Fraunhofer
ILT

FRAUNHOFER INSTITUTE FOR LASER TECHNOLOGY ILT

ANNUAL REPORT 2011

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FRAUNHOFER INSTITUTE
FOR LASER TECHNOLOGY
2011

Machines and then electronics each brought about a new era in human history, with far-reaching social consequences that changed people's way of living and the quality of their lives. The advent of the first machines in the 19th century sparked off an industrial revolution and radically changed the way people worked. It became possible to manufacture goods cheaply in large quantities and distribute them to a wide market. The 20th century saw the rise of electronics, leading to the introduction of computers, information technology, automatic feedback control systems, and ultimately automated production lines. These changes, too, had a direct impact on society, to the extent that we now take always-on communication and global mobility for granted.

In the 21st century, we are witnessing the emergence of another epoch-changing technology: photonics. Its impact is immediately evident in the increased data transfer rates of optical networks, which are capable of transmitting previously unimaginable quantities of data. New medical devices make it possible to perform surgical operations that were once inconceivable. LED technology is not only being implemented in energy-saving lamps but also opens up new design opportunities for car manufacturers. And without photonics it would not be possible to manufacture and operate the latest generation of displays.

The combination of machines, electronics and photonics offers exciting prospects. This symbiosis is about to create a paradigm shift in the world of production technology: away from the efficiency concerns of mass-produced standard products and toward a more personalized approach. In future, customized solutions and the cost advantages of high-volume production will no longer be mutually exclusive goals. Already today, dental prostheses are fabricated in parallel processes rather than being manufactured in series. And soon the bricks-and-mortar warehouses in which manufacturers store spare parts for their tools and machines will be replaced by virtual storage systems in which the parts can be printed on demand on the basis of computerized data. Worn-out metal components, regardless of their age, can then be rapidly replaced by a three-dimensional reproduction generated from the stored CAD data, using a laser additive manufacturing (LAM) process.

Fraunhofer ILT develops processes that will help to accomplish this paradigm shift in the manufacturing industry. To do so, our laser specialists pool their expertise with designers, medical engineers, control system experts, and materials scientists. They work together in interdisciplinary teams to develop new manufacturing processes and open up new horizons for users in diverse sectors of industry. It is an exciting challenge, and one from which you too can benefit. If you want to learn more about these and many other innovations that our researchers are working on each day, I recommend that you read this Annual Report. Don't hesitate to contact us if you yourself have an idea that you think we could help you turn into reality. That is what Fraunhofer is there for, and we would be delighted to invent the future with you.

We wish you a successful 2012, powered by our joint creative energy.

Yours

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

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PROFILE OF THE INSTITUTE

SHORT PROFILE

ILT - this abbreviation has stood for combined know-how in the sector of laser technology for more than 25 years. Innovative solutions for manufacturing and production, development of new technical components, competent consultation and education, highly specialized personnel, state-of-the-art technology as well as international references: these are guarantees for long-term partnerships. The numerous customers of the Fraunhofer Institute for Laser Technology ILT come from branches such as automobile and machine construction, the chemical industry and electrical engineering, the aircraft industry, precision engineering, medical technology and optics. With around 370 employees and around 11,000 m^2 of usable space, the Fraunhofer Institute for Laser Technology ILT is among the most significant contracting research and development institutes in its sector worldwide.

The four technology areas of the Fraunhofer ILT cover a wide spectrum of topics within laser technology. In the technology area »Lasers and Optics« we develop tailor-made beam sources as well as optical components and systems. The spectrum reaches from freeform optics over diode and solid state lasers all the way to fiber and ultrashort pulse lasers. In addition to the development, manufacture and integration of components and systems, we also address optics design, modeling and packaging. In the technology area »Laser Material Processing« we solve tasks involving cutting, ablating, drilling, cleaning, welding, soldering, labeling as well as surface treatment and micro manufacturing. Process development and systems engineering stand in the foreground, which includes machine and control engineering, process and beam monitoring as well as modeling and simulation. Along with partners from life sciences, ILT's experts in the technology field »Medical Technology and Biophotonics« open up new laser applications in bioanalytics, laser microscopy, clinical diagnostics, laser therapy, bio-functionalization and biofabrication. The development and manufacture of implants, microsurgical and microfluidics systems and components also count among the core activities here. In the technology area »Laser Measurement Technology and EUV Technology« we develop processes and systems for our customers which conduct inline measurement of physical and chemical parameters in a process line. In addition to production measurement technology and material analysis, environment and safety as well as recycling and raw materials lie in the focus of our contract research. With EUV technology, we are entering the submicron world of semi-conductors and biology.

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

DQS certified by
DIN EN ISO 9001
Reg.-No.: DE-69572-01

DECLARATION OF PRINCIPLES

Mission
We occupy an international top position in transferring laser technology to industrial application. We continually expand the knowledge base and know-how in our sector and make significant contributions to the ongoing development of science and technology. Working with our partners in industry, science and government, we create innovations on the basis of new beam sources and new applications.

Customers
The customers needs are the focus of our work. Discretion, fairness and a spirit of partnership are top priorities in our customer relationships. Our customers can rely on us. We tailor solutions and their cost-effective implementation to the demands and expectations of our customers, with the objective of creating a competitive advantage. We support industry's needs for new specialists and managerial staff through project-based partnerships with our customers. We want our customers to be satisfied because we want them to return.

Chances
We strategically expand our knowledge base across the network.

Facination Laser
The unique characteristics of laser light and the resulting diversity of applications, are a constant source of inspiration and fascination.

Staff
Teamwork between the individual and the group is the foundation of our success.

Strengths
Our broad spectrum of resources enables us to offer one-stop solutions.

Management Style
Cooperative, demanding and supportive. Knowing the value of our staff as individuals and the value of their know-how and their commitment forms the basis of our management philosophy. We involve our staff in the formulation of goals and the decision-making process. We place a high value on effective communication, goal-oriented and efficient work and clear decisions.

Position
We work within vertical structures, from research to application. Our expertise extends from beam source, machining and measuring techniques, to application, through to integration of systems into the customer's production line.

TECHNOLOGY FOCUS

LASERS AND OPTICS

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

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

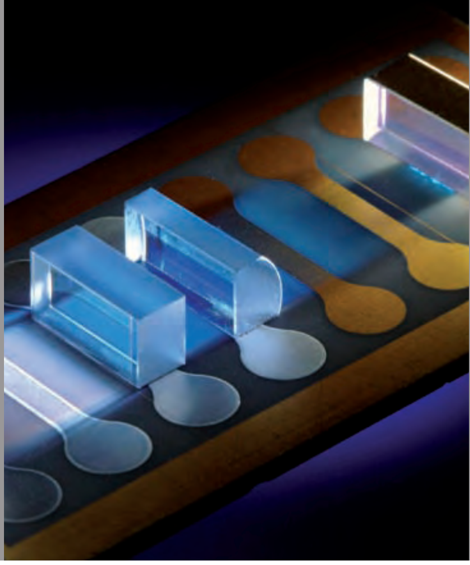
Furthermore, this technology field has a great deal of expertise in beam shaping and guiding, packaging of optical high power components and designing optical components. This field also specializes in dimensioning highly efficient free form optics. In general, the lasers and optics developed here can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

LASER MATERIAL PROCESSING

Among the many manufacturing processes in the technology field Laser Material Processing, cutting and joining in micro and macro technology as well as surface processes count among its most important. Whether it be laser cutting or laser welding, drilling or soldering, laser metal deposition or cleaning, structuring or polishing, generating or layering, the range of services spans process development and feasibility studies, simulation and modeling, as well as the integration of processes in production lines.

The strength of the technology field lies in its extensive know-how, which is tailored to customer requirements. In such a way hybrid and combination processes also result. Moreover, complete system solutions are offered in cooperation with a specialized network of partners. Special plants, plant modifications and additional components are the constituent part of numerous R&D projects. For example, special processing heads for laser material processing are being developed and produced, based on a customer's specific needs. In addition, process optimization by changing the design of components as well as systems to monitor quality on-line count among the specializations of this technology field.

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

MEDICAL TECHNOLOGY AND BIOPHOTONICS

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

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

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

LASER MEASUREMENT TECHNOLOGY AND EUV TECHNOLOGY

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

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

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

PRODUCTS AND SERVICES

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LASER MEASUREMENT TECHNOLOGY AND EUV TECHNOLOGY

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STRUCTURE OF THE INSTITUTE

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Director

Prof. Dr. Peter Loosen
Vice Director

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Dipl.-Phys. Axel Bauer
Marketing and Communications

Dr. Alexander Drenker
QM Management

Dr. Bruno Weikl
IT Management

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Lasers and Laser Optics

Dr. Arnold Gillner
Ablation and Joining

Dr. Konrad Wissenbach
Additive Manufacturing and Functional Layers

Dr. Reinhard Noll
Measurement Technology and EUV Sources

BOARD AND COMMITTEES

Board

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

- Dr. Norbert Arndt, Rolls-Royce plc
- C. Baasel (Chairman), Carl Baasel Lasertechnik GmbH
- Dr. Thomas Fehn, Jenoptik AG
- Dr. Ulrich Hefter, Rofin-Sinar Laser GmbH
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- Dr. Ulrich Steegmüller, Osram Opto Semiconductors GmbH & Co. OHG
- Dr. Klaus Wallmeroth, TRUMPF Laser GmbH & Co. KG

The 26th Board of Trustees meeting was held on September 14, 2011 at Fraunhofer ILT in Aachen.

Institutsleitungsausschuss ILA

The Directors' Committee advises the Institute's managers and is involved in deciding on research and business policy. The members of this committee are: Dipl.-Betrw. (FH) Vasvija Alagic MBA, Dipl.-Phys. A. Bauer, Dr. A. Gillner, Dipl.-Ing. H.-D. Hoffmann, Dr. S. Kaierle, Dr. I. Kelbassa, Prof. Dr. P. Loosen, Dr. R. Noll, Dr. D. Petring, Prof. Dr. R. Poprawe, Prof. Dr. W. Schulz, B. Theisen, Dr. B. Weikl, Dr. K. Wissenbach.

Health & Safety Committee

The Health & Safety Committee is responsible for all aspects of safety and laser safety at the Fraunhofer ILT. Members of this committee are: Dipl.-Betrw. (FH) Vasvija Alagic MBA, K. Bongard, M. Brankers, A. Hilgers, A. Lennertz, Dr. W. Neff, E. Neuroth, Dipl.-Ing. H.-D. Plum, Prof. Dr. R. Poprawe, B. Theisen, F. Voigt, Dipl.-Ing. N. Wolf, Dr. R. Keul (Berufsgenossenschaftlicher Arbeitsmedizinischer Dienst BAD).

Science & Technology Council

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

Members of the Council from the Fraunhofer ILT are: Prof. Dr. R. Poprawe, B. Theisen, Dr. C. Janzen.

Staff Association

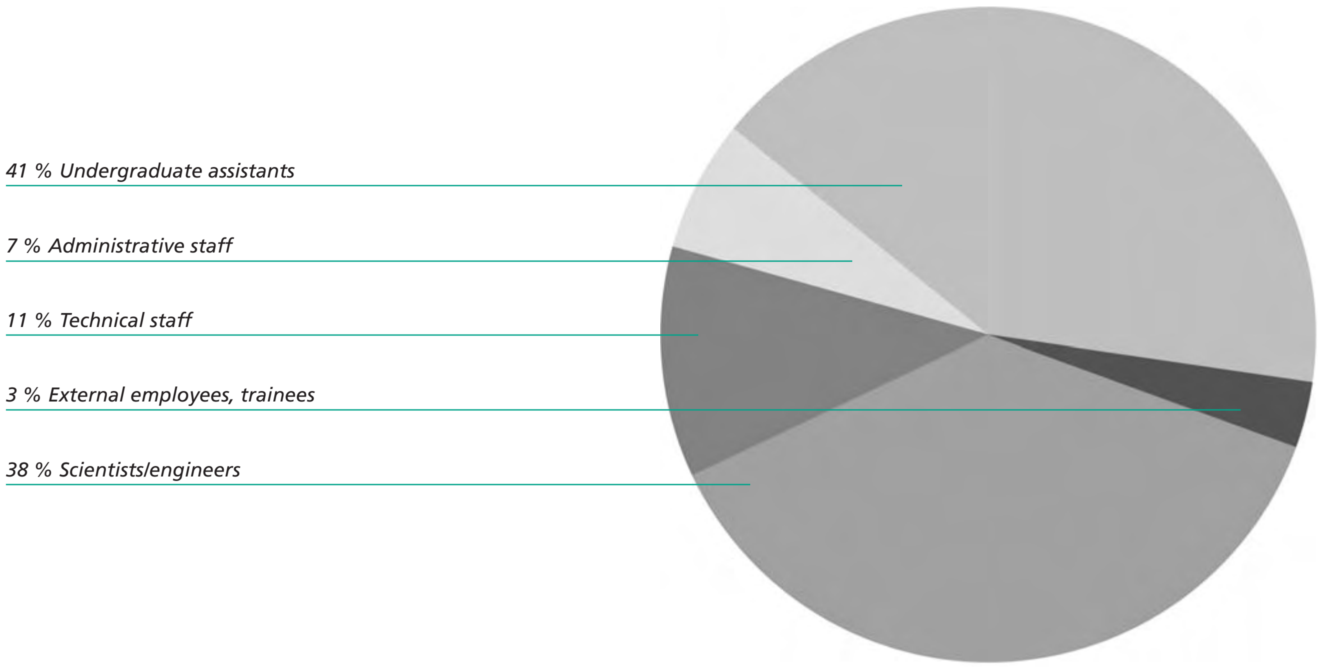
In March 2003 the staff association was founded by the employees of the Fraunhofer ILT and the Department of Laser Technology. Members are: Dipl.-Ing. P. Abels, M. Brankers, Dipl.-Ing. A. Dohrn, C. Hannemann, M. Janssen, Dipl.-Phys. A. Temmler, B. Theisen (Chair), Dr. A. Weisheit, Dipl.-Ing. N. Wolf.

FACTS AND FIGURES

EMPLOYEES

Employees at the Fraunhofer ILT 2011	number
Personnel	**204**
- Scientists and engineers	138
- Technical staff	42
- Administrative staff	24
Other employees	**165**
- Undergraduate assistants	153
- External employees	6
- Trainees	6
Total number of employees at the Fraunhofer ILT	**369**

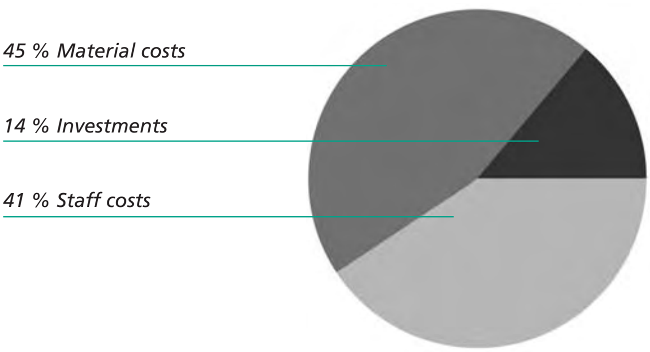
- 12 members of staff completed their doctorates
- 25 undergraduates carried out their final year projects at the Fraunhofer ILT



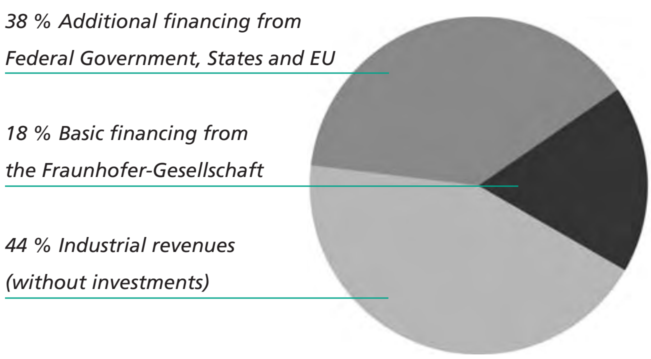
REVENUES AND EXPENSES

Expenses 2011	Mill €
- Staff costs	12,9
- Material costs	14,4
Expenses operating budget	**27,3**
Investments	**4,4**

Revenues 2011	Mill €
- Industrial revenues	11,9
- Additional financing from Federal Government, States and the EU	10,5
- Basic financing from the Fraunhofer-Gesellschaft	4,9
Revenues operating budget	**27,3**
- Revenues from projects abroad (already included in total)	3,2
Investment revenues from industry	**0,4**
Fraunhofer industry ρ_{Ind}	**45,0 %**



(100 % Operating budget und Investments)

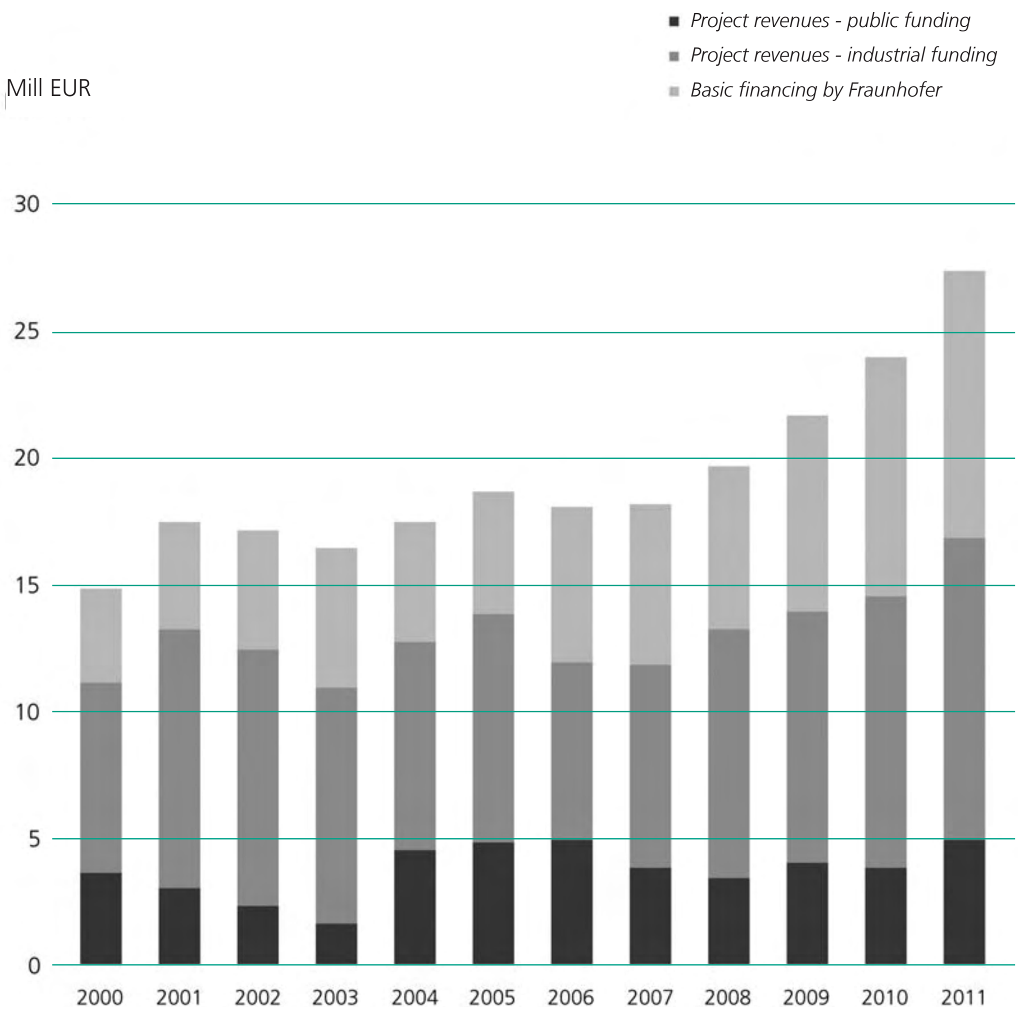


(100 % Operating budget)

FACTS AND FIGURES

BUDGET GROWTH

The following graph illustrates the budget trend over the last 12 years.



REFERENCES

February 2012. *Printed with the kind permission of our partners. The companies listed here represent a selection of the Fraunhofer ILT's many clients.*

COOPERATIONS

RANGE OF SERVICES

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

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

COOPERATIONS

The Fraunhofer Institute for Laser Technology ILT is cooperating with R&D-partners in different ways:
- realization of bilateral, company specific R&D-projects with and without public support (contract for work and services)
- participation of companies in public-funded cooperative projects (cofinancing contract)
- production of test, pilot and prototype series by Fraunhofer ILT to determine the reliability of the process and minimize the starting risk (contract for work and services)
- companies with guest status and with their own laboratries and offices at Fraunhofer ILT (special cooperation contracts)
- companies with subsidiaries at the RWTH Aachen Campus and cooperation with Fraunhofer ILT by the cluster »Photonics in Production«

By means of cooperation with other research organizations and specialized companies the Fraunhofer Institute for Laser Technology offers solutions even in the case of interdisciplinary tasks. A special advantage hereby consists in the direct access to the large resources of the Fraunhofer Society.

During the implementation phase of new laser processes and products, companies can acquire ‘guest status’ at the Fraunhofer Institute for Laser Technology and use the equipment, infrastructure and know-how of the institute as well as install their own systems.

FRAUNHOFER ILT ABROAD

Since its foundation, Fraunhofer ILT has been involved in many international cooperations. The objective of these cooperations is to recognize new trends and current developments and to acquire further know-how. The customers of Fraunhofer ILT can directly benefit from this. Fraunhofer ILT carries out bilateral projects as well as international cooperative projects with foreign companies and subsidiaries of German companies abroad. These companies can also contact Fraunhofer ILT through:

- international subsidiaries of Fraunhofer ILT
- foreign cooperation partners of Fraunhofer ILT
- liaison offices of the Fraunhofer Society abroad

FACILITIES

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

Technical Infrastructure

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

Scientific Infrastructure

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

Equipment

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

- CO_2-lasers up to 12 kW
- lamps pumped solid state lasers up to 3 kW
- disc lasers from 1 to 10 kW
- fiber lasers between 100 W and 4 kW
- diode laser systems from 1 to 12 kW
- SLAB laser
- excimer lasers
- ultra short pulse lasers up to 1 kW
- broadband tunable lasers
- five-axis gantry systems
- three-axis processing stations
- beam guiding systems
- robot systems
- sensors for process control in laser material processing
- direct-writing and laser-PVD stations
- clean rooms for assembly of diode and solid state lasers as well as laser optics
- clean rooms for assembly of diode lasers, diode pumped solid state lasers and fiber lasers
- life science laboratory with S1 classification
- devices for process diagnostics and high speed video analysis
- laser spectroscopic systems for the chemical analysis of solid, liquid and gaseous materials
- laser triangulation sensors for distance and contour measurement
- laser coordinate measuring machine
- confocal laser scanning microscopy
- scanning electron microscope
- extensive equipment for beam diagnosis for high-power lasers
- Shack Hartmann sensor to characterize laser beams and optics
- equipment to produce integrated fiber lasers
- measurement interferometer and autocollimator to analyze laser optics
- measurement equipment to characterize ultra-short pulse lasers: autocorrelators, multi-GHz oscilloscopes and spectrum analyzers

FRAUNHOFER USA CENTER FOR LASER TECHNOLOGY CLT

Short Profile

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

The goals of Fraunhofer CLT are:

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

The central philosophy of Fraunhofer USA is the creation of a German-American cooperation where give and take occur in harmony. The American partner universities' interest concentrates on:

1. Using the competence of the Fraunhofer Institutes
2. Using the experience in the introduction of new technologies into the market
3. Providing the connection between industry and university
4. Providing practical training for students and graduate students

The Fraunhofer CLT develops powerful, highbrilliance fiber lasers in collaboration with the University of Michigan. The basic research and concepts of new fiber geometries to achieve high (pulse) energies with diffraction limited beam quality are developed at the university, while Fraunhofer undertakes the development of high-brilliance pump sources, system integration, prototype construction and application tests.

In this context, the CLT has implemented new technologies and manufacturing methods for multi-single-emitter diode lasers that make diode lasers comparable to solid-state lasers in terms of their performance. In 2007 Arbor Photonics was founded in collaboration with the University of Michigan in order to commercialize the developments in the field of flexible fiber lasers with high beam quality and pulse power.

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

Lasers are being successfully used to improve efficiency in solar cell manufacturing. At Fraunhofer CLT, high-speed drilling processes are being developed for EWT cells and the productivity of laser drilling improved six-fold. Lasers are also being used for economic surface structuring of silicon and to structure the covering glass. They increase absorption in the cell by several percent.

The University of Michigan and the Fraunhofer-Gesellschaft set up an alliance to conduct research into renewable energy for transport applications. For the two-year pilot phase five projects were selected which offer an outstanding combination of scientific innovation and high market potential. The fields of innovative energy and power-storage devices, the associated cost-effective manufacturing, redox batteries and dynamic 3-D diagnostics of combustion processes are also covered. The first phase ended in the fall. In the course of

the project, the participating partners raised over $ 500,000 in third-party funding and submitted project proposals worth more than $ 20 million. The work conducted during this phase resulted in two patent applications, numerous scientific papers, and joint conference appearances. It also led to the creation of the spin-off company Inmatech, in which Fraunhofer holds a share.

Services

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

Facilities

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

Operating budget 2011

	Mill US $
Operating budget	**2.1**
- Staff costs	1.2
- Material costs	0.9

References

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

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

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COOPÉRATION LASER FRANCO-ALLEMANDE CLFA

Short Profile

At the Coopération Laser Franco-Allemande (CLFA) in Paris, the Fraunhofer Institute for Laser Technology ILT has been cooperating since 1997 with leading French research organizations, including the university MINES ParisTech, ARMINES and the Institut CAROT Mines in Paris, the École Nationale Supérieure de Mécanique et des Microtechniques ENSMM in Besancon, the engineer university ECAM Rennes Louis de Broglie and other major laser application centers in France. Multidisciplinary teams of specialists from Germany and France work together on the transfer of laser assisted manufacturing processes to European industry. The CLFA is a member of the French association of laser manufacturers and users, the Club Laser & Procédés, and actively participates in the organization of regional and national conferences and exhibitions. Thus, in September 2011 the CLFA organized the national conference »Journées Nationales des Procédés Laser pour l'Industrie« and the international congress »EUCOSS 2011«.

The goals of the CLFA are:

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

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

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

The French partners' interests concentrate on:

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

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

Major research projects

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

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

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

Services

The CLFA offers services in the field of laser material processing. This covers the entire spectrum from application oriented fundamental research and training, feasibility studies and process development to pre-series development and system integration. Small and midsized companies have the opportunity here to get to know and test laser technology in an independent system. The open development platform allows the French customers to test and qualify new laser supported manufacturing processes.

Employees

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

Equipment

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

Locations

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

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

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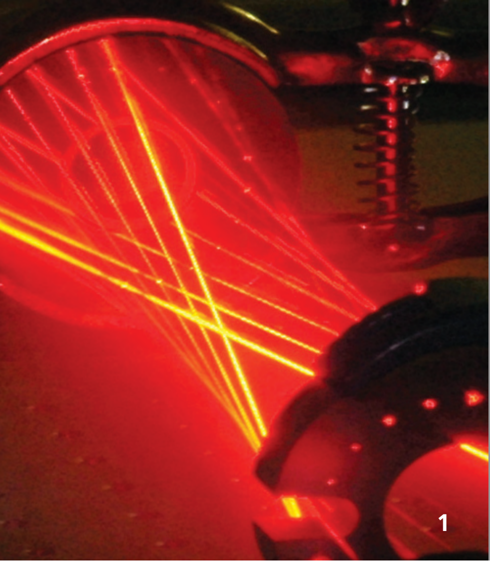

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FRAUNHOFER GROUP LIGHT & SURFACES

Competence by Networking

Six Fraunhofer institutes cooperate in the Fraunhofer Group Light & Surfaces. Co-ordinated competences allow quick and flexible alignment of research work on the requirements of different fields of application to answer actual and future challenges, especially in the fields of energy, environment, production, information and security. This market-oriented approach ensures an even wider range of services and creates synergetic effects for the benefit of our customers.

Core Competences of the Group

- Surface and coating functionalization
- Laser-based manufacturing processes
- Laser development and nonlinear optics
- Materials in optics and photonics
- Microassembly and system integration
- Micro and nano technology
- Carbon technology
- Measurement methods and characterization
- Ultra precision engineering
- Material technology
- Plasma and electron beam sources

1 Fraunhofer IWS
2 Fraunhofer IOF
3 Fraunhofer FEP
4 Fraunhofer ILT
5 Fraunhofer IST
6 Fraunhofer IPM

Business Areas

- Ablation and cutting
- Imaging and illumination
- Additive manufacturing
- Light sources and laser systems
- Lithography
- Material testing and analytics
- Medical engineering and biophotonics
- Micro systems and sensors
- Opticals systems and instrumentation
- Tooling and mold making

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www.light-and-surfaces.fraunhofer.de

Fraunhofer Institute for Applied Optics and Precision Engineering IOF
The Fraunhofer IOF develops solutions with light to cope foremost challenges for the future in the areas energy and environment, information and security, as well as health care and medical technology. The competences comprise the entire process chain starting with optics and mechanics design via the development of manufacturing processes for optical and mechanical components and processes of system integration up to the manufacturing of prototypes. Focus of research is put on multifunctional optical coatings, micro- and nano-optics, solid state light sources, optical measurement systems, and opto-mechanical precision systems.
www.iof.fraunhofer.de


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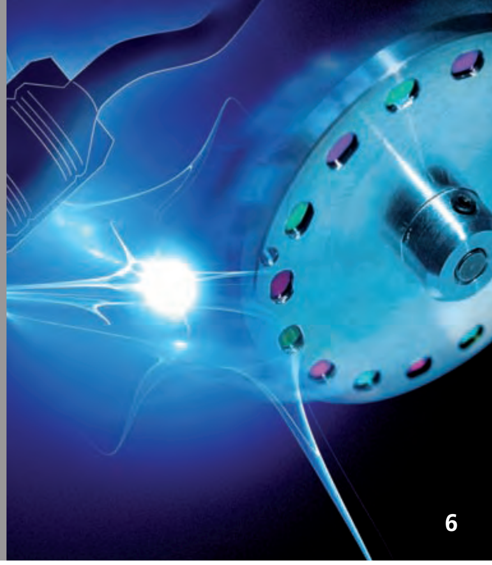
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Fraunhofer Institute for Electron Beam and Plasma Technology FEP

Electron beam technology, sputtering technology, plasmaactivated high-rate deposition and high-rate PECVD are the core areas of expertise of Fraunhofer FEP. The business units include vacuum coating, surface modification and treatment with electrons and plasmas. Besides developing layer systems, products and technologies, another main area of work is the scale-up of technologies for coating and treatment of large areas at high productivity.
www.fep.fraunhofer.de

Fraunhofer Institute for Laser Technology ILT

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

Fraunhofer Institute for Surface Engineering and Thin Films IST

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

Fraunhofer Institute for Physical Measurement Techniques IPM

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

Fraunhofer Institute for Material and Beam Technology IWS

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

THE FRAUNHOFER-GESELLSCHAFT AT A GLANCE

The Fraunhofer-Gesellschaft

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

At present, the Fraunhofer-Gesellschaft maintains more than 80 research units in Germany, including 60 Fraunhofer Institutes. The majority of the more than 20,000 staff are qualified scientists and engineers, who work with an annual research budget of € 1.8 billion. Of this sum, more than € 1.5 billion is generated through contract research. More than 70 percent of the Fraunhofer-Gesellschaft's contract research revenue is derived from contracts with industry and from publicly financed research projects. Almost 30 percent is contributed by the German federal and Länder governments in the form of base funding, enabling the institutes to work ahead on solutions to problems that will not become acutely relevant to industry and society until five or ten years from now.

Affiliated international research centers and representative offices provide contact with the regions of greatest importance to present and future scientific progress and economic development.

With its clearly defined mission of application-oriented research and its focus on key technologies of relevance to the future, the Fraunhofer-Gesellschaft plays a prominent role in the German and European innovation process. Applied research has a knock-on effect that extends beyond the direct benefits perceived by the customer: Through their research and development work, the Fraunhofer Institutes help to reinforce the competitive strength of the economy in their local region, and throughout Germany and Europe. They do so by promoting innovation, strengthening the technological base, improving the acceptance of new technologies, and helping to train the urgently needed future generation of scientists and engineers.

As an employer, the Fraunhofer-Gesellschaft offers its staff the opportunity to develop the professional and personal skills that will allow them to take up positions of responsibility within their institute, at universities, in industry and in society. Students who choose to work on projects at the Fraunhofer Institutes have excellent prospects of starting and developing a career in industry by virtue of the practical training and experience they have acquired.

The Fraunhofer-Gesellschaft is a recognized non-profit organization that takes its name from Joseph von Fraunhofer (1787–1826), the illustrious Munich researcher, inventor and entrepreneur.

Fields of Research

The Fraunhofer-Gesellschaft concentrates on research in the following fields:

- Materials technology, component behavior
- Production and manufacturing technology
- Information and communication technology
- Microelectronics, microsystems engineering
- Sensor systems, testing technology
- Process engineering
- Energy and construction engineering, environmental and health research
- Technical/economic studies, information transfer

Target Groups

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

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

Range of Services

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

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

Research Facilities in Germany

LASER TECHNOLOGY AT RWTH AACHEN

JOINTLY SHAPING THE FUTURE

The RWTH Aachen University Chairs for Laser Technology LLT, the Technology of Optical Systems TOS, and for Nonlinear Dynamics of Laser Processing NLD, represent an outstanding cluster of expertise in the field of optical technologies. This permits supercritical treatment of basic and application-related research topics. The close cooperation with the Fraunhofer Institute for Laser Technology ILT not only permits industrial contract research on the basis of sound fundamental knowledge, but also provides new stimuli for the advanced development of optical methods, components and systems. The synergy of infrastructure and know-how is put to active use under a single roof.

This structure particularly benefits up-and-coming young scientists and engineers. Knowledge of current industrial and scientific requirements in the optical technologies flows directly into the planning of the curriculum. Furthermore, undergraduates and postgraduate students can put their theoretical knowledge into practice through project work at the three chairs and at the Fraunhofer ILT. University courses are drawn up jointly as well. The interdisciplinary collaboration between physicians and engineers, for instance, has resulted in a university seminar for advanced dental training being set up. Teaching, research and innovation - those are the bricks with which the three university departments and the Fraunhofer ILT are building the future.

Chair for Laser Technology LLT

The RWTH Aachen University chair for Laser Technology LLT has been engaged in application-oriented research and development in the fields of ultrashort pulse processing, in-volume structuring, drilling, additive manufacturing and integrated production since 1985.

Its activities in in-volume structuring focus on investigating the integration of high-power diode lasers with waveguide lasers and beam-shaping optical components, as well as the development of novel integrated power lasers. The Cluster of Excellence »Integrative Production Technology for High-Wage Countries« in the field »Digital Photonic Production« is working largely on the integration of optical technologies into manufacturing processes and on the production of optical systems. Ultra-short pulsed lasers are being tested in basic experiments and used to process nano and micro components of practical relevance by ablation, modification or melting. Single-pulse, percussion and spiral drilling techniques as well as trepanning are being used to process metals and multi-layer systems mostly made up of metals and ceramics. This technology is useful for drilling holes in turbine blades for the aerospace industry, for example. Work in the field of generative processes focuses mainly on new materials, smaller structures, higher build-up rates, micro coating, process monitoring and control, and the development and enhancement of the university's own plants and systems.

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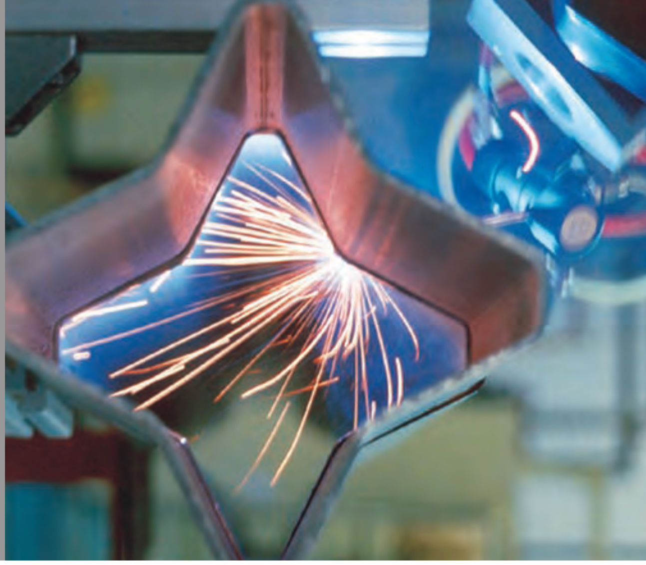

Chair for the Technology of Optical Systems TOS

By establishing the Chair for the Technology of Optical Systems in 2004, RWTH Aachen accorded recognition to the increasingly central role of highly developed optical systems in manufacturing, the IT industries and the life sciences. Research activities focus on the development and integration of optical components and systems for laser beam sources and laser devices.

Highly corrected focusing systems for a high laser output, beam homogenization facilities and innovative beam shaping systems are all key components of laser systems used in production engineering. The performance of fiber lasers and diode-pumped solid state lasers, for instance, is determined by optical coupling and pump light homogenizers. Free-form optics for innovative laser beam shaping are yet another topic of research. In the area of high-power diode lasers, micro- and macro-optical components are developed and combined to form complete systems. In addition, assembly techniques are optimized.

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Chair for Nonlinear Dynamics of Laser Processing NLD

Founded in 2005, the chair for Nonlinear Dynamics of Laser Processing NLD explores the basic principles of optical technology, with emphasis on modeling and simulation in the fields of application macro welding and cutting, precision processing with ultrafast lasers and PDT in dentistry and dermatology.

Mathematical, physical and experimental methods are being applied and enhanced to investigate technical systems. The application of mathematical models is helping to achieve a better understanding of dynamic interrelationships and to create new process engineering concepts. The results of these analyses are made available to industrial partners in the form of practical applications in collaboration with the Fraunhofer Institute for Laser Technology ILT.

The main educational objective is to teach a scientific, methodological approach to modeling on the basis of practical examples. Models are derived from the experimental diagnosis of laser manufacturing processes and the numerical calculation of selected model tasks. The diagnostic findings and the numerical calculations are then used to mathematically reduce the model equations. The solution characteristics of the reduced equations are fully contained in the solutions to the starting equations, and are not unnecessarily complex.

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LASER TECHNOLOGY AT RWTH AACHEN

Experimental Physics Study and Research Department: »Nano-Optics and Metamaterials«

The »Nano-optics and metamaterials« junior professorship was created as part of the excellence initiative at the RWTH Aachen in 2008. With the addition of this thematic research area, Professor Thomas Taubner will expand the research activities in the field of physics to include new imaging techniques with nanometric spatial resolution.

This technology is based on so-called »field amplification« in metallic or dielectric nanostructures: locally amplified electric (light) fields enable innovative sensors to detect organic substances, but also support innovative imaging methods such as optical near-field microscopy, or super-lenses which far surpass the diffraction-limited resolution of conventional microscopes.

The research focuses on the mid-infrared spectral range: here infrared spectroscopy can provide chemical information on molecular compounds, the crystal structure of polar solids and the properties of charge-carriers.

This basic research at the RWTH supplements the ATTRACT junior-staff group at the Fraunhofer ILT. This group, which is also headed up by Professor Taubner, is evaluating potential applications of new nano-optic concepts using laser technology.

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CLUSTER OF EXCELLENCE

Cluster of Excellence »Integrative Production Technology for High-Wage Countries«

In the Cluster of Excellence »Integrative Production Technology for High-Wage Countries« process engineers and materials scientists based in Aachen are developing new concepts and technologies offering a sustainable approach to industrial manufacturing.

A total of 18 chairs and institutes of RWTH Aachen, together with the Fraunhofer Institutes for Laser Technology ILT and for Production Technology IPT, are working on this project, which in the first instance will run until the end of 2012.

Funding of approx. 40 million euros has been granted to this Cluster of Excellence, an initiative that unites the largest number of research groups in Europe devoted to the objective of preserving manufacturing activities in high-wage countries.

Production in High-Wage Countries

The competition between manufacturers in high-wage and low-wage countries typically manifests itself as a two-dimensional problem, opposing production efficiency and planning efficiency.

In each case there are divergent approaches. With respect to production efficiency, low-wage countries tend to focus exclusively on economies of scale, whereas high-wage countries are obliged to seek a balanced equilibrium between scale and scope, in other words being able to satisfy customer requirements in respect of a particular product while at the same time attaining a minimum production volume.

A similar divergence is evident with respect to the second factor, that of planning efficiency. Manufacturers in high-wage countries aim to continuously optimize their processes, using correspondingly sophisticated, capital-intensive planning methods and instruments, and technologically superior production systems. In low-wage countries, by contrast, production needs are better served by simple, robust, supply-chain-oriented processes.

In order to maintain a sustainable competitive advantage for production sites in high-wage countries, it is no longer sufficient to aim for a better position that maximizes economies of scale and scope or reconciles the opposing extremes of a planning-oriented and a value-oriented approach. Instead, the goal of research must be to cancel out these opposite poles as far as possible. Ways must be found to allow a greater variability of products while at the same time being able to manufacture them at cost levels equivalent to mass production. This calls for value-optimized supply chains suited to each product, without excessive planning overheads that would compromise their cost-effectiveness.

Tomorrow's production technology therefore requires a thoroughly new understanding of these elementary, interrelated factors which are acquired in the four research areas Individualized Production, Virtual Production, Hybrid Production and Self-Optimizing Production in the framework of the Cluster of Excellence.

In efforts to bring down production costs, Fraunhofer ILT has for example increased the efficiency of its selective laser melting (SLM) processes by a factor of 10, an improvement that goes a long way toward eliminating the scale-scope dilemma. With its research into methods of self-optimization for laser-cutting systems and the automated assembly of solid-state lasers, Fraunhofer ILT is helping to break down the distinction between a planning-oriented and a value-oriented approach.

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RWTH AACHEN CAMPUS

RWTH Aachen Campus

Taking its lead from the Stanford University and Silicon Valley model, the RWTH Aachen will create one of Europe's largest technology-oriented campuses over a total area of approximately 2.5 km^2, making it one of the leading national and international knowledge and research centers. The location will be the former university extension site in Aachen Melaten along with part of the Aachen Westbahnhof (Aachen West Train Station). This setup will connect for the first time the core areas of the RWTH Aachen in the city center, in the Hörn district and in Melaten, to create an integrated campus.

Research Catalyst and Innovation Generator

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

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

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

Development and Timetable

The RWTH Aachen Campus will be created in three stages. The first stage was started in 2010 with the development and construction of Campus Melaten with its 6 clusters. The land-use plan and development of the Campus Westbahnhof will follow, involving another 9 clusters. The second stage will see the development and construction of Campus Westbahnhof with 4 clusters. And the final stage will focus on the growth and consolidation of 19 clusters in Melaten and the Westbahnhof as well as upgrading the infrastructure, including the construction of a congress hall, library and hotels.

Clusters

The relevant industry frontline themes will be tackled jointly in up to 19 clusters - focusing on production technology, power technology, automotive technology, ICT technology as well as materials technology.

On February 18, 2010, RWTH Rector Prof. Ernst M. Schmachtenberg and NRW Minister President Dr. Jürgen Rüttgers took part in the groundbreaking ceremony for the RWTH Aachen Campus. 92 companies, including 18 international key players, together with 31 chairs at the RWTH and a study department at Aachen University of Applied Sciences, signed up to long-term collaboration and to relocating to the RWTH Campus in Melaten. These eight to ten building complexes covering a gross area of 60,000 m² will be home to the following six clusters in the first phase from 2010 through 2014:

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

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

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

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2

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

2 RWTH Aachen Campus II - Melaten, Sketch: rha reicher haase + associierte, Aachen.

RESEARCH RESULTS 2011

Selected Research Results
of the Fraunhofer ILT

Note from Institute Director

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

TECHNOLOGY FOCUS
LASERS AND OPTICS

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

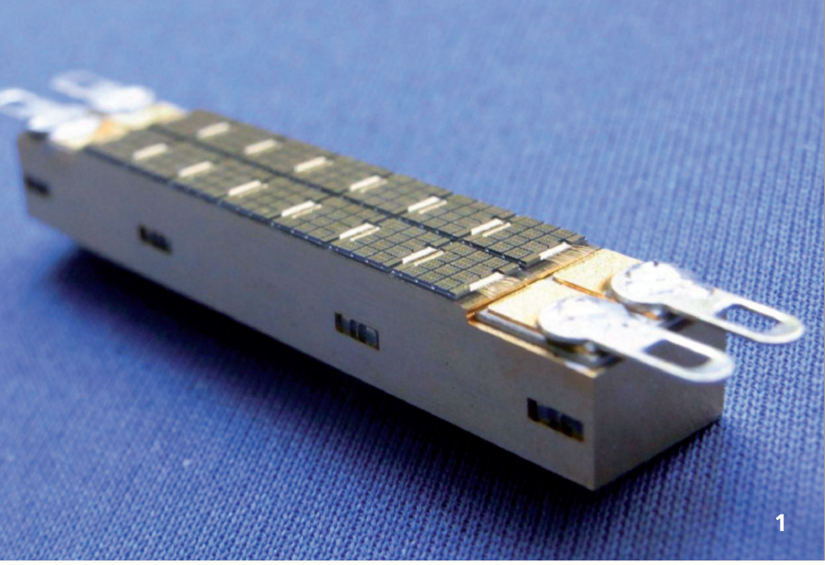
In the field of solid-state lasers, oscillators as well as amplification systems with excellent power data hold the center of our attention. Whether our customers are laser manufacturers or users, they do not only receive tailor-made prototypes for their individual needs, but also expert consultation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

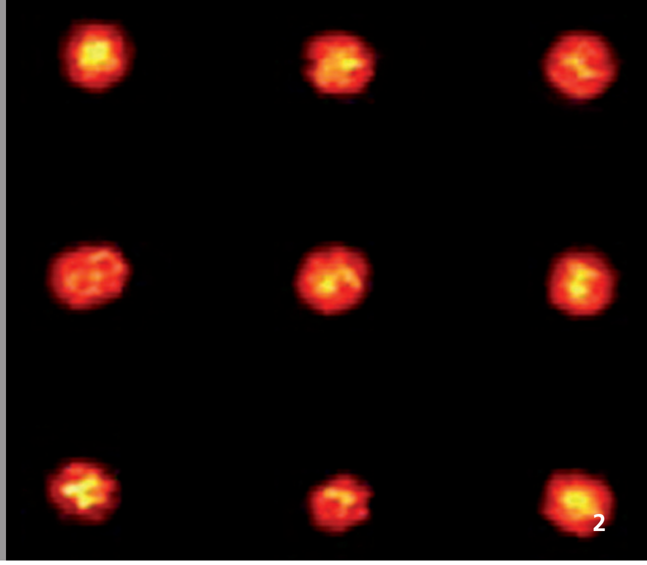
Furthermore, this technology field has a great deal of expertise in beam shaping and guiding, packaging of optical high power components and designing optical components. This field also specializes in dimensioning highly efficient free form optics. In general, the lasers and optics developed here can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

LASERS AND OPTICS

CONTENTS

Fiber-integrated Raman amplifier for picosecond pulses.





