Fraunhofer IWS

FRAUNHOFER INSTITUTE FOR MATERIAL AND BEAM TECHNOLOGY IWS

ANNUAL REPORT 2009

DRESDEN

Internet: www.iws.fraunhofer.de

FRAUNHOFER INSTITUTE FOR MATERIAL AND BEAM TECHNOLOGY IWS

ANNUAL REPORT 2009


CERTIFICATE

ISO 9001:2000

DEKRA Certification

hereby certifies that the company

Fraunhofer Institut Werkstoff- und Strahltechnik

Fraunhofer Institut für Werkstoff- und Strahltechnik

Business field:
Management and Infrastructure, PVD- /Nanotechnology, CVD Thin Film Technology, Thermal Coating, Joining & Surface Treatment, Ablation and Cutting

Location:
Winterbergstraße 28 * D-01277 Dresden

has successfully implemented the above mentioned quality management system according to the standard (12/2000) and applies it effectively. The conformity was inspected during the certification audit documented in audit report no. A0805388. This certificate is only valid in connection with the successful performance of the surveillance audits.

Date of the first certification:	30.12.1997	Date of the last certification:	24.01.2007
This certificate is valid until:	23.01.2010	Certificate registration no.:	91297819/4 duplicate
Last audit day:	12.01.2007		

DEKRA Certification GmbH
Stuttgart, 24.01.2007

QMS-TGA-ZM-05-91-00

Fraunhofer

60 years on behalf of the future

PREFACE

The best idea is of no use to anyone unless it is utilized.
Walter A. Heiby

Industrial investments typically slow down in times of economic uncertainty; however, the Fraunhofer IWS still successfully managed to finish a significant number of industrial technology transfer projects that had been started in 2008. More than ten new processes and systems were implemented in industrial production settings. Consequently 2009 turned out to be the most successful year in IWS history despite the economic crisis. Some of the highlights will be discussed on the following pages.

Energy related technologies are of strategic importance to IWS. Specific research and development topics include photovoltaics, friction reduction, optimization of turbine blades, development of energy storage materials, energy efficient joining processes and the reduction of eddy currents in transformer sheet metal. Every IWS department is involved in energy related research, which will be even further expanded in the future.

Last year witnessed the birth of the new alliance "DRESDEN-concept". Here a group of non-university research institutes of the Fraunhofer-Gesellschaft, the Helmholtz-Gemeinschaft and the Max-Planck-Gesellschaft, collaborate with the University of Technology Dresden to pool local strengths. As a first activity Dresden's Fraunhofer Institutes and the University of Technology Dresden founded an Innovation Center for Energy Efficiency, which is funded by the Fraunhofer-Gesellschaft and the State of Saxony.

A part of this network is the EU funded and IWS managed project LIFT "Leadership in Fiber Laser Technologies". More than 20 partners are involved in LIFT, which makes it Germany's largest current laser project.

The Fraunhofer IWS also coordinates two additional EU projects of similar size in the area of thin film technologies. BMW is coordinating a large project on friction reduction, which entirely focuses on IWS' Laser-Arc technology to manufacture DLC coatings. We believe that the completion of this project will mark the industrial breakthrough of our technology.

The economic crisis is not yet overcome. However, based on the longer-term nature of many of our projects and our strategic orientation the institute's outlook for 2010 is very positive.

Eckhard Beyer

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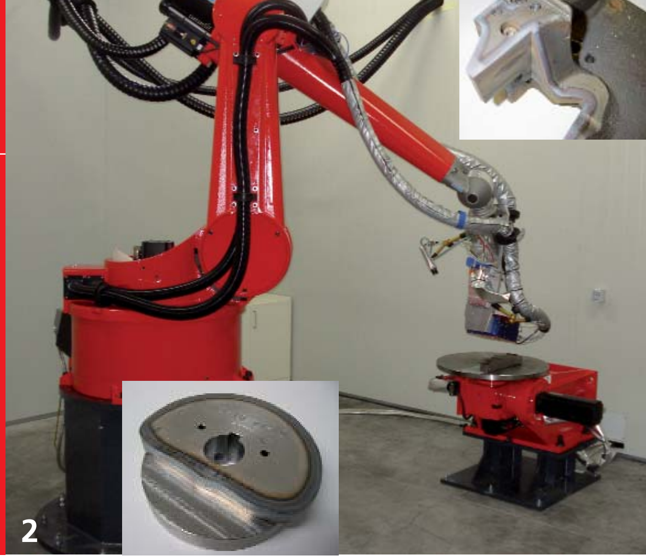
NETWORKS, NAMES, DATES

HIGHLIGHTS OF 2009



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REDUCED EMISSIONS WITH INCREASED MOBILITY

Seven companies and two Fraunhofer institutes tackle this challenge in a research project named "Pegasus". This four-year project began in July 2009 and is funded by the BMWI with 16.8 Mio Euros.

The Fraunhofer IWS Dresden works on the development of industrial manufacturing technology to produce friction reducing carbon coatings for transmission and other vehicle components. The IWS carbon coatings are harder, more wear resistant and chemically better suited for certain lubricants than previously commercially established carbon thin film materials. These properties hold an enormous potential for exceptionally low friction coefficients and thus reduced friction losses.

FIBER LASERS QUIETLY REVOLUTIONIZE THE WORLD

A broadly positioned European consortium was established to set new standards in particular in the field of fiber lasers. The 16 Mio Euro project "LIFT – Leadership in Fiber Laser Technologies" started in September 2009. LIFT's goal is the development of innovative fiber laser sources to expand Europe's strong position in science, manufacturing and production technology. Fifteen companies, two Fraunhofer institutes, three universities and a non-profit society from 9 countries are pooling their competences. The Fraunhofer IWS manages a strong research team of manufacturers of optical and opto-electronic components, producers of photonic fibers, laser and application developers as well as basic science researchers.

THE RESEARCH GROUP "ADHESIVE BONDING" WINS THE 2009 WILHELM-KLAUDITZ-AWARD FOR WOOD RESEARCH AND ENVIRONMENTAL PROTECTION

On September 17th 2009 Dr. Irene Jansen's (far right in Fig. 1) IWS research group was honored with the 2009 "Wilhelm-Klauditz-Award for Wood Research and Environmental Protection". The ceremony was held at the Fraunhofer WKI in Brunswick in the presence of Lutz Stratmann, Minister for Economic Affairs of the State of Lower Saxony.

The honored work addresses a new technique for the processing of edges during furniture manufacturing. An interdisciplinary team of researchers from Fraunhofer IWS, TU Dresden and the engineering firm Schwarz developed an industrial laser-based process for the coating of narrow surfaces on furniture materials. The process significantly improves a principle weakness during the processing of plate shaped wood materials. For the first time ever a laser beam technique is used to join materials in the wood and furniture industry.

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LARGE AREA PRECISION COATINGS FOR X-RAY OPTICAL APPLICATIONS

Researchers at the Fraunhofer IWS had previously developed a coating technology for X-ray optics. Collaborating with the company Roth & Rau MicroSystems GmbH (Hohenstein-Ernstthal) the team now scaled this coating process to work for large area substrates by applying magnetron-sputtering deposition technology. Shortly after starting up the new system (Fig. 4) it already achieved excellent results for the reflectivity of the nanometer multilayer coatings, the thickness uniformity and the reproducibility. Also during the start-up phase the researchers produced a specially defined reference multilayer coating system, which achieved a reflectivity of just 0.5 % shy of the worldwide reported maximum. Simultaneously the system produces an outstanding lateral uniformity: Over substrate areas with diameters of 300 mm and 450 mm the coating thickness uniformity was greater than 99.9 % and 99.8 %.

NESMUK KNIFE WITH DIAMOR COATING

The knife manufacturer Nesmuk KG contracted the development of a kitchen knife with lifelong sharpness. An additional design requirement was a sophisticated optical appearance. The Fraunhofer IWS Dresden supported the project by developing a special technology to produce an extremely wear protective carbon coating (Fig. 5). Such coated knives demonstrated a more than tenfold lifetime compared to an uncoated knife. The high value product is marketed with the brand name "Nesmuk DIAMOR®". It has received much international attention due to its uniqueness.

MORE WELDING AND HARDENING APPLICATIONS TRANSFERRED TO PRODUCTION

The machine manufacturer EMAG Maschinenfabrik GmbH and the Fraunhofer IWS Dresden share a long and successful history of commercializing induction assisted laser welding technologies. In September 2009 the team finished the tenth industrial installation of such a system in an industrial manufacturing environment. The machine is currently used to laser weld differential transmission with induction support.

We developed laser welding technologies for automobile differentials for an American automobile supplier using material combinations such as cast iron / cast iron, and cast iron / TMT steel. Thanks to a similar system technology at IWS the institute was able to support the process implementation at the Polish manufacturing site.

The company STAV in Barberino, Italy, built a robot based laser hardening machine with 6 kW diode laser. In March 2009 the Fraunhofer IWS Dresden supported this effort by delivering special components to the ALOtec Dresden GmbH and provided technology development services, training and start-up support for the system. The primary purpose of the machine is to harden tools (Fig. 2).

LASER ACOUSTIC MEASUREMENT SYSTEMS FOR INDUSTRY AND RESEARCH

In 2009 the institute delivered two of the LAwave® systems (previously recognized with the Joseph-von-Fraunhofer Award) to measure E-modulus and film thicknesses. One machine was installed in the semiconductor industry at Fujitsu Co., Japan. The second machine is used for highly precise measurements in a research environment.

NEWS FROM THE BOARD OF TRUSTEES

Photonics and materials sciences will be the key 21st century technologies for the raw materials starved Germany. In both areas the IWS is a worldwide leader.

We notice with great interest how the different business areas of the institute such as laser materials processing, system technology, and materials and coating technologies, process simulation and nanotechnology are complementary in an ideal way.

The work spectrum of the institute not only covers the scientific part of a topic, but reaches far in supporting the customer during the production implementation of the developed solution. The excellent collaboration with the university in Dresden allows cost effective basic research and access to supporting scientific manpower.

In addition to developing new production processes and integration methods the institute also works on actual customer parts in its laboratories. We are pleased to see that the institute's customers include large enterprises from the automotive and aerospace industries as well as many small and medium sized companies. The Board of Trustees values this development very positively. There are many examples of successful solution implementations for these customers such as the welding of highly alloyed steels using inductive preheating or the hardening of turbine blades and the fabrication of nanoparticles from carbon or ultrathin mirror coating structures for the X-ray and UV spectroscopy.

The success across such a diverse range of activities is possible due to the highly educated personnel and the substantial knowledge and long-term experience of the group leaders. In addition the IWS is internationally active in the USA and in Poland as well as in numerous research collaborations and networks.

We, the members of the Board of Trustees, are convinced that the steadily increasing trend to conserve energy and the step toward new vehicle powertrains and to application optimized materials properties will open new and important work areas for the institute. The Fraunhofer IWS is extremely well prepared for these new challenges.

Dr. Peter Wirth

The advisory committee supports and offers consultation to the Fraunhofer IWS. The 19th committee meeting took place on February 27, 2009, at Fraunhofer IWS in Dresden. Members of the advisory committee in 2009:

P. WIRTH, DR.
Chairman of Rofin-Sinar Laser GmbH, committee chair
Hamburg

R. BARTL, DR.
Manufacturing management of Siemens AG
Transportation Systems
Krefeld

T. FEHN, DR.
General manager Jenoptik Laser, Optik, Systeme GmbH
Jena

D. FISCHER
General manager EMAG Leipzig Machine Factory GmbH
Leipzig

W. HUFENBACH, PROF.
Director of the Institue for Lightweight Construction and Plastics Engineering of the Dresden University of Technology
(Guest)

U. JARONI, DR.
Member of the board of directors of the ThyssenKrupp Steel AG, automotive division
Duisburg

F. JUNKER, DR.
Member of the board of directors of the
Koenig & Bauer AG
Werk Radebeul

H. KOKENGE, PROF.
President of the Dresden University of Technology

U. KRAUSE
Karlsruhe Institute of Technology, branch Dresden

T. G. KRUG, DR.
Managing Director Hauzer Techno Coating BV
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P. G. NOTHNAGEL, MINR
Saxony Ministry of Economic Affairs and Labor
Dresden

H. RIEHL, MINR
Federal Ministry of Education and Research, manager of the production systems and technologies department
Bonn

F.-J. WETZEL, DR.
BMW motor-bike, business field planning, cooperation
München (Guest)

R. ZIMMERMANN, MR DR.
Saxony Ministry of Science and Art
Dresden

CORE COMPETENCES

The business fields of the Fraunhofer Institute for Material and Beam Technology IWS are in the areas of joining, cutting and surface technology. The research and development work is based on a substantial materials and nanotechnology know-how in combination with comprehensive materials characterization. In the following areas we developed and continuously expanded core competences:

LASER MATERIALS PROCESSING

- high speed cutting of thick metal sheets
- cutting and welding of plastics and other non-metals
- development of welding processes for hard-to-weld materials
- laser hybrid technologies such as
  · laser induction welding
  · laser induction remelting
  · plasma TIG or MIG assisted laser welding
- laser and plasma powder buildup welding
- laser surface layer hardening, alloying, and remelting as well as short-term heat treatment
- removal and cleaning
- process monitoring and control

PLASMA COATING PROCESSES

- plasma, flame, and HVOF spraying
- atmospheric pressure plasma assisted CVD (microwave and arc jet plasmas)
- plasma etching
- development and adaptation of plasma sources
- vacuum arc processes
- precision coating processes (magnetron and ion beam sputtering)
- laser arc processes as hybrid technology

MATERIALS SCIENCE, NANOTECHNOLOGY

- properties analysis of surface treated, coated and welded materials and parts
- failure and damage analysis
- optical spectroscopic characterization of surfaces and coatings down to the nanometer
- mechanical tribological characterization
- thermoshock testing of high temperature materials
- coating thickness and E-modulus measurements of nm to µm coatings

SYSTEMS TECHNOLOGY

- utilization of the process know-how to develop, design and build components, equipment and systems that can be integrated in manufacturing lines including software components
- laser system solutions for cutting, welding, coating and surface refinement
- development of process monitoring and control systems
- process focused prototype development of coating systems or their core modules
- components for PVD and CVD systems
- atmospheric pressure plasma assisted CVD sources
- measurement systems for the characterization of coatings and the nondestructive part testing using laser acoustic and spectroscopic methods
- systems for the spectroscopic monitoring of gas mixtures
- software and control techniques
- remote technology

PROCESS SIMULATION

The IWS develops complete modules for the simulation of processes and materials properties. Examples are:

- thermal hardening and laser hardening,
- laser welding,
- laser powder buildup welding,
- vacuum arc coating,
- gas and plasma flow dynamics in CVD reactors,
- optical properties of nano layer systems.

The results directly flow into process optimization. Additional commercially available simulation modules are deployed.

Business fields / Core services	Laser materials processing	Plasma coating processes	Materials / Nanotechnology	System technology	Process simulation
Removal / Cutting	□		▫	■	▫
Joining	■		■	■	□
Surface technologies					
Surface layer technologies	□	▫	□	■	□
Thermal coating	□	■	□	□	□
PVD vacuum coating technology		■	■	□	▫
CVD atmospheric pressure coating technology		■	□	▫	□

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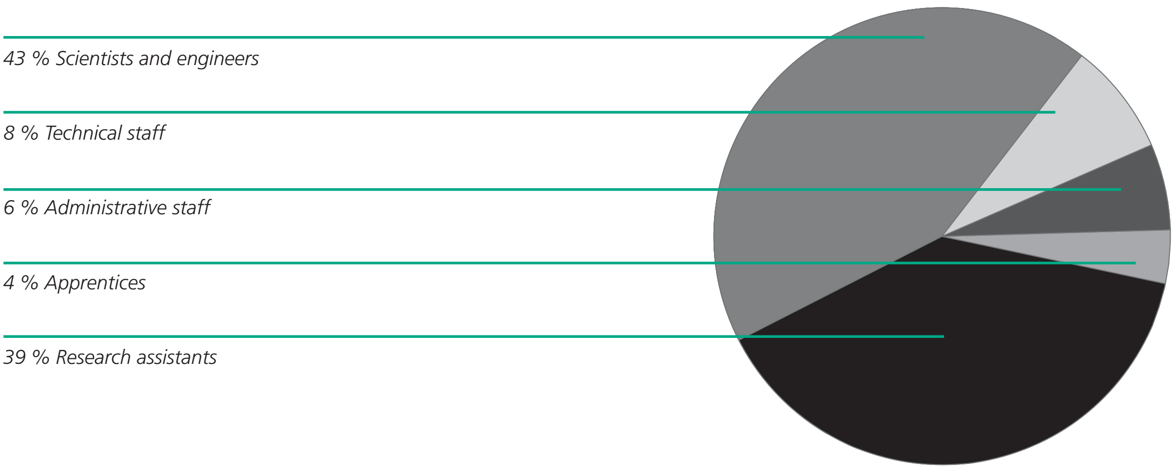
INSTITUTE IN NUMBERS

EMPLOYEES OF FRAUNHOFER IWS 2009

	Number
PERMANENT STAFF	**150**
- scientists	113
- technical staff	21
- administrative staff	16
ANOTHER STAFF	**129**
- apprentices	10
- research assistants	103
- employees CCL USA	16
EMPLOYEES OF FRAUNHOFER IWS (TOTAL)	**279**

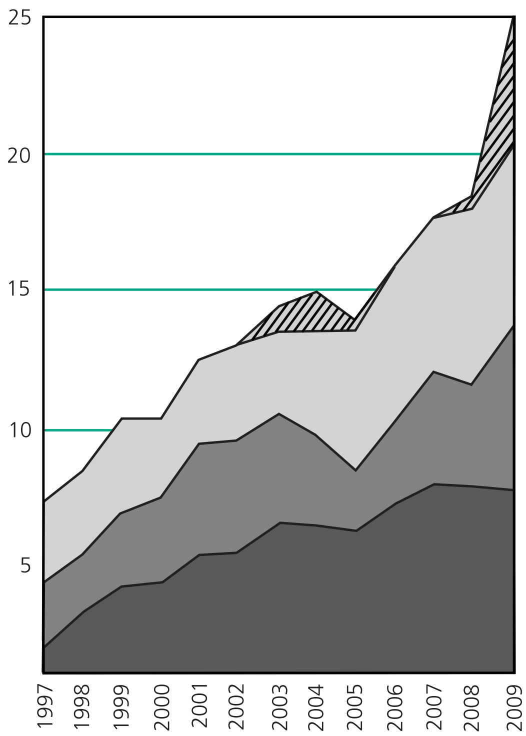
EMPLOYEES 2009



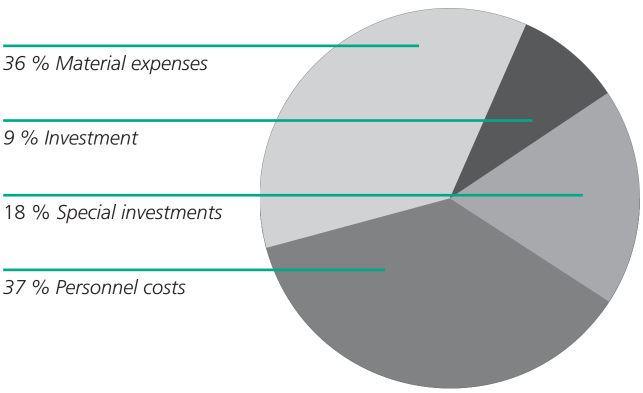
BUDGET AND REVENUE 2009 (JANUARY 2010)

	Mio. €
OPERATIONAL COSTS AND INVESTMENTS	**24.3**
Budget	**17.6**
- personnel costs	8.9
- other expenses	8.7
Investment	**6.7**
	Mio. €
REVENUE 2009	**24.3**
Revenue operations	**17.6**
- industrial revenues	7.6
- revenues of public funded projects	5.7
- Fraunhofer internal programs	1.0
- base funding IWS	3.3
Revenue investment	**6.7**
- industrial revenues	0.2
- base funding IWS	1.2
- strategic investment	0.8
- special investments economic stimulus package	1.4
- special investments (Saxony)	3.1

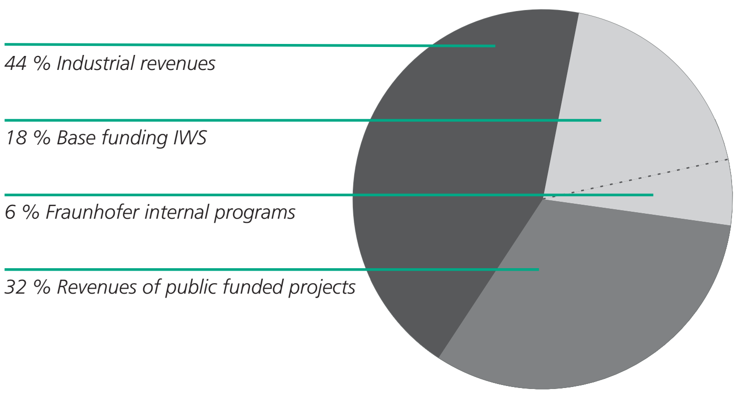
REVENUES (TOTAL)



BUDGET (TOTAL) 2009



REVENUES 2009



EXECUTIVE TEAM

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- **Surface Functionalization** – Dr. A. Lasagni, ext.: 3007
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Chair for Laser and Surface Technology
Prof. Dr. E. Beyer

Institute of Inorganic Chemistry
Chair for Inorganic Chemistry
Prof. Dr. S. Kaskel

Institute of Materials Science
Chair for Material Engineering
Prof. Dr. C. Leyens

BUSINESS FIELD ABLATION AND CUTTING

Editor: Dr. Wetzig, in January 2009 you took over the department "Laser ablation and cutting" from Dr. Morgenthal who retired. How will you continue the work and where would you like to set new emphases?

Dr. Wetzig: First of all I would like to point out that Dr. Morgenthal left me with a well ordered department. Thus we have to continue to develop business areas that are well established and successful. Here I would like to mention all activities involving laser cutting with highly brilliant beam sources, remote cutting, laser micro materials processing and the bio systems technology. We will expand the remote technology to include applications involving composite materials such as the cutting of glass and carbon fiber reinforced composites. The availabilities of multi kW highly brilliant beam sources and short pulse lasers at 100 W call for the further development of the remote technology, as well as the development of alternative concepts for beam guidance and deflection. Over the past year we also established a new research group "Surface Functionalization", which is managed by Dr. Lasagni. This group represents a good addition to the ongoing activities in the area of micro materials processing. We are proud to have Dr. Lasagni on our team; he is an excellent scientist and receives funding through the Fraunhofer internal "Attract" program to build up this new research area within the department.

Editor: 2009 was characterized by an economic crisis of a magnitude that Germany had not experienced since 60 years. The laser industry suffered a drastic drop in sales revenues and profits. How did this affect the industry revenues of your department?

Dr. Wetzig: The impact was surprisingly low. We experienced only a minor reduction in industrial contract research revenues. To a large degree this can be attributed to the fact that many of our industry customers only slightly reduced their development budgets despite the economic crisis. They target the development of new technologies and products in the areas of laser cutting and ablation to be well positioned to profit from the next economic upturn. In such times it is especially important to have long-term business relationships with industrial partners. And of course, last but not least, this success speaks for the quality of the work performed by our colleagues.

COMPETENCES

FIBER LASER AND SCANNER TECHNOLOGY

Frequently new system technology is required to fully exploit the technical and economical potential of new or further developed techniques in laser materials processing and more powerful and higher quality laser beam sources. We develop customer tailored solutions if these system components are not yet commercially available. Examples include processing optics with enhanced functionality and hard- and software components for online process monitoring and control.

LASER CUTTING

Laser beam cutting research topics include the development of technologies such as the process throughput optimization for components made from all materials that are used in modern manufacturing. At the IWS for these developments we use highly dynamic 2D and 3D cutting machines with direct liner drives and modern robots as well as laser of various power and beam quality levels. In addition to commercially processing optics for beam focusing we develop and use our own special solutions such as scanner systems for remote processing.

MICROPROCESSING

IWS engineers utilize substantial equipment and facility installations and solid know-how to perform applied research projects in the field of micro and fine processing with laser beams. Targeted applications are the miniaturization of functional elements in machines, systems, vehicles, instruments and medical devices. Examples include the fabrication of 3D structures of sub-millimeter dimensions and areal structures on polymers, metals, ceramics and quartzite and biocompatible materials as well as cleaning with laser technology.

SURFACE FUNCTIONALIZATION

New methods are developed to fabricate 2- and 3-dimensional micro- and nanostructures on surfaces of polymers, metals, ceramics and coatings. Thus it is possible to generate macroscopically large surface areas that exhibit properties that are typical on the micro- and nanoscopic scale. In addition to these topological modifications it is also possible to periodically vary electrical, chemical and / or mechanical surface properties. These structure surfaces are useful for biotech, photonic and tribology applications.

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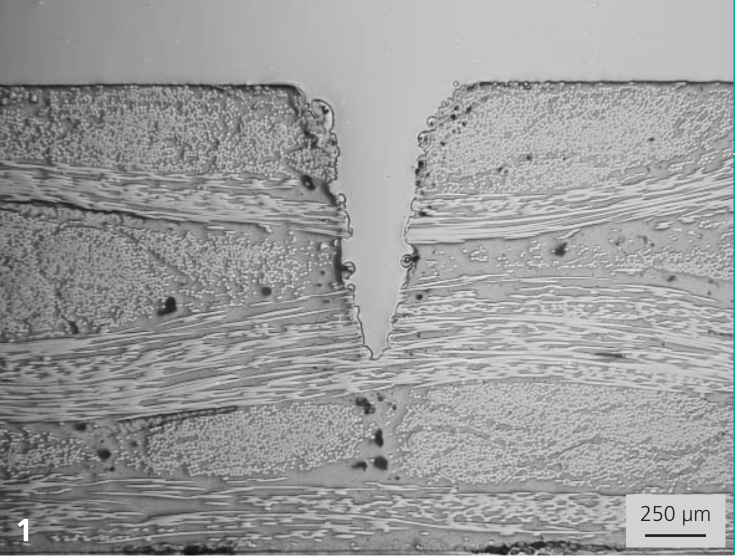
EXAMPLES OF PROJECTS 2009

FURTHER INFORMATION:

www.iws.fraunhofer.de/projekte/006/e_pro006.html

www.iws.fraunhofer.de/projekte/036/e_pro036.html

www.iws.fraunhofer.de/branchen/bra06/e_bra06.html



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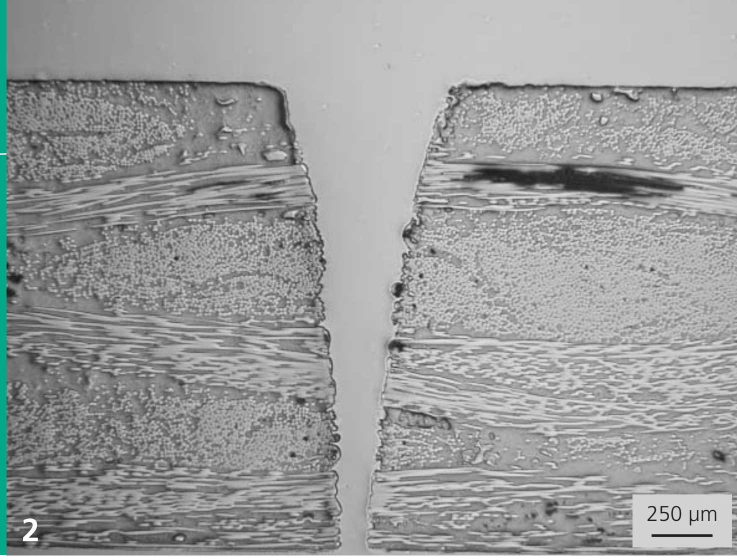

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FAST ABLATION AND CUTTING OF FIBER REINFORCED COMPOSITE MATERIALS WITH HIGH POWER LASERS

THE TASK

Originating from the aerospace industry, high performance fiber reinforced composite materials are now being established in many application areas. Optimally designed structures of these high performance composites combine an extreme mechanical loading capability with a minimal use of the material. These characteristics are mainly due to the mechanical properties, which include strength, stiffness and low density. These materials also offer excellent corrosion resistance and good damping performance, which are exploited in many applications.

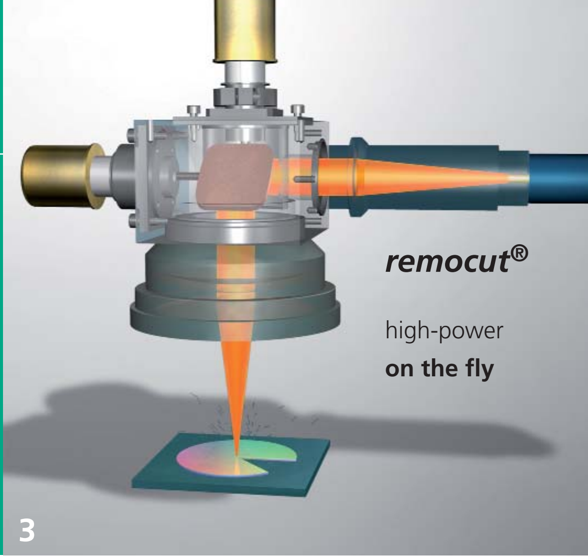
These composite materials consist of a polymeric matrix filled with high strength and stiff fibers, which makes them hard to cut since the individual material components have very different physical and substantial properties. This is true not only for the mechanical processing and water jet cutting, but also for thermal cutting processes. Key issues for the mechanical processing are tool wear and the general force impact on the component. The application of water jet cutting processes is limited with respect to accessing curved surfaces. The process also tends to delaminate the lowest fiber layers.

