Fraunhofer

IWS Dresden

FRAUNHOFER INSTITUTE FOR MATERIAL AND BEAM TECHNOLOGY IWS

ANNUAL REPORT
2012

www.iws.fraunhofer.de

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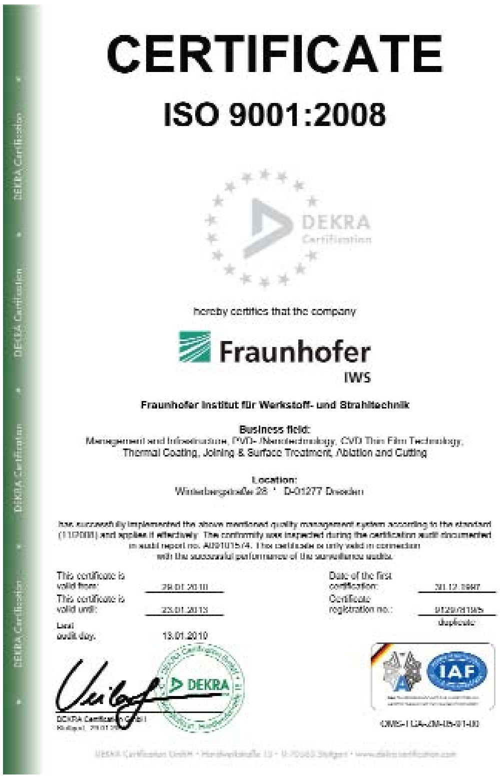


CERTIFICATE

ISO 9001:2008

hereby certifies that the company

Fraunhofer
IWS

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

This certificate is valid from:

This certificate is valid until: 23.01.2013

Last audit day: 13.01.2010

Date of the first certification:

Certificate registration no.:

duplicate

EXECUTIVE DIRECTOR PROF. DR. RALF ECKHARD BEYER

FOREWORD

> *“He who thinks about costs too late will ruin his business. He who thinks about costs too early kills creativity.”*
>
> Philip Rosenthal

Germany’s economy regained substantial momentum in 2012 with a positive outlook for the future. The increasing spending on research and development particularly evidences this trend. Likewise the business success of our institute reflects the healthy state of the economy. During the preceding difficult years, we still managed to increase our contract volume from industry. However, 2012 yielded more than 30 % increased industrial revenues. This result stands for a very positive economic development. But it also reflects the trust that our customers have in IWS, which is directly based on the quality of our work as well as the personal engagement of our employees.

Once again in 2012 IWS employees received prestigious recognitions. We mention here the prestigious award of the German Scientific Laser Society e. V. (WLT) and the Joseph-von-Fraunhofer award. During the past fifteen years IWS employees were awarded the latter prize five times.

Benjamin Franklin said, “An investment in knowledge pays the best interest.” Following this concept we have established a comprehensive internal education program. Employees receive a special certificate if they complete various courses.

An “IWS-Highlight” is a development effort that was transferred to manufacturing. For 2012 we accomplished several such highlights, some of which are discussed in this annual report.

A highlight of an entirely different nature was the 20-year anniversary celebration of all Fraunhofer institutes located in Dresden. Almost 2000 people participated in this event. Other large and very well attended IWS events included the international laser technology symposium “Fiber & Disc”, the joining technology symposium “Tailored Joining”, the workshop “Lithium-Sulfur Batteries” and the “Nanofair”.

“DRESDEN-concept” is a regional concept. Institutes of the Fraunhofer-Gesellschaft, the Max Planck Society, the Leibniz Association, the Helmholtz Center Dresden-Rossendorf and the University of Excellence are closely collaborating on a number of larger scale projects. An example of an IWS coordinated project is the development of stationary batteries. Several even larger projects are close to being funded.

In 2012 the IWS also expanded its collaboration network beyond the partners involved in DRESDEN-concept. IWS field operations in the USA as well as project groups in Dortmund and Wroclaw, Poland contributed to IWS’ success. A Center for “Tailored Joining” was founded jointly with the Technische Universität Dresden, which represents almost any available joining technology.

2012 was an extraordinarily successful year for IWS. We are very optimistic for 2013. I would like to take the opportunity here to express our sincere gratitude to all our project partners for their trust and the excellent cooperation.

CONTENTS

THE FRAUNHOFER IWS

BUSINESS FIELDS

"A phone book is full of facts but it does not contain a single idea."

Mortimer J. Adler

CENTERS, NETWORKS, AWARDS

HEAD START THROUGH EXCELLENCE

20 YEARS OF FRAUNHOFER IN DRESDEN

In 2012 the Fraunhofer institutes and laboratories located in the Dresden region celebrated 20 years of successful development. Dresden has the highest concentration of Fraunhofer institutes in Germany and is an important employer in the region with more than 1300 employees. The institutes are tightly networked with local industry and generate an annual turnover of more than 130 million Euros.

HEAD START THROUGH EXCELLENCE

Since 2012 the Technische Universität Dresden is acknowledged as one of the eleven Elite Universities of Excellence in Germany. The university was successful with its institutional strategy, two clusters of excellence and its graduate school. The Fraunhofer IWS actively supported the TU Dresden during the application process. The DRESDEN-concept initiative, a collaboration of research organizations and museums, promoted the excellence of research in Dresden.

The Fraunhofer IWS cooperation with the university was further expanded in 2012. On April 2nd 2012 Dr. Martina Zimmermann was appointed as Professor for Materials Testing and Characterization at the TU Dresden. The Fraunhofer-Gesellschaft funds this position. Simultaneously Prof. Zimmermann heads the IWS research group for materials characterization. On July 1st 2012 Dr. Andrés-Fabian Lasagni, head of the IWS research group for surface functionalization, was appointed as Professor for Laser Structuring in Manufacturing Technology at the TU Dresden. Both appointments are part of the Dresden Innovation Center Energy Efficiency DIZE^{EFF}, which opened in February 2009. An excellent education at the TU Dresden will provide excellent young talents for the IWS.

DRESDEN INNOVATION CENTER ENERGY EFFICIENCY DIZE^{EFF}

The Fraunhofer-Gesellschaft and the Free State of Saxony fund the DIZE^{EFF} project, which has yielded numerous new research results and innovations since 2012. Of special strategic interest to the IWS are results about low friction coatings (pg. 40/41), reactive multilayers and their applications in joining processes for hard-to-weld components (pg. 44/45) and micro- and nanostructuring applications in organic photovoltaics. These results are of importance for the acquisition of additional third party contracts.

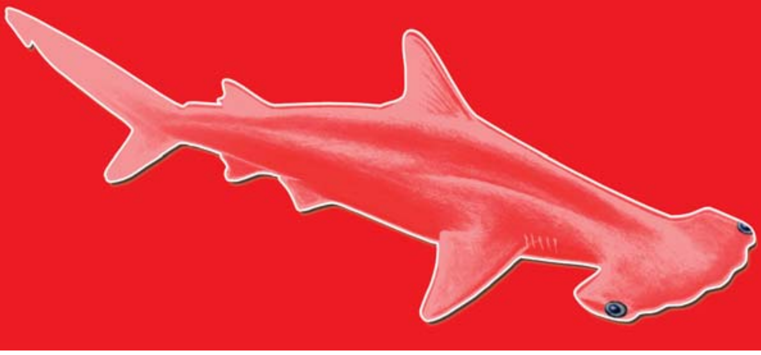
ENERGY RESEARCH AT THE IWS

A substantial fraction of 2012 IWS revenues originated from research and development projects in the fields of energy efficiency, conversion and storage. Industrial research contracts amounted to 5.9 million Euros. Public funding sources contributed 3.2 million Euros to these research areas. Internal funds of 2 million Euros were spent on basic and internal advanced research projects to invest in the development and fabrication of battery cells. A building expansion was completed, which will house a Center for Battery Research. This will further expand and strengthen this research focus.

DRESDEN CONFERENCE “FUTURE ENERGY”

Energy conversion, energy storage and efficient energy utilization are also topics of the next conference “Future Energy” in Dresden (May 28th-29th, 2013).
www.zukunftenergie-dresden.de

2012
HIGHLIGHTS



SPUTTER TECHNOLOGY FOR THE FABRICATION OF X-RAY OPTICS

In 2012 two additional large area sputter coating tools were delivered to industrial partners. The machines are equipped with six coating sources for especially efficient deposition. The system can handle substrates up to 680 mm. Such substrates are used as optical elements for X-ray and EUV radiation in lithography machines for the microelectronics industry.

WEAR PROTECTION THROUGH THE LASER-ARC MODULE

The Laser-Arc Module (LAM) was developed to deposit superhard amorphous carbon coatings (Diamor®) on tools and components. In 2012 two LAM 500 systems were delivered to industrial customers. One of these systems will be used for the coating of components with thick ta-C films. The second system is also equipped with a plasma filter. It will be used for toll coating operations for high-end tools and components (pg. 40/41 and Fig. 2).

ADDITIONAL INDUSTRIAL INSTALLATIONS OF REMOTE TECHNOLOGIES FOR AIRBAG CUTTING

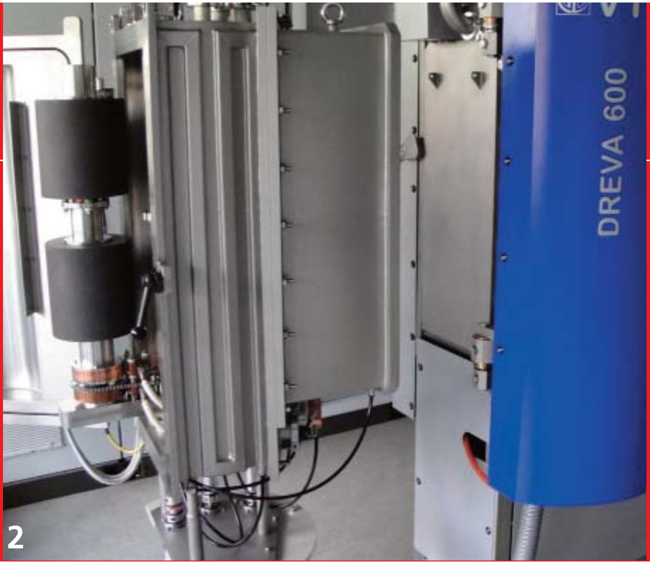
The company Held Systems and IWS had developed a compact system for the flexible laser cutting of airbag material. In 2012 such a system was sold to a new industry customer. This machine can cut flat web but also "OPW" (one piece woven) pieces by using a camera based geometry recognition technology. A previously installed machine at TRW in Mexico has been used in manufacturing since 2007. This system received an upgrade in 2012 with a new beam source that includes a scanner.

SCANNER TECHNOLOGY IN MANUFACTURING

Partners Rofin-Sinar, Maschinenfabrik Arnold and Fraunhofer IWS have jointly developed laser processing systems to reduce magnetic core losses in grain oriented electrical sheets by 10 %. These systems benefit from a unique arrangement of galvanometer scanners in combination with fast controllable high quality laser beams and achieve exceptional dynamic performance. Simultaneously the systems are very flexible while maintaining constant processing conditions. So far seven systems were installed worldwide with three of them delivered in 2012. Additional systems for present and new customers are being built or orders are imminent.

LASER ACOUSTIC MEASUREMENT SYSTEM FOR INDUSTRY AND RESEARCH

In 2012 two LAwave® systems were delivered to customers in research and industry. One machine is used to characterize the properties of nanometer coatings. The other system is used to monitor the quality of solar wafers during the manufacturing process (pg. 48/49 and Fig. 1).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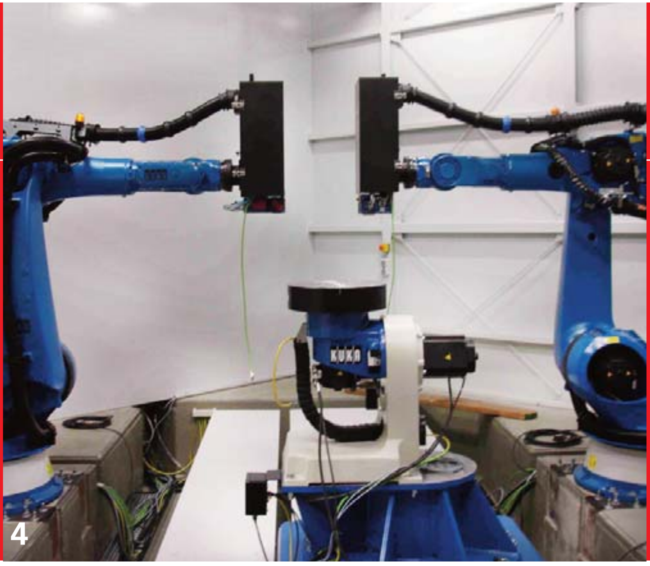
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LASER BEAM HARDENING AND BUILDUP WELDING MACHINE FOR LARGE TOOLS

In 2012 Fraunhofer IWS engineers supported Volkswagen AG to implement a robot based laser hardening and buildup welding plant for fixture construction. The system is especially tailored for the making of new tools for car body manufacturing. IWS contributed components included beam shaping, process control and powder delivery as well as a comprehensive laser hardening and buildup welding technology package. IWS engineers also supported plant installation and startup as well as training of VW employees. This was the second installation of such a system at VW, which was substantially support by IWS employees (pg. 58/59 and Fig. 3).


3

TECHNOLOGY TRANSFER AND SPECIAL PLANT CONSTRUCTION FOR HARDENING OF SAFETY RELEVANT VEHICLE COMPONENTS

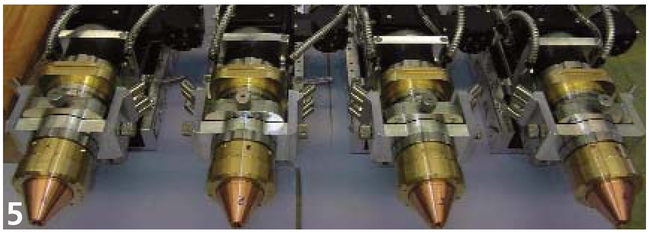
This special plant for hardening of vehicle components was delivered to BPW Bergische Achsen KG. Prior to the delivery the process was developed to accommodate laser hardening of the special component using rotating mirror optics. To assure 100 % quality the system uses IWS-developed process control components such as "E-MAqS" (temperature measurement) and "LompocPro" (process controller). The company's employees were trained at IWS. At the end of 2012 the system was delivered and started up.

HARDENING OF STEAM TURBINE BLADES WITH COOPERATING ROBOTS

A laser system for the dual-sided simultaneous hardening of steam turbine blades was installed at Siemens AG (Energy Sector) in Mühlheim, Ruhr. Two lasers and two robots are employed to generate optimum hardening zone geometries for steam turbine blades. Since 2006 a prototype of such a system has been successfully operated at Fraunhofer IWS laboratories. Siemens AG received an upgraded version of this machine, which includes some new technical solutions (Fig. 4). This transfer project included the IWS-developed components "E-MAqS" (temperature measurement), "LASSY" (dynamic beam shaping) and "LompocPro" (process controller).
The project will continue in 2013. Siemens aims at reducing manufacturing times and at implementing hardening technologies in-house. This technology to harden steam turbine blades is patented by IWS and it is also continuously being further developed and improved. First laser-hardened blades have been used in power plants since the mid 1980ies.

POWDER DEPOSITION HEADS FOR GENERATIVE MANUFACTURING AND REPAIR

Just as in previous years, IWS continued to deliver powder deposition heads for laser beam buildup welding applications to industrial customers. Component manufacturers such as Laserline, GTV and Maschinenfabrik Arnold ordered several systems for various customers. Six systems of the new CoaxPowerline series were installed at three different customers (Fig. 5).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FROM THE BOARD OF TRUSTEES

The Board of Trustees consults and supports the institute's management and the bodies of the Fraunhofer-Gesellschaft. The 22nd Board of Trustees meeting occurred on March 23rd 2012 at the Fraunhofer IWS in Dresden. The following members were active in the Board of Trustees during the reporting period:

FRANK JUNKER, DR.
Chairman of the Board of Trustees,
Independent Consultant,
Radebeul

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Chief Executive Officer,
EMAG Leipzig Manufacturing Systems GmbH,
Leipzig

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Director of the Institute for Lightweight Construction and
Synthetic Materials Technologies at the
Technische Universität Dresden

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Project Management Agency Karlsruhe,
Production and Manufacturing Technologies,
Branch Office Dresden

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Managing Director Hauzer Techno Coating BV,
Netherlands

HANS MÜLLER-STEINHAGEN, PROF. DR.
Rector (President),
Technische Universität Dresden

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Saxony Economic Development Corporation GmbH,
Dresden

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Hofheim/Taunus

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Federal Ministry of Education and Research,
Head of Department Production Systems and Technologies,
Bonn

CHRISTOPH ULLMANN, DR.
Chief Executive Offices, Laserline GmbH,
Mühlheim-Kärlich

FRANZ-JOSEF WETZEL, DR.
BMW Motorrad, Business Sector Planning,
Cooperation, Munich

PETER WIRTH, DR.
Rofin-Sinar Laser GmbH,
Hamburg

REINHARD ZIMMERMANN, MINR DR.
Saxony State Ministry of Science and the Arts,
Dresden

2012 was far away from an economic slowdown. Even at the beginning of this year the outlook for the German economy is good. The economy grew stronger than anticipated during the first half of 2012 and shows a positive trend for 2013. Export forecasts continue to be strong and appear to have sustainable effects in many fields. The US economy also appears to show again an upward trend. Similar forecasts are coming from China, Brazil and emerging economies in Asia and Latin America. However, the still lingering effects of the financial crisis also have an effect on the forecast. We hope however that this will soon be overcome.

The machine and plant building industry experiences a much better business climate than expected. While turnovers increased, there was however differentiation. One needs to note that special plants requiring specific know-how and niche products can do well even in slow economic times. Therefore technology leadership is of utmost importance. Only a few years ago the automotive industry suffered from overcapacities. This has completely changed. The trend for growth can be observed in all segments. Here a global orientation is of significant importance.

Awareness of safety and environmental aspects are in demand. Environmental and energy industries are dynamically developing. The chemical industry was able to maintain its exceptional position. Research results are providing momentum for growth but unfortunately not always at Germany manufacturing locations. The forecast for the electro industry is differentiated with respect to automation, electrical components and semiconductor manufacturing branches. The medical devices sector showed an excellent development in particular due to many new technologies.

The Fraunhofer-Gesellschaft with its highly qualified personnel and federal and state support is active in all these areas. A good overview was provided at the Fraunhofer Symposium "Netzwert" ("Network"), which was held in December 2012 in Munich. The results and Fraunhofer internal networking are convincing.

The Fraunhofer Institute for Materials and Beam Technology IWS very convincingly delivered in 2012 high level scientific results for products, technologies and services. With foci in surface and laser technologies, the institute performs projects of important scientific significance and high value for the user; addressing the fields of energy, mobility, material systems and medical technologies. The IWS obtained a technology leading position in battery research. The acquisition of third party contracts and the fraction of funding coming from industrial partners grew above average in 2012.

The science network DRESDEN-concept connects the basic research performed at the Technische Universität Dresden, the Max Planck Institutes, the Leibnitz Institute and the Helmholtz Center very closely with the Fraunhofer Institutes. This concept transformed Dresden into an excellent science region.

We as the trustees of the institute are very much delighted about IWS' development. We are looking forward to an exciting discussion in 2013 and support the strategic orientation of the IWS. The Board of Trustees expresses our gratitude to our customers, the employees, the institute's management team and all partners for the effort spent and the achieved results. We wish you a healthy future and continuing success.

Dr. Frank Junker

INSTITUTE PROFILE

CORE COMPETENCES

The transfer of current research results into industrial practice is an essential driving force for research efforts at the institute. To adequately meet this "mission" we have developed and continually expanded core competences in the following areas:

LASER MATERIALS PROCESSING

- high speed cutting of metals
- cutting and welding of plastics and other non-metals
- welding processes for hard-to-weld materials
- laser buildup welding and generating
- laser surface hardening, remelting and alloying in particular for highly stressed and complex components
- rapid heat treatments
- laser hybrid technologies, e.g.
    - laser induction welding and buildup welding
    - plasma, TIG or MIG assisted laser beam welding and buildup welding
- ablation, cleaning and structuring
- process specific monitoring and control

SURFACE FUNCTIONALIZATION AND COATING

- plasma, arc and flame spray processes with powder and suspensions
- high rate coating processes (vacuum arc, electron beam evaporation)
- precision coating processes (magnetron sputtering, ion beam sputtering)
- laser arc process as a hybrid technology
- plasma and chemical etching, ablation, cleaning and functionalization
- chemical vapor deposition
- paste deposition (also in roll-to-roll process)
- spray deposition of ultrathin coatings
- nano and micro structuring

SYSTEMS TECHNOLOGY

- implementation of process know-how in development, design and fabrication of components, machines and systems including associated software
- systems solutions for cutting, welding, ablation, deposition, surface refinement and characterization with laser, e.g.
    - processing optics, sensorics, beam scanning and monitoring systems including control software for high speed and precision processing
    - beam shaping systems and process control for surface refinement with high power diode lasers
- coating heads for the continuous free-directional powder or wire delivery as well as process monitoring and CAM control software
- process oriented prototype development of components and coating systems for the PVD precision and high rate deposition, the atmospheric pressure CVD as well as chemical and thermal surface refinement processes
- measurement systems for coating characterization, nondestructive component evaluation with laser acoustic and spectroscopic methods
- systems for the spectroscopic monitoring of gas mixtures
- software and control technology

MATERIALS SCIENCE / NANOTECHNOLOGY

- determination of material data for material selection, component design and quality assurance
- metallographic, electron microscopic and microanalytical characterization of the structure of metals, ceramics and coating compounds
- failure and damage analysis
- thermal shock characterization of high temperature materials
- property evaluation of surface treated, coated and welded materials and components
- optical spectroscopic characterization of surfaces and coatings (nm through mm)
- mechanical and tribological characterization
- coating thickness and Young's modulus measurements of nm to mm coatings with laser acoustics
- ellipsometry, X-ray reflectometry and diffractometry
- imaging surface analysis
- electrochemistry and electrode chemistry
- fabrication, functionalization and processing of nanoparticles and nanotubes

PROCESS SIMULATION

- in-house development of simulation modules for
  - thermal surface treatments and laser hardening
  - laser powder buildup welding
  - vacuum arc deposition
  - laser cutting and welding
- calculation of optical properties of nanocoatings with internal simulation tools
- use of commercial simulation modules for
  - laser beam welding and cutting
  - optimization of gas and plasma flows during coating processes and laser materials processing

	Core services				
Business fields	Laser materials processing	Surface functionalization and coating	Materials / nanotechnology	Systems technology	Process simulation
Ablation / cutting	■	☐	☐	■	☐
Joining	■		■	☐	☐
Surface technology					
Surface layer technology	☐	☐	■	■	☐
Thermal coating technology	☐	■	☐	☐	☐
PVD coating technology	☐	■	■	☐	☐
Surface and reaction technology		■	☐	☐	☐

■ core competence

☐ additional competence

DEPUTY DIRECTOR DR. ANJA TECHEL

"Only someone who goes his own way can't be passed by another"

Marlon Brando

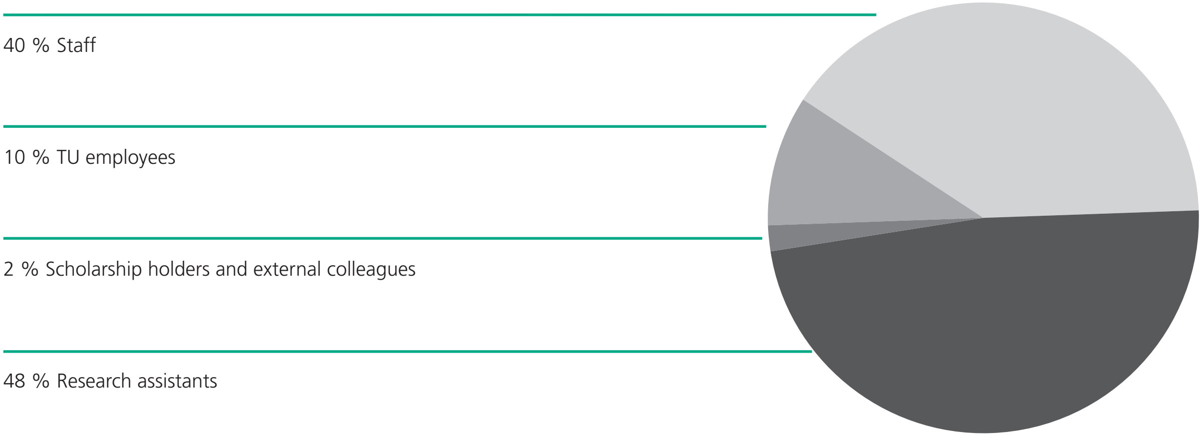
INSTITUTE DATA

IWS EMPLOYEES

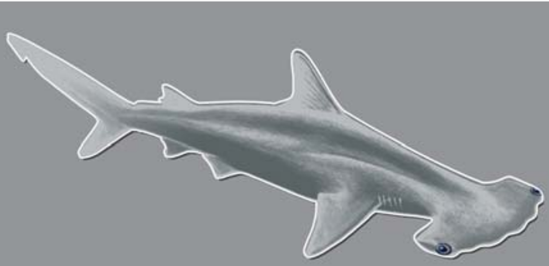
	number
Staff	**168**
Scientists / Engineers (TU/FH)	114
Skilled workers with technical or mercantile education	45
Trainees	9
TU Dresden employees (working at the IWS)	**41**
Scholarship holders and external colleagues	**8**
Research assistants	**201**
TOTAL	**418**

IWS PUBLICATIONS

	number
Dissertations	**6**
Diploma theses	**32**
Journal papers	**141**
TOTAL	**179**
Patents (first filing)	**13**



EMPLOYEES AT THE FRAUNHOFER CCL (USA)	**14**



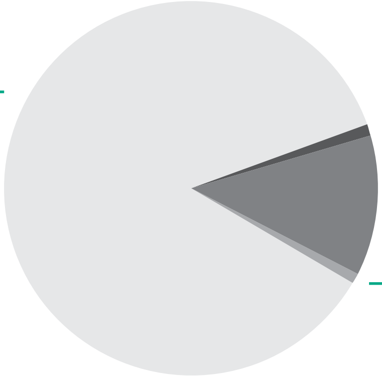
Revenues 2012 (Mio. €)*	Operation	Investments	Total
Project revenues from industry	12.8 54 %	0.6 26 %	13.4 52 %
Project revenues from federal, state and European sources	6.1 26 %	0.6 26 %	6.7 26 %
Base funding and Fraunhofer internal programs	4.6 20 %	1.1 48 %	5.7 22 %
	23.5	**2.3**	**25.8**

Expenditures 2012 (Mio €)*	
Personnel costs	10.2 40 %
Material costs	13.3 51 %
Investments	2.3 9 %
	25.8