MODELING OF VERTICAL-EXTERNAL CAVITY SURFACE-EMITTING DIODE LASERS (VECSEL)

Task

Vertical-cavity surface-emitting lasers (VCSEL) constitute a promising alternative to conventional, edge-emitting diode lasers by offering a superior combination of manufacturing costs, power consumption, modulation capability and radiation profile, as well as simple array implementation. The low output power in the single mW range has hitherto limited the usage of VCSELs primarily to optical data transmission and sensor systems. Over the past decade, various large-area VCSELs have been demonstrated with output powers in the order of 1 W. The VCSEL design only delivers these output levels with high multimode emission, i.e. low brightness. High-power emitters with high brightness can be implemented by combining the VCSEL with an external optical resonator (VECSEL), making surface emitters a compelling proposition also for applications previously dominated by edge emitters. As part of a contract from Philips, Fraunhofer ILT in collaboration with the Chair for TOS at RWTH Aachen University is developing simulation software to optimize the resonator design and to tailor beam-shaping optics for V(E)CSELs.

1 VCSEL module with micro-lens array.

2 Radiation characteristics of a VECSEL array made up of 9 emitters.

Method

A model is currently under development for predicting the power and radiation characteristics of the VECSEL that are dependent on operating current, with the aim of optimizing the single emitter. The model is based on decomposing the radiation field into the resonator eigen-modes and simulating the mode selection by describing the light-medium interaction in the rate-equation approximation. The challenge is essentially in calculating the eigenmodes of the system made up of the semiconductor chip with a complex 3D refractive index distribution and the external resonator. Once the single emitter has been optimized, the next stage will involve configuring emitter-array micro-optics that can be integrated into a wafer.

Result

A VECSEL model has been largely developed and implemented. Certain experimental results have been reproduced and some effects that limit brightness identified and quantified.

Applications

Large-area V(E)CSEL arrays are ideally suited for applications that require outputs of up to a few kW with low or medium brightness. Examples include pumping solid-state lasers or drying processes in the print industry.

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SIMULATION AND ANALYSIS OF APPLICATION-SPECIFIC VOLUME BRAGG GRATINGS

Task

Volume Bragg Gratings (VBG) are used to stabilize the center wavelength, to reduce the bandwidth of high-power diode lasers and to provide incoherent spectral superposition with a small center wavelength distance $\Delta\lambda < 3$ nm. Further development work is needed on simulating application-specific VBGs, manufacturing enhanced VBGs through twin-beam interference, and developing measurement techniques for characterizing VBG properties.

Method

The characteristics of application-specific VBGs are calculated for various manufacturing parameters on the basis of a matrix approach to layer systems. A test bench was developed to test the properties of VBGs. A tunable laser, a spectrally stabilized laser diode or a wide-bandwidth superluminescent diode is used as the beam source.

Result

Angular and wavelength selectivity of the gratings can be specifically altered by modifying the intensity distribution when manufacturing the VBGs. Simulation calculations are used to determine precise specifications for the manufacturing process. For instance, the secondary maxima can be reduced by means of a Gaussian apodization function from 8 dB to up to 60 dB. Disturbance variables in the manufacturing process of VBGs cause variations in the diffraction efficiency. The developed test bench managed to detect these.

Applications

The optimization of manufacturing and testing processes for VBGs paves the way for denser spectral superposition in relation to the incoherent power scaling of diode lasers and, in turn, more brilliant diode laser beam sources. Spectrally stabilized diode lasers also improve the properties of solid-state and fiber lasers by utilizing advantageous pump bands.

The test bench also makes locally resolved measurement of spectral and angle-dependent diffraction distributions in commercial gratings possible.

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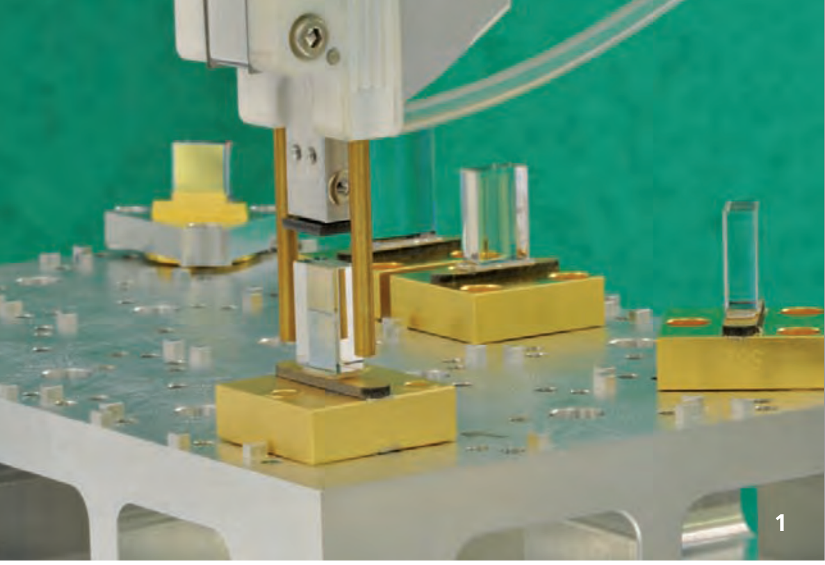
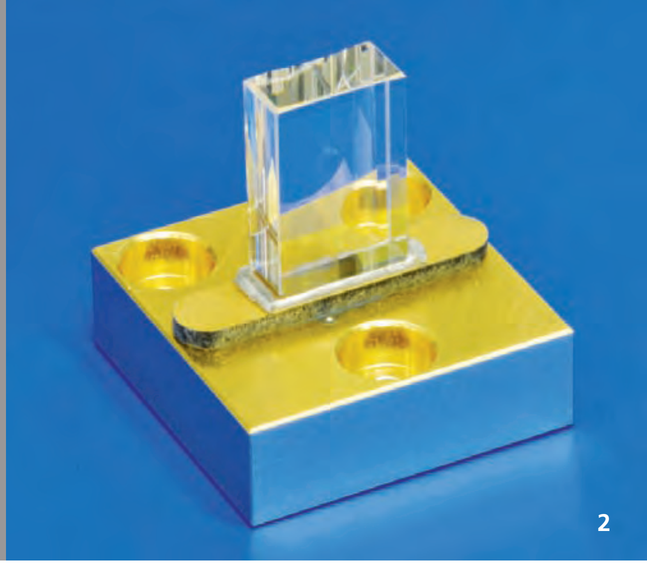
3 Optics for measuring volume diffraction gratings.





PICK & ALIGN – JOINING OPTICAL COMPONENTS WITH ACTIVE ALIGNMENT

Task

The notion of using soldering techniques to join optical systems is becoming increasingly popular, not only in aerospace applications but also in other areas. Laser systems for industrial applications are also benefiting from a joining technique that meets requirements for joint quality and reproducibility while also allowing optical components to be aligned.

Method

Fraunhofer ILT's Pick & Align resistance soldering technique is being used for soldered joints between materials such as quartz, BK7 or SF6 and ceramic materials. A crucial element in this process is the active alignment of optical components in the solder pool. A six-axis manipulator enables the components to be positioned with extreme precision during the soldering process. To further increase the strength and reproducibility of the joint produced, the soldering technique is being investigated in terms of long-term stability and positional accuracy. In particular, surface properties and metallization of the joining partners decisively influence the joint and must be tailored to thermal and mechanical stresses.

In addition, various solder geometries are being investigated in order to optimize the positional accuracy of optical components both during the soldering process and once exposed to the environment.

Result

Pick & Align enables assemblies to be manufactured from optical, ceramic and metallic components. The alignment based on multiple melting of the solder between the optics and metallic base substrate during the soldering process achieves a precision < 50 µrad. At the same time, shear testing demonstrated the high strength of the soldered joint in the temperature range between -40 °C and +50 °C.

Applications

The Pick & Align resistance soldering technique uses automated assembly techniques to successively put together beam-forming optics as well as deflection and resonator mirrors for laser and optics systems subject to thermal and mechanical loads.

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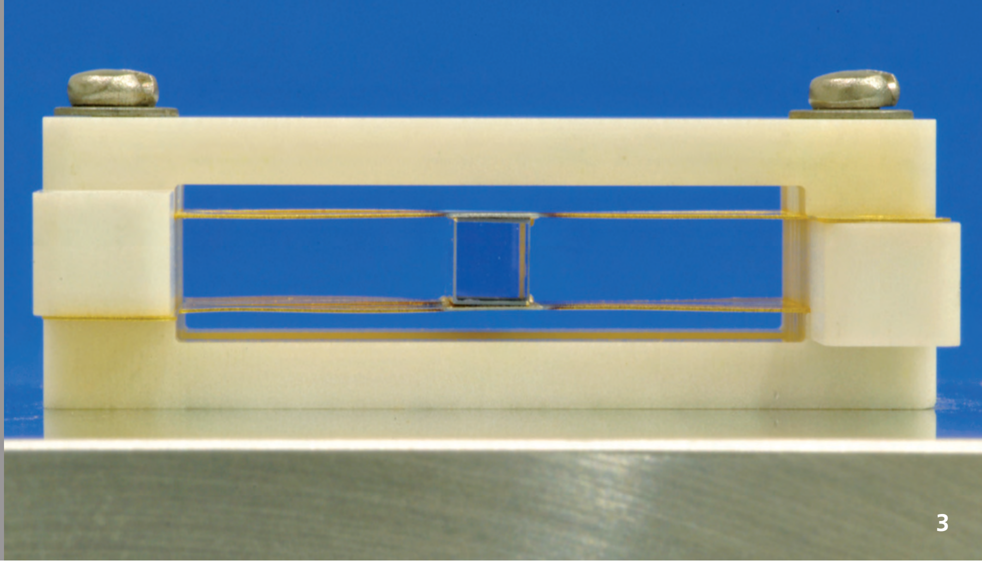
1 Pick & Align: Active alignment in the soldering process.

2 Soldered assembly made of quartz, ceramic and metallic main body.



POCKELS CELL FOR USE IN ROBUST LIDAR BEAM SOURCES FOR THE AEROSPACE INDUSTRY

Task

LIDAR beam sources for atmospheric research require mechanically and thermally stable laser components. Due to the variety of optical, electrical and thermomechanical conditions, assembling the crystals used in the Pockels cell poses a major challenge. Commercially available Pockels cell modules are unsuitable by virtue of the materials used and the mounting and contact methods employed. Research should therefore be focused on using a soldering technique to join and provide contacts for the crystal. As part of this process, particular attention needs to be paid to the coefficient of thermal expansion, which varies along the crystal planes ($\alpha 11/\alpha 33 = 1/9$). During start and maintenance phases in particular, thermal alternating loads of -40 °C to +70 °C may occur, and these may exceed the crystal's mechanical strength.

Method

The mechanical load in the BBO crystal can be reduced by designing the supporting structures to be elastic. The BBO crystal is soldered between two structured metal sheets onto which solder is vapor-deposited. The design reduces the area of the crystal that comes into contact with the solder. Furthermore, the structure allows the metal sheet to deform. The housing is manufactured from ceramic to provide electrical insulation.

Result

The assembly method developed at Fraunhofer ILT for Pockels cells guarantees a mechanically stable connection and a favorable response of the module to thermomechanical loads. With a crystal measuring 3 x 3 x 15 mm^3, the quarter-wave voltage is substantially exceeded at 4 kV. The Pockels cell has been successfully tested in a Q-switched solid-state laser.

Applications

In addition to use in beam sources for the aerospace industry, the process described here for assembling Pockels cells is generally suited for manufacturing of compact Pockels cells for industrial solid-state lasers, as used in medical technology and laser materials processing.

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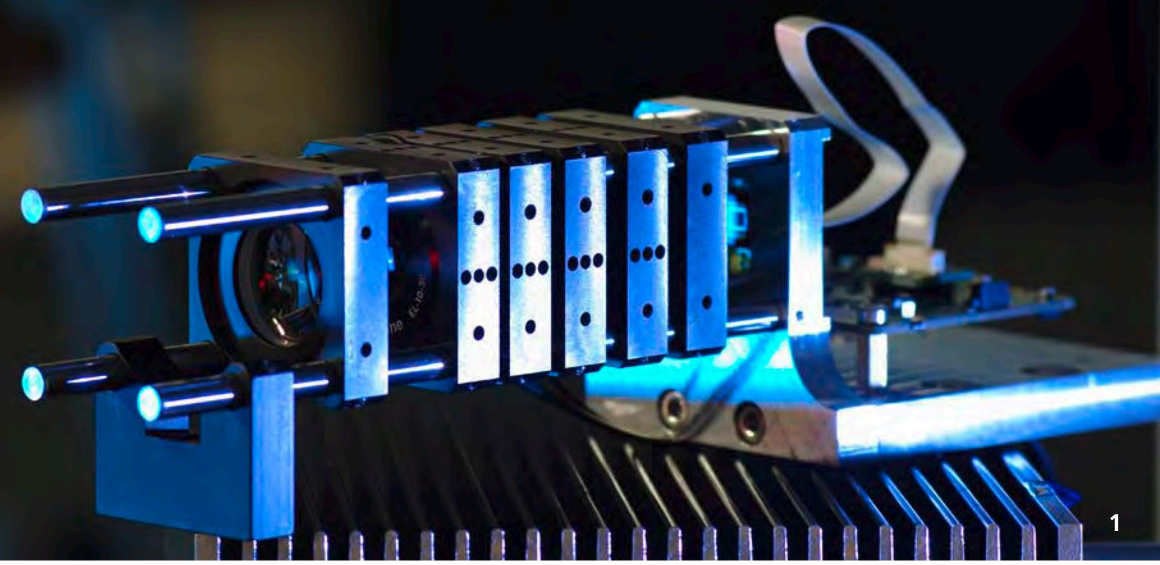
3 Assembled Pockels cell.



MODEL-PREDICTIVE CONTROL OF ACTIVE OPTICAL SYSTEMS

Task

In controlled systems, system behavior can be actively adjusted in response to changing process conditions. When applied to optical systems, traditional control approaches based on the feedback of a control variable are known to exhibit the following shortcomings in particular: detecting optical quality criteria often calls for costly, time-consuming measurement tools; and nonlinear and multivariable characteristics are often observed in conjunction with optical control steps. Model-predictive control overcomes these obstacles to controlling complex optical systems by using simulation models to predict control variables based on the simulated system behavior.

Method

Based on existing static simulation models for optimizing and evaluating optical system behavior, simulated parameters are translated into physical adjustment variables to precisely control the active components by dynamically integrating these static simulation models into an execution platform.

Result

The nonlinear multivariable behavior of an electrooptical zoom telescope can be used to demonstrate the principle of model-predictive control. ZEMAX ray-tracing software is used to map the optical system's behavior. Adjustment variables are generated based on the simulated control step by linking ZEMAX with the LabVIEW process environment. Based on the target values relating to image scale and object distance, the system behavior can be adjusted without any feedback of the necessary control variables.

Applications

The substitution of conventional feedback of control variables with model-predictive control is an ideal solution for active optical systems, particularly those that are mass produced. It also permits systems to be controlled where no measurement tool has yet been created to record the control variable.

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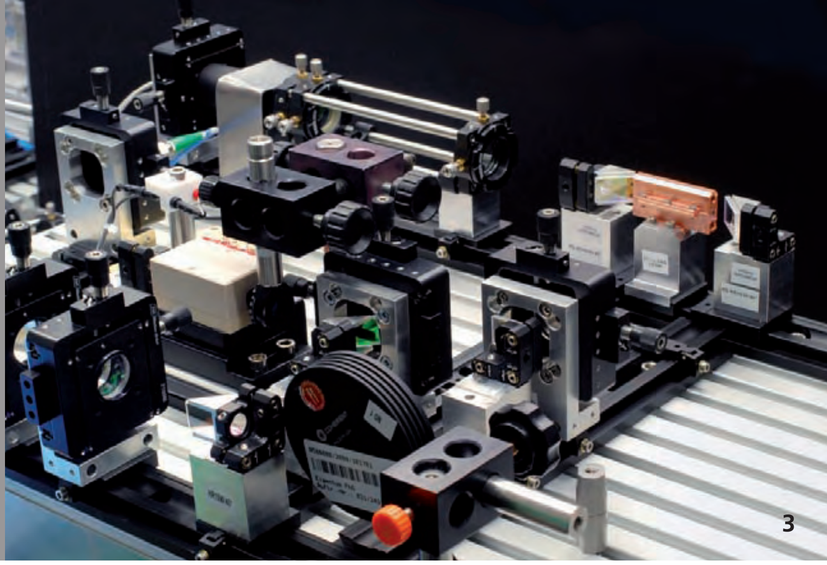
1 Electrooptical zoom telescope.



ERBIUM SOLID-STATE LASER AT 1.6 µm EMISSION WAVELENGTH

Task

The distribution and quantity of the greenhouse gases CO_2 and CH_4 in the atmosphere influence the climate and are, therefore, the subject of research. Absorption lines of molecules in the 1.6-µm range can be used to measure these gases with Lidar techniques. This technique requires narrow-band ("single frequency") laser radiation with a line width under 20 MHz, which has been implemented using non-linear conversion stages (OPO/OPA) to date. Generating this kind of laser radiation in solid-state lasers based on erbium-doped crystals dispenses with nonlinear processes and promises superior efficiency, robustness and smaller size.

Method

A solid-state laser with an erbium-doped laser crystal is set up, which is pumped with erbium-doped fiber lasers at a wavelength of 1532 nm. The solid-state laser is Q-switched at a repetition rate of 100 Hz and run in single-frequency mode with active resonator length control.

Under investigation is a computer model tailored to the properties of the laser sources under investigation (continual pump source, pulsed laser, saturation of the pump light absorption and thermal population of the lower laser level). The scaling limits of efficiency, energy and repetition rate are being calculated.

Result

A laser oscillator with an Er,Lu:YAG as a laser crystal has been set up and measured in continuous operation. This setup, which is optimized for pulse operation, has achieved a slope efficiency of 50 percent during continuous operation. 1.3 W output power at a wavelength of 1645 nm was obtained from the 7.5 W pump power. Calculations predict pulse energies of up to 10 mJ at 10 percent optical-optical efficiency from the oscillator. The damage thresholds of the optics limit efficiency, with higher repetition rates translating into increased efficiency.

Applications

The results to date are an important milestone on the way to a directly emitting laser source for the wavelengths relevant to detecting methane. Laser radiation with wavelengths around 1.6 µm also has uses in medical technology. Another potential application is in laser materials processing for materials that are transparent at visible wavelengths.

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

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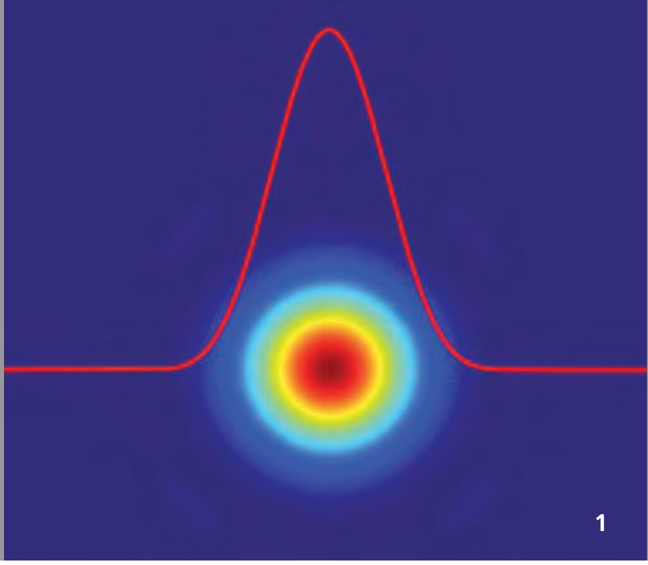
2 Pumped laser rod made of erbium-doped crystal.

3 Laboratory setup of the laser oscillator.



CONCEPT STUDY FOR THE GALA LASER TRANSMITTER ON THE EJSM SATELLITE MISSION

Task

EJSM-Laplace (new name: JUICE) is one of the three missions proposed as part of the European Space Agency's Cosmic Vision program. The aim is to measure the morphology and tidal deformation of Jupiter's moon Ganymede from an orbiter using a laser altimeter (GALA). The laser source must be compact, efficient and robust, and able to deliver various pulse parameters tailored to the orbiter's various flyover altitudes above Ganymede. Parameters include a pulse energy of 25 mJ with a repetition rate of 30 Hz or 4 mJ at 87.5 Hz, each with a pulse duration of 5 ns, an emission wavelength of 1064 nm and a diffraction-limited beam propagation.

Method

Various concepts are compared using analytical and numerical calculations, bearing in mind the particular requirements in terms of efficiency, volume, mass, and robustness. Potential laser concepts were preselected taking into account resilience to intensive ionizing radiation. This comparison included:

- Side and end pumping of the laser rod
- A single oscillator with two operating modes, two separate oscillators as well as an oscillator-amplifier setup
- Stable and unstable resonators

1 Simulated intensity distribution in the far field of a laser beam from an unstable resonator.

Result

Two separate oscillators, one oscillator with a stable resonator and one with an unstable resonator, each based on a side-pumped rod, proved the best solution for implementing the required laser parameters under the aforementioned conditions. The efficiency gain outweighs the disadvantages of the larger structural dimensions and weight.

Applications

The methods used here for the comprehensive analysis of spatial and energy-related laser beam properties in laser resonators and amplifiers can be applied to any optical system. In particular, two-dimensional field distributions (also polarization-resolved) can be calculated. In addition to designing resonators and amplifiers, virtual troubleshooting in existing optical systems is also facilitated.

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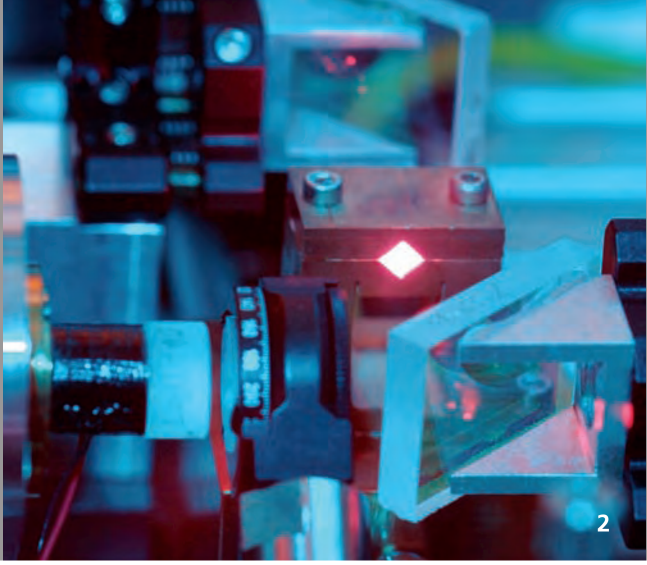

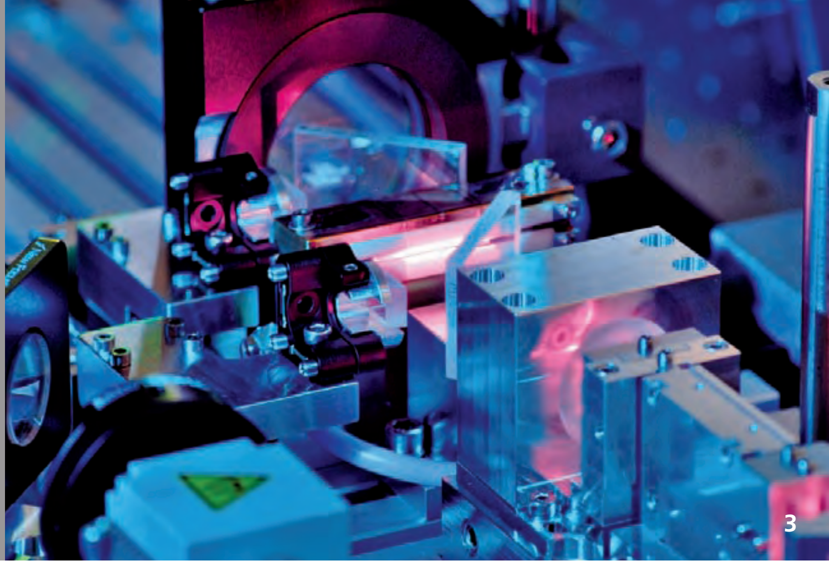

SINGLE-FREQUENCY PUMP SOURCE FOR A METHANE IPDA LIDAR

Task

The IPDA (Integrated Path Absorption) LIDAR process has established itself as the solution of choice for remote sensing of low methane concentrations in the atmosphere. Pulsed laser radiation with a wavelength around 3 µm can be used, and this is normally generated through frequency conversion of 1-µm radiation in optical parametric oscillators (OPOs). This 1-µm pump source must be tailored to the working point for a helicopter-based application to monitor gas pipelines. In addition to single-longitude-mode operation, this also requires excellent beam quality ($M^2 < 1.5$) and high energy stability under tough environmental conditions in terms of temperature and vibration. Efficient scanning and economic processing rates call for repetition rates of up to 1 kHz with a pulse energy of around 16 mJ.

Method

In order to meet the high spectral and geometric requirements under vibrational load and, at the same time, the requirements in relation to pulse energy and average output, a MOPA (Master Oscillator Power Amplifier) system was designed, which comprises a stable oscillator and an Innoslab amplifier stage. The oscillator is stabilized longitudinally using the Ramp&Fire process in order to guarantee single-mode operation.

Result

A laboratory setup was developed to demonstrate the requisite beam properties. At a repetition rate of 1 kHz, a pulse energy of 3.1 mJ in the oscillator and 18.1 mJ in the amplifier (total: 21.2 mJ) was generated with a diffraction index < 1.3 and a pulse duration of around 13 ns. The single-longitude-mode operation is inherently guaranteed even when subject to disturbances thanks to the powerful stabilization process. The requisite energy stability was also demonstrated.

Applications

In addition to the application mentioned above, these types of laser source can also be converted into different wavelength ranges and used, in particular, for remote sensing of different climatic parameters such as concentrations of trace gases or wind speeds.

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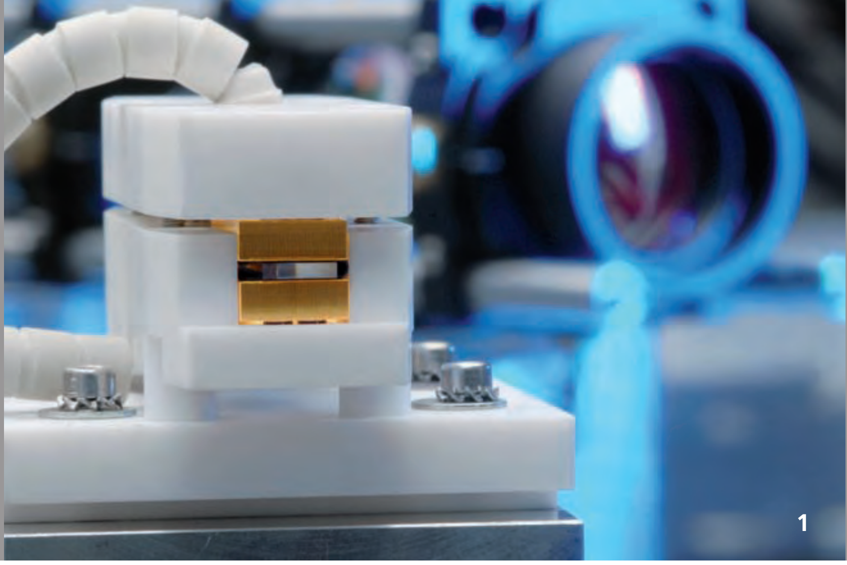
2 Rod oscillator in the laboratory demonstrator.

3 Innoslab amplification stage of the laboratory demonstrator.



TUNABLE LASER BEAM SOURCE IN THE MEDIUM INFRARED

Task

Absorption lines of a large number of elements and molecules lie within what is known as the fingerprint region of the medium infrared wavelength range. Laser beam sources in this wavelength range are required for spectroscopic analysis of chemical composition. In conjunction with near-field microscopy, spatial resolutions in the region of a few 10 nm are also possible. State-of-the-art beam sources are currently not available with the requisite properties.

Method

To generate wavelengths in the medium infrared, a system was developed which provides the requisite wavelength range based on a commercial picosecond laser and two nonlinear optical conversion stages.

Result

The initial conversion stage is an optical parametric generator using periodically poled lithium niobate crystals. The waves generated can be tuned from 1.7 µm to 2.05 µm (signal) and 2.28 µm to 2.8 µm (idler) by means of temperature.
In the second conversion stage, the difference frequency between these two waves is generated. At present, a wavelength range of 9 to 14 µm has been achieved through angle tuning using an $AgGaSe_2$ crystal. This is equivalent to wave numbers of 1125 cm^{-1} to 720 cm^{-1} with a spectral FWHM between 30 cm^{-1} and 70 cm^{-1}. The average output power is up to 10 mW. The standard deviation of the output is just 0.38 percent over an hour.

Both the tuning area and the line width can be extended further by using crystals with different cut angles or different crystal materials.

Applications

Using the laser system as a light source for near-field microscopy enables sample analyses to be conducted from a wide variety of research and development areas, ranging from bioanalytics, through semiconductor technology and plasmonics, to nanoparticle-doped fibers.

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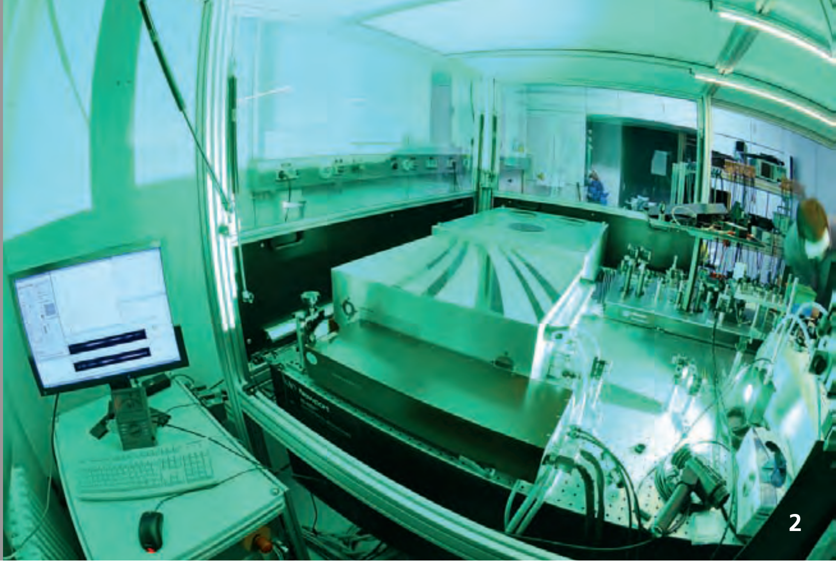
1 Crystal oven with PPLN crystal.



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HIGH-POWER ULTRAFAST BEAM SOURCE AT 515 NM

Task

In the micromaterials processing segment, ultrafast lasers provide precise, efficient material ablation coupled with minimal heat input. Frequency doubling of infrared sub-ps pulses opens up new applications for machining materials with little or even no infrared absorption. Furthermore, the wavelength reduction results in better focusability of the laser radiation. Improvement in brightness and pulse energy at high repetition rates also provides for scalable throughput when processing materials using ultrashort pulse beam sources.

Method

A Yb:YAG-MOPA (Master Oscillator Power Amplifier), whose amplifier based on INNOSLAB technology was developed and built at Fraunhofer ILT, is used as the infrared beam source to generate sub-ps pulses at 515 nm. In the infrared, the laser provided to investigate frequency conversion delivers an average power of up to 570 W at a repetition rate of 50 MHz, a pulse duration of 660 fs and almost diffraction-limited beam quality ($M^2 < 1.5$). The infrared radiation is frequency-doubled in a single pass by a critically phase-matched LBO crystal. Numerical simulations are conducted to configure the conversion process in which both thermal loading on the crystal and group delay effects are taken into account. It is therefore possible to identify a beneficial working point for the frequency doubling at which the short pulse duration is retained, combined with high conversion efficiency, pulse energy and average power with moderate intensity of the incident laser radiation on the conversion crystals.

Result

At 515 nm the laser delivers an average power of 377 W, which corresponds to a conversion efficiency of 66 percent and a pulse energy of 7.5 µJ. The pulse duration is virtually retained at 700 fs, resulting in an average pulse power of 11 MW at a pulse repetition rate of 50 MHz. The beam quality in the green is better than $M^2 = 1.7$.

Applications

Since April 2011 the laser has been used as part of a collaboration project with the Max Planck Institute of Quantum Optics to generate higher harmonics. Apart from micromaterials processing, other potential applications include doping silicon or cutting copper and composite materials.

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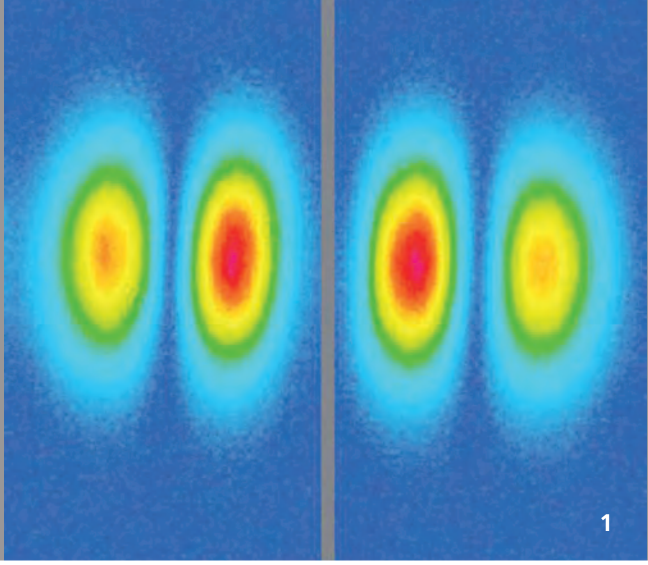
2 Laser in use at the Max Planck Institute of Quantum Optics in Garching, Germany.



1 Measured intensity distribution of a slit mode

TAILORED TRANSVERSE MODES

Task

Coherent radiation with wavelengths below 100 nm can be created in a gas jet as high harmonics of femtosecond laser radiation. In order to achieve the necessary intensity at repetition rates above 10 MHz and, at the same time, improve conversion efficiency, the power of the driving radiation is enhanced in a resonator. The output coupling of the frequency-converted radiation takes place geometrically through a hole or a slit in one of the resonator mirrors in order to prevent interaction with an optical element at the short wavelengths generated. This method is power-scalable, thus enabling the full potential of kW ultrafast lasers to be exploited. The aim is to design a resonator with a tailored field distribution which exhibits a point of high intensity on the optical axis combined with low intensity on the optical axis at another point in the resonator.

Method

Various resonators with a hole or slit in a mirror and a resonator-internal focus with field distribution suitable for the conversion process were tested analytically and numerically in terms of losses. By utilizing the degeneration of transverse modes in the enhancement resonator, field distributions can be excited which avoid the hole or slit and, as a result, suffer small losses and support high enhancement.

Result

A quasi-imaging resonator with a circulating slit mode was demonstrated experimentally in collaboration with the Max Planck Institute of Quantum Optics MPQ in Garching. A finesse of over 3,000 was achieved using a slit-shaped obstacle on the optical axis with a width of 5 percent of the Gaussian beam diameter – equivalent to a loss of just 0.02 percent, while the obstacle causes the fundamental mode to lose 15 percent. The degeneration of the modes is adjusted as a function of the distance between the curved resonator mirrors, with an accuracy of a few µm being sufficient.

Applications

A resonator with a hole in one resonator mirror coupled with small losses opens up a wide range of applications in the scientific field. In addition to output coupling of harmonics generated in the resonator, it can, for instance, be used for output coupling at Thomson backscattering at electrons for x-ray generation. A well-defined enhanced field distribution localized in three dimensions can, for instance, be used for dipole traps.

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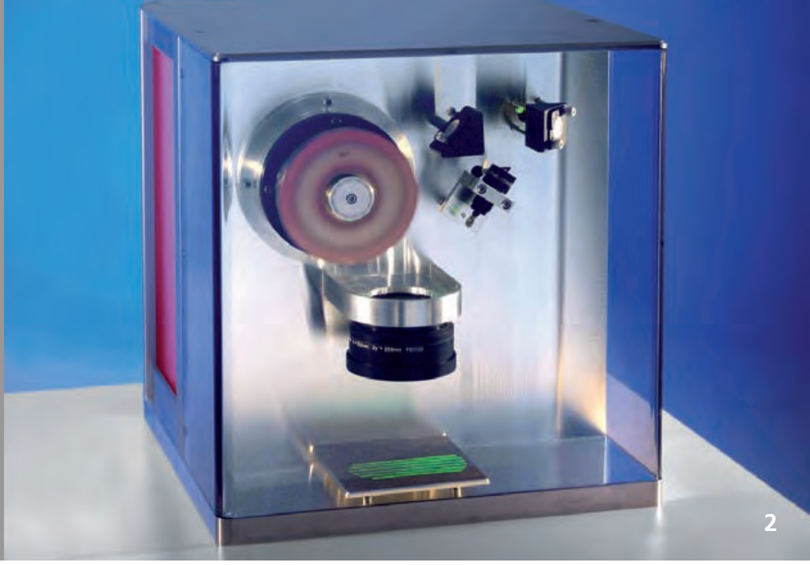

HIGH-SPEED POLYGON SCANNER FOR ULTRASHORT PULSE PROCESSING

Task

Current developments with ultrafast lasers are setting record after record in terms of average laser power and pulse rate. To generate high-quality processing results, individual laser pulses have to be distributed at low pulse energy in order to prevent the material from overheating. At pulse frequencies in the multi-MHz region, the scan speed of galvanometer scanners is no longer sufficient, with the result that these lasers may only be used with reduced power. Polygon scanners can be used to increase the processing speed several-fold; a minor pulse overlap can be achieved for an optimum result while utilizing the laser's full power.

Method

Polygon scanners feature a polygon mirror that rotates at a high constant speed. A laser beam that hits the polygon mirror is deflected along a line. Researchers at Fraunhofer ILT have supplemented this system with another scanner (e.g. galvanometer scanner) upstream of the polygon in order to make two-dimensional ablation areas possible. To implement precise pulse and position modulation of the laser beam, the system has been combined with a high-speed pulse picker which is synchronized with the rotation of the polygon and the laser pulses.

Result

Based on an initial prototype, Fraunhofer ILT is currently developing a polygon scanner system for a processing field of up to 100 mm with 160 mm optics and a scan speed of up to 320 m/s. The modulation of the laser beam at several MHz in sync with the laser cycle and the correspondingly adjusted positioning of the laser beam on the workpiece constitute the biggest challenges.

Applications

Applications include large-scale structuring or laser treatment of various materials using high-power ultrafast lasers. Besides the system's current applications for ultrafast lasers, researchers are also considering high-speed processes using cw lasers, such as line soldering of solar cells or dicing semiconductor wafers, which require multiple parallel beams.

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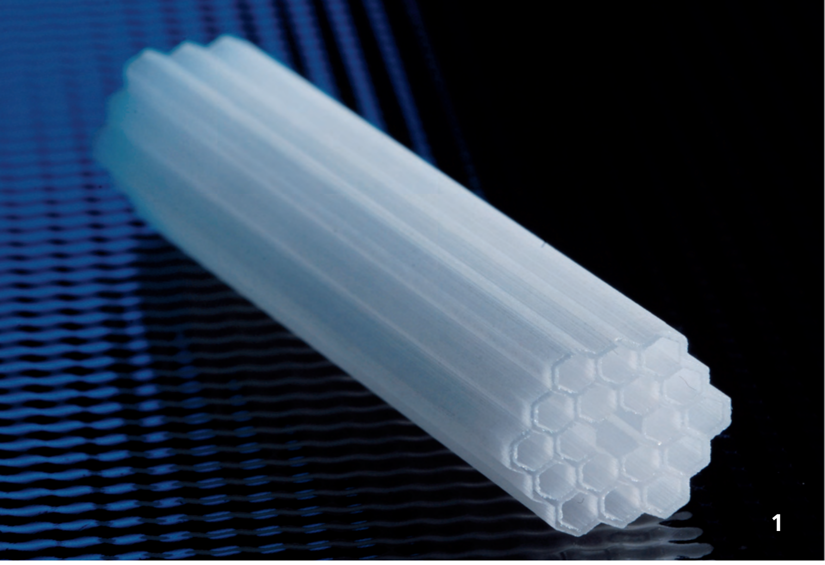
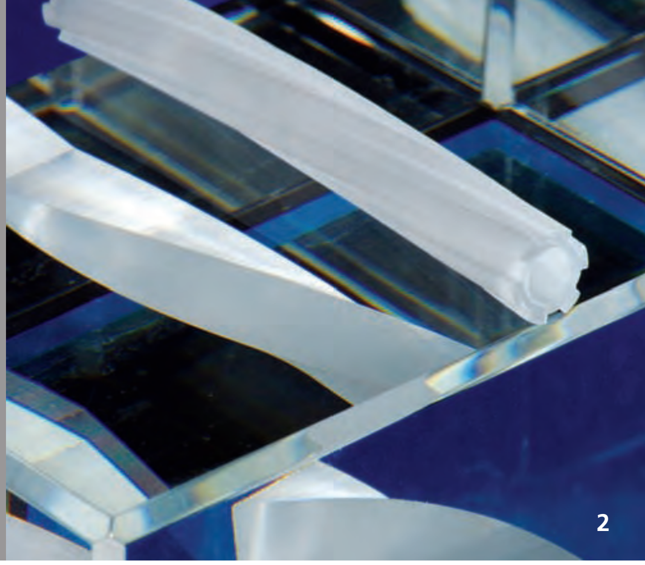
2 Demonstrator combination of polygon/galvanometer scanner.





MANUFACTURE OF FIBER PREFORMS AND OTHER 3D VOLUME STRUCTURES USING LASER DRILLING

Task

Complex glass components are required for a host of technical applications. Glass components destined for processing into optical components pose particular new challenges for the manufacturing process and its cost-effectiveness. During the manufacture of optical fibers, structures tend to be incorporated using mechanical drilling processes before the fibers are drawn out into the preform. The aim is to establish a manufacturing process that is as fully automated as possible using the inverse laser machining process, thus also paving the way for complex 3D volume structures which have been impossible to manufacture thus far.

Method

To process the glass components, the laser beam is focused on the underside of the workpiece and a defined region is scanned and ablated using individual laser pulses. Once this step is complete, the ablation layer is moved further into the material by a fixed value and ablated again. In this way, the required geometry is applied to the glass layer by layer. To further improve the process, a machining station is being set up using a Q-switched Innoslab laser (wavelength: 532 nm). Tests to improve the drilling depth, speed and reliability of the process as well as the influence of various glasses are being conducted.

Result

At present, holes with diameters of between 350 µm and 8 mm and a drill depth of 120 mm can be made in BK7. Drill depths of up to 60 mm with a diameter of between 600 µm and 8 mm have been achieved in silica glass. Moreover, it is possible to manufacture freely definable structures such as twisted polygons and filigree structures that cannot be produced using mechanical processes.

Applications

Because it is an automated and non-contact production process, inverse glass machining is suitable for use in various technical fields where 3D structures are required in glass materials. Initial fiber preforms have already been manufactured that will be used for further research into the manufacture of fiber optics.

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1 Photonic structure in BK7 glass (structure size: 12.8 mm, structure depth: 60 mm, rib width: 450 µm).

2 Rotated structure in BK7 glass (edge length: 1 mm).

FIBER-INTEGRATED RAMAN AMPLIFIER FOR PICOSECOND PULSES

Task

The high amplification per round trip in ytterbium-doped fiber amplifiers also leads to high amplified spontaneous emission (ASE). For short pulse durations with low repetition rates and generally with low average seed power, the high levels of ASE limit the output power. As an alternative concept, a Raman amplifier for short pulse durations with a pulsed pump source is to be set up and investigated. Here, the stimulated Raman scattering in fibers is utilized which, unlike direct amplification in the ytterbium fiber amplifier, does not lead to ASE.

Method

To implement the Raman amplifier, a pulsed ytterbium fiber amplifier with a wavelength of 1020 nm is set up as a pump source and used to amplify the signal of a single-mode diode via Raman scattering in a 25-m-long fiber.

Result

The signal, with a pulse duration of approx. 100 ps and a wavelength of 1064 nm, is amplified by up to 32 dB to a peak pulse power of around 200 W as a result of the pump pulse propagating simultaneously through the fiber with a pulse duration of 1.7 ns. The conversion of the pump pulse power to the signal pulse power is very efficient with up to 99 %. Due to the high power transfer and the instantaneous interaction of the Raman scattering, the problems associated with ASE development do not occur.

Applications

Thanks to its high amplification even at very low input power and short pulse durations, the Raman amplifier can be used as a low-noise, high-power seed source in cascaded amplifier chains. This means Raman amplifiers with subsequent re-amplification can be applied to typical fiber laser tasks in materials processing such as marking, cutting and welding, metrology and medical technology.

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

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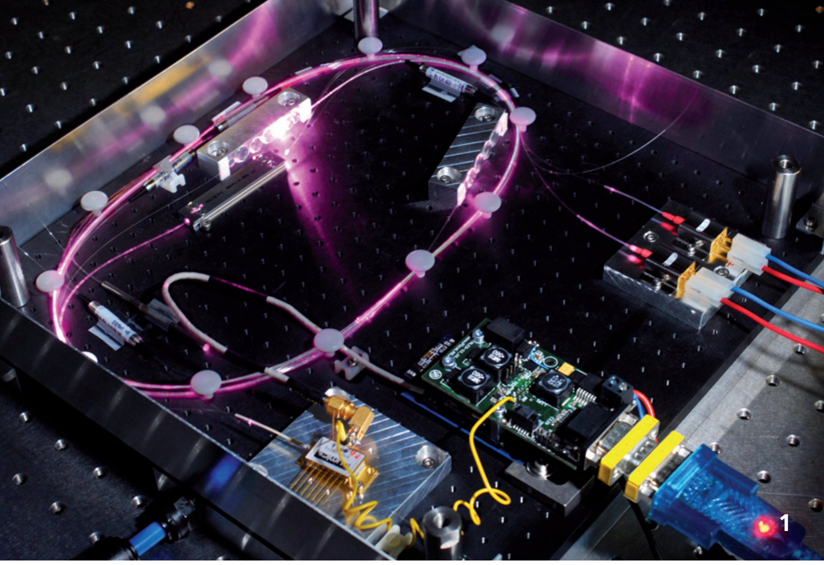
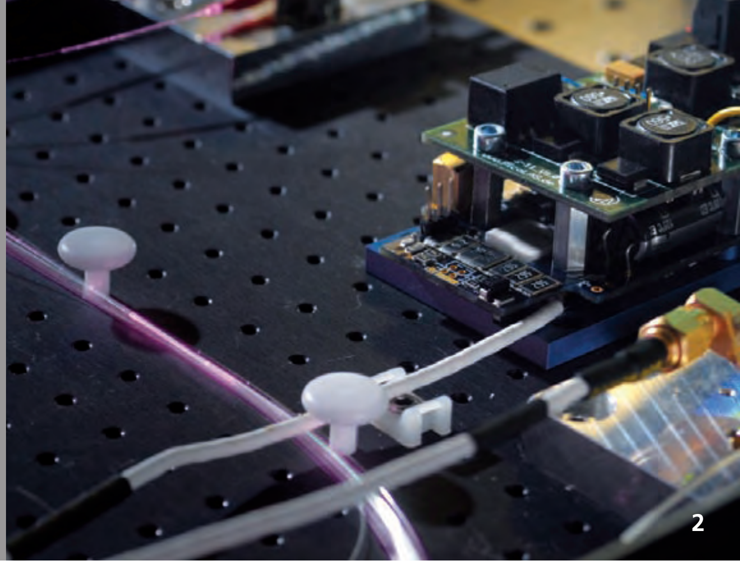
3 Raman amplifier demonstrator





TWO-STAGE LINEAR FIBER AMPLIFIER IN THE VARIABLE PICO- AND NANOSECOND RANGE

Task

One part of the FAZIT project funded by the German Federal Ministry of Education and Research (BMBF) is the investigation of basic concepts for robust and fully fiber-integrated amplifier systems in various pulse duration ranges from a few picoseconds to microseconds, and repetition rates of a few kilohertz to several megahertz. A concept for a linear amplifier system with pulse widths of single-digit nanoseconds to subnanoseconds is being developed and implemented. A small form factor, fundamental-mode beam quality as well as linear polarized radiation supplement the requirements profile.