A conventional gas assisted laser beam cutting process leads to a shift of the geometrical boundaries of both components of the composite material. The drastically different melting temperatures of fibers and the matrix material cause this problem. Depending on the type of material a completely cut fiber layer may lead to more or less damage of the matrix. The matrix material is mostly evaporated or burnt in the region affected by the heat. The adhesion reduces between the laminated layers, which deteriorates the tensile shear strength of the material. These considerations require the development of new flexible and process efficient technologies.

OUR SOLUTION

Fraunhofer IWS engineers demonstrated a clear quality improvement when laser processing polymer-based high performance fiber reinforced composites using a highly dynamic beam deflection technique. This technique rapidly projects the laser beam onto the material via quickly adjustable mirrors. Since the weight of the mirrors is very low they can be actuated with galvanometer scanners and maintain high precision even at high path velocities. Accelerations of several 10 g are possible.

The very high processing speed leads to a very short interaction time between laser beam and material. This results in a drastically reduced damaging of the matrix material compared to classic gas assisted laser cutting processes.

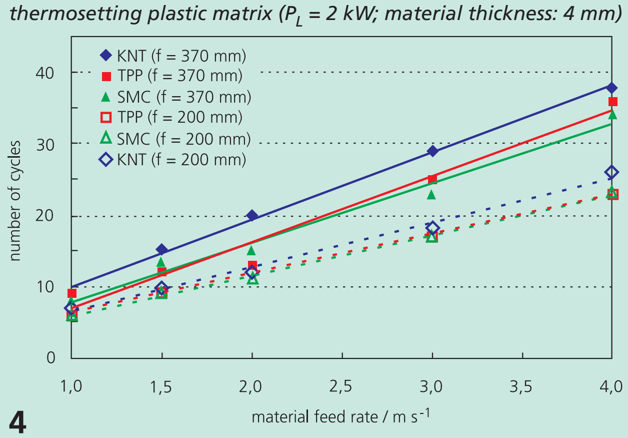


RESULTS

The shortened interaction time between laser beam and composite reduces the evaporation and carbonization of the matrix material, which leads to better ablation and cutting results. When using kW range lasers the ablation rates can be as high as several 100 µm depending on the material thickness and composition. Subsequently there is cyclical material ablation necessary when the material is several millimeters thick. The number of cycles to fully cut the material depends primarily on the beam focus intensity and the ablation rate.

Number of cycles as a function of material feed rate and aperture for various glass fiber reinforced polymers

KNT, TPP: long glass fiber + PP matrix; SMC: short glass fiber + thermosetting plastic matrix (P_L = 2 kW; material thickness: 4 mm)



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The fast beam scanning technique also allows cutting small structures or bores into the fiber reinforced composite materials at high speed and quality. It is also possible to actively couple the motions of the processing optics and other handling systems such as industrial robots. This approach is used to efficiently process complex 3D parts.

1/2 Cutting joints of a glass fiber PP composite after cutting with highly dynamic beam scanning

3 Principle of a high speed beam scanning

CONTACT

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INDUSTRIAL APPLICATIONS OF REMOTE CUTTING

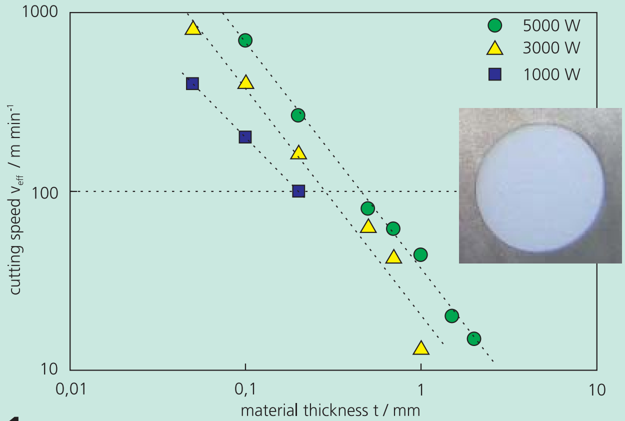
THE TASK

The enormous potential of remote cutting to cut metallic materials is based on its contour cutting speed of 800 m / min. The excellent beam quality of the laser guarantees highest intensities and thus does not require cutting gases in cw operation. The beam is manipulated via a highly dynamic mirror beam scanning system. An F-Theta plane field lens keeps the beam focus in the processing plane. The Fraunhofer IWS presented a laser processing machine using this technology at the LASER 2009 conference in Munich (Figs. 2 and 3).

A new 5 kW single mode cw fiber laser was used to demonstrate the cutting of 1.3 mm thick stainless steel (1.4301). The cutting speeds can reach up to 44 m / min with 1.0 mm thick material (Fig. 1).

The question is whether it is also possible to reach these processing speeds for any type of contour. Particularly challenging for the beam scanning system is the cutting of small radii and of rectangular corners.

Cutting of stainless steel 1.4301 as a function of material thickness and cutting speed (single mode, 25 µm fiber diameter)



1

OUR SOLUTION

From previously performed remote cutting experiments it is well known that one should not reduce the cutting speed during the process below a critical minimum. This is necessary to avoid undesired melting and incomplete cutting effects. This critical minimal cutting velocity is in the order of several m / s. This speed has to be maintained during directional changes as well. Thus the known concept of implementing delay times is not practical in this case. The solution is the addition of run-in and run-out phases as well as the combination of cw and modulated operation mode.

2

3

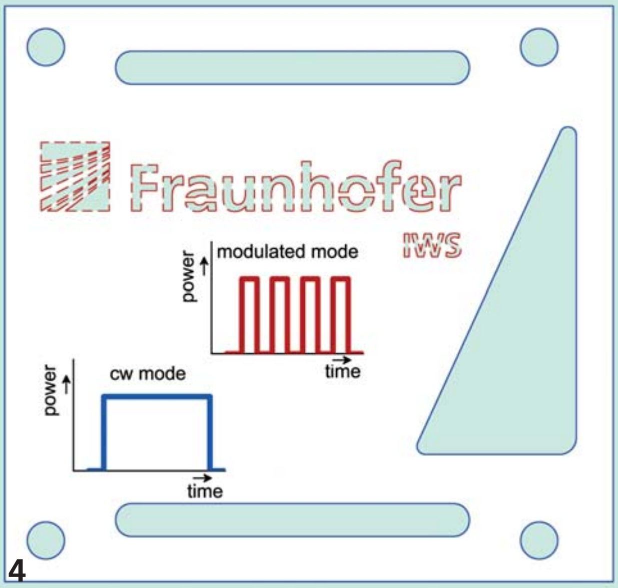
RESULTS

The addition of run-in and run-out phases maintains the critical process speed along the desired cutting contours by performing the necessary accelerations and delays. Depending on the desired contour the laser can be left on or off during these phases. In particular when creating inside corners the laser is turned off.

The used laser can quickly change between cw and modulated operation mode. The combination of both operating regimes offers a second possibility to increase the effective contour cutting speed in particular for components with detailed cutting geometries (Fig. 4). During all long distance cuts we operate the laser in cw mode to minimize the cutting time. During the cutting of short sections and fine contours we switch to modulated operation.

For example, the part shown in Fig. 4 has long sections in the outer contour and large inner geometries such as slit holes and circles, which were cut in cw mode. On the other hand, the structures of the Fraunhofer logo were cut using modulated operation. Since these geometries consist of relatively short cutting lengths their overall processing time is correspondingly short. Only by combining the cutting modes it was possible to achieve overall very high processing speeds.

An optimization of the processing of this part geometry was achieved by combining cw and modulated modes of laser operation.



4

2 Remote cutting system

3 Process photograph

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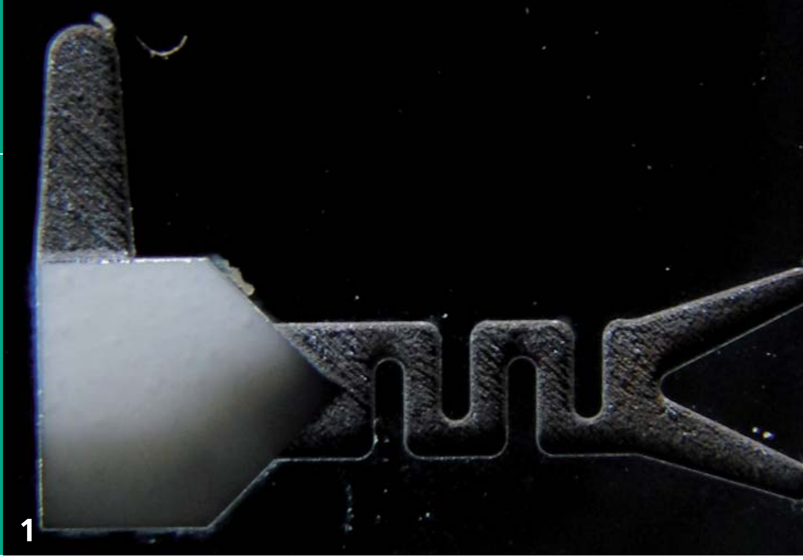

1

LASER BASED FABRICATION OF GLASS-SILICON-GLASS MICRO REACTOR SYSTEMS

THE TASK

Lab-on-a-chip and micro reactor systems are highly miniaturized, automated and designed to implement complex chemical and biological processes at a minimized technical and personnel effort. In addition to the low investment and operational costs these systems are also very compact and easy to operate in terms of process parameters. By fabricating specific complex structures it is possible to simulate certain microscopic environments.

These systems are becoming increasingly important for many applications in point-of-care diagnostics, active substance research and development, individual medicine and the testing of substances. Examples include diagnostic systems for marker detection such as DNA and antibodies. Of particular interest are testing systems to characterize cell and tissue reaction to certain substances.

OUR SOLUTION

Micro reactor systems need to be mechanically and chemically stable over a wide range to cover a large spectrum of experimental parameters. The material combination of glass and silicon offers excellent properties for this challenge. For example, when using glass and silicon the reaction zones are optically accessible.

Photolithographic processes are very well established to structure both materials. This technology requires at each vertical level a separate photo mask to expose the photoresist. Mask fabrication implies high system costs at a low production volume. Thus as an alternative fabrication process we implement laser based prototyping concepts, which are particularly beneficial to small series production requirements.

A CAD/CAM approach is utilized to implement the entire fabrication sequence from the 3D computer model to the final micro reactor system. The fabrication of the systems occurs layer-by-layer applying the various micro-structuring techniques based on laser processing. These include the cutting, structuring and the polishing of the materials.

The online monitoring of chemical and biochemical processes requires integrating sensors into the systems. These are created using PVD coating deposition techniques and laser fabricated shadowing masks. Laser bonding processes achieve the fluid-tight bonding of glass and silicon. The results are comparable to those known from conventional anodic bonding processes. It is also possible to bond these materials using biocompatible adhesives.

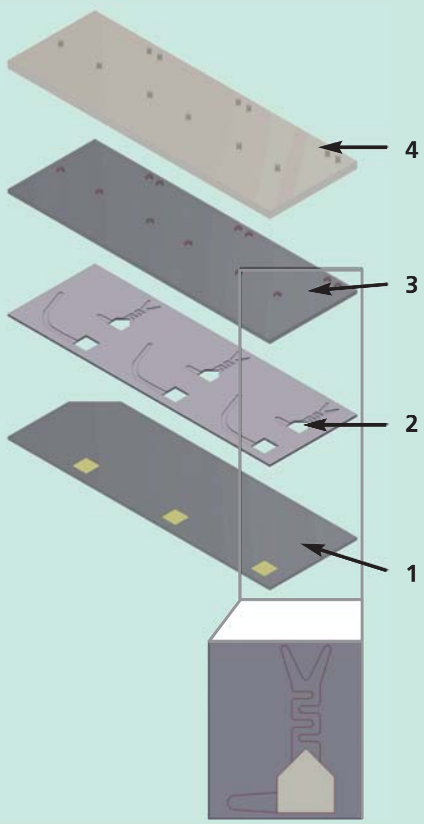
Fig. 2 shows the layer system. A glass layer forms the substrate of the system, which may be equipped with various sensor elements. On top of the glass substrate follows a silicon carrier with reaction zones, cavities, micro channels and micro actuators. Finally another glass layer covers the system. This layer contains the fluidic contacts of the system. Polydimethylsiloxane (PDMS) reservoirs form storage capacity.

RESULTS

The implementation of the discussed fabrication sequence enabled us to prototype and manufacture small series of micro reactor systems. At the Fraunhofer IWS we developed a system to photometrically monitor concentrations of lactate dehydrogenase. The system is partially automated and can be operated in different modes. The reaction controls the vitality of biological systems. The design was implemented on a silicon substrate and put into operation (Fig. 1).

Pharmaceutical screening represents an additional application area for micro reactor systems. We developed an especially adapted design to create cell assemblies, which as accurately as possible reflect the actual biological arrangement. This method can be used in the field of substance testing to sustainably predict the effect of these substances on humans. The micro reactor systems are also useful for the chemical industry. Here, due to the simplified handling of process parameters, critical reactions can be more easily implemented and monitored. The approach also significantly reduces the required amounts of catalysts since they only have to act upon very small volumes.

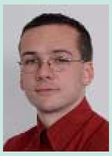
Layers of a micro reactor system:
- *glass layer with various sensor elements (1)*
- *silicon carrier with cavities (2)*
- *another glass layer containing the fluidic contacts (3)*
- *seal (PDMS) (4)*



2

1 *Laser structured silicon substrate with channel structures and cavity*

CONTACT



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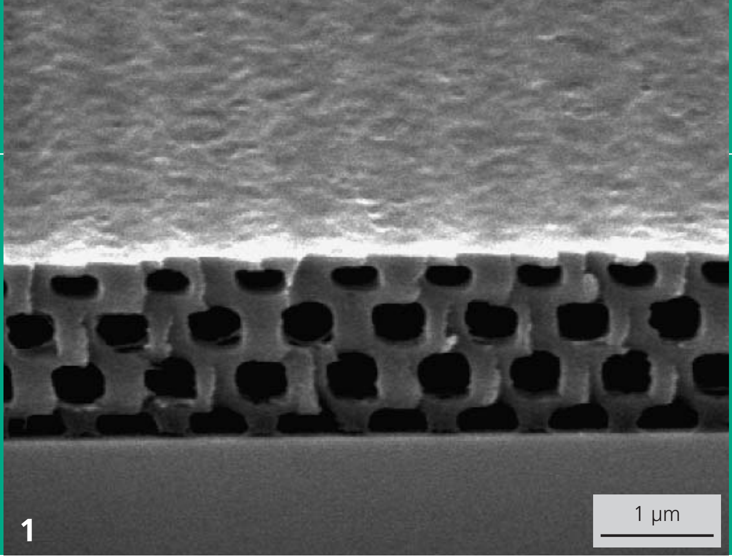


1

FABRICATION OF PERIODIC MICROSTRUCTURES ON METAL SURFACES

THE TASK

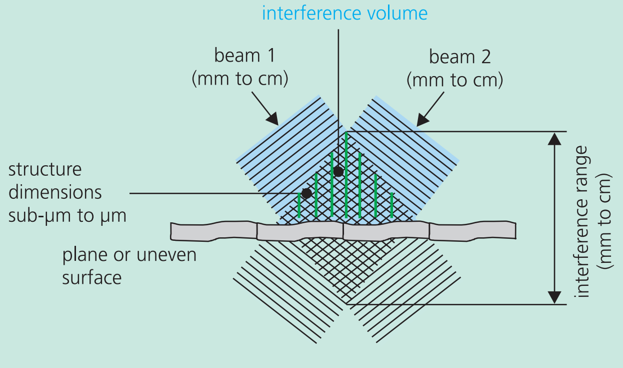
Various industry segments are increasingly interested in applications of periodic micro- and sub-microstructures on surfaces. Applications were developed in biotechnology, photonics and tribology. Surface structures, for example, can improve the tribological properties of surfaces. They can also be applied to tailor the biocompatibility properties of materials used in medical technology applications. However, currently there is no industrial process available to efficiently fabricate these structures over large areas at high speeds.

Here the Fraunhofer IWS offers a powerful and competitive process for direct surface structuring. Compared to conventional patterning methods it generates a large number of topographically complex structures. It is highly precise and can be applied to almost any part geometry. Thus this method is suitable for industrial applications.

OUR SOLUTION

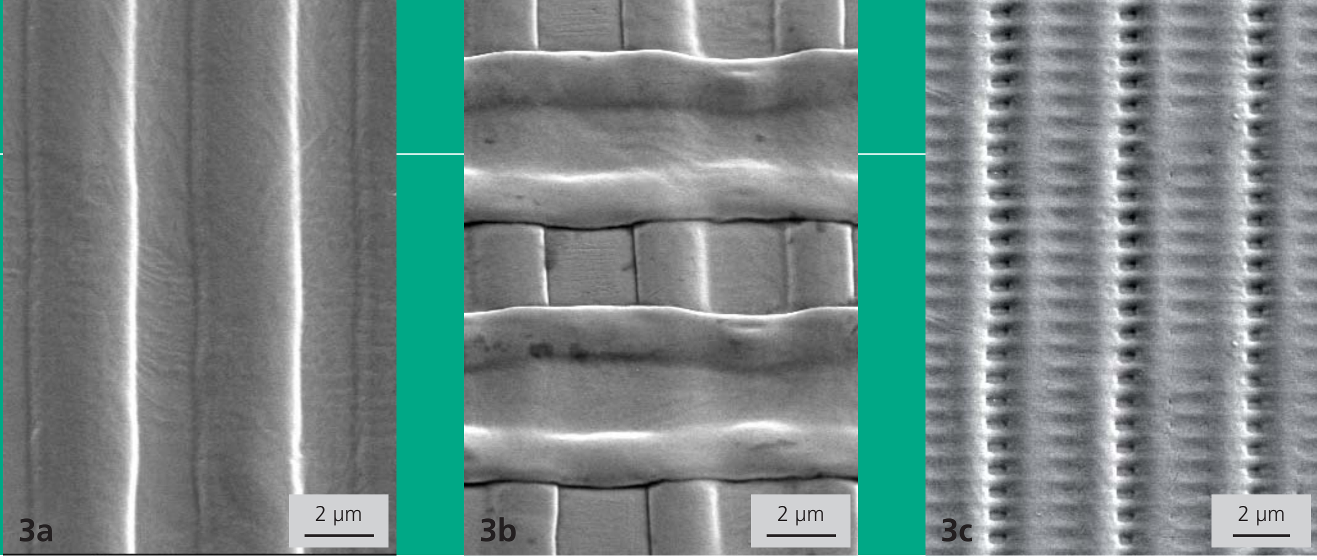
Direct laser interference patterning (DLIP) is used to produce 2- and 3-dimensional microstructures on all kinds of surfaces and part geometries. To synthesize an interference structure N collimated and coherent laser beams are superimposed onto the surface. The process provides the extraordinary opportunity to create structures on plane as well as uneven surfaces (Fig. 2).

Principle schematics of the direct laser interference structuring with two laser beams



2

A q-switched Nd:YAG laser with a fundamental wavelength of 1064 nm is used to generate wavelengths of 532 nm, 355 nm and 266 nm to precisely process polymers, metals, ceramics and coatings. By adjusting the parameters, this technique applies various metallurgical processes to the surface such as melting, healing, defect and phase formation. Electrical, chemical and / or mechanical surface properties are periodically varied by controlling the number of pulses and the pulse energies. Thus the structured surfaces show micro and nano characteristics over a macroscopic area. DLIP surface structuring is a fast process. It can treat several square centimeters per second where other techniques require hours or even days to achieve the same results.

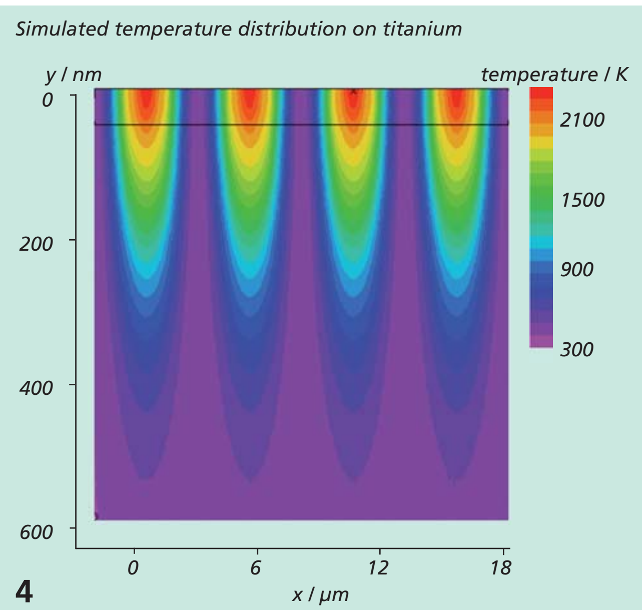


RESULTS

When using sufficient energy densities the direct laser interference patterning process will melt metal surfaces at the locations of the interference maxima. Due to the strong surface tension gradient, the melt will solidify alongside the interference maxima regions directly after the process. Thus the temperature difference between the surface regions exposed to interference maxima and minima generates patterns of varying material properties.

The thermal properties of the material determine the required laser parameters as well as the details of the resulting surface structures. Fig. 4 shows, for example, the simulated temperature distribution as it is generated on titanium, when using a laser pulse with an energy density of 0.5 J / cm^2 and a periodic structure of 5 µm. The temperature difference between interference maxima and minima is almost 2000 K.

Applying a two-beam interference process to titanium samples created the periodic surface patterns shown in Figs. 3a - c. These structures were created using a pulse with 0.5 J / cm^2.



The patterns shown in Figs 3b and 3c consist of overlapping structures of orthogonal lines. To fabricate these patterns we sequentially applied two interference patterns while rotating the substrate 90° between the applications.

Thus DLIP is for example an excellent method to fabricate tailored surface structures on biomedical implants with the goal to control the cell growth direction. In the same simple fashion one can functionalize component surfaces for tribological applications.

1 *Micro channels with highest aspect ratios in photo polymer material*

3 *SEM micrographs of patterned titanium surfaces*

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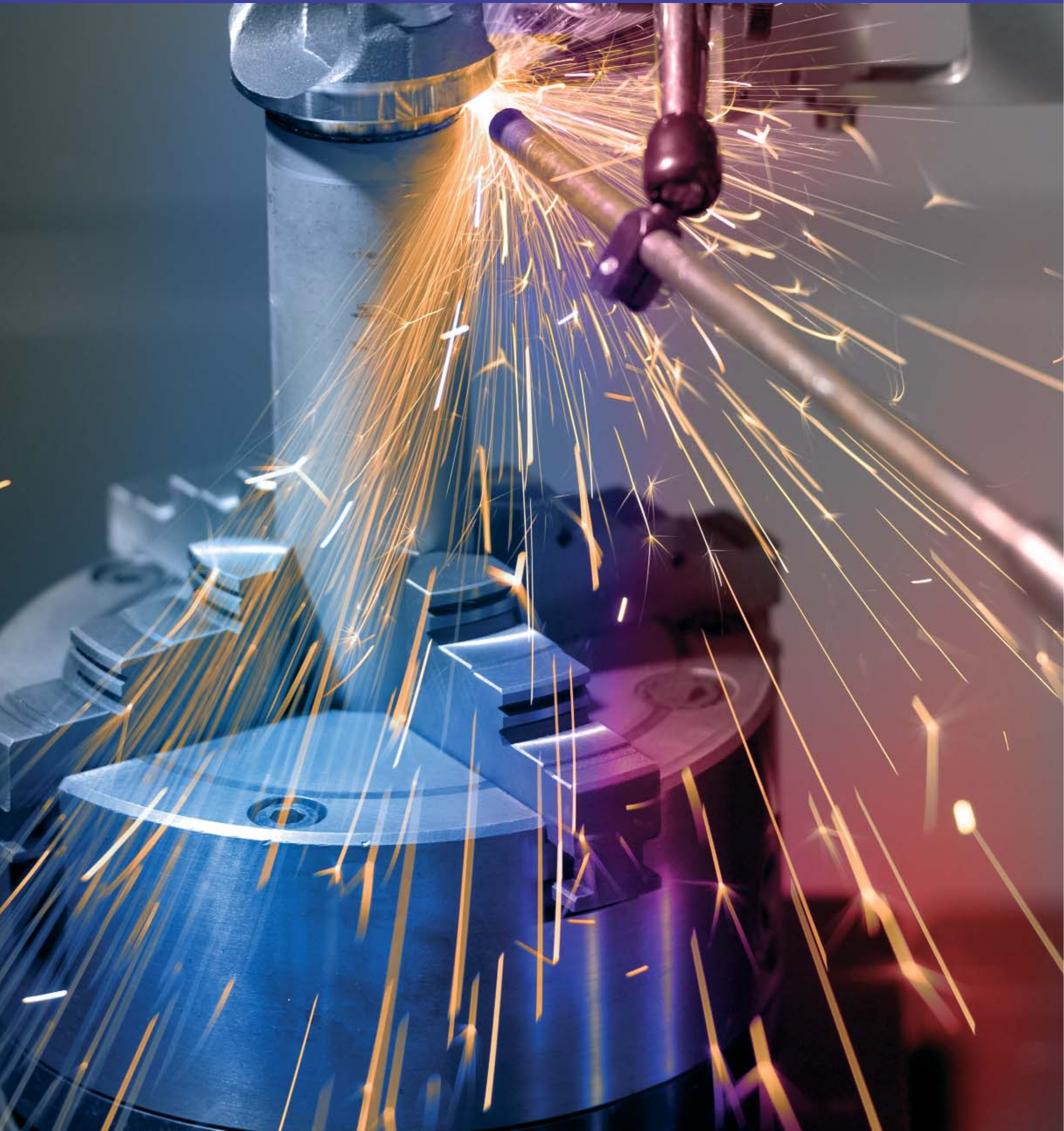

BUSINESS FIELD JOINING

Editor: The welding of vehicle powertrain components has been a core competence in your department for many years. However, more recently and in particular during the last year, it became evident that the automotive industry is facing dramatic challenges in a dynamically changing ecological and commercial environment. Customer expectations have substantially shifted. Thus we have to ask the question whether or not your unique expertise is still relevant in this context?

Prof. Brenner: The answer is a clear "Yes". This shift in industry is actually significantly increasing the demand for high quality, well automated, cycle time compatible and simultaneously cost reducing joining solutions. These solutions are required for lightweight vehicle manufacturing, for high performance joints in powertrain applications, for new and so far not sufficiently available material combinations and for the welding of electrically functional materials as well as in combination with mechanically functional elements.

The new joining techniques and process variations include the scanner welding with solid state lasers of highest brilliance, the various combinations of laser beam welding with process integrated inductive heating, laser beam welding with material adapted filler material, the friction stir welding, laser induction roll plating and the joining with electromagnetic pulse. In a publically funded program we develop jointly with partners from the automotive and laser industries scanner welding processes using high brilliance lasers. As a result, we anticipate a substantial expansion of the material selection that can be crack free welded without having to give up the manufacturing advantages of using laser technology.

The melting metallurgy of some material combinations cannot be controlled without a standard process portfolio. Conventional melting based welding processes for example are not usable to join materials such as stainless and construction steels, steel and aluminum, steel and copper or aluminum and titanium. However, these material combinations are needed for components and "transition joints". Therefore we develop laser induction roll plating processes to manufacture semi-finished parts from these difficult material combinations. These thermo-mechanical and mechanical processes are important to us. That is why we established a new workgroup based on "Special Joining Techniques".

Editor: Speaking of friction stir welding, a number of research institutions worldwide have been working on this technology for quite some time. Where do you as a newcomer see your chances and new approaches?

Prof. Brenner: Our approach is new in several aspects. First of all we are using a top of the line and especially equipped Pentapod milling machine tool with parallel kinematic motion principle. This is a type of tool with intriguing advantages based on the simplicity of its machining technology and a very high stiffness. The machine is characterized by a minimal amount of moving weights, a large workroom to physical volume ratio, a very energy effective machining process, a very good capability for 3D processing etc.. In terms of developing work we are aiming at industrially interesting integrated manufacturing flows. An example is the process sequence of milling to prepare the seam, laser beam welding for tacking and friction stir welding for the joining. All these steps are to be performed in one and the same machine if not even in one setup. We are especially delighted to have very interesting German aerospace industry projects lined up which require exactly this kind of technology.

COMPETENCES

WELDING OF HARD TO WELD MATERIALS

The modern laser beam welding process is broadly employed in particular in industrial high volume manufacturing environments. The integration of laser beam welding with short-term heat treatment and adapted filler materials provides a new approach to crack free welding of tough materials such as hardenable and high strength steels, cast iron, aluminum and special alloys as well as parts of high stiffness. Based on a comprehensive background in metal physical processes and system technologies we offer the development of welding technologies, pro totype welds, processes and system optimizations as well as the development of welding instructions.

SURFACE PRETREATMENT AND CONSTRUCTIVE ADHESIVE BONDING

During adhesive bonding process flows it is common to prepare the surfaces of the parts to be bonded. The treatment improves the wetting of the surfaces with the adhesive and ultimately the mechanical strength of the bond. At the IWS we focus on the development of pretreatment processes based on laser and plasma techniques. The pretreated surfaces as well as the bonded compounds are characterized by contact angle measurements, light microscopy, SEM / EDX and spectroscopic methods. A new direction aims at the integration of carbon nanotubes into the adhesives. This may improve the bonding strength and / or the manufacturing of electrically conductive compounds. Our offered services include pretreatment processes, surface characterization, constructive adhesive bonding of various materials and the determination bonding strength and aging.