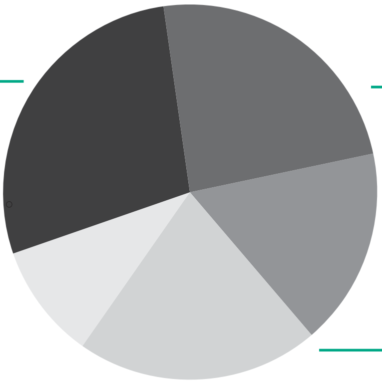
Fraunhofer industry ρ_{Ind} = 57.0 %

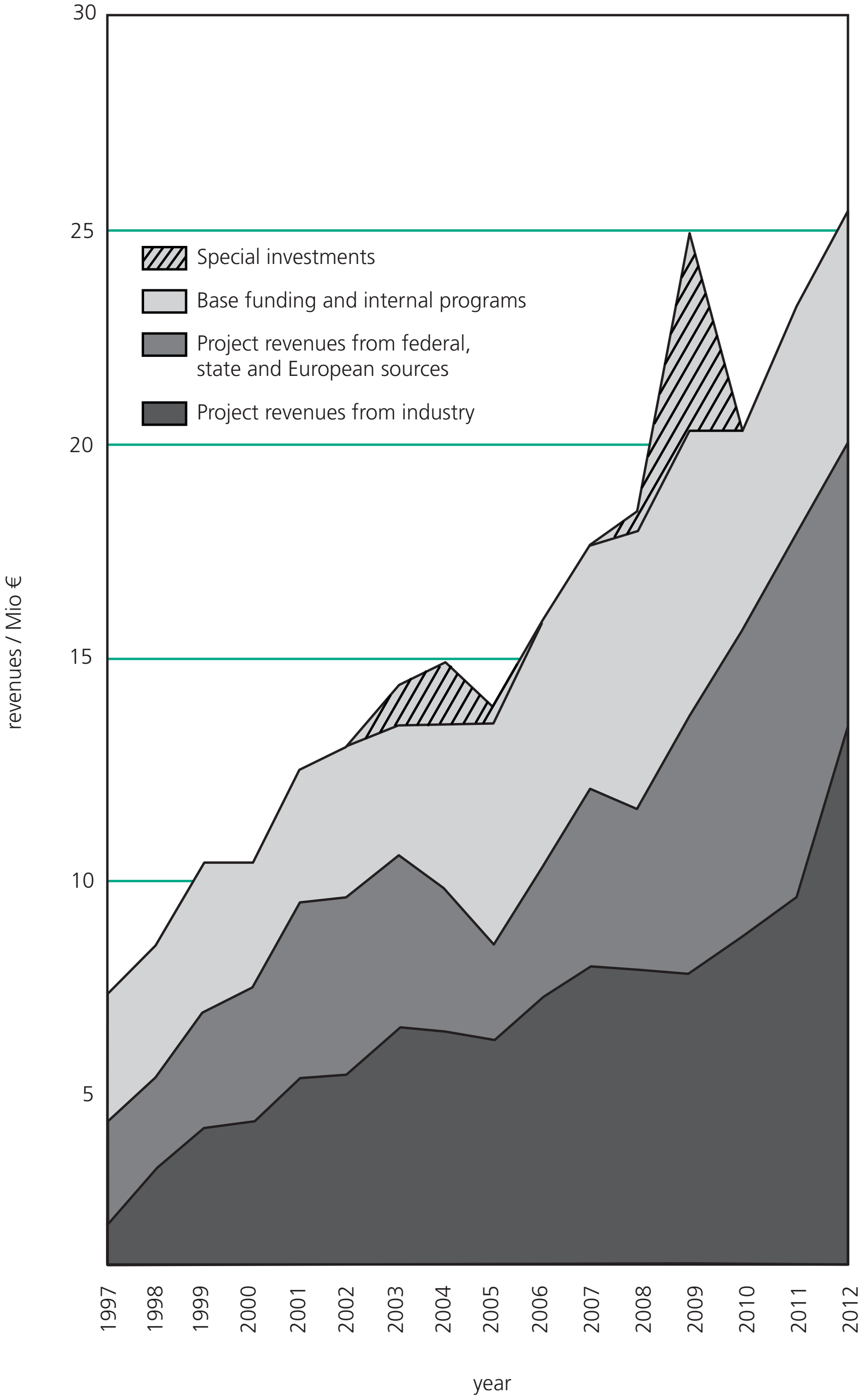
*FEBRUARY 2013

GEOGRAPHICAL ORIGIN OF INDUSTRIAL REVENUES



ORIGIN OF REVENUES FROM FEDERAL, STATE AND EUROPEAN SOURCES




30
25
20
15
10
5
revenues / Mio €
Special investments
Base funding and internal programs
Project revenues from federal, state and European sources
Project revenues from industry
1997
1998
1999
2000
2001
2002
2003
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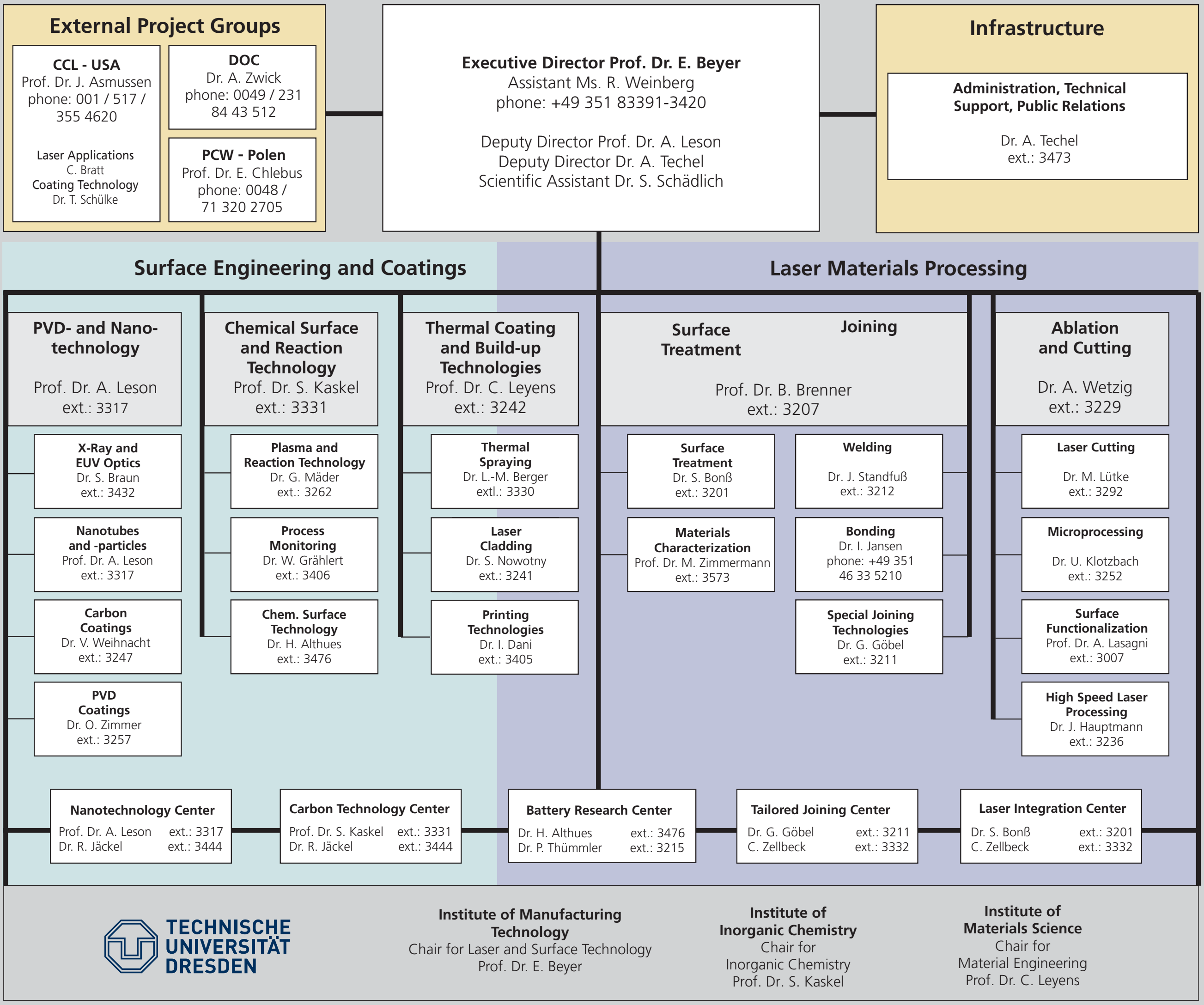
2005
2006
2007
2008
2009
2010
2011
2012
year

"Basically the connections with people are what gives life sense."

Wilhelm v. Humboldt

THE MANAGEMENT TEAM

ORGANIZATION AND CONTACTS



External Project Groups

CCL - USA
Prof. Dr. J. Asmussen
phone: 001 / 517 / 355 4620

Laser Applications
C. Bratt
Coating Technology
Dr. T. Schülke

DOC
Dr. A. Zwick
phone: 0049 / 231 84 43 512

PCW - Polen
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phone: 0048 / 71 320 2705

Executive Director Prof. Dr. E. Beyer
Assistant Ms. R. Weinberg
phone: +49 351 83391-3420

Deputy Director Prof. Dr. A. Leson
Deputy Director Dr. A. Techel
Scientific Assistant Dr. S. Schädlich

Infrastructure

Administration, Technical Support, Public Relations
Dr. A. Techel
ext.: 3473

Surface Engineering and Coatings

PVD- and Nano-technology
Prof. Dr. A. Leson
ext.: 3317

- **X-Ray and EUV Optics** Dr. S. Braun ext.: 3432
- **Nanotubes and -particles** Prof. Dr. A. Leson ext.: 3317
- **Carbon Coatings** Dr. V. Weihnacht ext.: 3247
- **PVD Coatings** Dr. O. Zimmer ext.: 3257

Chemical Surface and Reaction Technology
Prof. Dr. S. Kaskel
ext.: 3331

- **Plasma and Reaction Technology** Dr. G. Mäder ext.: 3262
- **Process Monitoring** Dr. W. Grählert ext.: 3406
- **Chem. Surface Technology** Dr. H. Althues ext.: 3476

Thermal Coating and Build-up Technologies
Prof. Dr. C. Leyens
ext.: 3242

- **Thermal Spraying** Dr. L.-M. Berger extl.: 3330
- **Laser Cladding** Dr. S. Nowotny ext.: 3241
- **Printing Technologies** Dr. I. Dani ext.: 3405

Laser Materials Processing

Surface Treatment / **Joining**
Prof. Dr. B. Brenner
ext.: 3207

- **Surface Treatment** Dr. S. Bonß ext.: 3201
- **Materials Characterization** Prof. Dr. M. Zimmermann ext.: 3573
- **Welding** Dr. J. Standfuß ext.: 3212
- **Bonding** Dr. I. Jansen phone: +49 351 46 33 5210
- **Special Joining Technologies** Dr. G. Göbel ext.: 3211

Ablation and Cutting
Dr. A. Wetzig
ext.: 3229

- **Laser Cutting** Dr. M. Lütke ext.: 3292
- **Microprocessing** Dr. U. Klotzbach ext.: 3252
- **Surface Functionalization** Prof. Dr. A. Lasagni ext.: 3007
- **High Speed Laser Processing** Dr. J. Hauptmann ext.: 3236

Nanotechnology Center
Prof. Dr. A. Leson ext.: 3317
Dr. R. Jäckel ext.: 3444

Carbon Technology Center
Prof. Dr. S. Kaskel ext.: 3331
Dr. R. Jäckel ext.: 3444

Battery Research Center
Dr. H. Althues ext.: 3476
Dr. P. Thümmler ext.: 3215

Tailored Joining Center
Dr. G. Göbel ext.: 3211
C. Zellbeck ext.: 3332

Laser Integration Center
Dr. S. Bonß ext.: 3201
C. Zellbeck ext.: 3332

TECHNISCHE UNIVERSITÄT DRESDEN

Institute of Manufacturing Technology
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

HEAD OF DEPARTMENT PROF. DR. STEFAN KASKEL

"The only remedy for superstition is knowlegde."
Henry Thomas Buckle

BUSINESS FIELD CHEMICAL SURFACE AND REACTION TECHNOLOGY

Editor: Prof. Kaskel, recently one could read in the FAZ (Frankfurter Allgemeine Zeitung) that you have developed a new battery that is of particular advantage to the automotive sector.

Prof. Kaskel: Indeed, last year we made breakthrough advances developing new battery concepts. We were able to introduce a new type of battery that is based on the reaction of lithium and sulfur and achieves twice the energy density of conventional lithium ion batteries. We did not invent this battery type. They have existed for some time, but had very limited cycle stability. This limits their use to special applications such as military drones.

Editor: What is new?

Prof. Kaskel: We developed a new electrode material, which is stable for more than 1000 cycles. We consider this a true breakthrough.

Editor: And by when will these batteries be commercially available?

Prof. Kaskel: In reality there are still many challenges. Our batteries are still very small so that they cannot yet be used for cars. In 2013 we will establish a new battery laboratory with automated manufacturing equipment. We will be able to explore new materials as well as perform the complete battery manufacturing sequence including roll-to-roll electrode fabrication, stacking and packaging the electrode stacks. We will be able to offer to German companies the possibility to test innovative products within the manufacturing chain. Today all battery manufacturers purchase their materials in Japan. This is concerning considering what German suppliers would get out of it. This includes not only the electrode materials but also the production machines.

We offer a platform to evaluate materials and production equipment under relevant conditions. We will also offer prototypes for potential end users.

Editor: Are you currently only working on batteries?

Prof. Kaskel: No, no. CVD methods are very widely used such as for example to synthesize diamond materials. We cooperate with CCL in the USA in this area. It is also possible to make barrier films with this method and also to produce nano materials.

COMPETENCES

PLASMA AND REACTION TECHNOLOGY

Plasma assisted chemical vapor deposition at atmospheric pressure enables the large area deposition of high quality functional coatings without the need for costly vacuum technology. Continuous high rate deposition processes are possible to coat temperature sensitive and slightly curved substrates of various thicknesses. Fraunhofer IWS engineers develop inline reactors with gas locks for the synthesis of oxide and non-oxide coatings. Gas phase reactors are developed for chemical and solar thermal processes operating at atmospheric pressure. The reactor designs are optimized based on experimental results and thermo fluid dynamic simulations. The modular reactor design makes it cost effective to adapt various processes to new applications and coating materials.

PROCESS MONITORING

The optimal function of industrial plants and the quality of the manufactured products are directly connected with the gas atmosphere inside the reactor. Gas analytics capable of industrial deployment is essential for quality assurance of chemical coating, etching and sintering processes. They are also necessary for monitoring emissions from industrial reactors. IWS engineers provide customer tailored sensor solutions to monitor the gas phase composition in such reactors. The sensors are based on NIR diode laser and FTIR spectroscopy. Surfaces and coatings are also characterized with methods such as FTIR spectroscopy, spectral ellipsometry and Raman microscopy.

CHEMICAL SURFACE TECHNOLOGY

The surface properties of many materials are of special importance for applications. Functional thin films for example provide surfaces with conductive, scratch resistant or self-cleaning properties. The development of nanostructured materials with defined surface chemistry is a necessary condition to decisively improve the performance of next generation double layer capacitors and batteries. In our group “Chemical Surface Technology” , we develop gas phase (CVD) and liquid phase processes for large area coating applications based on new materials. Foci are transparent, functional thin films, electrical energy storage and super capacitors.

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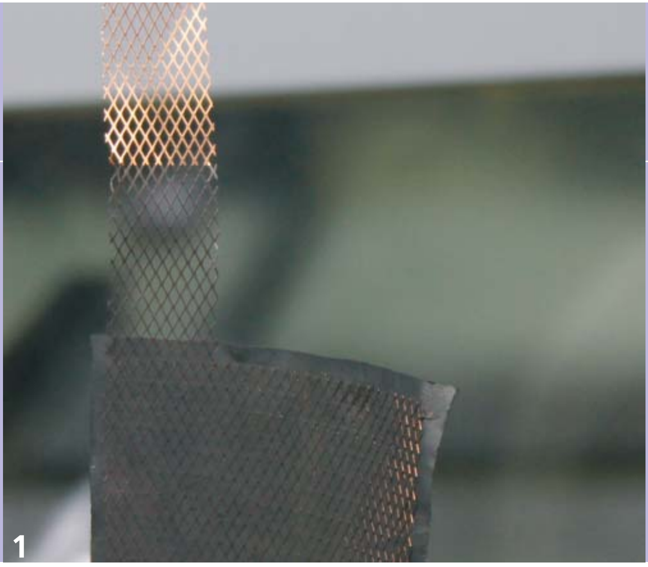

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DRY ELECTRODE FABRICATION AND PACKAGING FOR LITHIUM ION CELLS

THE TASK

The outlook for e-mobility applications in Germany demands a drastic cost reduction for battery energy storage. A large cost reduction potential lies in improving the efficiency of the manufacturing process. The high cost drivers are solvent-based coating processes for electrode fabrication as well as the special requirements for the manufacturing environment (low humidity dry room).

The solvent removal is performed in complicated drying stages. The toxic solvent (NMP) requires special treatment. A humidity of less than 2 % RH is to be maintained throughout the cell fabrication process (dew point < -30 °C / -22 F). In addition to the high costs, and the environmental and safety risks (toxic solvents, risk of explosion) the manufacturing process is also demanding for equipment operators due to the dry room conditions.

OUR SOLUTION

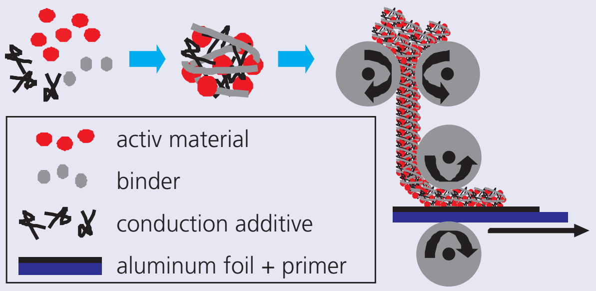
Fraunhofer IWS research had previously demonstrated water based coating processes (BMBF funded project DeLIZ No. 02PO2640). These processes can be used to fabricate high performance electrodes without the need for organic solvents (see IWS Annual Report 2011 pg. 84/85). The water-based process implies cost savings but it still requires a drying step. The water has to be completely removed from the electrodes for the cell chemistry to perform as designed.

Therefore a new project aims at developing a process for lithium ion cells completely free of solvents (BMBF DryLIZ No. 02PJ2302). The basis of this process is a binder that forms fibrils under shearing loads. This binder is already very effective at low quantities of about 5 % by weight. A special grinding process transforms the initial powder materials into a fibrillar agglomerated powder, which can be pressed into freestanding films of 50 - 150 µm thicknesses. These films can then be laminated to current collectors (metal foils), (Fig. 1,2).

Together with project partners we are working on mounting electrode materials onto electrically conductive fleeces without the use of solvents. Using this electrode design we expect a substantially improved electrical contact to the active materials. The process could lead to electrodes with improved performance or thicker electrodes with high energy densities at the cell level.

As part of this project we also work on systems technology for the cost efficient manufacturing of electrode foils. To increase the throughput of electrode packaging the foil is continuously fed at high speeds. We develop cutting processes that can maintain the required high edge quality under such high throughput conditions. IWS developed remote laser cutting is

Sketch of the solvent free electrode fabrications



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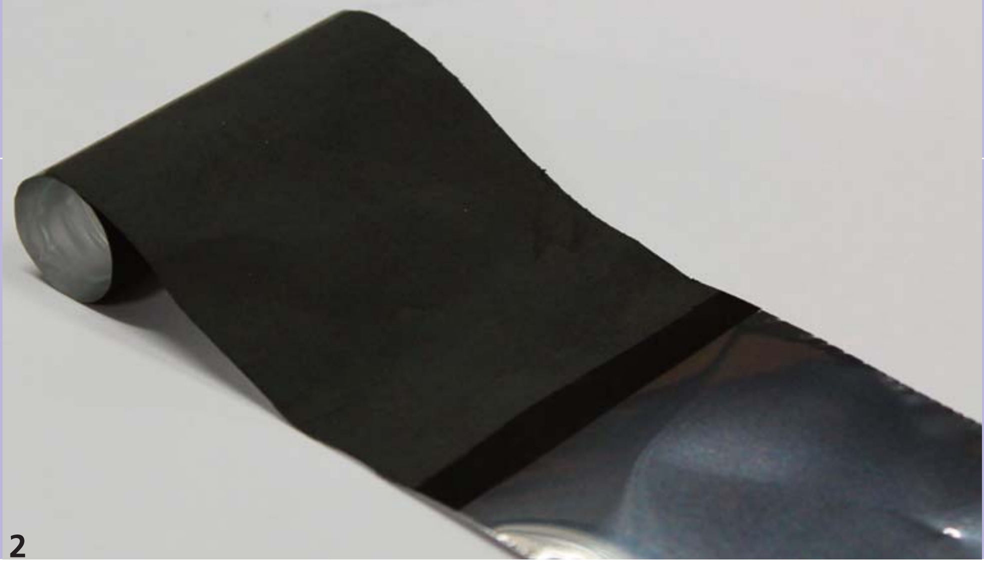

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evaluated if it meets the demands of these "on the fly" cutting processes. A project partner evaluates an alternative approach based on a high speed rotating punching process.

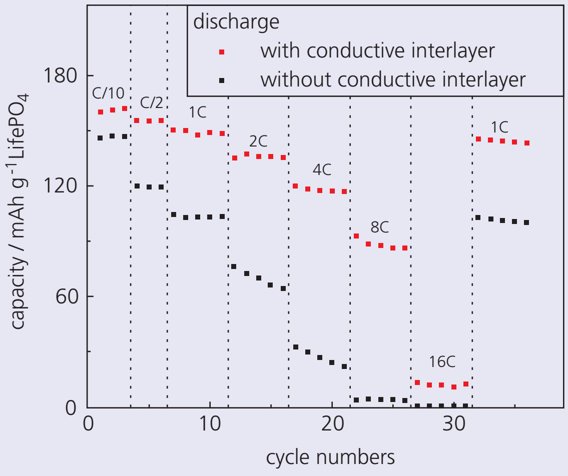
Minimum material feed rates for the cut electrode sheets are 0.25 m s^{-1}. While avoiding damage the electrode sheets have to be picked up, transported to the next processing station and there positioned with an accuracy of 0.1 mm. Electrode sheet transport and packaging is performed within a small and closed workspace. This station requires dry air supply and is designed by another project partner.

RESULTS

The great potential of these new methods was already demonstrated during the development of electrode materials. The fabrication of such electrodes was substantially simplified on the laboratory scale. The process is much faster when avoiding solvent-based processes. However, what is most critical is the performance of the electrodes. Freestanding electrode films were pressed onto an aluminum foil.
They were then electrochemically tested in a half cell setup against lithium. In direct contact with the aluminum foil the freestanding film achieves high capacities of 145 mA h g^{-1}. Yet this capacity drastically reduces with increasing charging rates (C-rates).

An excellent rate behavior is achieved when using a conductive primer film. This primer film reduces the contact resistance between current collector and active layer (Fig. 4) and also increases the adhesion. An additional improvement of the connection is obtained by using conductive fleeces, which are essentially three-dimensional current collectors. This solvent free process will also be beneficial to fabricate electrodes for future battery generations such as lithium sulfur batteries (pg. 26/27).

Capacities versus discharge cycles for different discharge rates. The $LiFePO_4$ electrode was fabricated without the use of solvents.



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1 *Photo of a freestanding electrode film with a metal mesh current collector*

2 *Photo of a dry processed $LiFePO_4$ electrode, which was laminated onto aluminum foil and primer film.*

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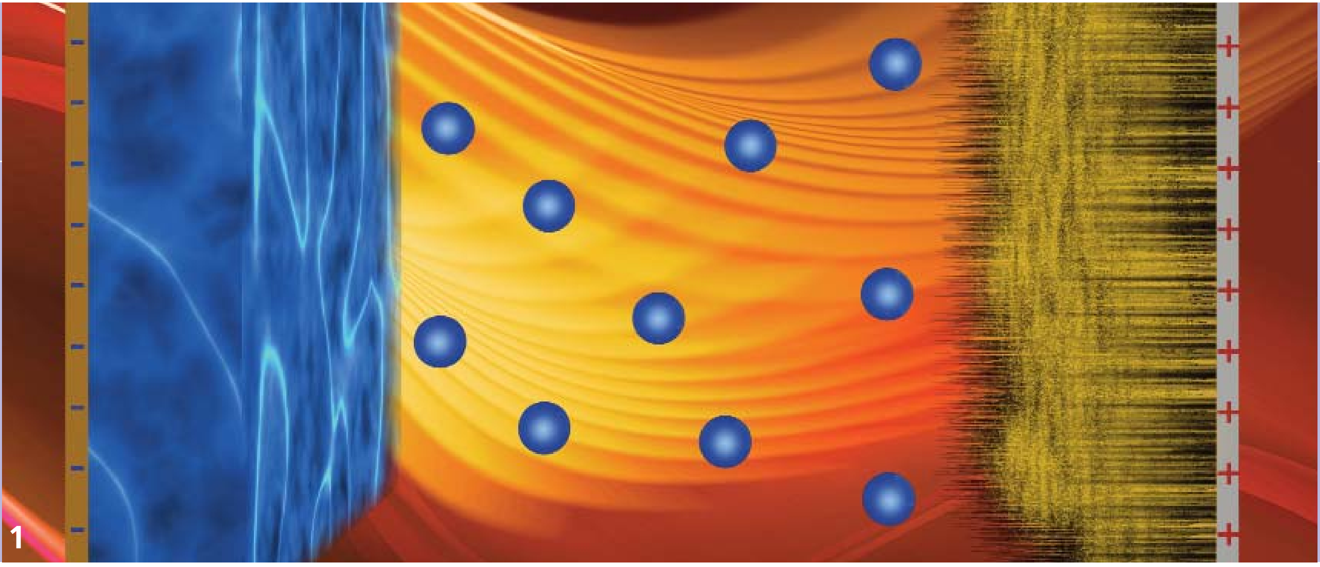
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NANO COMPOSITE ELECTRODES FOR LITHIUM SULFUR BATTERIES

THE TASK

Lithium sulfur batteries may be the next generation of energy storage devices for mobile applications. A special characteristic of lithium sulfur batteries is the potentially very high gravimetric energy density exceeding 400 W h kg^{-1}. This is twice the energy density of conventional lithium ion cells, which has a maximum value of 200 W h kg^{-1}. In addition it is possible to substantially reduce costs by replacing expensive transition metal cathodes (nickel, cobalt) with sulfur cathodes.