Method

The seed signal is generated by combining a prototype of a driver circuit to generate short current pulses and a single-mode laser diode with a wavelength of 1064 nm. It is amplified by two cascaded stages decoupled from each other using isolators. A wavelength of 915 nm and contradirectional pumping via a fiber fusion coupler was chosen to create the inversion within the ytterbium-doped active fibers.

Result

The result is a compact, completely fiber-integrated two-stage amplifier. A digital control system can freely adjust duty cycles from 1:333 to 1:2000 with pulse widths between 0.5 ns and 2 ns and repetition rates between 0.5 MHz and 2 MHz. A peak pulse power up to around 5.5 kW, a degree of polarization of approx. 30 dB and a signal-to-noise ratio of around 25 dB can be achieved.

Applications

The fiber amplifier can be used as an independent laser source for materials processing tasks such as marking and microstructuring, as well as in metrology or medical technology. However, its primary use is as a seed source for further high-power amplifier stages.

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

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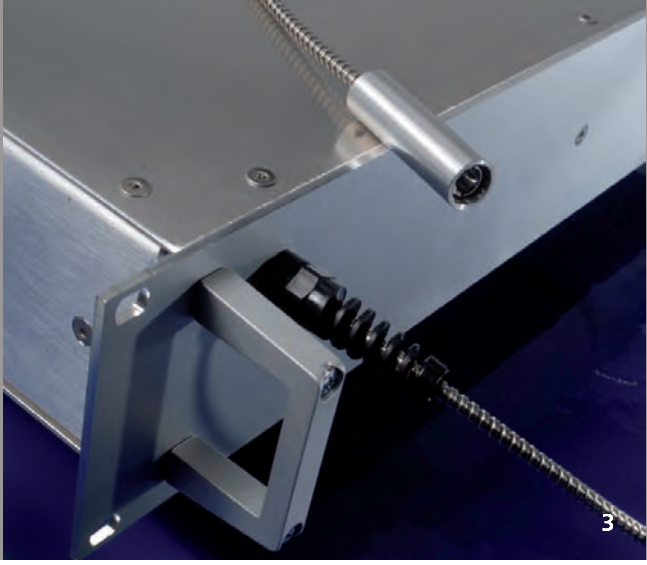
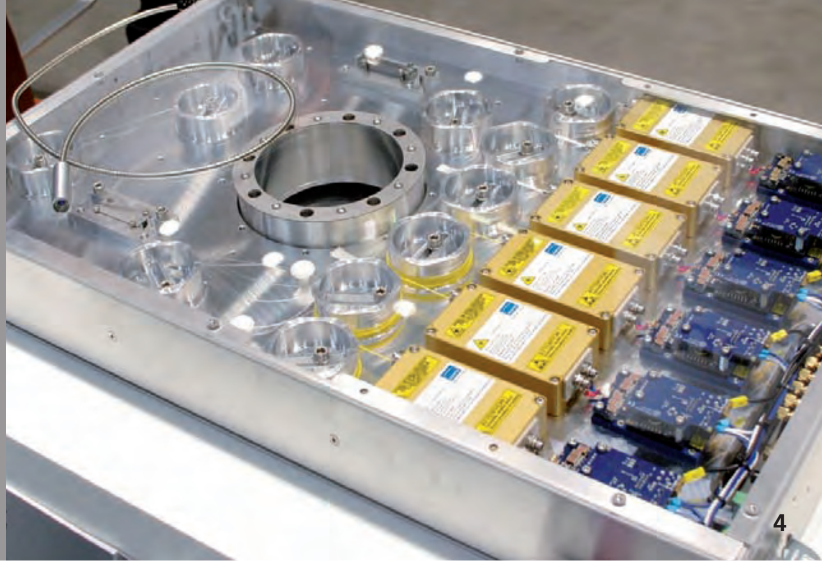
1 Fiber amplifier demonstrator.

2 Diode driver.





MONOLITHIC GAIN-SWITCHED FIBER LASER WITH PEAK POWER IN THE KW REGION

Task

As an alternative concept to conventional pulsed fiber laser systems, such as Q-switched fiber lasers or pulsed diode lasers with a linear fiber amplifier, a gain-switched fiber laser is to be set up and investigated as part of the FAZIT project funded by the German Federal Ministry of Education and Research (BMBF). The gain-switched fiber laser also enables low repetition rate areas to be covered, something which cannot readily be achieved using conventional fiber laser concepts on account of amplified spontaneous emission (ASE). Setting up the fiber laser as a resonator is also very simple and cost-effective and offers a great deal of versatility, since the laser can also be run in continuous continually (cw) or quasi-cw mode.

Method

A fully fiber-integrated resonator, comprising an active, ytterbium-doped fiber and fiber Bragg gratings, is pumped using short pulses in the sub-µs region so that the signal builds out from noise. Thus the gain-switched fiber laser also demonstrates minimal amplified spontaneous emission, even at low repetition rates of < 5 kHz. In order to achieve maximum available pump energy per pump pulse, the pump modules are run with a power that lies above the nominal cw power by approximately a factor of 4. Several commercially available pump diodes and modules were tested beforehand in terms of their pulsability to enable a suitable pump module to be found.

Result

As part of setting up the gain-switched fiber laser, six fiber-coupled pump modules are operated in pulsed mode via a special electronics control unit and coupled to the active fiber using a fusion coupler. Two fiber Bragg gratings with a wavelength of 1080 nm complete the fiber-integrated setup.

The pulse duration achieved with this setup is in the region of 100 ns with repetition rates ranging from single shot operation up to approx. 20 kHz. The signal-to-noise ratio is approx. 35 dB due to the good ASE suppression; peak outputs of several kW have been achieved.

Applications

Due to their very good beam quality and robust setup, gain-switched fiber lasers can be used in metrology, medical technology or in micromaterials processing applications. What is more, the addition of subsequent amplification stages makes them suitable for applications that call for higher power with variable repetition rates.

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

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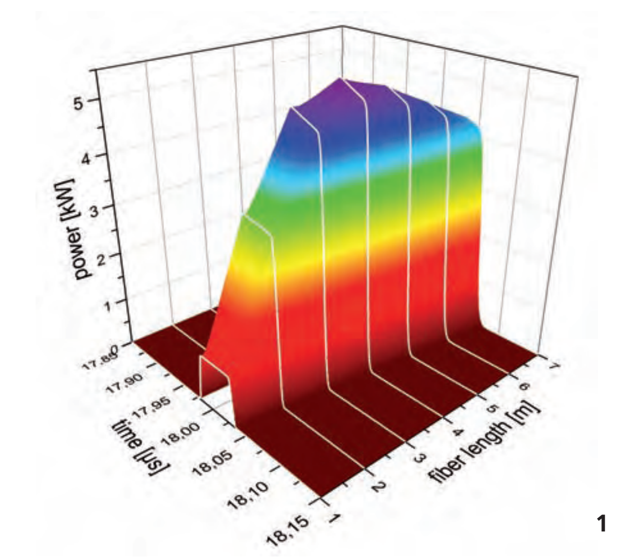
3 Prototype of the gain-switched fiber laser.

4 Interior view of the prototype.



TEMPORALLY AND SPECTRALLY RESOLVED SIMULATION OF PULSED FIBER LASERS

Task

Fiber lasers are ideally suited for many applications, such as materials processing, metrology and medical technology, thanks to their very good beam quality at high average power, their high efficiency, and their robust setup. However, in the case of pulsed ytterbium-doped fiber lasers or amplifiers, in particular, amplified spontaneous emission (ASE) constitutes a major limiting factor due to the high amplification in the fiber. Since no time- and wavelength-dependent simulation tool was available commercially that could comply with our demands, our aim was to develop a temporally and spectrally resolved software for the simulation of pulsed fiber amplifiers and lasers that are used to generate transverse mono- and multimode radiation.

Method

A numerical simulation was developed to model the fiber laser in which the active fiber is divided up longitudinally and the temporal rate equations are solved for each fiber element using a Runge-Kutta method; these equations take into account the absorption and stimulated emission of the signal and pump wavelengths, as well as the occurrence of ASE.

1 Development of the time-dependent pulse shape along the fiber axis.

Result

On the basis of the time- and wavelength-dependent pump and signal input power, the numerical simulation calculates the time-dependent inversion distribution across the fiber length and the time- and wavelength-resolved power distribution of pump and signal light for adjustable fiber-specific input parameters, such as numerical aperture, core and cladding diameter, length and doping concentration.

Applications

The accuracy of the simulation has already been demonstrated successfully in experimental setups of several linear fiber amplifiers and gain-switched fiber lasers with various output power ratings. The spectrally and temporally resolved simulation is now used to calculate and design Fraunhofer ILT prototypes and tailored prototypes for our customers.

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TECHNOLOGY FOCUS
LASER MATERIAL PROCESSING

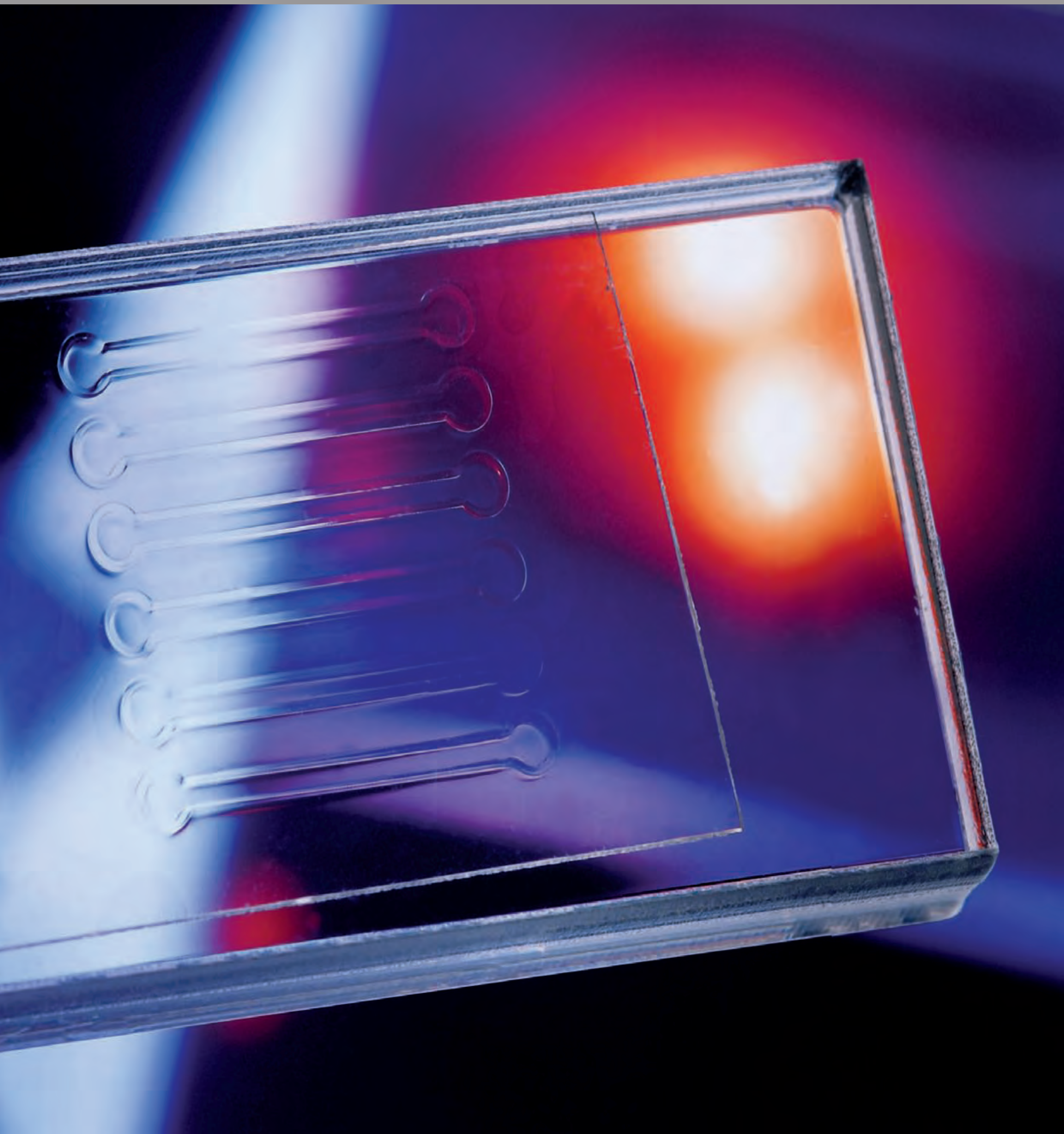
Among the many manufacturing processes in the technology field Laser Material Processing, cutting and joining in micro and macro technology as well as surface processes count among its most important. Whether it be laser cutting or laser welding, drilling or soldering, laser metal deposition or cleaning, structuring or polishing, generating or layering, the range of services spans process development and feasibility studies, simulation and modeling, as well as the integration of processes in production lines.

The strength of the technology field lies in its extensive know-how, which is tailored to customer requirements. In such a way hybrid and combination processes also result. Moreover, complete system solutions are offered in cooperation with a specialized network of partners. Special plants, plant modifications and additional components are the constituent part of numerous R&D projects. For example, special processing heads for laser material processing are being developed and produced, based on a customer's specific needs. In addition, process optimization by changing the design of components as well as systems to monitor quality online count among the specializations of this technology field.

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

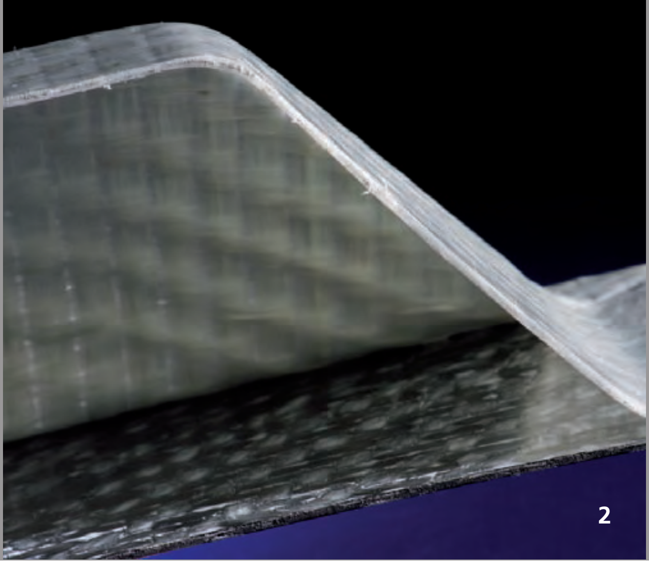
RESEARCH RESULTS 2011

LASER MATERIAL PROCESSING



CONTENTS

Cutting fiber-reinforced plastics.



CUTTING FIBER-REINFORCED PLASTICS

Task

Lightweight construction using fiber-reinforced plastics is key to meeting national and international energy-saving and climate-protection targets. There is a requirement for solutions for efficient production that also embrace the mass market. But long cycle times and limited automation in the manufacturing of fiber-reinforced components still pose a major problem. Laser cutting offers huge potential for reducing machining times and for automation, both within the process chain (cutting prepregs, organic sheet metal, tapes) and while trimming and cutting components. If composite materials are cut using a standard laser cutting process, the cut edge can be damaged as a result of varying absorption, heat conductivity, melting points and decomposition temperatures of the fiber and matrix. This damage takes the form of protruding fibers, delamination and deposits. The heat affected zones are typically 0.5 to 1.0 mm wide.

Method

Together with industrial partners, Fraunhofer ILT is working on an integrated process chain for manufacturing fiber-composite components. This also includes the development of laser cutting techniques that can be used to minimize damage of the cut edges. The aim is to minimize thermal influence and, in turn, material damage by using ultrashort pulse lasers and new short-pulse CO_2 lasers.

1 Cutting process immediately after cutting out the hole.

2 Laser-welded and laser-cut fiber-reinforced plastic component.

Result

Material damage is kept to a minimum through short interaction times. Thermal damage is reduced by employing high machining speeds and scanning ablative processes or by modulating the laser radiation. Tests using ultrashort pulse lasers illustrate the potential for cutting fiber-reinforced plastics at a wavelength of 1 µm. Good machining results can, however, also be achieved with CO_2 lasers due to the high intrinsic absorption of the radiation in the plastic matrix. Researchers expect that the use of short-pulsed CO_2 laser radiation will substantially increase quality.

Applications

Trimming and cutting are essential process steps for the manufacture of all fiber-composite components and are relevant to a wide range of industries, such as vehicle manufacturing, mechanical engineering, the consumer goods and sports equipment industry.

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

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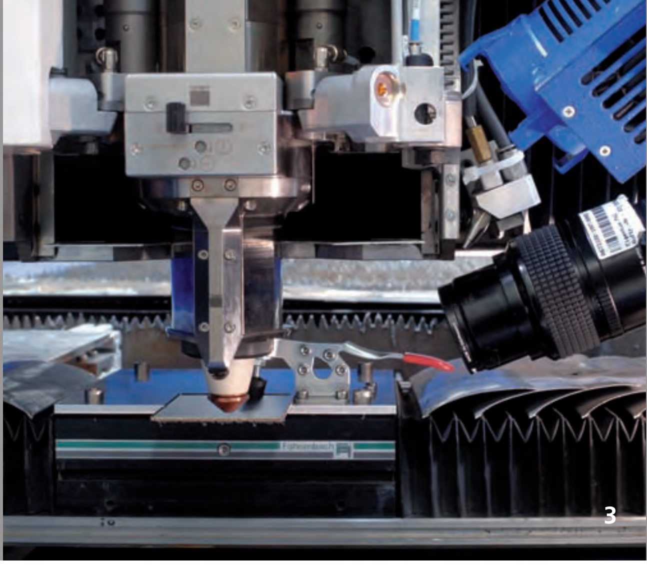

HIGH-SPEED PROCESS MONITORING DURING LASER CUTTING

Task

Laser cutting quality is to a large extent determined by the hydrodynamics of the melt pool at the cutting front. This property influences ripple structures on the cutting edges and the melt expulsion on the lower cutting edge. The latest monitoring techniques are already pushed to the limit by the combination of high melt dynamics, intense radiating process and small geometrical dimensions. Despite this challenge, the aim is to analyze dynamic melt processes using a high-speed camera in order to answer topical issues surrounding the temporal and spatial distribution of the melt flow.

Method

Defocusing was used to generate ultrawide cut gaps which, in turn, enabled the process to be monitored effectively. The variable monitoring concept provides a simultaneous view of the cutting front and lower edge of the metal sheet. Moving the workpiece while the cutting head remains stationary provides a pin-sharp image of the cutting process without the camera system having to track the process. The angle and brightness of the secondary light source placed to one side was adjusted so that the light emitted in laser machining and the secondary light source contributed equally to the brightness of the image. Typical imaging rates of 2,000 images per second were realized with an image resolution of 288 x 160 px.

Result

In addition to basic monitoring of the geometrical proportions such as the increase in the joint width as the laser output is increased and the change in the position of the cutting front relative to the laser beam axis, the monitoring process also revealed the formation of individual ripples and the deflection of the melt pool arising from the formation of adherent dross on the lower edge of the metal sheet.

Applications

Being able to evaluate detectable process changes whenever process parameters are varied paves the way for the development of a self-optimizing laser cutting machine.

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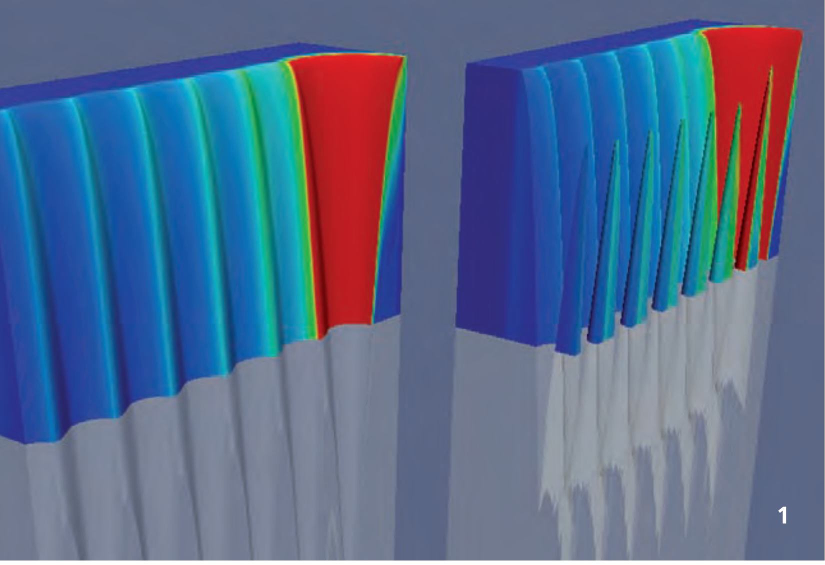
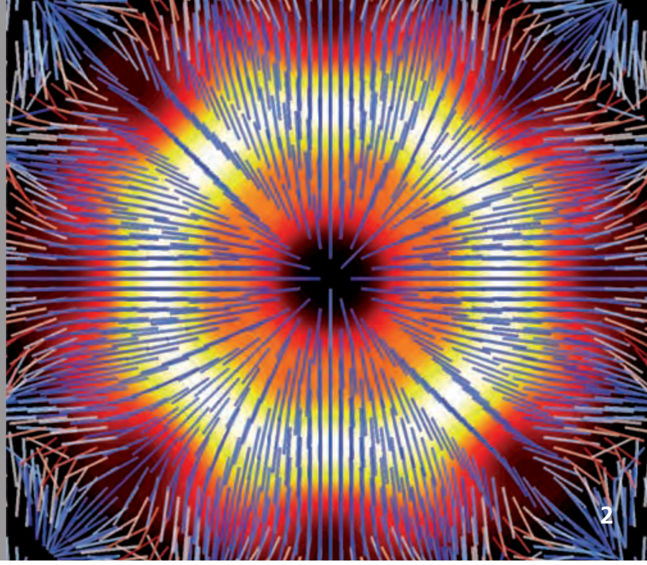
3 System setup for high-speed process monitoring.

4 Process image of a cut gap in 2 mm stainless steel.





CUTTING WITH RADIALLY POLARIZED LIGHT

Task

The polarization state of light is crucial for laser cutting applications. Currently, circular polarized light represents the state of the art, when the cutting result needs to be independent of cutting direction.

Radially polarized light, however, also meets this demand, but allows up to 100 percent better absorption compared to circular polarization and so offers substantially increased cutting efficiency.

Method

Research institutions, developers of laser sources and users joined forces in the InnoNet project KOMET (Compact solid state laser for efficient material removal by radially polarized light). By 2012 this project aims to develop a solid state laser that generates radially polarized light, and to put it to the test under production conditions. The intended prototype will have a power of 30 W at 1064 nm wavelength.

Result

As a first step, external polarizers were developed to convert the radiation of conventional lasers into radially polarized light. Cutting with radial polarization utilizing the external polarizers is being examined in an industrial environment at Fraunhofer ILT.

Applications

Specific applications include fine-cutting of silicon wafers, OLED masks, and stents made of shape memory alloys. In the medium term, many other laser manufacturing processes, such as cutting, welding and drilling, will be able to profit from the results.

The KOMET project is funded by the German Federal Ministry of Economics and Technology (BMWi) with approx. 1 million euros.

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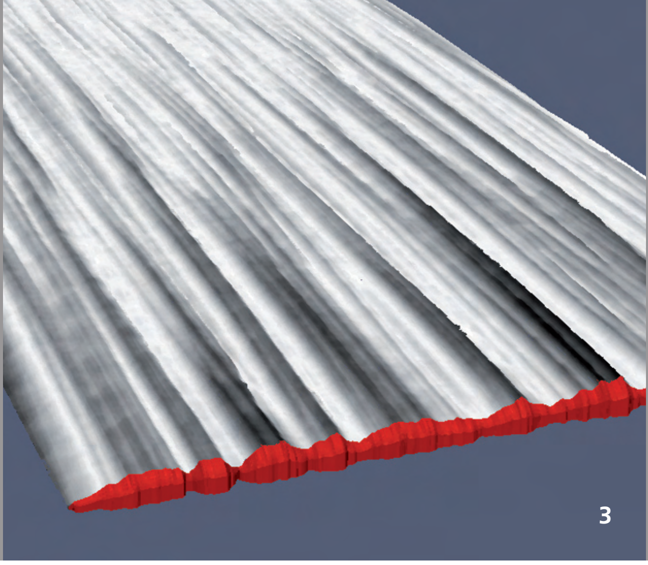
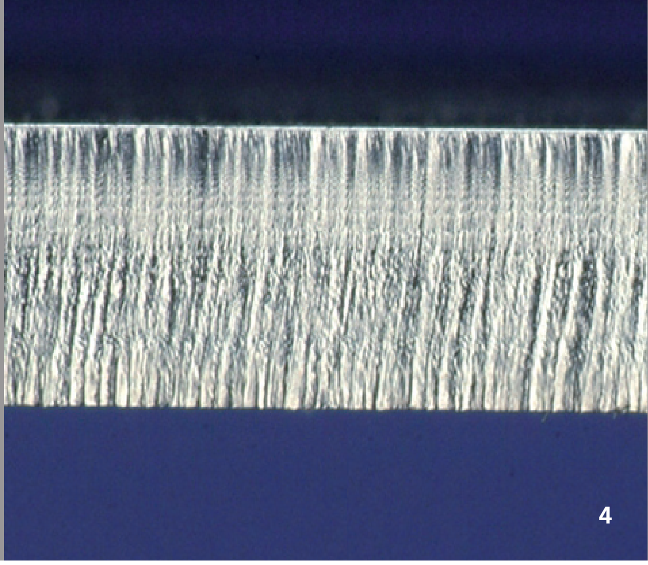
1 Cutting simulation: circular (left) and radial polarization (right).

2 Simulation of a radially polarized laser beam.





SURFACE ROUGHNESS IN LASER CUTTING

Task

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

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

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

Method

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

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

Result

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

Applications

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

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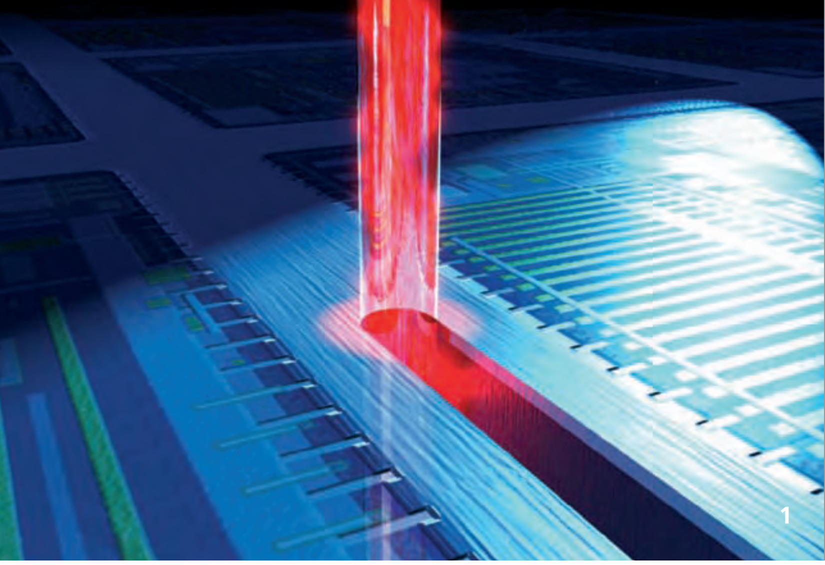
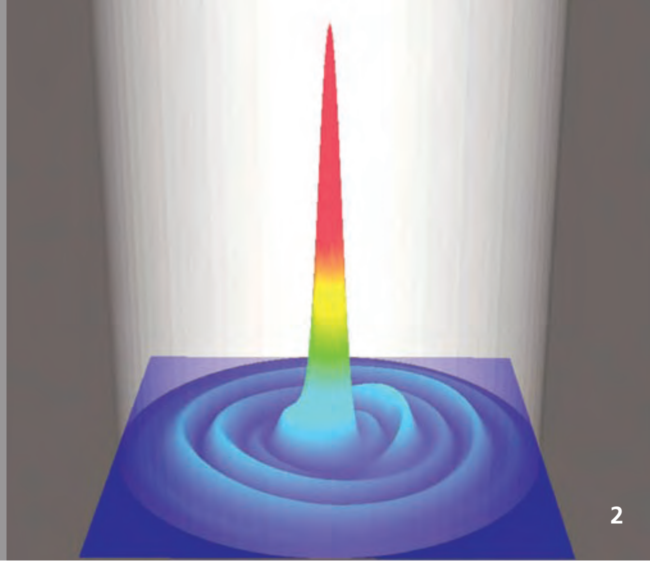
3 Ripples simulated using QuCut.

4 Ripples in an actual cut edge.





CUTTING USING WATER JET GUIDED RADIATION

Task

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

Method

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

Result

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

Applications

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

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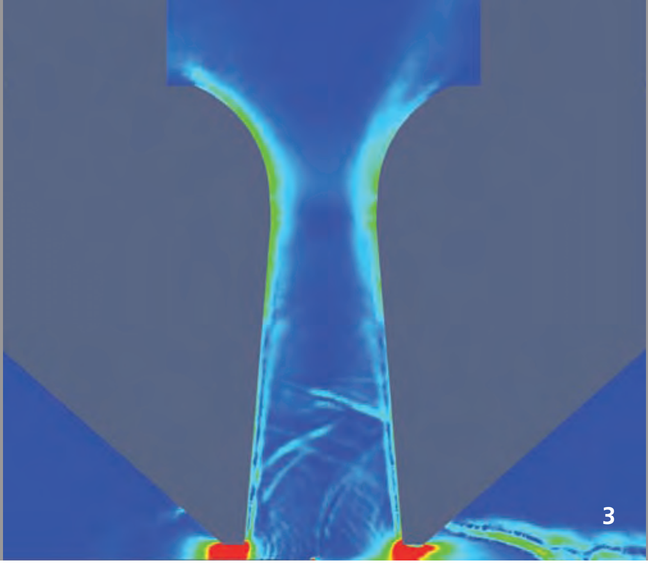
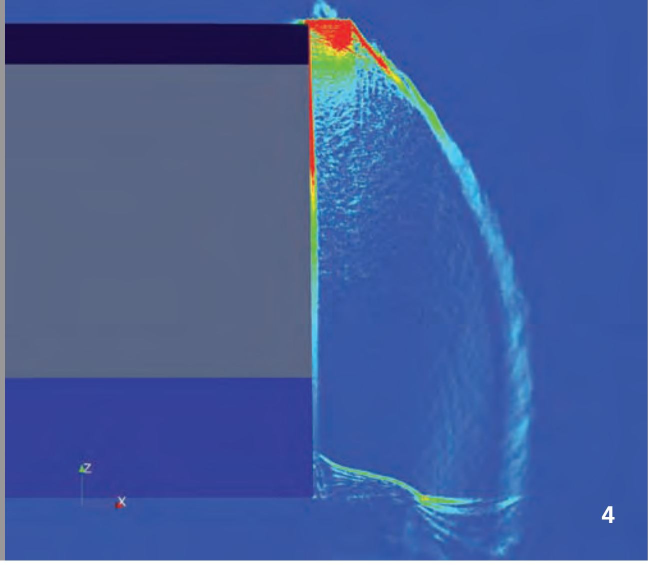
1 Illustration of the process.

2 Simulation of beam propagation in the water jet.





DISCONTINUOUS GALERKIN METHOD FOR GAS FLOWS

Task

In many laser-based manufacturing applications, it is the design of the gas flow that determines the quality that can be achieved in machining products. While the shearing forces transferred from the gas flow to the melt help determine the quality, these forces are often not measurable in an experimental setup. Simulations therefore constitute an important tool for gas-flow design.

Method

The underlying physical questions involve multiscale tasks which call for the use of tailored numerical methods. A discontinuous Galerkin method was selected and implemented based on these multiscale tasks' requirements of high accuracy and spatial resolution in boundary layer areas coupled with minimal computing times. While discontinuous Galerkin processes do represent a sophisticated mathematical model, they are not yet available commercially.

Result

The implemented discontinuous Galerkin method boasts a wide range of positive characteristics. The method allows compressible Navier-Stokes equations to be calculated on unstructured grids with virtually any polynomial order and is ideally suited for use on HPC systems thanks to hybrid parallelization. When running the calculation using 1,024 processor cores, a speedup of 800 was achieved compared with a single core. This calculation allowed the shearing forces in a thermal boundary layer along the cutting front and the dynamic effect in the gas nozzle to be calculated within three days.

Applications

The new calculation process can be used to simulate complex gas-flow issues relating to laser material processing with high resolution and minimal computing time. Specific applications include gas-flow design for laser cutting, welding and drilling.

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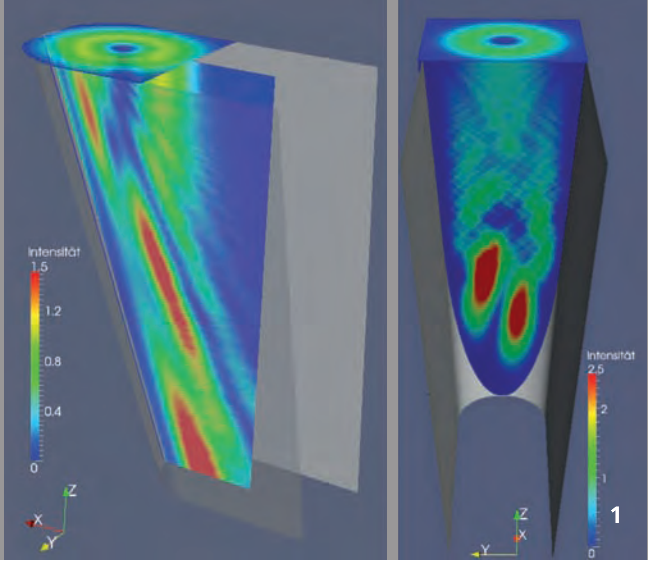
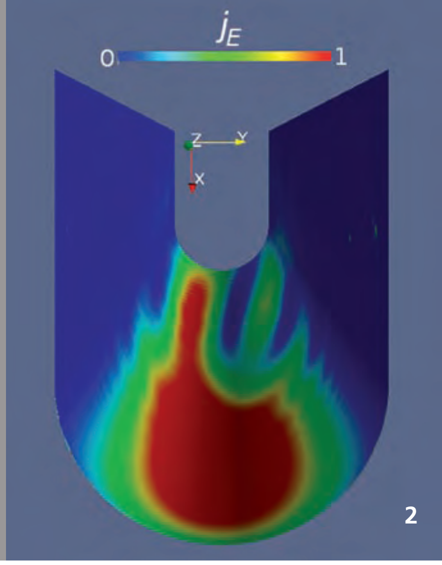
3 Simulation of cutting gas flow: density gradient in a nozzle.

4 Simulation of cutting gas flow: density gradient in a kerf.





WAVE-OPTICAL BEAM PROPAGATION IN LASER MANUFACTURING PROCESSES

Task

Until now, radiation fields in laser manufacturing processes have usually been either approximated using a free propagating laser beam or modeled using a geometrical-optical procedure. However, there are phenomena (such as the asymmetry of the radiation field inside a cutting kerf, as illustrated here) that require not only the wave-like nature of the beam but also the impact of the workpiece surface on the beam to be taken into account before they can be described. This requires a wave-optical procedure that facilitates quantitatively correct modeling both of the diffraction and of the reflection and absorption. Given the size of typical calculation domains in comparison with the wavelength, the simulations must not require much computing power to calculate a vectorial, three-dimensional radiation field. Any (commercial) software capable of meeting these requirements is not yet available.

Method

A vectorial beam propagation method (BPM) provides a rapid procedure, but this is per se unsuitable for calculating the reflection and absorption at the workpiece surfaces that occur during laser manufacturing processes. Nonetheless, the method can be supplemented by Leontovich boundary conditions (LBC). These LBCs, which are applied at the workpiece surface, describe the effect of the workpiece surface on the beam.

Result

The combination of BPM and LBC has been implemented and validated with model tasks. In the first application of this new simulation, which is laser cutting, substantial improvements have already been identified compared to previous approaches in beam propagation. These indicate possible explanations for phenomena revealed on laser cutting edges, such as asymmetric surface roughness.

Applications

The illustrated numerical procedure is particularly suited to beam propagation in areas involving metallic materials and can therefore be used for laser manufacturing processes including cutting, welding and drilling.

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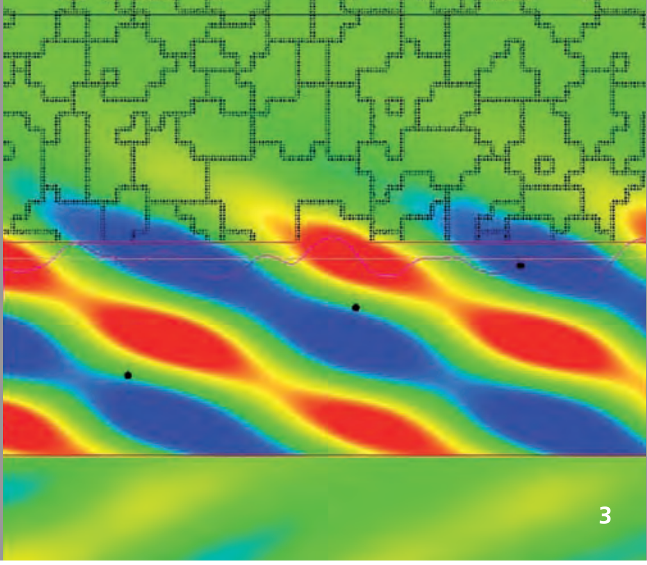
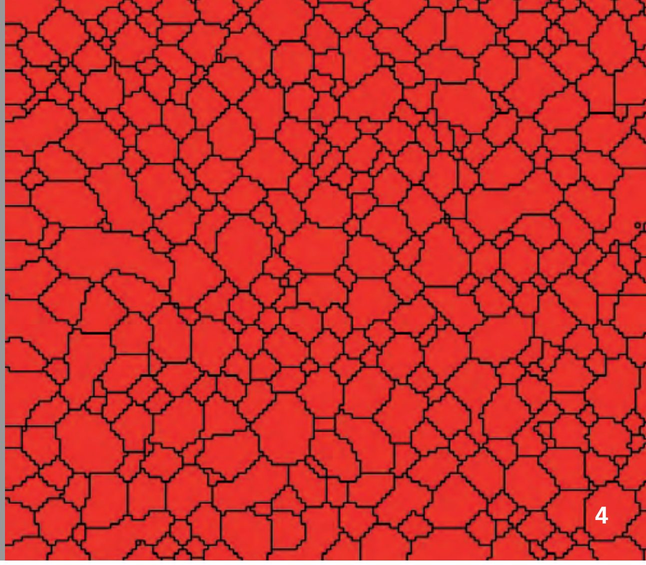
1 Radiation field in the cutting kerf.

2 Density of the absorbed energy flow.





BEAM PROPAGATION AT GRAIN BOUNDARIES

Task

Radiation absorption characteristics on the surface of inhomogeneous, microstructure-forming materials (such as steels) in particular, have previously not been factored into the simulation of laser manufacturing processes. The existence of an influence derived from the fineness of the particular grain structure has already been demonstrated in laser cutting. However, so far it has not been demonstrated how pronounced this effect really is and what microstructure would be most suitable for laser processing.

Method

The aim is to simulate laser manufacturing processes for materials with an inhomogeneous distribution of optical properties (e.g. caused by graining). This implementation can help determine the influence of the modified absorption of laser radiation on the particular manufacturing process.

Result

A suitable propagation procedure was initially sought and implemented to simulate the beam propagation in the surroundings of an inhomogeneous material with a grain structure. The finite-difference time-domain (FDTD) method has proven to be the method of choice since it enables material models to be integrated which take into account the varying optical properties of grains and grain boundaries (in particular varying conductivity). It was also possible to include the random structure of the grains in the simulation.

A software module for the statistical simulation of grains was implemented, and this provides the microstructure for the subsequent wave-optical simulation.

Applications

The illustrated simulation can determine the absorption of laser radiation in grain-forming materials, which will improve the accuracy of process simulations in cutting, welding or drilling. It can be used wherever there is a need to machine materials with a microstructure. It has initially been developed for use with laser cutting.

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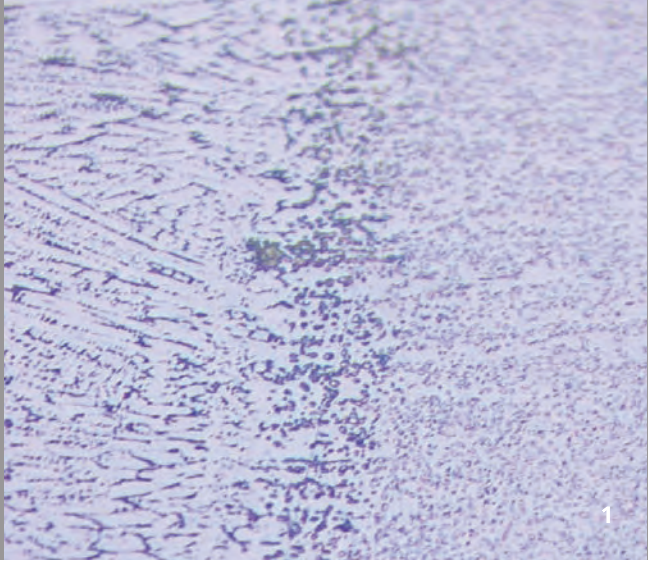
3 Wave-optical simulation with microstructure.

4 Simulated grain structure.



LASER BEAM WELDING OF ULTRA-HIGH-STRENGTH MARTENSITIC CHROMIUM STEELS

Task

Lean chromium Martensitic stainless steels offer outstanding properties for applications where high strength at low material thickness is required. High strengths that can be achieved by press-hardening, in particular, make these steels ideally suited for applications in the automotive industry and in general lightweight construction. At present, there are no process windows for welding material of this class steels that do not reduce strength.

Method

Welding tests were conducted on metal sheets of martensitic chromium steel containing 13 weight percent of chromium and various carbon contents. The properties of welded joints on metal sheets in the as-rolled and in the press-hardened states were determined. The input energy was varied in order to simulate the effect of laser systems used for industrial applications. Various heat-treatment processes were used to control the hardness in the weld metal and the heat-affected zone.

Result

The materials investigated in general were proven to be suitable for laser welding. This applies to rolled and press-hardened metal sheet. All welds were produced without cracks. Nonetheless, preheating to martensitic start temperature is recommended in order to limit the hardness gradient. Post heat treatment at 750 °C restores the properties of the base material in the weld zone in as-rolled condition. In the case of press-hardened materials, weld softening of around 15 percent occurs with respect to the base material.

Applications

The analyzed materials are ideal candidates for lightweight construction. Press-hardening can produce strengths of up to 2 GPa with sufficient elongation on fracture. The results of the investigations demonstrate the feasibility of welding in the state as-rolled for the manufacture of tailored blanks as well as for welding of press-hardened materials for the assembly process.

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1 Melt line in hardened 1.4034 steel without preheating.

INTEGRATED QUALITY ASSESSMENT WITH LASER HYBRID WELDING OF 3D SHIP STRUCTURES

Task

Laser-based joining techniques such as laser remote welding and laser hybrid welding require specific assessment methods for the process and the used system technology if they are to meet future requirements for three-dimensional weld designs in shipbuilding. There is a growing need for these methods given that the laser-based joining techniques provide an ideal solution for manufacturing thin-wall 3D structures (t = 4 mm to 10 mm) with low thermal distortions. The joining and process quality is determined under realistic conditions using a manufacturing demonstrator for flexible laser remote and hybrid welding with integrated quality diagnostics and assessment.

Method

Laser MSG hybrid welding emits intensive radiation across the entire optical spectrum (UV, VIS, NIR) from the process zone. The intensity of the radiation varies with the pulse frequency of the MSG arc. Spatially resolving imaging camera systems and spatially integrating sensor systems are used to provide contactless optical process monitoring.

The laser MSG hybrid welding process is observed and monitored coaxially through the focusing optics with Fraunhofer ILT's CPC system using a high-speed CMOS camera coupled with a narrowband optical bandpass filter. A super-pulsed diode laser, which is arranged laterally next to the focusing optics and controlled synchronously with the exposure of the camera, is used to provide "flash" illumination of the process zone.

Result

Synchronous exposure between the current pulses using the pulsed illumination beam source enables suitably analyzable image data to be recorded. The position of the keyhole relative to the split joint and the geometry of the molten bath are determined from these data. The aim is to provide automated joint tracking and online monitoring of the stability of the laser MSG hybrid process.

Applications

The implemented system can be expected to be used to provide data on the process quality and stability of laser-based joining techniques for applications in shipbuilding, steel construction, vehicle manufacturing, and tube production.

The work was funded by the German Federal Ministry of Economics and Technology (BMWi) as part of the QuInLas joint project.

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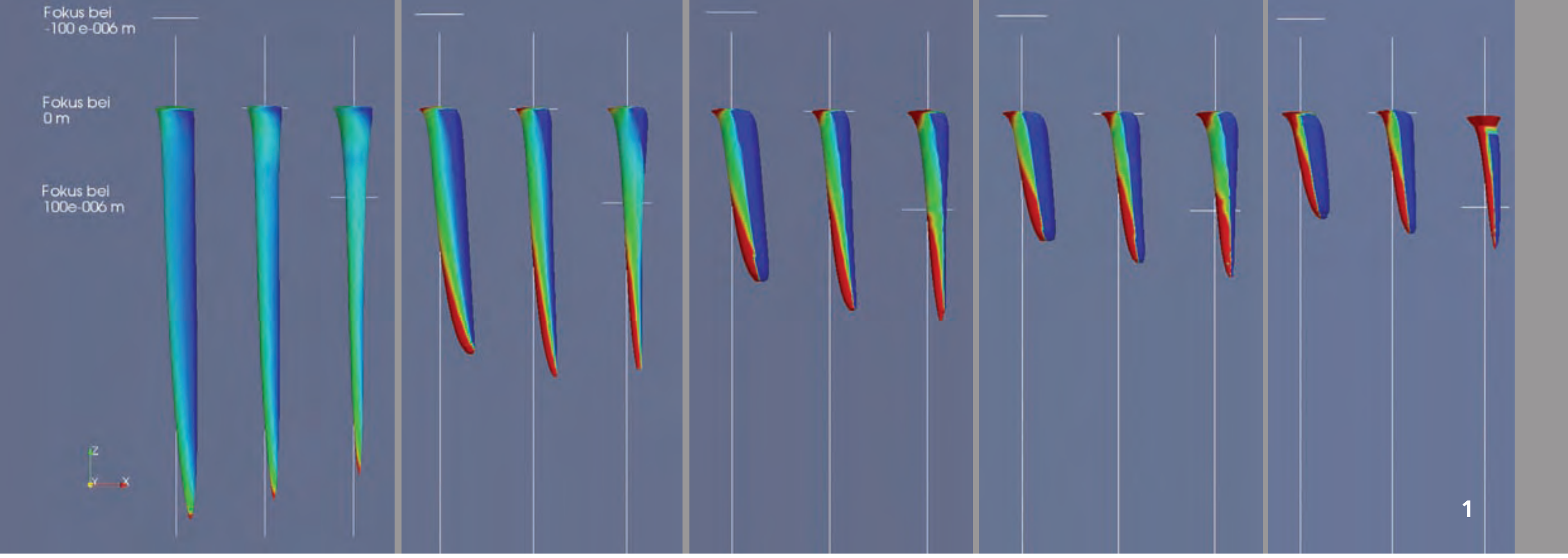
2 Snapshot of the laser hybrid welding process.



