Robert  
Bildverarbeitungsalgorithmen für die optische 3D-Geometrieerfassung bei Blechumformprozessen

Wypadlo, Markus  
Konstruktion eines Probenstands für die Laser-Präparation und -Analyse von Stahlproben
Adapted diode laser modules for materials processing
Proceedings of the 2nd International WLT-Conference on Lasers in Manufacturing 2
Seiten 13-15, 2003

J. Michel, S. Pfeiffer, W. Schulz, M. Niessen, V. Kostrykin
Approximate Model for Laser Welding
Radons, G. / Neugebauer, R. (eds.)
Nonlinear Dynamics of Production Systems
Seiten 1-16, 2003

J. Michel, S. Pfeiffer, W. Schulz, M. Niessen, V. Kostrykin, C. Maier
Approximate Model for Laser Welding
Proceedings of the 2nd International WLT-Conference on Lasers in Manufacturing 2
Seiten 321-326, 2003

E. W. Kreutz, L. Bölke, S. Kaierle, S. Mann, J. Ortman, J. Willach
Autonomous Production Cell for µm- and nm-Processing
Proceedings of SPIE 4977
Seiten 16-27, 2003

D. Petring
CALCut – Experiences in Calculating the Laser Cutting Process
Proceedings of the LCWG-Meeting, International Institute of Welding
IE-361-03
Seiten 1-26, 2003

M. Röhrer, H. Muentez, O. Schroeder, K. Boucke, R. Poprawe
Characterization Device for Diode-Laser-Stack Beam Propagation
Proceedings of SPIE 4932
Seiten 608-614, 2003

M. Traub, H.-D. Hoffmann, K. Du, R. Poprawe
Compact high-power diode laser pump modules for intersatellite communications
Proceedings of SPIE 4973
Seiten 128-134, 2003

Compact Laboratory EUV-Lamps: «In-House Beamlines» for Technologies Based on Extreme Ultraviolet Radiation
VDI-Buch: MicroNano Integration 16
Seiten 259-261, 2003

J. Willach, J. Michel, A. Horn, W. Schulz, E. W. Kreutz, R. Poprawe
Approximate Model for Laser Trepanning with Microsecond Nd:YAG Laser Radiation
Proceedings of the 7th International Conference on Laser Ablation 7
Seiten 1-3, 2003

J. Petring
Advances in welding automotive materials with high power diode lasers
Proceedings of the 11th Automotive Laser Application Workshop ALAW 11
Seiten 1-10, 2003

An example for modular diode laser systems: Minimizing warpage during transformation hardening of linear guiding rails
Proceedings of the 2nd International WLT-Conference on Lasers in Manufacturing 2
Seiten 33-38, 2003

C. Benter, B. Seme, D. Petring, R. Poprawe
Application of New Diode Laser Tools for Cutting and Welding
Proceedings of the 2nd International WLT-Conference on Lasers in Manufacturing 2
Seiten 85-91, 2003

Compact Laboratory EUV-Lamps: «In-House Beamlines» for Technologies Based on Extreme Ultraviolet Radiation
VDI-Buch: MicroNano Integration 16
Seiten 259-261, 2003

P. Abels, S. Fujinaga, S. Kaierle, S. Katayama, C. Kratzsch, A. Matsumiwa, K. Miyamoto, J. Peteraet, R. Poprawe
Correlation of Process Monitoring with X-Ray Observation of CO2 Laser Beam Welding
Proceedings of the 2nd International WLT-Conference on Lasers in Manufacturing 2
Seiten 1-5, 2003

N. Bönig, M. Röhner, K. Boucke, R. Poprawe
Demonstration device for individually addressed high-power laser bars
Proceedings of the 2nd International WLT-Conference on Lasers in Manufacturing 2
Seiten 93-96, 2003

R. Poprawe, W. Schulz
Development and application of new high-power laser beam sources
Riken Review 50
Seiten 3-10, 2003

R. Lebert, C. Wies, L. Juschkin, B. Jägle, W. Neff, J. Barthel, K. Walter, K. Bergmann
Extreme Ultraviolet Radiation From Pulsed Discharges: A New Access to »Nanoscopys« and »Nanotronics«
VDI-Buch: MicroNano Integration 16
Seiten 169-184, 2003

J. Gottmann, G. Schlaghecken, R. Wagner, E. W. Kreutz
Fabrication of erbium doped planar waveguides by pulsed laser deposition and laser micro-machining
Proceedings of SPIE 4941
Seiten 148-156, 2003

L. Bölke, E. W. Kreutz, J. Petereit, P. Abels, S. Kaierle, C. Kratzsch
Failure recognition and online processing control in laser beam welding
Proceedings of Laser Technologies in Welding and Materials Processing LTWMMP 1
Seiten 1-6, 2003

M. Röhrer, N. Bönig, K. Boucke, R. Poprawe
High-power diode-laser-bars with 19 up to 48 individually addressable emitters
Proceedings of SPIE 4973
Seiten 18-25, 2003

M. Traub, H.-D. Plum, H.-D. Hoffmann, P. Loosen, R. Poprawe
Homogenized high power diode laser systems for material processing and illumination
Proceedings of the 2nd International WLT-Conference on Lasers in Manufacturing 2
Seiten 29-32, 2003

D. Petring, C. Fuhrmann
Hybrid laser welding: laser and arc in concert
The Industrial Laser User 33
Seiten 24-26, 2003

D. Petring
Hybridschweißen – Laser trifft Lichtbogen
Metallbau 8
Seiten 68-70, 2003

A. Bollig, D. Abel, C. Kratzsch, S. Kaierle
Identification and predictive control of laser beam welding using neural networks
Proceedings of the European Control Conference ECC 1
Seiten 1-8, 2003

W. Schulz, U. Eppelt, H. Te Heesens, V. Kostrykin, J. Michel, M. Nießen
Identification of Dimension in Phase Space for Cutting
Proceedings of the 2nd International WLT-Conference on Lasers in Manufacturing 2
Seiten 351-355, 2003

U.-A. Russek
Innovative joining process – Laser beam welding of thermoplastics
Tagungsband zur Konferenz »Optische Technologien für die Kunststoffbearbeitung« 1
Seiten 1-12, 2003

U.-A. Russek
Innovative Trends in Laser Beam Welding of Thermoplastics
Proceedings of the 2nd International WLT-Conference on Lasers in Manufacturing 2
Seiten 105-111, 2003

C. Scholz, K. Boucke, R. Poprawe
Investigation of Indium Solder Interfaces for High-Power Diode Lasers
Proceedings of SPIE 4973
Seiten 60-67, 2003
V. Kostrykin, W. Schulz, M. Nießen, J. Michel

**Short-time dynamics in laser material processing**
Radons, G. / Neugebauer, R. (eds.)
Nonlinear Dynamics of Production Systems 1
Seiten 17-26, 2003

U.-A. Russek, H. Staub, A. Palmen, H. Kind

**Simultaneous laser beam welding of thermoplastics - innovations and challenges**
Proceedings of ICALEO 22
Seiten 1-9, 2003

M. Kraushaar, R. Noll, H.-U. Schmitz

**Slag Analysis with Laser-Induced Breakdown Spectrometry**
Applied Spectroscopy 57/10
Seiten 1282-1287, 2003

Y. Feng, J. Gottmann, E. W. Kreutz

**Structuring of poly ether ether ketone by ArF excimer laser radiation in different atmospheres**
Applied Surface Science 211
Seiten 68-75, 2003