SPECIAL JOINING TECHNOLOGIES

Conventional melting based welding processes are frequently insufficient to join modern functional materials. In the case of metals, this is for example true for many high strength aluminum alloys. The problem is even more difficult in the case of joining different metals such as aluminum and copper. Typically the melt forms intermetallic phases that drastically reduce the strength. Therefore at the IWS we develop new processes that avoid melt formation and the associated issues. Our primary focus is on friction stir welding, laser beam soldering and the electromagnetic pulse welding. We offer process development and prototyping services in these areas.

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2

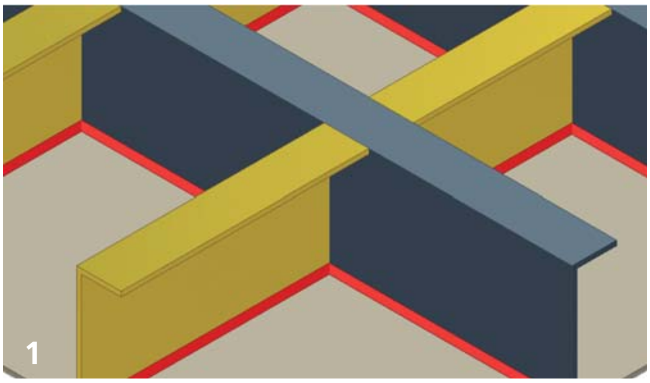
LASER WELDED INTEGRAL STRUCTURES FOR RAILROAD VEHICLES

THE TASK

Railroad vehicle assemblies such as the sidewalls of railroad cars are currently manufactured in a differential construction process. The connection of the outer skin sheet metal to the stiffeners is typically accomplished via point welds in lapped joints.

At the Fraunhofer IWS we have the goal to develop a novel fabrication method based on a design with a complete connection to the stiffeners based via integral construction (Fig. 1).

The advantages of this design are substantial weight reduction and increased structural strength and stiffness. Simultaneously laser beam welding of the metal skin to the stiffeners minimizes warping. This new approach presents as very economical manufacturing method.



1

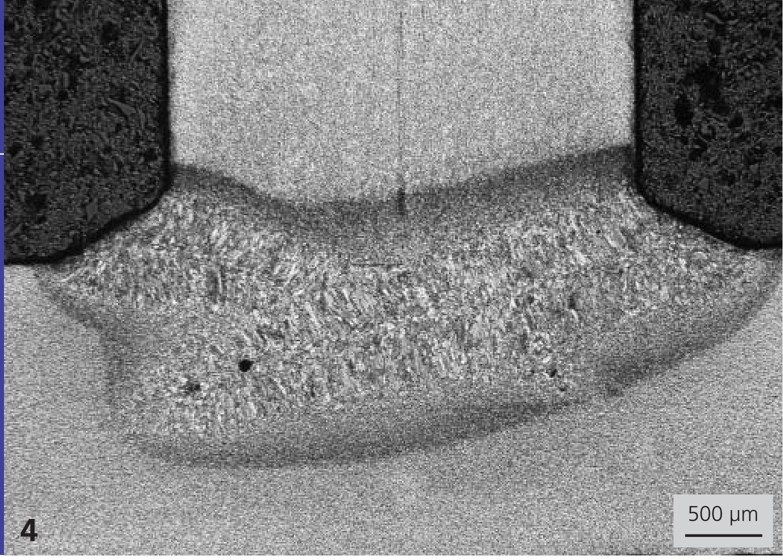
OUR SOLUTION

The basis of this integral construction method is the T-joint. Compared to the original lapping joint the T-joint significantly reduces weight by saving the overlapping material. Such a construction also allows the use of less complex stiffeners (L-profile) and a simplified dimensioning of the integral nodes (connections of the stiffeners with each other).

To fabricate these welding joints we developed a special technology. Dual laser beams under low incident angles are applied to simultaneously weld stiffener fins from both sides (Fig. 2). In areas with limited accessibility or zones of reduced quality requirements it is possible to apply single sided welding to achieve full connection. The key objective for designing the process is to achieve a complete connection of the fin cross section at minimized heat exposure of the material.

Current laser welding process speeds exceed 4 m / min. If consequently utilized, this process taps into an immense potential to save manufacturing time. Welding sequences are optimized for long uninterrupted welding paths, which leads to a marked reduction in auxiliary process time.

3



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At the Fraunhofer IWS we use a highly modern and large portal plant to process parts up to dimensions of 10 m x 3 m. The base plate is held by a vacuum-clamping jig. A process-integrated mobile clamping jig accomplishes the exact positioning and fixation of the elements to be welded. The welding head is sensor controlled, which guarantees a stable welding process and a constantly high weld seam quality.

RESULTS

The developed integral manufacturing process markedly improves the properties of sidewall elements for railroad cars if compared to the original differential method (Fig. 2). The advantages are:

- reduced part weight,
- constantly high weld seam quality,
- improved structural stiffness and strength,
- low part warpage due to minimal heat exposure,
- minimal angle warpage due to symmetrical welding,
- improved corrosion resistance due to avoidance of gaps,
- minimally affected surface quality on the visible side of the sidewall.

As a result of the developed laser welding technology it is possible to manufacture assemblies at high quality and reproducibility and in minimal time. The application of an integrated clamping technique avoids the need for a pre-tacking step.

2 Double-sided simultaneous laser beam welding of lateral fins

3 Laser beam welded integral structure of 1.25 m x 1.25 m and the principle of the integral construction of car sidewall structures for railroad vehicles

4 Cross section of a double-sided welded T-joint

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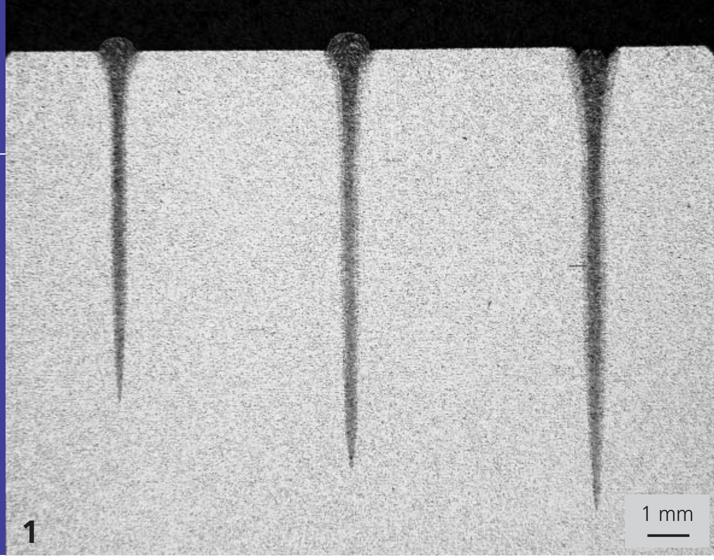


1

LASER BEAM WELDING WITH 5KW SINGLE MODE FIBER LASER

THE TASK

The 5kW single mode fiber lasers represent the latest development level in commercially available highly focusable laser beam sources combining high laser power with extreme beam quality. A beam parameter product of 0.5 mm·mrad and a fiber diameter of 30 µm lead to focusing and intensity conditions, which are comparable to or even exceed those of electron beam welders. The question is how to best utilize these features in laser welding applications.

First preliminary investigations aim at determining the process limits and potential applications.

OUR SOLUTION

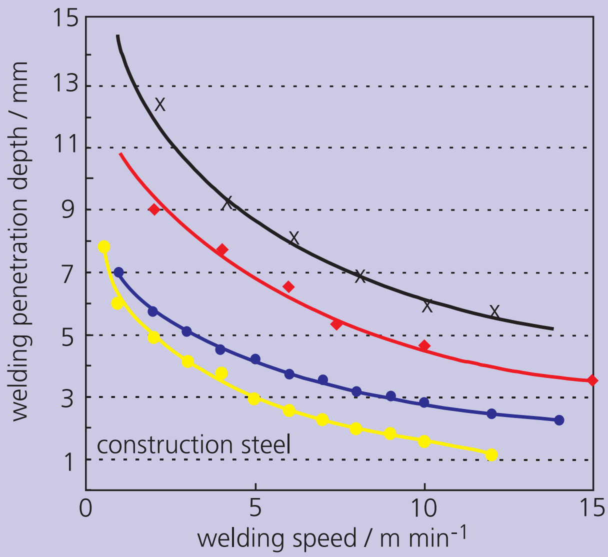
To compare laser systems, we use welding penetration curves. Laser beam penetration depths into a material and weld seam cross sections as a function of path energy and focus location are compared. The process stability is investigated based on flushing the optical path after focusing and analyzing its influence on the welding penetration depth.

The 5 kW single mode fiber laser is equipped with a standard collimator (aperture f_{coll} = 200 mm). The welding penetration depth experiments were performed at apertures of 300 mm and 500 mm. Un-alloyed constructions steels and naturally hard aluminum alloys were used as test materials.

RESULTS

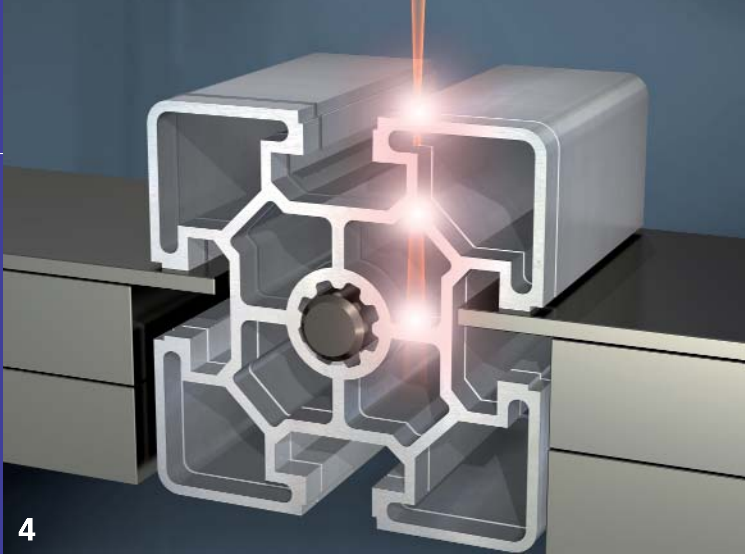
The new laser increases the welding penetration depth by more than 30 % (Fig. 2) compared to a 4 kW multi mode fibers laser (fiber diameter 50 µm, beam parameter product 2 mm·mrad).

Welding penetration depth for various laser types with different beam qualities (f - aperture, d_f - focus diameter)



X fiber laser, 4,0 kW, f = 300 mm, d_f = 30 µm, BPP: 0,5 mm·mrad
◆ fiber laser, 4,0 kW, f = 300 mm, d_f = 125 µm, Bpp: 2,0 mm·mrad
● disk laser, 4,0 kW, f = 200 mm, d_f = 200 µm, BPP: 8,0 mm·mrad
● fiber laser, 4,0 kW f = 200 mm, d_f = 510 µm, BPP: 18,5 mm·mrad

2



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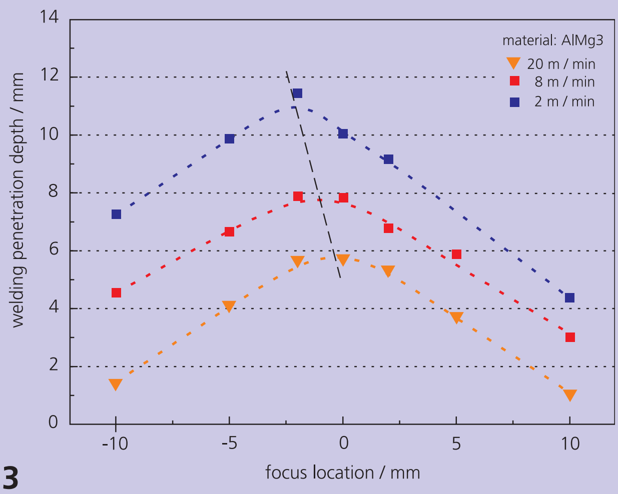
The weld seams are characterized by an extremely high aspect ratio and the seam flanks are very parallel. Strong welding penetration depths fluctuations were observed for low welding speeds ("spiking"). At such a high beam quality the intensity on the part surface has a strong influence on the welding penetration depth. Through experiments with a varying focus location and at a measured Rayleigh length of about 1.4 mm (at f = 300 mm) this becomes obvious. The highest welding penetration depths in aluminum were achieved with a focus location within the part (Fig. 3).

Welding penetration depth as a function of focus location for aluminum AlMg3 (5 kW laser power)



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Highly focusable laser beam sources such as the 5 kW single mode fiber laser investigated here are an excellent choice for the welding at hidden welding positions. In a first test we welded in a single pass simultaneously two lapping joints with focus locations 40 mm apart. The total sheet stack thickness was 8 mm with individual sheets being 2 mm thick. This implies substantial technological advantages for clamping, handing and process time.

1 *Welding penetrations in unalloyed steel at 5 kW with focus positioning at the surface, from left to right: 8 m / min, 6 m / min, 4 m / min*

4 *Possibility of welding at hidden weld positions with lasers of highest beam quality*

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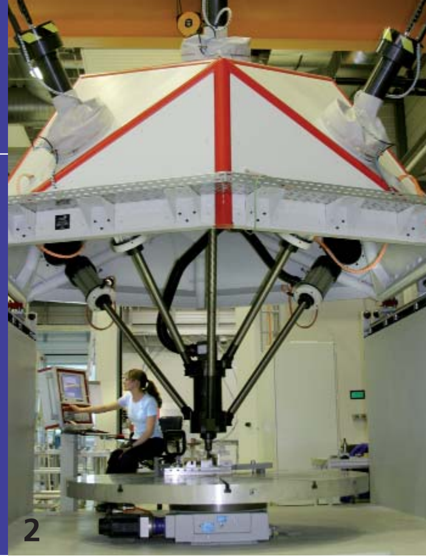


2

PENTAPOD MACHINE TOOL FOR WELDING AND HYBRID TECHNOLOGIES

THE TASK

An important component of Fraunhofer IWS project work is the transitioning of processing and technologies to industrial manufacturing. Customer desires to overcome current technical limitations and their wishes for greater flexibility in using existing manufacturing equipment and for lower investment costs require new ideas and concepts for machines and system technologies. The development presented here was initiated during a feasibility study. The goal, the reconditioning of gas turbines on site, was impossible to achieve with conventional system technology. Inquiries from the aerospace industry also indicated a deficit in the available machine concepts. Therefore the following objectives had to be fulfilled:

- precise 3D processing of large parts with a length exceeding 10 m including the option of laser beam welding at depths of up to 20 millimeters,
- optional friction stir welding,
- integrated seam preprocessing (precise milling of the seam forming edges) without changing the part clamping,
- quick and easy alternation between milling and welding,
- optional mobile use of the process (on site processing at construction site) with low time and cost effort for transport and setup of the system.

OUR SOLUTION

The solution is based on expanding the application areas of a so-called Pentapod milling machine tool. Such machines are based on a parallel kinematic principle and need to move much less weight (about 10 %) than conventional CNC machines with similar working room, stiffness and positioning precision. Typically these machines are stationary (Figs. 1, 2). However, a proper modular design can transform them for mobile applications.

The IWS developed laser beam deflection optics (SAO series) was adapted to be used in Pentapod machines as an interchangeable tool. The optics is simply moved into position just like a conventional milling cutter. As a result these machines can now easily switch between milling (for example to prepare the seam) and welding operations. Fraunhofer IWS engineers also developed a multi layer narrow gap welding process, which is used for the mentioned large welding penetration depths.

In addition to laser beam welding the Pentapod is also applicable for friction stir welding applications (Figs. 3, 5). Again, the flexibility of using different processes proves advantageous: the combination with milling and laser welding helps to overcome known limitations of friction stir welding. For example, the friction stir welding process requirement of high contour precision can also be achieved for less precise parts by a preprocessing milling step. There is also the risk of shifting parts due to the high processing forces. A preprocessing laser tacking step reduces this risk. Gap formation and warpage are minimized when processing low stiffness structures such as aircraft fuselage structures.

3

4

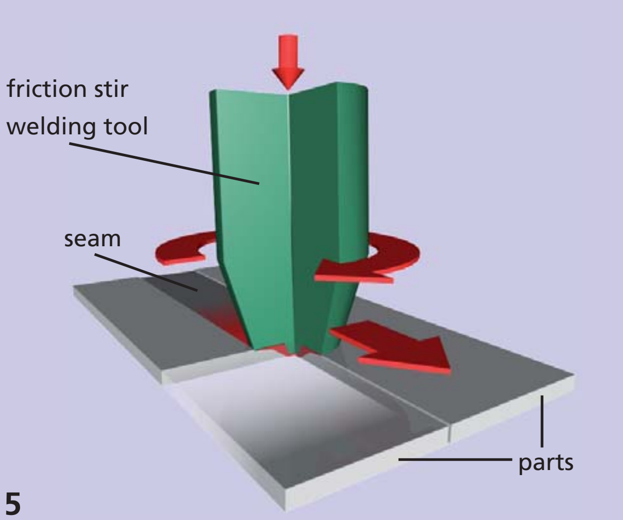
We also envision thermal and mechanical post processing steps for example to improve the long-term vibration strength by introducing compressive stresses or better material microstructures.

RESULTS

At IWS laboratories we demonstrated the feasibility to expand the Pentapod concept to new joining and process combinations as well as mobility. We used an equally easy to transport fiber laser. Fig. 4 shows examples of tools that can be interchangeably used in the machine: a laser welding head, a milling cutter and a tool for friction stir welding.

Recently the IWS received substantial funding from the State of Saxony and the EU to invest in a large field Pentapod machine (workroom 5 x 2 x 2 m^3) for in-house development work (Figs. 1, 2). The goal is to develop further process technologies and to introduce the concept to the aerospace industry.

Principle sketch of friction stir welding



5

1 *Outside view of the new stationary large field Pentapod system at the Fraunhofer IWS*

2 *Large field Pentapod with far extended main spindle*

3 *Deployment of the stationary system for the friction stir welding of aluminum structures*

4 *Adapted beam deflection optics as an interchangeable tool for the Pentapod, as well as milling cutter and a friction stir welding tool for comparison*

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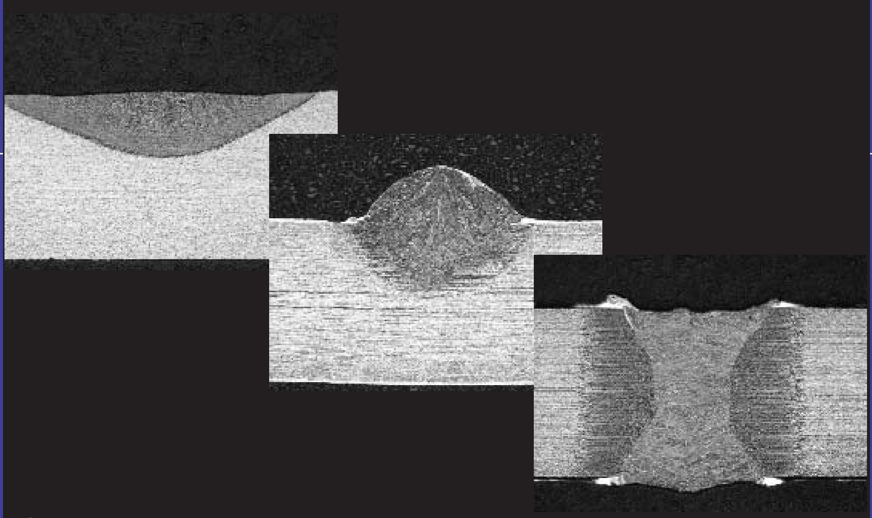


1

LOCALIZED LASER STRENGTHENING TO IMPROVE CRASH BEHAVIOR

THE TASK

Car body makers are increasingly implementing innovative lightweight construction concepts to effectively use resources and effectively decrease environmental issues. Many of the developed solutions are based on high strength materials such as cold hardened multi phase or press hardened steels. However, the processing of such high strength materials is very challenging in manufacturing. This is in particular so for:

- manufacturing process difficulties such as reduced forming capacity of high strength materials or of welded semi-finished parts and the limited weldability of high strength materials,
- increased forming forces, uncontrolled rebound behavior and unfavorable cutting conditions,
- and finally a limited loading capacity of the parts as a result of the complex material strain during fabrication.

The listed problems cause increased production efforts and considerable manufacturing uncertainties. They limit product properties and can lead to enormous cost increases.

OUR SOLUTION

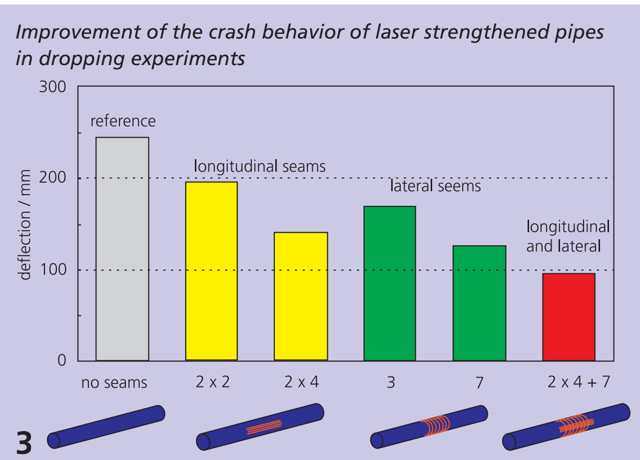
One approach in car body manufacturing is to introduce localized material strengthening only during the assembling step. Processes such as localized hardening, penetration welding and buildup welding can be used for hardenable steel sheet metals. High power lasers with corresponding beam shaping are very promising when it comes to requirements such as precise heat exposure and a modulated temperature field.

The goal is to modify the material's microstructure in part areas that are exposed to high operational loads. The following advantages are envisaged:

- improvement of part properties during operation (increased loading capacity by increasing the structural strength; optimized stress distribution and thus reducing the local strain in loading points of the body; load adapted part design and thus reduction of the total weight),
- improvement of the crash behavior and thus increasing the vehicle safety by increasing the locally tolerable loads, increase of the absorbable deformation energy, realization of controlled part failure,
- reduction of manufacturing costs through reduced fabrication efforts (parallel utilization of existing laser systems for welding in assembly and heat treatment, using of simpler and less costly semi-finished parts, realization of simpler forming and cutting operations).

RESULTS

Laser penetration welding is an advantageous manufacturing process and was applied to locally strengthen parts. The results showed a significantly improved crash performance. Compression experiments demonstrated a predictable part failure mode (Fig. 2).



Additional dropping experiments with laser strengthened pipes also showed a clearly reduced deflection (Fig. 3).

The localized laser strengthening process is thus capable of:

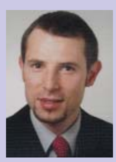
- generating part properties that are adapted to their specific and complex mechanical loading conditions,
- reducing the part weight by using thinner sheet metal,
- achieving high performance part properties while using low cost low strength steel qualities,
- being cost effective and flexible by using existing laser technology that is also used for other processes.

The research results were developed with the partners Volkswagen, IMA and FES within a SAB funded program.

1 Possibilities of localized strengthening of hardenable steels by laser hardening (top), buildup welding (middle) and penetration welding (bottom)

2 Laser penetration welding strengthened pipes show improved failure behavior during compression experiments

CONTACT



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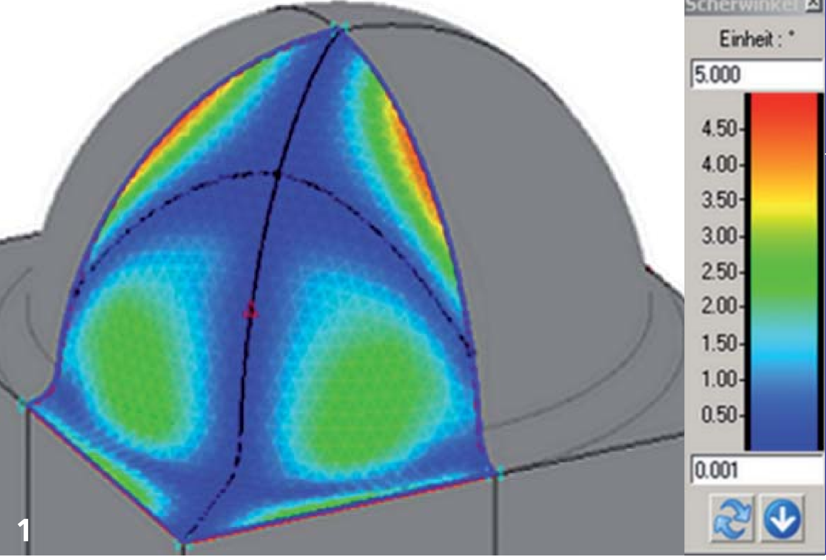

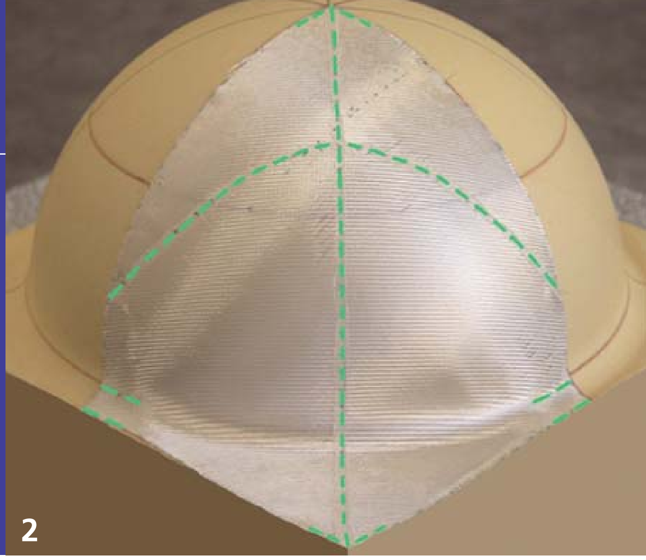

PREFORM FABRICATION FOR TEXTILE REIN-FORCED COMPOSITES

THE TASK

Compared to metallic materials, textile reinforced composites have interesting properties but also increased manufacturing costs. The fabrication of fiber reinforced composite materials is in particular for complex geometries cost effective using dry textile performs. Unfortunately, preform fabrication is not quite up to meeting the quality requirements in high technology areas. To make perform manufacturing more reproducible we aim at a process applying localized fixation with adhesive binders or laser radiation. This would avoid an undesired change of the textile semi-finished parts during the subsequent stapling and forming steps. However, this method must not limit the range of doable geometries and also should not have negative effects on the mechanical properties of the fiber reinforced composite material..

OUR SOLUTION

The draping behavior of the textile semi-finished parts was investigated using shear tests with shear frames. We also tested the properties of the composite using consolidated testing specimens with fixation (film stacking process) in a four-point bending experiment as well as in a test that reveals the apparent inter-laminar shear strength.

For the experiments involving adhesives, we used as reference materials glass fiber fabrics and the matrix materials polyester (PET) and polypropylene or glass fiber / polypropylene (GF / PP) hybrid yarn fabrics. Intensive literature search and experiments were performed to identify matrix compatible adhesives. The adhesives were applied either manually using varying nozzles or with robots.

In the case of the GF / PP hybrid yarn fabrics we also applied laser radiation for the fixation. The laser beam melts the PP yarn material and the fixation effect occurs after subsequent cooling. Initial experiments studied spectroscopically the absorption behavior of Nd:YAG and CO_2 laser radiation. Laser processing was investigated with fixed as well as robot coupled processing optics.

The reinforcement structures are designed for particular loads and it is critical to transfer them exactly to the 3D part shape without having to post process them. Thus the material precuts were tailored directly based on the model geometry. Inverse calculation methods were used to derive the precut shape from the 3D reference geometry. A subsequent distortion analysis served to find areas of little yarn shifts, spreads and angle changes, which could be used for local fixation (Figs. 1, 2). Thus, obstructions can be mostly avoided for shearing steps, which are necessary for the shaping process.

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3

RESULTS

The experiments revealed that the localized fixation does not create adhesion problems between the glass fiber and the selected adhesives. The spectroscopic laser process analysis also confirmed the expectations that CO_2 laser radiation would be more readily absorbed by the GF / PP hybrid yarn fabrics than Nd:YAG laser radiation. By selecting proper process parameters such as laser power both lasers can be applied to achieve the desired results. Shearing experiments of the treated material showed no adverse effects on the ability to drape the reference cuts if line-shaped fixation patterns are created. The composite tests lead to the conclusion that some adhesives maintain the mechanical strength of the material. There are several aspects to be considered in order to avoid negative effects. The binder has to be completely melt without leaving residues during the consolidation process. It also should not be thermally disintegrated and binder and matrix melts have to be compatible.

Both laser processes lead to slightly reduced loads in the bending test if compared to the reference samples. The reasons could be either damaging of the PP due to pyrolysis or destruction of the glass fibers. The pyrolysis effect cannot be removed if the Nd:YAG laser experiment is performed in a protective nitrogen gas atmosphere. We see additional possibilities to optimize the laser fixation process by using wavelengths with a higher absorption in polymers or by adding absorber materials to the matrix resin. Both the adhesive as well as the laser fixation processes can be implemented with robot technology.

After melt adhesive spray application the now fixated and intrinsically stable preform corresponds exactly to the desired geometry except for a changed thickness (Fig. 3). It can be easily removed from the forming tool and temporarily stored prior to the actual consolidation process. This leads to a reduced processing cycle time for the fabrication parts made from fiber reinforced composites.

This work was sponsored by the AiF in the program "Reproducible preform fabrication for textile reinforced composite materials" (IGF project Nr. 151 29 BR) and was performed in collaboration with the Institute for Textile Machines and Textile High Performance Materials Science of the TU Dresden.