MODELING OF LASER WELDING

Task

One typical problem encountered in modeling laser welding is to fit a suitable heat source from welding experiments. A stationary process model for welding has been derived from the stationary modeling of cutting in order to resolve this issue.

Method

The welding process is simulated using a model involving local balance equations. This model is capable of calculating the stationary shape of the welding keyhole in deep penetration welding with laser radiation, together with the temperature field that builds up in the workpiece. It is combined with the ray/beam tracing technique developed at Fraunhofer ILT.

Result

The reduced modeling of welding enables entire parameter variations to be carried out in an acceptable time frame in order to investigate variations of process quantities such as welding depth and focal position.

Applications

The welding model can be used on low-power welding in which plasma formation in the welding keyhole is not dominant.

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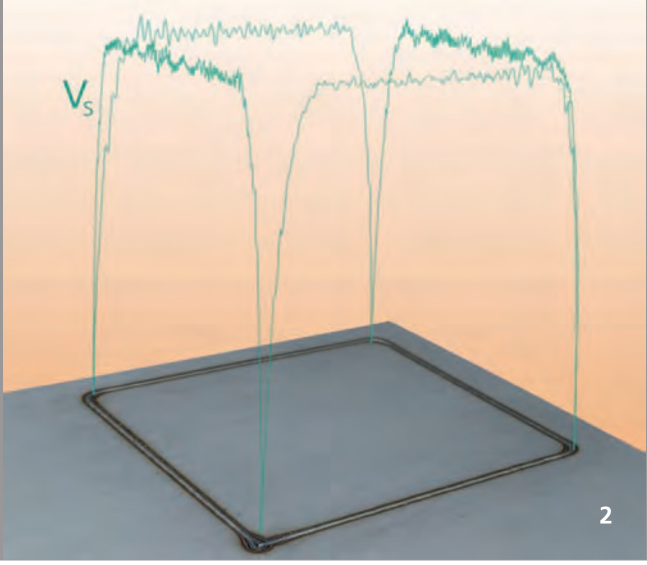
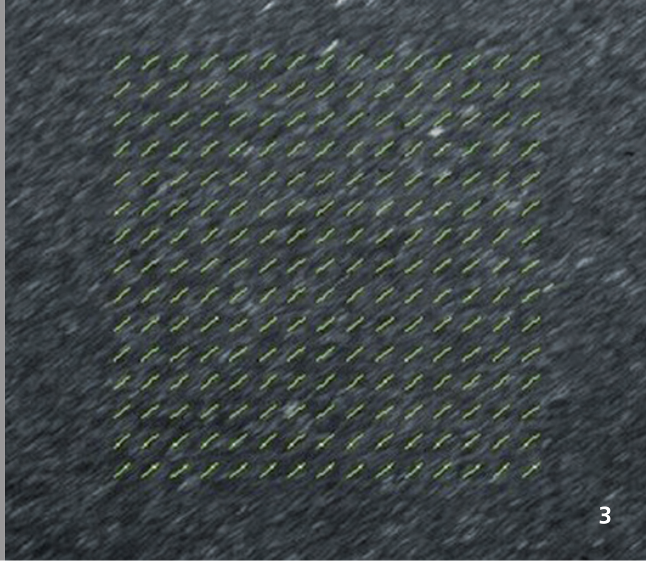
1 Calculated welding keyholes for various feed rates and focal positions.





LASER POWER OUTPUT CONTROL BASED ON ACTUAL SPEED

Task

Lasers with high output power at high brilliance provide the basis for a substantial increase in laser material processing speeds. Innovative drive concepts for scanners and fast moving fixed optics, enable high beam positioning speeds which today are virtually taken for granted. Even if the displacement between the beam and the work piece is calculated precisely, the position of the processing location may differ from the planned contour. One solution is provided by a monitoring system which precisely tracks the relative movement between work piece and processing beam. It allows deviations from the target contour and the target speed to be measured precisely.

Method

Coaxial Process Control tracks the characteristic surface structure of the work piece through the processing optics providing the basis to calculate the actual speed. A field programmable gate array (FPGA) chip calculates the work piece movement in real time with a latency of approximately 60 µs. The calculated value can then be transferred via an on board interface and a D/A converter directly to the laser power control system in order to compensate machine-related speed deviations by adjusting the power.

Result

Real-time power control based on motion detection enables a consistent processing result in manufacturing through consistent energy input per unit length, irrespective of speed fluctuations.

Set up of smooth tool paths for multi-axes beam delivery systems is facilitated by motion analysis. High measurement accuracy enables the detection of influences from inertia and drive control yielding correction factors for tool path optimisation.

Applications

In terms of measurement, it is irrelevant whether fixed optics or scanners are used. In both cases the system measures the movement of the processing location on the work piece. It therefore is capable to detect deviations from the target contour when the machine is being set up or during the process itself. A host of other applications such as robot-based processes and scanner applications are currently being investigated.

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2 Results of speed measurement along the tool path (welding).
3 Workpiece surface with calculated speed vectors.

LASER WELDING OF TYPE 18650 BATTERY CELLS

Task

Lithium-ion battery cells are increasingly being used as energy storage devices for electrically powered vehicles on account of their high energy density. Individual cells need to be connected electrically in order to make suitable battery packs. 18650 cells – which are mainly used in notebooks and power tools – provide an ideal solution thanks to their low price and ready availability.

Compared with large-format cells, these cells have low capacity, which is why several cells must be connected in parallel to create one large cell. Overlap welding is used to join a copper current collector and the battery housing – the negative pole – made out of nickel-plated stainless steel.

Method

For prototype production of the battery packs, a reliable joint between the copper and steel needs to be made, without welding through the stainless steel that is approx. 0.25 mm thick, to prevent the electrolyte from leaking and damaging the cell. A technique developed at Fraunhofer ILT involving spatial power modulation is used, which reduces the weld depth while increasing the connection cross-section. A single-mode fiber laser and a galvanometric scanner are used as system technology.

1 Large cell with welded negative pole current collector.

2 Image perpendicular to the overlapped weld seams.

Result

As part of the conducted tests and the prototype series, several hundred macrocells were produced, and these have been fitted to an electric vehicle as part of the "e performance" research project. Current research is focused on additional qualification of the connections to determine their long-term stability.

Applications

Lithium-ion battery cells are currently the most promising energy storage technology for electromobility applications. The cost-effective manufacturing of efficient energy storage devices must be regarded as the key technology for this fast-growing industry segment. Laser welding can make a major contribution in this respect.

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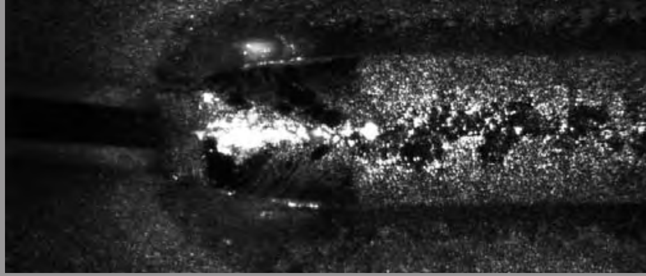

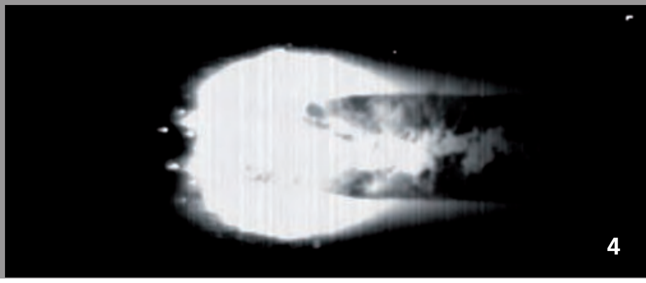
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ONLINE QUALITY ASSURANCE FOR LASER BRAZING

Task

Laser brazing is mainly used in the automotive industry for car body manufacturing wherever large gaps need to be bridged or individual subcomponents need to be joined together using a visible seam owing to the limitations of deep-drawing technology. The demands placed on the quality of the brazed seam in terms of the absence of pores and connection of the braze to the joint members are accordingly high. Suitable process monitoring should record all the requisite process parameters and provide data on the joint quality.

Method

Based on the CPC (Coaxial Process Control) system, two camera systems and an illumination source were integrated coaxially into the processing optics. The synchronized camera systems monitor the quality of the brazed seam in both the visible (VIS) and the near infrared (NIR) spectral range. A combined analysis of both camera images enables the process parameters (e.g. feed rate) as well as various seam imperfections (e.g. pores) to be identified and documented during the joining process. An online-capable prototype was implemented by means of adaption to tactile-guided processing optics. The quality of the brazed seam was analyzed during the process.

Result

In collaboration with the Institute for Communications Technology IfN of Braunschweig University of Technology and Fraunhofer IPT, the following results were obtained as part of the project work:

- Construction of a tactile-guided prototype
- Synchronized process imaging at 300 Hz
- Online detection of the feed rate
- Online identification of pores (d < 100 µm)
- Online detection of heat distribution
- Online documentation of product quality

Applications

Laser brazing is mainly used for joining metal parts together in the automotive industry. As the brazed seams are frequently in the visible area of the vehicle, quality monitoring is essential. The developed online monitoring system can replace post-process checking systems.

The research was conducted as part of the EQOS research project funded by the German Federal Ministry of Economics and Technology (BMWi).

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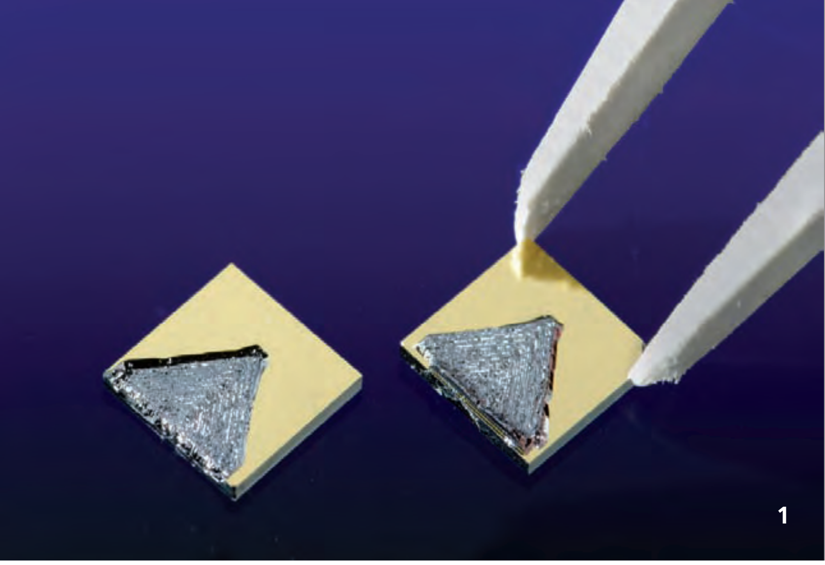
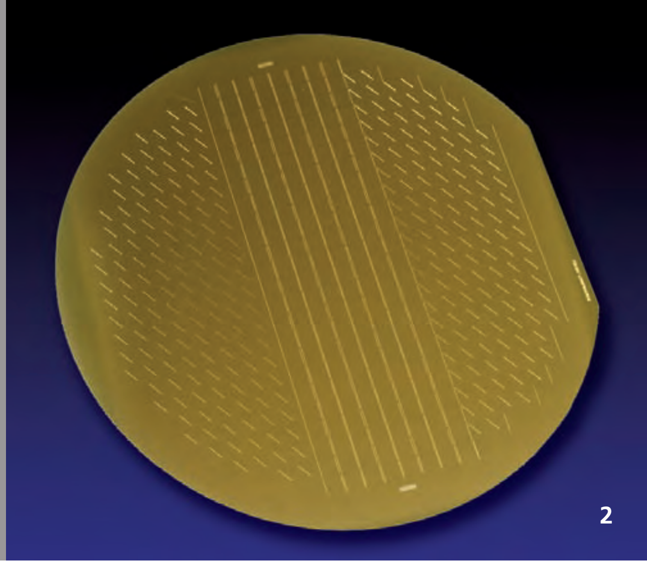
3 System integration of the CPC module with tactile-guided brazing optics.

4 Top: externally illuminated process image (VIS).
Bottom: heat distribution in laser brazing (NIR).





LASER TRANSMISSION BONDING OF METAL-COATED SILICON FOR WAFER-LEVEL PACKAGING

Task

Ongoing miniaturization in semiconductor technology and hybrid microsystems technology is leading to ever more exacting requirements being placed on the packaging in relation to the temperature load on sensitive, multifunctional chips. Conventional large-area bonding techniques such as anodic bonding or eutectic bonding can damage functional areas of the chips as a result of the high temperature load. Laser transmission bonding is an innovative laser-based joining technique which allows a much smaller heat affected zone and a substantially lower overall thermal load.

Method

Laser transmission bonding is based on transmission joining, whereby the laser radiation passes through one joining partner and is absorbed by the other joining partner. Absorbing interlayers can be used where joining partners are made out of the same material. Fraunhofer ILT is currently using a thulium fiber laser (λ = 1940 nm) for selective laser transmission bonding of silicon-silicon. The laser radiation employed is not absorbed by the silicon base material; metallic interlayers are used for absorption. As part of process development, the aim is to determine suitable process parameters such as laser power, feed rate, scan speed, and contact pressure for a range of metallic interlayer materials.

Result

Silicon-silicon bonds have been successfully implemented with the interlayer material combinations gold/titanium, gold/chrome, copper/titanium and copper/tantalum. Researchers have created bonds with a single joining partner with metallic interlayers as well as bonds where both joining partners are coated with the same interlayers. Modified process parameters and process strategies allowed large-area and selective bonding to be achieved with bond widths ≥ 50 µm.

Applications

Applications include semiconductor technology and hybrid microsystems technology with the packaging of silicon-based products such as acceleration, pressure and rate-of-rotation sensors for the automotive industry. Other potential applications are related to lighting/display technology and silicon photonics.

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1 Laser-bonded silicon test sample with gold/titanium coating after tensile test.

2 Microstructured 6-inch silicon wafer with gold/titanium coating.

SIMULATION OF NONLINEAR ABSORPTION IN DIELECTRICS

Task

The use of ultrashort-pulsed laser radiation to process dielectric materials (e.g. glass or aqueous biological tissue) allows energy to be deposited specifically in the material volume rather than on the material surface (as tends to occur with metallic materials). This is a compelling approach for applications such as welding and for volume-selective processing of glass materials. Data on the distribution of the energy absorbed by the material is required in order to optimize the process from a thermal or structural-mechanical standpoint.

Method

The aim of modeling and simulation is to provide a spatially resolved description of energy deposition when using ultrashort, high-intensity laser pulses. To this end, the dynamics of the electronic and phononic systems are determined and the effect on the propagating radiation field is calculated.

Result

A model which includes the subprocesses of nonlinear absorption, radiation propagation, and calculation of temperature and mechanical stress was implemented and tested on the basis of initial case studies. The model and the associated simulation are further applied and extended using the example of glass processing.

Applications

The implemented model can be applied to any material which absorbs incident radiation only through nonlinear processes such as multiphoton or impact ionization. Such materials include glass or aqueous biological tissue. Producing the necessary high intensities generally requires pulsed laser systems.

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3 Simulated isotherms caused by nonlinear absorption.

4 Cross-section of a welded joint in glass.

LASER WELDING OF THERMOPLASTIC FIBER-COMPOSITE COMPONENTS

Task

If fiber-reinforced plastics are to become a viable option for large-series production, manufacturing costs and cycle times need to be reduced dramatically compared with the conventional production chain for sheet-metal parts. In order to fulfill functional strength requirements, components are likely to become more complex, with a potential knock-on effect of higher manufacturing costs. Laser welding is an ideal alternative to complex fiber-reinforced plastic components, offering a solution for manufacturing clean, rapid and permanent fixed joints to create closed reinforced structures using overlap configuration.

Method

Laser welding based on an overlap configuration – a setup that is commonplace in industrial applications – relies heavily on the optical properties of the joining partners. The top joining partner must be sufficiently transparent for the laser radiation to penetrate the weld zone without any loss of intensity. The lower joining partner must be strongly absorbing so that the incident radiation can be converted into heat near to the surface. But the high fiber component in fiber-reinforced-plastic structural components gives rise to widely varying optical properties, thus significantly altering the way the radiation propagates. The welding process must tolerate these local changes if it is to meet the requirements of series-production welding. Moreover, the large component dimensions and the three-dimensional geometries mean the components cannot be pressed together using conventional joining devices to generate the necessary heat contact.

Result

By enlarging the process window, with a view to varying the optical properties as widely as possible, it was possible to determine a reliable working point for a high-quality welded joint. The use of a robot-controlled, flexible clamping mechanism with integrated machining optics (Leister) allows even three-dimensional components to be pressed together.

Applications

Laser welding of additional stiffening structure makes it possible to meet enhanced stiffness and crash-test requirements. In particular this allows a substantial weight reduction (~ 25 percent) in seat backrests, which have to meet more stringent requirements with the attachment of a third seat belt.

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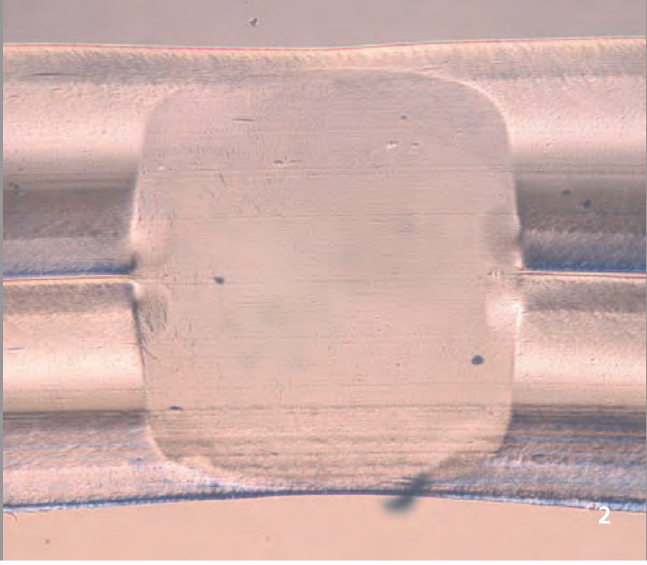
1 Laser welding a 2/3-split seat backrest (Weber).



LASER WELDING OF TRANS-PARENT PLANT CONTAINERS

Task

Special plastic containers made out of transparent polymers based on polypropylene (PP) are used to store and transport seedlings. The containers need to be closed with a lid that provides a gas-tight seal in order to prevent culture contamination. This lid is attached to the container by means of a tear-off strip, which is currently produced using ultrasound. The process is unstable since even minor deviations in the material, shape and contact force result in imperfect joints which leak. Laser welding provides a viable alternative to ultrasound welding since it meets the requirements for a contamination-free seal while ensuring greater process stability.

Method

Plastic containers for plant cultures must be transparent so that the seedlings receive sufficient sunlight. Conventional laser plastic welding would require the use of a suitable absorber, resulting in high additional costs and a tendency to impair transparency. A new welding technique developed at Fraunhofer ILT, which uses a diode laser in the near infrared spectrum region of 1.5 to 2.0 µm, no longer requires special absorbers since most plastics exhibit sufficiently high absorption in this wavelength range to generate the necessary melt. This technique has been used at Fraunhofer ILT to join plant containers made out of PP using an overlap process with a special fiber-guided diode laser source (wavelength = 1.7 µm). The welding speed was 1,000 mm/min with a laser power of 13 W; the weld width corresponds to the beam diameter of 600 µm that was employed.

Result

Figure 2 shows the cross-section of a joint welded between two 0.5 mm thick PP test samples using the new technique. The weld zone is homogeneous and extends sufficiently far over the two joining partners to achieve a high-strength weld. Highly flexible laser beam guiding allows the operator to switch rapidly between various container geometries without any time-consuming tooling changes.

Applications

Laser welding of transparent, unpigmented and film-like polymers is used for packaging applications and also for products from the areas of medical technology, microfluidics and bioanalytics.

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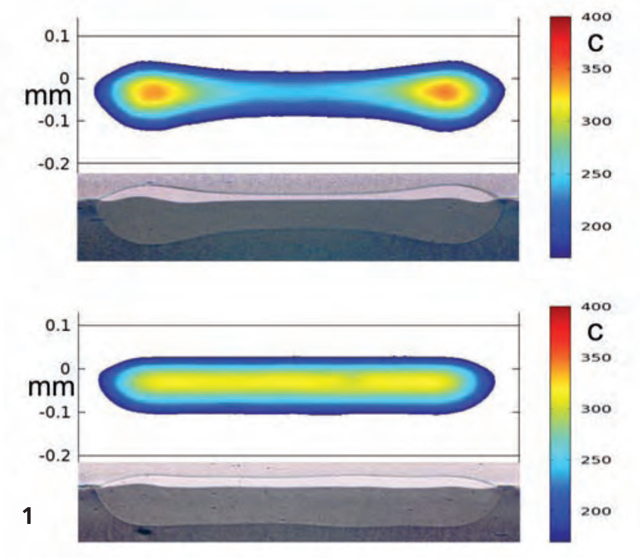
2 Microtomy section of laser welding on containers made out of 0.5 mm thick polypropylene (PP) with no radiation absorber; wavelength 1.7 µm.



INFLUENCE OF TWIST® PARAMETERS ON PLASTIC WELD JOINTS

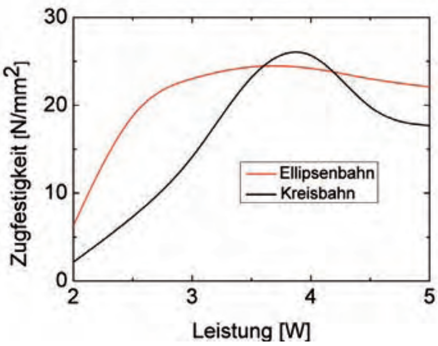
Task

Compared with contour welding, the TWIST® technique for laser welding plastics offers greater flexibility for optimizing the welding process, tailoring the weld joint width to the component, and increasing the joint's tensile strength. Optimum results can be obtained by establishing a homogeneous temperature distribution in the weld zone perpendicular to the weld speed. A suitable simulation basis needs to exist beforehand to optimize the weld parameters, and in particular the variability of the TWIST® process.

Method

Based on the general thermal conduction equation, the temperature distribution in the joining partners was calculated while varying important process parameters of the TWIST® process. The parameters that were varied are the ellipse radii (a: parallel, b: perpendicular to the feed) of the periodic component of the TWIST® motion. In parallel to the simulations, real-life testing on polypropylene was conducted to determine the strength using the following parameters: beam diameter = 80 µm, welding speed = 50 mm/s, TWIST® frequency = 2 kHz.

1 Temperature distribution and microtomy section for concentric path (top), for elliptical path (bottom).



Result

With a concentric path (a = b = 400 µm), the temperature distribution is inhomogeneous with the typical weld seam geometry (Figure 1 top). In the case of an elliptical path (a = 100, b = 400 µm), the temperature distribution and the weld seam depth are homogeneous (Figure 2 bottom). The tensile tests demonstrate that an elliptical path – and in turn a homogeneous temperature distribution – gives rise to higher tensile strength over a wider parameter range than a concentric path (see graphic).

Applications

The TWIST® technique can be used to set robust process windows with high weld seam strength especially for applications in the field of automotive, consumer and medical technology, which require minimal heat input and a mark-free joint.

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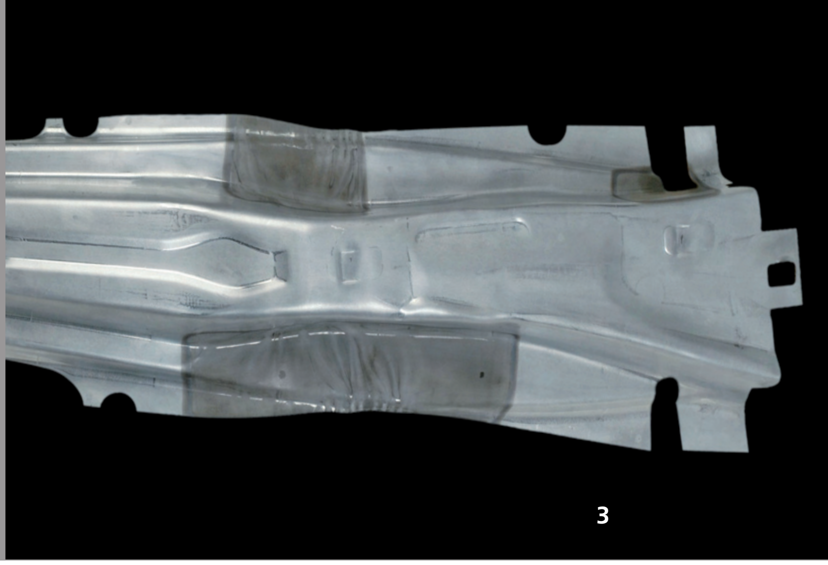

IMPROVED FORMING OF HIGH-STRENGTH STEELS USING LASER HEAT TREATMENT

Task

Lightweight construction is an effective method of reducing fuel consumption and CO_2 emissions in the automotive industry. At the same time, crash safety specifications are constantly being tightened. High-strength steels meet both requirements. However, these steels are more difficult to form than deep drawing steels since their higher strength compromises formability. Consequently, the LOKWAB project (reference number: 02PU2020), which is funded by the German Federal Ministry of Education and Research (BMBF), has been investigating local heat treatment with laser radiation, which should significantly improve the cold formability of high-strength steels with tensile strength of up to 1,200 MPa. The aim is to locally soften the material using heat treatment and thus improve the material flow during forming.

Method

Areas of blanks are locally heat treated with laser radiation prior to cold forming. The use of a fiber-coupled 10 kW high-power diode laser and optics with rectangular, homogeneous power density distribution of up to 90 mm width ensures even, rapid heat treatment. The locally softened blanks are formed into B-pillars in a subsequent stage.

Result

The heat-treated areas exhibit five times better material flow capability, allowing critical areas to be formed without any cracks or necking. Thanks to the locally modified mechanical properties of the blanks, B-pillars can be formed from steels that are approx. 50 percent stronger than previously. Multiple loops of simulation, heat treatment and forming prompted a reduction in the softening zone required for reliable forming, along with a cut in the processing time from over 2 minutes to 42 seconds.

Applications

The automotive industry is the main area of application. This technique allows a wider range of components to be manufactured from high-strength steels. Existing forming production lines can continue to be used. The aim is to reduce the processing time even further in future by further increasing the laser power and minimizing the softening zones.

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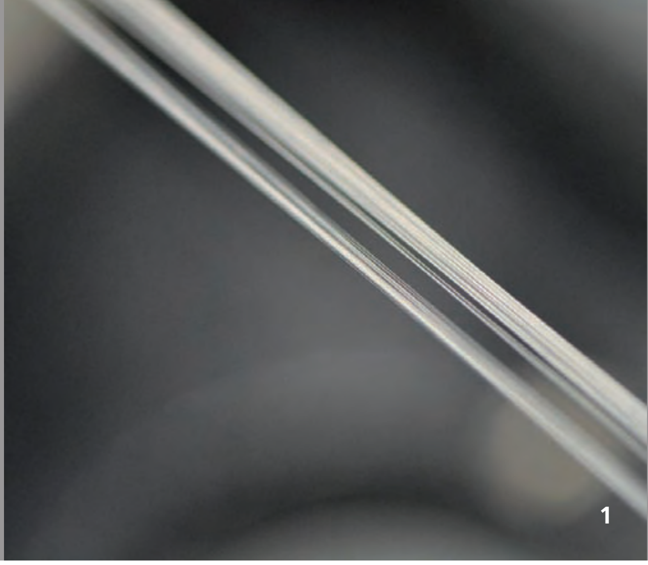
2 Cracked B-pillar made out of MS-W1200.
3 B-pillar made out of MS-W1200, manufactured from a laser-softened blank (softening zones = dark areas).



1 PAN fibers.

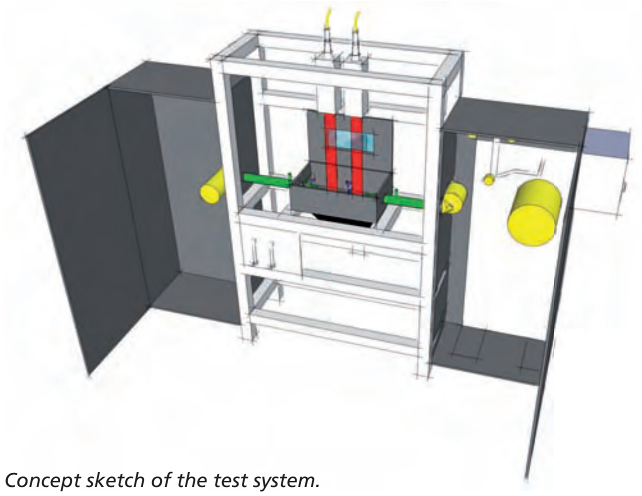
LASER-BASED EFFICIENT MANUFACTURING OF CARBON FIBERS

Task

Lightweight construction technologies are an important element in a sustainable CO_2 reduction strategy, particularly in the automotive and aerospace industries. Carbon fiber reinforced plastics (CFRP) provide an excellent starting point with a specific strength that is up to 2.5 times higher than aluminum. The proportion of this material group used in the aerospace sector has been constantly increasing for decades (examples include the Airbus A380 and the Boeing 787). One reason for the limited usage in the automotive industry to date has been the high material costs of carbon fibers. The two-stage heat treatment (stabilization and carbonization) required by the carbonaceous precursor fibers (mainly made out of polyacrylonitrile or pitch) to create carbon fibers accounts for just under half of the material costs. This is due to the long retention times in the furnaces (up to 2 hours) and the high energy consumption (temperatures up to 1,400 °C) necessary for the heat treatment process.

Method

The MegaCarbon project, funded by the North Rhine-Westphalia regional government and the European Regional Development Fund (ERDF), aims to develop in collaboration with the project partners a resource-efficient, highly productive manufacturing process for carbon fibers for a wide range of applications. In addition to conventional heat treatment of the precursor fibers in furnaces, research is also focusing on the use of laser radiation as an energy source for stabilization and carbonization.



Concept sketch of the test system.

Result

The project's initial focus is on evaluating the temperature-dependent optical properties of the precursor fibers made out of polyacrylonitrile. Simulation calculations are being used to investigate both beam propagation in the fiber bundle and temperature distribution in the direction of the fibers. At the same time, a system is being configured and built that will allow the heat treatment of moving fibers to be tested under an inert gas atmosphere.

Applications

Successful implementation will open up a much broader range of applications for CFRP components thanks to far lower manufacturing costs.

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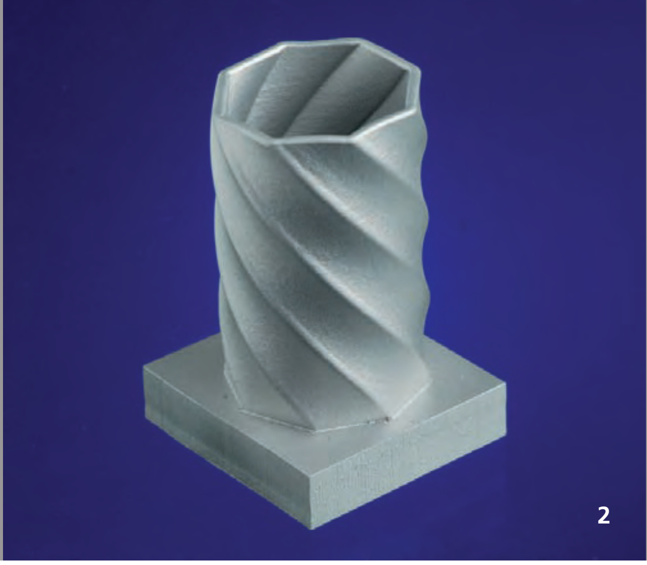

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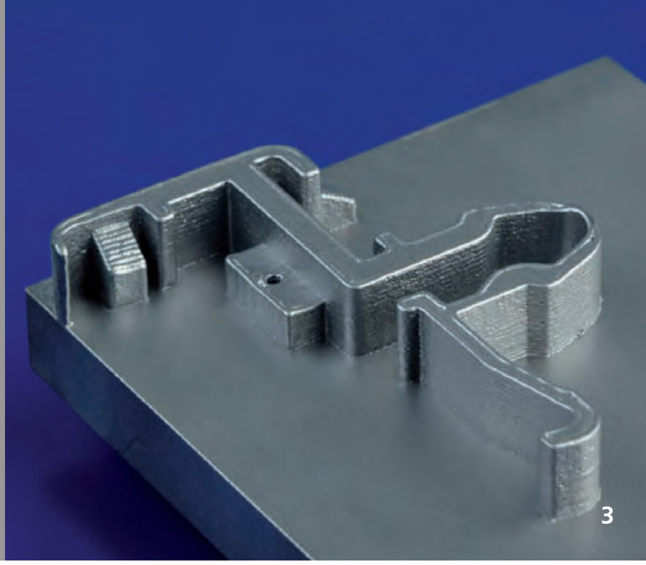

3

ADDITIVE MANUFACTURING USING LASER MATERIAL DEPOSITION

Task

Laser material deposition is an additive manufacturing process used to produce metallic components or to modify existing components with a view to functional integration (e.g. increasing rigidity). Against the backdrop of ever shorter product development times, this process offers a great deal of flexibility and supports the rapid manufacturing of small series and functional prototypes. This additive manufacturing technique builds up components layer by layer in a metallurgical process. The result is a near-net-shape component with virtually 100 percent density and a property profile that meets the material's series-production specifications.

Method

An inert carrier gas is used to guide a powder additive material to the machining location. The powder material is completely melted using a laser beam. At the same time the laser beam melts a thin surface layer of the previous layer so that a metallurgical bond is formed. Typically, each layer can be deposited with a thickness of 0.3 to 2 mm. Graded volumes can be built up by simultaneously feeding two materials whose quantities are adjusted for each layer. Similarly, hybrid components can be manufactured from various metallic materials. The tool paths are programmed offline with software customized for material deposition. Typical materials that can be processed include aluminum alloys, titanium alloys or steel. Preheating may be required in the case of hard materials in order to prevent cracks.

Result

The result is a virtually 100 percent dense near-net-shape component which is manufactured with an allowance of 0.2 to 0.5 mm. Hollow structures can be produced with wall thicknesses of less than 1 mm. The final processing of functional surfaces then involves processes such as milling or erosion. If necessary, the component can be heat-treated again (e.g. stress relief annealing, rolling).

Applications

Additive laser material deposition can be used to manufacture functional prototypes and (small-) series parts. Examples include tool and mold inserts, functional prototypes for automotive engineering, one-off components, and small-series components for aerospace applications.

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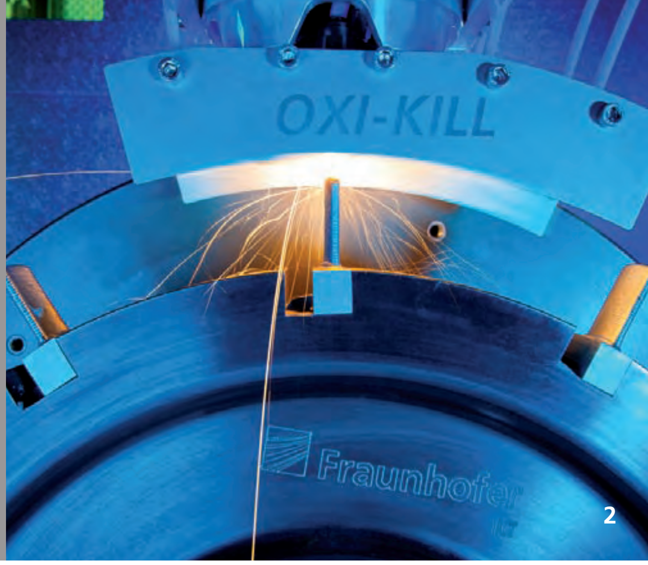
2 Additively manufactured blank made out of an aluminum alloy.

3 Additively manufactured blank made out of a steel alloy.



ADDITIVE MANUFACTURING OF BLISKS USING LASER MATERIAL DEPOSITION

Task

BLISKs are currently manufactured using a great deal of material (material loss approx. 80 percent), energy and time by means of 5-axis milling, which results in very high production costs given the high-quality materials used. The aim is to develop a new manufacturing technology that significantly reduces the aforementioned losses as well as production costs. The additive manufacturing of BLISKs reduces these losses and offers a promising solution: material savings of around 60 percent and a reduction in the manufacturing time of some 30 percent are predicted over conventional processes. The availability of the new additive manufacturing process ensures (a) manufacturing that saves resources and, in turn, time and money, (b) new design opportunities with no geometrical restrictions – designed for function, only – and (c) development of new, shorter, more efficient process chains.

Method

Initially, process diagrams are being developed which document parameter windows for significantly increased deposition rates for a selected material (e.g. IN 718). To this end, parameter studies with laser output powers up to 10 kW are being conducted. The track widths can also be varied by using zoom optics so that a near-net-shape can be produced even with a single-layer design, e.g. of the turbine blade.
To check the material properties, blade-like test structures are being manufactured for tensile and fatigue tests on a BLISK demonstrator (see figures). In another step the process is tailored to an OEM component.

Result

Deposition rates of up to 3.5 kg/h can be achieved with track widths of between 2 and 4 mm, and with material properties (investigated to date: tensile strength) close to those of cast IN 718. A model blade can be built up with near-net-shape within 2 minutes. The deposition rate achieved supports a tolerance of +/- 200 µm with a selected allowance of 500 µm in relation to the geometry for the final machining process.

Applications

Aerospace, in particular engine technology, is one application area. Another area relates to wear and corrosion protection for applications requiring high deposition rates coupled with exacting shape-retention requirements.

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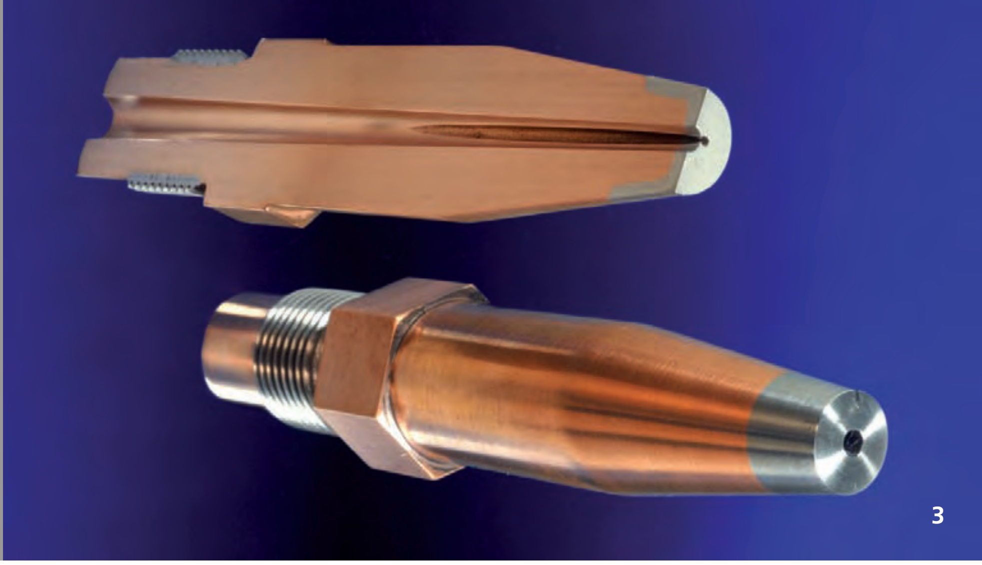
1 Material deposition of test blades on a BLISK demonstrator.

2 Innovative shielding of atmospheric gases in material deposition.



INNOVATIVE COMPONENTS FOR INJECTION MOLDING TOOLS MADE OUT OF COPPER MATERIALS WITH LOCAL WEAR PROTECTION

Task

The high thermal conductivity of copper makes it an ideal material for precise thermal management in an injection molding machine. This makes it possible to prevent the liquid plastic from solidifying as it moves from the extruder to the mold, or is held ready for injection in the hot runner nozzle. The disadvantage lies in the low service life due to copper's relatively low wear resistance compared with steel. One solution comes in the shape of local wear protection by applying a coating using laser material deposition. The aim is to increase service life by a factor of 3 to 4 compared with the state of the art.

Method

Laser material deposition involves applying metal powder to the interaction zone between the laser beam and material; this powder is then melted in the laser beam. Melting the surface layer of the substrate creates a metallurgical bond between the coating material and the substrate. Cobalt-base alloys (Stellite) are used as wear-protection materials. The wear-protection coatings are deposited on copper blanks from which the components are then finished. The coatings are only deposited wherever the areas of greatest stress occur in the finished component, e.g. near the gate bushing or the hot runner nozzle. Process development and component testing in the field trial are being conducted in collaboration with Schmelzmetall (a manufacturer of semi-finished copper products) and Pallas (a service provider for surface engineering) as part of the German Federal Ministry of Economics and Technology's Central Innovation Programme SME (ZIM) InKulas project.

Result

Stellite 21, Stellite 6 and Metco 42 C were deposited without crack formation and minimal pores on the materials K 220 and K 265. A buffer layer made out of a nickel alloy was previously deposited to provide an optimum bond with the copper. Hot runner nozzles are being manufactured from coated blanks. Field trials are the subject of ongoing work.

Applications

The main application involves the plastics processing industry and the associated suppliers. Other applications relate to areas where high thermal conductivity or electrical conductivity of copper coupled with high wear protection is necessary, such as in the die-casting industry.

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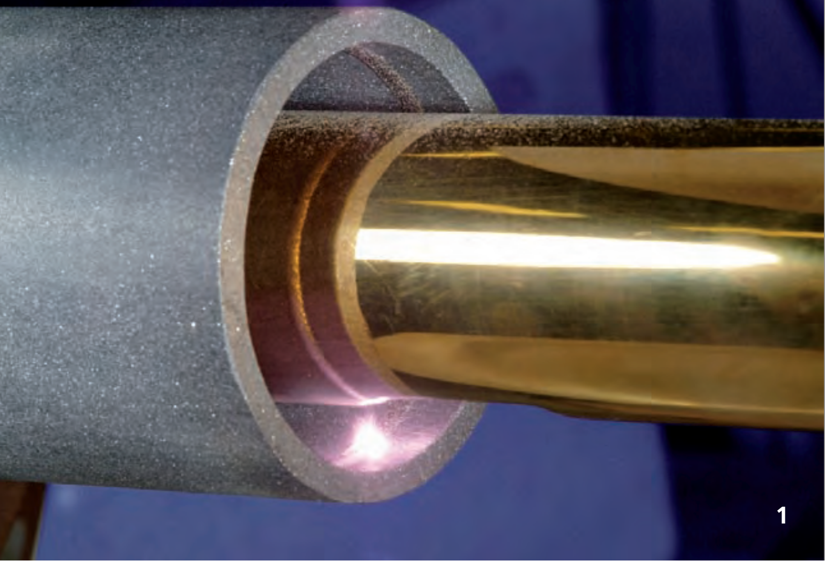
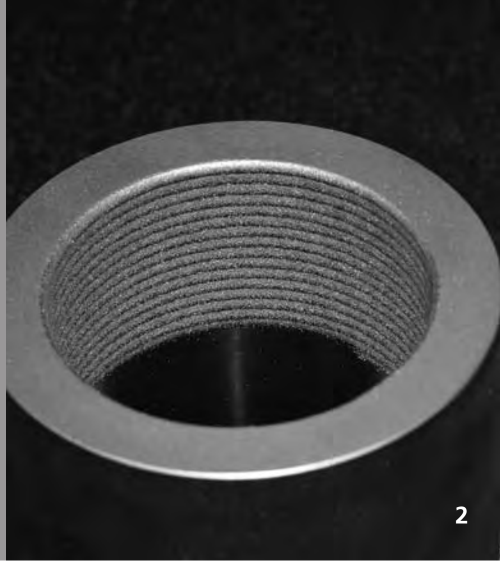
3 Cross-section of a coated machine nozzle (top), after approx. 6 months of industrial usage (bottom), material: K 265, tip: Stellite 21, thread: Metco 42 C (Netstal).





HIGH-POWER INTERNAL CLADDING HEAD FOR HIGH-SPEED LASER MATERIAL DEPOSITION

Task

Powder-based laser material deposition is a process that is used to repair and modify components. Applications where internal surfaces (mainly rotationally symmetrical) have to be coated are growing in significance for repair (e.g. engines, tools) or wear protection (e.g. bushings). Special machining heads with an integrated powder feed system are required for diameters under 100 mm. These heads do not yet have the service life needed for material deposition lasting several hours at high output power (> 2 kW). This shortcoming must be overcome if cost-effectiveness is to be improved and hence wider use promoted. The aim of the HIPOTIN project, which is funded by the German Federal Ministry of Education and Research (BMBF), is to develop an internal cladding head which can be used for laser power up to 6 kW (diode laser) and an internal diameter of the components to be machined of > 50 mm.

1 Optics for processing internal contours during operation.

2 Coated component.

Method

A cladding head with improved cooling of the entire tube and the deflection mirror has been developed. The temperature of the deflection mirror is monitored using a thermocouple in order to detect overheating early on. The focal spot size on the workpiece was enlarged to a diameter of 5 mm (previously 3 mm).

Result

In initial tests, layer thicknesses > 1 mm were achieved as part of endurance testing (t > 1 h) with the cladding head at laser power up to 4 kW in a single layer. The mirror heats up to a temperature of max. 60 °C. Deposition rates of 2 kg/h have been achieved so far.

At present the head is being tested under industrial conditions up to 6 kW. The aim is to achieve deposition rates up to 5 kg/h.

Applications

The new internal cladding head can be used for applications such as wear protection of bushings used in the oil industry. Another application is the repair of cylinder sleeves on large diesel engines.