A. Horn, E. W. Kreutz, R. Poprawe

**Ultrafast time-resolved photography of femtosecond laser induced modifications in BK7 glass and fused silica**
Proceedings of the 7th International Conference on Laser Ablation 7
Seiten 4-6 , 2003

E. W. Kreutz

**Verpackungsbeschriftung mit Lasertechnik**
Unterlagen zum Seminar »Verpacken medizinischer Artikel mit Kunststoffen« 1
Seiten 1-19, 2003

14.01.03 - E. W. Kreutz

**Einrichten von Laserbereichen**
Seminar Ausbildung Laserschutzbeauftragter, Berufsgenossenschaft Feinmechanik & Elektrotechnik, Bad Münstereifel

14.01.03 - R. Noll

**Lasermesstechnik im industriellen Einsatz**
Symposium Lasertechnik, FH Südwestfalen, Isenlohn

19.01.03 - T. Kramer

**Laserstrahlmikroschweißen**
IWF Kolloquium, ETH Zürich

22.01.03 - A. Ololwinsky

**Laserstrahlverfahren in der Mikrotechnik**
IWF Kolloquium, ETH Zürich

23.01.03 - J. Gottmann

**Pulsed laser deposition**
Seminar Laserzentrum, Hannover

23.01.03 - W. Neff

**Plasmabasierte XUV-Strahlungsquellen**
IPF-Plasma-Kolloquium, Universität Stuttgart, Stuttgart

24.01.03 - T. Mans

**Colquirite fs-sources for commercial applications**
Photonics West 2003, LASE 03, San José, USA

24.01.03 - M. Traub

**Compact high-power diode laser pump modules for intersatellite communications**
Photonics West 2003, LASE 03, San José, USA

24.01.03 - M. Röhner

**High-power diode-laser-bars with 19 up to 48 individually addressable emitters**
Photonics West 2003, LASE 03, San José, USA

24.01.03 - C. Scholz

**Investigation of indium solder interfaces for high-power diode lasers**
Photonics West 2003, LASE 03, San José, USA

25.01.03 - T. Kramer

**Out of the SHADOW: watch parts in the spotlight**
Photonics West 2003, LASE 03, San José, USA

25.01.03 - A. Ololwinsky

**Laser beam soldering: an attractive alternative to conventional soldering technologies**
Photonics West 2003, LASE 03, San José, USA

27.01.03 - E. W. Kreutz

**Autonomous production cell for µm- and nm-processing**
Photonics West 2003, LASE 03, San José, USA

28.01.03 - W. Meiners

**Das SLM Verfahren**
VDI Seminar »Rapid Technologies«

29.01.03 - W. Schulz

**Modellierung und Simulation am Fraunhofer ILT**
Themenverband NUSIM, Fraunhofer IWM, Freiburg

30.01.03 - U.-A. Russek

**Laser beam welding of thermoplastics**
Photonics West 2003, LASE 03, San José, USA

13.02.03 - A. Gasser

**Hochbelastbare Beschichtungen durch 2-stufige Verfahrenskombination**
Workshop »Rapid Tooling-Automatisierte Prozesse und neue Prozessketten«
Fraunhofer IWS, Dresden

14.02.03 - P. Loosen

**Optische Systemtechnik für Hochleistungs-Diodenlaser und Anwendungen**
Kolloquium »Technologie Optischer Systeme«, FB Maschinenwesen, RWTH Aachen

19.02.03 - E. Willenborg

**Polieren mit Laserstrahlung**
Thementag »Lasers: Doorbraak in metaalwerking«, Enschede

05.03.03 - J. Vrenegor

**Laser-Präparation und Laser-Analyse von Produktionskontrollproben**
10. Anwendertreffen Röntgenfluoreszenz- und Funkenspektrometrie, Steinfurt
durch Beschichten mit Laser-

108 Fraunhofer ILT Annual Report 2003
ExpoLaser 2003, Ancona
robust way to high quality joints
hybrid welding: an efficient and
tions offered by laser
tive materials with high power
Advances in welding of automo-
tation process
17.03.03 - D. Petring
Lasereinsatz in der Feinwerk-
technik
LFF 2003, Erlangen
12.03.03 - G. Vitr
Korrosionsschutz an Stahlble-
chen und ihren Schnittflächen
durch Beschichten mit Laser-
strahlung
3. Stahl Symposium »Werkstoffe,
Anwendung, Forschung«,
 STUDIENGESSELLSCHAFT STAHL, DÜSSELDORF
12.03.03 - D. Petring
Advances in welding of automo-
tive materials with high power
diode lasers
11th Annual Automotive Laser
Application Workshop ALAW 2003,
Detroit, USA
12.03.03 - S. Kaierle
New automotive laser applica-
tions require improved quality
control tools
11th Annual Automotive Laser
Application Workshop ALAW 2003,
Detroit, USA
17.03.03 - D. Petring
CALCut: experiences in calculating
the laser cutting process
IWW-LCWG Meeting, Paris
21.03.03 - D. Petring
Laser cutting: state of the art
and technological trends
Expolaser 2003, Ancona
21.03.03 - D. Petring
New possibilities offered by laser
 hybrid welding: an efficient and
robust way to high quality joints
Expolaser 2003, Ancona
21.03.03 - D. Petring
Laser cladding: innovative
applications for production and
repairing of moulds
Expolaser 2003, Ancona
24.03.03 - K. Bergmann
Hollow cathode triggered
pinch plasma as radiation source
in the extreme ultraviolet and
soft-x-ray range
Fruhjahrestagung der Deutschen
Physikalischen Gesellschaft, Aachen
24.03.03 - J. Barthel
Nanoscale applications with
laboratory size XUV-sources
Fruhjahrestagung der Deutschen
Physikalischen Gesellschaft, Aachen
24.03.03 - T. Lierfeld
Charge transfer measurement of
micro discharges in single-gap
and cascaded discharge setups
Fruhjahrestagung der Deutschen
Physikalischen Gesellschaft, Aachen
24.03.03 - C. Over
New lasers for new applications,
mass customization
Westec 2003, Los Angeles, USA
25.03.03 - E. W. Kreutz
Biologische Grundlagen und
zulassige Grenzwerte
Seminar Ausbildung Laserschutz-
beauftragter, Technische Akademie
Wuppertal, Wuppertal
25.03.03 - U. Eppelt
Spectral analysis of a boundary
layer flow
Spring Conference on Plasma
Physics and Short Time Scale Physics
2003, Aachen
26.03.03 - E. W. Kreutz
Laserauftragsschweissen für die
Herstellung und Instandsetzung
von metallischen Bauteilen
Fruhjahrestagung der Deutschen
Physikalischen Gesellschaft, Aachen
26.03.03 - O. Franken
Plasma sterilisation of polymer
foils by means of a cascaded
discharge setup (Poster)
Fruhjahrestagung der Deutschen
Physikalischen Gesellschaft, Aachen
27.03.03 - A. Horn
Investigation of the photon
matter interaction in the femto-
second regime by time-resolved
Nomarski-photography and
transient absorption spectroscopy
via the pump and probe method
Fruhjahrestagung der Deutschen
Physikalischen Gesellschaft, Aachen
27.03.03 - M. Talkenberg
UV laser-induced color centers in
photosensitive glass
Fruhjahrestagung der Deutschen
Physikalischen Gesellschaft, Aachen
27.03.03 - M. Heise
Characterisation of a cascaded
discharge set up by UV-VIS-spectro-
scopy
Fruhjahrestagung der Deutschen
Physikalischen Gesellschaft, Aachen
27.03.03 - H. te Heesen
Dynamics of the ablation front
in laser drilling
Spring Conference on Plasma
Physics and Short Time Scale Physics
2003, Aachen
28.03.03 - M. Dahmen
Feasibility study on welding of
FeCrAl foils
Seminare: Soudage laser des struc-
tures alveolaires pour pot cataly-
tiques en FeCrAl, Ecole des Mines
Pierre-Marie Fourn, Evry, Frankreich
04.04.03 - K. Wissenbach
Aktuelle Entwicklungen in
der Oberflächenbearbeitung
mit Lasern am Fraunhofer ILT
Seminar des AKL e.V., Aachen
08.04.03 - W. Neff
Kaskadierte Barrierenentladungen
VDI-Gespräch »Neuartige modulare
und selektive Plasmaquellen«,
VDI-Technologiezentrum, Düsseldorf
09.04.03 - V. Kostykin
Short-time dynamics in laser
material processing
Symposium Volkswagenstiftung
»Investigation on Non-linear Dyna-
ic Effects in Production Systems«,
Chemnitz
09.04.03 - J. Michel
Approximate model for laser
welding
Symposium Volkswagenstiftung
»Investigation on Non-linear Dyna-
ic Effects in Production Systems«,
Chemnitz
09.04.03 - W. Schulz
Modelling and simulation of
process monitoring and control
in laser cutting
Symposium Volkswagenstiftung
»Investigation on Non-linear Dyna-
ic Effects in Production Systems«,
Chemnitz
14.04.03 - J. Gottmann
Dynamik der Pulsed Laser
Deposition von Oxideramiken
Seminarvortrag, Universität
Hamburg, Institut für Laserphysik,
Hamburg
25.04.03 - R. Noll
Analytical applications of LIBS
Symposium »Laser ablation and
related techniques« OCAS, Zelzate,
Belgium
06.05.03 - H.-D. Hoffmann
Lasern: Mikrowellen von
Glas
Jahrestagung Glas-Fachhochschule,
Zwiesel
05.05.03 - E. W. Kreutz
Verpackungsbeschriftung
mit Laserlicht
Fachtagung »Verpacken medizi-
nischer Artikel mit Kunststoffen«,
Festung Marienberg, Würzburg
06.05.03 - U.-A. Russek
Laserschweißen medizini-
nischer Verpackungen
Fachtagung »Verpacken medizini-
scher Artikel mit Kunststoffen«,
Festung Marienberg, Würzburg,
06.05.03 - A. Bauer
Innovationsmanagement zwi-
sehen Methodik und Intuition
beim Beispiel »Kompetenznetz
Laserindustrie Aachen«
Adventur-Tagung »Markt
Deutschland«, Frankfurt
07.05.03 - U.-A. Russek
High power diode lasers for
polymer welding
4. Workshop »Industrielle Anwen-
dungen von Hochleistungsdiode-
lasern«, Fraunhofer IWS, Dresden
13.05.03 - S. Pfeiffer
Prozessüberwachung durch
bildgebende Verfahren
Seminar Fraunhofer FIT,
Schloss Birlinghoven, Bonn
21.05.03 - R. Poprawe
Wie funktioniert eigentlich ein Laser
Seniorenstudium der RWTH Aachen, Aachen