However, so far there has been a decisive disadvantage associated with lithium sulfur batteries. They had a very short lifespan of only a few hundred cycles. In addition it is necessary to develop materials, which make it actually possible to exploit the theoretical performance of this battery type. Current research aims at adapting electrode and electrolyte materials as well as at controlling the complex electrochemical processes that occur during cycling of these batteries.

The most important areas are:

- contacting, stabilizing and increasing the utilization of sulfur as the non-conducting active material
- stabilizing the lithium metal anode or replacement by alternative anodes
- suppressing the migration of polysulfide species and side reactions at the anode (shuttle mechanism)

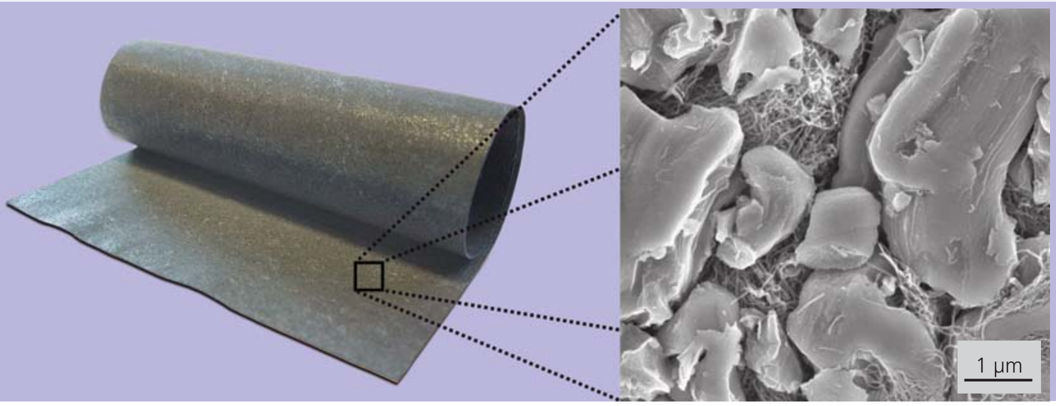
OUR SOLUTION

Fraunhofer IWS researchers work on solutions to address the challenges of the complex interactions between cathode materials, electrolytes and anode materials. Together with the TU Dresden we work on cathode materials based on vertically aligned carbon nanotubes and also porous carbon materials, which provide a conductive matrix for the sulfur. The sulfur melt infiltrates the carbon materials with nanometer pore sizes and thus forms novel nano composite materials.

To further process these materials we developed a manufacturing process void of solvents. The raw materials are ground in powder form with a binder and then pressed into freestanding films. These are laminated onto metallic current collectors. They can also be used without additional current collector if highly conductive carbon materials are added. The dry manufacturing process excludes potentially negative impacts of solvents on the active materials and also implies a substantial cost reduction since extensive drying and conditioning steps will not be necessary.

However, the most important goal is the improved performance of the resulting electrodes.

A special project (MaLiSu No. 01MX12009A) is devoted to studying the influence of pore geometry and surface functionalities for carbons on the performance of the lithium sulfur cell. Optimized materials will then be used for the fabrication of a demonstrator cell.



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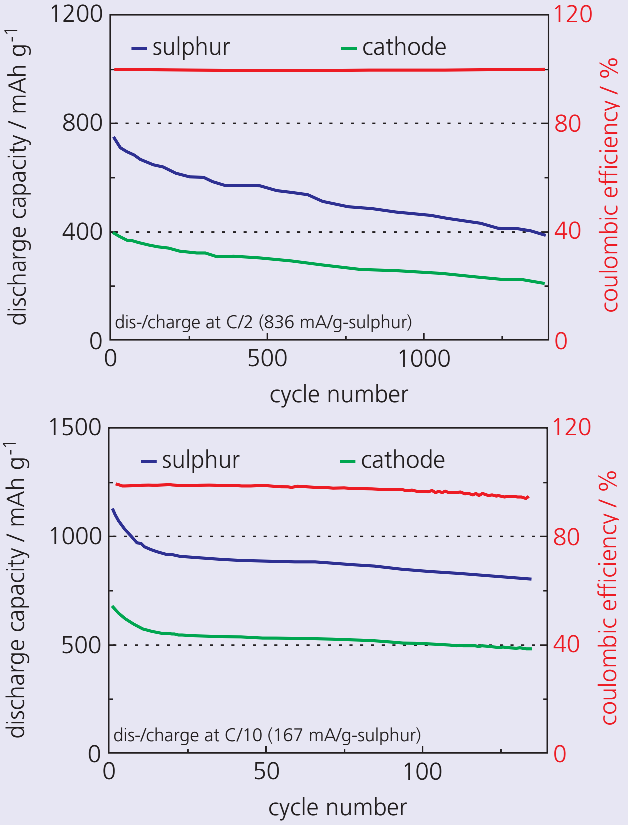
RESULTS

First experiments were performed with freestanding nano composite electrodes. The results show the enormous potential of this method. Specific capacities of more then 900 mA h g^{-1} with respect to the used sulfur were demonstrated over 80 cycles. This represents many times the values achieved by conventional cathode such as used in lithium ion cells. Then the lithium metal anodes were replaced with lithiated silicon anodes, which drastically increased the long-term stability.

A reversible capacity was demonstrated over 1400 discharge / charge cycles with a coulombic efficiency of nearly 100 %. The loss in capacity was only 0.08 % per cycle. These are outstanding results. They clearly show that lithium sulfur cells have the potential to not only outperform lithium ion cells in terms of capacity but also to achieve similar cycle stabilities.

Fraunhofer IWS researchers contribute to the development of improved materials. Additionally they focus on cost effective manufacturing processes. Future work will build on these concepts. In 2013 we will setup a 450 m^2 battery development laboratory with additional space to fabricate and test cells.

Capacity measurements versus cycles for a lithium sulfur cell with silicon/carbon composite anode (top) and lithium metal anode (bottom).



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1 *Schematics of a lithium sulfur battery*

2 *Freestanding electrode made from porous carbon and sulfur (photo and SEM image)*

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1

DETECTION LIMIT OF ULTRA BARRIER MEASUREMENTS IMPROVED BY ORDERS OF MAGNITUDES

THE TASK

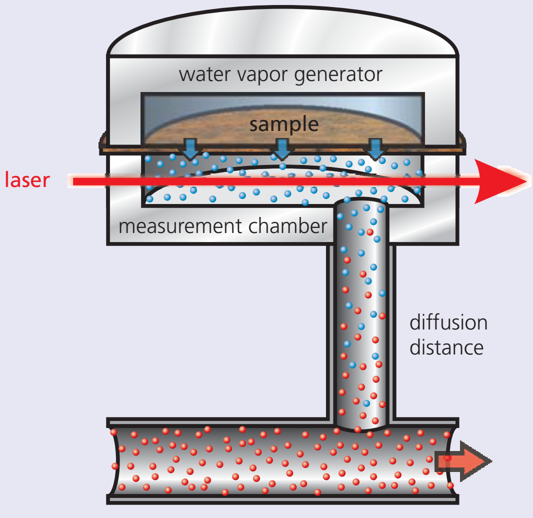
The water vapor transmission rates of so-called encapsulation materials are critically in determining the quality of technical products such as organic solar cells, vacuum insulation panels, lithium ion accumulators or e-readers. In particular the omnipresent water vapor is affecting the lifetime of such products. Required water vapor transmission rates (WVTR) are about 10^{-2} to 10^{-5} g m^{-2} d^{-1}. The currently highest demanding barrier applications are optoelectronic components such as OLED lights and displays. They require water vapor transmission rates as low as 10^{-6} g m^{-2} d^{-1}. Ultra barrier materials are developed based on coating high manufacturing volume plastic foils such as PE, PET and PP. In addition to developing the actual barrier materials it is also necessary to have reliable methods to determine such extremely low levels of water vapor transmission rates. This is a tremendous challenge, which requires new solutions and measurement concepts.

OUR SOLUTION

IWS engineers developed the barrier test measurement system HiBarSens® to detect the smallest amounts of water vapor transmission. The system is based on a highly sensitive laser diode spectroscopic concentration measurement. Water vapor transmission rates for ultra barrier films as low as 9×10^{-5} g m^{-2} d^{-1} can be measured by applying a carrier gas method where the permeating moisture is constantly being transported away for detection. A significant improvement of the detection level to 10^{-6} g m^{-2} d^{-1} is possible with a new measurement technique. Here the removal of the permeated vapor occurs by diffusion only. This diffusion controlled flow of permeated moisture is substantially smaller than a carrier gas flow. It can be mathematically described using Fick's first law. The diffusion controlled evacuation flow of the permeated vapor allows the detection of substantially smaller water vapor transmission rates.

A precondition for this measurement principle is a sensor that does not affect the concentration of the permeated vapor. As opposed to accumulating techniques the diffusion method implies a stable water vapor partial pressure on the dry side of the sample. Therefore the determination of water vapor transmission rates is not underestimated by adsorption.

Measurement chamber of the barrier test system



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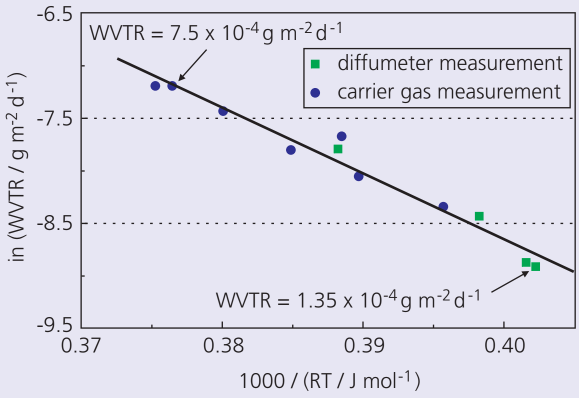
RESULTS

The diffusion based measurement principle (“diffumeter”) was integrated into the HiBarSens® permeation test system. It was compared to the state-of-the-art carrier gas method at different temperatures. The diffumeter data show a linear dependence in an Arrhenius plot. They correlate well with the carrier gas measurements. Beyond the plotted measurement range it is possible to reliably detect smallest water vapor transmission rates of 1 x 10^{-6} g m^{-2} d^{-1}.

The diffumeter concept decouples the detection limit of the water vapor transmission rate from the detection limit of the used sensor. This highly sensitive measurement principle can also be adapted to other vapors as well as to general leak detection applications.

Arrhenius plot of the water vapor transmission rate of a barrier foil at 38 °C, 90 % rel. humidity



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1 *Measurement chamber of the permeation systems*

3 *Humidity in the water vapor generator*

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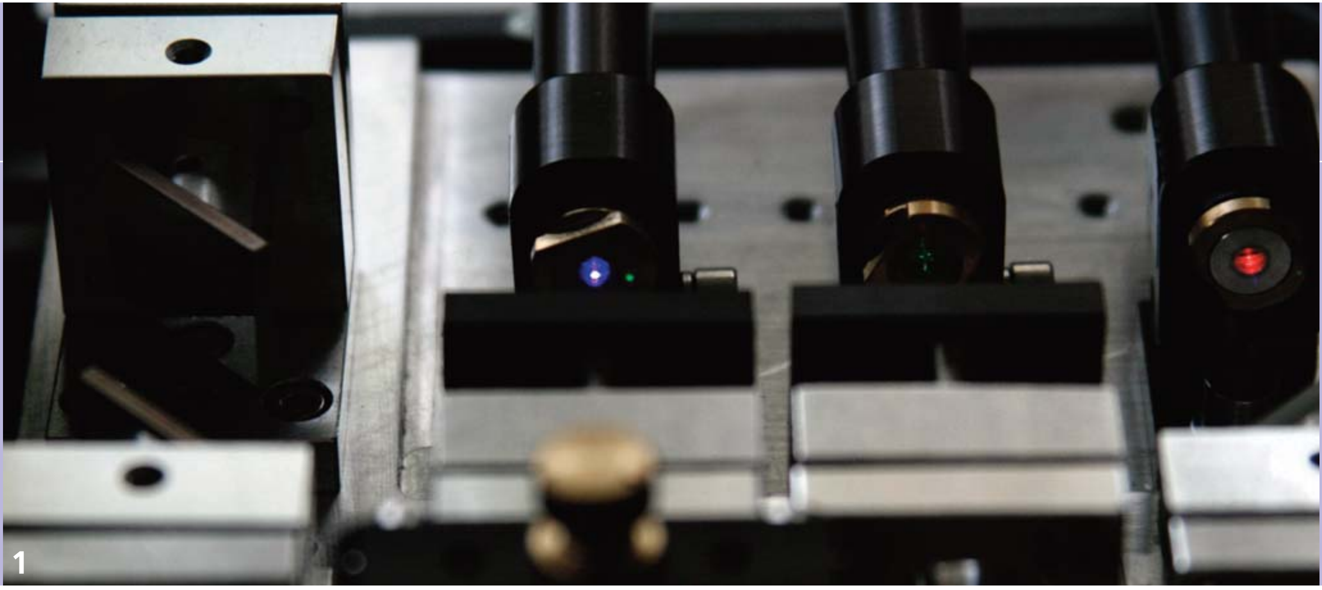
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SIZE DETERMINATION OF NANO PARTICLES DIRECTLY DURING THE MANUFACTURING PROCESS

THE TASK

Highly efficient lithium ion energy storage devices significantly benefit from nanoscale silicon materials added to the electrode materials. Compared to graphite it is possible to increase threefold the storage capacity. However, these and other applications are critically depending on the large-scale availability of these materials and thus depend on the reliability of functioning production processes.

Two dry processes are of relevance: direct current arc evaporation and inductively coupled plasma processes (ICP). Both use microscale raw materials, which are blown into the plasma zone and evaporated. The rapid cooling of the vapor (e.g. when injected into a cold gas) leads to nanoscale condensates since the rapid solidification terminates unlimited growth. Such particles have diameters of 20 - 200 nm.

Material as well as particle size are functionally important. Often the manufacturing processes require several hours and only afterward it is possible to determine the size distribution. This implies the risk that an entire batch may have to be scrapped. Desirable is in-situ monitoring of the particle size; then the process can be controlled.

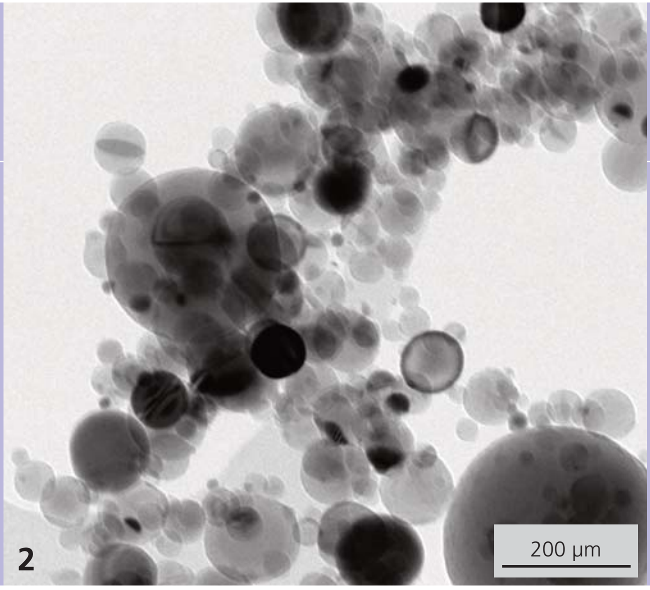
Dry processes in vacuum work with significantly lower particle concentrations than liquid phase processes. In-situ measurements of particle sizes of less than 1 µm are challenging. Nanometer particles can be reliably measured in suspension using laboratory type equipment, but there is no equipment available to measure gas-borne nanoparticles in a vacuum environment.

OUR SOLUTION

The demand for an in-situ monitoring technique originated from an industrial ICP manufacturing process for nano silicon. A multi wavelength extinction technique was implemented. The method detects the reduction of light intensities due to absorption and scattering when a laser beam is transmitted through a particle collective. This effect not only depends on the wavelength and concentration, but also on the size of the particle and is mathematically described by Lambert-Beer.

The use of three overlapping laser wavelengths eliminates concentration and interaction distance variables from the equation system. The extinction function Q_{ext} is calculated, which depends on size, wavelength and refractive index. The measured light intensity reduction I/I_0 can then be compared to the calculated extinction curves to determine the particle size.

This measurement principle was implemented in the form of an extinction spectroscopy system to measure silicon particle sizes during production. The core components are laser diodes with wavelengths of 405 nm, 532 nm and 635 nm. These are coupled with an integrated reference detector. A skillfully implemented timing ensures that the measurement is independently performed for each wavelength. The system also detects the influence of the background light. It is obviously necessary that the light can pass to and from the process under constant conditions. Therefore the system was designed with newly developed window ports that can be constantly cleaned inside the chamber by purge gas flow (Fig. 3).



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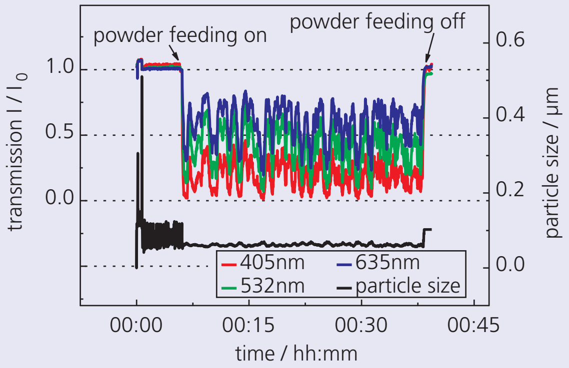
RESULTS

The system was designed using standardized components so that it was possible to integrate into the industrial ICP machine. The detector was physically placed before the collection bin for silicon nanoparticles. Initially there were difficulties due to the deposition of particles on the window ports, which occurred during leak test steps and associated pressure bursts. The purging regimes for the window ports were modified accordingly resulting in deposition free optical access.

The process operates with about 50 kW power at raw particle feed rates of 8 g min^{-1}. At these conditions we were able to achieve stable monitoring of the particle diameters. In addition to dimensions, the system also determines the nanoparticle concentration every second and thus indicates the raw particle feed rate (Fig. 4). The verification of the measured data was performed afterwards using transmission electron microscopy (Fig. 2).

The extinction spectroscopy proved to be the first long-term stable detection technique for in-situ size measurements of gas-borne nanoparticles. It was successfully evaluated in an actual manufacturing process. It is flexible in terms of the measurement distance. It works for low and high particle concentrations and can also be applied for suspensions. Particle sizes down to 30 nm can be detected.

Transmission of the three wavelengths and the calculated silicon particle size versus time



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1 *Multi wavelength extinction spectrometer (part of the optical setup)*

2 *TEM image of ICP generated nanoscale silicon particles*

3 *Internally cleanable window port with standard connector for extinction spectroscopy*

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1

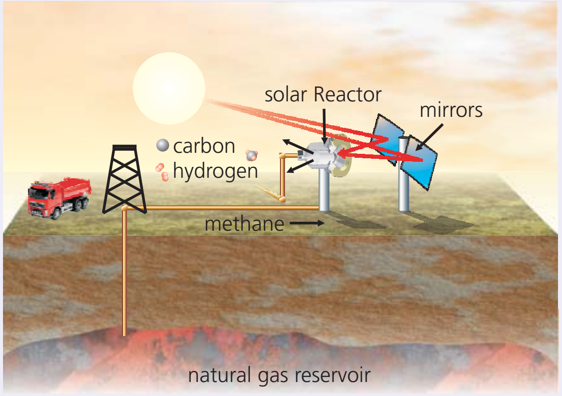
HIGH PERFORMANCE SOLAR SIMULATOR FOR SOLAR CHEMICAL REACTORS

THE TASK

Solar thermal technologies are globally considered to be a key future technology and also to have a broad application potential. Concentrated solar power (CSP) is converted into electrical energy or used to heat chemical reactors. In addition to electricity generation CSP systems are increasingly used to generate chemical raw materials while being CO_2 neutral.

The solar thermal generation of hydrogen from methane is a technology bridging the conventional hydrocarbon based and non-fossil based energy production. The carbon black generated during the process also determines its economy. Fraunhofer IWS researchers aim at developing solar thermal reactors that efficiently generate hydrogen and carbon black.

Schematics of solar thermal natural gas pyrolysis



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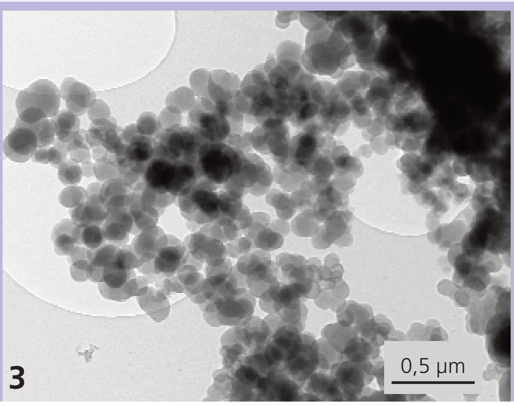
OUR SOLUTION

IWS scientists built a high power solar simulator for the laboratory (Fig. 1). The goal was to simulate highly concentrating systems such as tower power plants or solar dish systems in the laboratory under realistic conditions and independent from the weather. This test platform offers comprehensive possibilities to rapidly generate very high temperatures over areas of up to 200 cm^2 without requiring physical contact. The solar simulator is very well suited to evaluate:

- solar thermochemical reactors
- test the heat or radiation resistance of high temperature materials
- test the thermal cycle resistance of ceramics.

The system is has the following parameters:

- 10 high pressure Xe short arc lamps with each 15 kW electrical power, surrounded by an elliptical reflector (diameter 1 m), which focuses the lamp radiation onto a 3 m distant focus
- individual lamp adjustment via actuators
- separate current sources for power control
- 80 m^2 air conditioned laboratory space for reproducible environmental conditions
- IR and TV cameras and special pyrometers for temperature measurements
- data logging system for all process data
- MFC controlled gas flows for all process gases



A high temperature solar converter was developed to pyrolytically generate hydrogen. The reactor has a cooled conical head and a body made from high temperature ceramics. The concentrated solar radiation is directed into the reactor via a gas cooled quartz window to heat it up.

The reactor body is designed as a hollow resonator. Therefore the radiation losses through the input window are low. The resulting temperature inside the reactor can reach 1300 °C. A major challenge during the development of the solar reactor was to suppress the carbon deposition on the reactor walls. Carbon deposition occurs in particular on hot reactor walls when the produced carbon is not sufficiently fast removed. The IWS reactor concept implements an effective wall rinsing to avoid carbon deposition.

RESULTS

The high power solar simulator is capable of generating optical power levels exceeding 50 kW in the focal plane. This corresponds to a maximum power density exceeding 10 MW m^{-2} and a solar power concentration factor of 11000 compared to natural sunlight. About 40 kW optical power is available at an aperture of 15 cm diameter. These power densities achieve temperatures of 3000 °C at heating rates of 1000 K s^{-1}.

The solar thermal hydrogen generation was tried with several thermochemical solar reactors. The following results were obtained:

- high methane throughput (detected via FTIR spectroscopy)
- hydrogen yield of 80 % (byproducts: ethylene, acetylene)
- carbon black particle sizes range 50 – 150 nm (amorphous, Fig. 3)
- particle purity 99.7 %

1 High power solar simulator at the Fraunhofer IWS Dresden

3 Thermo chemically produced carbon black particles by breaking down methane

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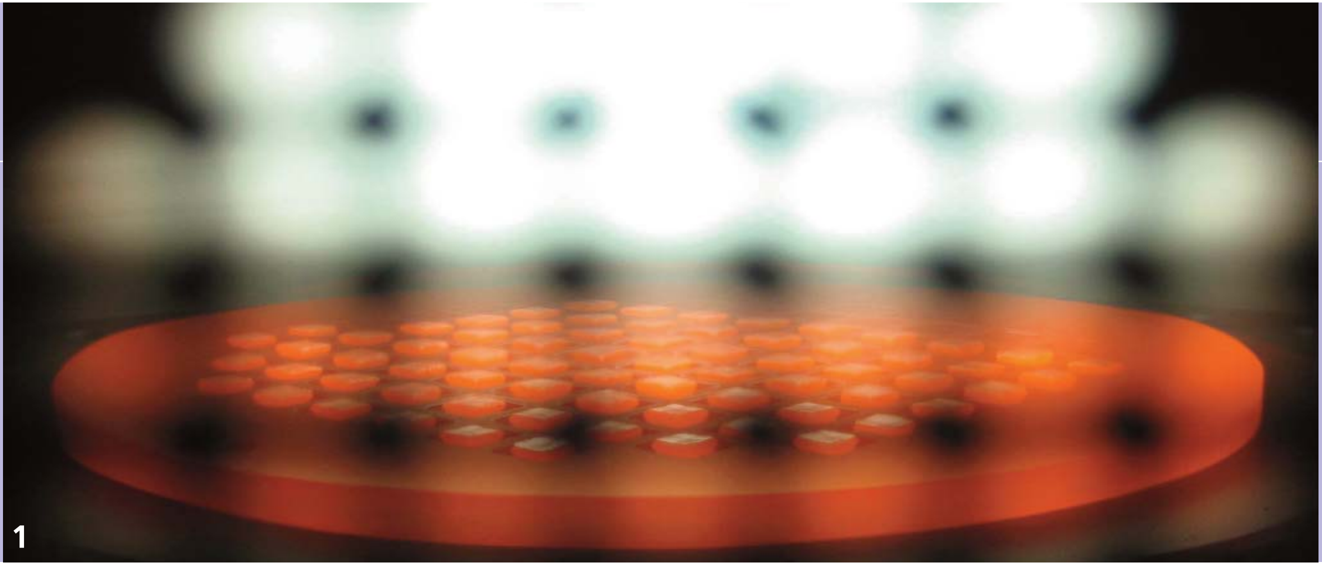
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CVD BASED DIAMOND FABRICATION FOR OPTICAL AND ELECTRONIC APPLICATIONS

THE TASK

Single crystalline diamond has a very high thermal conductivity (≈ 2000 W m^{-1} K^{-1}). Simultaneously the material does not absorb electromagnetic radiation over a wide wavelength range. This unique combination of physical properties makes diamond an interesting technical material for optical, X-ray optical and electronics applications. Diamond crystals can be used in semiconductor lasers with high power densities to remove heat directly from the site of laser beam generation. Diamond can also be used directly as a laser radiation emitting crystal. Low distortion X-ray monochromators use diamond crystals for high power densities. In addition diamond crystals are also of great interest for future application in nano (spin) and high power electronics.