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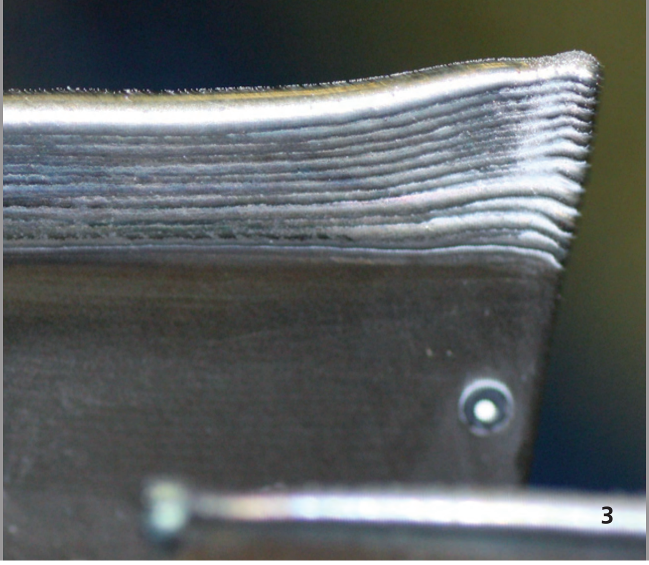

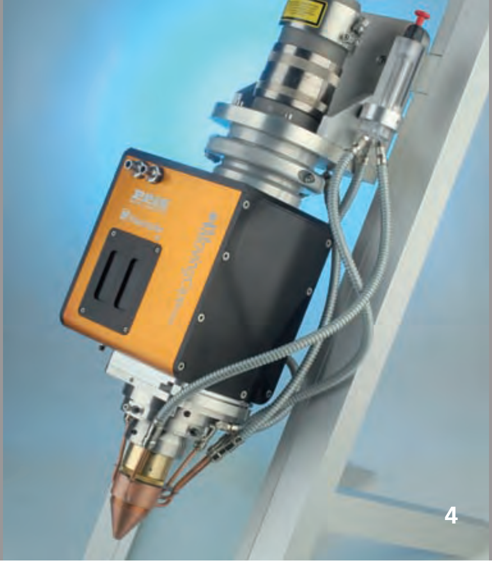

USE OF ZOOM OPTICS TO REPAIR BLADE TIPS

Task

Laser material deposition has been successfully rolled out in industry as a repair technique over the past few years. Typical application areas include the aerospace industry, where it is for example used in the repair of compressor blades. Modern compressor stages in aero engines use a BLISK (Blade Integrated Disk) design, i.e. the disk and all the blades of a compressor stage are milled directly from a single part. The tips of the blades are subject to wear through abrasion during operation. Due to the high material and manufacturing costs of the BLISKs, the aim is to develop a repair technique involving laser material deposition which facilitates repair to exactly fit the required contour with minimal distortion.

Method

The blade tip has a variable width of approx. 0.3 to 2 mm. Unlike standard optics, using zoom optics enables the laser beam at the machining location to be tailored on the fly directly to the particular width of the blade.

VarioClad – Moving Optics is used in combination with a Nd:YAG laser for the repair.

Result

The zoom optics was successfully used to repair the blade tips. The laser beam diameter was varied from approx. 0.6 to 2 mm, in accordance with the blade width. The laser power was also adjusted to the track width. A total of 23 layers were deposited to build up approx. 6 mm. The width of the laser-deposited volume is near-net-shape (approx. 0.2 mm oversize on each side), thus facilitating mechanical final processing to produce the required geometry.

Applications

The zoom optics can be used wherever a variable track width has to be produced or is advantageous. While this tends to involve web geometries, large-area coatings with high contour accuracy can also be implemented using a skin-core strategy (narrow tracks for the contour, wide tracks to fill the surface) without any retrofit, thus saving time. The optics is also a compelling option for service providers that intend to implement different coatings without a major retrofit. VarioClad – Moving Optics was developed in collaboration with Reis Lasertec.

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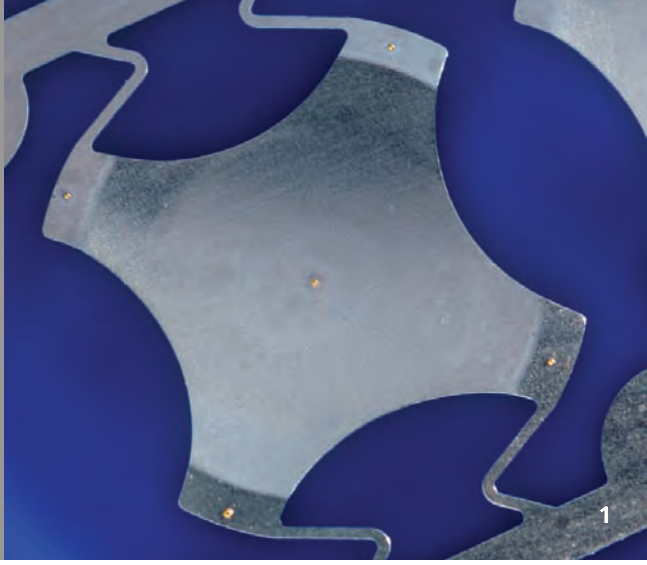
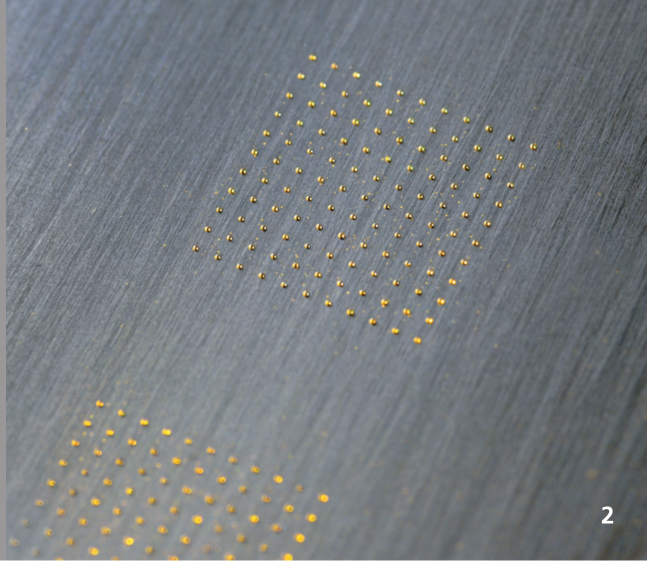
3 Laser-deposited blade tip.

4 VarioClad – Moving Optics.





MICRO LASER CLADDING FOR GOLD CONTACT SPOTS

Task

One of the applications micro laser cladding is suitable for is the fabrication of electrical contacts. The electrical and electronics industry uses a large number of components which are coated with gold in order to increase their electrical conductivity. Gold is usually applied upon the entire surface by a process such as electroplating. Selective deposition of gold contact spots using micro laser cladding means only coating the areas required to provide the electrical contact. This uses less of the expensive gold while retaining the requisite electrical contact properties.

Method

The micro laser cladding technique for gold contact spots uses a nozzle to feed the gold powder into the zone where the laser interacts with the substrate material (e.g. stainless steel, nickel alloy). The laser energy melts both a thin surface layer of the substrate and the gold powder to create a welded gold contact spot which is metallurgically bonded to the substrate. Using gold powder with grain diameters smaller than 10 µm and a fiber laser with a beam diameter of less than 100 µm, contact spots can be applied with a diameter and height of well below 100 µm. In addition to pure gold, gold alloys can also be used to improve abrasive wear resistance.

Result

In the case of contacts for snap domes, it has been demonstrated that a gold coating over the entire area can be replaced by five selectively deposited gold contact spots. The electrical properties of these gold spots are comparable with those of the electroplated coating. A lifecycle test involving 100,000 operations was successfully completed on a test bench. To increase the process speed, the MIFULAS project – which is funded by the German Federal Ministry of Education and Research (BMBF) – is currently investigating simultaneous material deposition of up to 20 spots by means of multiple beam processing using beam splitting.

Applications

Micro laser cladding of contacts made out of precious metals is a method that, in principle, is suitable for all metal parts which currently rely on electroplating techniques to provide electrical contacts. Examples include the switches used in cell phones or bipolar plates for fuel cells.

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1 Gold contact spots on a snap dome (source: INOVAN).

2 Micro gold spots on stainless steel.

SELECTIVE LASER MELTING OF NICKEL-BASE SUPERALLOYS

Task

The Selective Laser Melting (SLM) additive manufacturing process allows complex metallic components to be manufactured directly. SLM provides a cost-effective alternative to conventional manufacturing processes for small-series or prototype manufacturing. Manufacturing of components exposed to high temperatures by SLM is currently limited by the processable materials. Nickel-base superalloys, which exhibit high mechanical strength combined with oxidation and corrosion resistance at high temperatures, are a key material. The high-temperature stability of these alloys increases as a function of the volume fraction of the γ' phase, a precipitation in the form $Ni_3(Al, Ti)$. However, as in welding, cracks tend to form in superalloys with a high γ' content when they are processed using SLM. In collaboration with industry partners, the processability of these alloys is currently being investigated in various projects. The aim is both to gain an understanding of the underlying crack-formation mechanisms and to develop solutions based on these insights to provide crack-free processing.

Method

In SLM, specific modification of process parameters allows various solidification conditions to be set, which in turn makes it possible to investigate the variables affecting crack formation in a systematic way. The influence of the preheating temperature in the process is one area under focus. Nickel-base superalloys need preheating temperatures of > 1,000 °C, which will have to be realized in laboratory setups through new heating concepts.

Result

In the laboratory, the basic feasibility of crack-free processing of alloys with a high γ' content was demonstrated by using preheating temperatures > 1,000 °C. Development is currently focused on process layout and systems technology, in order to apply the results in building up complex components.

Applications

Nickel-base superalloys processed using SLM offer huge potential in the energy and aerospace industries in the field of gas turbines. Turbine blades can, for instance, be manufactured with complex internal structures to increase cooling efficiency or to reduce weight.

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3 Stator and rotor of a micro gas turbine manufactured out of superalloy using SLM. Designed by Fraunhofer IPT.

PROCESS MONITORING FOR SELECTIVE LASER MELTING

Task

Additive manufacturing became widespread in industrial product development in the early 1990s. Components manufactured using Selective Laser Melting (SLM) exhibit largely series-identical properties in terms of density, microstructure and mechanical properties. As a result, the technique can also be potentially used in direct series production. One obstacle to series production is the lack of quality assurance and control during the process. Flaws often go undetected during the production process, which can last several hours (up to 100 h). The aim is to develop methods for monitoring the SLM process in order to identify problems early on, remove affected components, and/or correct any problems.

Method

As part of the GenErgie project funded by the German Federal Ministry of Education and Research (BMBF), the first step entails visually capturing the melt pool geometry as the basis for a control system. The light emitted by the molten material and the reflected laser radiation are suppressed using a filter positioned in front of the camera; the monitored area is illuminated using a diode laser, and a CMOS camera is used to monitor the process. Both the camera and the diode laser are arranged coaxially to the processing laser. As part of the investigation, several CMOS cameras and illumination systems were tested.

Result

The best results were achieved using coherent, coaxial illumination with a wavelength of 810 nm. High illuminances were achieved to support a time resolution of approx. 10 µs/image. The camera resolution of approx. 15 x 15 μm^2/pixel allows the process to be recorded with a frequency of up to 15 kHz. The camera's spectral sensitivity is between 320 and 1100 nm. It is possible to achieve an image size of approx. 4 mm^2. At this resolution, the melt bath geometry measuring approx. 200 µm, individual powder grains with a size between 20 and 45 µm, and powder movement on the test sample can be resolved and monitored at scan speeds of approx. 800 mm/s. Simulated flaws in the form of grooves and irregular powder deposition can be detected directly.

Applications

A process monitoring system for the SLM process can be used to advantage across all SLM applications.

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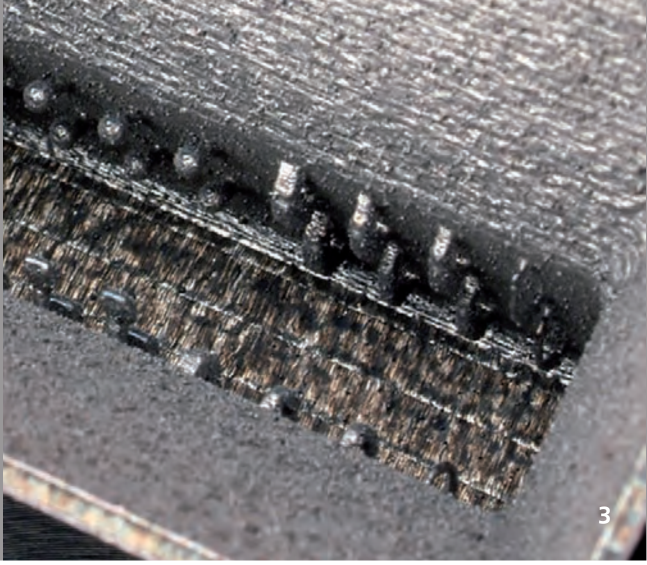
1 Dental prosthesis, manufactured using SLM.

2 Festo end stop, manufactured using SLM.



TOOLS MADE OUT OF A COMBINATION OF MATERIALS

Task

Selective Laser Melting (SLM) is used widely to manufacture mold inserts for injection-molded machine tools. The large degree of geometrical freedom of SLM is used to produce inserts with conformal cooling channels. Effective temperature control can be attained in this way. The construction of conformal cooling channels can, however, be extremely challenging depending on the thermal surroundings.

Method

As an alternative for temperature controling using complex conformal cooling channels, Fraunhofer ILT has been developing a process for manufacturing mold inserts from a combination of materials. The work is undertaken as part of the GenCast project funded by the German Federation of Industrial Research Associations (AiF) in collaboration with the Casting Institute of RWTH Aachen University and industrial partners. The aim is to combine the advantages of tool steel, with its higher wear resistance, and metals such as copper or aluminum, with their high heat conductivity, within a single component. Manufacturing involves a two-stage process. In the first stage, only the shell of the tool is additively manufactured from wear-resistant tool steel, such as 1.2343. The second stage then involves filling the core with a highly heat-conductive material, such as aluminum. Finally, conventional manufacturing technology is used for finishing. The primary aim is for the shell/core composite to be joined flawlessly, thus ensuring optimum heat dissipation. To this end, the shell interior includes cottering features and undergoes material pre-treatment.

Result

The initial results demonstrate that complete flowaround can be achieved as a function of the geometry of the cottering features. Pre-treatment of the shell interior will be investigated in a subsequent step.

Applications

The technology described can be applied in all areas where the following advantages of such mold inserts can be effectively utilized:

- Short production time for additive manufacturing
- Wear-resistant shell
- Very homogeneous temperature control of the tool thanks to the highly heat-conductive core
- Lower production costs since only a simple temperature-control channel if any is necessary

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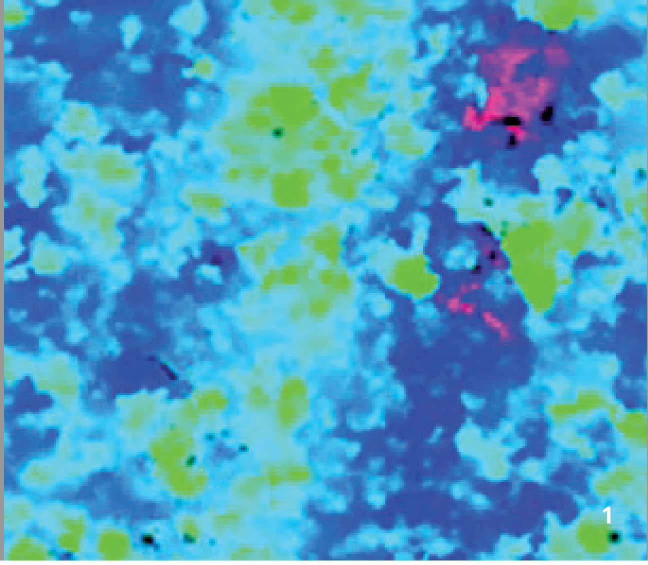
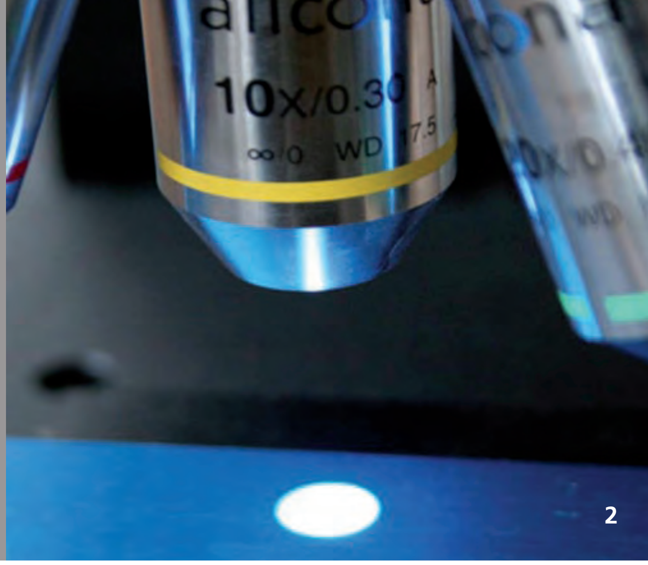
3 Wear-resistant shell body with connector features, manufactured using SLM.

4 Filling the shell body manufactured using the additive process.





SURFACE CHARACTERIZATION OF SLM COMPONENTS USING RA SPECTRUM

Task

The reduction of surface roughness is one of the key research topics for the additive manufacturing process Selective Laser Melting (SLM), since surface finishing constitutes one of the key factors in determining the cost and time involved. Until now, surface roughness was improved by selecting a smaller laser spot and/or thinner powder layers, but this in turn also increased production time. Targeted reduction of the surface roughness that develops during the SLM process requires an understanding of the physical processes that are responsible for the development of roughness. An initial step in this respect is to use a measurement technique which not only describes amplitude parameters (Rz,a) as previously, but also takes into account the spectral distribution of the roughness.

Method

The process involves analyzing surface roughness of SLM test samples using Ra spectra. To obtain an Ra spectrum that describes amplitude parameters and the spectral distribution of the roughness, an optical measuring device is used (Infinite Focus from Alicona) to measure the surface (1.5 x 5 mm^2 due to statistical considerations). The 3D topography obtained is exported as a data matrix and further processed using Gaussian filters, then Fourier transformed in order to separate the component's surface profile into its short-, medium- and long-wave components, and to sort these by their wavelength. This result is provided in the form of roughness Ra as a function of the assigned wavelength range.

Result

By sorting the surface roughness Ra by wavelength it is possible to identify the typical surface structures of the SLM surfaces as local maxima. Initial studies show that a local maximum on the SLM surface typically lies at wavelengths between 640 and 1280 µm. These are significantly greater than typical process parameters such as layer thickness, beam diameter or powder grain size. This aspect is indicative of fluctuations in the melt pool volume during the process.

Applications

The surface characterization of SLM components is an important analysis technique for investigating the component quality in all SLM applications.

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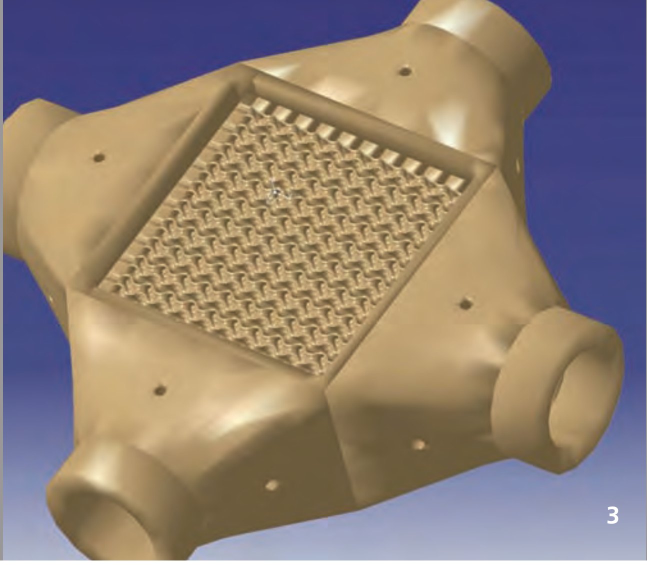
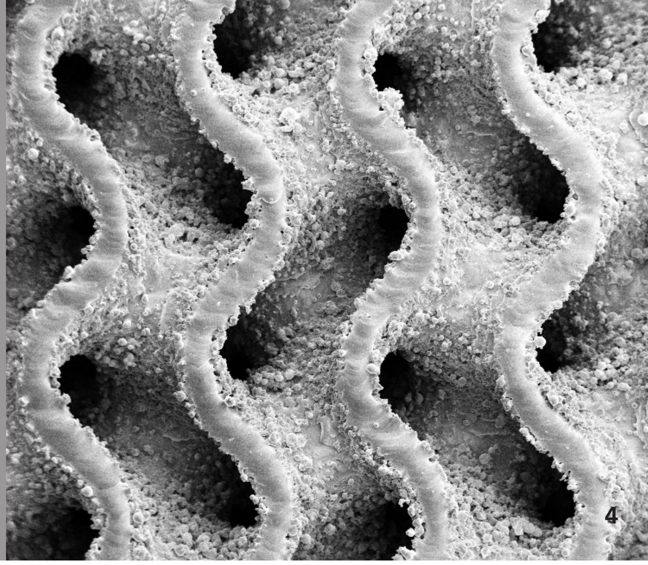
1 False colour representation of a SLM surface.

2 Infinite-Focus-Mearurement, Source: Alicona.





ADDITIVE MANUFACTURING OF MICRO-ENGINEERED COMPONENTS USING THE (µ-)SLM TECHNIQUE

Task

The increase in high-tech applications, e.g. in the field of microtechnology, calls for ever greater miniaturization of products coupled with enhanced functionality, integration density, and individualization. More demanding requirements – such as smaller structure sizes, greater precision, smaller component geometries and new functionalities – are being placed on both products and production processes. One part of the MicroGen joint project, funded by the German Federal Ministry of Education and Research (BMBF), aims to develop the Selective Laser Melting (SLM) additive manufacturing process so as to manufacture micro-engineered components (µ-SLM) with structure sizes < 100 µm.

Method

The potential of the SLM additive manufacturing process has already been highlighted for the manufacture of complex and innovative macrocomponents (structure sizes > 500 µm) for various applications. But there is still a need to develop both the requisite process understanding and tailored systems technology before complex components with structure sizes in the region of 10 to 100 µm can be manufactured from metallic series-production materials. To this end, the aim is to investigate the influence on the processing result of key process parameters such as laser power, scan speed, and layer thickness. In terms of systems technology, modifications have been made in powder deposition and in beam shaping and guidance in order to allow manufacturing of the aforementioned structure sizes.

Result

Initial investigations have been conducted on a SLM system using a brilliant laser beam source (fiber laser). A modified deposition mechanism was used to deposit ultrafine fractionated powders (< 10 µm) reliably, and a beam diameter of 30 µm implemented using corresponding optics configuration and adjustment. On the basis of this basic research work, initial components (structure sizes ≤ 100 µm) have been built up with layer thicknesses of 10 µm.

Applications

Extending the process into the ≤ 100 µm region augments its application potential and the product portfolio for which it can be used. New applications can be developed using this micro-additive manufacturing process in various industries, e.g. medical technology, electrical engineering and electronics, optical technologies, and solar technology.

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3 Example application micro-heat exchanger, source: Chair of CVT at RWTH Aachen University.

4 Demonstrator heat exchanger manufactured using µ-SLM (REM).

MACHINE TOOL FOR LASER POLISHING

Task

Manual polishing is the state-of-the-art technique in tool and mold making. Nonetheless, the time and money this requires means there is a great demand for automated polishing processes of complex 3D surfaces in industry. Together with several partners from industry and as part of the BMBF-funded project "Alpine", Fraunhofer ILT is developing a machine tool for automated laser polishing metallic components that meets the requirements of industrial production.

Method

The development is based on extensive experience garnered from process development and testing machinery in the laboratory. This experience has been translated into robust machinery that is suitable for industrial production. The basis of the machine is a 5-axis portal system that positions the workpieces and initiates slow feed movements. This axis system is combined with a fast dynamic 3-axis laser scanner that supports the requisite process speeds of up to 1 m/s.

However, machine kinematics with 5 + 3 axes pose a considerable challenge for the CAM-NC data chain, so Fraunhofer ILT is developing solutions that will enable the operator to also use the tried-and-trusted milling CAM system to compute the tool paths for laser polishing applications.

Result

The machine tool for laser polishing is suitable for components with a diameter of up to 450 mm and a weight of up to 100 kg. A process chamber, which opens ergonomically to the side, enables the machine to be easily tooled, either manually or using a crane. A sensor records the position of the workpieces for the zero-point alignment between the CAM planning and the machine.

Applications

Both the machine and the CAM-NC data chain are available to customers for component- and application-specific testing. The main application field is the tool and mold making industry whereby focusing on applications where medium surface qualities are required, such as glass forming, embossing and forging dies.

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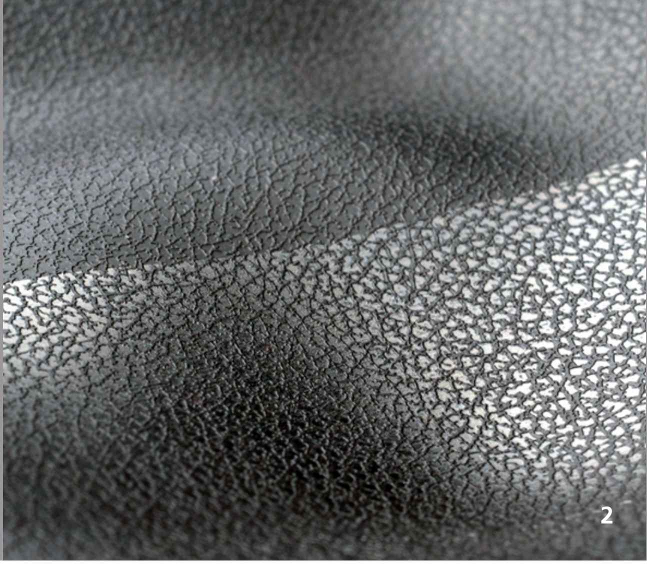
1 Machine tool for laser polishing.




SELECTIVE LASER POLISHING

Task

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

Method

Selective laser polishing is being investigated in the EFFILAS project, which is funded by the German Federal Ministry of Education and Research (BMBF), on the basis of tool inserts with different geometries (e.g. spheres and cylinders) as well as grained surfaces made out of 1.2343 tool steel. First the complete surface is digitized using an optical sensor system with a resolution of 1040 dpi. Selective laser polishing of only the indentations of the leather grain structure, for instance, involves separating the leather grain structure from the underlying tool geometry. This is done by means of adapted profile filtering of the digitized surface using Fourier analysis. The process involves scanning the surface in a meandering pattern while the laser beam focus is adjusted in accordance with the tool geometry. In addition, the laser power is modulated along the processing paths as a function of the existing structures (only the indentations are laser polished).

Result and Applications

By locally modulating the laser power, roughness is reduced while the degree of gloss in the indentations of the structure is increased to create a dual-gloss effect. Depending on the selected laser power, the degree of gloss can be adjusted from the initial state through to very high glosses. So far, tool inserts have been successfully selectively laser polished with freeform surfaces and etched leather graining, and plastic components with a dual-gloss effect molded by these tool inserts. The processing time is at present approx. 30 to 60 s/cm^2 with a resolution of 1040 dpi. The smallest selectively laser polished structure is currently 150 µm x 150 µm and is determined by the diameter of the laser beam used. Future research work aims primarily to transfer the findings to actual tools, e.g. for automobile instrument panels, and to test the process in an industrial environment.

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2 Selectively laser polished freeform surface made out of 1.2343 tool steel.

3 Freeform surface molded in plastic from Fig. 2 with dual-gloss effect.

LASER POLISHING OF EMBOSSING DIES

Task

Hand polishing embossing dies is time-consuming and expensive. Handheld tools are used to laboriously pass abrasive polishing media over the surfaces to be polished. Difficulty of access makes corners and filigree geometries extremely difficult to polish. Consequently, Fraunhofer ILT and Robert Bosch GmbH are working together to test laser polishing for embossing dies that are used to manufacture claw poles.

Method

A laser beam remelts a thin surface layer of the embossing die. During this process, surface tension gives the surface a polished finish. A CAM-NC data chain developed at Fraunhofer ILT is used to generate the tool paths for the 3D surfaces of the embossing dies. The resulting contour-adapted paths allow complex geometries and even filigree corners to be machined, which would be very difficult to polish using conventional polishing techniques. As part of the project, laser-polished embossing dies are used in the production of claw poles, and compared, in particular, with the service life of hand-polished embossing dies.

Result

As part of the tests, the processing time was reduced from approx. one hour per embossing die for hand polishing to approx. 14 minutes for laser polishing. Roughness of $Ra \approx 0.2\ \mu m$ was achieved. Initial tests of laser-polished embossing dies in production applications show promising results. More extensive testing is now needed to demonstrate whether and how laser polishing affects the service life of embossing dies.

Applications

In addition to the investigated embossing dies, laser polishing can replace hand polishing for a large number of tools. However, the focus is not on reducing roughness compared with hand polishing, but on automating polishing to meet average quality requirements and thus substantially reducing costs.

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1 Laser-polished embossing die and the claw pole manufactured using the die.

POLISHING TITANIUM- AND NICKEL-BASED ALLOYS USING CW LASER RADIATION

Task

Titanium- and nickel-based alloys are the materials of choice for aero engines. The Ti alloy Ti6Al4V boasts high strength up to a maximum operating temperature of 400 °C coupled with low density. High thermal strength up to a maximum operating temperature of 700 °C makes the Ni alloy Inconel 718 ideally suited for parts used in the hot gas area of the engine.

Certain areas of the components made out of these alloys must be polished following machining, e.g. to reduce air flow resistance. Hand polishing is both time-consuming and costly due to the high strength of these materials. Laser polishing is being used in order to reduce the time and effort spent on polishing. However, laser polishing of finely milled surfaces has to date only been investigated using pulsed laser radiation. The use of cw laser radiation to polish titanium- and nickel-based alloys is now being investigated as part of the HYBMAN project funded by the Volkswagen Foundation.

Method

Laser polishing involves remelting a thin surface layer and allowing surface tension to give the surface a smooth finish. Unlike conventional grinding and polishing techniques, no material is removed: it is simply remelted. This fundamentally different active principle of laser polishing is being combined with process automation to provide a faster, more cost-effective solution than conventional surface machining of titanium and nickel alloys, which is both time-consuming and costly.

Result

The surface roughness was reduced from Ra = 1.0 µm to Ra = 0.16 µm on turned flat specimens of the titanium alloy Ti6Al4V with a processing time t = 7 s/cm^2. With the nickel alloy Inconel 718, the surface roughness was reduced from Ra = 0.36 µm to Ra = 0.12 µm in a processing time of t = 53 s/cm^2. The results garnered from the initial parameter studies demonstrate application potential and lay the groundwork for further process optimization aimed at reducing roughness and processing time.

Applications

In addition to use in engines for aerospace applications, another potential application is in the production of optical effects or biocompatible surfaces made out of Ti6Al4V for medical applications.

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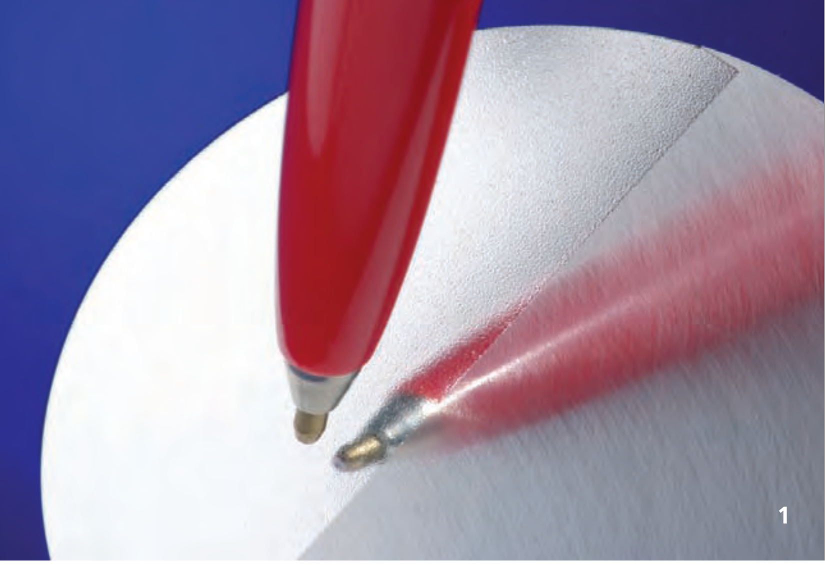
2 Laser-polished test fields in Inconel 718.



LASER MICRO POLISHING OF ALUMINUM MATERIALS

Task

The functional surfaces of components made out of aluminum materials often have to be polished. Except for a few specialized applications, three-dimensional freeform surfaces are almost exclusively hand polished owing to a lack of automated manufacturing processes. For a number of years, Fraunhofer ILT has been developing a polishing technique for steel and titanium materials using pulsed laser radiation. This technique can be used, in particular, to remove the microroughness from surfaces and increase the degree of gloss. Apart from the high machining speed, the main advantages relate to process automation and accuracy of geometry. The range of materials to which this process is suited is now to be extended to include aluminum materials.

Method

Once the process parameters have been adjusted, the aluminum materials are laser micro polished using a suitable process gas atmosphere and a TruMicro7050 disc laser with pulse lengths in the region of t_p = 1 - 2 µs. Tests are being carried out on flat specimens made out of EN AW-6082 (AlMgSi1Mn) and EN AW-7022 (AlZn5Mg3Cu). Typical applications for these materials include trim and design strips (EN AW-6082) as well as blow molds for plastics processing (EN AW-7022).

Result

Micro polishing using pulsed laser radiation reduced surface roughness for EN AW-7022 from Ra = 0.20 µm to Ra = 0.05 µm. In the case of EN AW-6082, roughness was reduced from Ra = 0.13 µm to Ra = 0.07 µm. The processing speed is approx. 6.5 s/cm^2 for both materials.

Applications

In addition to applications for trim and design strips as well as blow molds, the results can be applied wherever aluminum materials need to be polished to produce a surface finish. This includes components used in engine manufacture, lightweight construction, and in aerospace engineering.

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1 Laser micro polished surface made out of EN AW-7022.

ABLATION AND POLISHING OF GLASS USING LASER RADIATION TO MANUFACTURE OPTICAL COMPONENTS

Task

One way to meet the more exacting requirements placed on optical elements in relation to imaging quality, reduced weight and smaller volume is an increased use of aspherical or freeform optics. However, conventional production methods for optical elements with non-spherical surfaces are time-consuming and costly, and therefore not able to economically manufacture individual optics in small batches. As part of the BMBF funded FoPoLas project, Fraunhofer ILT is developing a laser-based manufacturing process which can generate virtually any surface geometry in a short time.

Method

Within a process chain (patent pending), the laser-based manufacturing of optics is split up into three process steps. First, using cw CO_2 laser radiation, material is ablated from a glass blank and the rough shape generated. Next comes a polishing step, again using CO_2 laser radiation, to reduce surface roughness by remelting, without any further material ablation or modification of the surface shape. In the final process step, high precision laser ablation minimizes any remaining inaccuracies of surface shape and ensures the optics meet the desired geometry.

Result

Using suitable scan strategies allows virtually any structures to be produced with an ablation rate of over 20 mm^3/s and a resulting roughness of Ra < 5 µm. Starting with ground test samples, the polishing process achieves roughness of Rq = 3 nm and Wq = 8 nm (measured according to ISO 10110 on measurement fields of 1 x 1 mm^2 or 16 x 16 mm^2) making it already suitable for illumination optics. These figures can also be achieved on spheres, aspheres and freeform surfaces. The high precision laser ablation supports an ablation depth of 2 nm per pass; this depth can be varied with a spatial resolution of < 250 µm. In addition, first combinations of these individual process steps have already produced promising results.

Applications

Apart from applications involving the manufacture of spherical and, in particular, non-spherical optical components, these process steps can also be employed singly or, if desired, combined with conventional manufacturing methods. The polishing process can, for instance, also be used for the internal polishing of drilling holes with a diameter of several millimeters or larger.

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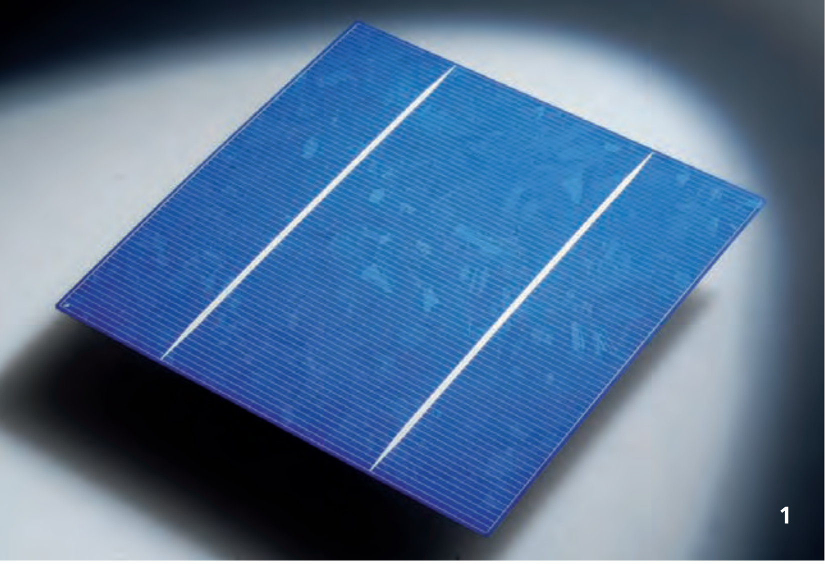
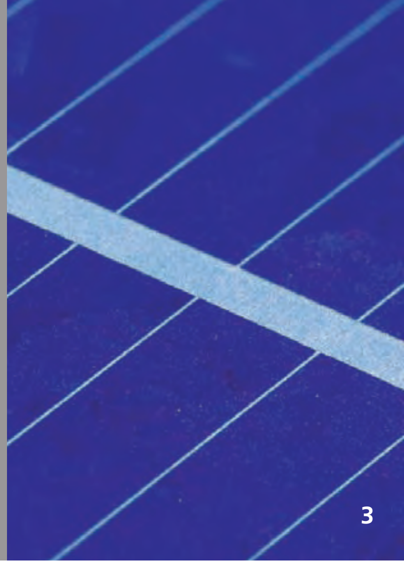
2 Stages of the process chain.

3 Laser polished lens and initial state.





LASER ABLATION OF PASSIVATION LAYERS ON CRYSTALLINE SOLAR CELLS

Task

During the production of crystalline solar cells the electric contacts on the front side are currently created by screen-printing of silver paste and a subsequent firing step. Using laser radiation to locally open the passivation layer paves the way for implementing low-temperature metallization and high efficiency cell concepts on a mass production scale. In particular, removing the silicon nitride passivation layer on the front of the cell enables the use of advanced metallization methods such as electroplating or inkjet printing. The width of the contact fingers can also be reduced substantially below 100 µm.

Method

Damage to the solar cell emitter has to be avoided while the passivation layer is ablated since this will reduce the efficiency of the solar cell. To avoid the kind of thermal damage that occurs with nanosecond lasers, the influence of various laser parameters (wavelength, pulse duration of 200 fs to 10 ps, fluence and pulse overlap) on the cell's electrical properties has been investigated. The study was conducted on finished solar cells – an approach that kept the characterization relatively simple – by ablating part of the surface between the metal contacts.

1 Standard crystalline silicon solar cell.

2 Ablation process with a wavelength of 532 nm.

3 Result of laser ablation.

Result

A sharp increase in degradation of the electrical properties was observed when using a wavelength of 532 nm and at pulse lengths in the ps and ns region. Suitable results can only be achieved with pulses in the fs region. Using the 355 nm wavelength reduces the degradation to the extent that there is no discernible deterioration in the electrical properties. In any event, processing very near to the ablation threshold is beneficial, since high fluences result in greater laser-induced damage. It was observed that a high pulse overlap (> 85 percent) improves the ablation quality, since this means sufficient line widths are achieved directly at the ablation threshold.

Applications

The above investigation of laser ablation took into account that the process was designed for use in the mass production of crystalline silicon solar cells. A similar laser process is being used both for the production of contacts on the rear of the cell (PERC concept), and for thin-film solar cells and OLEDs.

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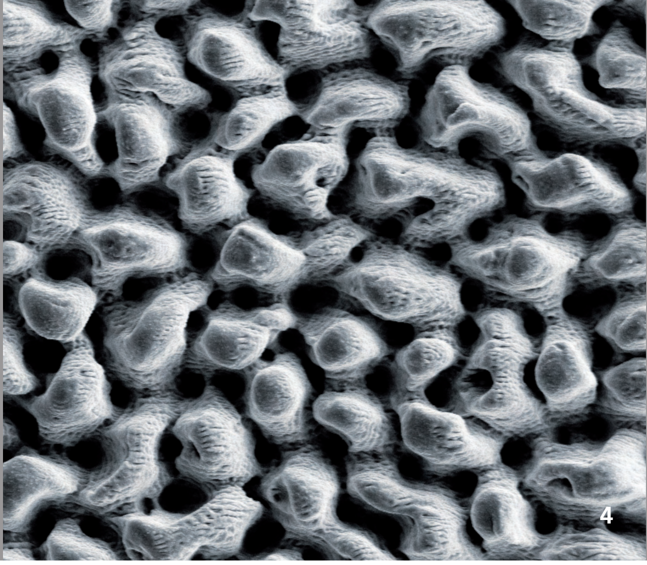

ULTRAHYDROPHOBIC AND ULTRAHYDROPHILIC METALLIC SURFACES

Task

The manufacture of ultrahydrophobic or ultrahydrophilic surfaces calls for a rapid, effective roughening process. In addition to chemical anodizing techniques or plasma etching techniques, laser roughening is a locally selective solution that supports a wide variety of freeform structures.

Method

Laser ablation using high-power ultrafast lasers allows microstructures and microforms to be ablated with high quality and accuracy. It also allows ultra-rough surfaces to be manufactured. The surface area of workpieces, in particular those made out of metals, can be quickly enlarged many times using simple laser structuring.

The surface topography produced using this technique exhibits different wetting behavior to water than a polished surface. The surface energy of the surface dictates the direction of the wetting change (hydrophilic/hydrophobic), while the surface topography determines the extent of the change. The surface energy of the material can be decisively influenced using a coating applied at Fraunhofer IFAM. Based on a low-pressure plasma technique, various polymers with layer thicknesses in the nanometer range can also be deposited on freeform surfaces.

Result

Depending on the type of coating, ultrahydrophobic and ultrahydrophilic surfaces can be manufactured through a combination of laser structuring of metallic surfaces and subsequent coating. The laser structuring creates surfaces that are at least 12 times larger than the base area of the substrate. The advantages of a coating lie primarily in the long-term durability of the effect, as well as the precise adjustment of the surface energy.

Applications

Applications involve medical technology (hydrophobic needles) or the locally selective modification of wetting properties of freeform components.

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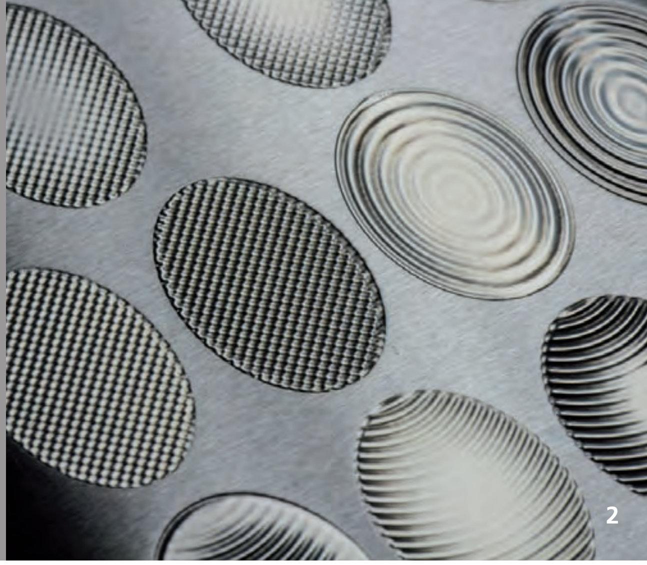
4 REM image of the steel surface following roughening using an ultrafast laser. Two structure size regimes (cone-like protrusions and nanoripples) are discernible.

5 Ultrahydrophobic steel surface following laser roughening and coating with hydrophobic polymer.



STRUCTURING BY LASER REMELTING

Task

Components with structured surfaces are taken for granted in many segments nowadays. Injection molding tools made out of metal are often used to structure the surfaces, while photochemical etching is a standard technique for structuring the tools themselves. But this technique is time-consuming and costly since the bulk of the process is still carried out by hand. Laser ablation is also an established technique for structuring metallic surfaces. Both techniques produce rough surfaces. In areas where hygiene is an issue, these techniques cannot be used since the components machined in this way cannot be cleaned adequately. Low processing rates also constitute another frequent shortcoming.

Method

As part of the FluidStruc project funded by the Volkswagen Foundation, an innovative technique for structuring metallic surfaces is being developed that involves remelting a thin (~100 µm) surface layer using cw laser radiation. The laser beam is moved over the workpiece and the resulting heat input melts the metal surface locally. At the same time, the laser output power is modulated at frequencies between 10 Hz to 100 Hz in order to constantly change the size of the melt pool. This modulation of the size of the melt pool causes the material to be redistributed, creating mountains and valleys. This leaves half of the resulting structure lying above its initial level and the other half below it. The surface layer solidifies directly from the molten material, producing uniformly low roughness in addition to the structuring and giving the structured surface a polished finish at the same time. Complex location-dependent laser power signals are being investigated to extend the range of surface structures that can be created.

Result and Applications

Numerous innovative structures are being created on tool inserts made out of 1.2343 (Fig. 2) using adapted laser output modulation in order to demonstrate this technique. These surfaces feature a low micro-roughness and are molded reliably in plastic using the structured tool insert (Fig. 1). After eight successive machining steps, the height of the structures is approx. 60 µm at a structural wavelength of one millimeter. The processing time for the structures is currently approx. 2 min/cm^2. One area of application for these kinds of structures is in the hygiene segment, where a suitable look and feel of the structured surface are as important as a good cleanability. These structures can also be used in all areas which employ innovative visual and haptic design elements. The good moldability of the structures in plastic, in particular, opens up a wide range of applications.