16.05.03 - M. Nießen
Numerical simulation of free boundary problems in laser assisted manufacturing
MPCCI User Forum, Fraunhofer SCAI, Schloss Birlinghofen, Bonn

17.05.03 - L. Boeske
Failure recognition and online processing control in laser beam welding
Laser Technologies in Welding and Material Processing, Katsveli, Ukraine

17.05.03 - A. Olowsky
Laser beam micro forming as a new adjustment technology using dedicated actuator structures
Spie «Microtechnologies for the new Milenium», Maspalomas, Gran Canaria

20.05.03 - E. W. Kreutz
New lasers and applications in innovative technologies
Laser Technologies in Welding and Material Processing, Katsveli, Ukraine

21.05.03 - R. Noll
Prüfung von Nockenwellen mit Lasertriangulation
PhotonAix- Anwenderforum «Optische Messtechnik in der Produktion», Fraunhofer ILT, Aachen

21.05.03 - D. Petring
Recent progress and trends in laser hybrid welding
AILU Technology Workshop «Efficient use of lasers in sheet metal working», Kidderminster, England

02.06.03 - U.-A. Russek
Advances in laser beam welding of polymers and automotive prospects
9th International Conference »TPOs in Automotive 2003«, Maastricht, Nederland

04.06.03 - R. Noll
On-line characterisation of zinc coatings LIBSCOAT ECSC E Technical Group Meeting, Luxemburg

13.06.03 - W. Schulz
Maßgeschneiderte Simulation freier Randwertaufgaben Themeverbund NUSIM, Fraunhofer SCAI, Schloss Birlinghofen, Bonn

21.06.03 - T. Mans
Direct diode pumped, regenerative 100μJ sub 100fs amplifier on the basis of colquiriite crystals
CLEO Europe 2003, München

21.06.03 - J. Willach
Melt expulsion by a coaxial gas stream for trepanning with microsecond Nd:YAG laser radiation
LPM 2003, München

21.06.03 - K. Bergmann
Gas discharge based sources in the EUV and soft x-ray range for industrial applications
Summer School, Plasma Physics, Diagnostics and Plasma related Applications, Kudowa, Polen

21.06.03 - M. Röhner
Individually addressed high-power diode-laser-bars for material processing
CLEO Europe 2003, München

21.06.03 - E. Bremus-Koebberling
Laser structuring and modifi- cation of surfaces for chemical and medical micro-components
LPM 2003, München

22.06.03 - M. Traub
Homogenized high power diode laser systems for material processing and illumination
WLT-Konferenz »Lasers in Manufacturing 2003«, München

22.06.03 - K. Klages
Laser beam micro welding of dissimilar metals
LPM 2003, München

22.06.03 - C. Benter, B. Seine
Application of new diode laser tools for cutting and welding
WLT-Konferenz »Lasers in Manufacturing 2003«, München

23.06.03 - A. Drenker
An example for modular diode laser systems: Minimizing warpage during transformation hardening of linear guiding rails
WLT-Konferenz »Lasers in Manufacturing 2003«, München

23.06.03 - W. Schulz
Identification of dimension in phase space for cutting
WLT-Konferenz »Lasers in Manufacturing 2003«, München

24.06.03 - R. Noll
Multi-beam laser triangulation for the measurement of geometric features of moving objects in production lines
CLEO Europe 2003, München

24.06.03 - M. Heise
Influence of homogeneity of dielectric barrier discharges on spore inactivation
16th International Symposium on Plasma Chemistry, Taormina, Italien

24.06.03 - B. Jungbluth
Widely tunable, narrow line-width all-solid-state laser system
CLEO Europe 2003, München

24.06.03 - A. Knitsch
Adapted diode laser modules for materials processing
WLT-Konferenz »Lasers in Manufacturing 2003«, München

24.06.03 - N. Boenig
Demonstrator für einzeladressierbare Hochleistungsdiodenlaser
WLT-Konferenz »Lasers in Manufacturing 2003«, München

24.06.03 - D. Petring
Investigations and applications of laser-arc hybrid welding with the integrated Nozzle WLT-Konferenz »Lasers in Manufacturing 2003«, München

24.06.03 - J. Michel
Approximate model for laser welding
WLT-Konferenz »Lasers in Manufacturing 2003«, München