1 Simulation to determine the fixation lines

2 Reference geometry

3 The finished preform on the forming tool

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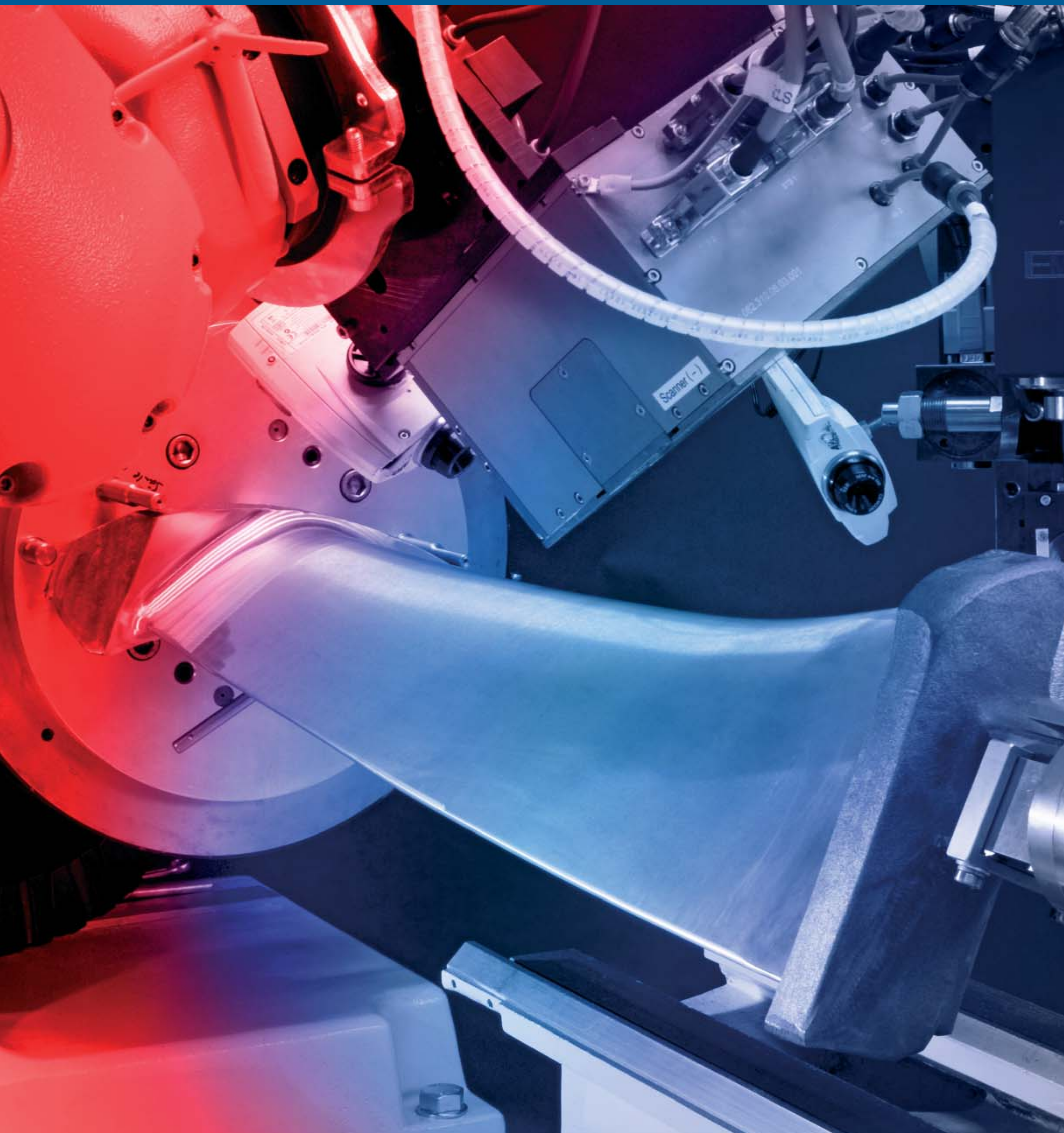
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BUSINESS FIELD SURFACE TREATMENT

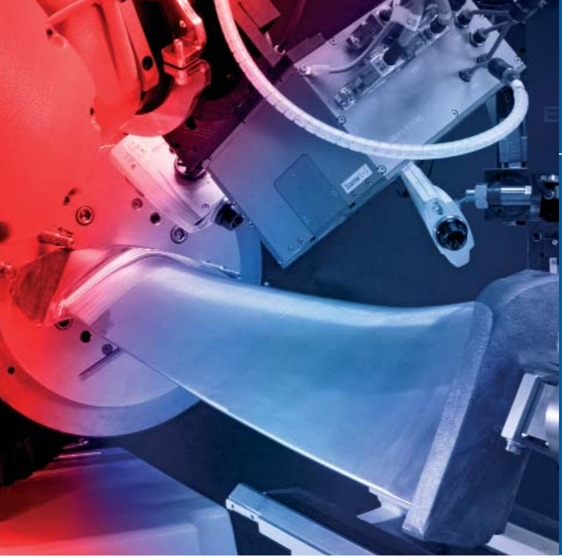
Editor: In recent years the business field of surface technologies frequently accomplished very interesting industrial technology transfer activities. How did the economic crisis affect this business last year?

Prof. Brenner: First of all I would like to point out that we are very grateful to our business partners that they continued to work with us during these difficult times. We consequently were able to accomplish industrial transfers at an unprecedented level. Simultaneously we are very glad that we could provide our customers with process and system technologies that made them more competitive in economically difficult times and that we could convince them that R&D expenditures during times of crises is well invested money. We tried hard to tailor our solutions even more precisely to the exact desires of our customers.

Together with IWS spin-off ALOtec GmbH we delivered a robot based laser hardening machine to a foreign customer. For the first time, this system was equipped with our flexible beam shaping optics LASSY and integrated austenitization temperature control technology. The further development of a high speed temperature control system for the laser beam soldering of solar cells was also very successful. Several systems were delivered and integrated into machines at industrial customer sites. The development of such system components is tightly linked to process development and simultaneously process development frequently generates the need for new system technology.

Editor: Can you explain this concept using an example?

Prof. Brenner: Absolutely. Last year we applied system technology know-how to build our own laser robot system for multiple purposes. This system is equipped with numerous add-ons that are otherwise not commercially available. It is equipped with a 5 kW fiber coupled high power diode laser with two exit ports for a 0.4 mm and a 1.5 mm fiber. Thus the machine can be used to develop processes for laser beam soldering as well as laser beam hardening, melting, gas alloying, soft annealing etc.. We have an in-house developed very flexible protection gas chamber, which can be used for many oxidation free thermal heat treatment processes. A very interesting industry project, we are currently working on, is a scaled up process for laser gas alloying of 3D curved parts. Another very special add-on is for rotational hardening inside surfaces of spheres. This is an interesting task, which has not been sufficiently accessible so far to laser and induction hardening. Our dual robot laser machine is used for development and industrial transfer activities of processes involving the double-sided simultaneous laser beam hardening of turbine blades without generating a heat-affected zone. Especially here we see many interesting industrial opportunities to surface treat without heat-affected zones large 3D curved parts with closed and also toward each other tilted hardening paths.



COMPETENCES

OPTIMIZED TECHNOLOGIES FOR THE HARDENING OF STEEL COMPONENTS USING LASER AND INDUCTION

The laser hardening technology offers new approaches to create wear resistant surfaces, where conventional hardening technologies fail due to limitations with respect to part geometries, failure modes and materials. This is in particular true for the selective hardening of parts with multi dimensional curved and inner surfaces that are difficult to access, for bores and notches, and for parts that easily warp. Based on many years of experience and interdisciplinary know-how we offer services from analyzing the failure mode to implement hardening technology:

- development of surface hardening technologies with high power diode lasers, CO_2 lasers, Nd:YAG lasers or induction or both,
- surface refinement of development and prototype samples.

COMPLEX MATERIALS AND COMPONENT CHARACTERIZATION

Mastering modern joining and surface processes requires knowledge about the occurring structural changes in the material and about the resulting part properties. Based on experience and an excellently equipped mircoanalytical and materials characterization laboratory we offer:

- metallographic, electron microscopic (SEM, TEM) and microanalytic (EDX) characterization of the material structure of metals, ceramics and composites,
- determination of material parameters for part dimensioning and quality assurance,
- property evaluation of surface treated and welded parts,
- strategies for the material and loading adapted part design,
- failure analysis.

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EXAMPLES OF PROJECTS 2009

FURTHER INFORMATION:

www.iws.fraunhofer.de/technologien/laserstrahlhaerten/e_tech03.html

www.iws.fraunhofer.de/branchen/bra05/e_bra05.html

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COMPONENTS FOR LASER SURFACE REFINEMENT

THE TASK

Hardening is a standard process to improve the wear resistance or strength of machine and vehicle parts made from steel or cast iron. Remelting and alloying are used for other metallic materials to increase the lifetime of loaded part areas. The localized application of these processes offers advantages with respect to the total heat exposure of the part and eventually also with respect to the overall energy consumption. Warpage related post processing can be avoided and energy costs can be reduced. A key objective is always the reproducibility and reliability of the manufacturing processes. This is in particular true for new machine installations. The successful implementation of reliable and reproducible hardening, surface alloying and remelting processes requires in addition to the laser machine system technical control components.

OUR SOLUTION

Over a period of ten years Fraunhofer IWS engineers have developed exactly such control systems, which are now commercially available. Meanwhile there exists a number of such components that were developed for specific customer requirements and that are adaptable for a variety of tasks. Thus a set of flexible control systems emerged, driven by customer demand and specifications.

RESULTS

These control systems are based on the process module “LompocPro”, which is a software controller variably adapted to interact with different hardware components. For example, various types of temperature monitoring systems can be attached. A special development is the camera based temperature monitoring system “E-MAqS” (Fig. 1). With a sampling frequency of more than 200 Hz this system can record temperature distributions starting at about 600 °C. The data are interpreted in appropriate ways to derive process control parameters that are then sent to the process controller.

Part of the system set is a fast pyrometer “E-FAqS”, which is used for high speed processes. This unit can detect temperatures greater than 160 °C at sampling speeds of less than 100 µs. “E-MAqs” is primarily used in laser hardening applications. The significantly faster “E-FAqS” is meanwhile implemented in several industrial soft soldering machines.

Remelting and hardening processes frequently require special laser beam shapes. Laser and optical component manufacturers offer solutions with a fixed profile. A significantly quality improvement for various part geometries can be achieved with the flexible dynamic beam shaping system “LASSY” (Fig. 2). It is an oscillating mirror optics, which spreads out the beam perpendicular to the processing direction. The energy distribution in the laser spot can be simultaneously adapted to variable thermal conductivity conditions. Thus it is for example possible to use the mirror oscillations to achieve a uniform hardening depth in parts of locally varying thickness. “LASSY” typically incorporates a reliable “E-MAqS” temperature monitoring system (Fig. 3).

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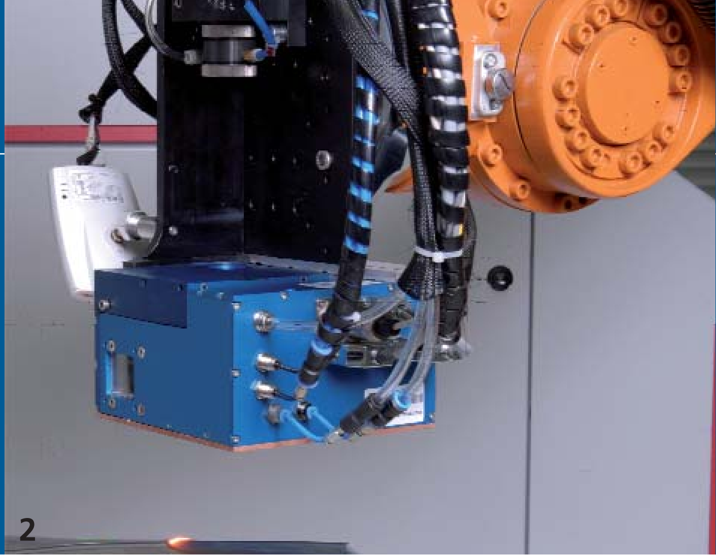

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The process controller “LompocPro” adjusts the power of the energy source to quickly follow a given nominal set point. A number of sensors monitor critical states such as the temperature of functionally critical and heat exposed components within “LASSY”. A separate controller analyses these states and sends the results to the main controller. If desired by the customer, all components can be controlled via industrial bus systems. Time critical signals can be directly transmitted.

The process controller “LompocPro” has variably adjustable process monitoring functions. Temperature and laser power timings are exactly monitored. Minimal deviations from the standard process are detectable even before the scrap part is being manufactured. It is also possible to work with variable set points during the process.

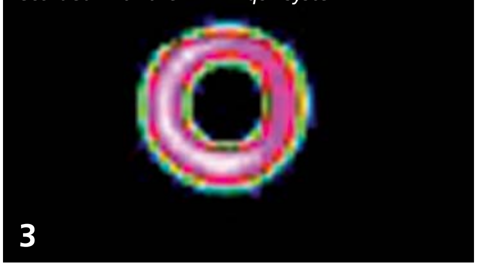
The camera based “E-MAqS” system cannot only measure the current temperature but also determines the size of the surface area that exceeds a temperature threshold. This feature is used to control the size of the melt during remelting and buildup welding processes. During liquid phase processes, this type of control is frequently preferable over temperature based monitoring. Depending on the specific customer requirements all data can be recorded and archived including the videos of the temperature monitoring system “E-MAqS”. Variations of telediagnostics offer the possibility for remote diagnostics of customer processes.

IWS engineers utilize the available set of surface refinement system components on a daily basis for process development. Thus these components are constantly further developed based on the gained experience and new customer requirements.

1 Camera based temperature monitoring system “E-MAqS”, mounted to laser optics for coaxial process observation

2 Dynamic beam shaping unit “LASSY” during a laser beam hardening process, mounted to a roboter

False color image of a laser beam hardening process with a ring shaped laser beam spot, recorded with the “E-MAqS” system



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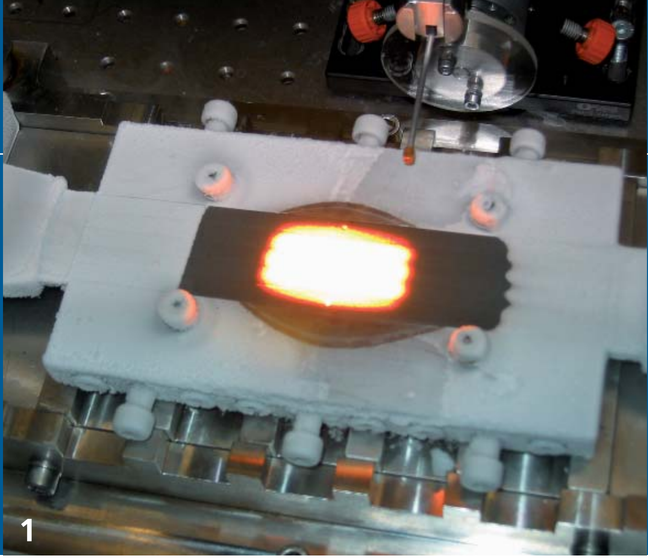
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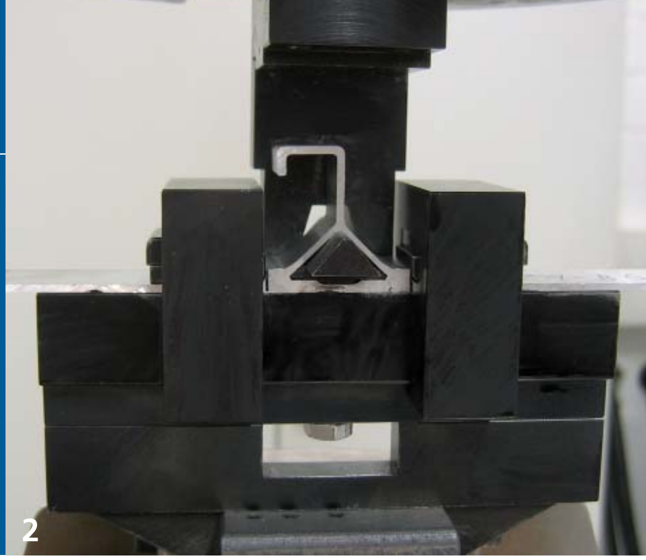
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NEW TESTING METHODS FOR JOINED AND SURFACE REFINED PARTS

THE TASK

Over recent years joining and localized hardening processes have been established in modern manufacturing lines. For quality assurance this state of affairs requires the simultaneous development of techniques and testing processes to evaluate the performance of the treated zones under realistic mechanical loading and tribological wear conditions.

Standard material testing techniques are typically not useful to predict the wear and stability performance of surface treated parts and welded constructions and testing with actual parts is much too complicated. Consequently Fraunhofer IWS engineers focused on the development of special testing techniques and on the adaptation of existing tests to special geometries and application conditions. Here we introduce some current examples, which are of relevance to various industry sectors.

APPLICATION EXAMPLES

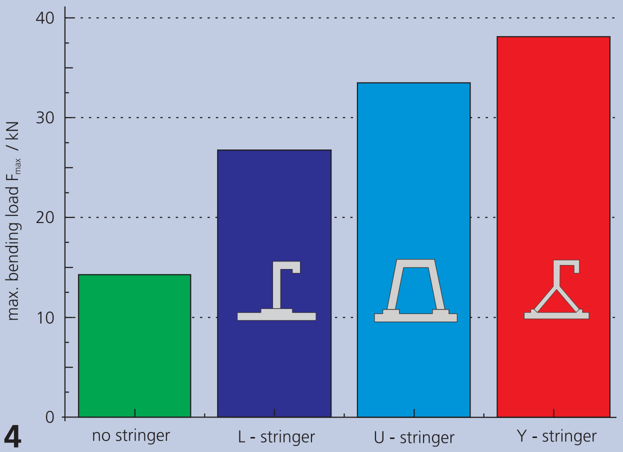
Stiffened skin sheets of aircraft fuselage structures tend to dent in and out on both sides of the stringer under shear and compressive loading. The question was how this particular loading profile affects the structural integrity of the welds. Furthermore, how can the loading profile be simulated in an appropriate experiment and is it possible to even increase the structural strength using optimized dimensioning and welding processes. To address these questions we derived the task to develop a mechanical testing procedure that uses small samples compared to actual fuselage structures and simulates a realistic loading profile of weld seams all the way to failure.

First calculations were performed to understand the deformation behavior (denting modes) of stiffened skin sheets under compressive loading. The output was used to design and build a ten-point bending rig, which can deform simple components and yield qualitatively similar results if compared to actual parts (Fig. 3).

A quantitative analysis of the mechanical loading capacity is possible if the experiments are performed with stiffeners of equal cross sectional area but varying geometry that are welded onto strip samples. Fig. 4 clearly shows the maximal loading capacity advantage of closed structure stiffeners (Y- and U stringers) over conventional stringers (L-stringers). In addition we developed a testing rig to quantify the weld seam strength of the stringer geometries using a so-called head pull test (Fig. 2).

3

Maximal bending load in a ten-point bending experiment for various stringer geometries



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Further development efforts in the area of mechanical and tribological surface testing techniques include, for example, processes for the precise and reproducible hardness measurement on curved surfaces, the partially automated measurement and plotting of two-dimensional hardening profiles, thermoshock testing methods for coatings and joined structures, and methods to analyze crack propagation in wear protective coatings in different environments. An additional topic is the characterization of the thermoshock / thermocycling resistance of coatings and joined structures (Fig. 1).

Another typical example is the further development of a testing technique to predict the fatigue behavior of new and already worn hardened surfaces. The problem was to introduce defined notches into the already hardened and thus brittle surfaces without causing cracking. For this reason and due to the limited thickness of the hardened layer the traditional methods of sawing or eroding to create starter notches were not useful. However, a suitable approach was to introduce Vickers impressions with varying loads and to apply four point bending testing to the samples.

This method proved useful to provide reliable results for the cracking sensitivity, long-term vibration strength and notching sensitivity of laser gas nitrided titanium samples. It was also possible to derive conclusions as to how the fatigue behavior of equally gas nitrided parts would change with wear for example in turbine blade applications.

1 *Thermocycling test of coated test structures for jet engine components*
2 *Head pull test for closed structures (opened rig)*
3 *Ten-point bending rig in action*

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BUSINESS FIELD THERMAL COATING

Editor: The department Thermal Coating is under new management since November 2009. Does everything change from now on?

Prof. Leyens: We will continue to count on proven technologies and on the implementation of new things. In particular our technical competence in materials will be expanded with a focus on applications. Here we benefit from the close cooperation with the TU Dresden.

Editor: New fiber and disk lasers are currently revolutionizing the area of laser materials processing. Does this also influence the buildup welding technologies?

Dr. Nowotny: Indeed it does. The possibility to combine an excellent focus with a long working distance opens new possibilities for buildup welding. Today it is possible to make metal structures with lateral dimensions of only 50 µm, which are in particular interesting for turbo machinery applications. However, the field of buildup welding is still dominated by modern fiber coupled diode lasers. Current industrial applications cover a broad spectrum from high precision to high productivity.

Editor: Will the laser buildup welding replace conventional welding processes?

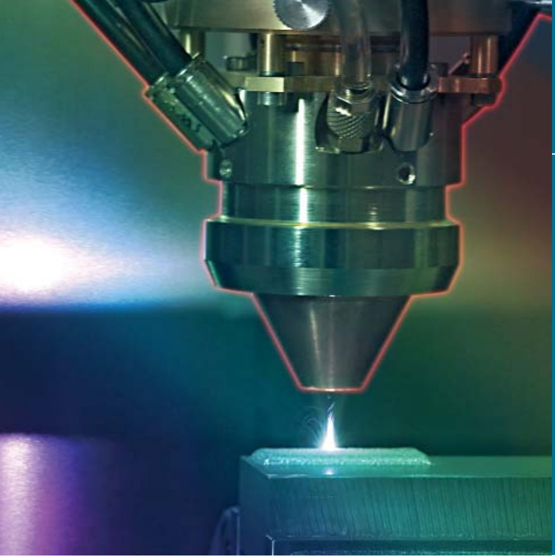
Dr. Nowotny: Of course not. The cost effective and efficient arc and plasma processes will continue to produce high quality coatings for classic applications. The laser beam complements these advantageously in all those areas that require in addition to a high deposition rate good final contours, smallest intermixing as well as special materials. Examples include our current R&D projects addressing combined wear and corrosion resistant coatings for mining tools including oil production and innovative solutions for vehicle powertrain applications.

Editor: How did Thermal Spraying do last year and what processes are now available?

Dr. Berger: For quite some time we have been focusing on thermal spray coatings of oxide ceramic materials based on Al_2O_3-Cr_2O_3-TiO_2 and hardmetals. Hardmetal coatings are produced using high velocity oxy-fuel (HVOF) spraying. However, oxide ceramic materials can be sprayed using several processes. We mainly use atmospheric plasma spraying (APS) but also HVOF and increasingly suspension spraying. In addition to the classical plasma spraying techniques a just recently developed method is also available, which uses three anodes. This process will substantially improve coating quality and efficiency. In the area of high velocity oxy-fuel spraying we installed a third process at the IWS, which is called high velocity air fuel spraying (HVAF) because it uses air for the combustion rather than oxygen.

Editor: You mentioned the suspension spraying. What is the development status?

Dr. Berger: Since three years we have been successfully working on this technology, which uses powder suspensions instead of classical feedstock powders. The phase composition and the resulting properties of the coatings are substantially different. In addition there is the possibility to make good coatings in the thickness range between 10 – 50 µm.



COMPETENCES

THERMAL SPRAYING

At the Fraunhofer IWS we have available atmospheric plasma spraying (APS) and high velocity oxy-fuel (HVOF) spraying technology with powders and suspensions to coat parts made from steel, lightweight metals or other materials with metals, hardmetals and ceramics.

Our offer, in cooperation with other Fraunhofer Institutes in the Dresden region, includes:
- design of application specific coating systems,
- development of complete coating solutions from the material to the coated part,
- development and fabrication of system technical components,
- support of system integrations,
- support of the customer during technology transfer.

CLADDING AND BUILDUP WELDING

The available technologies are laser beam and plasma powder buildup welding as well as hybrid technologies combining lasers, plasma and induction heating. The processes are applied to repair and coat parts, forms and tools. Metal alloys, hard materials and ceramics are applied as thick coatings and 3D structures through deposition, alloying or dispersing. All technologies make use of a closed process chain including digitizing, data preparation and final processing.

For these applications we offer:
- simulation of buildup welding processes,
- coating and shape forming laser buildup welding with highest precision,
- processing heads and CAM software for industrial use of laser technology,
- on-site support of the technology transfer.

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EXAMPLES OF PROJECTS 2009

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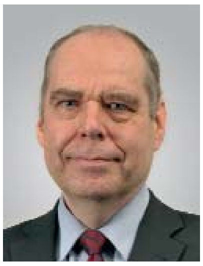

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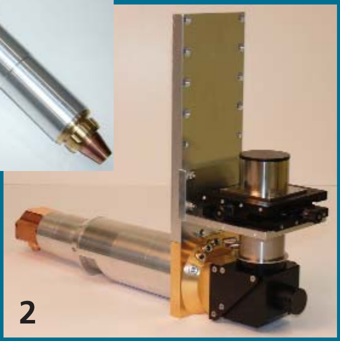

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PROCESSING HEADS FOR 3D LASER BUILDUP WELDING UNDER DIFFICULT ACCESSIBILITY

THE TASK

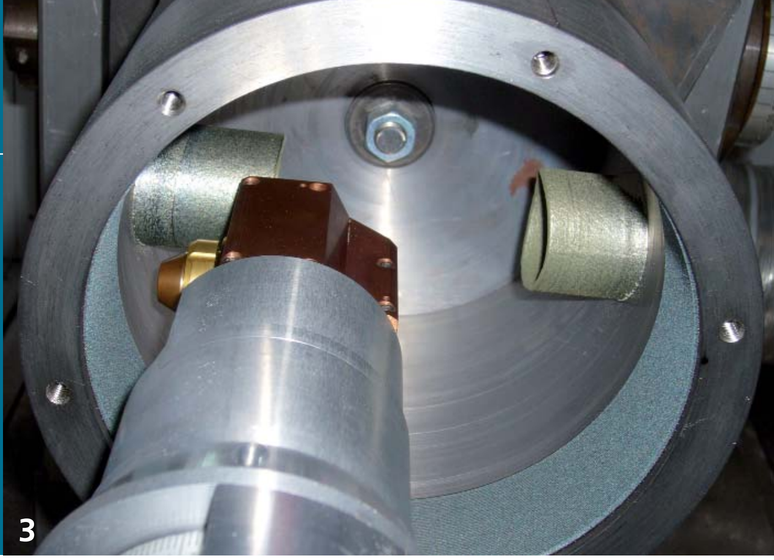
Laser based cladding processes are the key to modern manufacturing and repair processes in the aerospace industry, in energy generation and in tool and die making. Powerful beam tools are required for the surface functionalization, repair and design changes of long living and complex components and tools. Different materials need to be metallurgically bonded or shaped into structures. Frequently the part designs require the welding material deposition in very narrow and deep gaps and onto inside surfaces, which are difficult to access. These requirements in combination with the need for reproducibility are challenging for the laser optics and processing heads. It is also often necessary to simultaneously implement a direction independent deliver path for the weld material to coat contours and create real three-dimensional structures. To best accommodate our customers the welding heads also need to be compatible to current material processing lasers and powder feeders.

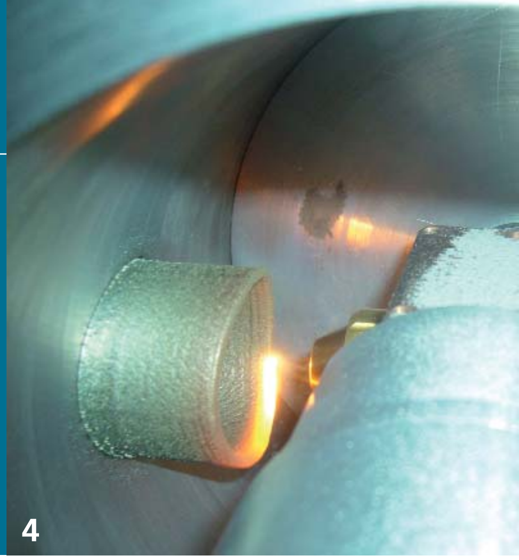
OUR SOLUTION

We have a portfolio of system technical solutions for these tasks. Here we use the examples of a coaxial powder nozzle from the IWS-COAXn family and an inner diameter cladding head to introduce these solutions.

The coaxial design of the powder nozzle utilized the advantages of the long aperture, excellent focus of modern solid state lasers. Directional independence of the powder delivery is achieved by splitting the powder jet forming nozzle tip into 4 circle segments, which reduces the influence of gravity on the powder jet.

The core element of the inner diameter cladding head is also a coaxial multi jet powder nozzle. In this case it is miniaturized. Using a modular design achieves deep plunging lengths of more than one meter. All media delivery hardware is safely packaged inside the processing head.





RESULTS

The coaxial powder nozzle COAX13 has a 180 mm long cylindrical nozzle body with a maximal diameter of 30 mm. Thus it is a good design to reach difficult to access welding positions for precise contour welds. All media including protection gas are delivered through the inside of the head. The entire processing head is water cooled down to the tip of nozzle. This allows the uninterrupted operation of the head for hours with laser powers of up to 2.5 kW. Typical metal powder feed rates range from 0.6 to 1.2 kg / h. The nozzle tip is a low cost spare part, which can easily be replaced.