1 Component molded in plastic with different fingerprint-sized structures.

2 Tool insert made out of 1.2343 with various innovative fingerprint-sized structures.

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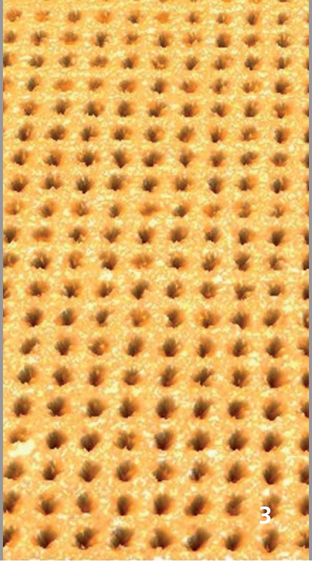

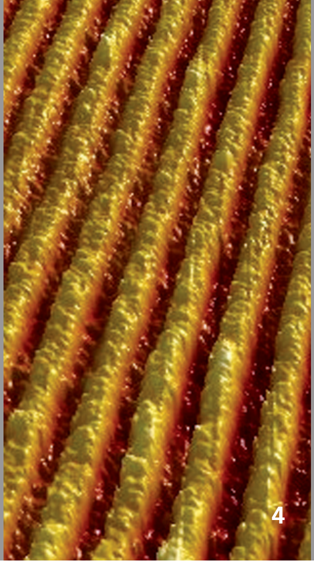

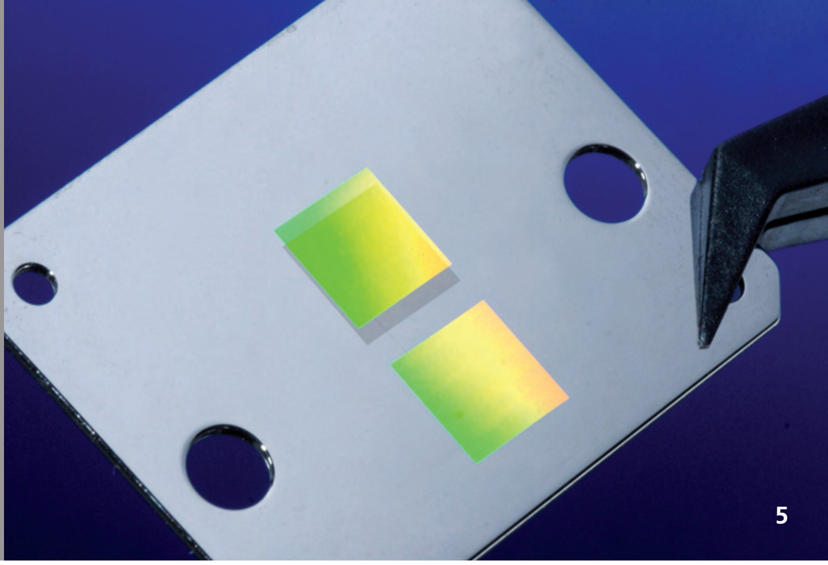

FOUR-BEAM INTERFERENCE STRUCTURING OF METALS

Task

Nanotechnology ranks as one of the key technologies of the 21st century, paving the way for a raft of new products thanks to the particular characteristics of nanoscale structures. Cutting-edge laser technology methods allow these functions to be employed cost-effectively in a range of industries by enabling functional surface structures to be produced which influence properties such as wettability, adhesion or light transmission.

Method

A four-beam laser interference system was set up to create nanoscale structures. The system uses a 1D or 2D phase mask to split the laser beam into two or four coherent partial beams, which are then superimposed with a Schwarzschild objective at a preset angle. The resulting interference pattern is used to generate structures in the material below the diffraction limit. The Schwarzschild objective consists of a small primary convex mirror and a larger secondary concave mirror. This objective is free of chromatic and spherical aberrations, and even allows for the correction of coma and astigmatism. Thanks to these properties, laser sources that only have a short coherence length can be used for interference structuring. The used laser source was a frequency-tripled Nd:YAG laser with a pulse length of 10 picoseconds.

3 AFM scan of a hole structure in steel.

4 AFM scan of a line structure in brass.

5 Large-area nanostructure in steel.

Result

The system generated holes with a diameter of approx. 350 nm in a square arrangement. The holes are approx. 300 nm deep, with the depth being controlled as a function of the laser pulse energy and the number of pulses. The period of the structure is determined by virtue of the selected wavelength and the numerical aperture of the Schwarzschild objective used, and is approx. 700 nm in this case. Suitable laser beam widening and sufficient pulse energy allows more than 100,000 holes to be generated with a single laser pulse. These structures have already been produced in various metals such as steel, brass, copper or aluminum.

Applications

Nanostructures are increasingly being used in the area of photovoltaics for surface enlargement. They are used as locally selective, functional surfaces in biotechnology and medical technology applications. They can also be used to minimize friction or as a security marking or anti-counterfeiting measure, rather like a barcode. Steel or copper components structured in this way can be used as masters for injection molding or embossing applications.

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HIGH-RESOLUTION LASER STRUCTURING OF TRANSPARENT CONDUCTING MATERIALS FOR ORGANIC ELECTRONICS

Task

Plastic electronics are on the edge of market release. There are already a host of products on the market that incorporate OLEDs for example. Apart from flexibility and the wide range of options available, one major advantage of organic electronics relates to the potentially very low production costs using roll-to-roll printing techniques. However, these processes can only be used to produce structure sizes of at least 10 µm, which is insufficient for fast, highly integrated electronics. In order to produce smaller structures, very slow processes such as lithography or micro contact printing are used which are incompatible with a high-speed roll-to-roll process. So there is a need for a rapid, high-resolution structuring process to facilitate the market launch of many other products.

Method

Laser ablation using excimer laser radiation is one way of generating high-resolution, large-area structures quickly. Since the layer thicknesses in organic electronics are typically a few 100 nm, mask projection can be used to structure a large area with a single or a few pulses. Despite the relatively low repetition rate of excimer lasers, this method is capable of a high throughput.

1 Comb structure in PEDOT/PSS required for thin-film transistors.

Result

The wavelengths in the deep UV around 200 nm are particularly ideal for ablating organic electronics given their very high absorption in these materials. Structure sizes of around 1.5 µm can be achieved in the organic transparent electrical conducting material poly(3,4-ethylenedioxythiophene)/ poly(styrenesulfonate) (PEDOT/PSS). A slightly lower resolution of around 5 µm can be achieved by means of excimer ablation in the inorganic transparent conducting material indium tin oxide (ITO). In both cases, a single pulse is sufficient to ablate the entire layer.

Applications

High-resolution structuring of organic electronics plays a particularly key role in the manufacture of multifunctional RFID tags, high-resolution flexible displays, and locally resolved large-area sensors.

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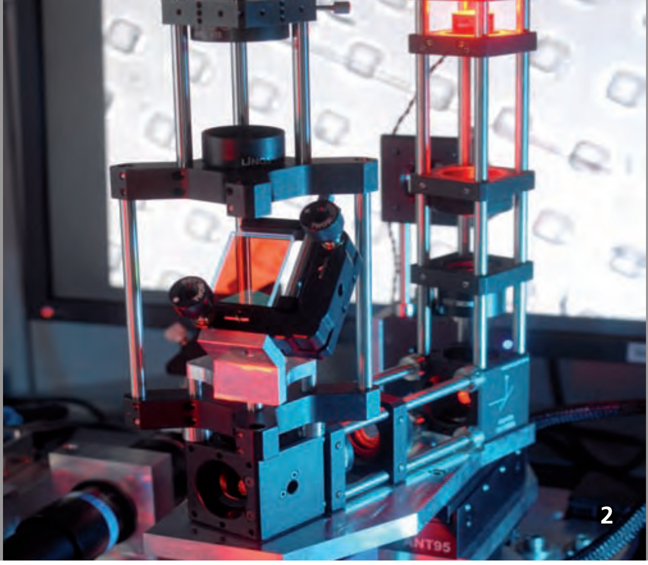

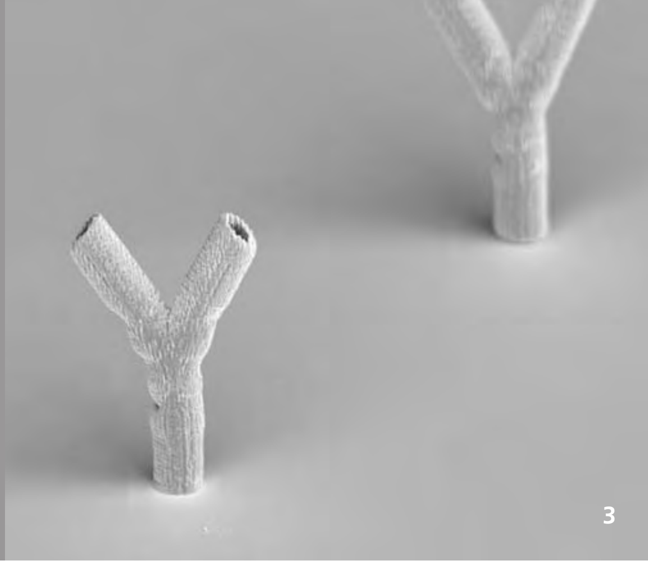

DESKTOP SYSTEM FOR MANUFACTURING HIGH-RESOLUTION MICROSTRUCTURES

Task

Two-photon polymerization is a laser-based direct writing process used to manufacture microstructures with sub-µm resolution. These kinds of microstructures are becoming more important in areas such as photonic crystals and meta-materials, as well as for the creation of defined 3D cell culture microenvironments in biology. Current machine implementations of this technology tend to be large and expensive, which hampers their widespread adoption.

Method

Fraunhofer ILT has developed an outstandingly compact, cost-effective desktop system for microstereo and multiphoton lithography. The aim was to combine the high resolution of the two-photon technology with a large processing field. The formation of the 3D structures is not dependent on the substrate material, making this system easy to combine with other additive manufacturing processes. Fraunhofer ILT is working in close cooperation with Fraunhofer IPA on a combination of high-resolution two-photon technology with a 3D printing process. This approach paves the way for new manufacturing processes for complex structures that for instance combine materials with different mechanical properties or dramatically reduce processing time.

Result

Two-photon technology was successfully used to manufacture microscale 3D structures. Examples include branched capillaries with an internal diameter of approx. 20 µm, which were manufactured from an elastic polymer, as well as defined protein microstructures and combinations of polymers and proteins. The feasibility of combining the 3D printing and two-photon technology processes was also demonstrated. A complete system that implements this combination is currently being set up.

Applications

Fraunhofer ILT focuses its development work on biomedical research. The versatility of the method enables complex 3D cell culture environments to be created which allow specific cell biology issues to be investigated. The combination with 3D printing has turned the manufacture of macroscopic structures using microscopic, high-resolution structures, such as a multi-branched blood vessel system for tissue engineering, into a realizable goal.

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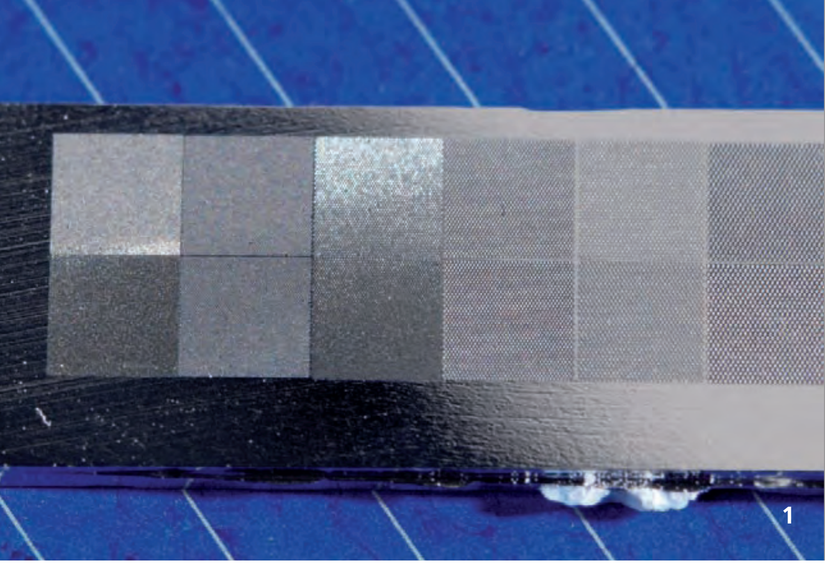
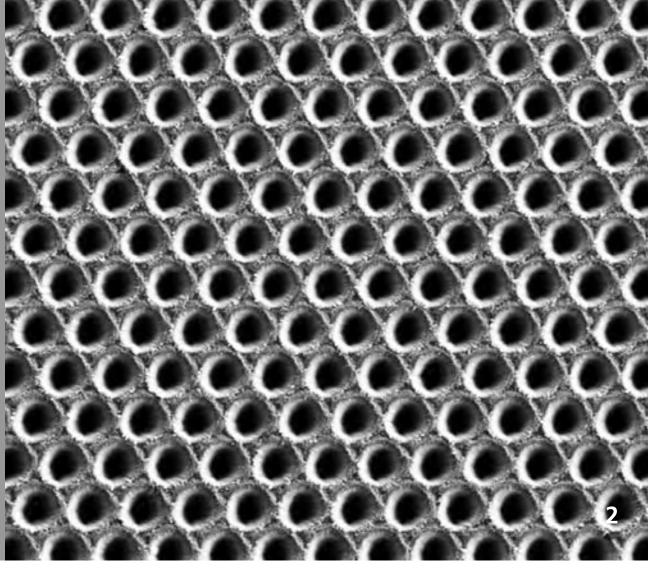
2 Prototype for the manufacture of microstructures.

3 Branched capillaries with internal diameter 20 µm.





MICROSTRUCTURING OF METALLIC GLASS

Task

Amorphous metals or metallic glasses are alloys which have an amorphous rather than a crystalline structure at the atomic level. Metallic glasses are generally harder, more wear-resistant and stronger than conventional metals. Cooling rates of up to 10^6 K/s are required to preserve the amorphous state. When structuring the shape or modifying the surface, it is necessary either to avoid heat input into the material as far as possible or to ensure a similar cooling rate. Mechanical structuring processes do not meet these requirements.

Method

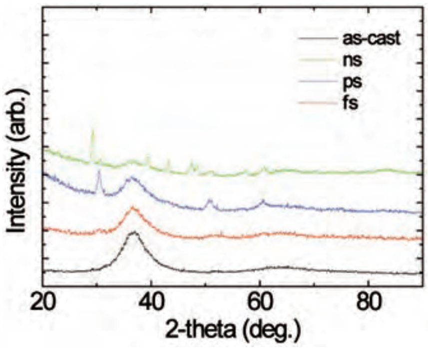
Laser material processing with pulse durations in the femtosecond region minimizes heat input into the base material, with almost complete dissipation of the input energy in the evaporation product. The surface is structured or the surface property modified using ultrashort-pulse laser radiation. X-ray diffractometry (XRD) is used to measure the structure in terms of its amorphous and crystalline components.

1 Surface-modified metallic glass test sample.

2 Micro-dents with 5 µm diameter structured using fs laser radiation.

Result

XRD measurements of the surface processed using fs laser radiation show no structural change whatsoever compared with the as-cast starting material; the amorphous structure is retained. During processing with pico- and nanosecond laser radiation, the peaks in the XRD measurement showed either partial or complete formation of a crystalline structure.



Applications

Owing to their mechanical, magnetic and optical properties, metallic glasses are used in electrical and electronics engineering, consumer electronics and in the sports equipment segment (golf clubs). Their biocompatibility makes them also suitable for medical technology applications.

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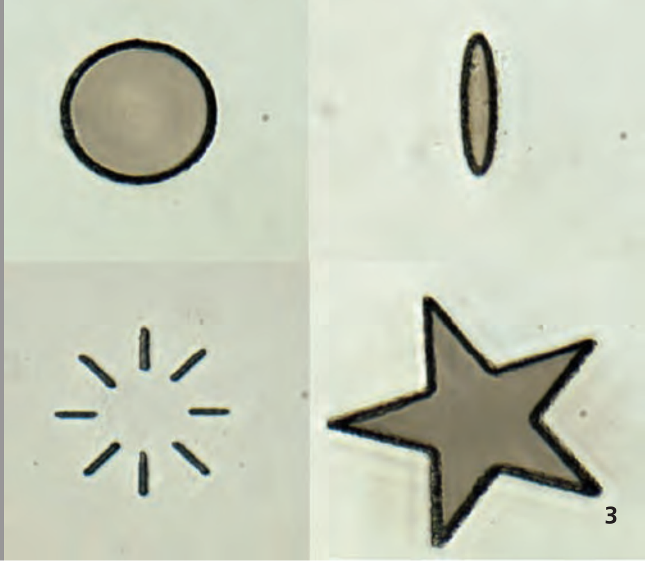

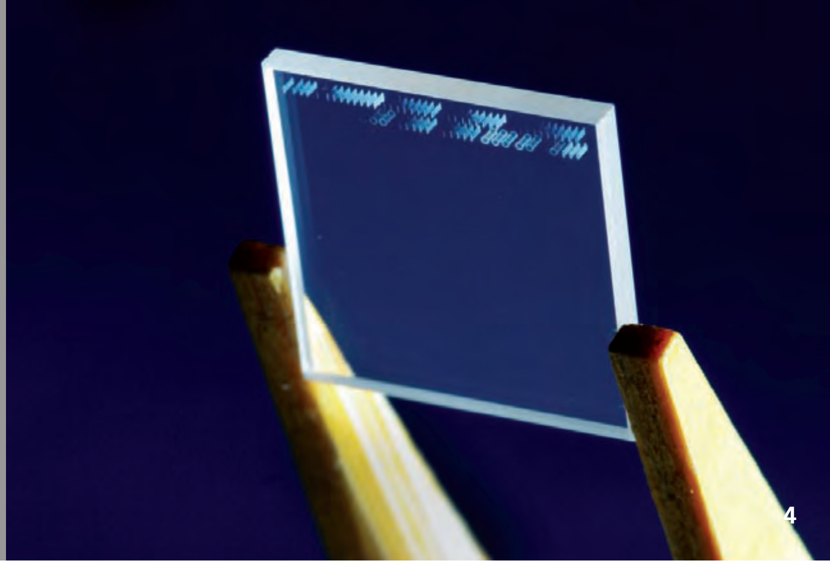

OPTICAL WAVEGUIDES WITH ARBITRARY CLADDING GEOMETRY

Task

Waveguiding structures in transparent dielectrics are being used in integrated optics to modulate light in minimal space. Flexible design of the waveguide geometry allows targeted shaping and guidance of diode laser radiation. By configuring the waveguide geometry, the beam profile of the guided radiation can be tailored to individual requirements. Voluminous optical systems can be replaced with an integrated and hence more compact solution.

Method

In the volume of a transparent material, focused femtosecond laser radiation is used to induce a local change in the refractive index, thus constituting a waveguide. The modifications are generated with a resolution in the micrometer range in three spatial dimensions. A precision scanner combined with a 3-axis traveling system provides flexible beam guidance to write the modifications. Light can be guided and shaped within the generated structures. Owing to nonlinear absorption processes, the in-volume waveguides can be produced in virtually any transparent material such as glass, plastic or crystals.

Result

Waveguides with elliptical and star-shaped cladding geometry have been produced in the volume of fused silica and sapphire. The core diameter of the 2 mm long waveguide was varied from a few micrometers to over 100 micrometers. A numerical aperture NA > 0.1 was demonstrated. The precision scanner supports manufacturing times < 1 second and allows the waveguide geometry to be adjusted to the laser diode's radiation characteristics.

Applications

Due to flexible beam guidance by the precision scanner during structuring, waveguides can be tailored individually and rapidly to optical requirements. The manufactured waveguides are suitable for beam shaping and beam guidance of diode laser radiation. Biomedical applications are possible in combination with microfluidic components. The use of integrated solutions allows optical systems to be more compact and flexible.

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3 Waveguides with different cross-sectional shape.

4 Fused silica sample with in-volume waveguides.

PRECISION COMPONENTS MADE OF RUBY

Task

Ruby in the form of watch jewels is used in the watchmaking industry due to its low friction coefficient (ruby/steel oiled: 0.04 - 0.05), high hardness (9 Mohs) and the resulting low wear of the individual components. The manufacture of jewel bearings using mechanical abrasive machining is very time-consuming and costly and results in high loss of material. Producing complex jewel bearing geometries calls for a combination of different manufacturing processes. The aim is to use In-volume Selective Laser Etching (ISLE) to manufacture high precision components out of brittle-hard material such as ruby with a single process.

Method

The material for the required component is initially modified using In-volume Selective Laser Etching with tightly focused ultrashort-pulse laser radiation. A highly precise scanner system is used to produce any kind of 3D structure in the volume of transparent materials. The following etching step removes the modified areas using an etching fluid. The unirradiated material remains virtually unaffected, thus creating channels in the volume. This irradiation process is conducted layer by layer and enables complex, 3D components to be produced.

Result

In addition to manufacturing components in ruby such as cylinders and tubes, cubic hollow volumes and channels have already been produced in sapphire with an aspect ratio of 1000:1 up to a length of 10 mm.

Applications

Precision components made of brittle-hard materials such as ruby and sapphire are used extensively in the watchmaking industry, the chemicals industry, and in medical technology. The good accessibility of the laser beam in the contactless ISLE manufacturing process also enables component geometries to be produced which were previously impossible to manufacture due to the limitations of conventional manufacturing processes. The two-stage ISLE technique replaces manufacturing processes involving up to 30 individual steps, thus reducing the manufacturing time severalfold.

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1 Tube manufactured using ISLE from ruby (1 mm length, 900 µm external diameter, 400 µm internal diameter).

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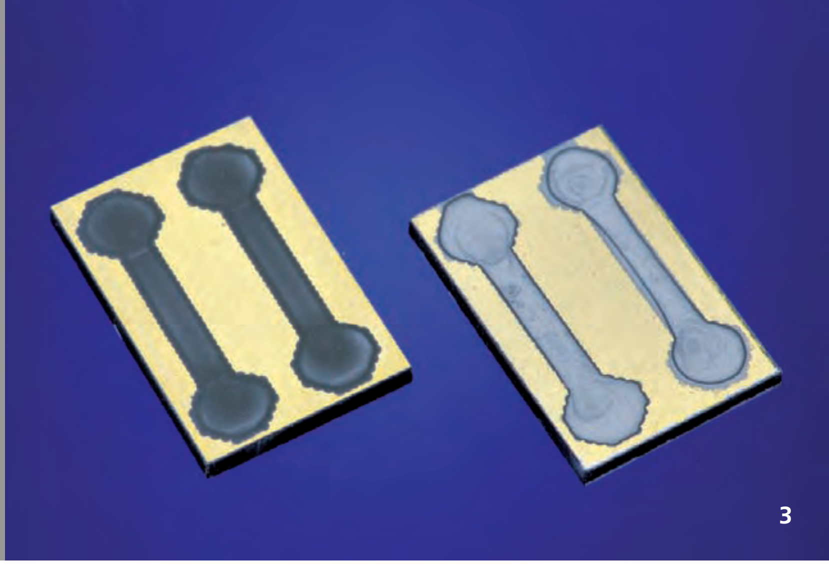

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COMBINED PRINTING AND LASER TECHNIQUE FOR MANUFACTURING SELECTIVE FUNCTIONAL LAYERS

Task

Functional metallic layers are often deposited using costly and time-consuming PVD and CVD processes. These techniques entail a high technology overhead through the use of vacuum chambers and inflexible mask techniques. Mask-less printing processes (e.g. inkjet) can be used for the locally selective in-line deposition of metal particle dispersions. The requisite functional properties can only be achieved through additional thermal post-treatment such as drying or sintering/melting (mainly furnace processes). The aim is to carry out this required post-treatment using a laser technique that protects the substrate and is energy-efficient.

Method

When using lasers to dry and functionalize thin layers, the laser radiation is tailored to the absorbance of the layer material and coupled locally into the material being processed. This allows the layer to be dried first before being subsequently sintered or partially melted. In the case of metallic layers, this technique produces conductivity similar to that of the bulk material.

Result

Structured metallic layers made out of µm particle dispersions were deposited using printing techniques on different substrates (e.g. ceramic and plastic foil). Laser radiation can be used for the thermal post-treatment of the layers that are nonconductive after printing and drying, such that conductivity of up to 50 percent of the bulk material can be achieved.

Applications

The combined printing and laser technique can be used wherever coatings are required locally selectively or conventional thermal post-treatment is not possible due to temperature-sensitive substrates, e.g. in the case of functional layers for electronics such as insulating layers, conductive paths or contact spots.

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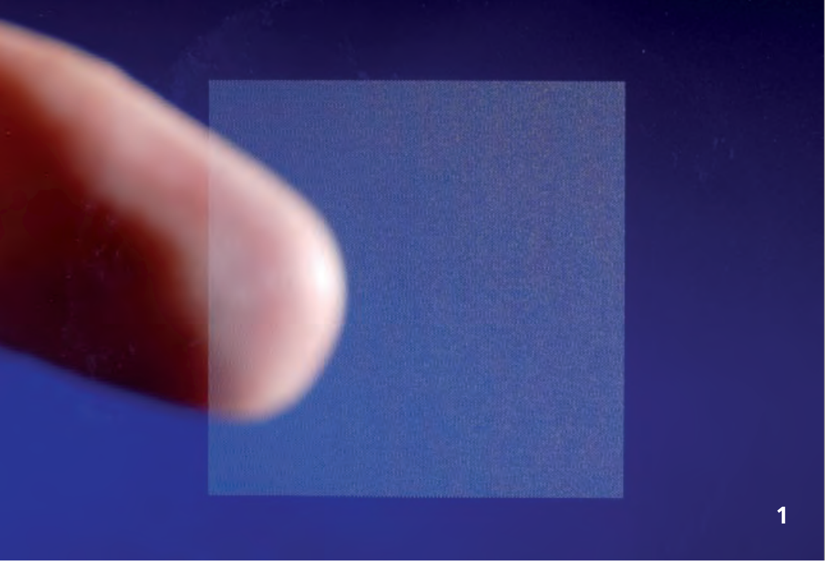
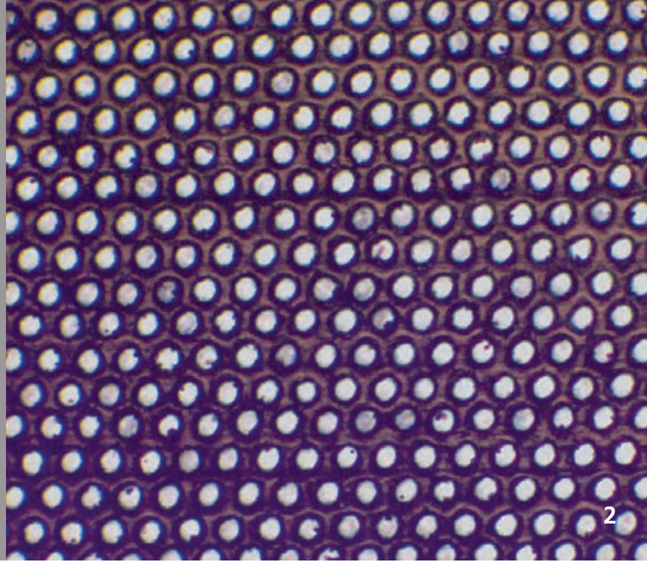
2 Silver conductive path on polymer foil (inkjet printing).

3 Tin solder pad manufactured using PipeJet printing.





PRECISION DRILLING OF THIN METALLIC AND GLASS FOILS USING PICOSECOND LASERS

Task

There is an increasing need for microscale holes in medical devices and engineering products, e.g. for ventilation or drug dosing. The diameter of these holes mostly is in the region of < 20 µm, drilled in materials with a typical thickness of 50-100 µm. Several thousand such holes can be required, at a drilling rate of > 1,000 holes per second. The layout, number and diameter of the holes vary according to the customer's requirements, hence the need for an easily adaptable system. The materials to be drilled include thin foils made out of different materials such as various metals, glass, ceramics and plastics.

Method

To achieve the necessary small hole diameters, a frequency-tripled Nd:YAG ps laser and a lens with a short focal length are used. A galvanometric scanner is used as a flexible, rapid means of positioning the laser beam.

1 Perforated thin glass. Glass thickness 50 µm, hole diameter 20 µm.

2 Perforated aluminum foil with a hole diameter of 6 µm and foil transmission coefficient of 23 percent.

Due to the ps laser the thermal stress on the foil during machining is minimized and thus damaging the materials is avoided. The arrangement of the drill holes in the scan field is transmitted to the software via a CAD/CAM link. The drilling strategy and the processing parameters are tailored to the particular materials. Depending on the material, the processes are optimized for different results, e.g. processing speed for metals, absence of cracks for glass.

Result

Using the ps laser hole diameters from 3 to 6 µm at drill rates > 1,200 holes/second were achieved in 50 µm thick aluminum. The minimum spacing between the centers of two holes is < 10 µm with a minimum bridge width of 5 µm. Therefore a maximal foil transmission (ratio of drilled surface to entire foil surface) of 23 percent was achieved. In 50 µm thick glass foils, hole matrices with hole diameters < 20 µm were achieved.

Applications

The main applications of the technique relate to microfiltration and ultrafiltration technology for mechanical water purification, the production of solar cell back contacts for photovoltaics, or in the field of lithium-ion batteries.

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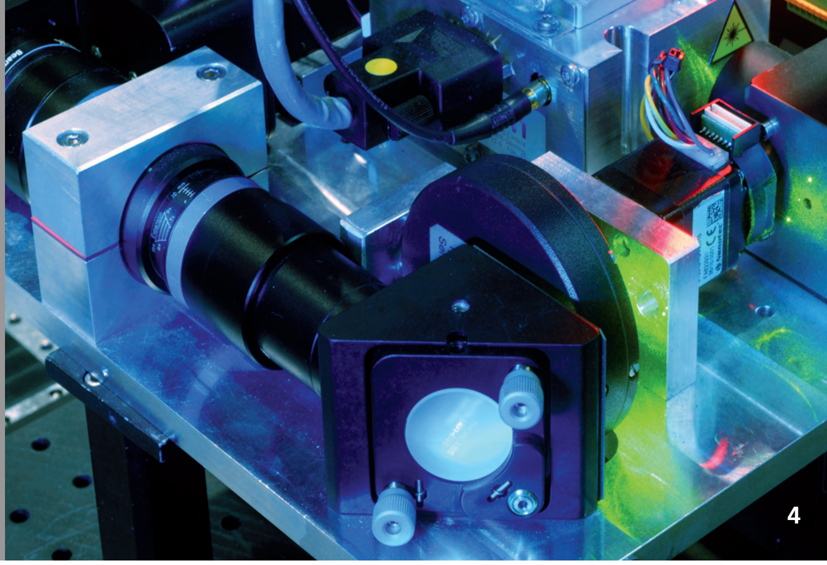

CAMERA-BASED 3D FOCUS POSITIONING FOR MICRODRILLING

Task

Laser machining of microcomponents places high demands on process sensor systems and system technology. In series manufacturing, this means not only ensuring process stability but also reliably positioning the component. When machining microcapillaries with a wall thickness in the region of 20 µm and a diameter of 200 µm, simple gripping and machining of parts is already challenging for an automated manufacturing process. Even greater demands are placed on the machine and optics if a component requires reference-free positioning relative to the beam focus with an accuracy of a few micrometers.

Method

When manufacturing holes with a diameter of less than 4 µm in plastic microcapillaries, laser focusing requires exact knowledge of the focus position relative to the workpiece. Camera-based monitoring of the microcapillaries through the processing optics makes it possible to determine the focus precisely relative to the surface. This uses the imaging quality of the structure of the workpiece surface to determine the focus position. Once the distance between the lens and the object is determined, the distance profile is recorded with a positioning drive and used to determine the component's main axis. The spatial position of the microcapillaries determined in this way is forwarded to the machine control unit to carry out the drilling process.

Result

Determining the actual distance between workpiece surface and focus position does not depend on adjustment of the positioning drives and optics. This setup therefore facilitates reference-free determination of the position of the microcapillaries, as well as precise automated positioning. Moreover, coaxial monitoring and signal analysis make the processing system tolerant to variations during clamping.

Applications

Applications involving measurement technology and processing technology relate primarily to laser material processing of microcomponents requiring flexible clamping, and to flexible components where a component's positioning cannot be guaranteed via a precise workpiece holder, as is the case with pipettes and analysis components in medical technology and analytics.

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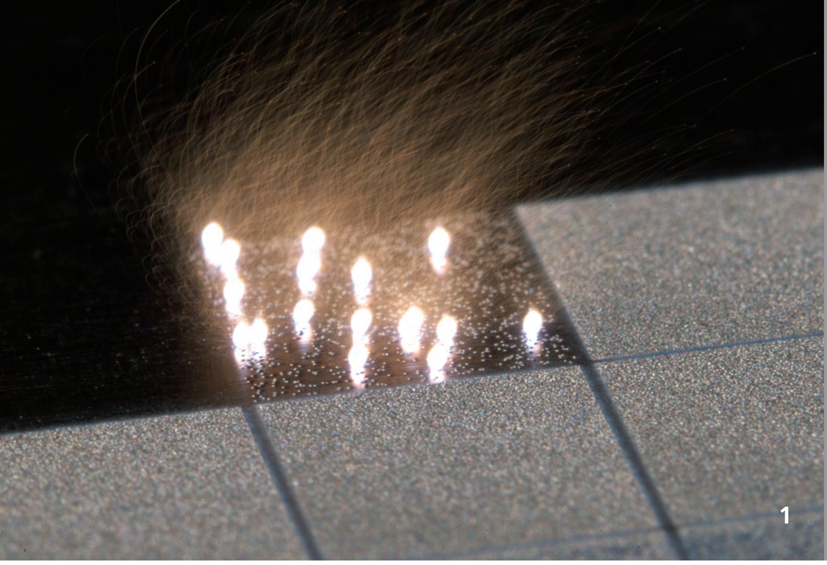
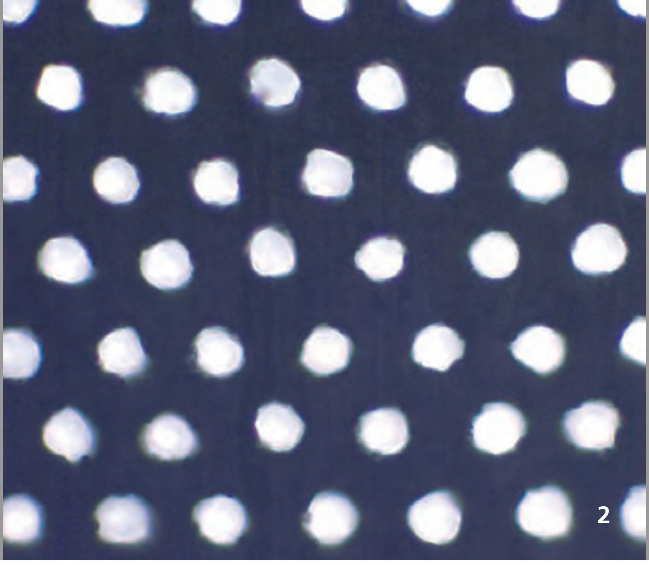
3 Polyimide microcapillary with process monitoring.

4 Optics module for the processing system with microchip laser (532 nm, 600 ps, 67 mW, 7 kHz).





PERFORATED CURRENT COLLECTOR FOILS FOR LITHIUM-ION BATTERIES

Task

Lithium-ion batteries consist of electrodes in which the anodes and cathodes are made up of active masses which are coated on a metal current collector foil. The foil serves as an electrical conductor and mechanical support, and also helps to dissipate heat from the battery. The intercalation compounds employed as the active mass have a tendency to swell or contract during charging and discharging, as a result of the inclusion or exclusion of lithium ions. The mechanical load this induces causes a reduction in battery life. The effect is particularly significant in the case of full cycling, where the changes in volume reach their maximum. The aim of this project is to introduce a hole pattern in the metal film as a means of improving the mechanical contact between the active mass and the foil, and preventing mechanical rupture of the electrical contact.

Method

A frequency-tripled Nd:YAG laser with a pulse duration in the ns region is used to manufacture a microperforated foil. The short wavelength and the use of very short focal lengths allow a focal diameter of less than 5 µm to be achieved. A galvanometric scanner is used to position the laser beam.

A software program is used to define the position of the holes and the order in which they are drilled within the scanning field. Particular attention is paid to the factors that limit the stability of the perforation process.

Result

Two main factors that influence the roundness of the holes as well as the standard deviation of the hole diameter have been determined. One factor is the pointing stability of the laser used. This influences the hole due to its elliptical fluctuation. The second factor relates to thermal effects which are influenced by the sequence of holes in the hole matrix. These effects are superposed and hence can be minimized by selecting a suitable drilling strategy.

Applications

In addition to applications in the field of lithium-ion batteries, the high-speed drilling technique also has potential uses in microfiltration and nanofiltration technology for mechanical water purification, the production of back contacts for photovoltaic cells and the filtration of liquids.

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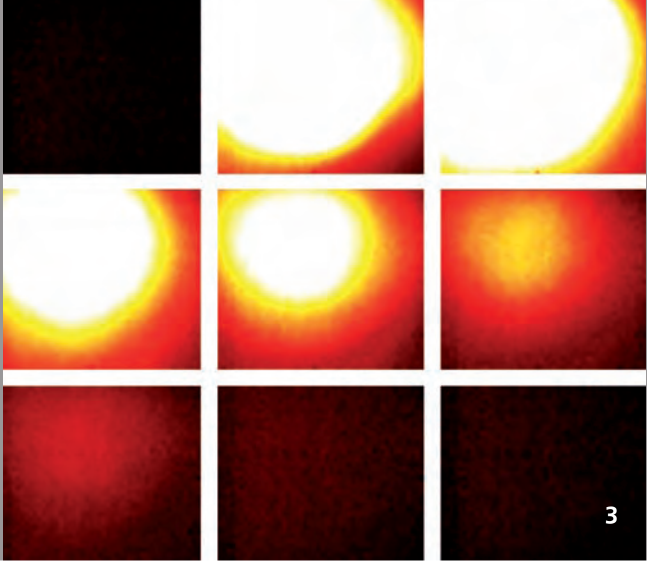
1 Light emitted by the process during perforation of a metallic film.

2 Perforated aluminum film with a hole diameter of 12 µm and a distance of 27 µm between the centers of two holes.



OPTICAL BREAKTHROUGH RECOGNITION FOR LASER PERCUSSION DRILLING

Task

Turbine blades on aircraft gas turbine engines are subject to extreme thermal loads. The hot exhaust gases from the engine combustion chamber come into direct contact with the turbine blades, with the exhaust temperatures exceeding the melt temperatures of the blade materials. Consequently, turbine blades need to be cooled by an additional air flow. This cooling air flows from the cavities in the hollow turbine blades through holes onto the blade surface to form a protective coolng film. The cooling air holes are introduced into the turbine blades using laser drilling (percussion drilling). Since turbine blades are safety-related components, each hole needs to be tested for complete breakthrough. At present, this quality check is conducted entirely manually using special testing pins. The aim is to use an automated testing process to provide reliable, automated optical detection of the breakthrough for laser percussion drilling.

Method

An existing system was upgraded with coaxial monitoring based on a high-speed camera. During ongoing series production of turbine blades, around 10,000 holes were made on this system and recorded using a camera with an image rate of 20 kHz. The images were saved along with the associated process parameters in a database, analyzed using specially developed image processing algorithms, and these results were then statistically analyzed. One particular challenge was ensuring the process was robust enough to cope with various angles of incidence of the laser beam and different drilling depths.

Result

Any process monitoring system has to seek a compromise between "false positives" (errors that go undetected) and "false negatives" (results falsely declared erroneous decisions). Due to the safety implications of the components, false positives with a rate below one per mille were specified for this application. As a result of the aforementioned monitoring process, reliability equivalent to a very low figure in the per-mille range for the false negative rate has been achieved.

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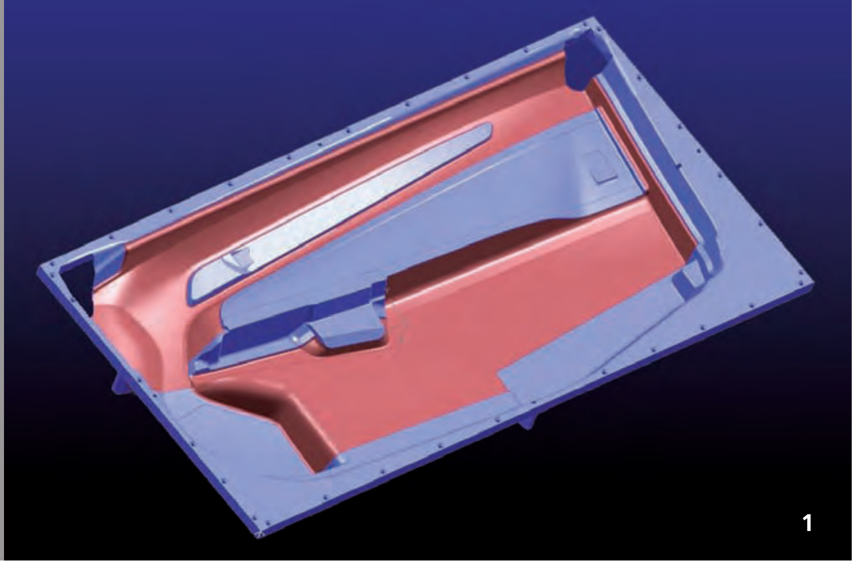
3 Process images in temporal and spatial resolution.

4 System technology for laser material processing.



AUTOMATED LASER DRILLING OF TOOL MOLDS

Task

Rotation sintering, also known as slush molding, is used to manufacture molded skins, such as cockpit or door trim for cars. At present, approx. 80 percent of molded skins are manufactured using electroforms due to the complex free-form surfaces, and surface structures such as leather graining. Depending on the level of complexity of the geometry and given the numerous process steps involved, the manufacture of these electroforms is time-consuming and expensive. The aim is to replace conventional electroforms with laser-drilled molds.

Method

The aim is to manufacture the holes using laser radiation in tool molds as part of an automated process. The system consists of a robot with a fiber-laser beam source. A CAx process chain has been developed for this purpose in which the CAD data of the tool molds are processed, drill hole fields generated, and a machine-specific NC program created. Process-specific fundamentals, such as suitable process windows and process control, have been devised to manufacture holes using fiber-laser radiation.

1 CAD model: tool mold for passenger car door trim.

Result

The use of laser-drilled tool molds offers the following advantages over electroforms:

- New, e.g. sharp-edged tool mold geometries
- New surface structures
- Shorter market response time and time to market
- Lower costs per tool mold by reducing the required manufacturing steps by approx. 50 percent

Applications

The advantages of the new laser-drilled tool molds may result in the substitution of conventional electroforms, allowing old markets to be re-entered or additional markets created and targeted through new molds or lower costs.

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TECHNOLOGY FOCUS
MEDICAL TECHNOLOGY AND BIOPHOTONICS

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

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

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

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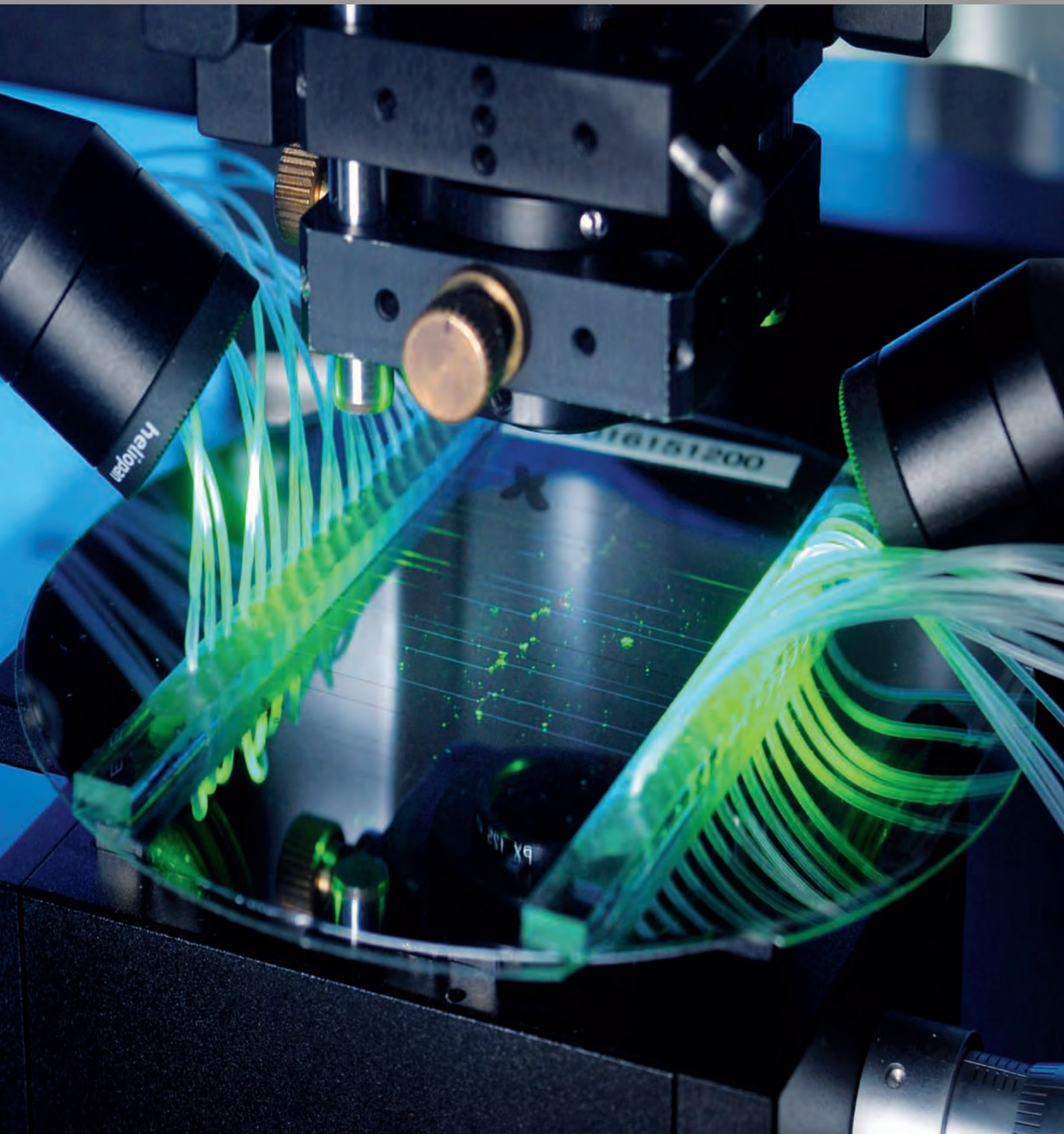
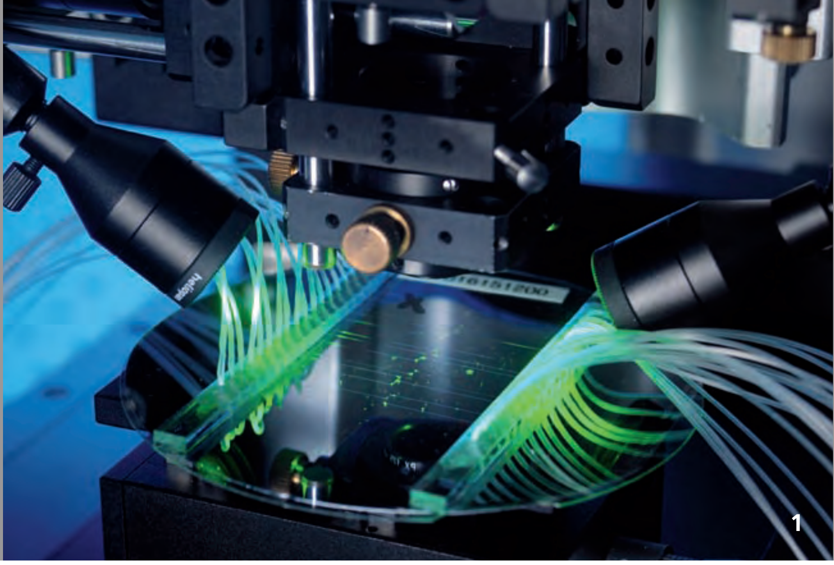
MEDICAL TECHNOLOGY AND BIOPHOTONICS



CONTENTS

High-speed sepsis diagnostics
in the microfluidic sorter.