25.06.03 - H. Bette
Laser-induced breakdown spectroscopy at 1000 Hz with single pulse evaluation for high-speed, high-resolution chemical element mapping
CLEO Europe 2003, München

25.06.03 - C. Janzen
Spectrochemical elemental analysis of small liquid droplets
CLEO Europe 2003, München

25.06.03 - K. Nicklaus
Pulsed high power solid state laser for high-speed precision machining
WLT-Conference »Lasers in Manufacturing 2003«, München

25.06.03 - U.-A. Russek
Innovative trends in laser beam welding of thermoplastics
WLT-Konferenz »Lasers in Manufacturing 2003«, München

25.06.03 - V. Kostrykin
Perturbation of spectral subspaces International Workshop on Operator Theory and its Applications, Cagliari, Italien

02.07.03 - C. Over
Laserschmelzen - Ein generatives Fertigungsverfahren für die Serienproduktion
IW3 Seminar »Mit Rapid Technologien zum Aufschwung«, Augsburg

03.07.03 - R. Poprawe
Jubiläumsansprache 10 Jahre Bayisches Laserzentrum
Bayisches Laserzentrum BLZ, Erlangen

04.07.03 - R. Noll
Industrielle Anwendungen der Lasermesstechnik für Prozessführung und Qualitätssicherung in der Produktion
VDI Wissensforum »Optische 3D-Messtechnik für die Qualitätssicherung in der Produktion«, Jena

13.07.03 - S. Keutgen, E. W. Kreutz
Basis on laser cladding of titanium for the repair of damaged compressor blades for jet engines
10th world Conference on Titanium, Hamburg
10.07.03 - W. Meiners
Generative Herstellung von Ti-Tauleiten mit SLM
10th world Conference on Titanium, Hamburg

16.07.03 - V. Kostrykin
Über den Adiabatensatz
Oberseminar, Institut für Reine und Angewandte Mathematik, RWTH Aachen, Aachen

29.07.03 - V. Kostrykin
Eine singuläre strömungs-theoretische Aufgabe für die Ricatti-Gleichung
International Congress on Mathematical Physics, Lissabon, Portugal

31.07.03 - M. Nießen
Simulation freier Randwertaufgaben und ihre Anwendungen in der Lasermaterialbearbeitung
Seminar, Institut für Geometrie und praktische Mathematik, RWTH Aachen, Aachen

03.09.03 - B. Jungbluth
Widely tunable all-solid-state laser system with nanosecond pulses
Deutsch-kanadische Konsultationen zur WTZ, Workshop: »Young Scientist in Photonics«, Ottawa, Kanada

08.09.03 - B. Jungbluth
Grundlagen eines durchstimm-baren All-Solid-State-Lasers hoher Leistung - Statusbericht
BMBF-Projekt-Verbund-Treffen »Grundlagen neuer lasergestützter Screeningmethoden«, SCREEN, Münster

10.09.03 - E. W. Kreutz
Biologische Grundlagen und zulässige Grenzwerte - Klassifizierung von Lasereinrichtungen
Seminar »Schulung zum Laser-schutzbeauftragten«, Südwestdeutsche Metall Berufsgenossenschaft, Lengfurt

10.09.03 - C. Janzen
Spectrochemical elemental analysis of small liquid droplets
Colloquium Spectroscopicum Internationalis XXXIII, Granada, Spanien

17.09.03 - U.-A. Russek
Laserstrahltechnik - Technologie der Zukunft für Kunststoffverarbeiter
Vortragsreihe Kunststoff-Cluster, Neue Technologie zur Bearbeitung von Halbzugen und Formteilen, Schloss Puchberg, Österreich

22.09.03 - K. Boucke
Trends and developments of high-power diode lasers
Lasership 5, Les Eyzies/Tursac, Frankreich

24.09.03 - E. W. Kreutz
An autonomous production cell for processing with laser radiation
5th Symposium on Laser and Application, Les Hautes de Marquay, Sarlat, Frankreich

25.09.03 - R. Poprawe
Angewandte Forschung im Innovationsprozess der Lasertechnik
Stuttgartter Laseragte 2003, Stuttgart

26.09.03 - E. W. Kreutz
Laser cladding and laser surface melting for manufacturing of metal parts
5th Symposium on Laser and Application, Les Hautes de Marquay, Sarlat, Frankreich

28.09.03 - K. Wissenbach
Lasereinsatz in der Oberflächenbehandlung
Otto Kolleg »Lasereinsatz in der Fertigung und M Hartbearbeitung«, Regensburg

30.09.03 - O. Rosier
Lasergestützte Präparation und deren Auswirkung auf die Schweißnaht
Seminar Laserstrahl-Kunststoffschweißen, Bayisches Laserzentrum, Erlangen

03.10.03 - J. Willach
Approximate model for trepanning with microsecond Nd:YAG laser radiation
Conference on Laser Ablation 2003, Hornissos, Kreta, Griechenland

01.10.03 - M. Poggel
Parameteränderungen beim Laserstrahl-Kunststoffschweißen und deren Auswirkung auf die Schweißnaht
Seminar Laserstrahl-Kunststoffschweißen, Bayisches Laserzentrum, Erlangen

03.10.03 - A. Brysch
Multi-elemental analysis of aerosols in a high-pressure atmosphere
EMSILIBS II, Hersonissos, Kreta, Griechenland

03.10.03 - A. Horn
Ultra fast time-resolved photography of femtosecond laser induced modifications in BK7 glass and fixed silica
Conference on Laser Ablation 2003, Hornissos, Kreta, Griechenland

04.10.03 - H. Horn-Solle
Cleaning and/or modification of technical materials by laser radiation for improvement of adhesive bonding

05.10.03 - J. Gottmann
Fabrication of Er:BaTiO3 planar waveguides by pulsed laser deposition and laser micromachining
Conference on Laser Ablation 2003, Hornissos, Kreta, Griechenland

06.10.03 - A. Brysch
Lasergestützte Multi-Element-Analyse von Gichtstaub für die Prozesskontrolle in der Stahlindustrie
23. Spektrometertagung, Linz, Österreich

06.10.03 - J. Makowe
Schnelle Identifikation von Leichtmetall-Legierungen mit Laser-Emissionsspektrometrie für das werkstoffliche Recycling
23. Spektrometertagung, Linz, Österreich

06.10.03 - V. Sturm
Eigenschaften und Vorteile der schnellen Stahlreinheitsanalyse mit Laser- Emissionsspektrometrie hoher Ortsauflösung
23. Spektrometertagung, Linz, Österreich

09.10.03 - C. Janzen
MLA: A universal laser based micro-measuring and processing platform for proteomics
Innovationsforum Biotechnica 2003, Hannover

10.10.03 - S. Mann
Autonomous production cell for laser beam welding
ICALEO 2003, Jacksonville, USA

10.10.03 - J. Ortmann
Online detection of defect classes for laser beam welding
ICALEO 2003, Jacksonville, USA

10.10.03 - A. Gillner
Forschungs- und Entwicklungsaktivitäten im Bereich Life Sciences am Fraunhofer ILT
Seminar des AKL e.V., Aachen
10.10.03 - C. Schnitzler
Fiber coupled kW class high-power slab laser
ICALEO 2003, Jacksonville, USA

11.10.03 - M. Traub
High speed cleaning of railheads with a fiber-coupled Nd:YAG laser
ICALEO 2003, Jacksonville, USA

11.10.03 - K. Klages
Laser beam micro welding of dissimilar metals
ICALEO 2003, Jacksonville, USA