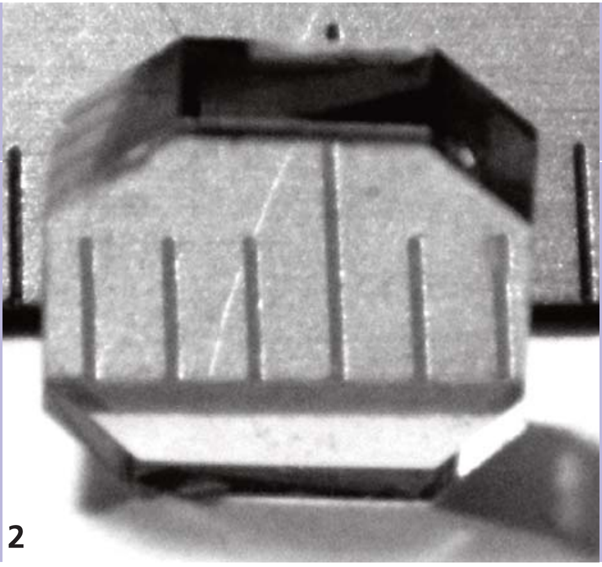
These applications require diamond crystals of highest quality, which are commercially available only in comparatively small dimensions. Typical size limitations are 10 x 10 x 0.5 mm^3. The limited quantity availability of such diamond crystal plates leads to high material costs of about 3000 Euros per piece. These limitations in diamond availability and costs inhibit the development of products and new technologies. Many of them would tremendously benefit from diamond's material properties. For some of the applications diamond would be an enabling component, if available at reasonable costs. The cost effective fabrication of large and high quality diamond crystals is therefore a challenge, which the Fraunhofer IWS approaches with its Fraunhofer Center for Coatings and Laser Applications (CCL) in Michigan, USA.

OUR SOLUTION

The possibility to synthetically produce diamond has been known for quite some time. Two principally different methods are established. One of these processes essentially simulates the natural growth process of diamond in a high pressure (≈ 6 GPa) and high temperature (≈ 2000 °C) environment. This process requires large presses and is capable of producing high quality crystals in limited quantities and sizes.

Fraunhofer CCL applies the second method, which is the homoepitaxial chemical vapor deposition of diamond, or diamond CVD. In this case diamond is synthesized at relatively high deposition rates of several 10 µm h^{-1}. The new diamond material grows homoepitaxially on previously produced diamond plates and uses a microwave plasma sources. This process requires moderate vacuum conditions (≈ 7 - 40 kPa), hydrogen (≈ 90 - 99 %) and methane (≈ 1 - 10%). Deposition temperatures are about 1000 °C.

Theoretically it is possible, with this method, to deposit high quality diamond over areas of 300 mm diameter. Unfortunately the diamond crystal substrates for homoepitaxial growth are only available in sizes ranging from 1 to 100 mm^2. However, already today it is possible to simultaneously synthesize many smaller crystals (Fig. 1).



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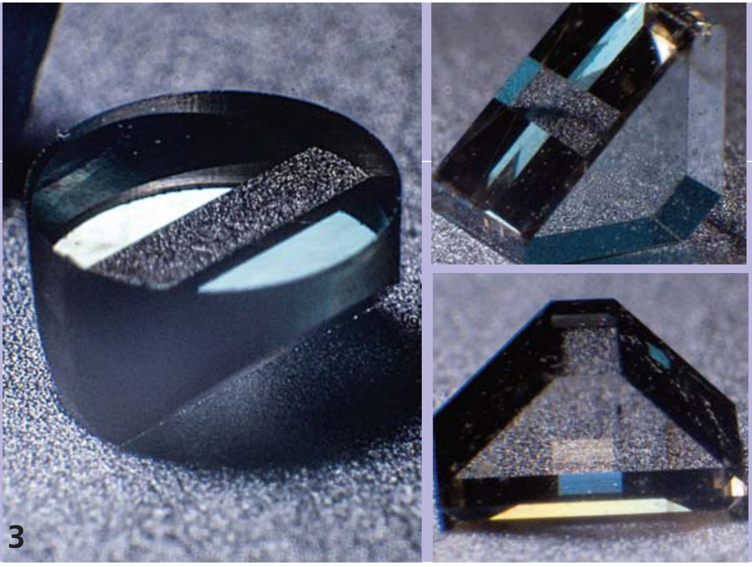

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RESULTS

Fraunhofer CCL engineers have established a laboratory scale manufacturing line to produce high quality diamond plates and customer specific diamond products in larger quantities. Continuing development of the reactor technology lead to substantial increases of the diamond growth rate (Fig. 4).

The quality requirements for the diamond crystals are defined by the application. Possible crystal defects that could limit applications include micro and macroscopic growth defects, lattice defects, the formation of growth sectors and the uncontrolled incorporation of non-carbon atoms. For electronic applications the concentration of nitrogen atoms with respect to carbon in undoped (intrinsic) crystals should be $< 5 \times 10^{-9}$. However, for most optical applications a nitrogen concentration of 10^{-6} is acceptable. Thermal and mechanical applications tolerate a nitrogen concentration of 10^{-3}.

Diamond growth rate as a function of the process pressure and reactor configuration

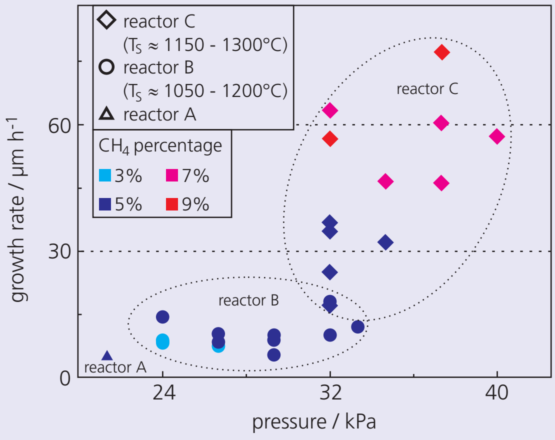

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Fig. 2 shows a diamond plate of optical quality. At appropriate thickness this plate can be processed into an optical component. Post diamond growth processing steps at Fraunhofer CCL include plasma etching, laser cutting and polishing. These techniques are used to shape the diamond crystals according to customer specified geometries (Fig. 3). Laser cutting can even fashion jewelry type diamonds.

Current research work focuses at the improvement of the reactor and process technologies to further reduce the production costs of single crystal diamond materials. In other words this means to increase growth rates and yields of making high quality diamond crystals.

1 *Simultaneous fabrication of 70 diamond crystals in a CVD process*

2 *CVD synthesized single crystal diamond plate for numerous applications*

3 *Diamond crystals for optical applications, processed and finished to customer specifications*

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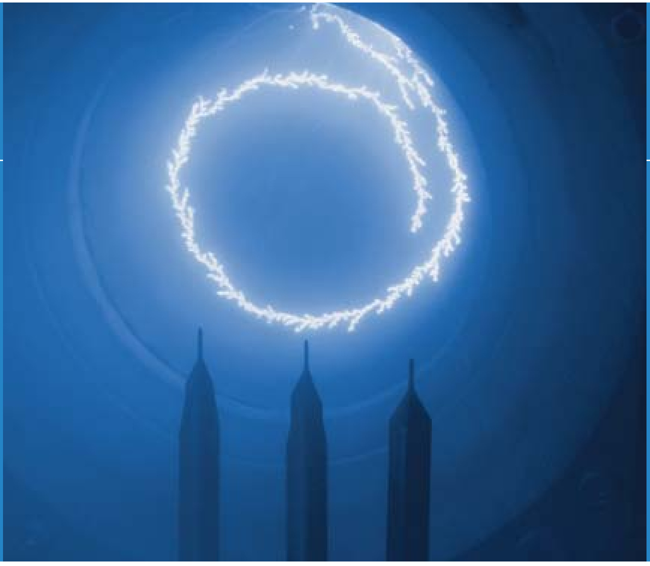
HEAD OD DEPARTMENT PROF. DR. ANDREAS LESON

"It is not enough to have sufficient knowledge – the knowledge needs to be applied.
It is not enough to want to – one has to do it."

Johann Wolfgang von Goethe



BUSINESS FIELD PVD VACUUM COATING TECHNOLOGY

Editor: The demand for research services in the business field PVD Vacuum Coating Technology increased again in 2012. The project volume grew markedly. What are the current research topics that create this strong interest?

Prof. Leson: EUV optics is a growing area in which we have been active for many years. Such optical components are key to the next generation of lithography equipment, which operates at the extremely short wavelength of 13.5 nm to produce even smaller structured microchips than those that are possible today. EUV lithography is close to being introduced to the market. There is now an increasing need for improvements and optimizations of the optical components. Since mid 2012 we have been working with Carl Zeiss, other companies and research institutions in a BMBF project to develop new generation optics. Here we aim at a resolution of 14 nm. With pleasure we would like to point out that Dr. Braun, representing our team, was honored with the Joseph-von-Fraunhofer award in 2012.

Editor: Multilayers are not only of interest for short wavelength optics but also for other applications. Can you point out some these application areas?

Prof. Leson: Indeed, we are using our competence in depositing multilayer coatings for other applications as well. For example, we fabricate so-called reactive multilayer coatings, which consist of numerous nanoscale individual layers and serve as a defined heat source. The coatings are used in special joining applications, where they generate only very limited heat loads and can also join entirely different materials. Such joints are metallic in nature and have excellent electrical properties. All these properties led to interest and customer inquiries, which we consequently address. This way we explore the broad application spectrum of this new joining technology.

Editor: Your department's group working on carbon coatings achieved a particularly strong growth in 2012. The topic is not new. What are the reasons for this uninterrupted interest and the high demand?

Prof. Leson: This is directly related to the exceptional properties of such carbon coatings. In particular the hydrogen free carbon coatings, our specialty, show extreme wear resistance. In combination with adapted lubricants these coatings also achieve extremely low coefficients of friction. This property combination is especially of interest to the automotive industry, since the coatings improve energy efficiency and reduce CO_2 emissions. However, the application potential of these coatings go far beyond that. The coatings provide benefits wherever there is friction and wear. I am convinced that we will see in coming years a continuing strong interest in these coatings and the associated systems and machine technologies.

COMPETENCES

X-RAY AND EUV OPTICS

EUV and X-ray optical components require individual and multilayer coatings with thicknesses in the nanometer range. We are using magnetron and ion beam sputtering processes as well as pulsed laser deposition. The coatings meet the highest requirements with respect to film thickness precision, roughness, chemical purity, lateral homogeneity and reproducibility. The coating stacks are used in X-ray optics and X-ray optical systems as well as reactive multilayer coatings for precision joining tasks. In addition to developing precision coatings, we offer our experience in the areas of characterization and modeling of nanometer coatings.

NANOTUBES AND -PARTICLES

Fraunhofer IWS engineers have developed a technology for the synthesis of single-walled carbon nanotubes and non-oxide core-shell nanoparticles. These materials with special properties are produced in technically relevant quantities. Both material classes change the properties of composite materials even when incorporated only in small quantities. We offer the materials at various processing stages with completely new functionalities. Composite material development is supported by modeling and comprehensive characterization efforts.

CARBON COATINGS

Fraunhofer IWS engineers have developed amorphous carbon coatings (Diamor®), which are high performance wear protective films. They can be deposited over a wide range of thicknesses with excellent adhesion to the substrate. The deposition occurs at low temperatures in vacuum with a specially developed pulsed arc process. The IWS partners with companies to supply the deposition chambers and quality control tools (LAwave®) that are necessary for the industrial introduction of the Diamor® coatings.

PVD COATINGS

Physical vapor deposition (PVD) enables the synthesis of high quality tribological and functional coatings. The process covers the thickness range from a few nanometers to several ten micrometers. The Fraunhofer IWS laboratories are equipped with various deposition chambers from high deposition rate evaporators to highly activated plasma processes and their combinations. A special emphasis is placed on the comprehensive exploitation of arc discharges, as they are the most efficient source of energetic vapor particles.

BUSINESS FIELD PVD VACUUM COATING TECHNOLOGY

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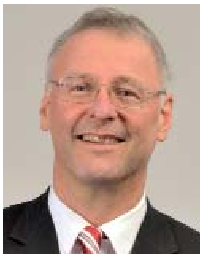

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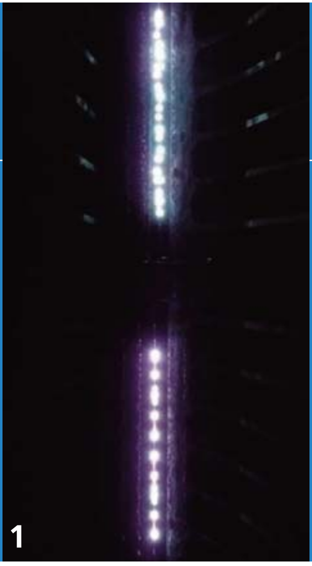
2012 PROJECT EXAMPLES



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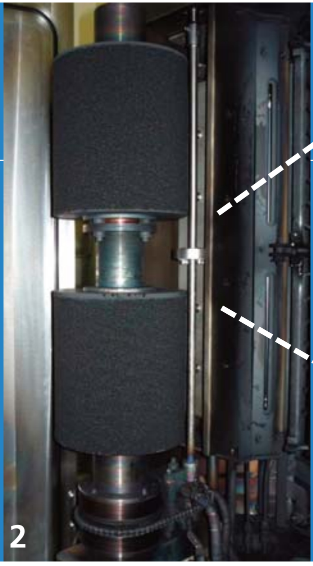

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INDUSTRIAL IMPLEMENTATION OF THE LASER ARC TECHNOLOGY FOR COATING DEPOSITION

THE TASK

Diamond-like carbon (DLC) coatings offer a unique combination of low friction and high wear resisting properties. These materials are experiencing a constantly growing interest as performance enhancing tool and component coatings. Among the numerous DLC coatings the so-call tetrahedral amorphous carbon coatings (ta-C) are becoming increasingly important. The ta-C coatings consist of 100 % carbon and have a two- to three-fold hardness advantage over classic hydrogenated DLC films. As such they open up new possibilities to provide durable surface coatings for extreme wear conditions.

Classic DLC coatings are generated from hydrocarbon gases. The ta-C coatings on the other hand can only be deposited from solid graphite using PVD processes. Currently the only economical process for ta-C deposition is the arc process. The implementation of this process for industrial high volume production is a current research topic at the institute.

OUR SOLUTION

Classic arc processes to deposit ta-C coatings face well-known difficulties. Fraunhofer IWS engineers addressed these by introducing the laser controlled vacuum arc. Short laser pulses ignite pulsed vacuum arc discharges at defined locations on the surface of the graphitic cathode cylinder. The discharges generate completely ionized plasma flashes of highly energetic carbon particles. The laser spot moves along the length of the cathode cylinder while the cylinder rotates. This concept ensures a uniform deposition over the entire length of the cylinder as well as very cathode cylinder utilization.

The experiences made with the first generation of Laser Arc modules led to the development of a next generation scaled to 500 mm deposition height. The deposition rate was increased to a level required for industrial high volume production.

The module can be integrated into existing batch coaters as they are used in many PVD toll coating operations. The basic functionality (vacuum generation, part movements, plasma cleaning, standard hard coating deposition) of the batch coater remains intact and usable. The deposition of ta-C can then be combined with existing processes.

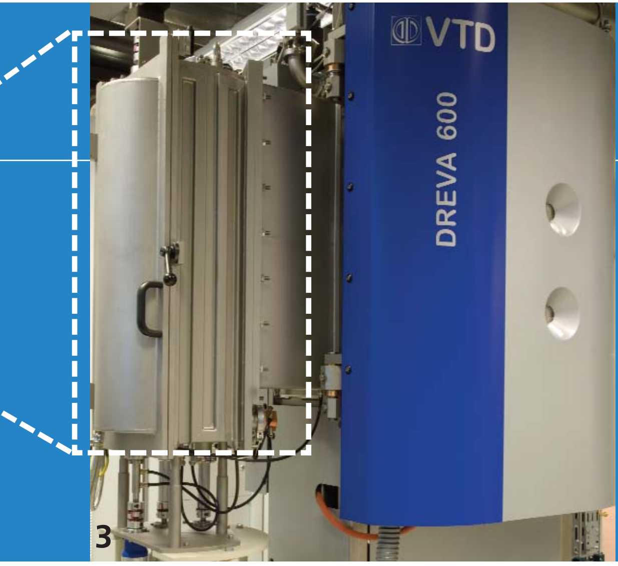
The new generation LAM 500 is also available with an optional plasma filter. This filter separates macro particles from the deposition plasma and enables the deposition of very smooth ta-C coatings.

RESULTS

The coater module LAM 500 was intensively tested in two system installations. The first system did not include the plasma filter option and was designed for very high deposition rates. The second system included the filter option to produce smooth ta-C films with very low defect densities.

Both systems were tested for long-term deposition and process stability over many deposition cycles.

The LAM 500 system without filter demonstrated the capability to perform long-term deposition processes. The process was running at deposition rates of 1.0 - 1.5 µm h^{-1} with a fully loaded PVD chamber and the



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deposited ta-C films had maximum hardness. Deposition rates exceeding 2.0 µm h^{-1} are also possible with a fully loaded chamber resulting in films with a slightly reduced hardness due to increasing heat loads in the substrates.

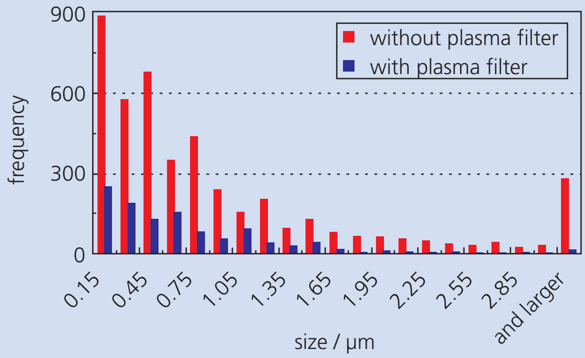
The LAM 500 system with plasma filter also demonstrated its long-term deposition capability. The effect of the filter is a substantially increased quality of the ta-C films. Roughness and defect densities are markedly decreased (Fig. 4). The absolute fraction of defects over the entire surface is reduced by about 93 % due to the plasma filter.

The carbon plasma transmission through the filter exceeds 50 %. The system achieves a deposition rate of 1.0 µm h^{-1} with a fully loaded PVD chamber.

The LAM 500 system was delivered to two industrial customers. One machine is used for the deposition of thick ta-C coatings on components. The other system includes a plasma filter and is used in a toll coating service operation for high-end tools and components.

Current research work is being performed on the next generation of Laser Arc module for industrial applications. This unit is designed for a coating height of 850 mm and will also include the plasma filter option.

Particle frequency versus particle size class for 1 µm thick ta-C coatings, comparison for ta-C films deposited with and without plasma filter



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1 *Plasma discharge on graphite cathodes*

2 *Graphite cylinder in a LAM 500 after operation*

3 *Complete machine for ta-C coating (PVD system with LAM 500 at IWS Dresden)*

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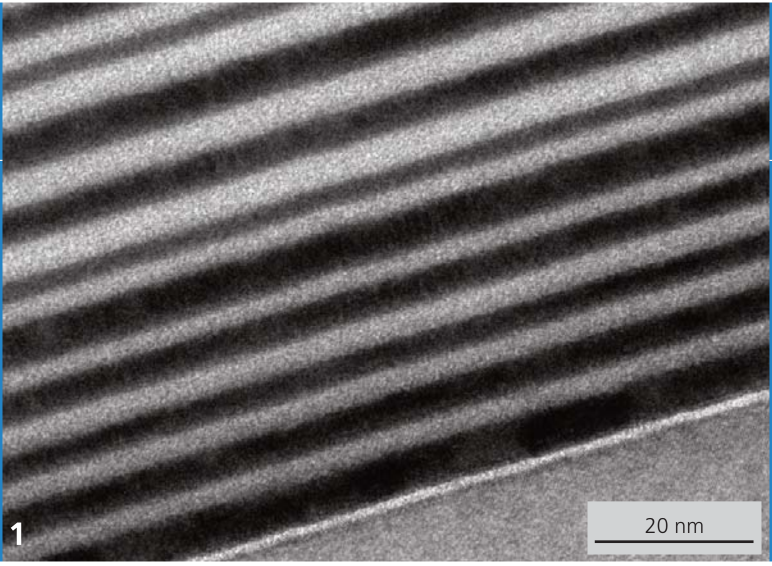


EUV REFLECTIVE COATINGS FOR FUTURE LITHOGRAPHY MIRRORS

THE TASK

The semiconductor industry uses optical imaging techniques to manufacture integrated circuits. The wavelength of the light source and the numerical aperture of the optical system determine the resolution and thus the miniaturization limit for the fabricated structures. The transition to EUV radiation with a wavelength of 13.5 nm already led to structures with minimum line widths of < 22 nm.

A further size reduction to structure widths of 14 nm place new demands on the mirrors:
- increase the numerical aperture of the optical system
- further reduce the diffusely scattered background

The increased numerical aperture leads for some mirrors to a broad variation of the EUV radiation incident angle $\Delta\alpha$. Aperiodic multilayer coatings accepting a wider angle could offer the preferred solution. Reducing the diffusely scattered background requires a further reduction of the coating roughness. The current state-of-the-art process applies an intrinsically rough coating onto an ideally smooth substrate surface. This requires improvement. Our goal is to develop self-smoothing coatings with high reflectivity for EUV radiation.

OUR SOLUTION

In order to build EUV mirrors that reflect the radiation over an increased angle it may be useful to depart from a strongly periodic multilayer films stack. Instead the individual layer thicknesses of the stack may be different along the growth direction (Fig. 1). Typically each individual film has a different thickness with a precision of 2 - 3 picometers.

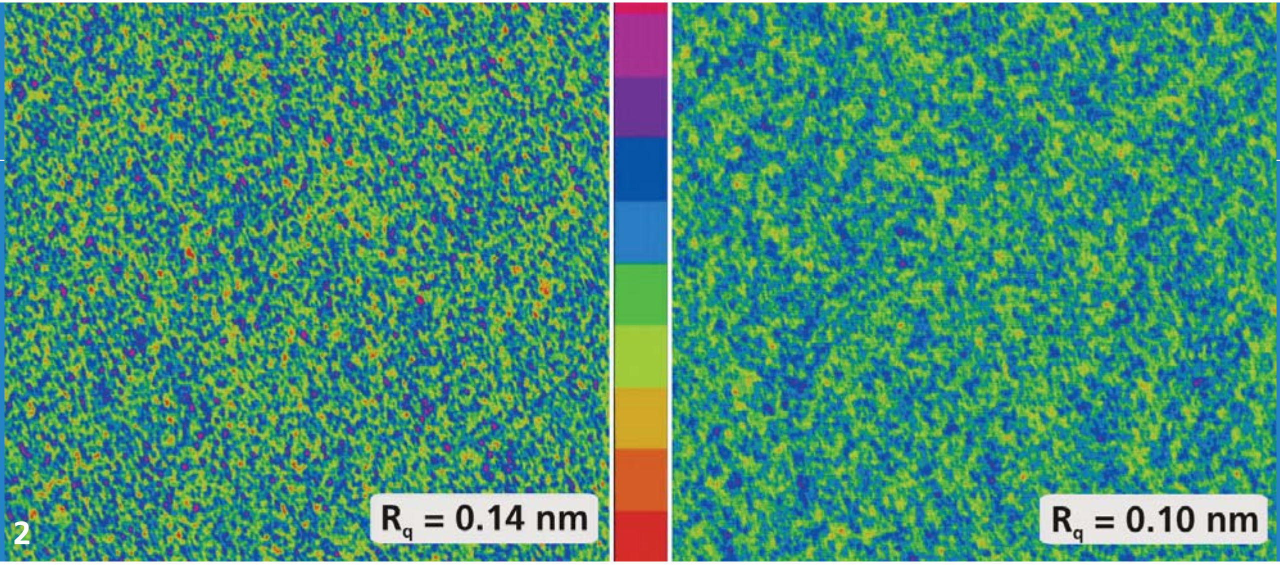
The thickness of an individual layer in nanometer multilayer stack is defined by the following parameters:
- deposition rate of the material
- contraction at the interface due to chemical reactions

When the deposition rates are determined it is possible to deposit any individual coating thickness at high precision within a depth-graded multilayer. First reference mirrors were coated with such EUV broadband designs.

RESULTS

The decisive criterion for the evaluation of broadband reflective coatings is the quality of the match between experimentally determined reflectance spectrum with the target spectrum. The targeted reflectance spectrum is calculated based on a model coating system. In Fig. 3 we show modeled and measured spectra for a given wavelength and fixed incident angle. This example shows a good match.

In addition to broadband features the mirrors should also reflect less scattered light. This required the further reduction of the coating roughness, which in turn demands the activation of surface diffusion processes.



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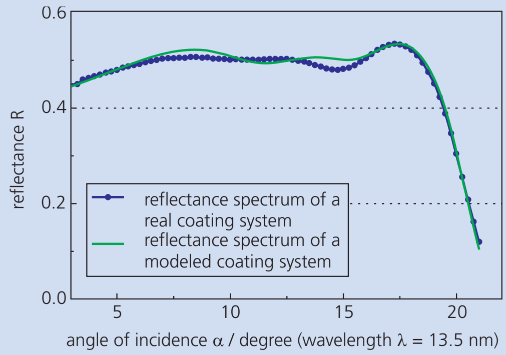
Comparison of reflectance spectra of a real and a modeled coating system



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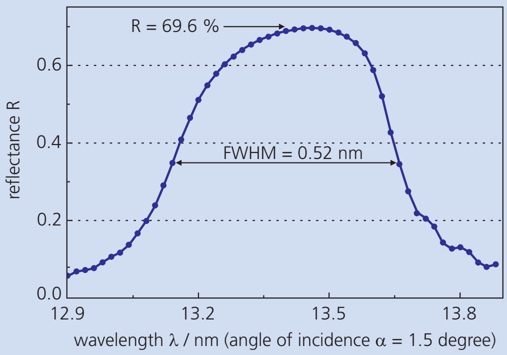
EUV reflectance of a multilayer coating with 500 periods



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If surface diffusion is active the atoms can move and find positions that are energetically more favorable.

In practices this activation is performed by moderate bombardment with ions during the film growth process. It is important that the additional ion bombardment does not activate volume diffusion. This would lead to a broadening of chemical transition regions at the interfaces.

Current standard coatings on the best surfaces (rms roughness of < 0.1 nm) achieve rms roughnesses of 0.14 - 0.17 nm. The additional ion bombardment during the film growth led to reduced rms roughnesses of 0.10 - 0.12 nm (Fig. 2).

Therefore such coatings do not increase the roughness of the substrate surface. These modified deposition conditions can deposit multilayers of several hundred periods of high reflectance. In Fig. 4 we plot the reflectance of an EUV coating with 500 periods.

This mirror achieves a reflectance of 69.6 % at 13.5 nm and 1.5 degrees angle of incident. This is just half a percent below the current record.