The basic body of the inner diameter cladding head consists of ring shaped norm segments, which can be combined to the desired plunging depth. If the plunging depth exceeds 600 mm a ball roll guide is used to lead the head along the part surface. All media (powder, protective gas, cooling water) are led through special channels along the inside of the ring modules. The fine adjustment of the laser spot with respect to the powder focus is realized via an x/y adjustment of the collimated raw beam outside of the actual processing zone.

Fig. 3 illustrates the technological possibilities of the processing head during direct metal deposition. The figure shows two three-dimensional cylindrical structures, which were directly generated on the inside surface of the pipe in horizontal position. Thus in addition to performing contour welds it is also possible to buildup material with permanently changing welding directions, which drastically deviate from a flat position.

Commercially available standard metal powders can be used with common sizes (i.e. 63 - 150 µm). Up to 3.5 kW laser power and a welding speed of 0.7 m / min generates a track width of 3.5 mm. A stable and uninterrupted operation of up to one hour was demonstrated. The minimal inner diameter of the part to be coated is currently 100 mm.

1 Coaxial processing head COAX13 for buildup welding in jet engine repair

2 Modular inner diameter cladding system for contour buildup welding on deep-set inner surfaces

3 Surface area coating and generated 3D form structures on cylindrical inner surfaces

4 Buildup welding process on vertical wall

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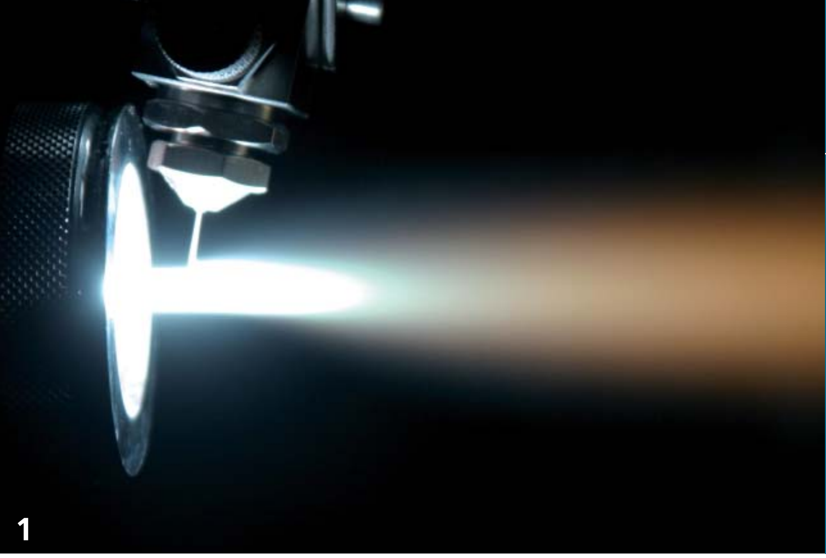

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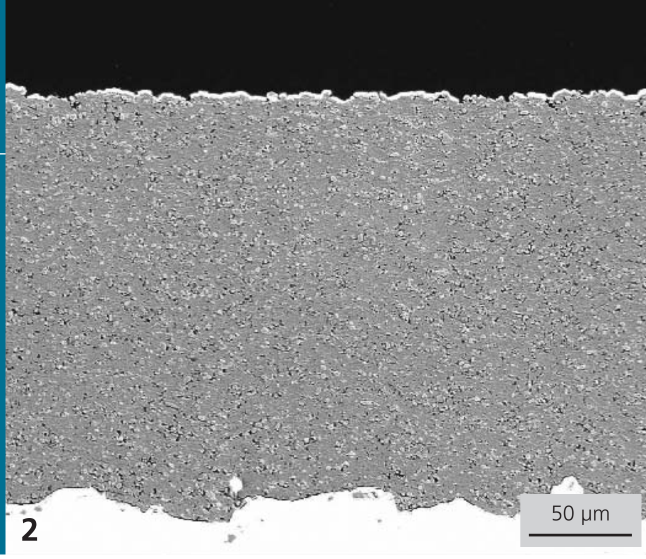

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SUSPENSION SPRAYING – A NEW THERMAL SPRAYING PROCESS

THE TASK

Thermal spraying represents a group of surface technology processes that are highly flexible with respect to methods and materials. Atmospheric plasma spraying (APS) and high velocity oxy-fuel spraying (HVOF) are important representatives. Typically the coating thickness ranges between 100 µm and 500 µm. For many materials the preferred coating powders have particle sizes in the range from 10 – 50 µm.

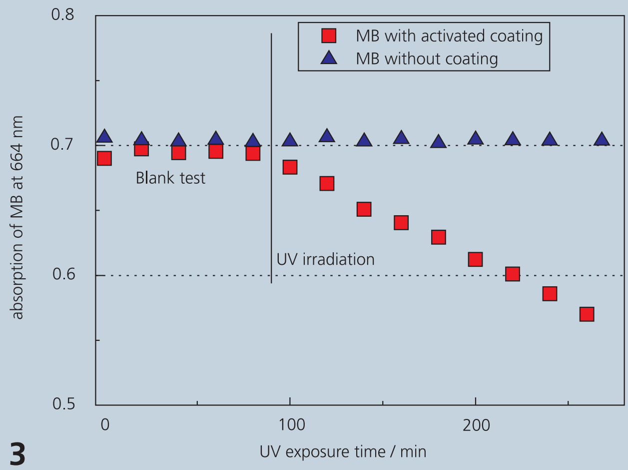
The use of suspensions instead of feedstock powders promises several advantages. One of which is the possibility to directly use finely dispersed powders, which saves the manufacturing step to make special feedstock powders and enables the deposition of nanostructured coatings. It is also of importance to find principle and reliable ways to make thermal spray coatings with a thickness of less than 100 µm. Thus, suspension spraying may lead to closing the coating thickness gap between classic spray coatings and CVD / PVD coatings.

In the following we discuss the development of suspension sprayed coatings based on aluminum and titanium oxides and their special properties.

OUR SOLUTION

The fabrication of suspension sprayed coatings requires a modification of systems that are used for APS and HVOF spraying. It also needs appropriate suspension supplying systems and the aqueous and alcoholic suspensions themselves have to be prepared. Coatings based on aluminum and titanium oxides have multi functional applications. Suspension sprayed coating development focuses for both oxides on the long-term stable electrical properties and in the case of titanium oxide on the photocatalytic properties.

Photocatalytic test: bleaching of a methylene blue solution (MB) in the presence of a suspension sprayed photocatalytically active TiO_2 coating



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Both materials easily form well adhering coatings in the thickness range from 10 – 50 µm. The hardness of suspension sprayed coatings are comparable to those made from powders. Meanwhile we also achieve economically attractive spraying and deposition rates.

RESULTS

Suspensions can be used with both APS and HVOF spraying processes. Suspension sprayed coatings differ in phase composition and microstructure from coatings made with conventional powders. The coatings have a structure in the nano scale. In the case of titanium oxide, the coating consists of the photocatalytically active anatase phase. The graphics shows the photocatalytical activity of a titanium oxide coating, which was tested based on decoloration of a methylene blue solution.

The use of a special aluminum oxide suspension creates a high fraction of corundum in the coating without the need for additional stabilizers. The method was patented. The long-term stability of the electrical properties is currently under investigation.

1 *Suspension spraying with APS*

2 *SEM micrograph of a suspension sprayed aluminum oxide coating*

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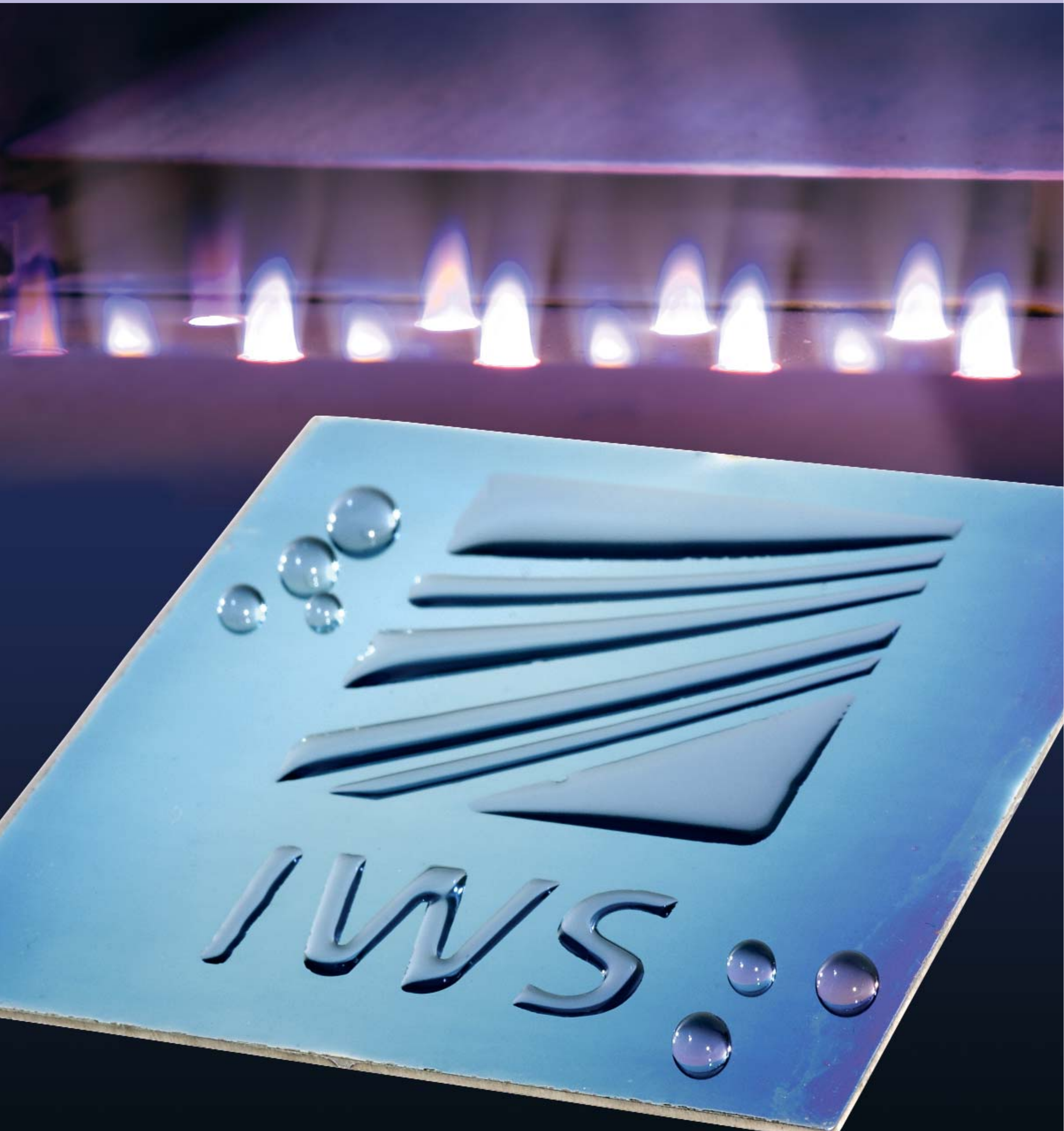
IWS

BUSINESS FIELD ATMOSPHERIC PRESSURE CVD COATING TECHNOLOGY

Editor: You redefined for your department the thematic "Materials4Energy". What does this mean?

Prof. Kaskel: In the mid-term a shortage of resources and energy reserves will give rise to substantial problems, which have to be resolved based on new materials and energy efficient processes. We see numerous new and different challenges such as solar cells of highest efficiencies, batteries with larger storage capacity and fuel cells with a longer service life. All these very different technologies rely on thin film coatings for decisive improvements in efficiency.

Editor: Can you give an example?

Prof. Kaskel: New developments for super capacitors are a key topic. These are electrical energy storage devices to replace batteries, which can be charged within seconds. You know well enough how long it takes to recharge a normal battery. You've got to wait for hours.

Using chemical vapor deposition (CVD) we can make forests of carbon nanotubes. This requires a very good catalytic coating, which we produce of course in-house. The special alignment of the carbon nanotubes provides an energy storage device, which can be rapidly charged and discharged. Using our atmospheric pressure processes we can fabricate foils of virtually any size. In cooperation with the TU Dresden we found a new material that offers considerably improved energy storage compared to CNTs. Therefore we are planning to setup a small production line at the Fraunhofer IWS to make the new super capacitors available to a broader range of applications.

Editor: Initially you also mentioned solar cells?

Prof. Kaskel: We are concentrating our efforts on the development of transparent electrodes for the thin film photovoltaics. We developed a new atmospheric pressure process, which also allows a structured deposition. This way we create a hierarchical micro / nanostructure, which provides optimal light coupling conditions and thus improves efficiency. Alternatively, the same effect can be achieved with regular coating deposition and subsequent plasma chemical etching to form the absorbing structures. We also see a cost savings potential for the classical manufacturing of solar cells from Si wafers by optimizing certain processes. One of groups exclusively deals with process monitoring and control tasks. The tasks are not limited to photovoltaic and chemical processes but also include nanoparticles manufacturing on an industrial scale.

Editor: Nanoparticles, isn't that dangerous?

Prof. Kaskel: Nano materials have extraordinary properties. Whether they are toxic or not depends as always on the chemical composition and the dose of exposure. Critical are dusts when nanoparticles get into the breathing air. But this is exactly in our focus. To make nanoparticle generating processes safe we apply new methods and technologies that determine particle sizes and concentrations. In areas of potential exposure to dangerous particles we can exactly say if there is a risk to be expected. Thus, hopefully we can contribute to the safety of industrial processes and to a cleaner environment.

COMPETENCES

ATMOSPHERIC PRESSURE CVD TECHNOLOGIES

Plasma assisted chemical vapor deposition processes at atmospheric pressure allow a large area deposition of high quality functional coatings with the need for cost intensive vacuum equipment. The technology is used for continuous and high rate deposition processes on temperature sensitive materials and on slightly curved substrates of various thicknesses. At the Fraunhofer IWS we develop prototype pass through reactors with gas locks for plasma assisted deposition of oxide and non-oxide coatings and for plasma chemical etching at atmospheric pressure. The optimization of the reactor design is based on experimental results and thermo fluid dynamic simulations. The reactor design is modular, which makes it easily adaptable to the requirements of new applications and coating materials.

PROCESS MONITORING

The optimal function of industrial systems and product quality are frequently directly related to the composition of the gas atmosphere inside the reactor. An industry grade in-situ gas analytics is essential for quality assurance of chemical coating, etching and sintering processes and for the monitoring of emissions from industrial systems. The Fraunhofer IWS offers sensors that are based either on NIR diode laser or FTIR spectroscopy. They can be deployed in custom tailored solutions to continuously monitor the chemical composition and concentrations of gas mixtures. In addition, we characterize surfaces and coatings with methods such as FTIR spectroscopy, spectroscopic ellipsometry and Raman microscopy.

CHEMICAL SURFACE TECHNOLOGY

The most different requirements exist for surface properties and functions of many materials. Examples include corrosion and scratch resistance, anti fingerprint and self-cleaning effects, electrical conductivity and optical transparence. Special coatings and surface treatments create these properties. But the associated processes also have to be cost effective and applicable to large areas. The workgroup Chemical Surface Technologies develops special gas phase (CVD) and liquid phase chemical process to generate diverse functions for different material surfaces.

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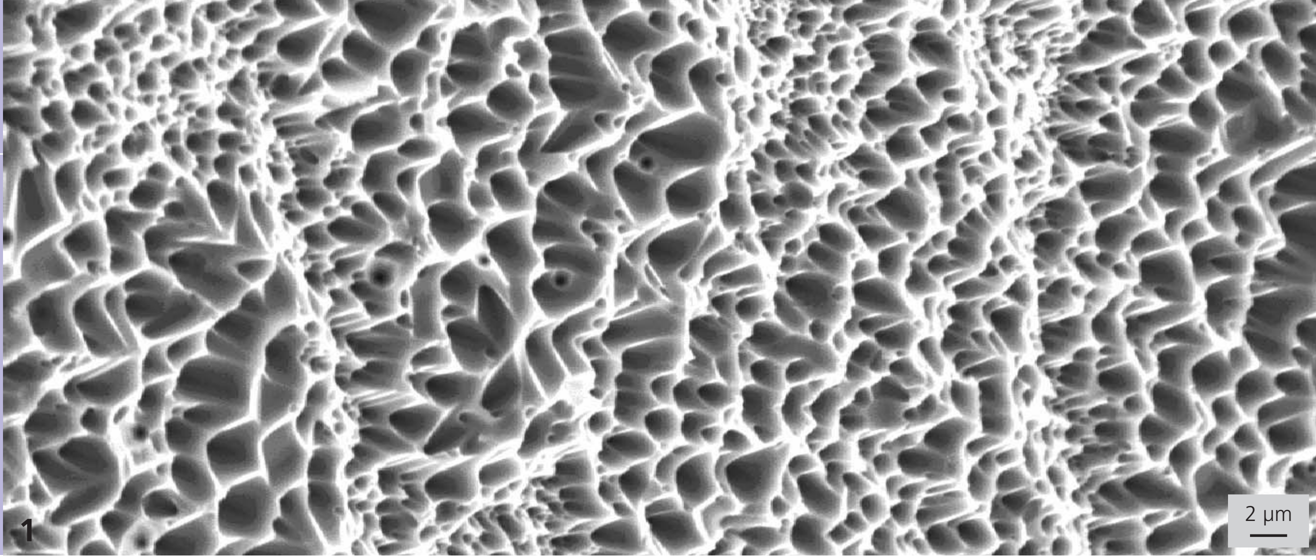


CLIMATE CONSERVING ETCHING GAS FOR THE SILICON PHOTOVOLTAICS – EVALUATION OF COF_2 FOR PLASMA CHEMICAL ETCHING PROCESSES AT ATMOSPHERIC PRESSURE

THE TASK

Industrial manufacturing processes of crystalline silicon solar cells mostly rely on wet chemical etching steps. The deposition of anti reflective and passivation layers is done using plasma assisted chemical vapor deposition (PACVD) processes. The combination of these different processes generates high costs in particular through the massive use of robots for wafer handling. A continuous production process with a small number of processing steps requires the deployment of similar technologies for as many steps as possible. Atmospheric plasma processes and systems are flexible, compact and designed for continuous operation in particular for such a process chain.

Fraunhofer IWS engineers develop continuous plasma etching processes at atmospheric pressure for future in-line production machines. So far the processes relied on etching gases such as NF_3 and SF_6. However, these gases have a high relative greenhouse potential, which may limit their applicability for the photovoltaic industry. As a more climate friendly alternative we evaluated the use of COF_2 to etch silicon and phosphorus silicate glass.

OUR SOLUTION

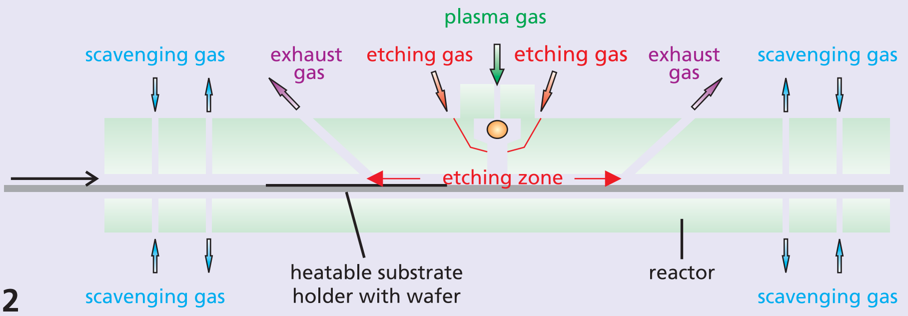
To break down etching gases we use a dc arc discharge linear plasma source (LARGE). The discharge length in the plasma source is about 250 mm. This allows to uniformly and continuously processing wafers of up to 156 mm x 156 mm. The etching process generates gaseous volatile products, which can be easily removed from the surface. The industrial applicability of plasma chemical etching at atmospheric pressure was tested for several steps in the production chain. In addition to the typical semiconductor industry gases SF_6 and NF_3, we tried for the first time COF_2, which has a very low greenhouse potential of 1. Due to its longevity SF_6 is for example 22880 times more damaging for the climate than CO_2, the factor for NF_3 is 17200.

RESULTS

The use of COF_2 as an etching gas yields high etching rates, which is a requirement for industrial processes. Dynamic etch rates of 0.42 µm m min^{-1} were achieved. These etching rates are comparable to those of SF_6. However, COF_6 is much more environmentally friendly than SF_6.

COF_2 is also useful for the texturing of silicon surfaces. A textured frontside of the solar wafer reduces reflections and thus increases the utilization of the impacting light and the efficiency. The largest reduction of diffused reflections was achieved with porous nanostructures (Fig. 1).

Schematics of a reactor for the plasma chemical etching at atmospheric pressure



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COF_2 is useful for the selective etching of phosphorus silicate glass (PSG). This is in particular interesting for the manufacturing of crystalline silicon solar cells since the process requires the removal of a thin PSG film after the emitter formation step. However, the underlying doped silicon emitter material must not be destroyed during this step. Therefore the ratio of PSG-to-Si etch rates (selectivity) needs to be high. The COF_2 based etch rate for PSG is about 15 times higher than for silicon. In comparison, for NF_3 or a mixture of CHF_3 and O_2 the etch rate ratios are only 1.8 and 12. Thus the application potential of COF_2 is great for the removal of phosphorus silicate glass films.

1 SEM micrograph of a COF_2 etched surface

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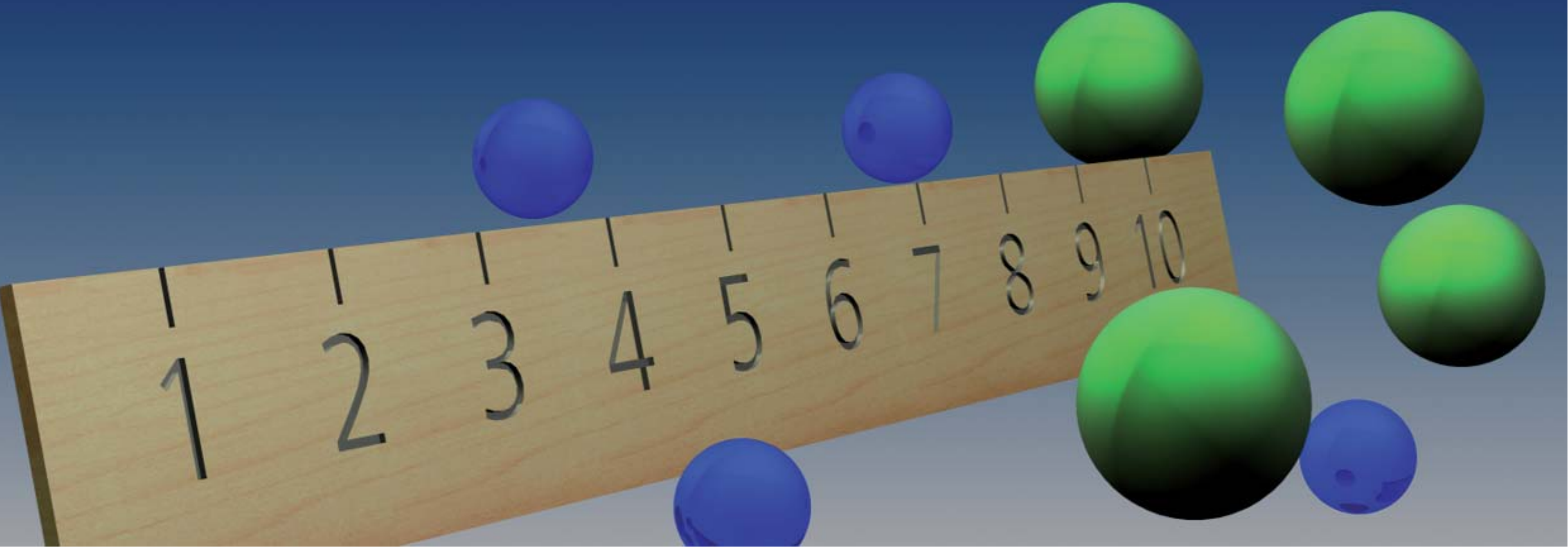


RELIABLE DETECTION OF NANOPARTICLES – A RULER FOR 10^{-9} METERS

THE TASK

For years nanoparticles are increasingly penetrating the societal conscience. Right from the beginning the expectations were high and the steadily increasing number of useful applications seems to fulfill the promise. However, simultaneously increasing is also the awareness with respect to health concerns. This leads to challenging requirements for reliable detection techniques. The knowledge about particle types and quantities is often a decisive factor to understand and optimize processes in high technology sectors and in particular in industrial and close-to-industry environments. It is also a powerful tool to eliminate process deficiencies.

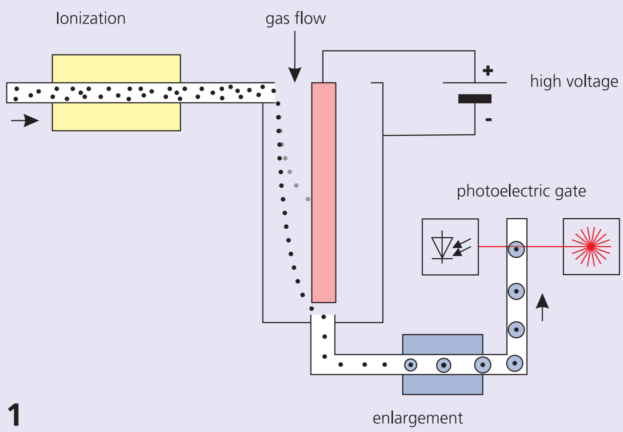
For users, interesting particles have diameters from 10 to 1000 nm and concentrations of up to 10^8 cm^{-3}. There are several reliable characterization techniques to analyze particles down to a few nanometers if they are in a suspension. The detection of gas-borne particles (aerosols) and their size classification are much more difficult since all physical interactions are very small due to much lower particle concentrations. Suitable measurement systems are therefore complicated and require a substantial know-how to interpret the results.

Fraunhofer IWS engineers develop application tailored metrological solutions to evaluate particle-containing atmospheres.

PRINCIPLES AND POTENTIAL SOLUTIONS

Fractionation based on electro mobility and subsequent counting is an internationally accepted reference technique. The aerosol has a surface charge and is analyzed for size distribution in a force equilibrium between a flow and a high voltage field. Due to the extremely small size of the particle, a subsequent step increases the particle size in a saturated butanol atmosphere by using it as a condensation nucleus. The enlarged particles can then be counted using laser optical detectors, which are similar to a photoelectric gate (Fig. 1). At the Fraunhofer IWS we use this metrology in form of a state-of-the-art SMPS (Scanning Mobility Particle Sizer) system to characterize particle containing gas atmospheres (Fig. 2).

Schematic function principle for the fractioning of poly disperse aerosols with subsequent counting



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Often there are conditions in particle containing processes for which the electro mobility method is no applicable. This is for example the case in low or high pressure environments or in aggressive and reactive process gas atmospheres. In these cases we use extinction spectroscopic methods, which provide information about particle size distributions and concentrations via optical analysis.

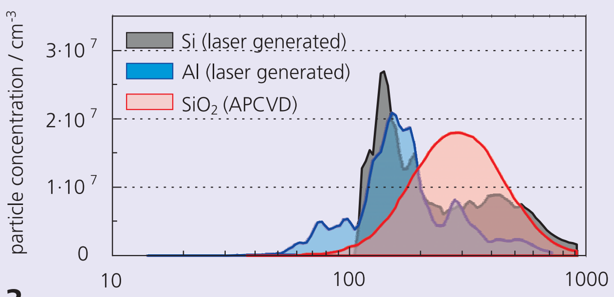
APPLICATIONS AND RESULTS

In various measurement campaigns we analyzed laser and chemical vapor deposition processes with respect to nanoparticle generation, which may not have been the primary purpose of those processes. These experiments proved the excellent capability of in-house short pulse solid state lasers to tailor semiconducting, metallic and metal oxide nanoparticles with narrow size distributions (Fig. 3).

For many years atmospheric pressure chemical vapor deposition processes (APCVD) have represented a research focus at the Fraunhofer IWS. As a challenge there is always a certain amount of particles during the uniform deposition. In order to develop minimization strategies for particle concentration, it is necessary to measure and quantify it. Other processes such as the chemical vapor synthesis (CVS) are designed and optimized for particle generation. These processes are monitored to support development efforts to increase the particle yield. Examples include the characterization of industrial processes to generate soot or nanoparticular silicon dioxide.

Another highly current area of activity is the quality assurance to monitor, for example, the process gases that are specified by the vendor to be particle free. In this case it is often also necessary to evaluate the potential particle contamination that may occur during the path from the gas container to the point of use. In parallel to technical tasks it is always also of interest to address inhalation toxilogical questions. Aerosol investigations were used to determine the particle contamination of the laboratory air in rooms that are used to generate particles. Such it was for example possible to quantify the particle contamination during combustion processes.