12.10.03 - A. Olowinsky
Advances in laser beam micro forming for micro positioning
ICALEO 2003, Jacksonville, USA

13.10.03 - A. Knitsch
Diode laser systems for cutting applications of thin materials
ICALEO 2003, Jacksonville, USA

14.10.03 - R. Noll
Online multi-elemental analysis using laser-induced breakdown spectroscopy (LIBS) - research fields, industrial applications and future perspectives
ICALEO 2003, Jacksonville, USA

14.10.03 - U.-A. Russek
Simultaneous laser beam welding of thermoplastics - innovation and challenges
ICALEO 2003, Jacksonville, USA

14.10.03 - D. Petring
Investigations and applications of laser-arc hybrid welding from thin sheets up to heavy section components
ICALEO 2003, Jacksonville, USA

15.10.03 - E. W. Kreutz
Laser in der Metallverarbeitung und andere optische und elektrische Gefahren
Lehrgang Schulung zum Laser-Schutzbeauftragten, Technische Akademie Esslingen, Esslingen

16.10.03 - J. Ortmann
Online detection of defect classes for laser beam welding
ICALEO 2003, Jacksonville, USA

21.10.03 - H.-D. Hoffmann
Festkörper- und Diodenlaser für das Schweißen von Kunststoff
Seminar »Laserstrahlschweißen von Kunststoffen«, Süddeutsches Kunststoffzentrum SKZ, Würzburg

22.10.03 - U.-A. Russek
Parameteränderungen beim Laserdurchstrahlsschweißen von Thermoplasten und deren Auswirkung auf die Schweinaht Seminar »Laserstrahlschweißen von Kunststoffen«, Süddeutsches Kunststoffzentrum SKZ, Würzburg

23.10.03 - R. Noll
Chemische Analyse mit Laserstrahlung - Grundlagen, Anwendungen und Perspektiven Mathematisch-Technisches Kollegium, RheinAhr Campus, Remagen

24.10.03 - A. Gasser
Laserstrahl-Auftragsschweifen Osthochsweizer Technologiesymposium OTS3, St. Gallen, Schweiz

24.10.03 - V. Kostrykin
Einige Abschätzungen für die Hallegruppen-Differenz Kolloquiumsveranstaltung, Institut für Mathematik, TU Clausthal

28.10.03 - K. Wissenbach
Laser einsatz in der Werkzeugtechnik - Ein Überblick Aachener Laserseminare, Laser in Werkzeug- und Formenbau, Fraunhofer ILT, Aachen

28.10.03 - C. Over
Laserschmelzen – Fertigung von Serienwerkzeugen Aachener Laserseminare, Laser im Werkzeug- und Formenbau, Fraunhofer ILT, Aachen

28.10.03 - A. Weisheit
Reparaturschichten von Werkzeugen und Herstellung von Funktionschichten mit Laserstrahlung Aachener Laserseminare, Laser im Werkzeug- und Formenbau, Fraunhofer ILT, Aachen

28.10.03 - C. Johning, E. Willenborg
Reinigen und Polieren von Werkzeugen mit Laserstrahlung Aachener Laserseminare, Laser im Werkzeug- und Formenbau, Fraunhofer ILT, Aachen

28.10.03 - A. Gillner
Laserabtrag zur Herstellung von Mikrowerkzeugen Aachener Laserseminare, Laser im Werkzeug- und Formenbau, Fraunhofer ILT, Aachen

29.10.03 - A. Olowinsky
Justieren mit Laserstrahlung - schnelle Montage, µm-genaue Positionierung Aachener Laserseminare, Laser im Feinwerk- und Mikrotechnik, Fraunhofer ILT, Aachen

29.10.03 - A. Olowinsky
Präzisionswerkzeug mit Laserstrahlung in der Feinmechanik Aachener Laserseminare, Laser in Feinwerk- und Mikrotechnik, Fraunhofer ILT, Aachen

29.10.03 - L. Bosse
Löten mit Laserstrahlung - selektiv und prozesssicher Aachener Laserseminare, Laser in Feinwerk- und Mikrotechnik, Fraunhofer ILT, Aachen

29.10.03 - A. Gillner
Laserstrahlschweißprozesse für die Präzisionsbearbeitung: Welcher Laser für welche Anwendung Aachener Laserseminare, Laser in Feinwerk- und Mikrotechnik, Fraunhofer ILT, Aachen

29.10.03 - V. Kostrykin
A random necklace model Internationale Konferenz »Random Media«, Mathematisches Forschungsinstitut, Oberwolfach

30.10.03 - A. Gillner
Strukturieren und Bohren von Metallen mit Laserstrahlung Aachener Laserseminare, Laser in Feinwerk- und Mikrotechnik, Fraunhofer ILT, Aachen

30.10.03 - M. Wehner
Strukturieren und Bohren von Polymeren und Keramiken mit Laserstrahlung – Hohe Präzision vom Mikrometerbereich bis zu Nanostrukturen Aachener Laserseminare, Laser in Feinwerk- und Mikrotechnik, Fraunhofer ILT, Aachen

04.11.03 - M. Wehner
Erfahrungen im Betrieb einer VUV-Laseranlage 5. Arbeitstreffen des AK DUV/VUV, Optik, Leica Microsystems, Wetzlar

10.11.03 - J. Michel
Simulation der Beugung an Kugeln in technischen Anwendungen Kompetenzzentrum Prozesssimulation Aachen SIMPro, Aachen

11.11.03 - U.-A. Russek
Laserstrahlschweißprozesse als modernes Fügeverfahren in der Mikro- und Feinwerktechnik VDI Tagung »Optische Technologien für die Mikrofertigung«, München

11.11.03 - R. Noll
Innovative Verbindung - Grundlagen zum Laserleistungs- schweißen von Thermoplasten VDI, OTK 2003 - Optische Technologien für die Kunststoffbearbeitung, München

11.11.03 - V. Kostrykin
Differentialoperatoren auf Graphen International Workshop on Spectral Problems, Humboldt Universität zu Berlin, Berlin

17.11.03 - R. Poprawe
Zukunftschancen der Optischen Technologien in NRW Optische Technologien Zukunftstechnologie für NRW, Landtag NRW, Düsseldorf

18.11.03 - K. Bergmann
Extreme ultraviolet (XUV) for nanometer scale analysis and engineering NanoForum Seminar, Wien, Österreich

20.11.03 - E. W. Kreutz
Safety beim Umgang mit Ultra-kurzpuls-Laserstrahlung (ps, fs) Laser-Strahlshutzkurs für medizinische Anwendungen, Haus der Technik, Essen

20.11.03 - O. Klein
Industrielle Anwendungen der Lasermesstechnik für Prozessführung und Qualitätssicherung in der Produktion VDI Wissensforum »Optische 3D-Messtechnik«, Magdeburg

25.11.03 - R. Poprawe
Perspektiven der Anwendung von Lasertechniken in den Life Sciences ALSA-Seminar des Lifetec Aachen Jülich e. V., Aachen
Lectures

26.11.03 - U.-A. Russek
Laser und Kunststoff - eine feste Verbindung
Aachener Laserseminare, Kunststoffbearbeitung mit Laserstrahlung: eine vielseitige Technologie, Fraunhofer ILT, Aachen

26.11.03 - A. Gillner
Laserstrahlquellen für die Kunststoffbearbeitung
Aachener Laserseminare, Kunststoffbearbeitung mit Laserstrahlung: eine vielseitige Technologie, Fraunhofer ILT, Aachen