1 *TEM image section of a depth-graded multilayer coating*

2 *AFM image to demonstrate the reduced roughness, scan length 3 µm, height scale 1 nm*

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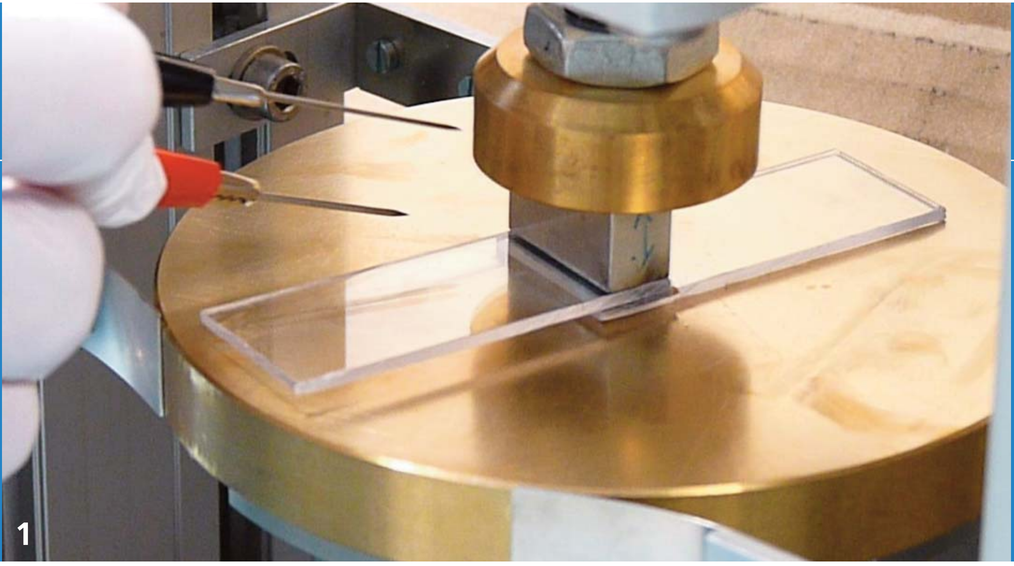


NANOMETER REACTIVE MULTILAYER COATINGS FOR PRECISE JOINTING PROCESSES WITH LOW TEMPERATURE IMPACT

THE TASK

A frequently reoccurring task is to solidly join two different parts. Ideally one just has to hold the two parts together and press a button to immediately form a solid joint. The reality is different. Adhesive bonding processes require curing the adhesive. Soldering and welding require heating the parts to be joined. New joining processes can overcome these limitations and they are of particular importance for the following applications:

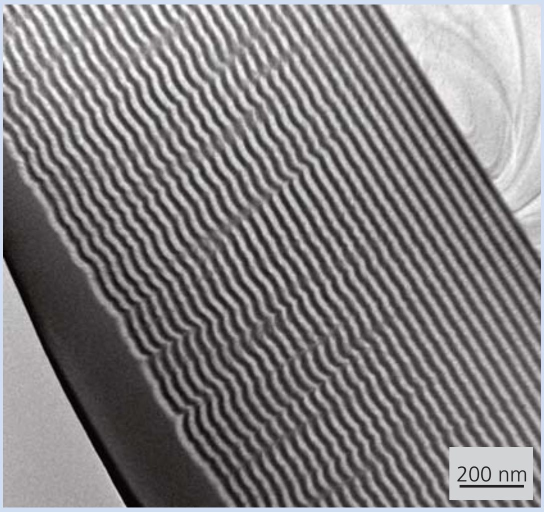
- low heat impact precision joining of micro system components
- joining of parts made from very different materials (e.g. ceramics and metals)
- short and precise heat impact to join polymers

OUR SOLUTION

Fraunhofer IWS engineers use a new approach, which could make the ideal joining process vision a reality. A reactive multilayer coating is placed between the surfaces to be joined. An electrical pulse activates the multilayer and within milliseconds the parts are connected without overheating (Fig. 1).

The principle is based on an effect observed on specially designed nanolayer film structures. Initially the foil consists of many individual layers made from at least two different materials (Fig. 2). The activation of atomic diffusion in such multilayers causes chemical reactions to initiate. These exothermic reactions then briefly release heat in a very localized region defined by the foil location. This heat is used to melt a solder placed on both sides of the multilayer. It can also melt the surfaces of the parts to be joined. When solder or surfaces are solidified the parts are joined. There is almost no limitation with respect to the parts. Metals, ceramics, semiconductors, diamond and most recently even polymers can be effectively joined.

TEM image of a cross section through a nanometer reactive multilayer (Picture: Dr. Rümmeli, IFW Dresden)



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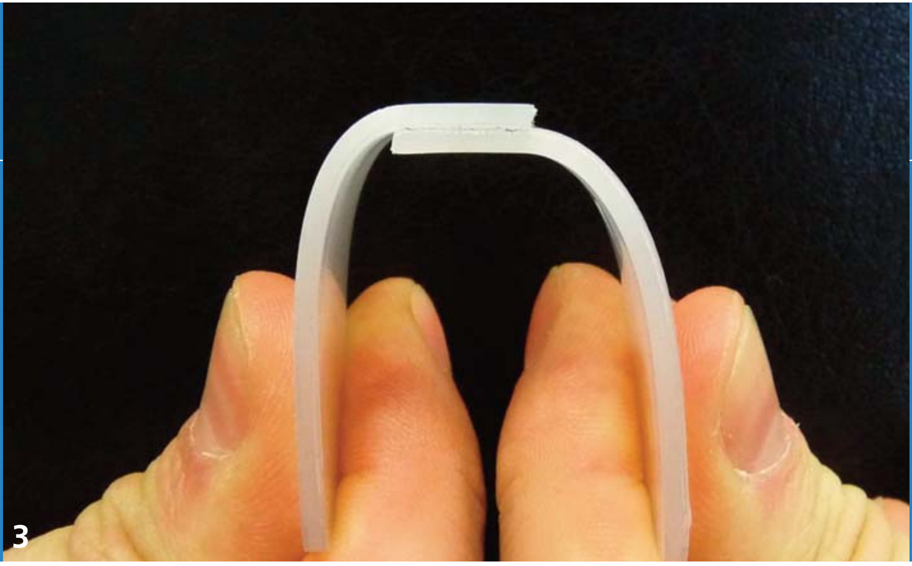

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RESULTS

Recently the basic technique was further developed to also include solders with higher melting points. The previously exclusively used soft solders melted at 200 - 300 °C. The process can use hard solders that melt above 700 °C. Parts joined with such solders can be used at high temperature loads.

Such solders also improve the strength of the joints. The application of these solders was made possible by doubling the energy amount store in reactive multilayer coatings. This work is being continued with the goal to enable solders with melting temperatures exceeding 1000 °C. This is a very interesting temperature region for joining ceramic materials.

A second very important aspect of recent work is the joining of polymers (plastics). Within a short time we were able to achieve very interesting results. Polymers can be joined without the use of solders. The foil provides energy to directly melt the surfaces of the polymer parts. Thus the polymer parts are directly welded.

Especially advantageous in this case is that the energy amount to be delivered by the foil is precisely adjusted via the design of the nanolayers. The precise energy delivery avoids burning of the polymers and established a well-defined liquid phase. The mentioned examples and developments show that tailored reactive foils can make "joining upon pressing a button" a reality.

1 Joining of polymers with RMS

3 Strength test of polymer parts, which were joined by reactive multilayers

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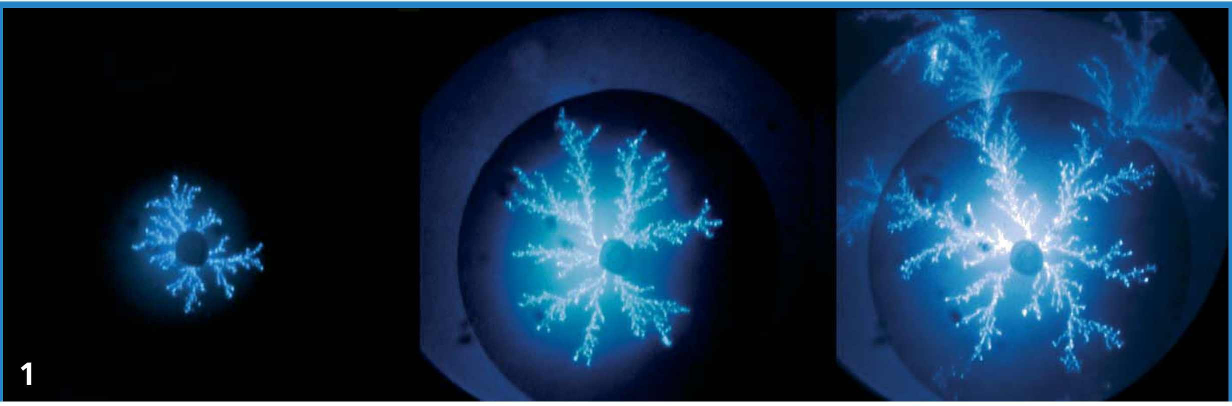
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TRANSPARENT METAL FILMS WITH HIGH ELECTRICAL CONDUCTIVITY

THE TASK

The technical realization of transparent electrodes or contacts is a key component for future technologies including solar technology, optoelectronic components and display technologies. Such transparent electrodes are typically based on selected ceramic materials (TCO: transparent conductive oxides). However, the electrical conductivity of such materials is comparatively low. These ceramic films have mechanical properties that do not suit many applications and they are also relatively complex to manufacture. Principle innovations in this field could offer new momentum in many high-tech applications.

Alternative coatings materials can be thin metal films. Electrical conductivities of such films are 10 - 1000 times higher than those of common TCO materials. Therefore the metal films can be made very thin and thus remain transparent.

Conventional deposition technologies such as vacuum evaporation and sputtering require a minimum film thickness often of more than 10 nm to form a dense film. This is caused by a film growth mechanism forming individual metal islands first. These islands only grow together at increasing thickness building a solid film. At such thicknesses however the metal film is less transparent. The task is to develop a process depositing very thin and homogeneous metal film.

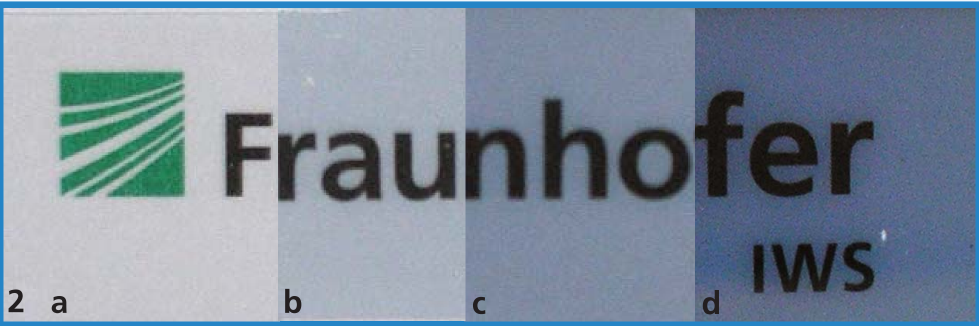
OUR SOLUTION

Fraunhofer IWS engineers have developed a pulsed high current arc process (High Current pulsed Arc – HCA) that generated metal plasmas with extremely high ionization degrees and energies. Coatings made by such a process do not form islands during deposition. Instead the metal ions are subplanted into the substrate surface. The process creates very dense and uniform structures. The HCA technology operates in pulse mode, which makes it very flexible in terms of creating appropriate plasma parameters for optimum film growth.

The HCA process was used to deposit silver onto glass substrates. The films were then analyzed with respect to optical transmission and electrical conductivity.

Thin metal films under normal atmospheric conditions are unstable since they oxidize. Oxidization leads to loss of electrical conductivity. To avoid oxidation the metal films are encapsulated with thin transparent ceramic passivation layers, which can also be deposited by the HCA process.

A positive side effect is that the encapsulating ceramic film can be designed to serve as an antireflection layer to the metal film. This improves the optical transmission of the overall system and improves the longevity of the electrode.



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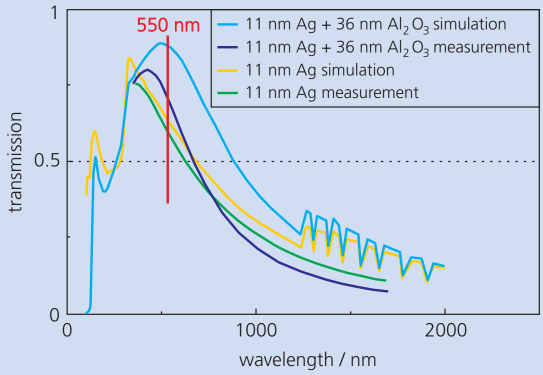
RESULTS

In Fig. 2 we show an uncoated glass substrate (a) and more substrates with transparent silver coatings with thicknesses of 7 nm (b), 11 nm (c) and 17 nm (d). As expected the underlying Fraunhofer logo becomes less visible with increasing thickness.

A good compromise between electrical conductivity and optical transmission is the 11 nm silver film. The sheet resistance $R_\square$ is about 5 Ω and the visible transmission at 550 nm is about 60 %. An indium tin oxide (ITO) film of the same resistance requires a thickness of about 200 nm. A ceramic passivation layer (in this case Al_2O_3) provides long-term protection against passivation. Simultaneously the passivation layer provides antireflective properties.

Fig. 3 shows the measured optical transmission data of the coatings on glass as a function of the wavelength. Plotted are data from an individual 11 nm silver film and from an 11 nm silver film covered with a 36 nm Al_2O_3 passivation layer.

Improvement of optical transmission of an 11 nm thick Ag film by addition an Al_2O_3 top coating



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The transmission increases from 60 % sans passivation layer to more than 70 % at 550 nm, which is the center of the visible spectral range. For comparison we added simulation results to the graph. The data suggest that there is even more room for improvement. An optimized film thickness could achieve and optical transmission of almost 90 %.

It is also possible to adapt the coating system to meet specified target parameters. For example, reducing the silver film thickness increases the optical transmission at a slightly increased resistance.

The presented transparent conductive coating system based on thin metal films offers a useful alterative to existing TCO solutions. Advantages are the low film thickness and the associated minimized material requirements.

1 High current arc discharges of varying pulse lengths on metal cathodes

2 Glass samples,
a: uncoated,
b-d: coated,
b: 7 nm Ag, c: 11 nm Ag,
d: 17 nm Ag.

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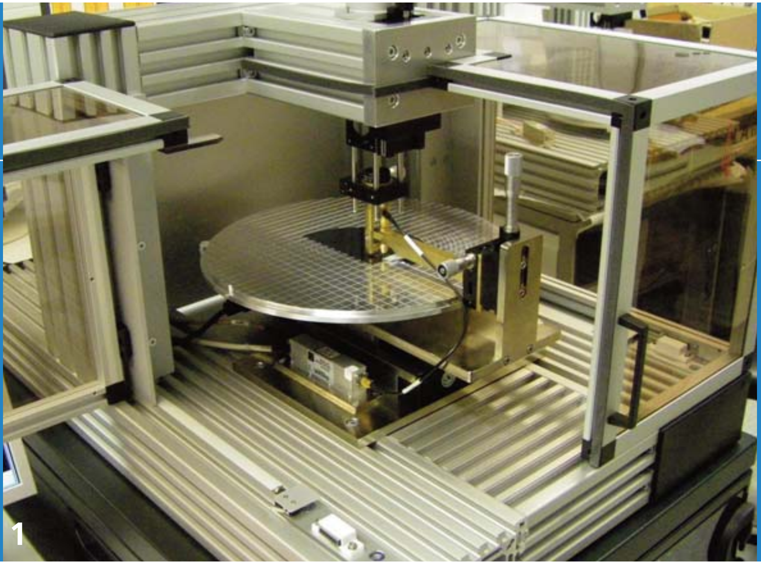


NONDESTRUCTIVE EVALUATION OF COATINGS AND SURFACES USING LAWAVE®

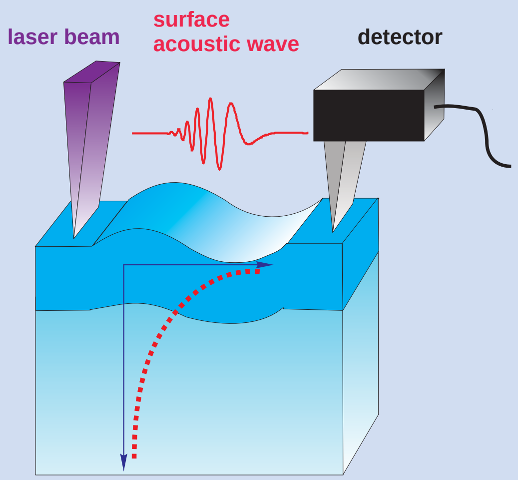
THE TASK

Coatings are used in various surface applications with thicknesses ranging from a few nanometers to several hundred micrometers. They provide corrosion and wear protection or have defined mechanical, chemical, electrical, optical or magnetic functions. To develop new coating materials or to ensure quality control on coating manufacturing requires testing of certain material properties. Those properties can be special coating functions. In most cases however it is desirable to know coating characteristics such as thickness, density, hardness, Young's modulus and adhesion. The coating thickness in many cases is measured using magnetic, electrical or optical methods. Mechanical properties on the other hand are typically determined by a destructive method and in many cases this approach is relatively complicated. In addition to coating analysis it is increasingly also of interest to measure changes in surface conditions. An example is the modification of silicon wafers as they are used as substrates in semiconductor and photovoltaic manufacturing. The wafer fabrication involves steps such as sawing and polishing, which leave surface affecting processing zones. These zones need to be very precisely analyzed. Just like for coatings it also of interest to find nondestructive methods to characterize such surface zones.

OUR SOLUTION

Fraunhofer IWS engineers have developed the LAwave® method to nondestructively analyze coatings and surfaces. The principle technique utilizes the propagation of surface waves, which depends on the materials. Short laser pulses initiate the surface waves. Each laser pulse generates a broad frequency spectrum. The high frequencies in this spectrum are propagating closer to the surface whereas the longer wavelengths propagate in the deeper regions of the test specimen. If the tested sample consists of substrate and coating the waves will move in different materials. The propagation velocity of the waves depends on the material properties (especially Young's modulus and density). Therefore the waves will travel at different velocities depending on the frequency. This is the so-called dispersion relation, which serves as the basis for the LAwave® method and is determined during each measurement. The material properties are derived from the dispersion relation using a nonlinear fitting routine that finds the best match to a given model dispersion function. The following picture shows the LAwave® principle. The excitation is performed with a nitrogen pulse laser. The sound signal is detected with an acoustic sensor that is placed onto the substrate surface at a defined distance from the laser initiation of the sound wave. This signal is then amplified and recorded by an oscilloscope.

LAwave® principle



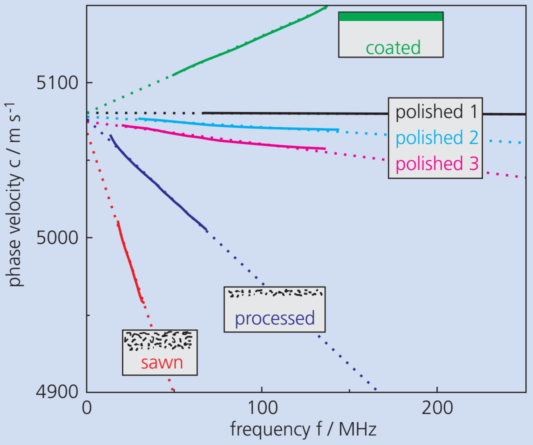
LA wave

RESULTS

The LAwave® testing system was developed to nondestructively characterize various coatings and surfaces. Depending on the task one can measure elastic properties (E modulus), density or film thickness. Physical properties such as the E modulus are often affected by structural modifications such as porosity, grain size or crystal defects (micro cracks, dislocations). This makes the LAwave® system a very effective tool to detect various material conditions in surfaces. The most typical application areas are:

- measurement of the modulus of elasticity and thickness of ultra thin and thin films
- measurement of density and E modulus of diamond-like carbon coatings (a-C:H, ta-C) as well as crystalline diamond films
- evaluation of porosity and defect density in thermal spray coatings
- determination of the damage layer depth in semiconductor and photovoltaic wafers to optimize sawing, grinding and polishing processes

Dispersion curves of acoustic surface waves in a silicon wafer, the slope S reduces with each processing step



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The diagram demonstrates, based on the example of a silicon wafer, how strongly smallest surface modifications affect the LAwave® measured sound wave propagation. This illuminates how sensitively mechanically induced damage layers or thin films can be characterized.

In recent years many LAwave® systems were delivered to customers in research, development and industrial production. Applications include the development of hard coatings, the characterization of implant coatings and the measurement of wafers in semiconductor and photovoltaic manufacturing. Currently we work on a LAwave® handheld detector for the evaluation of compact components, which greatly enhances the application range of the system.

1 Measurement stage of a LAwave® tool for the characterization of 300 mm wafers

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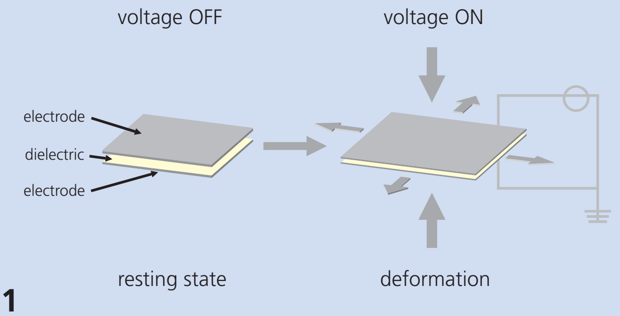
BUSINESS FIELD PVD VACUUM
COATING TECHNOLOGY

INTEGRATION OF CARBON NANOTUBES IN SILICONES TO PRODUCE ELASTOMERIC ACTUATORS

THE TASK

Dielectric elastomeric actuators (DEA) are very interesting material systems for industrial applications and thus present an important field of current research efforts. A DEA consists of at least three layers with a dielectric layer (to prevent electric breakdown) being sandwiched between two electrically conductive layers. The working principle of a DEA is based on electrostatic pressure generated by the charged electrodes. This pressure elastically deforms the system.

Principle of a dielectric elastomer actuator



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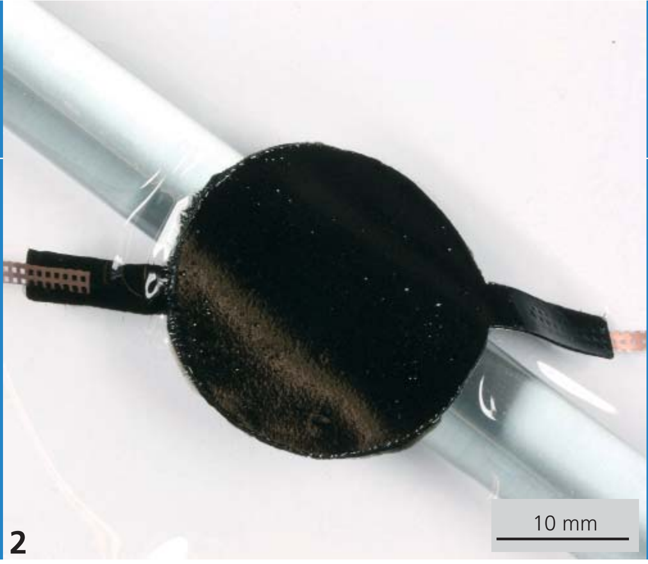
The electrodes can be made from metals, which are significantly stiffer than the dielectric layer. This difference in stiffness limits the expansion as well as the lifetime of the actuator. To avoid these disadvantages one can build the system completely from polymers. The concept is to use one and the same polymer for both the dielectric and the electrically conductive layers. Lifetime and actuator function can be improved if the layers are well matched. Depending on the desired layer properties the elastomer can be modified with conductive or dielectric nanoscale filler materials.

OUR SOLUTION

A two component additively networked silicone material was selected for the actuator material. The elastomeric electrode material incorporates carbon nanotubes (CNT). The dielectric properties were improved by the use of ceramic particles. The individual materials for the actuator layers have to follow certain conditions, which have to be considered during filler material integration. Such conditions include for example the breakup of agglomerates and the homogeneous distributions of freed particles. The properties of dispersion, the networked layers and layer stacks need to be well controlled.

Experiments were performed to investigate various processes. For particle dispersion we used an agitator, a speed mixer, an ultrasonic sonotrode, a calender and a high pressure dispersant. Single wall carbon nanotubes (SWCNT) and ceramic particles require different approaches. Particle type, their degree of agglomeration and their filling degree all affect the process. The different layers and particle types required optimization including different process sequences. The experiments yielded long-term stable and reproducible dispersions, which can be assembled into individual layers, composite layers and stacked layers.

Specific material knowledge was obtained from numerous characterizations of individual layers and layered stacks. It was essential to the success of the project that dispersion and layer fabrication were jointly optimized.



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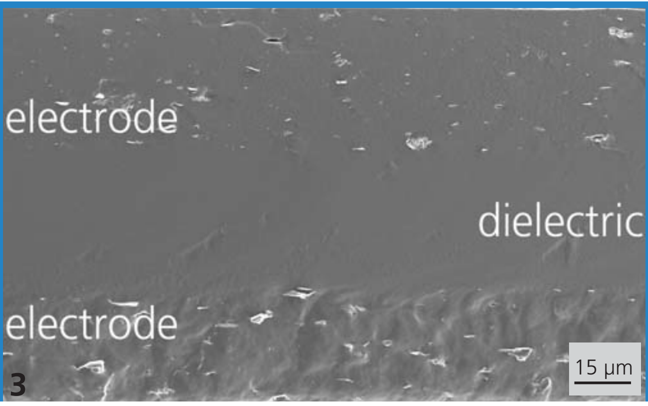

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RESULTS

SWCNT were successfully dispersed into silicone. This reduced the specific resistance from 10^{14} Ω cm to 10 Ω cm. The so modified silicone is now suitable as an electrode material. Further optimization can reduce the resistance even more.

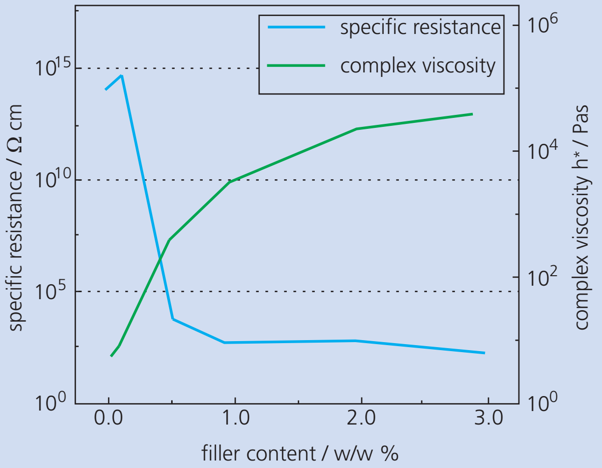
The deagglomeration and homogenization of SWCNT changes the dispersion viscosity as a function the filler material concentration. This has an effect on processing since the viscosities increase from 4.7 Pas to 43.3 kPas.

The manufacturing process had to be designed so that such dispersions can be handled for the reproducible fabrication of DEA.