Exemplary particle distributions during laser ablation and APCVD processes



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2 *System to characterize nano particles containing gas atmospheres (SMPS^{TM})*

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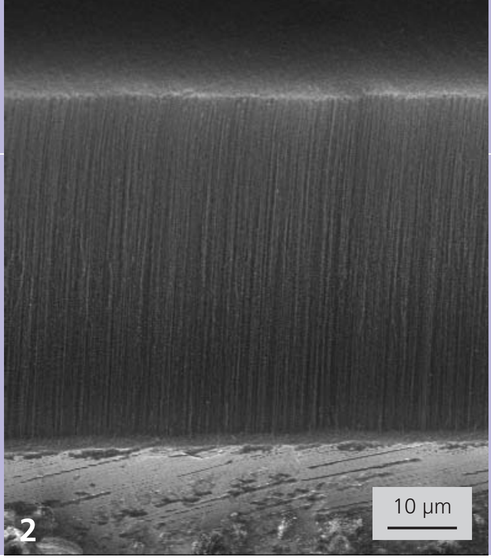

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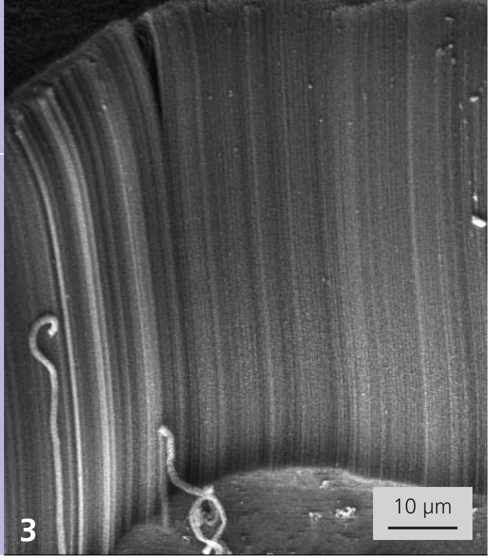

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SMALL TUBES FOR LARGE ENERGY STORAGE: CARBON NANO TUBE FORESTS AS ELECTRODE MATERIAL

THE TASK

Carbon nano tubes (CNTs) combine a high specific surface area with high electrical conductivity and thus are a promising material to store electrical energy. CNT forests on surfaces made from vertically oriented tubes are of particular interest. To utilize these forests for energy storage the CNTs need to be connected to conducting substrates. Therefore the goal was to develop cost effective and scalable processes for the direct growth of CNT forests on metal foils.

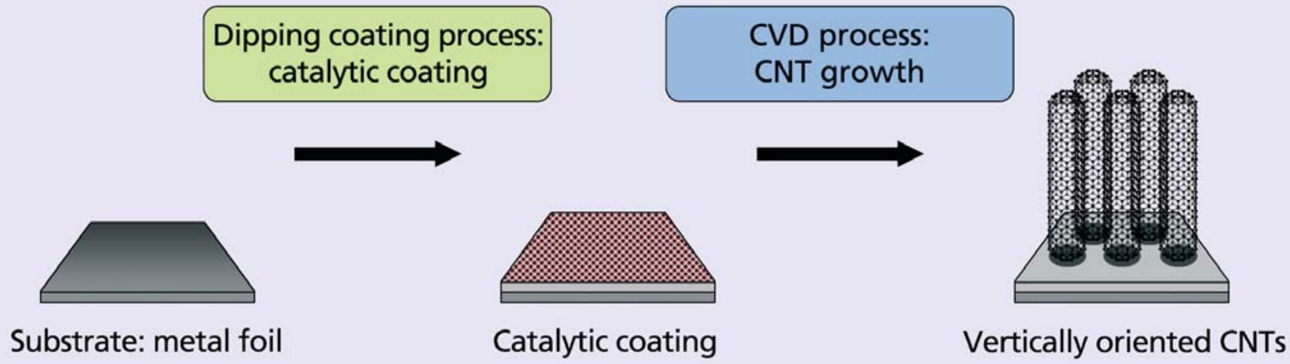
OUR SOLUTION

The process to fabricate CNT forests essentially consist of two steps:

- application of the catalytic film,
- CNT growth.

IWS engineers developed a scalable dipping process to apply the catalytic film. The process uses low cost ingredient materials and very cost effectively generates nanometer coatings on various substrate materials. To grow CNTs we use chemical vapor deposition at atmospheric pressure. At a temperature of 750 °C a gaseous carbon precursor is decomposed to initiate the CNT growth.

Fabrication process of CNT forests



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Both processes operate at atmospheric pressure and are principly scalable to continuous band coating.

In summary there are the following advantages:
- availability of low cost ingredients,
- short process duration,
- applicable to different substrate materials,
- double sided coating of foils in one step,
- processes at atmospheric pressure.

RESULTS

The Fraunhofer IWS process achieves in only a few minutes a CNT forest of up to 200 µm thickness. The CNTs are bonded to the substrate and the thickness corresponds to the length of the individual tubes. The CNT forests consist of single and multi wall carbon tubes with diameters of about 10 - 20 nm. In addition to the standard deposition on silicon wafers, it was possible to apply the process to technical metal foils made from stainless steel and nickel. The coated conductive foils are directly useful to build energy storage devices such as for example double film capacitors.

Current work addresses the electro chemical analysis of the CNT coatings and the transfer of the synthesis to a continuous process. First electro chemical investigations demonstrate the principle suitability of the coatings for this application. Within an EU project “N2P” research aims at the further development of the CNT coatings and at the scaling of the synthesis technology to a continuous production process.

The IWS participates in Fraunhofer's "Electro-mobility" system research initiative. Here we work on further functionalizing CNTs by coating them so that they can be used as electrode materials in next generation battery and capacitor systems.

1 CNTs on rough nickel foil

2 CNTs on polished nickel tape

3 CNTs on steel foil

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BUSINESS FIELD PVD VACUUM COATING TECHNOLOGY

Editor: Your department emphasizes PVD thin film and nanotechnologies. Which activities were and are foci?

Dr. Leson: The energy thematic is certain a very current topic. Energy efficiency is a very important area for us in addition to alternative energy generation. An example is the coating of powertrain components in vehicles, which can significantly improve energy efficiency and CO_2 emission reduction. In the past we proved that our Diamor® coatings offer excellent properties such as an extreme loading capacity and a drastic friction reduction. Currently we collaborate with automotive manufacturers, suppliers and equipment makers within a large federal project to optimize Diamor® coatings for exactly these applications. In addition we are qualifying the Laser-Arc technology to deposit these coatings for industrial deployment.

Editor: Your department has substantial experience in the synthesis of ultra precision thin films as they are required for X-ray and EUV optical applications. Is there any progress to report?

Dr. Leson: Absolutely. The user requirements have been continuously increasing over the past years. This concerns the number of individual film periods, the interface precision and the precision on uniformity of the deposition process. Here we achieved substantial improvements and managed to reinforce our leading position. But questions such as process scaling are also important in particular from an industrial application standpoint. Last year we were able to scale our technology to large areas and to transfer the technology to industry by collaborating with an equipment manufacturer.

Editor: Your department also works on the synthesis of carbon nanotubes. How about progress in this field?

Dr. Leson: Our effort in carbon nano tube technologies focuses on manufacturing high quality single wall tubes, which is different from the work of many other groups. Single wall carbon nanotubes are more difficult to synthesize but they also offer substantially improved properties. We manufactured larger quantities in the kg range, which affords us now to explore the special application potential of this material. We are intensively collaborating with numerous partners within the BMBF initiative InnoCNT.

COMPETENCES

X-RAY AND EUV OPTICS

Magnetron and ion sputtering as well as pulsed laser deposition are processes that we utilize to synthesize nanometer single and multilayer coatings. These coating systems fulfill highest demands with respect to thickness precision, smoothness, chemical purity, lateral uniformity and reproducibility. In addition to developing and manufacturing these coatings we also offer our experience in characterizing and modeling of nanometer coating systems.

CARBON NANOTUBES

Carbon nanotubes offer special properties, which create even in small quantities completely new functionalities for matrix materials. IWS engineers developed a novel evaporation based synthesis process to fabricate single wall carbon nanotubes with a well defined property spectrum. We offer carbon nanotubes in various qualities and processing stages. Composite material development efforts are support by modeling and comprehensive characterization work.

CARBON COATINGS

The IWS developed amorphous carbon coatings (Diamor®) are exceptionally useful as protective coatings. Films of a thickness range from a few nanometers to tens of micrometers are deposited achieving excellent adhesion and performance. The synthesis process operates at low temperatures in a vacuum environment with a special pulsed arc process. IWS engineers collaborate with industrial partners to commercialize Diamor® coatings and the associated coating machine technology. As part of this portfolio we have developed the unique thin film testing technique LAwave®, which is applied for coating optimization and quality control.

PVD COATINGS

Physical vapor deposition (PVD) processes are employed to synthesize high value adding tribological and functional coatings. Thicknesses range from a few nanometers to tens of micrometers. IWS facilities include various processes such as high rate evaporation and highly activated plasma techniques as well as their combinations. A special focus is placed on using arc discharges as the most efficient source of energetic vapor jets.

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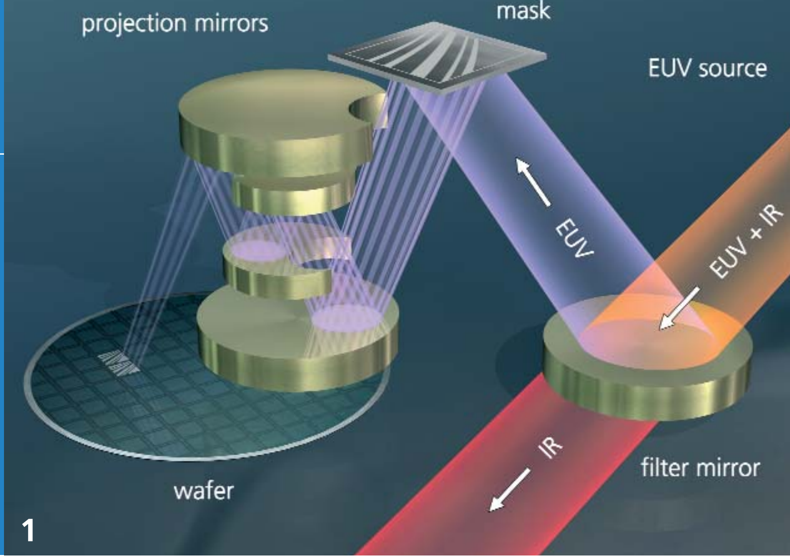

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NEW EUV MIRRORS WITH MINIMIZED IR REFLECTION

THE TASK

Future lithography systems for patterning smallest structures in semiconductor manufacturing will use extremely short wave EUV (extreme ultraviolet, λ = 13.5 nm) radiation (Fig. 1). Latest developments indicate that the process of laser pulse plasma generation (LPP) will be the prevailing synthesis method of this radiation. The radiation source is a plasma, which is generated by a high intensity CO_2 laser that rapidly evaporates melted tin droplets.

One of the problems of this type of radiation synthesis is that only a fraction of the laser energy is actually converted into useful EUV radiation. A by far larger fraction of the energy is lost by scattered CO_2 radiation (λ = 10.6 µm) in the form of UV and IR (heat) radiation. Thus it is critical for a successful EUV lithography to protect sensitive photoresist as well as masks and optics from this radiation.

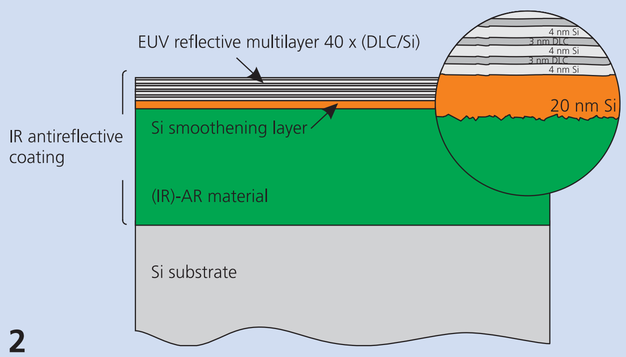
Conventional EUV mirrors consist of molybdenum-silicon multilayers. These are excellent reflectors not only in the EUV range but also of infrared radiation (R > 80 % at λ = 10.6 µm). Thus previous techniques to spectrally filter the radiation relied on separate optical components such as thin metal foils, refractive gratings etc. These components however are very limited with respect to transparency and thermal load capacity and they require a substantial fabrication effort.

OUR SOLUTION

Our new approach to spectrally filter the LPP source radiation is based on DLC/Si multilayer coatings in combination with an IR antireflective film (Abb. 2). This system combines high performance EUV mirror properties with high IR transmission.

The concept is based on the very good IR transparency of silicon and diamond like carbon (DLC) and the good optical contrast for EUV radiation. It is possible to reduce the IR reflectivity of DLC/Si mirror to nearly zero in combination with a standardized IR antireflective coating.

Schematics of the multilayer design of a IR transparent DLC/Si EUV mirror



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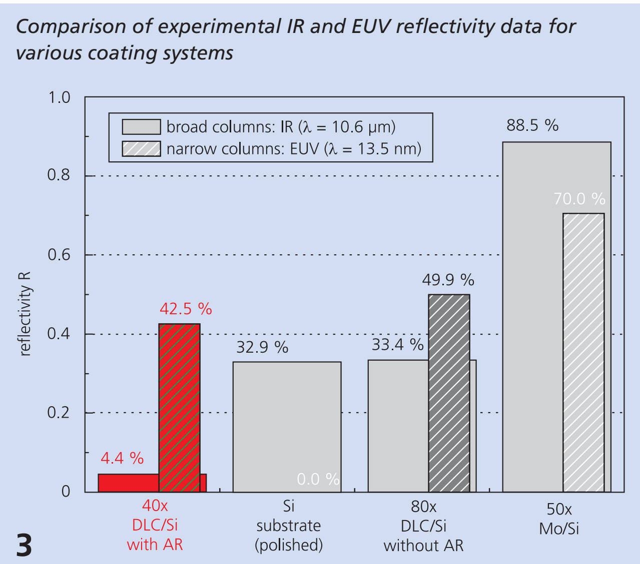

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1 Principle of an EUV lithography system with IR transparent filter mirror

RESULTS

Two critical problems had to be solved in order to fabricate the coating system of the IR transparent EUV mirror as shown in Fig. 2. One issue was that the multilayer EUV mirrors require the surface and interface roughness to be in order of only a few angstroms (0.1 nm). Conventional antireflective films are not available at such a low roughness. The second challenge was that the deposition of diamond like carbon had never been demonstrated in such a highly precise multilayer configuration.

Both aspects were addressed in one machine using ion beam surface polishing and ion beam sputter deposition (IBSD). Alternating deposition and polishing steps were applied to deposit a smoothening silicon layer. This layer's roughness of about 0.2 nm is sufficiently low for the subsequent DLC/Si multilayer coating. Fig. 3 shows experimental data for EUV and IR reflectivities of various coating configurations. A prototype IR transparent EUV mirror was fabricated with 40 x DLC/Si layers on a silicon wafer and with a IR-AR coating. The remaining IR reflectivity was 4.4 % at EUV reflectivities of about 42.5 %. These numbers are very close to theoretically modeled values and underline the functionality of the coating system and the excellent capability of the ion beam polishing and deposition process.

CONTACT

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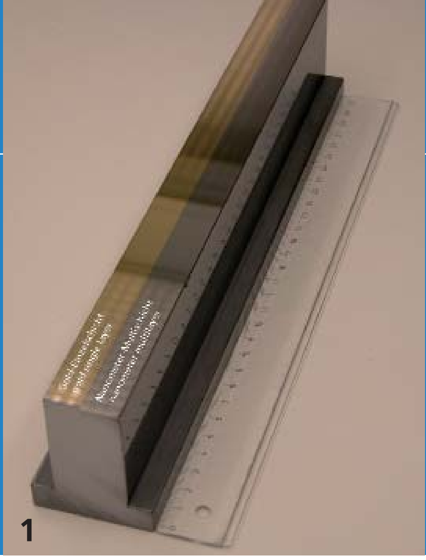
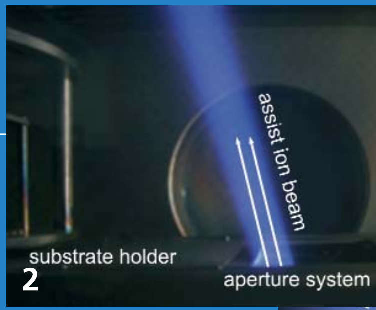
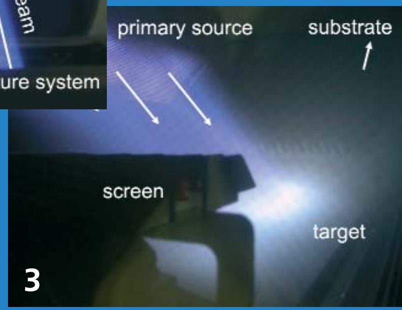






X-RAY OPTICS FOR SYNCHROTRON APPLICATIONS

THE TASK

Synchrotron rings such as BESSY and DESY deliver extremely brilliant X-ray radiation. This radiation opens up completely new opportunities to pursue physical, biological and materials science research. Today many basic research investigations would be unthinkable without synchrotron radiation.

A synchrotron ring stores the radiation. X-ray optical components are inserted into the optical path in order to extract a specific spectral range. Multilayer X-ray mirrors (Fig. 1) are very beneficial for applications that require a large photon flux at moderate spectral selectivity. The technical challenges for the fabrication of these mirrors include requirements for highest reflectivities, excellent coating uniformity and long-term radiation stability.

OUR SOLUTION

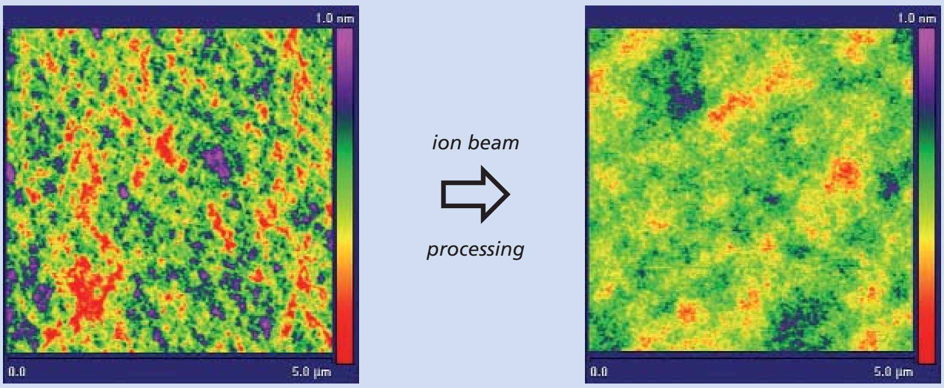
X-ray mirrors for synchrotron radiation consist of a substrate with reflective coatings, which determine the spectral reflectivity of the device. It is extremely important that the substrate surfaces themselves are atomically smooth, clean and defect free. IWS engineers developed ion beam cleaning and polishing processes to improve over conventional surface finishing techniques (Fig. 2). Depending on the process parameter it can remove surface adsorbents or reduce the surface roughness. These processes also improve the adhesion of the subsequently deposited coating.

X-ray mirrors typically consist of 100 – 1000 individual nanolayers with thicknesses in the range from 0.5 – 5 nm. Sputter deposition techniques are applied to deposit these coating atomically smooth, dense and fully covering. Ion beam (Fig. 3) and magnetron sputtering processes were developed to offer reproducibility, precise coating fabrication and a broad material range.

RESULTS

Various vendors offer substrates with a typical surface roughness in the order of 0.2 nm rms. This is already very good. However, it is not sufficient for applications that require a period thickness of less than 2 nm. The solution is an IWS developed ion beam polishing process, which can also be used for single crystalline silicon (100) surfaces. Fig. 4 shoes scanning force microscopic images of surfaces prior to and after ion beam polishing. The analysis of the height profiles showed a roughness reduction from 0.18 nm rms to 0.12 nm rms.

Scanning force microscopy image of a 5 µm x 5 µm silicon substrate surface prior to (left) and after (right) ion beam processing



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1 *Synchrotron mirror with two different reflection layers: individual gold layer for total reflection, nanometer multilayer for Bragg reflection at larger glancing angles*

2 *Process photo of the ion beam technique for X-ray optical surface preparation (cleaning, polishing)*

3 *Process photo of the ion beam technique for the coating of optical components with individual or multilayer nano coatings*

Deposition processes were developed that are optimized for super polished silicon wafer substrates. These optimized coatings show improved surface quality. Interface widths (roughness + interdiffusion) of less than 0.3 nm are typical. As a result we achieved for the material system Ni/B_4C Cu-Kα radiation (λ = 0.154 nm) reflectivities exceeding 90 %.

Low-d-spacing multilayers with individual layer thicknesses of less than 1 nm were produced, which despite these extremely low thicknesse yielded reflectivities of greater than 70 % (Mo/B_4C with dp=1.5 nm at λ = 0.0775 nm).

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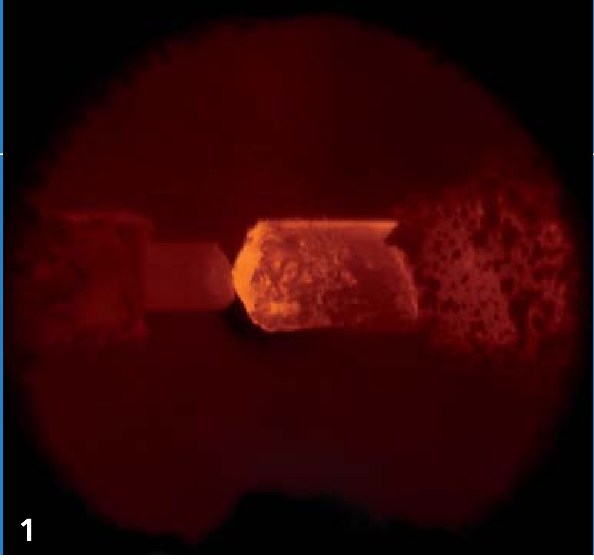

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SCALED UP SYNTHESIS AND PROCESSING OF SINGLE WALL CARBON NANOTUBES

THE TASK

In particular, single wall carbon nanotubes (SWCNT) have been of interest to researchers and technologies for more than 15 years. They have unique properties and achieved world record performances when tried for a vast variety of applications. SWCNTs are orders of magnitude lighter than multi wall carbon nanotubes and carbon nanofibers while simultaneously offering the same or even better mechanical and electrical properties.

For many years the production process of carbon nanofibers and multi wall carbon nanotubes have been manufactured tons of these materials so that there is worldwide a sufficient supply of them for development and applications. This is not so for single wall carbon nanotubes despite years of R&D efforts to scale up the fabrication processes.

The properties of SWCNT can be utilized in composite materials. Thus the integration of SWCNTs with the selected matrix materials is another challenge in addition to the need for scale-up. This requires to first exfoliate the SWCNTs from bundles and then to disperse them into suitable matrix materials or their precursors.

OUR SOLUTION

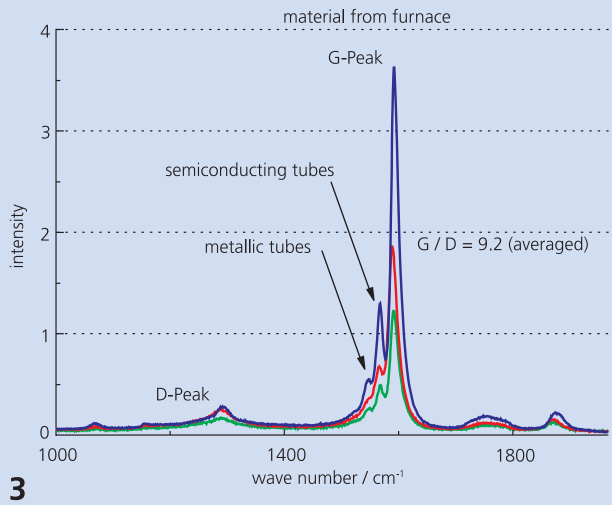
Fraunhofer IWS engineers developed a pulsed high current arc process that operates near atmospheric pressure and achieves very high evaporation rates of the raw material, which is metal containing graphite. This high evaporation rate is the necessary condition to synthesize large quantities of single wall carbon nanotubes. Special gas flushed furnaces were also developed to cool the metal and carbon containing vapors, which ensures the undisturbed condensation and further growth of single wall carbon nanotubes. Finally, the nanotubes are washed out of the gas phase with a so-called gas washer using standard solvents or water. After this step the nanotubes are pre-dispersed, pose no health risk and are ready to be processed.

RESULTS

Larger quantities of single wall carbon nanotubes were manufactured using a single electrode process yielding more than 1 kg of SWCNTs per week. The SWNTs are offered for R&D purposes in dispersed and pasty form but also as very low-density powders. Future work will aim at the development of multi electrode processes to further increase the synthesis rate.

The diagram below shows the results of Raman measurements performed on an SWCNT filled paste, which demonstrate the quality of the SWCNTs.

Raman measurements (λ = 785 nm) showing SWCNT features



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These SWCNTs were produced using the scaled-up process. The Raman data show a low defect density (high G / D peak ratio) and clearly distinguishable peaks for metallic and semiconducting SWCNTs, which would not be possible for multi wall carbon nanotubes.

Thus we can offer high quality and light weight single wall carbon nanotubes in technologically relevant quantities. We expect a mid-term time frame to commercialize the material.

1 / 2 View into the scaled up arc discharge synthesis process of single wall carbon nanotubes. This process is capable to manufacture single wall carbon nanotubes in technically relevant (large) quantities.

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1

2

FOREVER SHARP COOKING KNIVES DUE TO DIAMOR® COATING

THE TASK

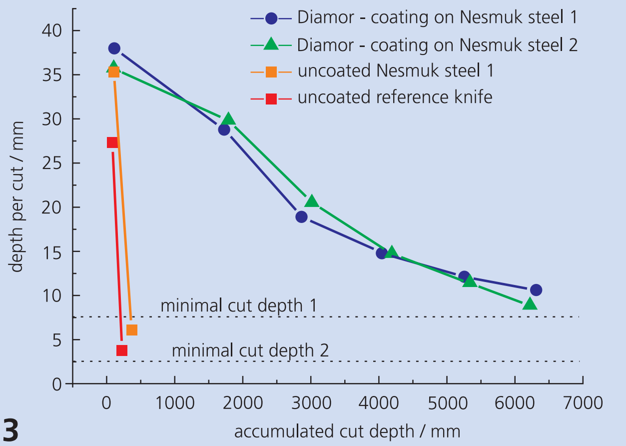
The fabrication of sharp knives is considered as an art of craftsmanship. Its origins can be traced back to the early middle ages. The oriental blades made from damask steel, a special multilayer material consisting of hard and soft layers are very famous. Modern high-end cooking knives are rarely made in damask steel technology. Instead equally strong monolithic steels are used. No matter how sharp a blade is ground, during use the sharpness rapidly drops to only a fraction of its initial value. It is critical for how long a knife can maintain an acceptable sharpness.

The coating of blades with thin CVD or PVD hard coatings is a promising approach to extend the sharpness for example of razor blades or technical cutting tools. Cooking knives applications however have so far not been convincing. The Fraunhofer IWS ta-C Diamor® coatings offer a great potential for this application. They are very wear resistant so that a very thin layer protects the cutting edge very well without addition too much curvature to it. The approach was tested with the goal to substantially extend the cutting live of high-end Nesmuk knives. An additional objective was to generate an attractive design of the blade, which is hollow ground on both sides.

OUR SOLUTION

A previous research project funded by the FGW (Research association for tools and materials e. V.) indicated that a double sided coating of a blade with ta-C would not yield substantial improvements. However, a single sided application helped to drastically reduce the loss of sharpness. A film thickness of 3 µm appeared to be optimal. The by the FGW employed testing specification DIN EN ISO 8442-5 is based on the repetitive cutoff of paper card stacks. The number of severed cards per cut represents a measure for blade sharpness.

FGW test for a cooking knife by cutting paper stacks
minimal cut depth:
1 requirement for knives that are not to be resharpened
2 requirement for knives that are to be resharpened



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The experiment involved four knife blades. In addition to the reference knife (test winner of a well-known testing institute) we tested an uncoated Nesmuk knife (1.4153) and two with 3 µm Diamor® coated Neskmuk knives made from different steels (1.4116 and 1.4153).

RESULTS

The results plotted in the diagram show a significant difference in cutting performance for the uncoated and the Diamor® coated blades. The uncoated blades turn dull within a short time and have only a fraction left of the initial sharpness. On the other hand both Diamor® coated blades maintain an acceptable sharpness for an extraordinary amount of time. An acceptable sharpness means for not-to-resharpened knives a cut depth of 7.5 mm, and 2.5 mm for knives that have to be resharpened. Both Diamor® coated knives maintain values above both specification even after a total cutting length of 6 m. Based on these results Diamor® knives can be basically considered to be indefinitely sharp.

To meet the design requirements was a technological challenge. The coating had to be applied in form of a narrow strip along the edge while all other surfaces should remain free of coating. To meet these requirements a special fixture was designed and built, which also ensures high quality coating capability for larger quantities and process reproducibility.