27.11.03 - U.-A. Russek
Schweißen und Schneiden von Polymeren mit Laserstrahlung - Etabliert und trotzdem nicht abgehakt, Ideen für die Zukunft
Aachener Laserseminare, Kunststoffbearbeitung mit Laserstrahlung: eine vielseitige Technologie, Fraunhofer ILT, Aachen

27.11.03 - G. Otto
Lasereinsatz in der Verpackungstechnik – Selektive Bearbeitung führt zu neuen Produktlösungen
Aachener Laserseminare, Kunststoffbearbeitung mit Laserstrahlung: eine vielseitige Technologie, Fraunhofer ILT, Aachen

27.11.03 - A. Gillner
Strukturieren, Trennen und Modifizieren von Polymeren mit Laserstrahlung
Aachener Laserseminare, Kunststoffbearbeitung mit Laserstrahlung: eine vielseitige Technologie, Fraunhofer ILT, Aachen

27.11.03 - P. Loosen
Polymer-/Organische Laser – Potentielle Systeme und Anwendungen
Workshop PolyLas, Schloss Krickenbeck, Nettetal

03.12.03 - A. Gillner
Photonik in Life Science
Erstes Fachforum »Moderne Optische Technologien«, Regensburg

04.12.03 - V. Sturm
Stand und aktuelle Entwicklungen der Laserspektrometrie für Anwendungen in der Stahlindustrie
Stahlinstitut VDEH, Chemikerausschuss LUA-Analytische Chemie, Düsseldorf

10.12.03 - J. Willach
Bohren von Metallen mit μs-Festkörperlaserstrahlung
Seminar Lasertechnik ILT, RWTH-Aachen, Aachen

17.12.03 - R. Poprawe
Perspectives of Photonics in Life Science
Philips Medical Workshop, Aachen

18.12.03 - S. Kaierle
Neue Entwicklungen in der Laser-Prozesskontrolle am Fraunhofer ILT
Seminar des AKL e.V., Aachen

07.04. - 12.04.2003
Hanover
HANNOVER FAIR 2003
The international industrial trade fair

The microengineering department of the Fraunhofer ILT exhibited at the joint microengineering stand hosted by IVAM NRW e.V.
ILT topics: assembly and interconnection, laser applications in plastics and paper manufacturing, the life sciences, and microstructuring.

19.05. - 24.05.2003
Frankfurt/Main
ACHEMA
International Exhibition-Congress on Chemical Engineering, Environmental Protection and Biotechnology

The microengineering department of the Fraunhofer ILT participated in the joint exhibit by the Fraunhofer Protein Chip Network.

23.06. - 26.06.2003
Munich
LASER World of Photonics
International trade fair and congress

The Fraunhofer ILT was present at the joint Fraunhofer stand. ILT topic: selective laser melting in the manufacture of dental prostheses.

07.10. - 09.10.2003
Hanover
BIOTECHNICA
International Trade Fair for Biotechnology

The microengineering department of the Fraunhofer ILT participated in the joint exhibit by the Fraunhofer Protein Chip Network.

13.10. - 16.10.2003
Jacksonville, USA
ICALEO 2003
International Congress on Applications of Lasers & Electro-Optics

The European Laser Institute, co-founded by the Fraunhofer ILT, took part as an exhibitor in the Vendor Session of ICALEO 2003.
09.01.2003, Chair for Laser Technology LLT at RWTH Aachen Lecture in association with the RWTH Colloquium on Laser Technology
Prof. Dr. U. Kreibig, First Institute for Physics at RWTH Aachen University:
»CLUSTER generation by laser radiation«.

15.01.2003, Chair for Laser Technology LLT at RWTH Aachen Lecture in association with the RWTH Colloquium on Laser Technology
Prof. Dr. W. Lauterborn, Third Institute for Physics at the University of Göttingen:
»Cavitation as a means of modifying the properties of materials«.

06.02.2003, Chair for Laser Technology LLT at RWTH Aachen Lecture in association with the RWTH Colloquium on Laser Technology
Dr. G. Esser, Bayerisches Laserzentrum GmbH, Erlangen:
»Laser-assisted generation of conductive electrical structures«.

04.04.2003, Aachen 10th seminar of »Aix Laser People«
the alumni club of the Fraunhofer ILT and the Chair for Laser Technology LLT, with lectures by Dr. Kurt Wissenbach, Fraunhofer ILT, on
»The latest developments in laser surface processing at the Fraunhofer ILT« and by Dr. Georg Erkens, CemeCon AG, Würselen, on
»Super nitrides – A new class of coating materials for high-performance machining«, followed by a visit to the premises of CemeCon AG in Würselen.

08.05.2003, Chair for Laser Technology LLT at RWTH Aachen Lecture in association with the RWTH Colloquium on Laser Technology
Prof. Dr. B. Lengeler, Second Chair for Experimental Physics (A/B) at RWTH Aachen:
»Refractive X-ray lenses: properties and applications«.

12.05.2003, Chair for Laser Technology LLT at RWTH Aachen Lecture in association with the RWTH Colloquium on Laser Technology
Prof. Dr. C. N. Afonso, Instituto de Optica, CSIC, Madrid, Spain:
»Nanostructured thin films for integrated photonic devices«.

12.06.2003, Chair for Laser Technology LLT at RWTH Aachen Lecture in association with the RWTH Colloquium on Laser Technology
Prof. Dr. B. Brenner, Fraunhofer Institute for Material and Beam Technology IWS, Dresden:
»Combined laser techniques in research and development«.

15.06. - 21.06.2003, Ven, Sweden Bio-Photonics 03, International Graduate Summer School organized by the Danish Center for Biomedical Optics and New Laser Systems with the participation of the European Laser Institute, co-founded by the Fraunhofer ILT.

25.06.2003, Munich 11th seminar of »Aix Laser People«
the alumni club of the Fraunhofer ILT and the Chair for Laser Technology LLT, with a stage debate on the topic of "Living and working in France«.

The following former members of staff took part in the debate:
- Aresh Amiri-Khosrov, ALSTOM Management S.A., France
- Dr. Wolfgang Knapp, CLFA, France
- Dr. Christian Koerber, Kienbaum Management Consultants GmbH, Düsseldorf
- Jörg Smolenski, Quantel S.A., France
- Axel Bauer, Fraunhofer ILT (who chaired the debate).
03.07.2003, Chair for Laser Technology LLT at RWTH Aachen

Lecture in association with the RWTH Colloquium on Laser Technology

Prof. Dr. H. P. Strunk, Institute of Microcharacterisation, University of Erlangen-Nuernberg, Erlangen »Laser crystallization of silicon films«.

11.07.2003, Chair for Laser Technology LLT at RWTH Aachen

Lecture in association with the RWTH Colloquium on Laser Technology

Prof. Dr. R. Menzel, head of the Photonics group in the Institute of Physics at the University of Potsdam: »Improving the beam quality of solid-state lasers«.

14.07.2003, 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 Gymnasium Haus Overbach Jülich.

31.07.2003, Institute for Geometry and Practical Mathematics (IGPM) at RWTH Aachen

Lecture as part of the advanced course of the Institute for Geometry and Practical Mathematics (IGPM) at RWTH Aachen in cooperation with the Fraunhofer ILT and the Chair for Laser Technology LLT at RWTH Aachen »Simulation of free boundary problems and their application in laser material processing«.

22.09. - 26.09.2003,

Les Hauts de Marquay, France

LaserAp 5, European Summer School

organized by the French Club Laser et Procédés with the assistance of the European Laser Institute, co-founded by the Fraunhofer ILT.