The stiffening of the electrodes due to SWCNT can be counter acted to make layer composites with identical or comparable properties. For example, large elasticity modulus differences between layers can prevent or affect the actuator function.

The developed DEA with nanoscale filler materials proved to function according to the laws of electrostatic pressures. This successfully demonstrates the possibility of making actuator from polymers based on modified silicones. These DEA also showed an improved lifetime compared to conventional DEA. This project was funded by the BMBF (No. 13N10661 and 13N10660).

Specific resistance and complex viscosity versus SWCNT filler material concentration



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2 *Flexible three-layer actuator with circular electrodes*

3 *SEM image of a three-layer actuator after cryofracture*

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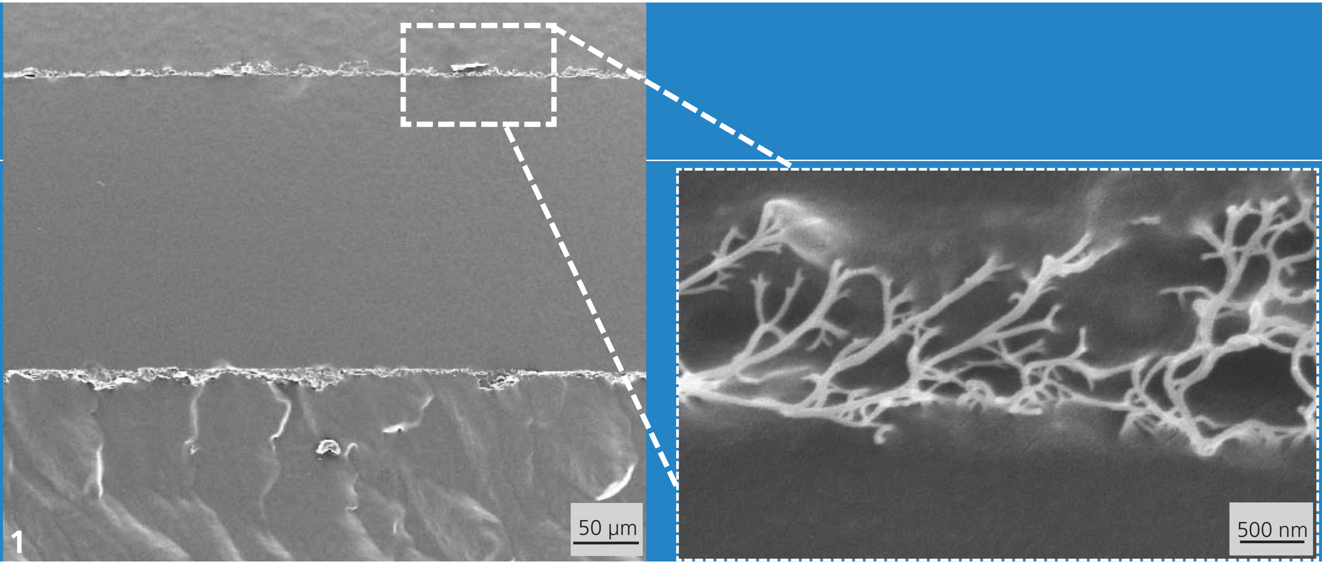

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HIGHLY FLEXIBLE ELECTRICAL CONDUCTORS FOR ELECTRONIC, ACTUATOR AND SENSOR APPLICATIONS

THE TASK

It is challenging to produce highly conductive electrical conductors that are simultaneously structurally flexible, robust as well as chemically and thermally long-term stable. So far such electrical conductors simply do not exist.

However, potential applications for highly flexible electrical conductors are huge in particular if these conductors can be made in the form of coatings. Applications include shielding from electromagnetic interferences (EMI), resistive and capacitive sensors and electric PCB tracks. A particular highlight is the fabrication of such flexible conductor coatings for electrostatic actuators, which tolerate large strains. Display applications are feasible if conductivity and flexibility properties can be combined with transparency.

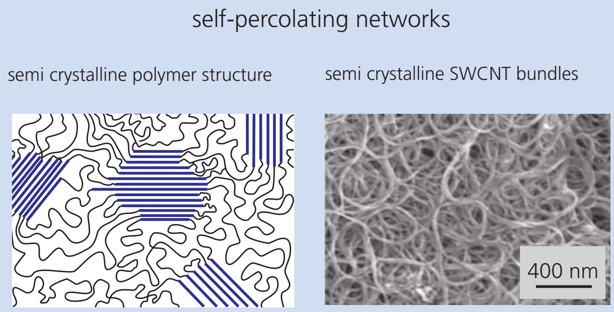
Fraunhofer IWS engineers and other research institutions in Dresden are jointly developing such electrical conductors. The goal is to produce these materials in virtually any shape and dimension using cost effective and industrially established production technologies.

OUR SOLUTION

The base material for flexible electrical conductors is a long chain polymer with a small amount of conductive additives. Ideal materials are semi crystalline long chain polymers and elastomers such as PE, PP or silicones in combination with semi crystalline long chain conductive polymers. Conductive polymers of this type are single wall carbon nanotubes (SWCNT), which can be cost effectively produced in large quantities by Fraunhofer IWS laboratories.

Fig. 1 shows an example of a thin, conductive and polymer infiltrated fibrous interlayer between two dielectric polymer layers. This fibrous interlayer is of similar flexibility as the basis polymer. The flexible single wall carbon nanotubes self organize similar to the semi crystalline basis polymer and form semi crystalline bundle structures, see also Fig. 2. Both components are compatible and can be easily combined. The conductive component provides the basis polymer and its layers and shapes the desired electrical conductivity and lifetime.

Structural analogy of semi crystalline long chain polymers and bundled SWCNT



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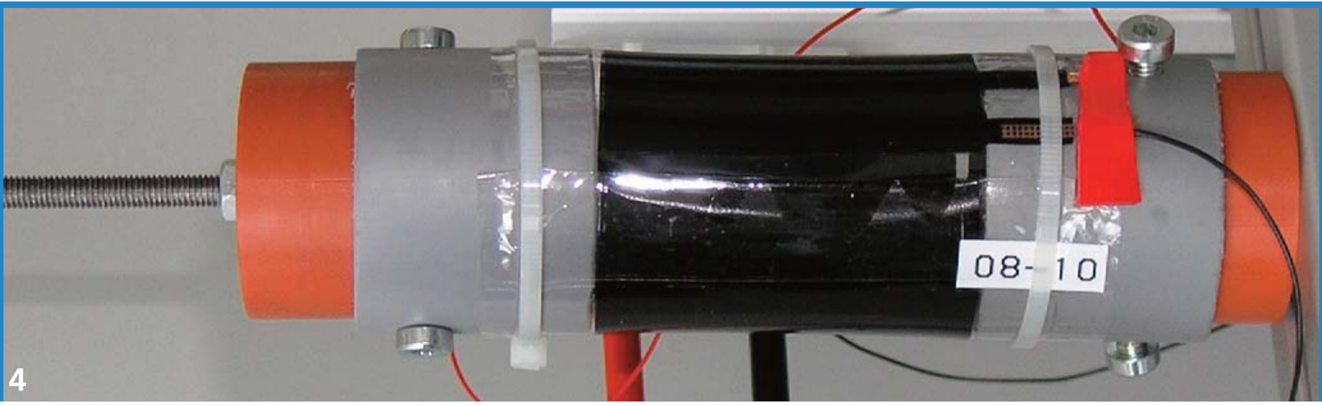

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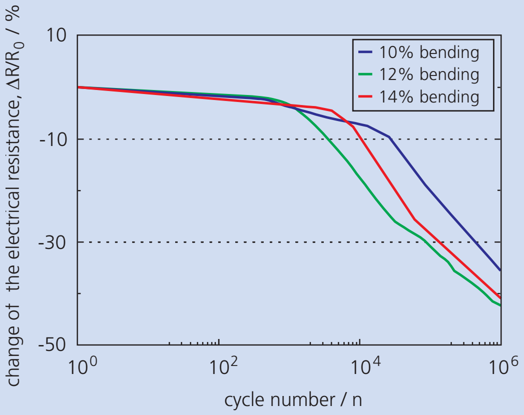
RESULTS

Fraunhofer IWS engineers apply a spray technology for homogeneously dispersed single wall carbon nanotubes. The process is optimized based on the applications so that it requires a minimum of material. Only a few micrograms of single wall carbon nanotubes are necessary to achieve substantial electrical conductivities even at 98 % transparency. This keeps the costs low. The required amount increases to the two-digit milligram range if higher conductivities are needed. Such films are then nontransparent.

The special compatibility of the developed composite solution is reflected by an interesting lifetime. Fig. 3 plots the electrical conductivity of a three-layer design with a central conductive layer sandwiched between two dielectric layers. At elongations of up to 15 % with uniaxial loads along the layers there occurs no degradation of the electrical conductivity over 10 million cycles. In fact the opposite is the case. Since contract resistances are reduced over time the electrical conductivity improves.

Dielectric elastomer actuators demand particularly high quality of the layer stack. These have to survive a large number of strain cycles while maintaining high dielectric properties. Jointly with Fraunhofer IKTS and TU Dresden we developed and fabricated such actuators. Fraunhofer IWS provided the multilayer stacks. Fig. 4 shows an example of a ring actuator. This is a fully functional demonstrator based on the described technology.

Change of the electrical resistance versus cycle number for conductive layer under uniaxial strain



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1 *Five layer design made from dielectric polymer layers with thin electrically conductive interlayers made from SWCNT*

4 *Actuator with a ring shaped rolled up multilayer stack (black area), which is the active actuator structure*

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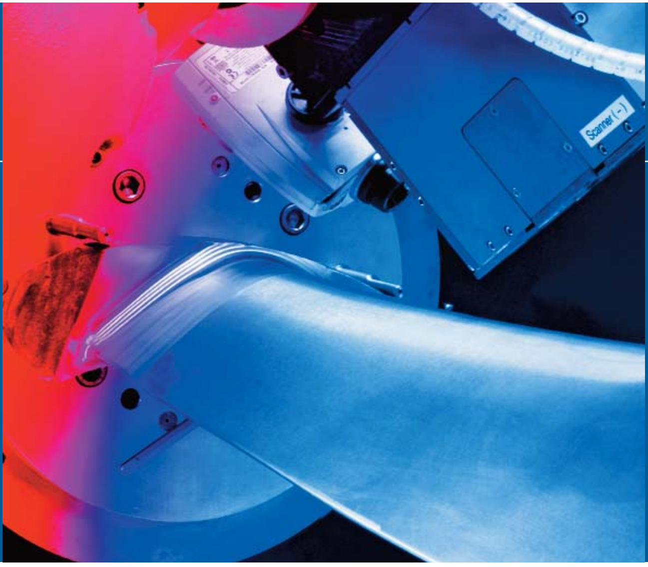
HEAD OF DEPARTMENT PROF. DR. BERNDT BRENNER

"Anticipating what is to come, this is the dictum of true science"

Auguste Comte (1798-1857),
French philosopher and sociologist



BUSINESS FIELD SURFACE TECHNOLOGY

Editor: The business field "surface technology" has been developing as very goal oriented since many years. Which results from the past year are especially noteworthy?

Prof. Brenner: I would like to mention the systems technology developments. These developments were consistently aimed at increasing and improving a product portfolio, which led to a stable revenue source and contributes substantially to the budget of this business field. On the other hand systems technology is also an important link to deliver process technology developments to our customers in a most direct way avoiding difficulties during manufacturing startup. Tightly connecting technology development with process specific systems technology has proven to be very valuable. We can quickly respond to customer requirements and reliably test the suitability of new process variations and components for volume manufacturing prior to delivery.

Editor: Can you give us an example?

Prof. Brenner: Yes, a good example is the hardening of inner surfaces in brake components. There was no solution to this task in the market place. The process development and technology transfer happened in three stages:

1. Process development to harden the inner surfaces of hemispheres without heat affected zones. A laboratory setup was used with the part being rotated.

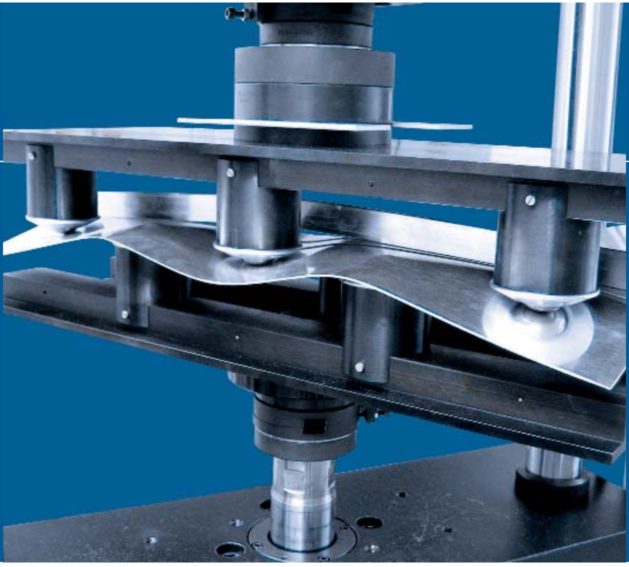
2. Concept, design and testing of a suitable beam shaping unit with sufficiently fast whirling laser beam. So treated components were tested to prove that the process works.

3. Concept, design and testing of an indexing plate type system to semi automatically laser beam harden brake components. The system was tested for its high volume manufacturing capability and subsequently delivered to the customer.

Editor: How were you able to strengthen your systems technology efforts?

Prof. Brenner: Surface refined and also welded components respond to cyclical loading with changing internal stress distributions and, at high cycle counts, suffer (almost) reversible local plastic reactions. Therefore we are very glad to have now the opportunity to expand our capabilities in the area of high and highest loading cycle fatigue testing. This year we were able to develop the testing concepts.

We are in the process of acquiring the corresponding testing machines and hope to present first results in the next annual report.



COMPETENCES

TECHNOLOGIES FOR THE CUSTOMIZED LASER AND INDUCTION HARDENING OF STEELS

Laser hardening offers new approaches to generate wear resistant surfaces when conventional processes fail due to geometric and material limitations or extreme wear conditions. This is in particular true for selective hardening requirements on difficult to reach surfaces such as on multi-dimensionally curved and heat sensitive parts, in bores or notches. Our know-how is based on many years of wear analysis, material behavior and researching the influence of short-term temperature fields on materials. We offer:

- the development of surface hardening technologies with high power diode lasers, CO_2 lasers, Nd:YAG lasers or induction or a combination thereof,
- the surface refinement of prototype parts.

COMPLEX MATERIALS AND PART CHARACTERIZATION

Modern welding and surface engineering requires a thorough knowledge of the structural changes that occur in the processed materials and how these affect the application performance of treated parts. Therefore we are equipped with a comprehensive selection of modern microanalytical and mechanical characterization tools and offer:

- metallographic, electron microscopic (SEM, TEM) and microanalytic (EDX) characterization of the material structure of metals, ceramics and composite materials,
- determination of material properties for part dimensioning and quality control,
- property evaluation of surface treated and welded parts,
- strategy development for material and application customized design,
- failure analysis,
- operational training in the field of metallography.

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2012 PROJECT EXAMPLES

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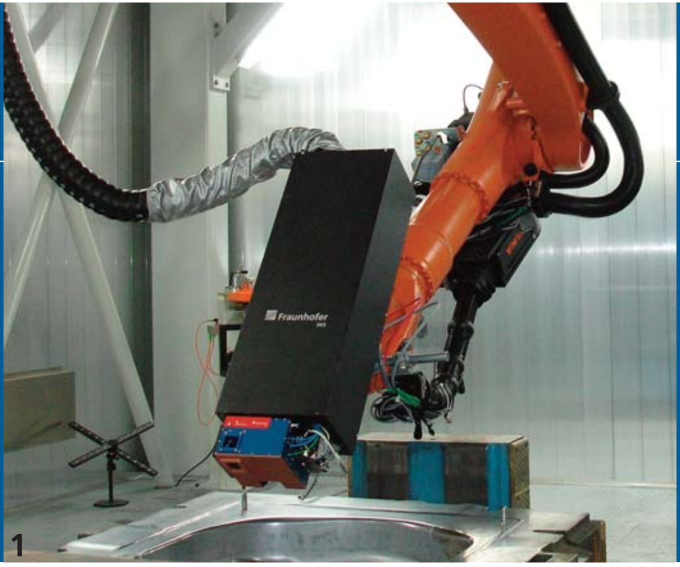

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LASER BEAM HARDENING FOR CAR BODY TOOLMAKERS

THE TASK

Making a car body requires approximately 350 sheet metal parts. Each one of these parts requires toolsets of up to five stages. The use of higher strength sheet metals in car bodies increases tool wear during cutting and forming operations. Cutting tools are made from highly alloyed tool steels. The cutting edges suffer higher loads. Forming is accomplished with grey cast iron tools facing increased contact pressures. Thus tool wear becomes critical.

Simultaneously tools are getting more costly as a consequence of shortened product lifecycles and increasing product varieties. However, tool costs and also manufacturing times need to be reduced. The approach is to increase the wear resistance on those tool surfaces that suffer the highest loads. It is also important to implement this surface treatment at the toolmaker's shop. This reduces costs for transporting the tools to service providers and saves time.

OUR SOLUTION

Laser beam hardening has become a competitive technology to processes such as flame and induction hardening, which were typically used to treat large tools. The laser process has the advantage that it is very precise and reproducible. It is using advanced process monitoring and control components. Laser beam hardening occurs at atmospheric pressures without addition gases or liquids. Its integration with machining operations in tool making is uncomplicated. A 2002 - 2006 BMBF project advanced this technology at a level that today's toolmakers want their own laser hardening plant, whether they belong to an automotive manufacturer or are independent toolmakers. The preferred system concept is to use buckling arm robots on or at a linear axis. This concept is suitable for large workspaces, which is mostly defined by the size of the car side frame tool. A robot-controlled process is ideal for moving tools of non-rotational symmetry on six axes. Such a tool is for example and often-used rectangular laser beam.

Fraunhofer IWS engineers developed the dynamic laser beam shaping unit "LASSY". Vibrational mirrors are used to generate quasi-static beam profiles with variable intensity distributions. Such flexible intensity distributions are required to create uniform hardening depths even if the local thermal energy dissipation conditions vary along the treatment zone. The process also makes use of the camera based temperature measurement system "E-MAqS". This system measures the surface temperature distribution on the part inside the laser beam.

The controller "LompocPro" regulates the laser power so that the surface temperature during process remains constant within a few kelvins. Process data including the temperature distribution information obtained via "E-MAqS" are recorded. These data can be provided to other systems for quality control purposes.

The process speed is relatively low when treating large tools. Here the operator can fine-tune the beam shaping for the tool even while it is being treated. To do this the dynamic beam shaping system is adjusted to match the false color image of the temperature measurements. A proven approach when using a robot is to dock a laser module via an exchange coupling. The module contains the laser optics, the beam shaping unit with integrated temperature measurement and the electronic control components. The laser fiber and all cables and lines are also held. A cover protects the components from dirt. The laser module is mounted to the robot hand with a joint that can be fixed in two positions. The laser beam can then exit at 90° or 45° with respect to the sixth robot axis. This increases the access possibilities to the part. The exchange coupling is used so that one can use selectively other laser modules for example for measurements or buildup welding processes. Toolmakers of large tools are in particular interested in the combination of hardening and buildup welding processes.

RESULTS

In 2010 a hardening and buildup welding plant with laser module and IWS process components was delivered to Audi AG in Ingolstadt. The robot is attached to a ceiling mounted linear axis. The plant is designed and positioned so that standard palettes holding the tools move automatically from machining to laser processing operations.

The laser source is a fiber coupled 6 kW diode laser. This laser creates hardened surface tracks of up to 60 mm width. A second fiber port is used by the buildup welding module. Fraunhofer IWS engineers supported Audi AG during startup and delivered the technology know how.

In 2012 a similar system was delivered to Volkswagen AG in Wolfsburg. This plant can handle tools with a footprint of up to 2.5 x 6 m^2 and a weight of 25 tons. Here too IWS engineering provided all the necessary process components and the operator training. The latter was done directly with the installed machine. The in-house hardening capability saves Volkswagen AG valuable time in making tools.

1 Laser hardening module at the robot, system at Audi AG Ingolstadt

2 Hardening process for large tools at Audi AG Ingolstadt

3 Test hardening of the material 1.2379, 60 mm wide, about 1.5 mm deep

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PRECISE TEMPERATURE CALIBRATION FOR INDUSTRIAL HEAT TREATMENT PROCESSES

THE TASK

The core component in laser hardening systems is the temperature control unit. This unit is critical to establish stable process conditions and is increasingly used as a quality control tool. In particular when treating highly alloyed steels and cast iron it is necessary to maintain the temperature within a range of a few kelvins to achieve the required hardening results in terms of hardness, residual austenite contents and hardening depth.

Cameras and pyrometers are used to measure the temperature during laser hardening. These components are often mechanically, optically and electrically completely integrated in complex manufacturing systems. This requires the final temperature calibration to occur onsite at the customer location with a setup plant. A typical problem is the unknown attenuation of the NIR temperature signal by protective windows, lenses and other optical components. In addition this attenuation can change during use of the equipment as a consequence of contaminations etc. For quality control it is therefore required to have a fast and precise method to check the calibration and to recalibrate if necessary.

OUR SOLUTION

The demands are increasing for the reliability and accuracy of temperature measurements in industrial laser hardening. IWS engineers and other European project partners are working on a suitable calibration process for the high temperature range from 1000 - 1500 °C (EMRP project “HiTeMS”).

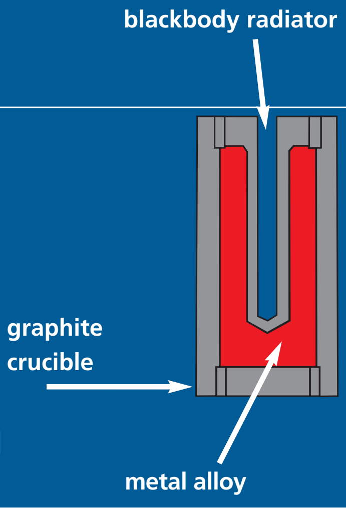
The most accurate calibration techniques currently for contactless temperature measurement devices use so-called fixed point cells (Fig. 1). At high temperatures these cells are typically graphite cylinders, which are filled with metal alloys of known melting temperature. They are designed as blackbody radiators and useful for a wide wavelength range. In furnaces the fixed point cell is heated up close to the melting temperature of the metal alloy. Temperature plateaus form during the melting or solidification phases and provide precise calibration points (Fig. 3).

Principally fixed point cells achieve extremely precise calibrations. The uncertainty is typically some 10 - 100 mK. The mobility, cycle times and flexibility of fixed point cells are enhanced by using inductive heat sources.

A part of the HiTeMS project is dedicated to the optimization of fixed point cells and the associated device design for inductive heating. In addition FEM and FDM simulation work is performed. The optimization included the materials, dimensions, induction coil and holders as well as the housing. The goals were to achieve a most homogeneous temperature field inside the fixed point cell, to evenly melt the metal alloy and to ensure long-term stability of the overall system.

RESULTS

Based on IWS FEM and FDM simulations a mobile and inductively heated fixed point device was designed, built and tested to calibrate pyrometers and heat imaging cameras. Project partner was PTB Berlin. The fixed point cell can be heated up to 1500 °C within a few minutes. Several



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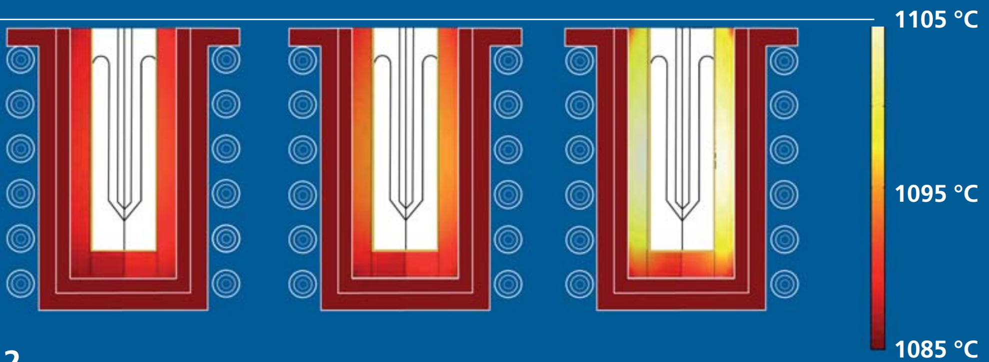

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measurement cycles to establish calibration points can be performed within an hour.

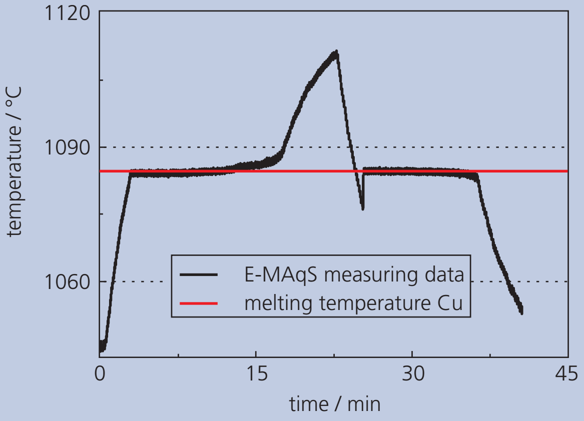
To maintain the thermal stability of the graphite components the heating is performed in an enclosure filled with an inert gas. The housing is water-cooled. Even at maximum temperature the device can be continuously used for a long time. The device has several interfaces to connect the induction coil, the vacuum pump, and the inert gas lines and to measure the temperature.

Recording several calibration points is required to perform the calibration of a temperature measurement system. At these calibration points the signal strength is determined at an exactly known temperature and an emissivity of 0.999x %. From these data points it is quickly possible to accurately perform the complete calibration of the measurement devices.

Measuring the absolute process temperature requires knowing the exact surface emissivity. Current HiTeMS project work is therefore focused on establishing the surface emissivities for various conditions that typically occur on laser hardenable steels and cast iron materials. This database should help the operator to reliably adjust the emissivity. The absolute accuracy of temperature measurements compared to conventional techniques is significantly increased.

The European Union and EURAMET partner countries are funding the EMRP HiTeMS project. (http://projects.npl.co.uk/hitems/)

Melting and solidification plateaus of an inductively heated copper fixed point, recorded with the E-MAqS camera system



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1 *Typical setup of a fixed point cell for the calibration at high temperatures*

2 *FEM simulation of the temperature distribution in a inductively heated fixed point cell as a function of the inductor frequency (125, 250, 1000 kHz)*

CONTACT

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1

SURFACE PROPERTY OPTIMIZATION WITH LASER GAS NITRIDING

THE TASK

High static and cyclic strength, low density, excellent corrosion resistance and a good biocompatibility make titanium alloys very attractive for a variety of applications, for example for aircraft, biomedical devices, biochemical and offshore equipment. Generally these alloys are not very resistant against abrasive, erosive and cavitation induced wear. Laser gas nitriding is a process to improve the wear resistance of titanium alloys. However, the industrial use of laser gas nitriding is limited or even completely hindered since it can induce cracks and considerably reduces the static and fatigue strength of the nitrided alloys.