HIGH-SPEED SEPSIS DIAGNOSTICS IN THE MICROFLUIDIC SORTER

Task

The rapid diagnosis of pathogens involved in bacterial diseases and the effectiveness of antibiotics is often the determining factor in patient survival within the clinical environment.
In Germany, 150,000 people suffer from sepsis every year, resulting in some 60,000 deaths. What makes the disease fatal is usually a failure to identify effective antibiotics early enough. This situation is unlikely to improve as multiresistant pathogens become more widespread. It should be possible to cut diagnosis times significantly by using fluorescence sensors and microfluidics technology.

Method

The process is based on marking the pathogens using fluorescent dye antibody conjugates. Sensitive fluorescence sensors enable individual pathogens to be detected in a solution and separated from other pathogens in a microfluidic device. The challenge lies in the huge variety of pathogens. That requires a multistage sorting process and simultaneous identification of the pathogens at different locations. However, sensors must still meet the requirements for detection sensitivity and robustness even after miniaturization and when operated in parallel.

Result

A fluorescence sensor was set up on a laboratory scale which reliably detects fluorescence-marked beads with volume flows up to dV/dt = 30 µl/min using beam forming tailored to the fluidic channel. A signal-to-noise ratio of SNR = 30 dB was achieved.

Applications

Apart from clinical applications, where earlier identification of bacterial pathogens increases survival probability and lowers the cost of intensive care provision, this process is ideally suited to the food industry. The rapid identification of contaminated ingredients and products enables processing and distribution to be halted promptly, thus reducing follow-up costs.

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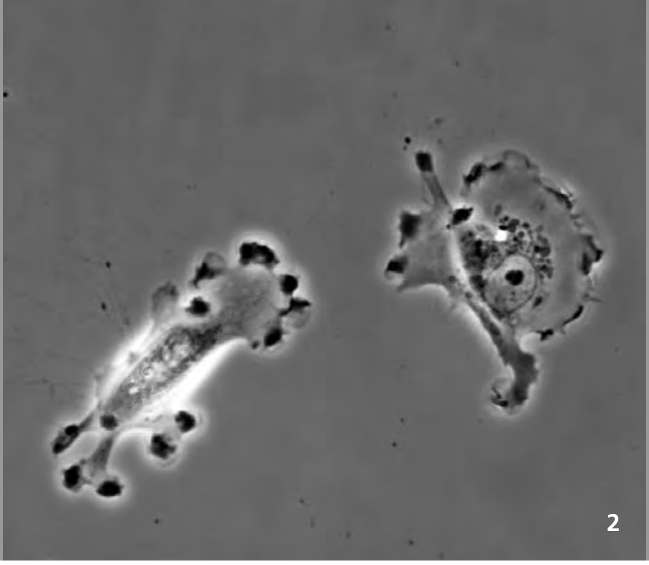
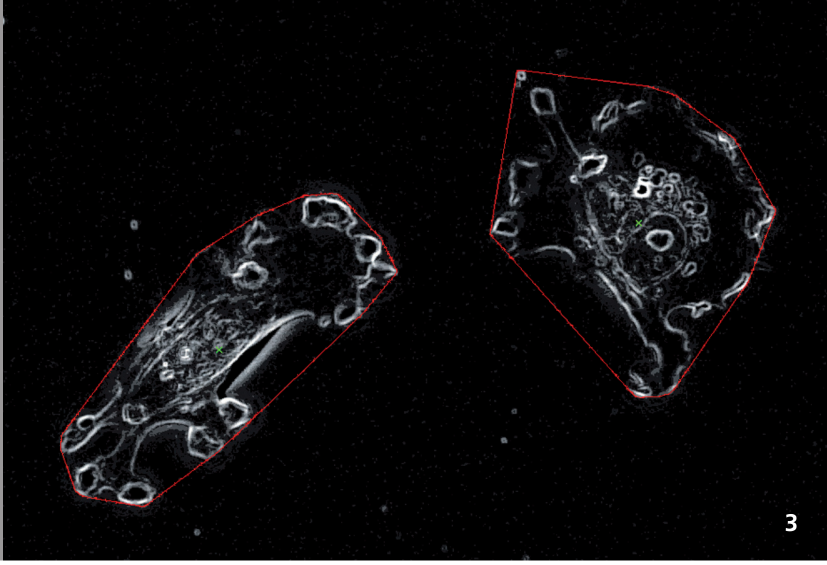
1 Fluidic sorting structure in the fluorescence sensor.





AUTOMATED MEASUREMENT OF STEM CELL MORPHOLOGIES

Task

The use of stem cells is becoming increasingly important in medicine. Researchers are looking for ways of generating skin cells, hematopoietic cells and, in future, entire organs from stem cells. As part of a cooperation project between the Max Planck Society and the Fraunhofer-Gesellschaft, research is being done into the necessary conditions for differentiating hematopoietic stem cells on the basis of multilayer three-dimensional stem cell systems. In addition to precise cell positioning, Fraunhofer ILT's remit also includes the automated analysis of cell ensembles.

Method

The morphology of the stem cells is determined by means of layered 2D scans of high-resolution microscope images of cell cultures. The cell contours of each layer are determined using analytical image processing techniques. The cell contours of the individual layers are combined in a subsequent step to create a three-dimensional cell morphology. One particular challenge lies in differentiating spatially between two adjacent cells. Based on the chronological sequence of the cell morphology, it should, however, be possible to make the difficult distinction between individual cells and cell groups.

Result

Strategies for detecting cell contours in an individual layer are already being tested on microscope images of individual cells. After suitable preprocessing (contrast image), pixels with similar intensity are clustered together. The outline and center of gravity of a cluster characterize the cell expansion in the layer, thus providing the cell contour line of a layer, see Fig. 3.

Applications

Applications for these developments include targeted in-vitro production of stem cell niches together with their environment and associated automated analysis. The insights gained help explain the processes that play within the stem cell niches and thus promote the use of in-vitro stem cell niches in developing drugs over the long term.

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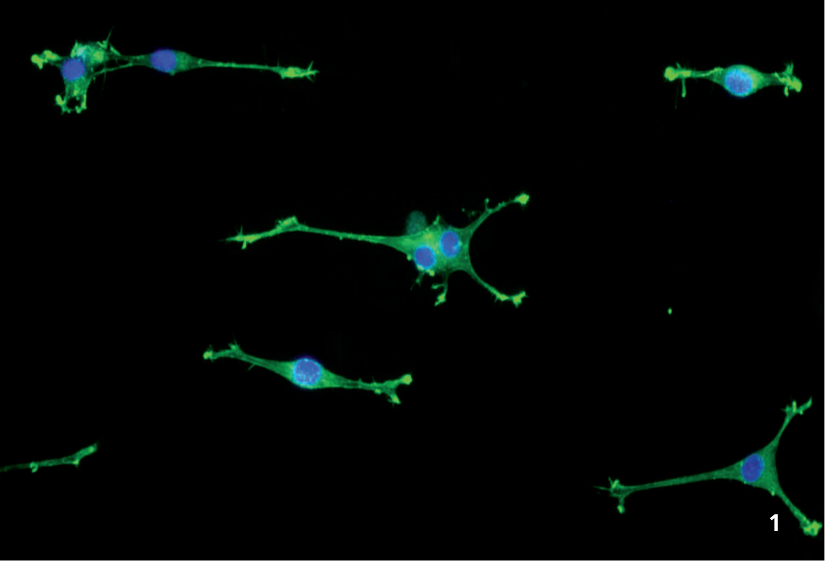
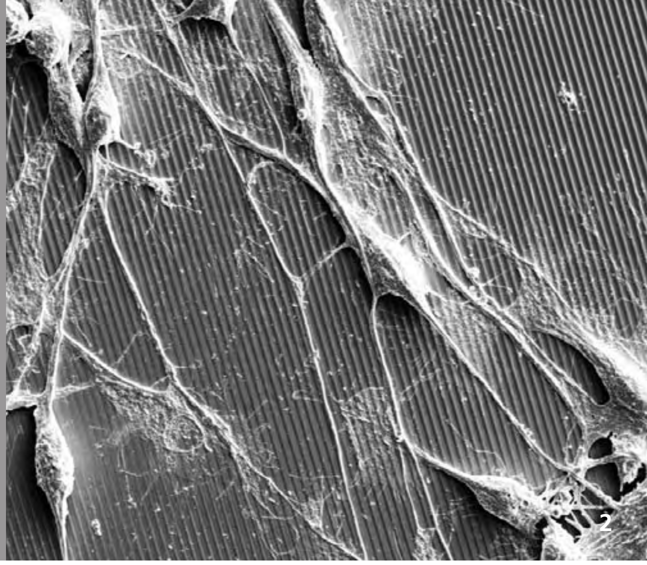
2 Microscope image of two cells, taken at the Max Planck Institute for Molecular Biomedicine.

3 Contour identification based on the contrast image.





TOPOGRAPHICAL AND CHEMICAL NANOSTRUCTURES FOR CELL GUIDANCE SUBSTRATES

Task

Cell growth and alignment are influenced by the external conditions of the respective substrate. Surface topography and chemical composition are often decisive in terms of how cells react to artificial materials such as implants or in-vitro cell assays. Nanostructures and nanofunctionalities play a major role in this respect, since the natural environment of the cells is determined by structures at this scale. The targeted manufacture of nanostructures measuring 90 nm to 1000 nm in biocompatible polymers combined with nanoscale photochemical modification aims to determine the influence of these kinds of surfaces on cells, and thus draw conclusions about how to optimize implant surfaces.

Method

Interference structuring is based on the generation of sinusoidal intensity profiles by overlaying two laser beams; this setup enables structures in the nanometer range to be produced. Refinements of this technology enable various widths and depths of grooves and ridges as well as combinations of the two to be produced in biocompatible polymers. Chemical nanostructuring involves the use of photoactivatable compounds, such as azides, which only bond with the polymer in irradiated areas above a threshold energy. These azides have a second functionality which facilitates the binding of proteins or other biomolecules.

1 Alignment of neuronal cells (B 35) with nanopattern, DAPI/phalloidin double staining.

2 Neuronal cells (B 35) line up along the 1 µm wide, 650 nm deep grooves.

Result

The basic feasibility of the approach to photochemical nanomodification was demonstrated on the basis of XPS and fluorescence spectrometry data. Cell culture studies with neuronal cells on generated nanostructures exhibit oriented outgrowth and axonal alignment along the grooves, especially if these grooves are of a certain depth, i.e. an aspect ratio greater than 0.6. Further systematic studies on various materials, using different cells and combinations of topographical and chemical effects, are the subject of ongoing research work.

Applications

The results of these studies are being used in tissue engineering in order to facilitate better ingrowth of implants. These kinds of topographical and chemical nanostructures can help to influence cells in a targeted way, particularly when it comes to culturing of different cell types. This approach will allow guidance structures to be manufactured according to biomimetic criteria. The work is being funded as part of the DFG priority program SPP 1327.

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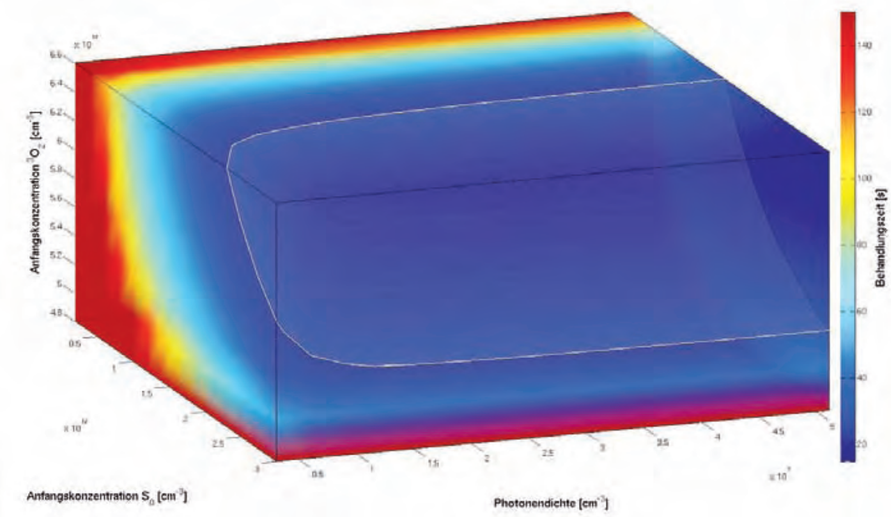

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ANALYSIS OF THE ANTI-MICROBIAL PHOTODYNAMIC THERAPY PROCESS

Task

Antimicrobial Photodynamic Therapy (aPDT) is a process used in periodontal treatment to kill bacteria. However, the discrepancy between successful in-vitro studies and the limited success of clinical studies necessitates an in-depth investigation of the processes at play in aPDT.

Method

The key variables can be identified by analyzing the chemical reactions and physical interactions between the substances involved in the process. The opto-chemical processes are analyzed using a system of six coupled standard differential equations. The solution behavior of the equation system is being investigated in order to find parameter ranges for which the solution is not sensitive to variations in the patient-dependent parameters. An additional criterion in ensuring treatment is successful is to have a small concentration of bacteria after a treatment period that is as short as possible.

Result

Analysis of the equation system revealed a threshold in the parameter space which, if exceeded, results in a superlinear increase in treatment success. This insight paves the way for developing a relationship between suitable measurement signals and successful treatment; further research is currently being done in this area. The analysis provides information about a favorable selection of treatment parameters that ensure the treatment outcome is not affected by parameter variations.

Applications

The research work outlined above lays the groundwork for meeting the long-term aim of treatment that is increasingly model-based. In addition to periodontal treatment, other compelling applications include tumor therapy and water sterilization.

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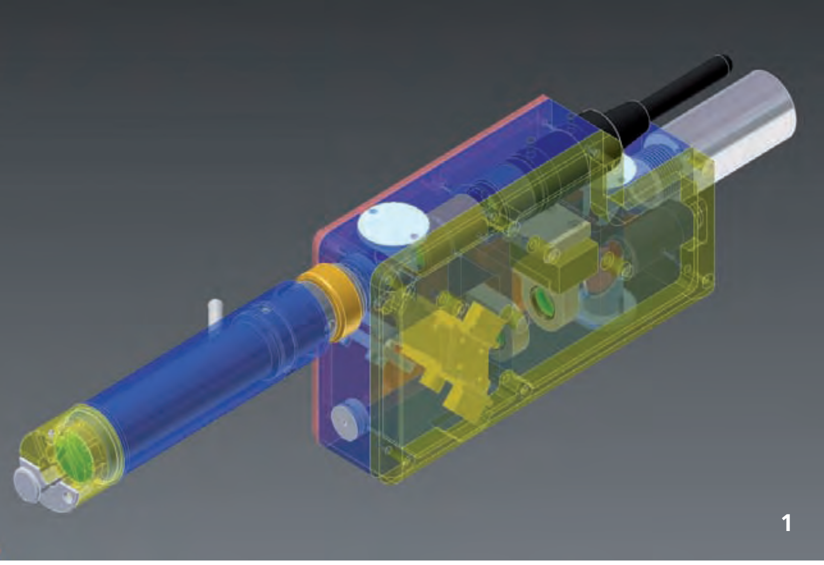
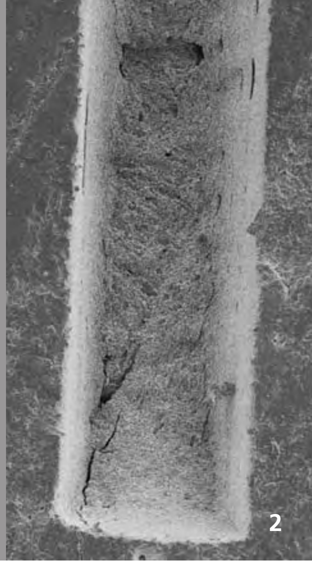
3 Treatment time in the parameter space.





MICROSURGERY LASER SCALPEL WITH REAL-TIME ASSISTANCE SYSTEM

Task

In order to conduct microsurgery on the brain, the overlying bone tissue first needs to be removed. Short pulse lasers provide a better solution for cutting open the cranium than state-of-the-art techniques because, unlike mechanical trepanning, laser radiation does not require any contact pressure. This technique minimizes the risk of injury to the meninges. Laser cuts can also be made in hard tissue without chips with a cut width of just 0.5 mm; this improves the cosmetic result when the bone tissue is reinserted.

Method

The high-intensity picosecond laser beam is integrated into a handpiece that the surgeon uses to follow the marked cut lines. The surgeon retains control of the process. The integrated microscanner technology ensures exact three-dimensional positioning of the laser focus in the kerf. A 3D measurement system can be used to monitor the residual thickness of the kerf and the depth profile in real time. A 2D imaging system automatically analyzes the cutting process and can compensate for deviations caused for instance by slight trembling movements of the surgeon's hand. An integrated rinse and suction system removes the ablated tissue fragments and blood from the operation area. A height-adjustable dura separator is used to separate the meninges from the cranium. All the components that come into direct contact with the patient can be sterilized.

Result

A demonstrator for preclinical studies is being set up as part of Fraunhofer's MILOS cooperative project. Laboratory experiments designed to evaluate the cutting process have achieved ablation rates of 8 mm^3/min on hard tissue without thermal damage and with cut depths of up to 3.5 mm.

Applications

The handpiece can be used in hard and soft tissue surgery wherever a manual cutting process with high cutting accuracy is required, such as in spinal and maxillofacial surgery.

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1 Laser scalpel with microoptics.

2 Laser cut in hard tissue.

3 High-power picosecond laser.

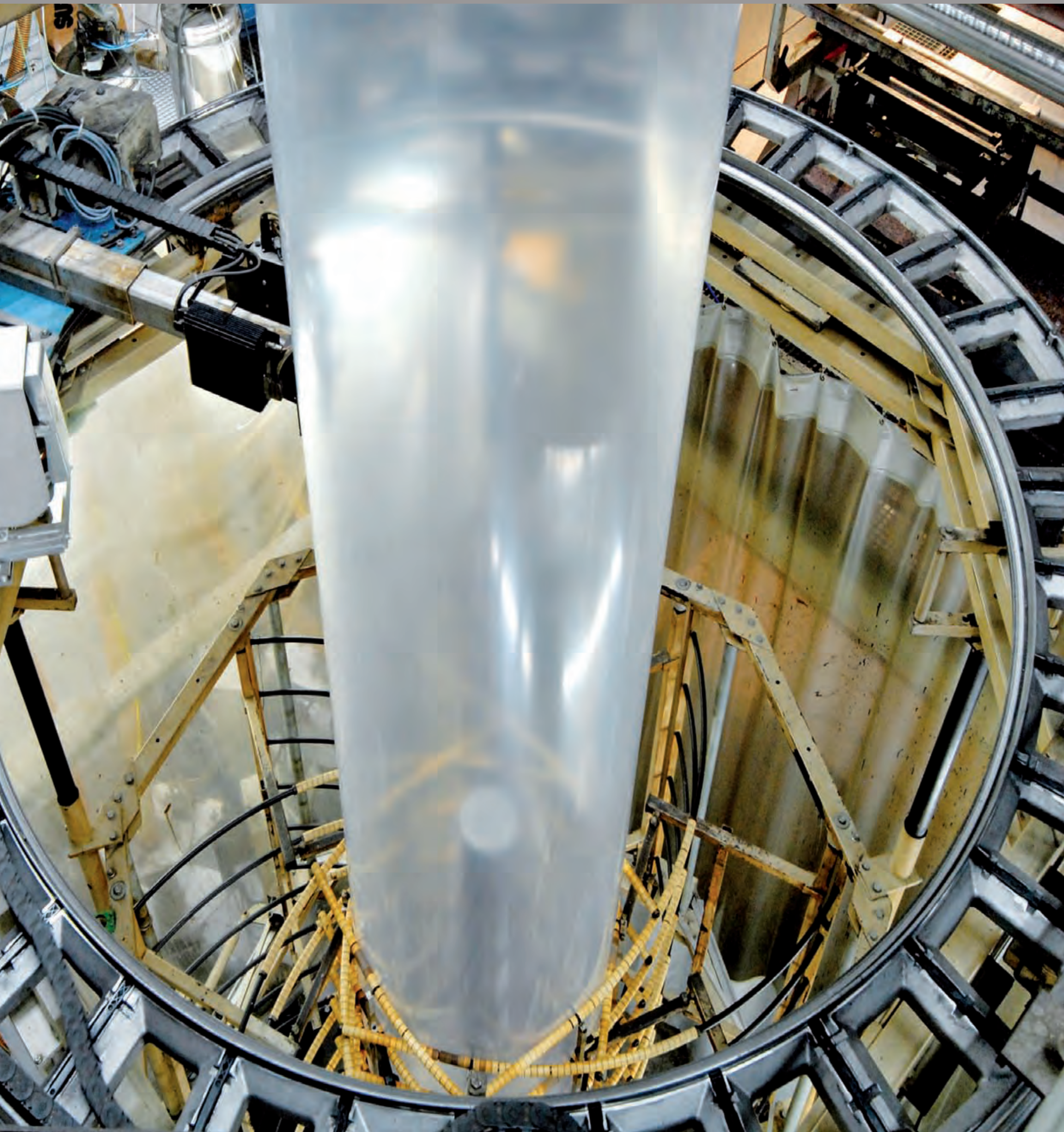
TECHNOLOGY FOCUS
LASER MEASUREMENT TECHNOLOGY AND EUV TECHNOLOGY

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

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

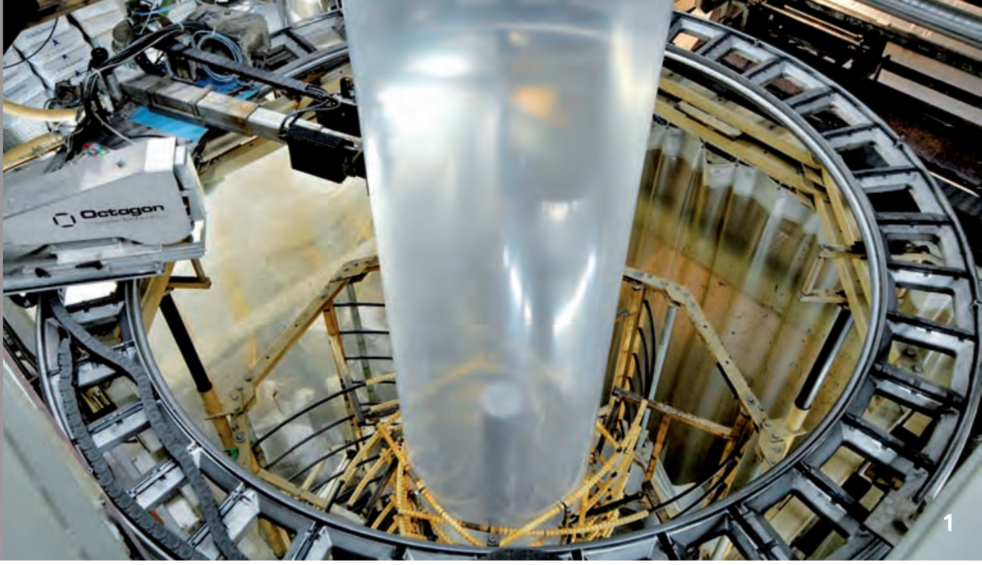
In EUV technology, Fraunhofer’s experts develop beam sources for lithography, microscopy, nanostructuring or x-ray micro-scopy. Optical systems for applications in EUV engineering are calculated, constructed and manufactured as well.

LASER MEASUREMENT TECHNOLOGY AND EUV TECHNOLOGY



CONTENTS

Optical sensor for the measurement of individual layer thicknesses on a blown film line.



INLINE MEASUREMENT OF INDIVIDUAL LAYER THICK-NESSES OF PLASTIC FILMS

Task

Plastic films, in particular those used for food packaging, consist of multiple individual layers, each of which fulfils a specific function. For example, some layers provide mechanical strength, while others act as diffusion barriers to keep the packaged products fresh for a prolonged period of time. The goal of minimizing the consumption of raw materials requires a reliable inline quality control system which is designed to manage the process and keep waste to a minimum. Measuring systems used to determine total film thickness for quality control and process control purposes are already state of the art in the manufacture of plastic films. However, no film inspection systems are currently available that are capable of performing inline measurements of the different layers of multilayer films.

Method

The optical sensor developed by Fraunhofer ILT uses the measuring beam light that is backscattered at the boundaries of individual film layers to measure the separate layer thicknesses of a composite film. The scientists first performed a series of laboratory tests to confirm the basic suitability of the measurement process for measuring individual layer thicknesses. In the second stage of the development process, an optical sensor was integrated in a customer's blown film line, where it is being tested under industrial conditions in a long-term test.

1 Optical sensor for the measurement of individual layer thicknesses on a blown film line.

Result

Within a measurement range of 4.5 mm, inline measurements are obtained of the individual layers with thicknesses of at least 10 µm. During the measurement process, the optical sensor traverses the film sleeve in order to measure the individual layer thicknesses across the full dimension of the film. An analytical software tool continuously evaluates the raw data, identifies the layer boundaries and presents the measured individual layer thicknesses on a monitor to enable the film manufacturer to systematically check the operation of the blown film line.

Applications

Inline measurement of individual layer thicknesses enables film manufacturers to make rapid adjustments to the manufacturing process if the product deviates from the target values for individual layer thicknesses. This makes it possible to produce the individual layer thicknesses with a narrower tolerance range, resulting in reduced material consumption and cost savings.

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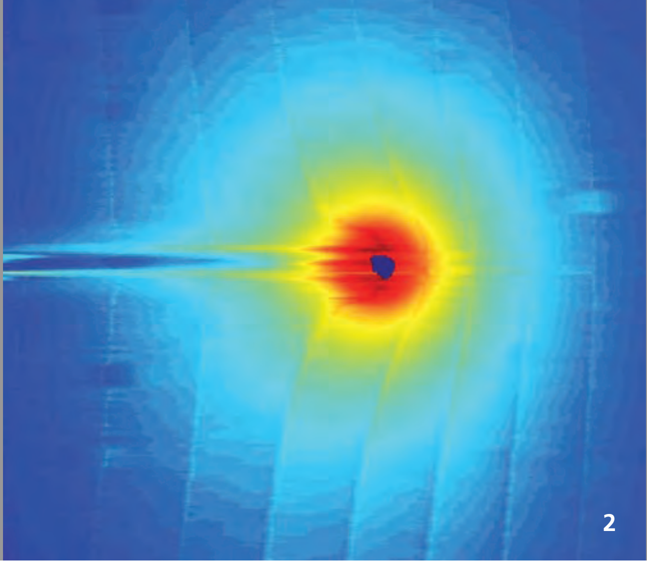

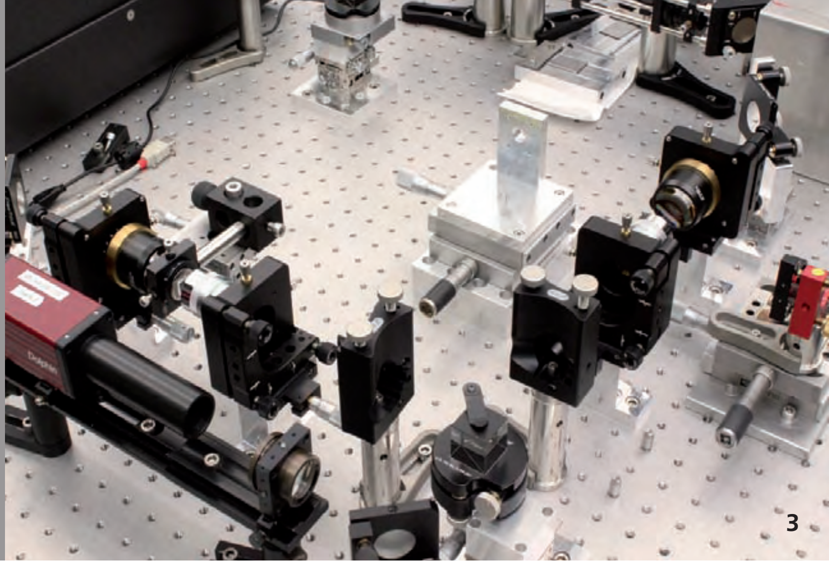

INTERFERENCE MICROSCOPY FOR PROCESS ANALYSIS

Task

By focusing femtosecond laser light in the volume of transparent materials, it is possible to achieve a modification of the material limited to less than 10 µm³. The modification consists of a change in the refractive index without cracking and an increase in wet-chemical etchability. These induced effects can be employed for the fabrication of integrated optical and microfluidic components and the welding of glass. Developing a process model designed to enable process optimization and monitoring requires a means of measuring local temperature distribution.

Method

Transmitted-light interference microscopy achieves the space-resolved in-situ determination of temperature distribution by measuring the heat-induced change in refractive index in the material.

Using a Mach-Zehnder interferometer with an integrated microscope, the laser-induced change in optical path length is determined from the deflection of the interference fringes. Knowledge of the temperature dependence of the refractive index makes it possible to determine the temperature in the material.

Result

The transmitted-light interference microscope developed at Fraunhofer ILT is the first device to enable the determination of temperature during in-volume structuring of transparent materials using a focused femtosecond laser beam at process temperatures between 2000 and 5000 K.

Applications

In addition to process analysis for in-volume structuring of transparent materials, transmitted-light interference microscopy also provides a method for the in-situ analysis of process gas streams in laser material processing.

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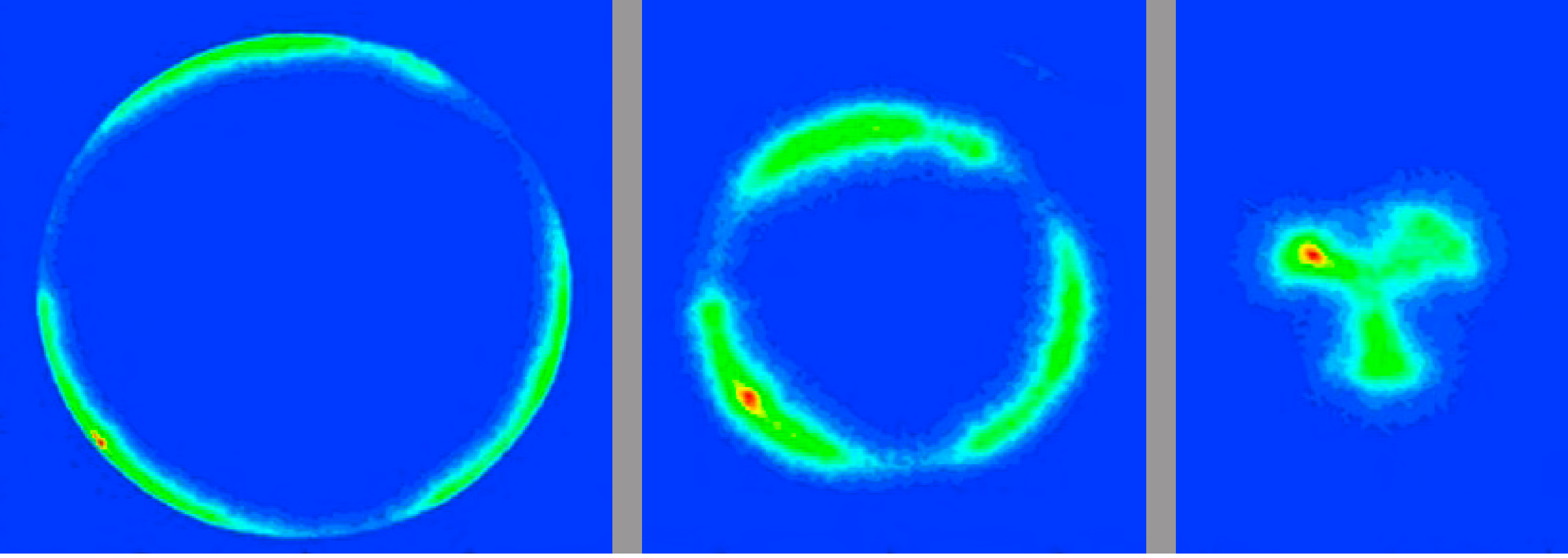
2 Phase map calculated from interferometric data during in-volume modification of Borofloat 33.

3 Interferometer.



MEASUREMENT OF PARTICLE DENSITY DISTRIBUTION OF POWDER NOZZLES

Task

The powder flow to the melt pool is a crucial element in laser material deposition. This factor is significant in determining the powder mass flow efficiency, the extent to which oxidation occurs through reaction with the surrounding atmosphere, and the roughness of the coating layer. Hence the need to characterize the powder gas stream to ensure process quality. No process is currently available that supports 3D measurement of the powder gas stream.

Method

In considering a powder gas stream, the important variables that need to be monitored include the constancy of the powder mass flow, the symmetry of the powder gas stream, and the position and size of the powder focus. In order to measure the requisite variables, the powder gas stream is illuminated from the side using a laser line and monitored by a coaxially aligned camera through the powder nozzle. A high image rate allows the number and position of individual powder particles to be recorded. Individual layers are imaged by means of a gradual process along the powder gas stream. Relevant algorithms can be used to calculate the particle density distribution from these images. The spatial particle density distribution of the powder gas stream can be calculated by superimposing the individual layers.

Particle density distribution at various levels within a powder gas stream.

Result

The measurement principle was successfully tested on various powder nozzles. A test bench for automatic powder gas stream measurement has been set up to document the calibration of individual powder nozzles and their particle density distribution. The measurement process makes it possible for the first time to fully characterize a powder gas stream.

Applications

Applications include all activities in the field of laser material deposition which call for a precise understanding of the powder gas stream. These insights can be used for process development, nozzle development and the production of components with exacting quality requirements. The process can also be used for applications that involve measurement of the spatial particle density distribution or the particle rate. It is irrelevant in this respect whether the particles are in a solid or liquid state.

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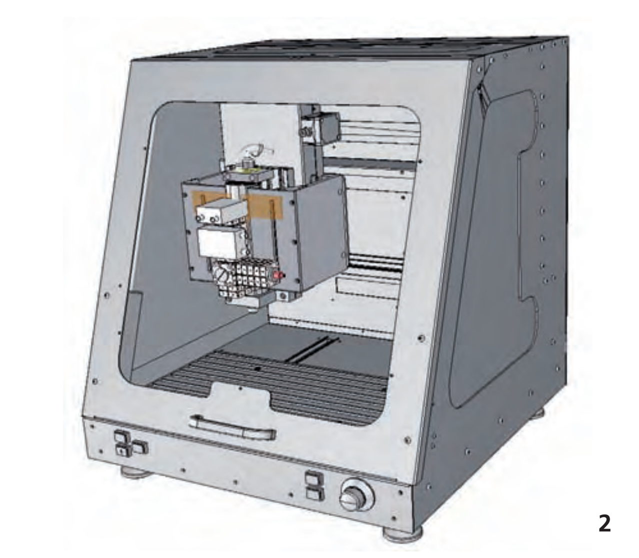

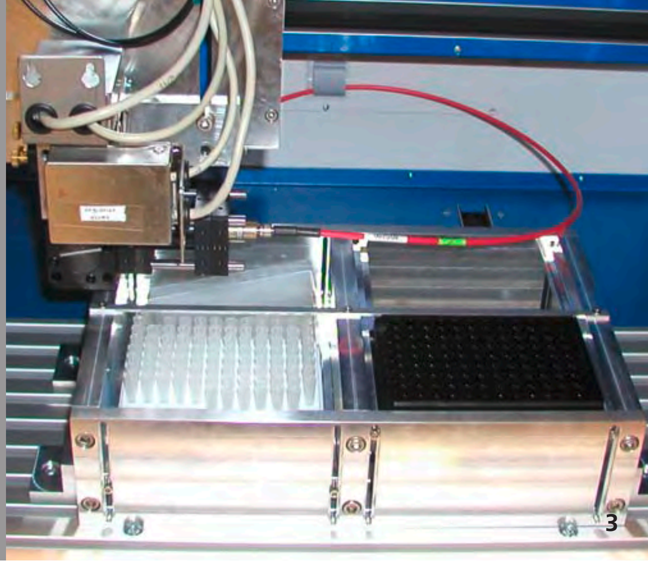

TOXIN ANALYSIS BY FLUO-RESCENCE POLARIZATION

Task

Cereal products must be monitored continuously during storage and processing due to the risk of contamination with mycotoxins. Fluorescence polarization is a highly specific and sensitive method of antibody-based analysis which can be used to detect a range of toxins. Researchers at Fraunhofer ILT are working with industry and research partners to further develop and enhance this method of multitoxin analysis.

Method

The aim of the project is to develop a demonstrator for quantitative, highly sensitive mycotoxin analysis that can be used in mills and silo storage facilities as well as in a laboratory setting. The intention is to conduct the analysis in microtiter plates and to extensively automate the sample preparation and measurement processes in order to exclude the possibility of incorrect operation by inadequately trained personnel.

Result

Working together with project partners from industry and the research community, experts at Fraunhofer ILT built a demonstrator for automated multitoxin analysis. The demonstrator included a facility to automatically prepare samples and automatically measure the fluorescence polarization. Biochemical assay components and an extract obtained from the cereal product were dispensed into a microtiter plate, with a software-controlled pipette ensuring high-precision dosing of the quantities required for analysis. The optical measurement process was then performed.

Applications

The primary area of application is food analysis, in particular mycotoxin analysis of cereal products. Other related areas of application include oil-containing seeds and nuts (pistachios, almonds, peanuts, Brazil nuts, etc.) in which mycotoxins also occur with similar frequency. In principle, the demonstrator developed by the project partners is capable of detecting any analyte for which a specific binding antibody is available.

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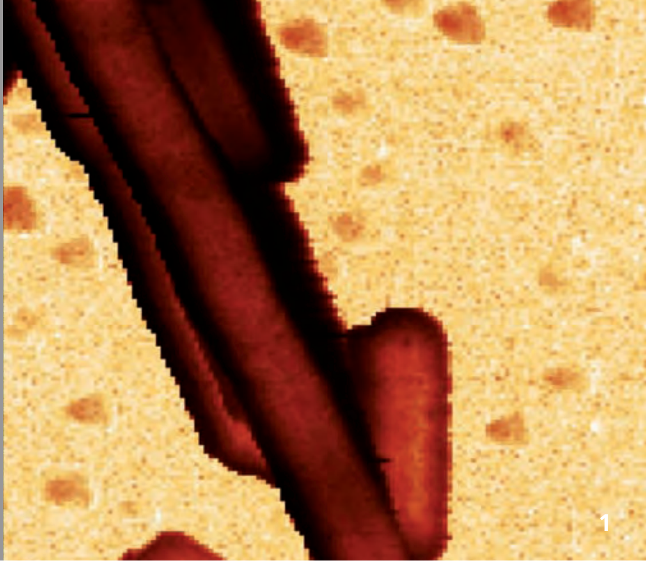
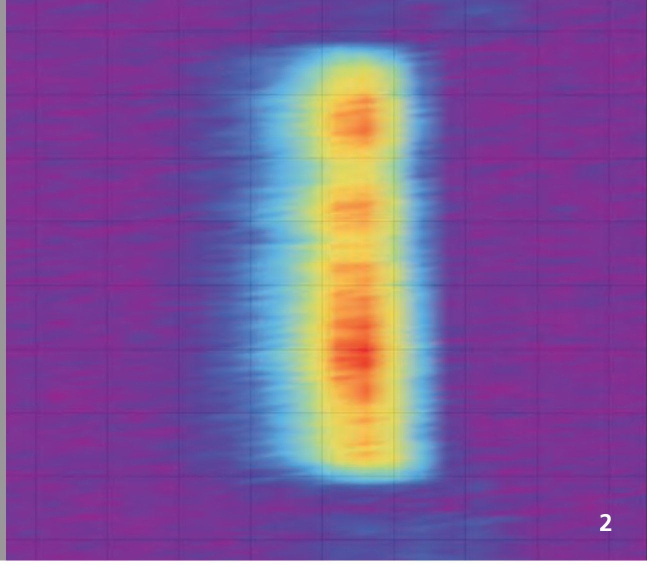
2 Design drawing of the demonstrator for mycotoxin analysis.

3 Detailed view of the analysis unit positioned above a microtiter plate.





NEAR-FIELD MICROSCOPY: INFRARED SPECTROSCOPY WITH SUB-MICROMETER SPATIAL RESOLUTION

Task

Nanostructures and nanocomposite materials are increasingly being used as a means of improving material properties. Characterization of these materials requires imaging techniques with high spatial resolution. Near-field microscopy offers the ability to record infrared spectra with a spatial resolution of a few 10 nm. Measurements in the fingerprint region (mid-infrared) make it possible to chemically characterize different sample systems and distinguish between crystal structures. Examples include the study of strain and nano-cracks in crystals.

Method

Acquisition of high spatial resolution spectra is performed using a scattering-type scanning near-field optical microscope (s-SNOM). This can be used both with narrow bandwidth lasers with fixed wavelengths and with broadband lasers. The technique is non-destructive. A CO_2 laser tunable between 9.2 µm and 10.8 µm is available for sequential spectroscopy and is used in particular for acquiring overview images at a fixed wavelength. Researchers at Fraunhofer ILT have developed a broadband tunable laser system for broadband near-field microscopy which covers the spectral region from around 8.9 µm to 13.8 µm. This broadband laser offers the ability to record spectra with a spatial resolution of up to 20 nm. Furthermore, the greater wavelength range makes it possible to determine the properties of additional materials.

Result

The broadband near-field microscope was used to perform preliminary studies of polar crystals. The spectra clearly show the characteristic bands of the material. The individual regions of the specimen can be clearly distinguished.

Applications

Potential applications of broadband near-field microscopy include the characterization of nanocomposite materials such as textile fibers and semiconductor structures, as well as semiconductor doping. It also has potential to be used for the detection of nanoscopic inclusions.

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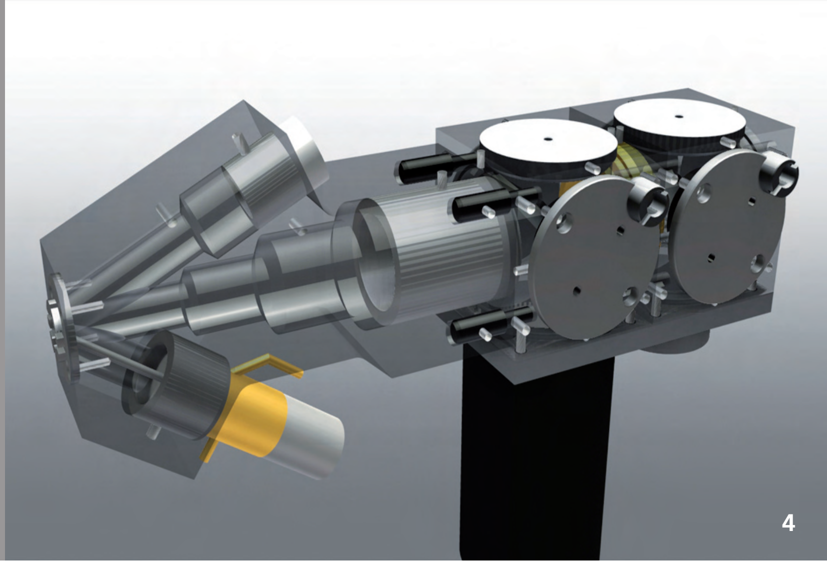
1 SNOM imaging of a silicate structure.

2 Line scan of a gold/silicon carbide/gold structure.


3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MOBILE MICROWAVE-ASSISTED LASER-INDUCED BREAKDOWN SPECTROSCOPY

Task

Metals recycling is taking on increasing importance as metal and energy resources become scarcer. Incoming and outgoing goods inspections are an essential part of achieving the high levels of quality and purity that are required in this industry. However, current mobile systems are unable to deal with all elements and sample types, and these inspections require elaborate sample preparation. Analysis systems based on laser-induced breakdown spectroscopy (LIBS) which deliver adequate levels of accuracy are currently still too large and heavy for mobile use. The aim of this project is to use a combination of laser and microwave excitation to reduce beam power while increasing analytical performance in order to create a mobile analyzer for aluminum and high-alloy steel samples.

Method

In a compact sensing head, the laser-induced plasma of a fiber laser is spatially superimposed with a microwave-excited argon plasma. This argon plasma is generated by a hollow cathode. This system can be made lighter and more compact than conventional systems of microwave excitation. The superposition boosts the plasma, leading to increases in both the duration and intensity of the spectral line emission.

Result

Researchers built an initial prototype of the hand-held analyzer and investigated its suitability for the task. Preliminary tests were carried out to characterize the geometrical parameters. The researchers tested two methods of microwave generation and compared the system's analytical performance with conventional methods that are already on the market. In comparison to laser excitation alone, the results showed an increase in line intensity and a longer emission duration.

Applications

The method can be used to carry out chemical analysis of metallic objects. The small interaction area and the hand-held nature of the analyzer make it possible to analyze virtually any parts, including large, composite objects. This makes the method a good choice for characterizing components of decommissioned aircraft and large-scale installations, for example.

The R&D activities are BMBF-funded in the framework of the cooperative project »Wave«.

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3 Secondary aluminum ready to be sorted.

4 3D CAD model of the hand-held sensing head, (Source: LSA GmbH).

COMPACT SOURCE OF EXTREME ULTRAVIOLET RADIATION

Task

Novel discharge-based radiation sources offer a compact and cost-effective solution for future applications with extreme ultraviolet radiation (EUV). They open up a wide range of innovative applications in materials analysis, metrology, life sciences and microscopy. Certain fields, notably next-generation chip fabrication, require sources for metrology which emit at a design wavelength of 13.5 nanometers. For example, mask inspection requires high brilliance EUV sources emitting in the region of 30 W/(mm² sr) in a spectral bandwidth of 2 percent around the central wavelength. No sources of this type are currently commercially available.

Method

Based on the technology for a discharge source previously developed in collaboration with Philips EUV, researchers constructed a new radiation source which features a number of improvements, particularly in regard to the source brilliance that can be achieved. The principle is based on a discharge of electrically stored energy in which xenon is heated and compressed with a high pulsed current to such an extent that it emits characteristic radiation at 13.5 nanometers.

Result

In an initial series of experiments, the researchers were able to achieve a brilliance of 20 W/(mm² sr) in a bandwidth of 2 percent with a central wavelength of 13.5 nm. This represents a level of brilliance that is higher than commercially available sources by more than a factor of two. Subsequent experiments have confirmed the potential to achieve in excess of 50 W/(mm² sr) using this technology.