10.10.2003, Aachen

12th seminar of »Aix Laser People«

the alumni club of the Fraunhofer ILT and the Chair for Laser Technology LLT, with lectures by Dr. Arnold Giller, Fraunhofer ILT: »Research and development activities in the field of life sciences at the Fraunhofer ILT« and by Dipl.-Ing. Frauke Legevie, Impella Cardio Systems AG, Aachen, on »The function and manufacture of minimally invasive cardiovascular support systems«. The lectures were followed by a tour of the Helmholtz Institute (HIA) and a visit to the premises of Impella Cardio-Systems AG.

12.10.2003, Fraunhofer SCAI, Schloss Birlinghofen, Bonn

Lecture in conjunction with the MPCCI User Forum, held by the Fraunhofer SCAI in cooperation with the Fraunhofer ILT Dipl.-Phys. M. Nißlen, Chair for Laser Technology LLT at RWTH Aachen, Priv.-Doz. Dr. W. Schulz, Fraunhofer ILT »Lightweight construction concepts - Numerical simulation of free boundary problems in laser assisted manufacturing«.

20.10.2003, Aachen

»Career opportunities at Fraunhofer«

Event organized by Fraunhofer Institutes in Aachen (Laser Technology ILT, Molecular Biology and Applied Ecology IME and Production Technology IPT) for students at RWTH Aachen. In addition to speeches by the President of the Fraunhofer-Gesellschaft, Professor Hans-Jörg Bullinger, and the institute directors Professor Reinhard Poprawe, Professor Rainer Fischer and Professor Fritz Klocke, talks were given by the junior scientists Ingomar Kellbassa of the ILT, Nicole Raven of the IME and Sebastian Schöning of the IPT, as well as invited guests. The latter included human resources expert Heiko Mell, the Chairman of the Fraunhofer Senate and former DaimlerChrysler research director Professor Klaus-Dieter Vöhringer, and the managing director of CERO- BEAR in Herzogenrath, Matthias Popp.

The meeting was hosted by science journalist Ranga Yogeshwar, and focused on career opportunities for science and engineering graduates. Over 700 students attended the 2-hour information session and subsequent discussion forum, and visited the accompanying exhibition.

28.10.2003, Aachen

Aachen Laser Seminar »Lasers in tool- and diemaking«, potential applications and reports from the field.

Seminar organized by Carl Hansen Verlag, Munich, in cooperation with the Fraunhofer Institute for Laser Technology ILT in Aachen. Further information available at www.aachenerlaserseminare.de.

29. - 30.10.2003, Aachen

Aachen Laser Seminar »Laser processing in precision and micro engineering«, precise joining and structuring.

Seminar organized by Carl Hansen Verlag, Munich, in cooperation with the Fraunhofer Institute for Laser Technology ILT in Aachen. Further information available at www.aachenerlaserseminare.de.

26. - 27.11.2003, Aachen

Aachen Laser Seminar »Plastics processing by laser radiation: a versatile technology«, welding, structuring, cutting, labeling.

Seminar organized by Carl Hansen Verlag, Munich, in cooperation with the Fraunhofer Institute for Laser Technology ILT in Aachen. Further information available at www.aachenerlaserseminare.de.

27.11.2003, Chair for Laser Technology LLT at RWTH Aachen

Lecture in association with the RWTH Colloquium on Laser Technology

Prof. Dr. Karsten Buse, Physikalisches Institut, University of Bonn: »Nonlinear optics for information technology and telecommunications«.

08.12.2003, 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 KGS Am Römerhof Aachen.

11.12.2003, Chair for Laser Technology LLT at RWTH Aachen

Lecture in association with the RWTH Colloquium on Laser Technology

Dr. J. Köhler, Institut für Physikalische Elektronik, University of Stuttgart: »Laser processing of polycrystalline and single-crystal silicon«.

18.12.2003, Aachen

13th seminar of »Aix Laser People«

the alumni club of the Fraunhofer ILT and the Chair for Laser Technology LLT, with lectures by Dr. Stefan Kaierle, Fraunhofer ILT, on »New developments in laser process control at the Fraunhofer ILT« and by Dr. Christoph Maier, Hydro Alumini um Deutschland GmbH, Bonn, on »R&D for the automobile industry at a company manufacturing aluminium semi-finished parts«.

02.12.2003, 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 Monheim.
»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.

»Services and Contacts 2004/5«
(German/English)
This brochure gives an overview of current services offered and contacts within the Institute. It also introduces focal points of each division of the Fraunhofer ILT.

Annual Report 2003
(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.

Mirror of the Press 2003
In the mirror of the press, the institute’s activities are presented from the press’ point of view.

Proceedings of the Aachen Colloquium for Laser Technology AKL’04
The technical proceedings of the Aachen Colloquium for Laser Technology AKL’04 (April 28-30, 2004) contains reports from 34 laser manufacturers and users outlining the latest developments and technology trends in industries such as optics, automobile, metal production, tool and die making, electrical and electronic engineering, plastics and glass. Practical case studies highlight various laser processes such as laser metrology, laser microengineering, laser beam welding/cutting and laser surface technology.

The proceedings of the AKL’04 can be obtained for a fee by contacting the publishers at the following address:

Verlagsgesellschaft Grütter GmbH & Co. KG
Frau Julia Ibenthal
Lägenfeldstraße 8
30952 Ronnenberg/Empelde
Phone: +49 (0)511/4609 -322
Fax: +49 (0)511/4609 -320

Proceedings of the AKL’04 Laser Business Conference
The proceedings of the Laser Business Conference, which took place on 28.04.04 in Aachen with a panel of ten experts in financial services, technology marketing, intellectual property rights and business consulting, are addressed primarily toward managers of expanding high-tech firms and newly established small companies. The publication provides a succinct overview of the emerging trends and opportunities offered by laser technology in production engineering, communication engineering and medical engineering. At the same time, it also sheds light on many financial, legal and marketing questions confronting businesses at various stages of their evolution. The publication can be ordered from:

WirtschaftsWoche Vertriebsservice
Leserservice
Postfach 37 52
90018 Nürnberg
Phone: +49 (0)911/2748 -100
Fax: +49 (0)911/2748 -222
wiwo.leserservice@vhb.de

Programme of the Aachen Colloquium for Laser Technology AKL’04
28.-30. April 2004. The programme for AKL’04 can be obtained by calling +49 (0)241/8906 -109 (fax -121) or via Internet at www.ilt.fraunhofer.de.
Technical Brochure »High-Power Diode Lasers« (German only)
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.

Technical Brochure »LASIM® - Laser Simulator for Training« (German/English)
This technical brochure gives an overview of the advantages of using multimedia software to train laser users and students. It introduces the application fields, program contents and the system demands of the LASIM® software. This was developed at the Fraunhofer ILT for the training of laser welding and cutting. The LASIM® CD ROM with corresponding program instructions is available at the Fraunhofer ILT.

Technical brochure »Laser Technology for Surface Modification and Forming« (German only)
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.

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

Technical Brochure: »Laser Beam Deposition Welding« (only German)
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.

Technical Brochure: »Rapid Prototyping and Rapid Manufacturing of Metal Parts« (only German)
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.

Technical Brochure: «Laser Cleaning» (German/English)
This technical brochure explains the possible applications of laser beam cleaning.

Technical Brochure: »Lasers in Microstructuring« (German/English)
This technical brochure describes processes such as laser ablation, precision cutting, drilling and laser-assisted microforming.
Technical Brochure: »Lasers in Mounting and Connecting Techniques« (German/English)
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.