Consequently the relationship between structure and material properties needs to be explored. The goal is to identify the structural elements which are responsible for the materials degradation. Process windows need to be established that add improved wear resistance while maintaining the required material strength.

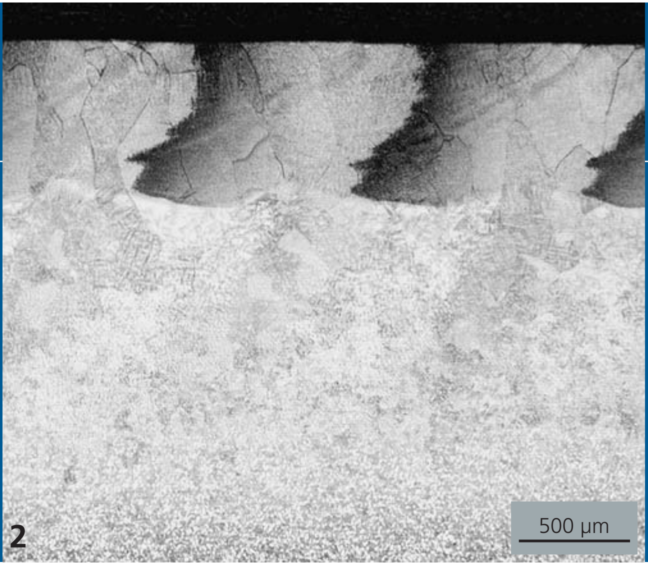
OUR SOLUTION

IWS engineers developed equipment and a technology for the laser gas nitriding of three-dimensional components. The system is flexible, productive and suitable for industrial deployment. It consists of a process chamber, a swiveling yoke and a bell shaped cover through which the gas and laser radiation are delivered to the processing zone (Fig. 1). Adjustable process parameters include the amount of nitrogen, the laser power, the track offset and the speed. Several titanium alloys were treated with varied parameter sets. The laser gas nitriding process forms microstructures, which were analyzed in detail using optical and electron microscopic methods. The mechanical properties and the wear behavior of the treated samples were characterized in detail.

RESULTS

By varying the process parameters it was possible to generate wear resistant surface layers with thicknesses ranging from 0.1 - 1 mm (Fig. 2). The hardness ranged from 400 - 1500 HV. Conventional laser gas nitriding reduces the normally high mechanical load bearing capacity of titanium alloys. The material becomes more sensitive to cracks under static bending and loses fatigue strength with increasing nitrogen content. Microstructural elements responsible for the deterioration of these properties were identified. These include coarse titanium nitride phases ($TiN_{0.3}$, TiN) and thin surface layers (Fig. 3). The thin surface layers are formed during cooling when more nitrogen is absorbed, which leads to subsequent solid phase diffusion. They consist of titanium nitride phases and coarse α-Ti grains ("α-case") and contain small pores and cracks.

The fatigue strength of laser nitrided Ti-6Al-4V can reach or even exceed the very high levels of the as delivered state if the formation of coarse and brittle titanium nitrides is prevented



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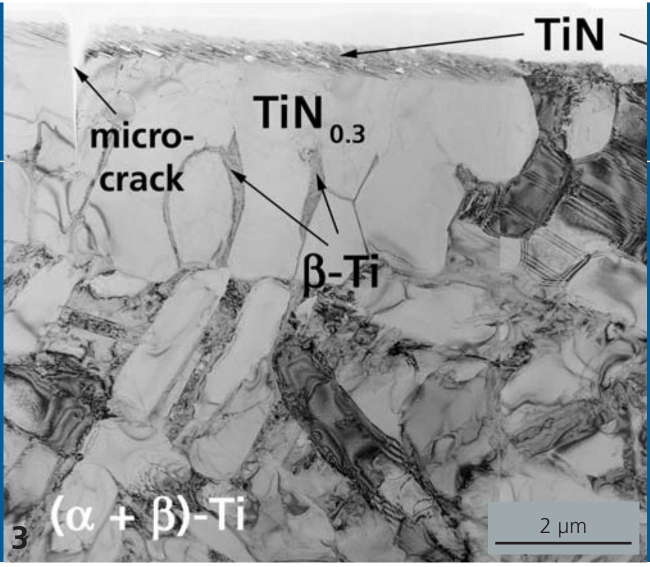

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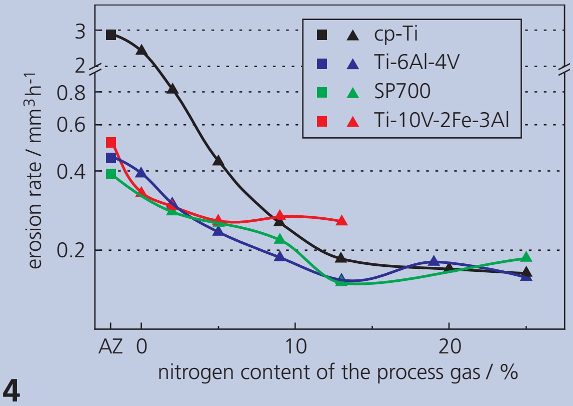
by reducing the nitrogen content of the processing gas and additionally if the thin top layers are removed by grinding or shot peening.

During laser gas nitriding only small quantities of nitrogen are sufficient to increase hardness and erosion resistance of titanium alloys (Fig. 4). The erosion resistance in all titanium alloys is mainly determined by the solid solution hardening due to the nitrogen being dissolved in the hexagonal titanium lattice. The most nitrogen can be interstitially dissolved in cp-Ti. This is also the titanium alloy which exhibits the lowest resistance to induced wear. Therefore the effect is the largest for this titanium alloy.

So far experts agreed that laser gas nitriding of titanium alloy should not be applied to cyclically loaded components. The desired increase in hardness was simultaneously connected with a drastic loss in cyclic strength. However, within the current project we are exploring novel strategies to make it possible to combine high wear resistance with reasonable high static and cyclic strength. This offers new opportunities to use laser gas nitriding in the future for components made of titanium alloys and used under high cyclic loads.

Cavitation erosion resistance of different laser nitride titanium alloys in dependence of the nitrogen content of the processing gas



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1. *Systems technology for laser gas nitriding*
2. *Cross section through Ti-6Al-4V after laser gas nitriding*
3. *TEM cross section in the surface near region with top layers, fine pores and cracks after laser gas nitriding*

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HEAD OF DEPARTMENT PROF. DR. CHRISTOPH LEYENS

"Today's technology is tomorrow's bread – today's science is tomorrow's technology."

Richard von Weizsäcker (*1920)

BUSINESS FIELD THERMAL COATING

Editor: For a long time coating technologies have been an established process to improve the surface properties of parts. Now it seems that the generative or three-dimensional fabrication of parts is of interest to industry. What does the IWS contribute to this field?

Prof. Leyens: The additive generative manufacturing, as we are calling this approach of making parts, is indeed forging ahead. At the IWS we use powders and wire based processes to make coatings and 3D parts with very little additional machining effort. This is especially important for parts that alternatively require a large fraction of material removal. The generating processes deliver the appropriate material to the exact location. The customer profits from time and cost savings.

Editor: Are there additional advantages of these innovative manufacturing processes?

Prof. Leyens: Part repairs are easy and quick to perform by reading a CAD file and subsequent generation. This makes it unnecessary to manufacture a new part. Also, it is possible to replace costly inventory by on-demand manufacturing. This is advantageous for products with long lifecycles or frequent model changes. And finally it is also possible to use additive generative processes to build parts with novel and application specific property profiles, which are based on innovative multi material concepts.

Editor: Are the conventional manufacturing processes such as forming and casting obsolete?

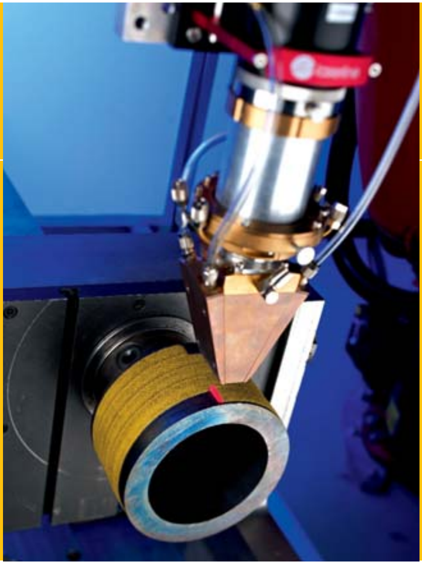
Prof. Leyens: Absolutely not! The IWS develops solutions that complement classical manufacturing processes in a useful way. We just built up printing technology and are now using IWS capabilities to build parts from the micrometer scale up to large volumes. This is done according to customer specifications, with high precision and at impressive cost efficiency.

Editor: Printing of structures is a new competence of this business field. What applications do you see?

Prof. Leyens: The application possibilities are manifold. Currently we are focusing on functional applications such as printed batteries, sensors and thermoelectric generators to convert waste heat into electric energy.

Editor: Aren't there also activities in the field of thermal spraying?

Prof. Leyens: Yes, we are working in a publically funded research project on a functional model of a thermoelectric generator. Thermal spraying produces its core components. Special challenges are the thermoelectrically active elements. Many questions need to be addressed by basic research in materials science with the goal to make sprayable systems with an appropriate thermoelectric efficiency.



COMPETENCES

THERMAL SPRAYING

Thermal spray technologies available at the Fraunhofer IWS include atmospheric plasma spraying (APS), flame spraying and high velocity flame spraying (HVOF and HVAF). All processes use powders or suspensions to thermally coat parts made from steel, lightweight metals and other materials with metals, hard metals and ceramic coatings.

In cooperation with other Fraunhofer Institutes in Dresden our offer includes:

- design of customized coatings,
- development of complete coating solutions from the material to the coated part,
- development and fabrication of system components,
- support during system integration,
- support during technology implementation.

BUILDUP WELDING

For surface coating, repair, and direct generation of parts, laser buildup welding is available for a wide variety of practical applications. Through laser cladding, alloying, and dispersing, a functionally optimized surface modification is applicable, even at large area surfaces. Additionally, laser additive layer manufacturing ALM is ready for the direct production and repair of complex shaped components and tools of metal alloys. Finally, the innovative hybrid techniques of coupled energy sources as laser and induction or hot-wire offers the opportunity of high-performance laser cladding for large and heavily loaded tools and parts.

In particular, our services include:

- computer simulation of laser deposition processes,
- basic process development as well as processing of real components,
- customer-specific system technology, e.g. laser cladding heads, for the practical application and introduction of the laser techniques into series production,
- on-site support and training of the end-user.

PRINTING TECHNOLOGIES

Printing provides the possibility to generate 2D and 3D structures on surfaces with high precision and reproducibility at comparatively low costs. The IWS is establishing competences in this field to address increasing customer demands for large area deposition technologies for structured coatings and generatively fabricated micro components. The processed materials include metals, conductive oxides, barrier coatings, thermoelectric materials and CNTs.

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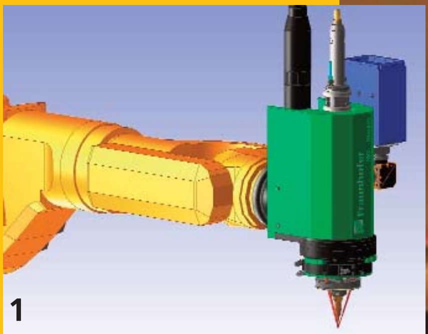
2012 PROJECT EXAMPLES



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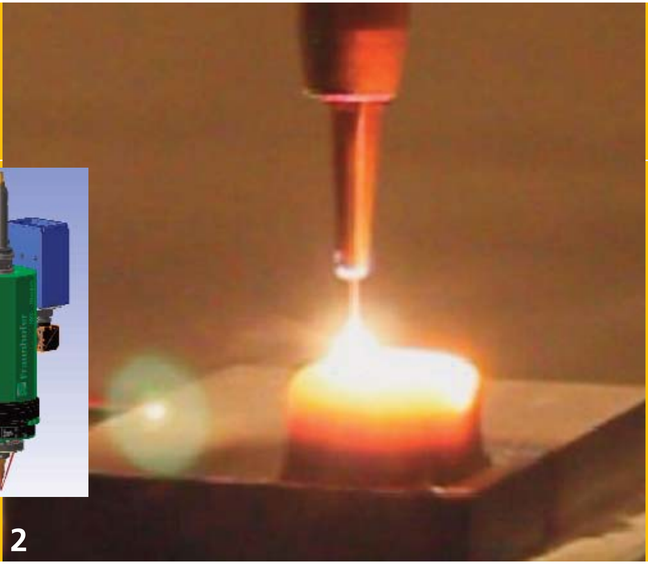


2

GENERATIVE LASER WIRE BUILDUP WELDING

THE TASK

Laser buildup welding is a form giving generative manufacturing technology. Using wires as an alternative to powders has a number of important advantages. For example, independent from the part geometry the material utilization is always 100 %. The material delivery is not affected by gravity. It is a clean welding process, which is much less dangerous for operators and machines. The wires also have smaller specific surfaces, which provide advantageous conditions for processing materials prone to chemical reactions with the surrounding atmosphere. This includes for example titanium and aluminum. It requires complex systems technology to make the wire delivery independent from the welding direction. Therefore the repair of more complex three-dimensional metal structures remains so far the domain of the established handheld laser guns. These are efficient and flexible but suffer from subjective influences due to the manual the operator. Lower buildup rates and part dimensions also limit them.

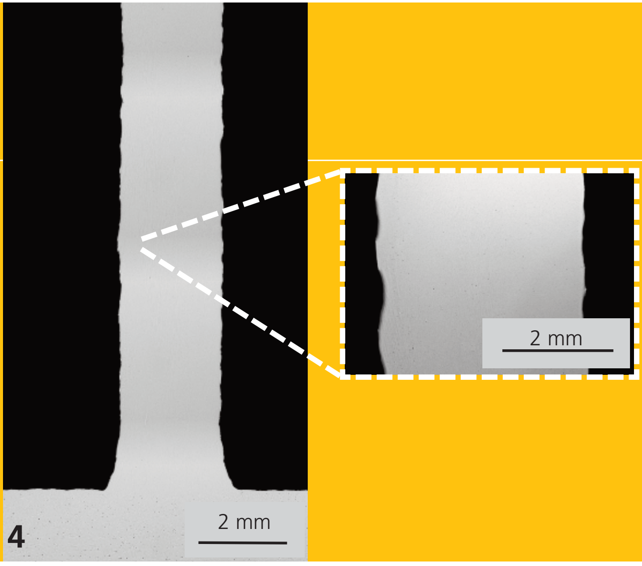
With this in mind we are experiencing an increasing interest by industrial users in wire based generative processes that can be implemented in automated manufacturing lines using close process chains. A primary condition for this to work is a practical and cost effective solution for reliable, machine controlled and directionally independent wire delivery. It also requires welding strategies and process parameters to build defect free structures from branch typical metallic construction materials.

OUR SOLUTION

Based on test results of previous multi beam optics we developed a new optical system for solid-state lasers (slab, disk, fiber) up to powers of 4 kW. The system uses reflecting optical elements (Fig. 1). It is designed to deliver the wire exactly along the center of the laser beam axis and is completely directionally independent. This independence is maintained even if the welding direction deviates significantly from a down hand position. Fig. 2 shows the typical welding processes for generative buildup of a massive structure. Wire diameters range from 0.8 - 1.2 mm and in principle it is also applicable to wires as thin as 300 µm.

To increase the buildup rate it is possible to integrate a hotwire technology into the processing head.

In order to generatively build parts precisely with desired surface qualities the buildup strategy consists of the three components laser generative metal buildup, optical measurement of the manufactured contour and final machining.



RESULTS

The central wire delivery method is used to deposit multilayer buildup welds to generate three-dimensional metallic structures without the requirement for intermediate processing steps. The minimum lateral structure dimensions are 1.8 mm. The as-deposited surface roughness R_z perpendicular to the weld tracks is comparatively low at 100 µm. Using a 3 kW laser yields a deposition rate for Inconel624 of 1.3 kg h^{-1} in coldwire and 1.9 kg h^{-1} in hotwire configurations. The volume specific buildup rate is 150 - 225 cm^3 h^{-1}. The buildup rate can also be normalized with respect to the required energy. Here powder and coldwire based process achieve similar rates of 0.43 kg kW^{-1} h^{-1} (coldwire) and 0.47 kg kW^{-1} h^{-1} (powder). The hotwire process achieves 0.63 kg kW^{-1} h^{-1} and thus substantially exceeds the traditional laser powder buildup welding.

A first example is the structure shown in Fig. 3. This was made from a hard to weld nickel alloy Inconel718. The optimized laser wire process builds crack free structures with a low surface roughness of R_z = 67 µm as measured in a direction across the weld tracks. The texture as shown in Fig. 4 is defect free and has a fine crystalline epitaxial microstructure. In addition to nickel alloys we developed processes for steel (e.g. tool steel 1.2343) and alloys of titanium, aluminum and copper. It is also possible to process filled wires with carbide hard metals or hard cobalt alloys.

1 Compact laser wire buildup welding head

2 Process of a laser wire contour weld

3 Sample geometry made from Inconel718

4 Cross section of the generatively manufactured sample shown in Fig. 3

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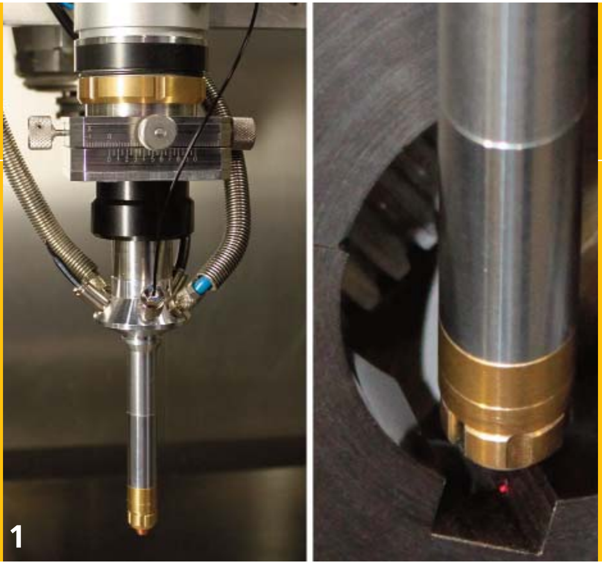


1

SURFACE FUNCTIONALIZATION BY LASER GENERATED METAL STRUCTURES

THE TASK

The laser beam buildup welding process is established as a coating technology with high precision and excellent quality. Such coatings are very convincing since they cause little intermixing with the substrate material yet benefit from and excellent adhesion due to the metallurgical connection. They have almost no porosity, tailored mechanical properties and can be made from a broad selection of mostly metallic materials.

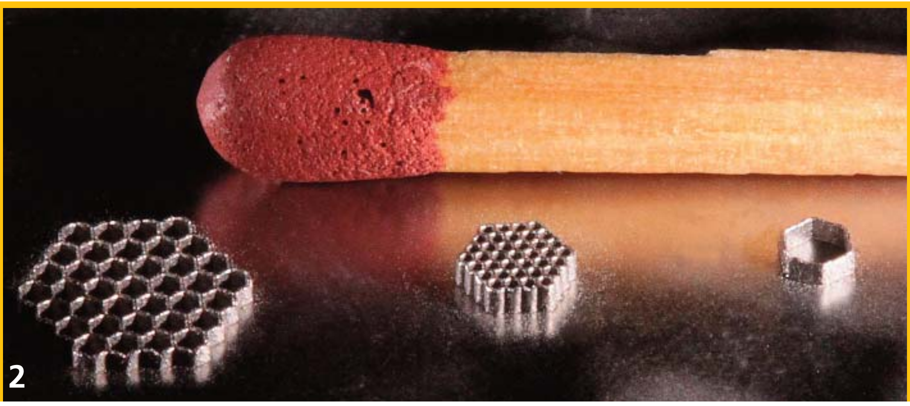
So far the typical applications used weld tracks exceeding 1 mm in width. Increasing industrial requirements for component coatings are now specifying a more detailed track resolution down to the two-digit micrometer range. However, the available systems technology was limited with respect to generating miniaturized parts and functionalizing surfaces in the sub millimeter range at high quality.

The process parameter windows are relatively narrow. The combination of such process windows with the small geometric dimensions made process control difficult and subject to external influences. The use of conventional system to make smallest structures required significant alignment efforts and suffered from inefficient use of resources and inacceptable reproducibility.

OUR SOLUTION

Laser buildup welding system components and powder nozzles had to be further developed to meet the new precision requirements. Specific development goals included to improve the precision of nozzle adjustment capabilities and also to establish possibility to deliver finest powders in small quantities. The achievable precision is also improved using modern fiber or disk lasers with high brilliance. Processing strategies were adapted to make structures in the sub millimeter range to optimize the material buildup. Optimizing all relevant technology components and strategies was required to provide the solution, which does not only achieve the required precision but also the necessary stability and robustness for industrial deployment.

In many cases the surface functionalization with fine structures does not only require precision but is also more difficult due to the limited accessibility of the surfaces to be treated. To address this difficulty Fraunhofer IWS engineers developed very narrow powder delivery nozzle systems (Fig. 1). Such nozzles are about 100 mm long and only 15 mm in diameter. In combination with high brilliance laser beam sources the resulting melt is only few micrometers in size. This enables the deposition of weld tracks with widths as small as 30 µm. By varying the parameters it is possible to use the same setup to make structures in the millimeter range, which opens up new application fields.



RESULTS

The described component and process strategy changes led to the capability of making finest structures such as shown in Fig. 2. The new process has advantages including the capability to deposit material very close to the final shape. There is also only a very minimal intermixing of coating and substrate materials. Applications were already demonstrated in the aerospace, tool making and medical device industries. Such industrial examples required free three-dimensional structure deposition and thus the functionalization of freeform surfaces by metallic material buildup.

It is also possible to fabricate complex micro volumes or geometries using commercially available systems technology (Fig. 3). Even though the process is scaled down to smallest geometries, the structures are pore free. They are very close in dimensions to the final shape with only a few micrometers to be removed. The treated component is only exposed to a minimum energy input and thus does not experience any damage while the typically excellent material adhesion to the substrate is maintained.

Previous Fraunhofer IWS laser buildup welding technologies dealt with deposition rates on the order of 15 kg metal powder per hour. The new high precision systems now cover the other end of the spectrum. The smallest weld track widths of 30 µm compare to the largest of > 20 mm. Thus the covered track width range extends to almost three orders of magnitude. Such a broad possible working range is currently unique to the Fraunhofer IWS Dresden.

Parts of the discussed results were funded by the BMBF (No. 13N10063, MABRILAS).

1 COAX16 – miniaturized nozzle system for best accessibility

2 Functionalization of surfaces by laser generated structures

3 Helical structure, generated by high precision laser buildup welding

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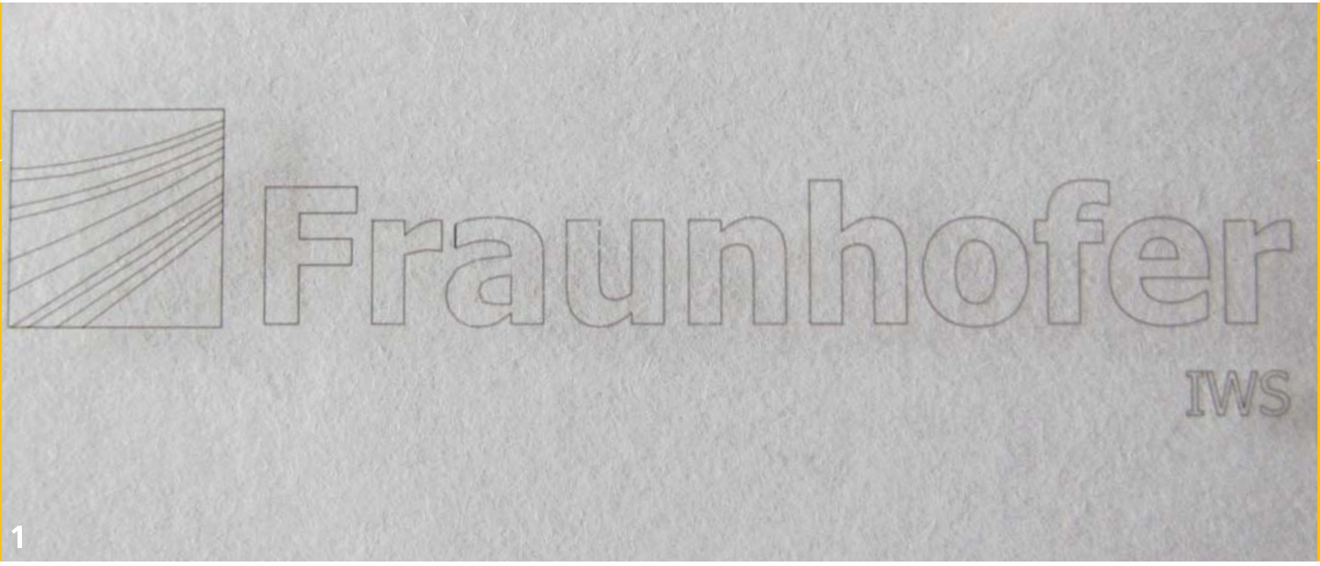

1

FINEST STRUCTURES FOR PRINTED ELECTRONICS

THE TASK

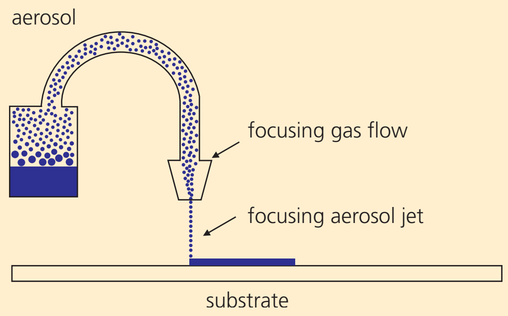
"Printed electronics" refers to electronic components, devices and applications fabricated by printing technologies. In this context "printing inks" are electronically functional materials. Printing electronics reduces costs and also offers to fabricate electronics on flexible substrates. This opens up new application fields for electronics, which are inaccessible for conventional devices. Today's examples of printed electronics include organic solar cells, RFID tags (radio frequency identification) or sensors.

A growing application field is the direct printing of functional structures without the need for masks. Structures such as contacts, conducting lines, electrodes, antennas and sensors can be directly printed onto various substrates. Challenges include the increasing demands for the spatial resolution of the structures and also the required flexibility with respect to ink materials and substrates. The various technology components have to be compatible and optimized such as printing process, printed materials and substrate tolerable sintering processes. This optimization process is the core working area in printed electronics development.