1 Mask fixture for exact contour coating of the knife blade

2 Coated blades

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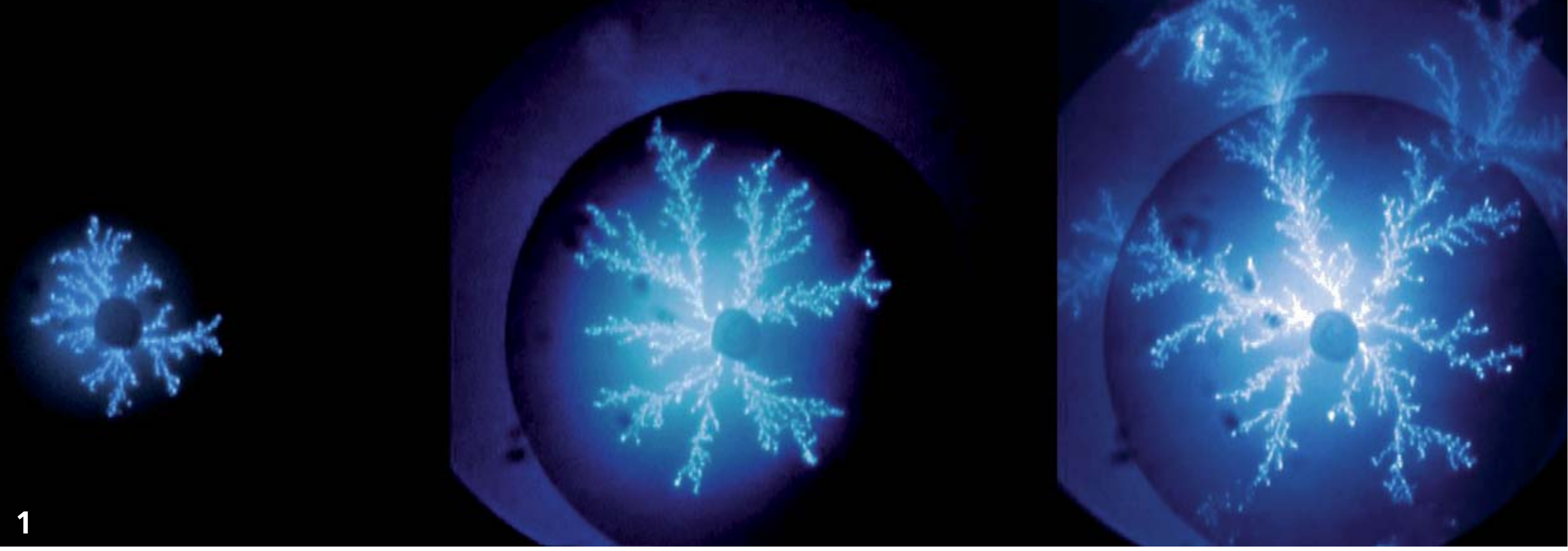

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COATING DESIGN WITH HIGHLY ACTIVATED METAL PLASMA

THE TASK

The technical realization of transparent electrodes is a key issue for the development of future technologies in solar applications, for the development of optoelectronic devices and for display technologies. Today's electrodes are primarily made from selected transparent conductive oxides (TCO). However, the electrical conductivity of these materials is relatively low, their mechanical properties are for many applications less favorable and the manufacturing processes are relatively costly.

Fundamental innovation in this area could offer new momentum for many high-tech applications. Alternative coating materials are for example very thin metal films. The achievable conductivities are 100 – 1000 times higher than those of TCO materials. Subsequently the coatings can be made much thinner and thus transparent.

Conventional thin film coating technologies such as evaporation and sputtering typically lead to island type growth kinetics. A minimal film thickness (percolation threshold) has to be deposited to interconnect the islands and get a conductive film. For most materials this occurs for thicknesses beyond 10 nm, which reduces the transparency of the films so that they are not useful as transparent electrodes.

OUR SOLUTION

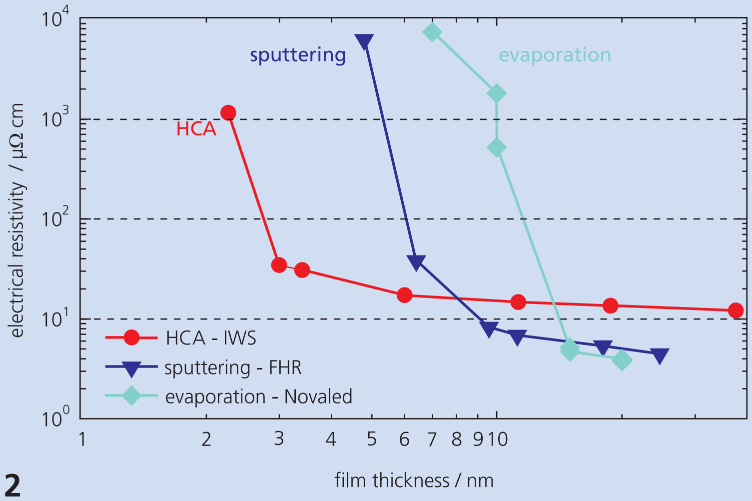
Fraunhofer IWS engineers develop a pulsed high current arc process (High Current pulsed Arc – HCA) that generates metal plasmas with extremely high ionization degrees and ion energies. Coatings produced with this process do not start the film growth in the form of islands. Rather the incoming ions are subplanted into the substrate surface. This leads to extremely dense and uniform structures. Due to the pulsed mode of operation the HCA technology offers a high flexibility with respect to the adjustable process parameters, which makes it an ideal tool to optimize coating conditions.

The HCA technology was deployed to deposit silver onto glass substrates. Transparency and electrical conductivity were measured. The coatings were also compared to those made by project partners with evaporation and sputtering processes.

RESULTS

The diagram shows results of the electrical resistivity measurements as a function of the silver film thickness.

Conductivity of thin silver films, which were deposited using different coating processes



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Clearly visible are the different percolation thresholds for the electrical conductivity and various coating processes. The films deposited by evaporation show a significant resistivity drop for thicknesses beyond 10 nm. Sputtering shows the effect between 5 - 6 nm. The HCA technology achieves the increase in conductivity already at thicknesses between 2 - 3 nm. The HCA coated silver films are sufficiently transparent and conductive for many applications. Current research projects focus on the further optimization and development to commercialize these coatings as an additional alternative to know TCO materials.

1 High current arc discharges of different pulse lengths on a metal cathode. The cathode spots of the discharge, which are eroding an increasingly larger area with increasing pulse length are visible (in the picture from left to right). High current arc discharges in the kilo ampere range generate highly ionized plasmas with multiply charged ions.

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PRICES AND HONOURS 2009

Saxony's best junior skilled worker in the trade of materials testing comes once again in 2009 from the Fraunhofer IWS Dresden. On November 2nd 2009 Ms. **Lisa Tengler** received the certificate from Saxony's Minister for Culture and Sports, Prof. Dr. Roland Woeller, and IHK president Hartmut Paul.

For the fourth time the Fraunhofer IWS Dresden was honored as an outstanding professional training institution in the skilled trades.

IHK Industrie- und Handelskammer Dresden

Urkunde

Ausgezeichneter Ausbildungsbetrieb 2009

Fraunhofer Institut für
Werkstoff- und Strahltechnik

wird für herausragende Leistungen
in der dualen Berufsausbildung

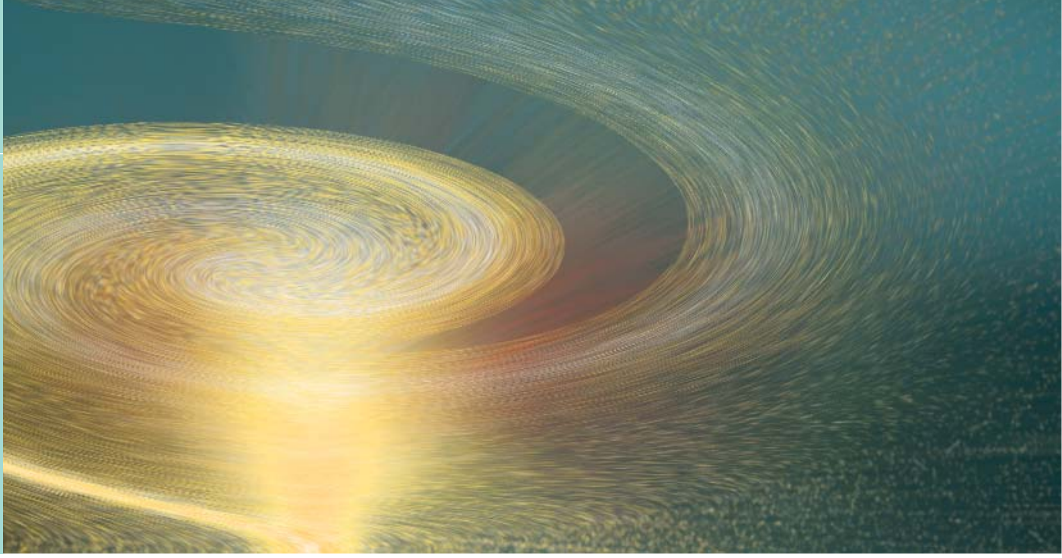
besondere Anerkennung

ausgesprochen.

The 2009 IWS prizes were awarded on December 18th:

The award for the **best innovative product idea to open a new business field** went to the high-speed temperature control system "E-FAqS". The new control system achieves very short response times in high-speed processes. A perfect application example is the laser soldering of solar cells. Here the system is capable to very accurately monitor the very narrow process window from melting to overheating. **Stefan Kühn, Marko Seifert, Sven Bretschneider** and **Udo Karsunke** (in photo from left to right) utilized a wealth of experience in building control systems and software development to create an affordable and flexible control system and to demonstrate its suitability for industrial deployment.

Over only two years the system generated revenues of about 500 kEuro, which impressively demonstrates its innovation potential. 23 units were installed by the company teamtechnik where it is used in systems for the laser beam soldering of solar cells. One unit is installed for temperature control in a laser assisted machine tool at Sitec and another serves a laser beam welding process of plastic materials. The system is also used for internal process development and optimization such as for example the laser soft annealing of surgical needles, the hardening of seal plates and of cutting lines.



Marko Schneider (2nd from left), **Andreas Brückner** (3rd from left) and **Annett Döring** (2nd from right) received the award for outstanding technical performance. They developed a technology for the partial and one-sided coating of high value knife blades to create a self-sharpening effect. The scientific and technical results of this work are presented on pages 78 / 79 of this annual report.

The award for the **best scientific achievement of a junior scientist** went to Mr. **Georg Dietrich**. Since he finished is diploma thesis in 2007, he has been working on the fabrication of reactive nanometer multilayer coatings for precisely controllable joining applications. The coatings consist of several hundreds to thousands of 10 to 100 nm thick individual layers of alternating materials (mostly metals). These can perform and exothermal reaction to provide a precisely definable amount of heat based on coating design and reaction temperature. Mr. Dietrich uses magnetron and ion beam sputtering processes to fabricate coatings that can be as thick as 100 µm and are deposited directly onto the workpiece or onto foils. First soldering applications are under development.

Three prizes for **outstanding student achievements** were awarded:

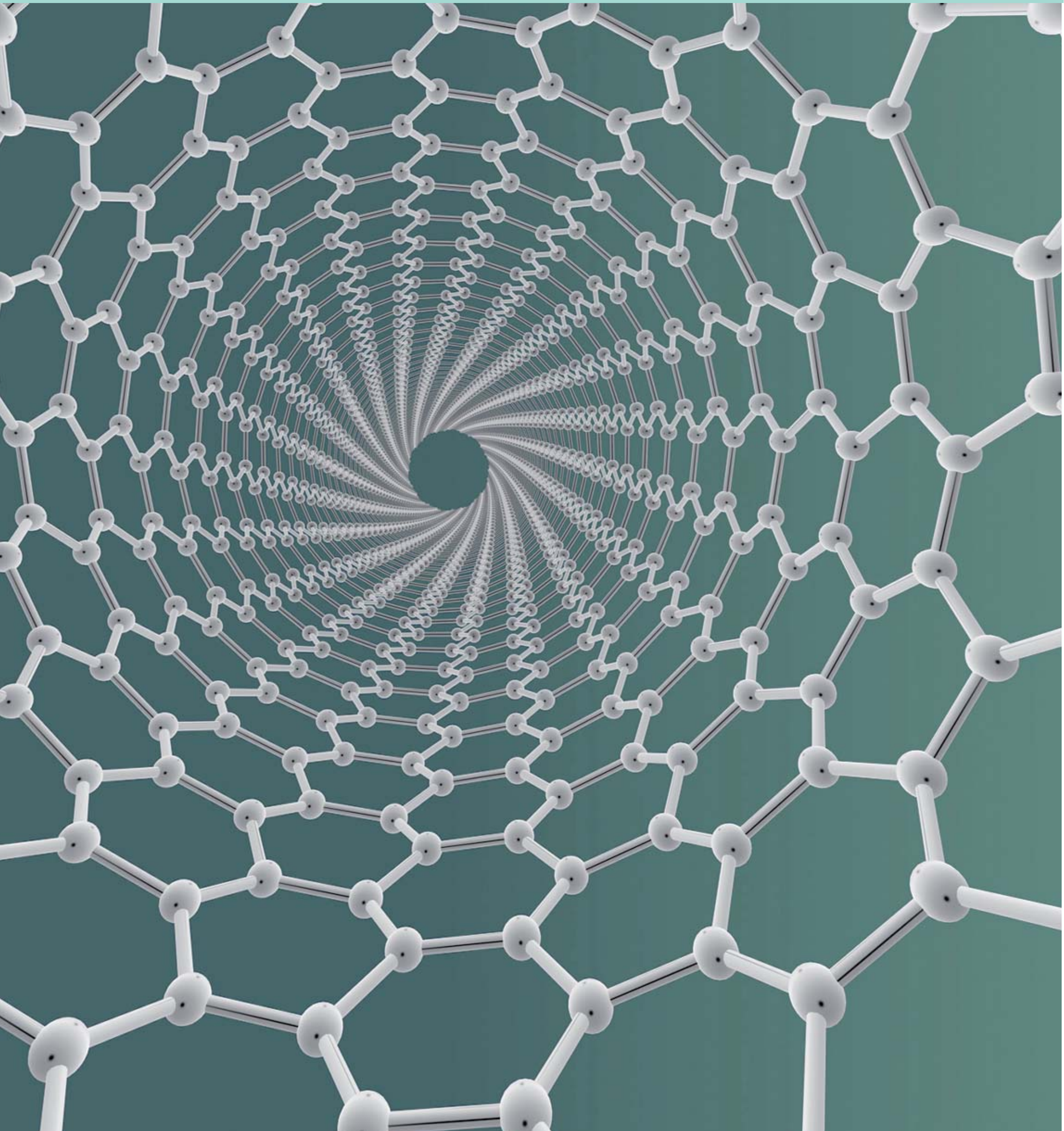
Ms. **Blanca Menendez-Ormaza** successfully devoted her effort to the topic "Laser interference lithography to fabricate complex periodic lattices in photo polymers" and created complex periodic lattices and sub-µm channels. Instead of splitting the beam in three or four partial beams and then combining them on the substrate surface, she went with two beams and performed multiple exposures of the substrate under different angles. Multiple exposures allow the fabrication of the most different 2D patterns. If the substrate is in addition tilted it is possible to make microchannels (< 500 nm) with a very high aspect ratio (> 2000!). Such structures are useful for micro filter and mixer applications but also offer new optical properties.

Ms. **Susanne Dörfler** was honored for her work on synthesizing vertically oriented carbon nanotubes using thermal CVD on electrically conductive substrates. She supported the development of cost effective and scalable processes for the direct growth of CNT forests on metal foils as discussed in detail on pages 66 / 67 of this annual report.

Mr. **Frank Kubisch** received the award for is constructive development work of a modular inner diameter cladding optics for direction independent 3D laser buildup welding. The novel and IWS patented system for deep plunging depths is discussed in detail on pages 54 / 55 of the annual report.

Special institute prizes went to Mrs. **Birgit Mörbe** for her excellent patent related services and consulting and to Mr. **Frank Stauber** for is outstanding engagement in maintaining the IT systems.

NETWORKS



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.

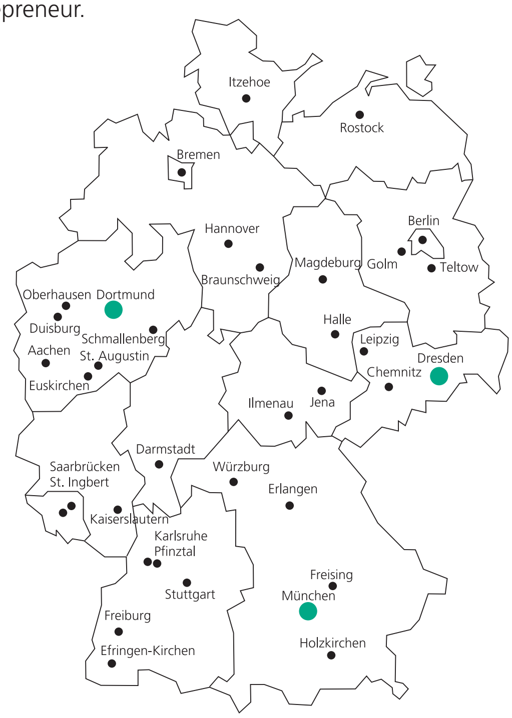
At present, the Fraunhofer-Gesellschaft maintains more than 80 research units in Germany, including 59 Fraunhofer Institutes. The majority of the 17,000 staff are qualified scientists and engineers, who work with an annual research budget of €1.6 billion. Of this sum, more than €1.3 billion is generated through contract research. Two thirds of the Fraunhofer-Gesellschaft's contract research revenue is derived from contracts with industry and from publicly financed research projects. Only one third is contributed by the German federal and Länder governments in the form of base funding, enabling the institutes to work ahead on solutions to problems that will not become acutely relevant to industry and society until five or ten years from now.

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

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

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

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



CONNECTION TO THE UNIVERSITY OF TECHNOLOGY (TU DRESDEN)

CHAIR FOR LASER AND SURFACE TECHNOLOGY

During 2008, 35 employees and 17 research assistants were employed in the university department. The third party revenues yielded more than 1.0 million euros.

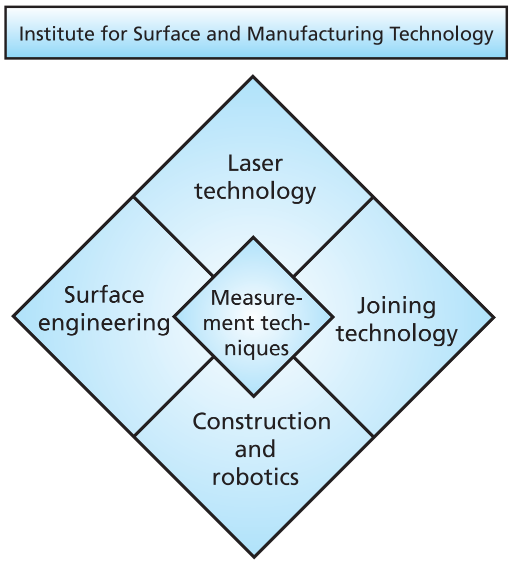
The department of laser and surface technology is the driving component of the institute for surface and manufacturing technology at the faculty of mechanical engineering. The performed projects are more basically oriented and are intended complementaryly to the work of the IWS.

The following courses were offered:
- Prof. Beyer: Manufacturing technology II
- Prof. Beyer: Laser basics
- Prof. Beyer: Laser system technology
- Prof. Beyer: Plasmas in manufacturing technology
- Prof. Beyer: Rapid prototyping
- Prof. Beyer: Laser robotic, lasertronic
- Dr. Leson: Nanotechnology
- Prof. Schultrich: Thin film technology
- Prof Günther: Micro and finish processing

Lehrstuhl
Laser- und Oberflächentechnik LOT

COOPERATION FRAUNHOFER IWS - TU DRESDEN

A special agreement regulates the co-operation between the IWS and the TU Dresden. Prof. Beyer works simultaneously as the executive director of the IWS as well as a chairman at the University. The work is distributed as follows: Research and education are performed at the university and applied research and development are performed at the IWS. IWS employees are tied into projects at the university and vice versa. In the end the IWS and university form one unit with a different emphasis for each part.



The advantages for IWS are:
- cost effective basic research,
- education of junior scientists for the IWS,
- access to scientific helpers.

The advantages for the TU are:
- R&D involvement in industrial projects,
- integration of newest R&D results into education,
- training of students on the most modern equipment.

DRESDEN
concept

"DRESDEN-CONCEPT"

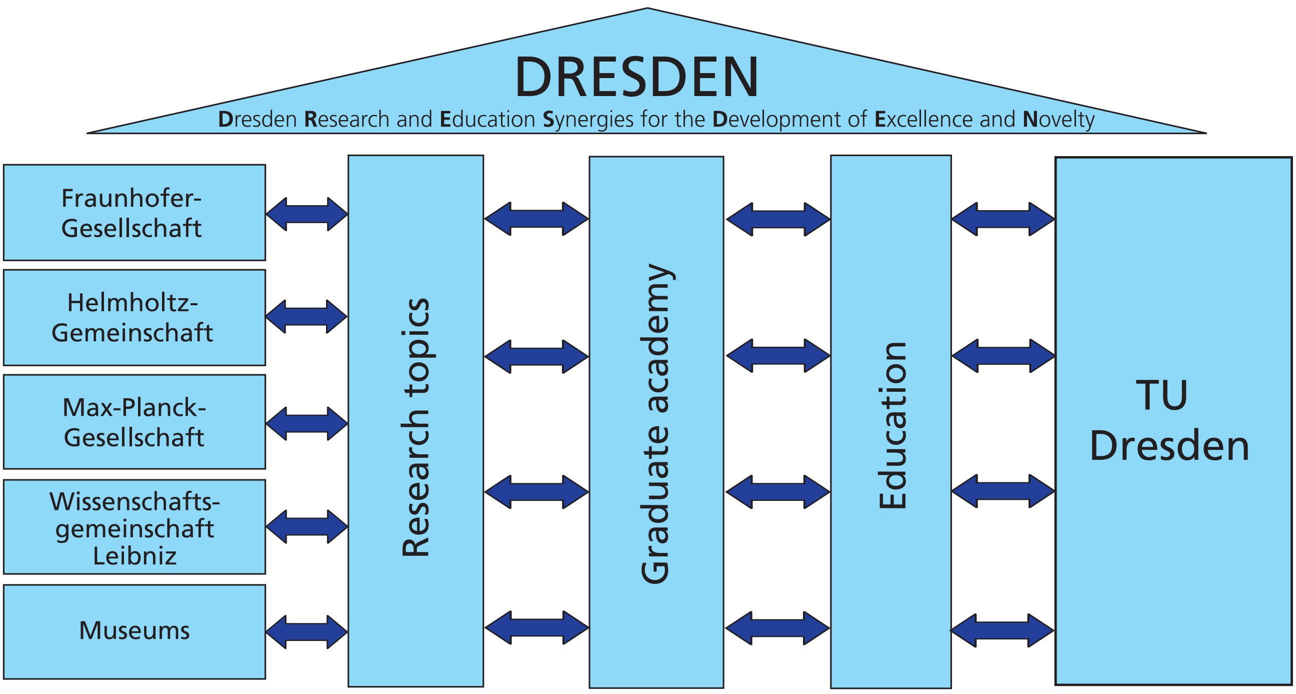
Dresden is a leading research location in Germany. The region has a high density of scientific institutions including ten universities and institutes of higher education (including the TU Dresden and the University of Applied Science HTW), three institutes of the Max Planck Gesellschaft and four Institutes of the Leibniz Gemeinschaft such as the Research Center Dresden-Rossendorf.

To further enhance this lead and to prepare the TU Dresden for the next federal iteration of its Excellence Initiative the scientific region undergoing substantial networking efforts to create the most excellent research and university educational environment. Since February 2009 Dresden's extramural research institutions, state capital museums and the TU Dresden a forging a worldwide unique top-notch research alliance.

The program of the alliance is its name: DRESDEN-concept (**D**resden **R**esearch and **E**ducation **S**ynergies for the **D**evelopment of **E**xcellence and **N**ovelty). Synergies are being created between extramural institutions and the TU Dresden with respect to research, graduate education and scientific infrastructure.

The following concrete goals of the DRESDEN-concept are agreed upon:

- definition of joint research topics,
- foundation of graduate schools in these fields,
- collaboration to attract excellent scientists from all over the world,
- utilizing synergies based on the existing infrastructure (laboratories, equipment) and the education of students.



"DRESDEN INNOVATION CENTER ENERGY EFFICIENCY (DIZE^{EFF})"

The Dresden Innovation Center Energy Efficiency (DIZE^{EFF}) was started in February 2009 as the first "construction phase" of DRESDEN-concept. This particular effort is extending the very successful collaboration between the University of Technology Dresden and the Fraunhofer-Gesellschaft with thematically specific research. For years the Fraunhofer-Gesellschaft has been tightly connected to the University via the joint appointments of institute directors.

The goal of the Innovation Center is to use the close scientific cooperation to strengthen academic teaching in innovation competency of both institutions. This in turn is very beneficial for the research location Dresden and the entire region.

Four institutes of the Fraunhofer-Gesellschaft and ten TU Dresden institutes leverage their particular strengths and work on a common energy efficiency research thematic in the following areas:

- high power solar cells,
- light weight construction and energy efficient manufacturing,
- energy saving displays,
- high temperature energy technology,
- fuel cells.

These areas are of great interest to industry due to the high demand for research services and for excellently educated scientists and engineers.

The Fraunhofer IWS coordinates this joint project and is the authorized contact partner.

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The Dresden Innovation Center Energy Efficiency achieves a new performance level due to leveraging the excellent basic research capabilities of the University of Technology Dresden and the Fraunhofer-Gesellschaft to implement research and development results in industry. Innovations are faster transferred to industries and markets. Thus, the University and Fraunhofer strengthen the German economy.

Within the Dresden Innovation Center the TU Dresden and the Fraunhofer-Gesellschaft are engaged in supporting junior scientific talent. They provide young researchers with excellently equipped and attractive working conditions.

The Fraunhofer-Gesellschaft provides six million Euros in funding for the Innovation Center and the Free State of Saxony contributes another four million Euros. This funding supports numerous highly qualified science related jobs from 2009 through 2013. Additional industry funds guarantee the creation if more science positions in the following years.

TU institutes	Fraunhofer institutes: Material and beam technology	Electron beam and plasma technology	Ceramic technologies and systems	Photonic microsystems
Surface and manufacturing technology	■			
Inorganic chemistry	□		□	
Applied physics		□	□	
Materials science			■	
Applied photonics				□
Lightweight construction and polymer technology	□			
Semiconductor and microsystems technology				□
Electronic packaging laboratory				□
Solid-state electronics		□		
Power engineering		□	□	

PROJECT GROUP AT THE DORTMUNDER OBER-FLÄCHENCENTRUM (DOC)

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The DOC Dortmunder Oberflächencentrum develops tailored coatings using continuous processing of steel band. Development goals include the further development of functions such as corrosion resistance, scratch resistance and cleaning properties.

The Fraunhofer IWS is a partner at the DOC and has a project group operating on site. This group develops coating processes based on PVD, PACVD and spraying techniques as well as focuses on laser materials processing.

Novel zinc alloy coatings (ZE-Mg) present an outstanding result of this collaboration. At half the thickness of convention zinc coatings these new coatings offer the same corrosion protection combined with significantly improved laser weldability. Hybrid and combination processes were developed and in particular the hybrid welding of high strength steel components. It is also possible to combine cleaning and welding or welding and post galvanizing processes.

In its 1100 m^2 facility the Fraunhofer group offers a number of complementary process for surface refinement. State-of-the-art equipment is used to generate nearly pore free and extremely adhering plasma spray coatings. Highly stressed areas of parts and tools are protected with millimeter thick wear protective cladding using laser buildup welding. The vacuum coating capabilities include machines that handle meter sized and ton heavy parts, which are coated with nano- and micrometer thick high performance coatings such as Diamor®. These coatings provide outstanding hardness and excellent sliding properties. Coating materials are under development offering additional corrosion protection capability.

It is frequently possible to combine these various state-of-the-art processes. The resulting broad technology spectrum in combination with the Fraunhofer IWS know-how provides confidence to TKS or other customers that they will receive a technically and economically optimal solution. A compact new type of 8 kW solid-state laser of high beam quality is used for process development but can also be deployed for trouble shooting missions directly at the customer's plant.

PROJECT CENTER (PCW) LASER INTEGRATED MANUFACTURING IN WROCŁAW

"To jointly shape the future" is the goal of German and Polish engineers and scientists who are collaborating at the "Fraunhofer Project Center for Laser Integrated Manufacturing". In the presence of Germany's chancellor, Dr. Angela Merkel, the research center was officially inaugurated in Wrocław on September 24th 2008.

At the Fraunhofer project center, German and Polish researchers will bundle their know-how in a holistic approach to further develop and improve rapid prototyping technologies. Fraunhofer IWS engineers are experienced in the development of laser technologies and the scientists from the TU Wrocław are specialists in manufacturing and process technologies. Together they can explore and develop new technology areas. The development of new prototyping techniques requires joint competences.

A series of joint projects is lined up. For example, one project will utilize a laser process to build structures, which are mechanically finished in between and post processing steps in one and the same machine setting. This and similar projects aim at the expansion of rapid prototyping to rapid manufacturing with the ultimate goal to develop generating fabrication processes for individualized manufacturing of unique products.

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From Wrocław the team wants to develop international markets. Potential customers for innovative rapid prototyping are automotive suppliers and manufacturers of household and electro appliances in East and West.

The partnership with the Technical University in Wrocław represents the first Fraunhofer cooperation in Poland. The effort plays a vanguard role in establishing German-Polish collaborations in applied research.

FRAUNHOFER CENTER FOR COATINGS AND LASER APPLICATIONS (CCL)

The US market is one of the most important international benchmarks and innovation driving forces for applied research and development. Since 1997 the Fraunhofer IWS Dresden has been concentrating its USA activities within the "Fraunhofer Center for Coatings and Laser Applications" (CCL).

The Fraunhofer Center for Coatings and Laser Applications mirrors the main activities of the IWS in laser and coating technologies. With an annual turnover of $4.4 Mio the center is one of the strongest Fraunhofer centers in the USA. Since 2003, Dr. Jes Asmussen heads the CCL. He is a professor at Michigan State University and his previous work in diamond coatings and synthesis ideally complement the know-how of the Fraunhofer IWS in the area of Diamor® coatings.

The CCL consists of two divisions,
the "Coating Technology Division" at the Michigan State University in East Lansing and the "Laser Applications Division", which is situated at the Fraunhofer USA Headquarters location in Plymouth, Michigan.