Applications

In addition to metrology applications in the field of extreme ultraviolet lithography, other fields of application include:

- Soft X-ray microscopy
- Mask inspection for EUV lithography
- Technology development in the EUVL sphere, e.g. resist development, characterization of optics
- EUV-based metrology for the nanosciences

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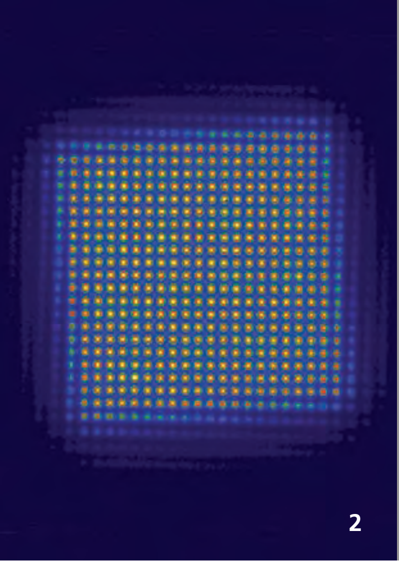
1 Radiation source for extreme ultraviolet light.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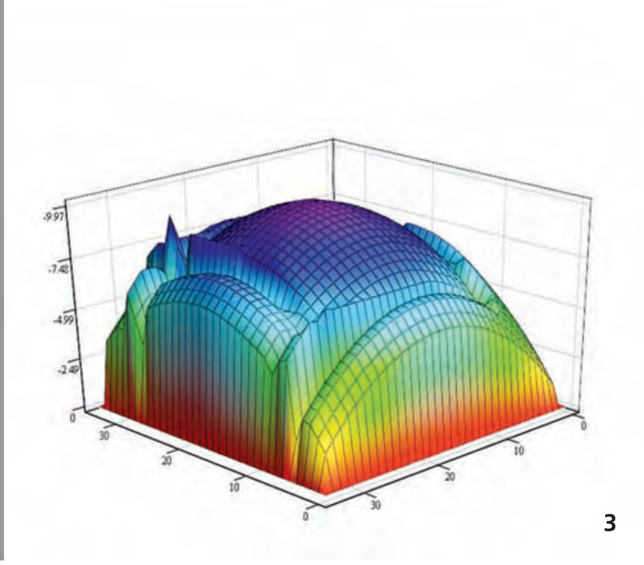

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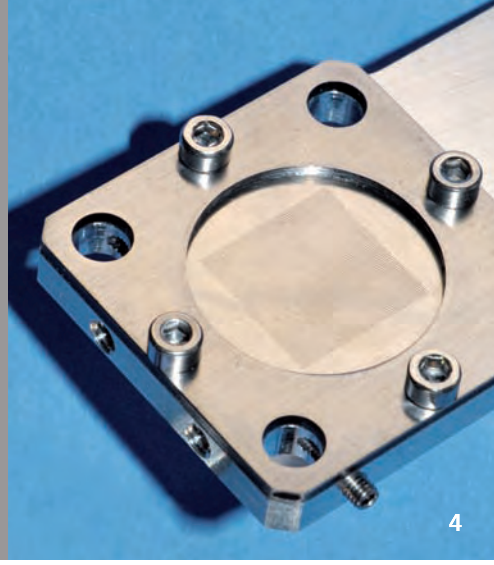
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EUV HARTMANN WAVEFRONT SENSOR

Task

Measurement of wavefront profiles in the short wavelength spectral region offers a unique opportunity to simultaneously record the amplitude and phase distribution of an incident or reflected wavefront. This opens up a broad range of applications, such as the characterization of radiation sources in the short wavelength spectral region, and quality control measures to determine the flatness of masks and mirrors based on multilayer systems. The aim of this project was to provide a comparison of the wavefronts of laser-produced plasma (LPP) sources and discharge-produced plasma (DPP) sources.

Method

Unlike interferometric methods, a Hartmann Wavefront Sensor (HWS) does not require coherent radiation. In addition, no scanning optics are required for an HWS and it is simpler and cheaper to build – yet it still achieves high sensitivity and resolution.

Using a special aperture array, an HWS divides the incident radiation into a defined number of beams which are then imaged on the detector. When an unknown wavefront impinges on the aperture array, the positions of the images of the apertures change on the detector depending on the phase front of the incident unknown wavefront. The phase front can be determined from the displacement of the spots of light on the detector.

Result

The HWS technique employs a charge-coupled-device camera and an array that consists of 65 x 65 apertures (diameter 80 µm, spacing 225 µm). In measuring the LPP source, the discretized individual beams reveal enlargement in one axis in the image plane compared to the DPP source. Furthermore, their amplitude distribution exhibits more noise and inhomogeneity. The sensor can detect wavefront deviations in a range between one-fifth of the wavelength employed and approximately 7.5 µm.

Applications

The HWS can be used for characterization and alignment of optical components or systems in the short wavelength spectral region. The characterization process focuses on surface accuracy in respect of shape and roughness and can be used for quality control.

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2 Hartmann intensity distribution.

3 Reconstructed phase front.

4 Hartmann array, produced by laser cutting.

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25.01.2011 - R. Poprawe: *High power diode lasers - The ultimate source for economic photons in the next decade. Laser Market Place, Photonics West 2011, San Francisco, CA, USA*

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25.05.2011 - A. Gillner: *System- und process technology for high throughput and high quality laser processing of solar cells and module. Laser 2011 Application Panel, München*

25.05.2011 - J. Holtkamp: *Mikro- und Nanostrukturierung mit Ultrakurzpulslasern. Laser 2011 Application Panel, München*

25.05.2011 - A. Diatlov: *Investigation of methods for surface topography quantification of Selective Laser Melting (SLM) built parts. Rapid 2011, Minneapolis, MN, USA*

25.05.2011 - A. Temmler: *Design surfaces by laser remelting. LiM2011, München*

26.05.2011 - P. Lott: *Design of an optical system for the in situ process monitoring of Selective Laser Melting (SLM). LiM2011, München*

26.05.2011 - S. Heidrich: *Development of a laser based process chain for manufacturing freeform optics. LiM2011, München*

26.05.2011 - D. Hawelka: *Laser based inline production of wear protection coatings on temperature sensitive substrates. LiM2011, München*

31.05.2011 - O. Maryasov: *Investigation and comparison of XUV wavefronts produced by LPP and DPP sources. COST MP0601 Meeting, Dublin, Irland*

07.06.2011 - I. Kelbassa: *Laser Additive Manufacturing. Pacific Additive Manufacturing Forum PAMF 2011, Melbourne, Adelaide, Sydney, Brisbane, Australien*

08.06.2011 - R. Noll: *Inline elemental characterization of scrap charging for improved EAF charging control and internal scrap recycling. RFCS meeting, TGS9, Budapest, Ungarn*

09.06.2011 - M. Schulz-Ruhtenberg: *Industrietaugliche Laserprozesse zur Erzeugung selektiver Emitter auf kristallinen Solarzellen. SPECTARIS-Forum, München*

16.06.2011 - A. Gatej: *Kombinierte thermo-optische Simulation für optische Systeme. DGAO-Jahrestagung, Ilmenau*

17.06.2011 - V. Morasch: *Generierung dynamischer Intensitätsverteilungen für die Oberflächenstrukturierung durch Umschmelzen mittels Laserstrahlung. DGAO-Jahrestagung, Ilmenau*

23.06.2011 - Y.-C. Hagedorn: *Additive manufacturing of alumina (Al2O3) zirconia (ZrO2) ceramic compounds by Selective Laser Melting. ECERs XII, Stockholm, Schweden*

27.06.2011 - Y.-C. Hagedorn: *SLM of ceramics: New opportunities for the dental industry. 4th Additive Manufacturing Forum: Novel materials & new business models in the creative industries, Barcelona, Spanien*

29.06.2011 - M. Schaefer: *Laser ablation of transparent conducting materials for organic electronics. LOPE-C, Frankfurt a. M.*

29.06.2011 - A. Roesner: *Laser transmission welding of FRP using the example of a rear seat back. AWL, CE Harderwijk, Niederlande*

30.06.2011 - A. Bäuerle: *Auslegung abbildender und nicht-abbildender optischer Systeme. Seminar »Optische Kunststoff-Formteile in Design und Technik«, Würzburg*

01.07.2011 - L. Jauer: *RESOBONE - Ersatzknochen aus Laserschmelze. Woche der Gesundheitswirtschaft, Aachen*

01.07.2011 - J. Holtkamp: *Micro and nano structuring with ultra short pulsed lasers. JENOPTIK Laser GmbH - Customer Day, Jena*

05.07.2011 - A. Weisheit: *Lokale Wärmebehandlung von Platinen und Bauteilen aus hochfesten Stählen zur Verbesserung der Umform- und Funktionseigenschaften. 5. Märkischer Werkstofftag, Hagen*

12.07.2011 - S. Kaierle: *Eco efficiency of laser materials processing. ICFL, Changchun, Volksrepublik China*

12.07.2011 - I. Kelbassa: *Additive BLISK manufacture. ICFL, Changchun, Volksrepublik China*

12.07.2011 - Y.-C. Hagedorn: *Generative Fertigung von 3D-Oxid-Keramiken mittels Selective Laser Melting. Tagung Arbeitskreis Keramik, Rheinbach*

15.07.2011 - M.-C. Funck: *Toleranzen - Analyse, Budgetierung und Toleranzoptimierung optischer Systeme. TU Ilmenau, Ilmenau*

10.08.2011 - Y.-C. Hagedorn: *Additive manufacturing of alumina/zirconia ceramics via Selective Laser Melting. 22nd Annual International Solid Freeform Fabrication Symposium, Austin, TX, USA*

21.08.2011 - M.-C. Funck: *Reducing asymmetric imaging errors through selective assembly and tolerance desensitization. SPIE Optics+Photonics 2011, San Diego, CA, USA*

***22.08.2011 - A. Bäuerle:** Optical system design for a reflector-based LED food lighting module. SPIE Optics+Photonics 2011, San Diego, CA, USA*

***24.08.2011 - R. Poprawe:** The physics in applications of ultrafast laser. Photonics Prag, Prag, Tschechische Republik*

***25.08.2011 - D. Ivanov:** MD-based modeling of swift heavy ion beam nanostructuring of dielectrics. 2011 Bio-Physics Congress Budapest, Budapest, Ungarn*

***30.08.2011 - R. Poprawe:** KW-fs laser technology - enabling a new dimension of materials processing. CLEO Pacific RIM, Sydney, Australien*

***06.09.2011 - A. Bäuerle:** Freeform lens for an efficient wall washer. SPIE Optical System Design, Marseille, Frankreich*

***07.09.2011 - M. Schulz-Ruhtenberg:** Laser processes for the production of solar cells. EU PVSEC, Hamburg*

***12.09.2011 - R. Noll:** Plasmas as light sources from IR to extreme-UV - from LIBS to next generation lithography: an overview. EMSLIBS 2011, Cesme, Izmir, Türkei*

***12.09.2011 - S. Hölters:** Low coherence interferometry for the inline measurement of translucent multilayer structures. IMEKO-Symposium 2011, Braunschweig*

***14.09.2011 - A. Olowinsky:** EU-Project POLYBRIGHT, laser plastic welding. JNPLI 2011, Paris, Frankreich*

***14.09.2011 - R. Poprawe:** KW fs lasers and their potential for opening a new aera of materials processing. 2nd International Symposium on Functional Surfaces, Aachen*

***14.09.2011 - S. Engelhardt:** Tool integrated photonic induced functionalization of polymer parts (TOPAS). 2nd International Symposium on Functional Surfaces, Aachen*

***14.09.2011 - A. Temmler:** Structuring by laser remelting. 2nd International Symposium on Functional Surfaces, Aachen*

***14.09.2011 - P. Werheit:** Automated LIBS sorting system for single piece analysis in metal recycling. EMSLIBS 2011, Cesme, Izmir, Türkei*

***15.09.2011 - G. Vossen:** On a new inexact gradient descent method for parabolic optimal control problems. IFIP TC 7 Conference on System Modeling and Optimization, Berlin*

***15.09.2011 - M. Hörstmann-Jungemann:** Processing of transparent materials using femtosecond laser radiation. JNPLI 2011, Paris, Frankreich*

***15.09.2011 - C. Franz:** Advances in quality monitoring in laser processing. JNPLI 2011, Paris, Frankreich*

***16.09.2011 - C.-A. Hartmann:** Ultra short pulse laser structuring for automotive and tool applications. JNPLI 2011, Paris, Frankreich*

***19.09.2011 - J. Stollenwerk:** Thin film laser processing. E-MRS 2011 Fall Meeting, Warschau, Polen*

***20.09.2011 - D. Riester:** Single cell transfer for in vitro assays (presentation award). Summer School on Biomaterials and Regenerative Medicine, Riva del Garda, Italien*

***21.09.2011 - S. Engelhardt:** Fabrication of three-dimensional polymer-protein hybrid scaffolds by two-photon induced crosslinking (presentation award). Summer School on Biomaterials and Regenerative Medicine, Riva del Garda, Italien*

***27.09.2011 - M. Dahmen:** Knocking on Africa's door - Scouting for laser application in South Africa. AFRIMOLD 2011, Sandton Convention Centre, Johannesburg, Republik Südafrika*

27.09.2011 - M. Dahmen: *Functionally graded multi-layers by laser cladding for increased wear and corrosion protection. AFRIMOLD 2011, Sandton Convention Centre, Johannesburg, Republik Südafrika*

28.09.2011 - J. Holtkamp: *Micro- and nano-structuring of tools with ultra short pulsed lasers. AFRIMOLD 2011, Sandton Convention Centre, Johannesburg, Republik Südafrika*

28.09.2011 - A. Gasser: *Laser applications in tool and mould making. AFRIMOLD 2011, Sandton Convention Centre, Johannesburg, Republik Südafrika*

29.09.2011 - R. Poprawe: *Yb: Innoslab femtosecond amplifier with 1.1 kW average power. 2011 Ultrafast Optics Conference, Monterey, CA, USA*

29.09.2011 - J. Miesner: *Soldering by lasers and packaging by soldering - activities at Fraunhofer ILT. 8. »User Meetings micro assembly«, Berlin*

01.10.2011 - A. Diatlov: *Towards surface topography: Quantification of Selective Laser Melting (SLM) built parts. VRAP 2011, Leiria, Portugal*

03.10.2011 - A. Bäuerle: *Freeform optics at Fraunhofer ILT and RWTH Aachen University. OSA Freeform Optics Incubator Meeting, Washington, DC, USA*

06.10.2011 - P. Abels: *Produktivität und Qualität durch Lasereinsatz in der Fertigung. Laser Herbstforum »Laser in der Automation«, Hannover*

06.10.2011 - D. Petring: *Simulation and optimization of* CO_2*, fiber and disk laser cutting by using CALCut. BLECH Nordic, Stockholm, Schweden*

06.10.2011 - M. Schulz-Ruhtenberg: *Laser processing of semiconductors. EPIC Workshop »Manufacturing Processes for Photonics«, Berlin*

06.10.2011 - J. Wüppen: *Ultrafast tunable mid IR source. IRMMWTHZ 2011, Houston, TX, USA*

11.10.2011 - G. Vossen: *H2,* α*-norm model reduction for optimal control of PDEs with applications in laser processing. International Workshop on Control and Optimization of PDEs, Graz, Österreich*

12.10.2011 - A. Gasser: *Laserpulverauftragschweißen aus der Praxis. Reis Lasertage, Obernburg*

14.10.2011 - R. Poprawe: *The common master degree program of Tsinghua and RWTH-Aachen – A success story since 10 years. 5th Sino-German University Presidents Meeting, Wuhan, Volksrepublik China*

18.10.2011 - K. Bergmann: *Brilliance scaling of discharge based EUV sources. EUV Lithography Symposium, Miami, FL, USA*

20.10.2011 - A. Gillner: *Robuste und werkstoffangepasste Laserprozesse für die Batteriefertigung. 1. Materials for Batteries Kongress, München*

21.10.2011 - S. Danylyuk: *EUV interference lithography with laboratory gas-discharge plasma source. EUV Lithography Symposium, Miami, FL, USA*

24.10.2011 - A. Olowinsky: *Laser polymer welding: From research to high volume industrial applications. ICALEO® 2011, Orlando, FL, USA*

24.10.2011 - M. Reininghaus: *Non-thermal ablation of graphite by ultrashort pulsed fs-laser radiation. ICALEO® 2011, Orlando, FL, USA*

25.10.2011 - J. Witzel: *Additive manufacturing of a blade-integrated disk by laser metal deposition. ICALEO® 2011, Orlando, FL, USA*

25.10.2011 - J. Witzel: *Development of a model for prediction of material properties of laser cladded inconel 718 AS related to porosity in the bulk material. ICALEO® 2011, Orlando, FL, USA*

25.10.2011 - N. Hambach: *Stability limits of laser drilled holes on large areas. ICALEO® 2011, Orlando, FL, USA*

25.10.2011 - H.-D. Hoffmann: *Festkörperlaser und Diodenlaser für das Schweißen von Kunststoffen. Süddeutsches Kunststoffzentrum, Würzburg*

27.10.2011 - J. Holtkamp: *Micro and nano structuring with high power ultra short pulsed laser – current applications and perspectives. ICALEO® 2011, Orlando, FL, USA*

27.10.2011 - M. Hörstmann-Jungemann: *Surface functionalization with fs-laser radiation. ICALEO® 2011, Orlando, FL, USA*

25.10.2011 - C. Hong: *Advantages of laser metal deposition by using zoom optics and MWO (Modular Welding Optics). ICALEO® 2011, Orlando, FL, USA*

26.10.2011 - C. Franz: *Real-time process control by machine vision. ICALEO® 2011, Orlando, FL, USA*

26.10.2011 - D. Schaefer: *Waveguides and markings inside transparent materials by fs-laser radiation, ICALEO® 2011, Orlando, FL, USA*

26.10.2011 - C. Vedder: *Laser-based manufacturing of metallic conducting paths. ICALEO® 2011, Orlando, FL, USA*

26.10.2011 - J. Dietrich: *Drilling with fiber lasers. ICALEO® 2011, Orlando, FL, USA*

26.10.2011 - Y.-C. Hagedorn: *Additive manufacturing of AlSi10Mg-CNT composites via Selective Laser Melting. BIT's 1st Annual World Congress of Nano-S&T, Dalian, Volksrepublik China*

27.10.2011 - S. Kaierle: *Strategies of R&D and international networking towards the evolution of future laser materials processing. ICALEO® 2011, Orlando, FL, USA*

29.10.2011 - S.-J. Merkt: *Integrative technology model for SLM. ICMPMT 2011, Chengdu, Volksrepublik China*

29.10.2011 - D. Hawelka: *Physical and mechanical properties of ceramic wear protection coatings produced using a laser process. European Symposium on friction wear and wear protection, Karlsruhe*

02.11.2011 - S. Engelhardt: *Additive manufacturing of an artificial blood vessel system by the combination of inkjet-printing and two-photon polymerization. World Conference on Regenerative Medicine 2011, Leipzig*

03.11.2011 - S.-J. Merkt: *Complexity analysis in an integrative technology evaluation model for SLM. RAPDASA 2011, Vanderbijlpark, Johannesburg, Republik Südafrika*

08.11.2011 - A. Gasser: *Laser metal deposition for cladding, repair and additive manufacturing. Technologie Show bei TRUMPF, Ditzingen*

15.11.2011 - P. Russbueldt: *Ytterbium INNOSLAB amplifiers - the high average power approach of ultrafast lasers. LEI2011, Szeged, Ungarn*

15.11.2011 - A. Richmann: *Polieren optischer Präzisionsoberflächen mit CO_2-Laserstrahlung. POLILAS Abschlusskolloquium, Aachen*

15.11.2011 - D. Schaefer: *3D - Volumenstrukturierung von transparenten Materialien mittels fs-Laserstrahlung. POLILAS Abschlusskolloquium, Aachen*

15.11.2011 - S. Heidrich: *Herstellung von optischen Komponenten aus Quarzglas mit Laserstrahlung. POLILAS Abschlusskolloquium, Aachen*

16.11.2011 - R. Poprawe: *Laser additive manufacturing - The key to the next generation of economic custom production. MCPC 2011, San Francisco, CA, USA*

17.11.2011 - D. Wortmann: *Ultrafast ablation dynamics of graphite and deposition of graphene using FS-laser radiation. COLA 2011, Playa del Carmen, Mexico*

18.11.2011 - J. Hauck: *Characterization and optimization of an imaging micro-channel plate EUV detector with high temporal resolution. COST MP0601 Meeting, Paris, Frankreich*

18.11.2011 - S. Herbert: *Novel CMOS detector design for fast imaging applications in the extreme ultraviolet. COST MP0601 Meeting, Paris, Frankreich*

19.11.2011 - R. Poprawe: *Latest developments in additive manufacturing. MCPC 2011, San Francisco, CA, USA*

28.11.2011 - P. Russbueldt: *Kohärente Röntgenquelle zur Erzeugung und Analyse von Nanostrukturen. Fraunhofer Symposium »Netzwert«, München*

28.11.2011 - R. Noll: *Antibiotischer Resistenzschnelltest für die molekulare klinische Analyse - AESKULAP. Fraunhofer Symposium »Netzwert«, München*

01.12.2011 - M. Leers: *Wärmemanagement von Hochleistungslaser-dioden auf wassergekühlten Wärmesenken. Bayrisches Laserzentrum, Nürnberg*

14.12.2011 - J. Witzel: *Generative Fertigung am Fraunhofer ILT. Optikseminar am ITO, Universität Stuttgart, Stuttgart*

14.12.2011 - K. Wissenbach: *Laserbasiertes Beschichten und Funktionalisieren von Oberflächen. MST Kooperationsforum »Trends der Oberflächentechnik«, Köln*

CONVENTIONS AND CONFERENCES

23.2. - 24.2.2011, Aachen
International Conference on Turbomachinery Manufacturing – ICTM

By organizing the first International Conference on Turbomachinery Manufacturing (ICTM), Fraunhofer ILT and Fraunhofer IPT have created a new platform for sharing information on new technologies for the manufacture and maintenance of turbomachines. The conference was attended by 213 experts from 11 countries, drawn from the aircraft manufacturing and energy sectors and the domains of laser technology and production engineering. A special highlight of the conference, at which 19 papers were presented, was the 25 live demonstrations by the two Aachen-based Fraunhofer Institutes. On the basis of typical, real-life manufacturing and repair processes, the researchers showed how technological innovations can be implemented in an industrial environment and integrated in an end-to-end process chain adapted to the application at hand. Eleven industrial partners presented their latest products in the exhibition part of the conference. More information on ICTM can be found at www.ictm-aachen.com.

13.4. - 14.4.2011, Aachen
1st UKP (ultra-short-pulse) Workshop

The Fraunhofer ILT held the first UKP Workshop in Aachen on April 13 and 14, 2011. In informative sessions led by 20 experts from science and industry, the over 150 attendees discussed the operating principles of picosecond and femtosecond lasers, the choice of beam sources, and possible applications in precision engineering. The latest technological developments and their market potential were elucidated in open debating sessions, in which fundamental issues concerning the use of these new beam sources were addressed. The second of this series of regular workshops will be held in Aachen on April 17 and 18, 2013. A special seminar devoted to this topic was also held on May 9, 2012, in Aachen during AKL'12 (www.lasercongress.org). More information on the UKP Workshop can be found at www.ultrakurzpulslaser.de.

14.9. - 15.9.2011, Aachen
2nd International Symposium on Functional Surfaces

The second International Symposium on Functional Surfaces was held on September 14 and 15, as part of an initiative launched by the Volkswagen Foundation in November 2003 entitled »Innovative Methods for Manufacturing of Multifunctional Surfaces«. In the years between 2004 and 2009, the Volkswagen Foundation funded a total of 24 projects involving more than 60 research teams to the tune of almost 19 million euros. The latest results of these projects were presented to the around 100 people who attended the symposium in Aachen.

15.11.2011, Aachen
Closing Colloquium for the BMWi Collaborative Research Project »PoliLas«

In the closing colloquium for the PoliLas project, the participating partners presented their results and offered an outlook on the ways in which the technologies might be evolved, with a focus on the fabrication and characterization of optical components. They also provided insights into other areas of laser technology research pertaining to the glass-processing industry and the characterization of optical components.

Other topics discussed:
- The use of lasers in the manufacture and polishing of optical components made of quartz glass
- The characterization of thermal lenses in laser systems
- 3-D laser in-volume structuring of transparent materials
- Inverse glass drilling

COLLOQUIUM ON LASER TECHNOLOGY AT THE RWTH AACHEN UNIVERSITY

20.1.2011, Aachen
Chair for Laser Technology LLT at RWTH Aachen
Colloquium on Laser Technology
Prof. Dr. Michael Schmidt, Friedrich-Alexander Universität Erlangen-Nürnberg, Lehrstuhl für Photonische Technologien, Erlangen: »Macro and micro processing with lasers – processes and system technology«

10.2.2011, Aachen
Chair for Laser Technology LLT at RWTH Aachen
Colloquium on Laser Technology
Prof. Dr. Günther Tränkle, Ferdinand-Braun-Institut, Berlin: »High power diodes«

22.2.2011, Aachen
Chair for Laser Technology LLT at RWTH Aachen
Colloquium on Laser Technology
Prof. Dr. Milan Brandt, Royal Melbourne Institute of Technology - RMIT, Chair for Advanced Manufacturing, Melbourne, Australien: »In-situ repair of gas and steam turbine components by laser metal deposition«

21.4.2011, Aachen
Chair for Laser Technology LLT at RWTH Aachen
Colloquium on Laser Technology
Prof. Dr. Lin Li, The University of Manchester, School of Mechanical, Aerospace and Civil Engineering, Manchester, England: »Laser activities at the University of Manchester«

28.4.2011, Aachen
Chair for Laser Technology LLT at RWTH Aachen
Colloquium on Laser Technology
Prof. Dr. Johannes Wilden, TU Berlin, Fachgebiet Füge- und Beschichtungstechnik, Berlin: »Laser processes and metallurgy as key to new applications«

5.5.2011, Aachen
Chair for Laser Technology LLT at RWTH Aachen
Colloquium on Laser Technology
Prof. Dr. Wolfgang Osten, Institut für Technische Optik, Universität Stuttgart: »Making, testing, applying – new approaches in the field of micro optics«

19.5.2011, Aachen
Chair for Laser Technology LLT at RWTH Aachen
Colloquium on Laser Technology
Dr. Robert Scudamore, The Welding Institute, Cambridge, England: »Laser activities at The Welding Institute – TWI«

30.6.2011, Aachen
Chair for Laser Technology LLT at RWTH Aachen
Colloquium on Laser Technology
Prof. Dr. Ralf Bergmann, BIAS – Bremer Institut für angewandte Strahltechnik GmbH: »Optical metrology and non destructive testing at BIAS«

1 A lecture session during the 1st UKP Workshop in Aachen.
2 ICTM participants during live presentations at Fraunhofer ILT.

7.7.2011, Aachen
Chair for Laser Technology LLT at RWTH Aachen
Colloquium on Laser Technology
Prof. Dr. Wolfgang Sandner, Max-Born-Institut (MBI), Berlin: »European Projects for Extreme Light (ELI) and Laser Fusion (HiPER): Challenges and opportunities for basic laser research and application«

24.11.2011, Aachen
Chair for Laser Technology LLT at RWTH Aachen
Colloquium on Laser Technology
Dr. Rüdiger Grunwald, Max-Born-Institut (MBI), Berlin: »Programmable ultrashort-pulsed nondiffracting patterns«

15.12.2011, Aachen
Chair for Laser Technology LLT at RWTH Aachen
Colloquium on Laser Technology
Prof. Jeremy Witzens, RWTH Aachen, Fakultät für Elektrotechnik, Aachen: »Optische Kommunikation mit Silizium Photonik«

1 A lecture session during the 2nd International Symposium on Functional Surfaces in Aachen.

2 Aix-Laser-People event at Philips Technologie GmbH in Aachen.

3 Aix-Laser-People event at Jenoptik in Jena.

AIX-LASER-PEOPLE

11.2.2011, Jena
39th Seminar of the »Aix-Laser-People«
Alumni club meeting of Fraunhofer ILT and the Chair for Laser Technology LLT hosted by JENOPTIK in Jena, with a presentation of JENOPTIK's activities by its CEO, Dr. Michael Mertin, guided tours of the facilities of JENOPTIK Polymer Systems GmbH and JENOPTIK Optical Systems GmbH, an overview of the activities of the Lasers & Materials Processing Division by its President, Dr. Thomas Fehn, and a lecture on the latest developments in solid-state and diode lasers at Jenoptik by Dr. Guido Bonati, President Business Unit Laser / Vice President Lasers & Materials Processing Division.

25.5.2011, Munich
40th Seminar of the »Aix-Laser-People«
Alumni club meeting of Fraunhofer ILT and the Chair for Laser Technology LLT during the LASER 2011 convention in Munich. After the huge success of the business speed dating session that formed part of the Aix-Laser-People meeting held in connection with LASER 2009, past and present ILT employees were once again given the opportunity to meet and talk with one another in an hour of successive 10-minute brief encounters.

29.9.2011, Berlin
41st Seminar of the »Aix-Laser-People«
Alumni club meeting of Fraunhofer ILT and the Chair for Laser Technology LLT hosted by Rolls-Royce in Blankenfelde-Mahlow (Dahlewitz), featuring a presentation of the company's activities by Mieke Dichter-Van Hamburg, an overview of R&D at Rolls-Royce by Dr. Metin Taban, and specialist lectures by Joachim Rautenberg, Elke Weiss and Susanne Gebhard on the subject of laser applications in turbine manufacturing, followed by a tour of the aircraft-engine production facilities.

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22.12.2011, Aachen

42nd Seminar of the »Aix-Laser-People«

Alumni club meeting of Fraunhofer ILT and the Chair for Laser Technology LLT hosted by Philips Technologie GmbH in Aachen, featuring a guided tour of the LED production and the Lumiblade Creative Lab, an introduction to OLED technology by Gerlinde Haberl, Business Creation Manager at Philips, a lecture on laser machining techniques used in OLED manufacturing by Dr. Holger Schwab, Senior Project Manager at Philips, and a lecture on the use of ultra-short-pulse lasers in material processing by Dr. Arnold Gillner, who heads the competence area for ablation and joining at Fraunhofer ILT.

PRESENTATIONS FOR PUPILS AND STUDENTS

8.2.2011, Aachen

Guided tour for students of the RWTH Aachen Unversity

Forum organized by the Chair for Laser Technology LLT and the Fraunhofer ILT for students of the lecture laser technology at the RWTH Aachen University.

1.4.2011, Aachen

Guided tour for participants of the German young researcher network JuFORUM e.V.

Forum organized by the Chair for Laser Technology LLT and the Fraunhofer ILT for participants of the German young researcher network JuFORUM e.V.

5.4.2011, Aachen

Guided tour for pupils

Forum organized by the Chair for Laser Technology LLT and the Fraunhofer ILT for pupils in the framework of the European environment and media project »Environment builts bridges«.

14.4.2011, Aachen

Girls' Day event

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

26.7.2011, Aachen

Student University

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

28.7.2011, Aachen

Guided tour for students of the RWTH Aachen University

Forum organized by the Chair for Laser Technology LLT and the Fraunhofer ILT for students of the lecture laser technology at the RWTH Aachen University.

3.8.2011, Aachen

Guided tour for students

Forum organized by the Chair for Laser Technology LLT and the Fraunhofer ILT for students of the University Bielefeld.

7.10.2011, Aachen

Guided tour for students of the RWTH Aachen University

Forum organized by the Chair for Laser Technology LLT and the Fraunhofer ILT for students of the first semester mechanical engineering at the RWTH Aachen Unviversity.

TRADE FAIRS

25.1. - 27.1.2011
San Francisco, USA
Photonics West 2011
International trade fair for optics and photonics
Fraunhofer ILT took part in numerous conference sessions at the Photonics West international trade fair and presented papers on various aspects of lasers and laser optics. Fraunhofer ILT and the Chair for Laser Technology LLT at RWTH Aachen University were among the 51 German exhibitors, including six Fraunhofer Institutes, represented in the German Pavilion (Booth 4601). The main topics included new high-power lasers, precision assembly techniques for optical components, and new heat sinks for high-power diode lasers.

4.4. - 8.4.2011
Hannover
HANNOVER Messe / MicroNanoTec 2011
International industry fair
Fraunhofer ILT was present on two Fraunhofer stands and on the IVAM stand.
ILT topics: Laser processes for E-mobility, laser processes for surface technology and micro processing.

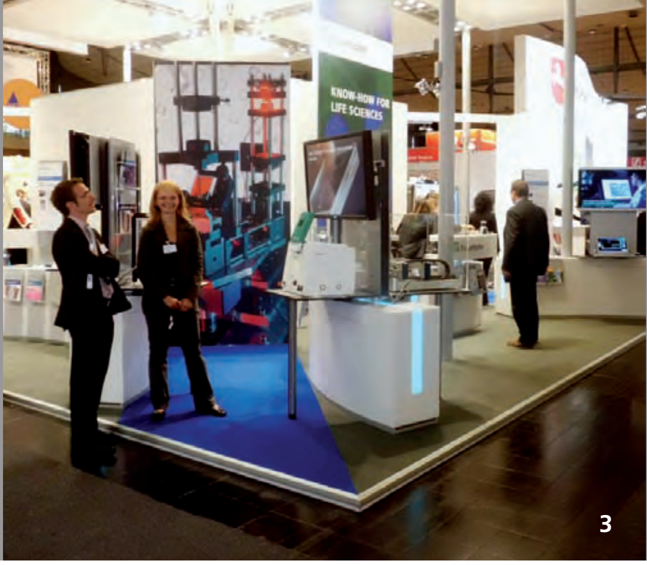
23.5. - 26.5.2011
Munich
LASER 2011
LASER 2011 World of Photonics and World of Photonics Congress 2011
Fraunhofer ILT occupied around 120 m^2 of the joint Fraunhofer booth in Hall C2.330, where it presented its latest R&D results to visitors. In over 60 different exhibits, the institute illustrated its entire range of laser sources and laser manufacturing processes for micro-scale and macro-scale applications. Central topics included laser applications for lightweight construction and e-mobility, and high-power femtosecond lasers.

5.9. - 9.9.2011
Hamburg
EU PVSEC 2011
26th European Photovoltaic Solar Energy Conference and Exhibition
At the joint Fraunhofer booth, Fraunhofer ILT presented the results of the EU-funded SOLASYS project and exhibited a polygon scanner for high-speed beam deflection of ultra-short-pulse laser sources. Visitors were also able to watch live demonstrations of a glass processing system developed in cooperation with EdgeWave GmbH.

27.9. - 28.9.2011
Chicago, IL USA
LME 2011
LIA’S Lasers for Manufacturing Event
Fraunhofer ILT and its American partner Joining Technologies Inc. presented processing heads for laser deposition welding.

1 Joint Fraunhofer booth at LASER 2011 in Munich.

2 Dr. Andres Gasser in conversation with a visitor at LASER 2011.



11.10. - 13.10.2011
Hannover
Biotechnica 2011
Trade show and conference on biotechnology and the life sciences
Among the Fraunhofer ILT exhibits at the joint Fraunhofer booth D10 in Hall 9 was the »Protoprinter«, a laser-based desktop system for the fabrication of protein microarray chips.

24.10. - 27.10.2011
Orlando, Florida, USA
ICALEO 2011
30th International Congress on Applications of Lasers & Electro-Optics
Participation of Fraunhofer ILT and Chair for Laser Technology LLT of the RWTH Aachen University in the presentation sessions and in the ICALEO vendor exhibition program.

15.11. - 18.11.2011
Munich
Productronica 2011
19th International Trade Fair for Innovative Electronics Production
As a special feature of this show devoted to innovative processes for the electronics industry, experts from Fraunhofer ILT presented live demonstrations of the laser welding of battery modules and the heat sealing of plastic antenna housings at the joint Fraunhofer booth in Hall B2.135.

16.11. - 19.11.2011
Düsseldorf
MEDICA / COMPAMED 2011
World Forum for Medicine and International Trade Fair
Fraunhofer ILT presented a wide range of products in the joint booth (F19) hosted by the IVAM Microtechnology Network in Hall 8a, including the TWISTER XS solution for the laser plastic welding of microfluidic devices, a laser catheter for the treatment of atrial fibrillation, and resorbable metal implants produced using selective laser melting (SLM). In a separate exhibit at the joint Fraunhofer booth F05 in Hall 10, another team of Fraunhofer researchers presented the latest developments in the fields of laser surgery and neuroendoscopy.

29.11. - 2.12.2011
Frankfurt/Main
EuroMold 2011
18th International Trade Fair for Tooling and Moldmaking, Design and Product Development
A special event at the joint Fraunhofer booth C66 in Hall 11 was the first public presentation of a new laser polishing machine for tool- and moldmaking, developed by researchers at Fraunhofer ILT in collaboration with the mechanical engineering firms Maschinenfabrik Arnold GmbH & Co KG, Ravensburg, and S&F Systemtechnik GmbH, Aachen. During the show, the exhibited system was used for a live demonstration of its laser polishing capabilities in the production of glassmaking molds. The polishing system received a great deal of positive feedback, as evidenced by the large number of customer inquiries. As a member of the Fraunhofer Additive Manufacturing Alliance, Fraunhofer ILT also made major contributions relating to the additive techniques of laser metal deposition (LMD) and selective laser melting (SLM).

3 Joint Fraunhofer booth at Biotechnica 2011 in Hannover.
4 The Fraunhofer ILT team at Photonics West 2011 in San Francisco, USA.

AWARDS AND PRIZES

Ferchau Innovation Prize 2011

On 4 April, 2011, the research team led by Dr. Ingomar Kelbassa was awarded the Ferchau Innovation Prize 2011. In the competition with the slogan »Save what's GOOD – energy, natural resources and primary products», the jury awarded the second place to ILT's resource-saving process for the manufacture of aircraft turbine engines. Through the use of the additive manufacturing technique of laser metal deposition (LMD), blade-integrated disks (blisks) and other turbine components can be produced much faster, and material wastage can be significantly reduced. The present version of the process is 15 times faster than the standard methods used only two or three years ago. A further advantage is provided by new zoom optics that simplify the generation of laminates consisting of layers of different thicknesses. The members of the team that worked on the project entitled »Additive manufacturing of blisks for aircraft engines« were Dr. Konrad Wissenbach, Dr. Andres Gasser, Stefanie Linnenbrink, Franz Mentzel and Patrick Albus of Fraunhofer ILT and Dr. Ingomar Kelbassa, Gerhard Backes, Dr. Bernd Burbaum, Johannes Witzel and Marco Goebel of the Chair for Laser Technology LLT at RWTH Aachen University. Industry representatives Dr. Thomas Haubold, Dr. Andreas Kohns and Dr. Carsten Loof of Rolls-Royce Deutschland Ltd & Co KG also formed part of the team.

1 Presentation of the Ferchau Innovation Prize 2011, from left: Dr. Andres Gasser, Johannes Witzel, Dr. Andreas Kohns, Dr. Ingomar Kelbassa, and Dr. Thomas Haubold.

NRW Innovation Award 2011

The Land of North Rhine-Westphalia selected Professor Poprawe and the leading members of his research team, Dr. Andres Gasser, Dr. Ingomar Kelbassa, Dr. Wilhelm Meiners and Dr. Konrad Wissenbach, as the winners of the NRW Innovation Award 2011 in the category »Innovation« for their work on additive manufacturing processes for metal parts using selective laser melting (SLM) and laser metal deposition (LMD). The Award, worth 100,000 euros, is one of the most prestigious research prizes in Germany. It was officially presented to the winning team on 14 November 2011 by the NRW Minister for Innovation, Science and Research, Svenja Schulze, in a ceremony attended by 500 guests from the worlds of science and business in the K21 art gallery in Düsseldorf, which was once the seat of North Rhine-Westphalia's parliament.

For over 20 years, the team of researchers at Fraunhofer ILT and at the Chair for Laser Technology LLT at RWTH Aachen University has been a driving force in the development of additive manufacturing technologies to serve as the basis for energy- and resource-saving production processes. In a systematic approach, the scientists have developed laser-based solutions for a wide range of materials and applications, and stepped them up to industrial scale. Selective laser melting (SLM) enables customized products such as medical implants or functional tool components to be manufactured economically in small batches on the basis of 3-D CAD data and delivered just-in-time with the minimum of delay. The pioneering role of the Fraunhofer ILT researchers in Aachen in the development of SLM has opened up new horizons in the field of rapid prototyping. The ability to fabricate parts by building up successive layers of material gives product designers a whole new range of options in terms of geometrical freedom and functional integration. The 3-D CAD data can be directly transformed into a physical part. As a result, industrial manufacturers will be able to offer entirely new business models such as mass customization, open innovation, or co-creation, in which the end user has a major say in the design of the product he or she intends to buy.

As well as being the pioneers of selective laser melting (SLM), the team of laser experts at Fraunhofer ILT in Aachen is also driving progress in laser metal deposition (LMD) techniques for use in maintenance, surface modification, and the fabrication of new parts. So far, these techniques have mainly been used to repair aircraft engine components and a wide variety of specialized manufacturing tools. The difference between these two technologies is that in SLM a laser is used to melt selected areas of a powder bed which are then solidified to create the final product, consisting of multiple layers which together form a complex, finely detailed part, whereas in LMD parts are produced by building up successive layers of material from a powder sprayed through a nozzle, which are then fused together by the heat of a laser beam. The second method is ideally suited for the manufacture and repair of large components.

Professor Poprawe personally thanked the members of his research staff for their consistent hard work at an internal celebration on December 2, 2011. He awarded a special certificate of recognition to each individual scientist who had contributed work of relevance to the field of additive manufacturing.

Their names: Patrick Albus, Gerd Backes, David Becker, Matthias Belting, Tim Biermann, Sebastian Bremen, Damien Buchbinder, André Diatlov, Dominik Dobrzanski, Ratmar Froembgen, Dr. Andres Gasser, Marco Göbel, Yves-Christian Hagedorn, Christian Hinke, Chen Hong, Lucas Jauer, Stefan Jung, Dr. Ingomar Kelbassa, Jochen Kittel, Wolfgang Kueppers, Stefanie Linnenbrink, Dora Maischner, Dr. Wilhelm Meiners, Frank Mentzel, Sörn Ocylok, Dr. Norbert Pirch, Prof. Reinhart Poprawe M.A., Jeroen Risse, Gesa Rolink, Rui João Santos Batista, Johannes Schrage, Dr. Andreas Weisheit, Dr. Konrad Wissenbach, Johannes Witzel.

The »Laserpoppnieter« ideas contest

Fabian Weirauch won second prize in the »Laserpoppnieter« (≈ laser staple gun) ideas contest, which took place during the Fraunhofer »Netzwert« symposium 2011 in Munich, a two-day event to promote networking among Fraunhofer Institutes. On each of the two days, 10 finalists out of 42 candidates were given an opportunity to present their idea to an audience of 400 symposium participants, in a quick-shot summary lasting no more than 90 seconds. Weirauch obtained 20.9 percent of the votes, and thus just narrowly missed winning the first prize. But the 25,000 euros in funding he received to pursue work on his project clearly indicates that the symposium participants were convinced by the viability of his idea.

The spark of inspiration came to Fabian Weirauch while working on his dissertation paper in the United States. His idea consists of using customized laser sources to join different types of plastic. By creating interlocking structures on adjoining surfaces, it will be possible to create high-strength, form-fitting joints.

2 Presentation of the NRW Innovation Award 2011, from left: Prof. R. Poprawe M.A., Fraunhofer ILT; Dr. N. Arndt, Rolls-Royce plc (who gave the laudatory speech); Dr. I. Kelbassa, Chair for Laser Technology LLT at RWTH Aachen University; S. Schulze, NRW science minister; Dr. A. Gasser, Fraunhofer ILT; Dr. W. Meiners, Fraunhofer ILT; Dr. K. Wissenbach, Fraunhofer ILT; Hannelore Kraft, Prime Minister of North Rhine-Westphalia.

EUROPEAN LASER INSTITUTE ELI

Short Profile

The European Laser Institute was founded in 2003 through an EU-funded initiative. The ELI mission is to strengthen and further enhance Europe's position in the field of laser technology. In addition, ELI aims to raise public awareness of the significance and prospects of the European laser technology industry. ELI is a network composed of almost 30 leading research facilities including the Fraunhofer ILT as well as small and medium-sized companies. This means that in addition to its participation in regional and national competence networks, as an ELI member the Fraunhofer ILT is also part of an influential, European-level laser technology network. Furthermore, the international cooperation of industry and research, especially in the field of EU research support, is forced by ELI. Amongst others, ELI creates adequate platforms by organizing conferences, workshops, summerschools etc. This is supported by the cooperation with the respective representations (e. g. EPIC, AILU, WLT). A strong cooperation with the Laser Institute of America (LIA) amongst others exists in the organization of international conferences (ICALEO, PICALO, ALAW) as well as the Journal of Laser Applications (JLA).

Executive Commitee

The members of the committee representing the ELI are:

- Dr. Stefan Kaierle (chairman)
  Fraunhofer ILT, Germany
- Dr. Paul Hilton
  TWI, Great Britain
- Dr. Wolfgang Knapp
  CLFA, France
- Prof. Dr. Veli Kujanpää
  Lappeenranta University of Technology, Finland
- Dr. Filip Motmans
  Lasercentrum Vlaanderen, Belgium
- Prof. Dr. José Luis Ocaña
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- Prof. Dr. Andreas Ostendorf
  Ruhr-Universität Bochum, Germany

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PHOTONAIX E.V. - COMPETENCE NETWORK FOR OPTICAL TECHNOLOGIES

PhotonAix
Kompetenznetz
Optische Technologien

Short Profile

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

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

Actual Highlights

Besides participating in Photonics West 2011 in San Jose, USA, and LASER 2011 in Munich as a joint exhibitor with the other German competence networks for optical technologies, the major events of 2011 were the European technology platform Photonics21 and the participation in the NRW cluster strategy.

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

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

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

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ARBEITSKREIS LASERTECHNIK AKL E.V.

Arbeitskreis Lasertechnik AKL e.V.
The Forum for Industrial Laser Applications

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

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

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

A continual exchange of information and development of a shared knowledge base, as well as the sustained improvement in training available, are key to achieving the association's aims. AKL e.V. has about 100 members.

AKL e.V.'s mission includes:

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

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TECHNICAL BOOKS

»Laser Technology for Manufacturing«
by Reinhart Poprawe
Principles, prospects and examples for the innovative engineer.

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

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

»Tailored Light 2« by Reinhart Poprawe
Laser Application Technology

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

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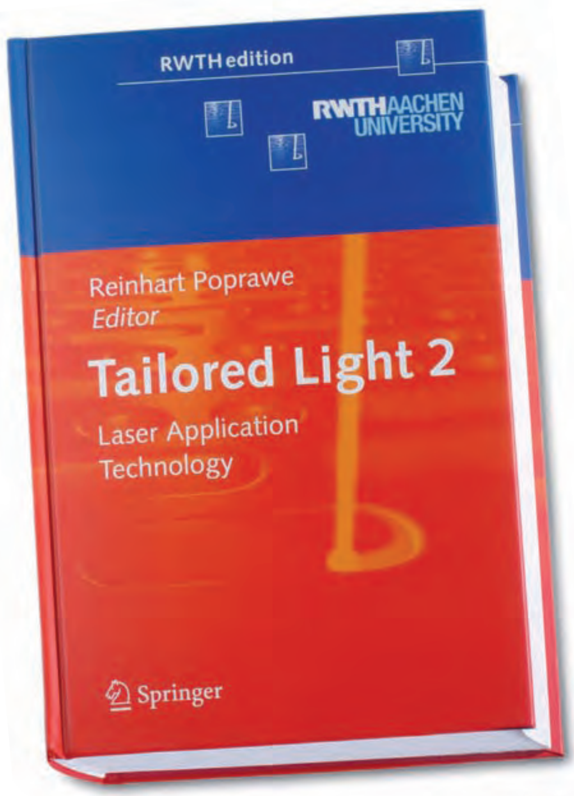

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If you would like more information about the research and development at the Fraunhofer Institute for Laser Technology please go to our website at www.ilt.fraunhofer.de. Information can also be ordered using this form.

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☐ ***Annual Report 2011*** ☐ ***2010*** ☐ ***2009***
(English versions only available online at www.ilt.fraunhofer.de)

☐ ***Proceedings of the International Laser Technology Congress AKL'12***
☐ ***Information Brochure »European Laser Institute ELI«*** *(English)*
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