Technical Brochure: »Lasers in Plastics and Paper Processing« (German/English)
This technical brochure describes the use of lasers in the processing of plastics, composite materials, paper and glass.

Technical Brochure: »Lasers in Life Science« (German/English)
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.

Technical Brochure: »Material Analysis and Identification with Laser Radiation« (German/English)
This technical brochure describes the processes and systems for analyzing the composition of materials with laser radiation, which were developed at the Fraunhofer ILT. The initial testing of different materials, testing for mixed products, sorting of materials as well as online analysis of melting problems can be solved quickly and reliably with the laser.

Technical brochure »Surfaces and Layer Analysis« (only German)
The technical brochure offers an overview of the present measuring methods for surface analysis at the Fraunhofer ILT and the LLT at the RWTH Aachen. This includes different spectroscopy processes, the ellipsometer and metallographic measuring methods.

Information Brochure »Laser Region Aachen« (German/English)
This brochure was published by the Aachen Society for Innovation and Technology AGiT mbH with close cooperation from the Fraunhofer ILT. It gives an overview of the laser activities in the Aachen region as well as the central participants in industry, science and the service sector.

Information Brochure »Networks of Competence« (German/English)
»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.

Information Brochure »European Laser Institute ELI« (only English)
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.
Video »Laser - the Extraordinary Light for Material Processing«
(German/English)

This training video was made at the Bergische Universität – Gesamthochschule Wuppertal in cooperation with the VDI-Technologiezentrum in Düsseldorf, the Fraunhofer ILT and other laser centers and companies and a new production was made in 2000. It delivers an overview of all important laser machining processes and was specially made for use at colleges, universities, technical colleges, vocational schools and internal company training. This especially applies to manufacturing engineering courses of study. The VHS video is 42 minutes long and is available in both English and German from the Bergische Universität – Gesamthochschule Wuppertal, Fachbereich D, Abteilung Maschinenbau.

Contact:
Prof. Helmut Richter
Phone: ++49 (0)202 / 439-2042
richterh@uni-wuppertal.de

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 Technical University Aachen RWTH in close cooperation with the Fraunhofer Institute for Laser Technology ILT.

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

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

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

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

Contact:
Diana Heinrichs
Phone: ++49 (0)241 / 8906-122
Fax: ++49 (0)241 / 8906-112
heinrichs@ilt.fraunhofer.de
Multimedia Software LASIM® (German/Englisch)

LASIM® is a multimedia training program for laser cutting and welding. The combination of text, pictures, sound and animation within the multimedia software has opened new horizons in laser training. In the theoretical part of the curriculum, complicated processes and models are vividly presented. This contributes to a better understanding of the material. In the practical part of the training, numerous experiments can be made through simulations. The user can personally set the process parameters without causing problems in the real laser system.

By installing several computer workstations, personnel costs can be reduced. Furthermore, the multimedia program is suited for private study. The laser user is able to work on experiments on the virtual system at any time.

Multimedia technology ideally supplements practical training on real laser systems. In the initial phase, the exercises are conducted at a beginner level. In the following phases, the user is able to use the knowledge acquired to solve concrete problems on real laser systems.

The advantages of using multimedia software for training of specialists and students are obvious:
- Visualization of complex correlations and process development
- Simulation of a real laser workstation
- Ability to carry out experiments on virtual systems with evaluation of results
- Unlimited availability and no risk from operator error
- Low support costs and suitability for private study
- Interactive theoretical and practical exercises to strengthen knowledge

The software LASIM® is obtainable from the Fraunhofer Institute for Laser Technology in both German and English. Current information and order forms are available through the internet site www.ilt.fraunhofer.de.

Contact:
Dr. Dirk Petring
Phone: 49 (0) 241 / 8906 -210
Fax: 49 (0) 241 / 8906 -121
dirk.petring@ilt.fraunhofer.de
If you would like more information about the research and development at the Fraunhofer Institute for Laser Technology please go to our website at www.ilt.fraunhofer.de. Information can also be ordered using this form.

- **Brochure: »Your partner for innovation«**
  - German
  - English

- **Brochure: »Services and Contacts 2004/5«**
  (German/English)

- **Annual Report 2003**
  German
  (English version only available online at www.ilt.fraunhofer.de)

- **Annual Report 2002**
  German
  (English version only available online at www.ilt.fraunhofer.de)

- **Annual Report 2001**
  German
  (English version only available online at www.ilt.fraunhofer.de)

- **Mirror of the Press 2003**

- **Mirror of the Press 2002**

- **Mirror of the Press 2001**

- **Order form for the proceedings of the Aachen Colloquium for Laser Technology AKL’04**
  (only German)

- **Order form for the proceedings of the Laser-Business-Day of the AKL’04**
  (only German)

- **Technical Brochure: »Hochleis-
tungsdiode diode laser« (High-Power Diode Lasers)**
  (only German)

- **Technical Brochure: »Lasertechnik für die Oberflächen-
modifikation und das Umformen«**
  (Laser Technology for Surface Modification and Forming)
  (only German)

- **Technical Brochure: »Lasertechnik für den Verschleiß-
und Korrosionsschutz«**
  (Laser Technology for Wear and Corrosion Protection)
  (only German)

- **Technical Brochure: »Laserstrahlauflauftragsschweißen«**
  (Laser Beam Deposition Welding)
  (only German)

- **Technical Brochure: »Rapid Prototyping und Rapid Manufacturing für Metallbauteile«**
  (Rapid Prototyping and Rapid Manufacturing of Metal Parts)
  (only German)

- **Technical Brochure: »Laser Cleaning«**
  German
  English

- **Technical Brochure: »Lasers in Microstructuring«**
  German
  English

- **Technical Brochure: »Lasers in Mounting and Connecting Techniques«**
  German
  English

- **Technical Brochure: »Lasers in Plastics and Paper Processing«**
  German
  English

- **Technical Brochure: »Lasers in Life Science«**
  German
  English

- **Technical Brochure: »Lasers in Life Science«**
  German
  English

- **Technical Brochure: »Lasers in Life Science«**
  German
  English

- **Technical Brochure: »Lasers in Life Science«**
  German
  English

- **Technical Brochure: »Lasers in Life Science«**
  German
  English

- **Technical Brochure: »Lasers in Life Science«**
  German
  English

- **Technical Brochure: »Lasers in Life Science«**
  German
  English

- **Order form for Multimedia Software LASIM®:**
  German
  English
  (also at: www.ilt.fraunhofer.de)

- **Order form for CD-Rom »Lasertechnik« (Laser Technology)**
  (only German)
Fraunhofer-Institut
für Lasertechnik ILT
Steinbachstraße 15
52074 Aachen
Fax: +49 (0) 241 / 8906 -121

Editorial Staff
Dipl.-Phys. Axel Bauer (responsible)
Stefanie Flock

Design and Production
Dipl.-Des. Andrea Croll

Lithography
Graphodata GmbH, Text- und Bildverarbeitung Digital, Aachen

Print
Rhiem Druck GmbH, Voerde

Paper
This Annual Report was printed on environment-friendly, unchlorinated and acid-free bleached paper.

Contact
Dipl.-Phys. Axel Bauer
Telephone: +49 (0) 241 / 8906 -194
Fax: +49 (0) 241 / 8906 -121
E-mail: axel.bauer@ilt.fraunhofer.de

All rights reserved. Reprint only with written permission of the editorial office.

© Fraunhofer-Institut
für Lasertechnik ILT, Aachen 2004