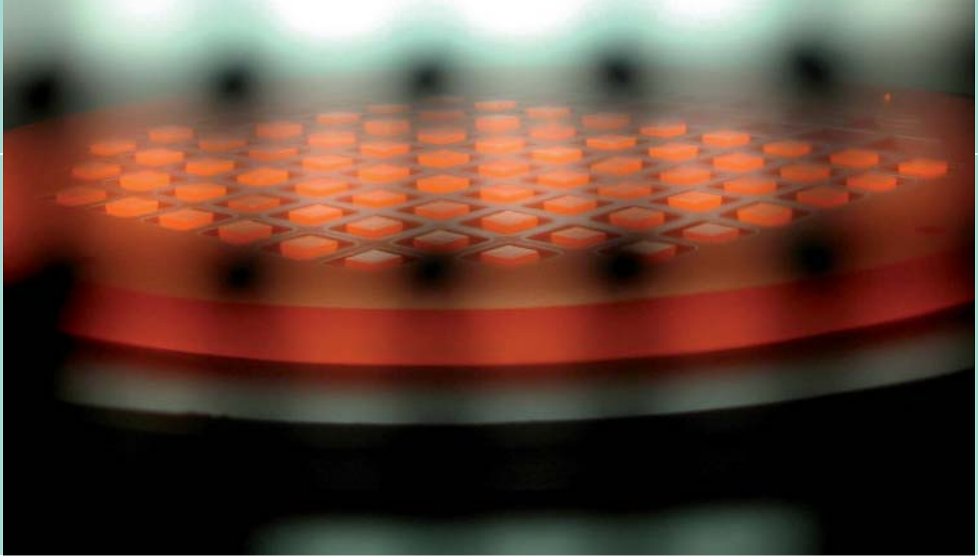
COATING TECHNOLOGY DIVISION

Prof. Jes Asmussen and Dr. Thomas Schuelke lead a group of experienced Fraunhofer researchers and German students in collaboration with faculty members and students of the Michigan State University. The team works in the following research areas:

- technologies involving amorphous diamond-like carbon coatings,
- chemical vapor deposition of ultranano-, poly- and single crystalline diamond materials,
- doping of diamond materials,
- physical vapor deposition technologies.

The amorphous diamond-like carbon coating research program utilizes the Laserarc® process, which was developed at the IWS Dresden. For several years CCL engineers have been applying this technology to coat tools for the machining and processing of aluminum materials. The amorphous diamond-like carbon coating significantly improves the lifetime of these tools. The Coating Technology Division collaborates closely with Michigan State University's Formula Racing Team. High performance wear resistant coatings are tested on various racecar components under race conditions. The collaboration provides the racing team with a competitive advantage and also returns critical information to CCL engineers for improving coating performance.

In recent years the Coating Technology Division have focused on research in the area of microwave plasma assisted chemical vapor deposition of diamond materials and in particular on the synthesis of doped and undoped single crystalline diamond. Here the team established an international reputation.



LASER APPLICATIONS DIVISION

The laser group of the CCL is located in Plymouth (Michigan), which is "next door" to the American automotive industry in Detroit. The group performs numerous laser beam welding projects of power train components such as differential gear sets, transmissions and drive shafts. In 2007 the CCL was presented with the Henry Ford Technology Award in recognition for the development of a laser beam welding process to improve the roof strength of Super Trucks.

A highlight of the research work is the development, patenting and licensing of a laser buildup welding process to generate highly abrasion resistant coatings. The coating consists of nearly mm-sized synthetic diamond particles, which are embedded in a metallic matrix. The technology is applied to drilling equipment for the oil production in the USA and Canada.

The close connection to the Fraunhofer CCL offers several advantages to the IWS. The awareness of the supply and demand situation helps to quickly recognize trends in the United States, which influence the technology development efforts at the IWS.

The research and development work performed in the United States generates additional know-how and competencies, which benefit the project acquisition in German and European markets. An exchange program offers IWS researchers the opportunity to work in the United States, which provides them with experiences that are beneficial for their entire career.

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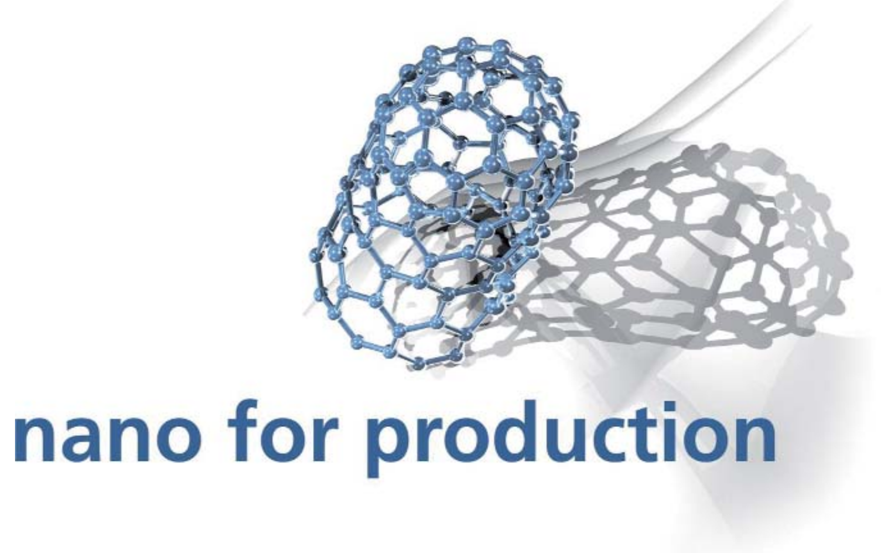

NANO TECHNOLOGY ACTIVITIES

All industry branches from automotive to medical technology benefit from nanotechnologies. Entrepreneurs and researchers are collaborating to quickly and effectively commercialize the research results of this strategic technology for Germany. Dresden is a very successful nanotechnology location. Since November 2006, companies and research institutions collaborate in the **nanotechnology innovation cluster "nano for production"**. The objective of this collaboration is to move nanotechnology forward from basic research to the threshold of industrial implementation, which would create a necessary condition for a wide range commercial utilization of the technology. Essential elements of nano production technology are being developed, tested and made available to a broad user range.

In September 1998, 51 companies, 10 university institutes, 22 extramural research institutions and 5 associations formed the **nanotechnology competence center "Ultrathin Functional Films"** to consequently explore possibilities for industrial applications. The Center was recognized by the BMBF (Federal Ministry for Education and Research) as Germany's leading competence in ultra thin functional films. Work at the competence center includes participating in exhibitions, supporting and performing events and the issuing of requests for proposals and funding of feasibility studies.

In the nanotechnology field the IWS was a co-organizer of the "Nanofair – International Nanotechnology Symposium", which was held on May 26th - 27th for the 7th time. Currently the 8th Nanofair is in preparation. The event will be held on July 6th - 7th 2010 at the International Congress center in Dresden under the joint sponsorship of the state capital, the Office for Economic Development and the Fraunhofer IWS.

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LASER INTEGRATION IN PRODUCTION TECHNOLOGY - INITIATIVE LIFT

The **LiFt initiative** aims at applying laser technologies to secure and expand the competitiveness of Saxony's machine and plant engineering and building industries. The initiative was launched in 2007 when the concept won the innovation competition "Industry meets Science", which was sponsored by the Federal Ministry of Transportation, Building and Urban Affairs (BMVBS).

Within the LiFt initiative the Fraunhofer IWS Dresden cooperates with the University of Applied Sciences in Mittweida and the Institute for Innovative Technologies, Education and Continuing Education (ITW) e.V. in Chemnitz. The institutions aim at commercializing innovations in the area of laser materials processing.

The goal of this network is to point out potential opportunities and offer services to machine builders and manufacturers. The potential advantages are:

- time and cost savings by shortening process chains,
- increase efficiency of manufacturing processes and products,
- unique selling features at the highest technology level.

As developers of technologies and educators, the LiFt project partners offer their services to small and medium sized companies not only in Saxony but also in other regions.

Consulting as a core project activity is based on already installed solutions as well as on individual requirements. In addition to information and consulting services the project also provides limited testing services.

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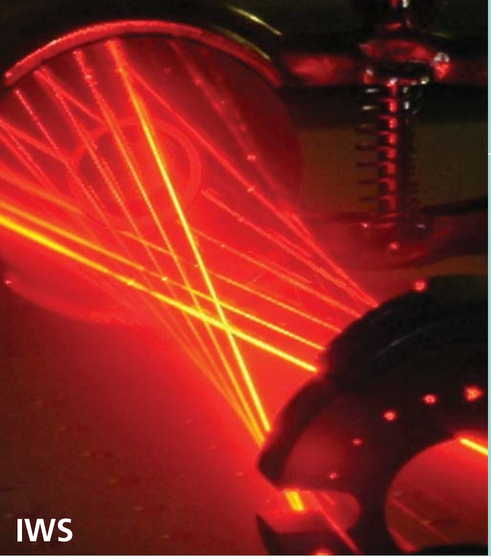
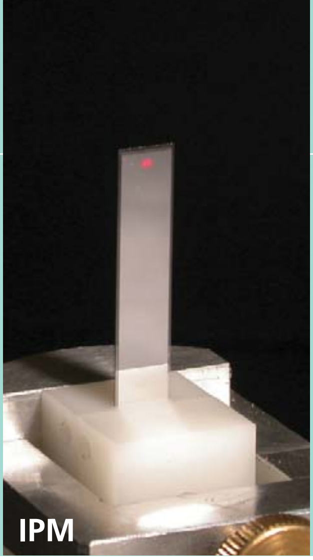
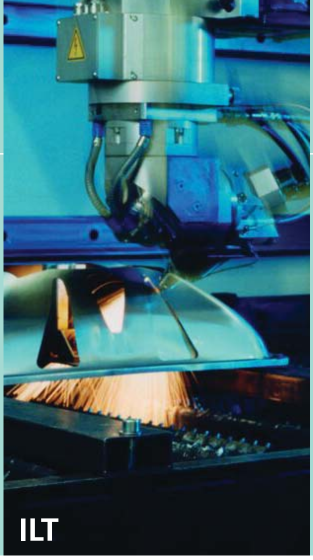
The project is funded by the Federal Ministry for Transport, Building and Urban Affairs (contract number 03WWSN019).







FRAUNHOFER ALLIANCE ”LIGHT & SURFACES”

Surface technology and photonics are two core competencies of the Fraunhofer-Gesellschaft. Their complexity is evidently based on the fabrication of optical and optoelectronic components and products. Laser technology is becoming increasingly important for surface technological manufacturing and characterization processes. Six Fraunhofer Institutes joined forces to form the Fraunhofer alliance ”light & surfaces” to efficiently leverage their competences and to jointly advance strategic developments.

Applied Optics and Precision Engineering IOF
www.iof.fraunhofer.de

Electron Beam and Plasma Technology FEP
www.fep.fraunhofer.de

Laser Technology ILT
www.ilt.fraunhofer.de

Physical Measurement Techniques IPM
www.ipm.fraunhofer.de

Surface Engineering and Thin Films IST
www.ist.fraunhofer.de

Material and Beam Technology IWS
www.iws.fraunhofer.de

RESEARCH IN THE ALLIANCE ”LIGHT & SURFACES”

The core competences of the group are the development of coating systems and deposition processes for various applications, the functionalization of surfaces, the development of beam sources, the development of micro-optical and precision mechanical systems, materials processing and optical measurement techniques. The alliance includes about 1080 employees and a budget of 86 million Euros to work on numerous research topics.

Research topics at the involved laser institutes are the development of innovative laser beam sources and components and the development of technologies and machine concepts for laser materials processing and laser integration in modern manufacturing. The related development of system technology for process monitoring, control and quality control is of increasing importance.

Surface technology and photonics are key technologies. With increasing technological progress they are used for numerous applications in manufacturing, optical sensors, information and communications technology and the area of biomedical technology.

ADVANTAGES OF COOPERATION

Balanced competences provide a permanent, fast and flexible research customization and rapid technological progress in all industrial application areas.

Coordinated and market driven strategies lead to synergy effects.

A broader range of service is offered to the benefit of the customer.

Competence distribution and service topics in the alliance

Core competences	FEP Dresden	ILT Aachen	IOF Jena	IPM Freiburg	IST Braun-schweig	IWS Dresden
Coating and surface technology	⬤	●	•	•	⬤	●
Beam sources	●	⬤	•	•		·
Micro and nanotechnology	·	●	⬤	•	•	•
Materials processing	●	●			·	⬤
Optical measurement techniques		•	●	⬤	•	•

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SPECIAL EVENTS

January 9th, 2009
Colloquium "Laser materials processing with innovative system technology" in honor of the 61st birthday of Dr. Lothar Morgenthal

January 21st, 2009
Workshop "AMZ Campus: Entrepreneurs and research in dialogue", sponsored as an alliance initiative of Saxony's automotive suppliers at the Fraunhofer IWS Dresden

January 29th - 30th, 2009
Congress "Laser applications in restoration and monument maintenance – basics, chances, perspectives" of the DBU in Osnabrück (organizer: Fraunhofer IWS Dresden)

February 27th, 2009
Opening ceremony of the Dresden Innovation Center Energy Efficiency of the TU Dresden and the Fraunhofer-Gesellschaft

March 4th - 5th, 2009
Workshop "Laser + sheet metal – laser applications in sheet metal processing" of the Carl-Hanser publishing house in Dortmund (co-organizer: Fraunhofer IWS Dresden)

March 10th - 11th, 2009
TAW symposium "Thermal coating with laser based manufacturing processes" of the Technical Academy Wuppertal e.V. in collaboration with the Fraunhofer IWS Dresden and the Rofin Sinar GmbH in Dresden

April 23rd, 2009
Participation of the Fraunhofer Institutes Center in the federal "Girls Day"

May 15th, 2009
"Technology Day Dresden" – 5th meeting of former employees of the Fraunhofer IWS Dresden and the LOT department of the TU Dresden

May 25th, 2009
"Junior Scientists Forum" – Meeting during the "Nanofair 2009" (organizer: Fraunhofer IWS Dresden)

May 26th - 27th, 2009
7th International Nanotechnology Symposium "Nanofair – New ideas for industry: at the International Congress Center Dresden (co-organizer: Fraunhofer IWS Dresden)

May 28th - 29th, 2009

"Commercializing Future Technologies for Energy and Energy Efficiency" – Event with guests from Japan and the UK during the "Nanofair 2009" (organizer: Fraunhofer IWS Dresden)

June 19th, 2009

Participation of the Fraunhofer Institutes Center at the "Long Night of the Sciences" in the state capital Dresden

September 30th - October 1st, 2009

5th International Workshop "Fiber laser" at the International Congress Center Dresden (organizers: Fraunhofer IWS Dresden and Fraunhofer IOF Jena)

October 20th - 22nd, 2009

V2009 – Industry Exhibition and Workshop Week "Vacuum coating and plasma surface technology" of the European Research Society "Thin Film Coatings" (EFDS) e.V. (co-organizer: Fraunhofer IWS Dresden)

Photo left:

Prof. Beyer during the opening of the "Long Night of the Sciences" event of the state capital Dresden

Photo right:

A dance show opens the International Fiber Laser Workshop at the Congress Center Dresden

PUBLICATIONS

rp = reviewed paper

[L01]
T. Abendroth, H. Althues, B. Leupolt, W. Grählert, S. Kaskel

"Atmosphärendruck-CVD liefert dünne, photokatalytisch aktive Titandioxid-Schichten"

Branchenindex Galvanotechnik / Dünne Schichten 1 (2009)

[L02]
D.-F. Acevedo, A.-F. Lasagni, M. Cornejo, M. Politano, C. Barbero, F. Mücklich

"Large Area Fabrication of Tuned Polystyrene / Poly(Methylmethacrylate) Periodic Structures Using Laser"

The ACS Journal of Surfaces and Colloids 25 (2009) 16, S. 9624-9628

[L03]
V. Albrecht, T. Himmer, J. Thieme

"Die entscheidende Wellenlänge besser"

Reportage, Industrieanzeiger 11 (2009)

[L04]
H. Althues, R. Pötschke, G.-M. Kim, S. Kaskel

"Structure and Mechanical Properties of Transparent ZnO / PBDMA Nanocomposites"

Journal of Nanoscience and Nanotechnology 9 (2009) 4, S. 2739-2745

[L05]
H.-A. Bahr, M. Hofmann, H.-J. Weiss, U. Bahr, G. Fischer, H. Balke

"Diameter of Basalt Columns Derived from Fracture Mechanics Bifurcation Analysis"

Physical Review. E 79 (2009) 5, Art. 056103, S. 9

[L06]
F. Bartels, A. Klotzbach, T. Schwarz, A. Techel, E. Beyer

"Gesteigerte Dynamik für das Laserstrahlschneiden"

Maschinenmarkt MM, das Industriemagazin (2009) 23, S. 24-26, ISSN 0341 5775

[L07]
L.-M. Berger, K. Lipp, U. May

"Influence of the Substrate Hardness on the Rolling Contact Fatigue of WC-17% Co Hardmetal Coatings"

International Thermal Spray Conference, 04.-07. Mai 2009, Las Vegas, USA, Proc. Eds.: B. R. Marple, M. M. Hyland, Y.-C. Lan, C. S. Li, R. S. Lima, G. Montavon, Mater. Park / OH, ASM International (2009) S. 1036-1040

[L08]
L.-M. Berger, S. Saaro, C.-C. Stahr, S. Thiele, M. Woydt

"Entwicklung keramischer Schichten im System Cr_2O_3-TiO_2"

Thermal Spray Bulletin 2 (2009) 1, S. 64-77, ISSN 1866 6248

[L09]
L.-M. Berger, J. Spatzier, J. Bretschneider, K. Lipp, S. Thiele

"Rollkontaktermüdung von HVOF-gespritzten Hartmetallschichten auf ungehärteten Substraten"

Thermal Spray Bulletin 2 (2009) 2, S. 40-56

[L10]
L.-M. Berger, C.-C. Stahr, S. Saaro, S. Thiele, M. Woydt, N. Kelling

"Dry Sliding up to 7.5 m / s and 800 °C of Thermally Sprayed Coatings of the TiO_2-Cr_2O_3 System and (Ti,Mo)(C,N)-Ni(Co)"

Wear 267 (2009) 5-8, S. 954-964

[L11]
L.-M. Berger, C.-C. Stahr, S. Saaro, S. Thiele

"Microstructure and Electrical Properties of Coatings of the Cr_2O_3-TiO_2 System"

International Thermal Spray Conference, 04.-07. Mai 2009, Las Vegas, USA, Proc. Eds.: B. R. Marple, M. M. Hyland, Y.-C. Lan, C. S. Li, R. S. Lima, G. Montavon, Mater. Park / OH, ASM International (2009) S. 103-108

[L12]
L.-M. Berger, C.-C. Stahr, F.-L. Toma, S. Saaro, M. Herrmann, D. Deska, G. Michael, S. Thiele

"Korrosion thermisch gespritzter oxidkeramischer Schichten "

Thermal Spray Bulletin 2 (2009) 1, S. 40-56

[L13]
L.-M. Berger, M. Woydt, S. Saaro

"Comparison of Self-Mated Hardmetal Coatings Under dry Sliding Conditions up to 600 °C"

Wear 266 (2009) 3-4, S. 404-416

[L14]
L.-M. Berger, C.-C. Stahr, S. Saaro, S. Thiele, M. Woydt

"Dry Sliding Wear Properties of Thermal Spray Coatings in the TiO_2-Cr_2O_3 System"

International Symposium on Friction, Wear and Wear Protection, 09.-11. April 2008, Aachen Proc. Eds.: A. Fischer, K. Bobzin, Weinheim, Wiley-VCH (2009) S. 404-416

[L15]
E. Beyer, M. Lütke, F. Bartels, T. Himmer

"Übersichtsvortrag Schneiden"

Laser+Blech 2009, Carl Hanser Verlag Tagungsband, CD-ROM

[L16]
E. Beyer, M. Lütke, A. Klotzbach, A. Wetzig

"Advanced Remote Cutting of Nonmetal Webs and Sheets"

28th International Congress on Applications of Lasers and Electro Optics ICALEO, Orlando/USA Proceedings, Cutting, Orlando / USA (2009), Paper 609, ISBN: 978 0 912035 59 8

[L17]
B. Brenner, J. Standfuß, U. Stamm, G. Göbel, S. Schrauber, V. Fux, A. Mootz

"Industrial Laser Beam Welding of Hart-to-Weld Materials for Powertrain Components"

Automotive Laser Application Workshop, 13.-14. Mai 2009, Plymouth, USA, Tagungs-CD

[L18] rp
P. Bringmann, O. Rohr, F.-J. Gammel, I. Jansen

"Atmospheric Pressure Plasma Deposition of Adhesion Promotion Layers on Aluminium"

Plasma Process. Polym. (2009) 6, S. 496-502

[L19]
F. Brückner, D. Lepski, E. Beyer

"Calculation of Stresses in two- and three-Dimensional Structures Generated by Induction Assisted Laser Cladding"

Proceedings of The 5th International WLT-Conference Lasers in Manufacturing, Stuttgart: AT-Fachverlag GmbH (2009), S.115-121

[L20]
S. Bonß

"Laserstrahlhärten – Integration in die Fertigung ermöglicht schlanke Prozesse"

Werkstoffe in der Fertigung, Ausgabe 3 (2009), S. 27-28

[L21]
S. Bonß, B. Brenner, E. Beyer

"Laser Beam Hardening – Energy Efficient Heat Treatment"

28th International Congress on Applications of Lasers and Electro Optics ICALEO, Orlando/USA Proceedings, Surface Modification II, Paper 502, Orlando/USA, 2009, ISBN: 978 0 912035 59 8

[L22]
S. Bonß, J. Hannweber, U. Karsunke, M. Seifert, B. Brenner, E. Beyer

"Precise Laser Automotive Die Hardening"

Heat Treating Progress März/April 9 (2009) 2, S. 44-47

[L23]
S. Bonß, C. Zellbeck

"Laserstrahlhärten – Integration in die Fertigung ermöglicht schlanke Prozesse"

VDWF im Dialog, Ausgabe 1 (2009), S. 18-20

[L24]
S. Bonß, C. Zellbeck

"Laserintegration in die Fertigungstechnik"

Produktionstechnik (2009), S. 40-41

[L25]
R. Böhme, L. Girdauskaite, I. Jansen, S. Krzywinski

"Komplexe 3D-Bauteile maßgeschneidert! - Reproduzierbare Preformfertigung für textilverstärkte Kunststoffe"

Lightweightdesign (2009) 6, S. 34-39

[L26]
J. Chen, C.-J. Lee, E. Louis, F. Bijkerk, R. Kunze, H. Schmidt, D. Schneider, R. Moors

"Characterization of EUV Induced Carbon Films Using Laser-Generated Surface Acoustic"

19th European Conference on Diamond, Diamond-Like Materials, Carbon Nanotubes, Nitrides and Silicon Carbide, 7.-11. September 2008, Amsterdam, Niederlande

[L27]
J. Chen, E. Louis, C.-J. Lee, H. Wormeester, R. Kunze, H. Schmidt, D. Schneider, R. Moors, W. van Schaik, M. Lubomska, F. Bijkerk

"Detection and Characterization of Carbon Contamination on EUV Multilayer Mirrors"

Optics Express 17 (2009) 19, S. 16969-16979

[L28]
I. Dani, E. Lopez, D. Linaschke, S. Kaskel, E. Beyer

"Trockenätzen von Solarwafern mit Oberflächenstrukturen im sub-Mikrometer Bereich"

EFDS Workshop 2009, Mikro- und Nanostrukturen an Oberflächen - Herstellung und Anwendungen, Dresden, 09. Oktober 2009, Tagungsband S. 5

[L29]
I. Dani, G. Mäder, P. Grabau, B. Dresler, D. Linaschke, E. Lopez, S. Kaskel, E. Beyer

"Atmospheric-Pressure Plasmas for Solar Cell Manufacturing"

Contrib. Plasma Phys. 49 (2009) 9, S. 662-670

[L30]
I. Dani, E. Lopez, B. Dresler, D. Linaschke, M. Leistner, W. Grählert, S. Kaskel, E. Beyer

"Atmospheric Pressure Plasma Processes for Crystalline Silicon Wafer Processing"

Complete Works of Innovative Solar Cell Technology taiyo denchi kakushinteki gijutuzenshuu 2009 Edition, S. 179-196
Publisher: Association of Information Technology (gijutsu joho kyokai)
ISBN978-4-86104-297-3 C3054

[L31]
P.-A. Dearnley, A. Neville, S. Turner, H.-J. Scheibe, R. Tietema, R. Tap, M. Stüber, P. Hovsepian, A. Layyous, B. Stenbim

"Coatings Tribology Drivers for High Density Plasma Technologies"

Surface Energineering 26 (2010) 1-2, S. 80-96

[L32]
G. Dietrich, S. Braun, P. Gawlitza, A. Leson

"Reaktive Nanometer-Multischichten als maßgeschneiderte Wärmequellen beim Fügen"

Vakuum in Forschung und Praxis 21 (2009) 1, S. 15-21

[L33]
D. Dittrich, B. Brenner, G. Kirchhoff, A. Reim, P. Horst, M. Sähn, J. Hackius

"Advanced Structure Concepts for Closed Metallic Stringer Geometries Regarding Lower and Upper Fuselage"

European Conference on Materials and Structures in Aerospace, 01.-02. Juli 2009, Augsburg

[L34]
C. Dölle, S. Böhm, M. Peschka, I. Jansen, S. Markus

"Klebtechnische Gemeinschaftsforschung im Auftrag der Industrie"

Adhäsion. Kleben & Dichten 53 (2009) 5, S. 34-37

[L35]
K. Florschütz, A. Schröter, M Körner, S. Schmieder, F. Sonntag, U. Klotzbach, G. Kunze

"Nachweis phytopathogener RNA – Viren"

9. Dresdner Sensor-Symposium / DECHEMA e.V., Dresden

[L36]
V. Franke, U. Klotzbach

"Lasers Join Ceramic and Polymer Components"

Industrial Laser Solutions 24 (2009) 10, S. 10-14

[L37]
V. Fux

"Induktiv unterstütztes Laserwalzplattieren: Schwer schweißbare metallische Werkstoffe schnell und effektiv verbinden"

Photonik 2 (2009), S. 15-16

[L38]
V. Fux, K. Merz, B. Brenner

"Laser-Walzplattieren erzeugt attraktive Werkstoffpaarungen: Bandbeschichtung"

Maschinenmarkt. MM, das Industriemagazin (2009) 5, S. 42-45

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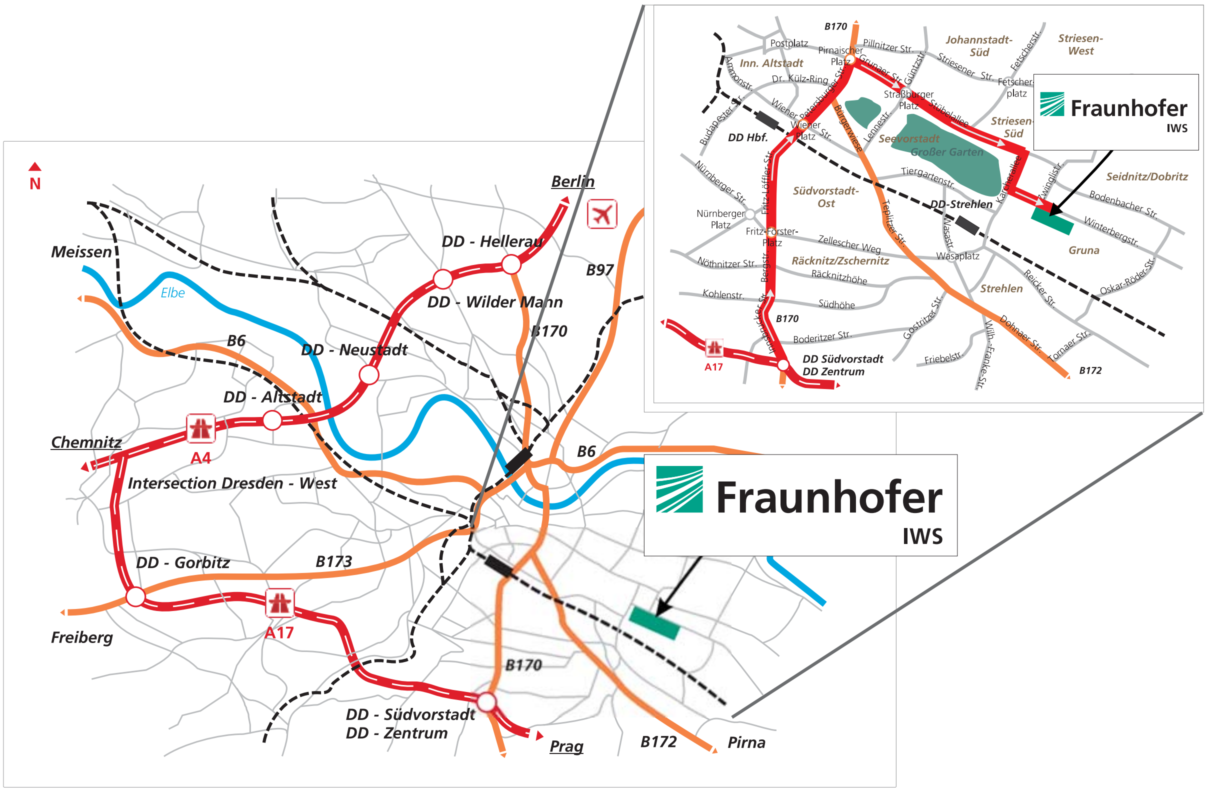

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