OUR SOLUTION

Fraunhofer IWS engineers are developing functional inks and associated printing and sintering processes for high-resolution structure printing. The basic Aerosol-Jet® technology can print metals, semiconductors, polymers or liquid etchants. Printing also requires substrate surface cleaning steps for which we have plasma and laser based processes that do not harm the substrates. These processes activate and functionalize the substrate surfaces. We print with in-house developed as well as commercial inks and adapt them to the particular application. Printed structures are then cured by heat. Heat sensitive substrates are treated in an RTA furnace (rapid thermal annealing) or with the help of lasers to keep the heat loads low on the substrates.

Schematics of the Aerosol-Jet® technology



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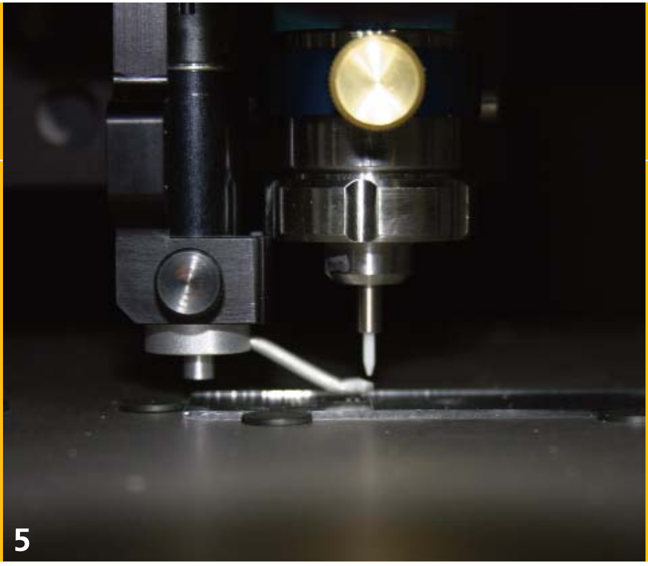
RESULTS

The Aerosol-Jet® process provides noncontact printing of fine structures with minimum line widths of 10 µm. The usable inks are manifold including pure liquids, dispersed systems such as conductive nanoparticle containing inks, carbon nanotube based inks, etchants and polymers. Inks are used extremely sparingly and are very efficiently utilized.

3



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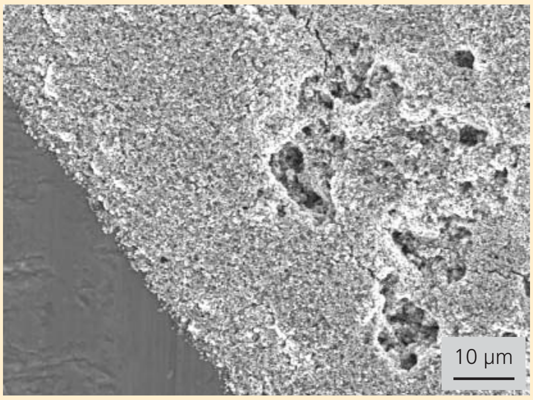
The ink's viscosity ranges from 1 - 1000 mPa s. It is pneumatically sprayed or ultrasonically transformed into a fog so that a dense aerosol forms. An inert carrier gas then transports the aerosol to the coating head. An enveloping curtain gas shapes the aerosol into a jet. The ink is never in direct contact with the nozzle, which avoids clogging. The distance from the coating head to the substrate can be varied from 1 - 5 mm. Due to this variable distance structured surface can be printed on. Selected examples are described in the following paragraphs.

Special inks were developed to use the aerosol pressure process to print electrodes for Li ion batteries. $LiFePO_4$ was printed onto aluminum foils and subsequently sintered. The structure has very good edge sharpness (Fig. 4). The high resolution of the print pattern enables the direct integration of secondary batteries in electronic devices.

Detail of a printed $LiFePO_4$ electrode structure



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Other ink materials were developed to fabricate electrically conducting paths. Various conductive inks were evaluated with different viscosities including those based on silver nanoparticles, doped metal oxides and dispersions from single wall carbon nanotubes. The printed conducting paths are used as RFID antennas or heating elements (Fig. 3).

A KOH based ink and an adapted etching process using aerosol printing were developed to isolate the edges of silicon wafers for photovoltaic applications. A key advantage of the process is the minimized use of etchant. The silicon wafer is preheated to 200 °C when the etchant is printed. This directly initiates the etching process. An etching width of less than 200 µm was achieved.

1	*Printed SWCNT ink*
3	*Printed heater element on glass*
5	*Printer head with shutter*

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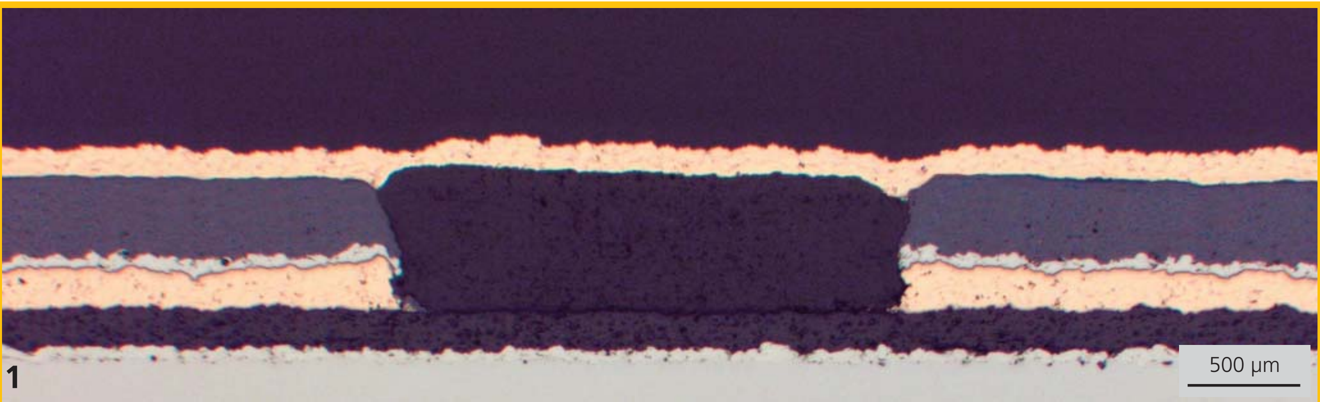

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THERMALLY SPRAYED THERMOELECTRIC GENERATORS

THE TASK

Using natural resources more efficiently often requires new technical solutions such as the utilization of waste heat. A direct conversion of waste heat into electric energy is possible with the help of thermoelectric generators (TEG).

A TEG consists of at least four parts. This includes the semiconducting thermoelectrically active p- and n-components, the electrical conductors to interconnect the semiconductors and electrical insulators. Optional components include filler materials and others. If a temperature gradient exists such a system converts it into an electric voltage.

New material solutions and manufacturing technologies for TEGs are needed to enable a wide range utilization of industrial waste heat. In addition to technology challenges it is particularly important to consider the process specific material behavior.

OUR SOLUTION

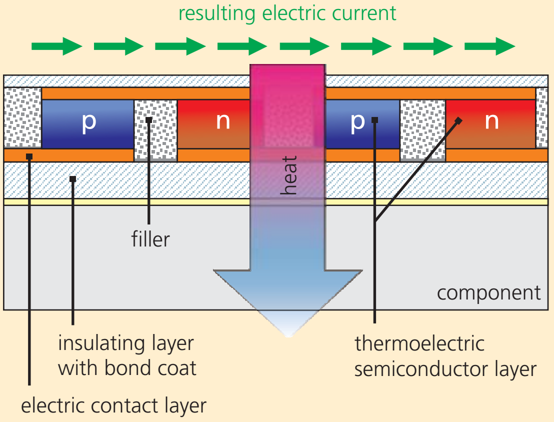
Thermal spraying is a surface technology that can produce functional multilayer systems such as coating based heater elements. The thermal spray fabrication of TEG is a new development step. A thermal spray deposited multilayer system has advantages. The individual components are in direct contact and the target geometry is flexible. No interconnect technology is required. Each individual component is fabricated using an optimized process.

RESULTS

Fig. 1 shows a section of a planar TEG design. It demonstrates the technical feasibility of using spray technology for multilayer device fabrication. First a steel substrate was coated with bond coat and an insulating layer. Then electrical and semiconducting layers and again an electrical were sprayed. An additional insulating layer is required to regulate the heat flow and to insulate the semiconducting elements from each other.

These materials are facing opposing technical requirements such as a low thermal conductivity, high electrical conductivity and a high Seebeck coefficient to achieve a high ZT values, the measure for thermoelectric activity. Currently the best materials for this purpose are Bi_2Te_3, PbTe and SiGe.

The key functionality for such TEGs falls to the thermoelectrically active materials.



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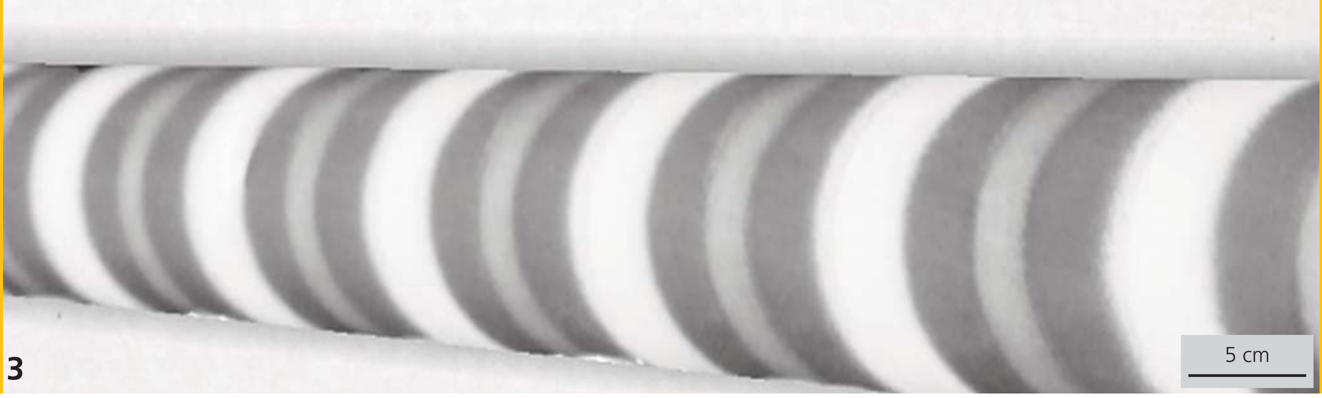
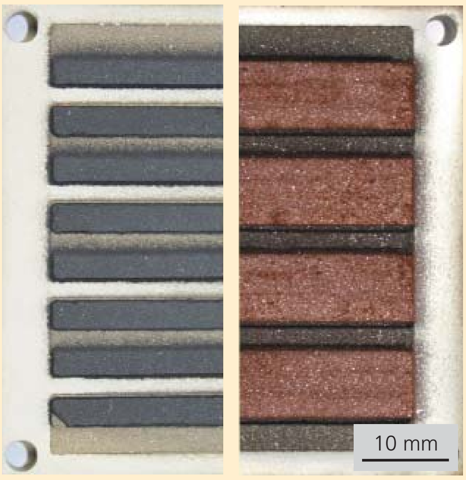


Thermal spraying however has additional requirements. First of all the materials have to be sprayable. The materials also have to be obtainable at reasonable costs and in a form that allows for spraying. There are also health and environmental requirements to meet. The listed materials and many other newer developments do not fulfill these requirements. This substantially limits the available material selection for thermal spraying. The coatings shown in Fig. 1, 3 and 4 are based on oxides, which have low ZT values. On the other hand oxide materials have the advantage of working at high temperatures.

Current IWS research on "Thermal spraying for industrial manufacturing of TEG modules" (No. 03X3554G) is funded by the BMBF (project Thermopower). The goal is to improve TEG layer structures for utilizing waste heat in the ceramics industry.

Thermal sprayed planar TEG design consisting of p- and n-semiconducting materials (left) and electric contact layer (right), (developed in BMBF project)



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The implementation of industrial scale thermoelectric devices requires both the development of the technology as well as of cost effective thermoelectric materials that can be sprayed, which will primarily be oxide materials.

1 *Cross section of a thermal sprayed planar TEG design: the section shows the semiconductor layers and the thermal insulation layer (filler material)*

3 *Tube shaped thermal sprayed TEG*

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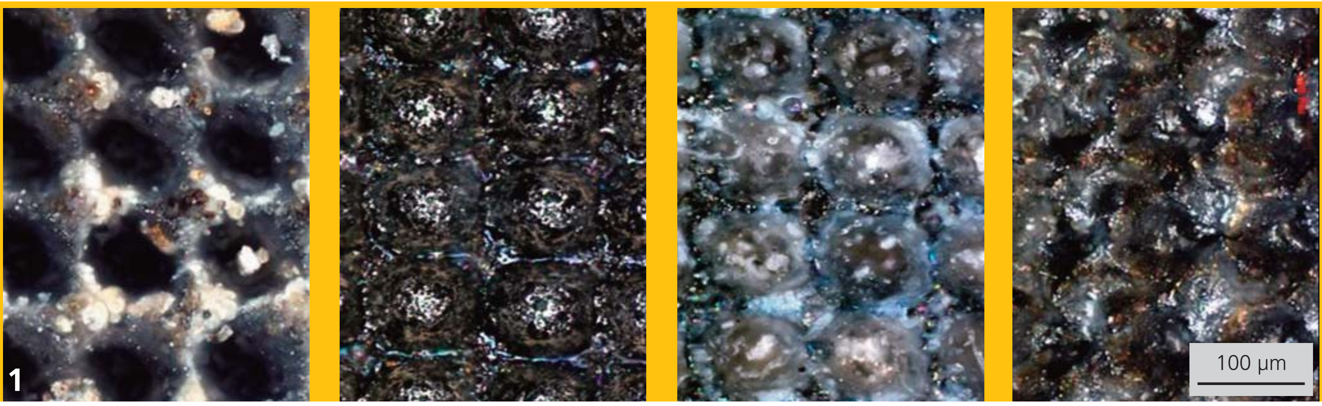
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FUNCTIONALIZATION OF CERAMIC SUBSTRATES THROUGH THERMAL SPRAYING

THE TASK

Thermal spraying is an important and rapidly developing process group within the field of surface technologies. The objective is to provide the functionality of a high performance sprayed material to the surface of a part made from a less costly material. Mostly these are metallic substrates.

The coating of ceramic substrates is rather rare. This represents an underutilized application area. The functionalization of ceramic parts could include electric heating, high temperature oxidation protection of non-oxide ceramics, and electrical insulation of thermally conductive ceramics or even self-cleaning surfaces.

The adhesion of thermal spray coatings to the substrate surface is mostly based on mechanical interlocking. This implies that the substrate surface has to fulfill certain conditions. Contaminations such as dust and grease need to be removed and the surface needs to be somewhat rough. The surface roughness of metallic substrates is typically adjusted by sandblasting. Porous ceramics may not require a roughening step.

Dense and smooth technical ceramics offer limited possibilities for surface roughening. The very high sintering density and the resulting hardness leads to ineffective sandblasting results. Almost no increase in roughness can be achieved in this way. However, sandblasting introduces microscopic and macroscopic surface defects when applied to porous as well as dense ceramics. Subsequently the mechanical strength of the ceramics suffers. New surface treatments are needed to avoid this disadvantage.

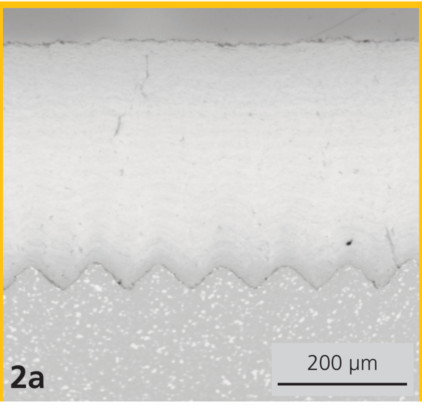
OUR SOLUTION

Structuring by laser ablation was tested as an alternative method for surface preparation. A pulsed solid-state laser was used with a wavelength of 1064 nm. The localized evaporation created defined dimple patterns on the surface of the ceramics. The research was performed as part of a AiF project named “Cerasan – functionalization of ceramic surfaces by thermal spray coatings”
(IGF No. 17371 BR / DVS-No. 02.064).

RESULTS

Depending on the process parameter selection during laser ablation it was possible to create dimple patterns of various forms, sizes and depths. Such dimple patterns are observed by using laser scanning microscopy. Fig. 1 shows different patterns on the surface of densely sintered Si_3N_4 ceramics. Laser power and pulse number per dimple were varied.

As a result of laser structuring thermally sprayed Al_2O_3 coatings achieved significantly improved adhesion levels on Si_3N_4 ceramic substrates. Microscope images of polished cross sections of the substrate-coating structure show the preferable



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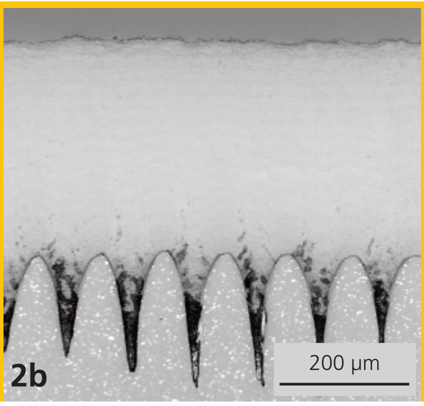
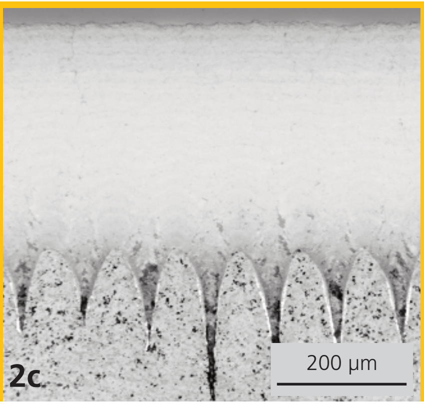


2b



2c

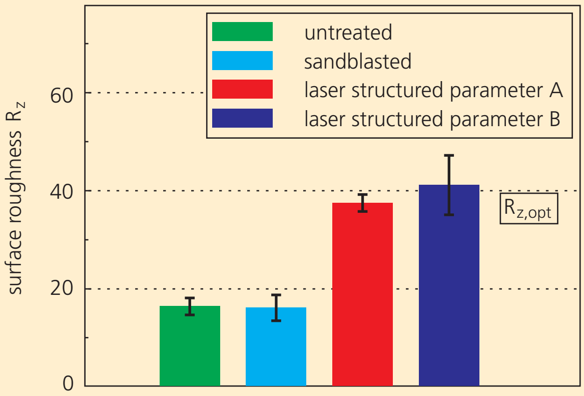
dimple structure for attaching the coating (Fig. 2a). This structure has a surface roughness of R_z = 40 µm.

If the dimple depths increase beyond 100 µm the tight connection to the spray particles suffers (Fig. 2b). The dimples are not completely filled and defects are introduced that create weakness in the compound.

If suspensions are used instead of powders for the thermal spray process the dimples are better filled at the same laser surface structure. The finer powder particles in the suspension improve the connection between Al_2O_3 coating and the substrate. An example of a HVOF sprayed coating is shown in Fig. 2c.

Laser ablation structuring is very suitable to spray thermal coatings onto ceramic parts. This expands the application areas not only for thermal spraying but also for the ceramic parts.

Increasing of the surface roughness of Si_3N_4 ceramics by laser structuring in comparison to sandblasting



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1 *Sintered Si_3N_4 ceramics with laser structure dimple patterns.*

2 *Laser structures Si_3N_4 ceramics with Al_2O_3*
(a,b) HVOF sprayed with powder,
(c) HVOF sprayed with suspension

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HEAD OF DEPARTMENT PROF. DR. BERNDT BRENNER

"We do not even know one millionths of a percent of things"

Thomas Alva Edison (1847-1931),
American Inventor

BUSINESS FIELD JOINING

Editor: In the past you pointed out the importance of developing welding processes for mixed material joints. What progress have you made in this area?

Prof. Brenner: Well, the selection of weldable materials and their combinations need to be expanded. In particular the welding of conventionally not weldable material combinations presents central challenge for future developments. The work aims at addressing the needs of lightweight construction. Efficient joining technologies and manufacturing processes are required. There is a strong industrial demand for line welding processes to join material combinations such as steel/aluminum, aluminum/titanium, steel/copper, aluminum/copper and so on. As soon as the mechanical strength of a spot joint is insufficient mechanical joining processes have disadvantages. This is in particular true for higher and ultrahigh strength steel sheets in combination with aluminum alloys especially if only one side of the material is accessible to the joining process. To solve this problem we developed four different approaches: Adhesive bonding with laser based preparation of the bonding surfaces, laser beam welding of newly developed plug-slot configurations, magnetic pulse welding and the generation of high strength Al-steel transition joints with laser induction roll plating. These transition joints are a semi-finished product, which can then be conventionally welded (laser, electron beam, inert gas welding) to similar materials.

Editor: I have to ask: Are you now actually working on inert gas welding?

Prof. Brenner: No, but in close cooperation with the joining technology group at the TU Dresden we utilized the fact that Dresden's research institutes have developed a wide range of joining technologies. We founded the joining technology center "Tailored Joining" (see pg. 112). We expect synergistic effects and new impulses for future developments from such concentrated competencies in joining technologies. This is in the interest of our customers. The complementary welding technology portfolio provides new stimulation and better conditions for the development of hybrid joining processes.

Editor: At which applications are you aiming with narrow gap laser welding processes?

Prof. Brenner: This process is currently in development. It aims at several applications in which conventional as well as beam welding processes are facing their limitations. Advantages compared to conventional welding are reduced warpage, welding material consumption and most importantly the drastic reduction in welding time. Compared to traditional laser welding processes this new process improves the welding depth. It is expected that the deeper welding depth will lead to a much-increased homogeneity of the weld deposit dilution across the weld seam depth. This would result in improved properties such as the avoidance of hot crack formation in materials prone to such effects.

COMPETENCES

WELDING OF HARD-TO-WELD MATERIALS

Laser beam welding is a modern joining process that has found a wide range of industrial applications, in particular in high volume manufacturing. Further refinements of the technology included process integrated short-term heat treatment, the addition of specially adapted supporting materials and high frequency beam manipulation. Such improvements of the traditional laser beam welding technology made the process capable of producing crack free welds of material combinations from heat treatable high strength steels, cast iron, Al and related special alloys, hot crack prone alloys as well as parts with a high stiffness. Our team has substantial background knowledge in metal physics and system engineering. We offer the development of welding technologies, prototype welding, process and system optimization and the development of welding instructions.

SURFACE TREATMENT AND CONSTRUCTIVE ADHESIVE BONDING

Prior to joining parts with adhesive bonding processes it is frequently useful to treat the surfaces to achieve good adhesive wetting behavior. Fraunhofer IWS engineers primarily use laser and plasma technologies to do so. Treated surfaces and bonded compounds are evaluated using techniques such as contact angle, roughness and thickness measurements, optical microscopy, SEM/EDX and spectroscopic methods. A new goal is the integration of carbon nanotubes into the adhesives to increase the bonding strength and/or to make electrically conductive adhesive bonds. We offer the pretreatment of surfaces and surface characterization services, constructive adhesive bonding of various materials, measuring the adhesive bonding strength and aging studies as well as consulting for all matters related to adhesive bonding.

SPECIAL JOINING TECHNOLOGIES

Standard melt based welding processes are frequently insufficient to join modern functional materials. This is for example, the case for metals such as aluminum alloys. The problem becomes even more critical when joining dissimilar metals such as aluminum and copper. The issues are caused by the formation of intermetallic phases in the melt that have lower strengths and weaken the joint. To address these challenges Fraunhofer IWS engineers are working on welding processes that purposely avoid the melting of the materials. The primary focus is on technologies such as friction stir welding, laser beam soldering, laser induction roll plating and electromagnetic pulse joining. We offer process development, prototype welding and system technology developments.

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2012 PROJECT EXAMPLES

LASER WELDED LIGHTWEIGHT PROFILES OF INTEGRAL MIXED DESIGN

THE TASK

The lightweight construction of car bodies is critical to meet future targets for reduced CO_2 emissions. Crash relevant parts of the body are made from high strength steel. These can absorb large amounts of energy. Alternatively lightweight alloys are used with low specific weights. The currently used mono material designs offer very limited opportunities for further weight reduction while maintaining mechanical strength.

Innovative laser welding technologies enable the implementation of new construction principles. These lead to significant weight reduction without compromising mechanical strength. In addition this construction technology is also very cost efficient. The starting point was the development of a new hybrid construction method for strength engineered crash profiles. This was accomplished by laser suitable integral construction and mixed metal construction. To effectively exploit lightweight construction principles the components and joining geometries are designed using FE crash simulations.

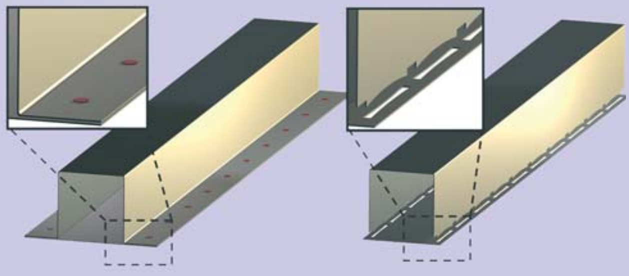
The development work pursued the following goals:

- reduction of the component weight if compared to conventionally welded structures
- maintaining or increasing the crash strength
- optimization of crash component designs using FE crash simulations

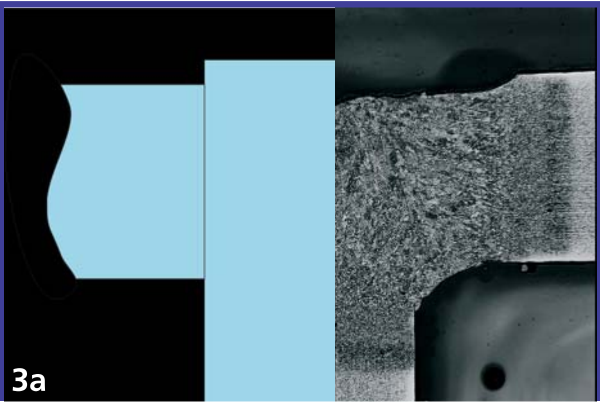
OUR SOLUTION

Conventional differential construction with resistance spot welding requires relatively wide flanges for lap joints. In some cases these account for up to 20 % of the total component mass. Laser beam welding is suitable to perform a novel integral plug-in construction method (Fig. 2). FE simulations help to select appropriate materials for the individual components depending on the part loading. These methods are also applied to select the geometries of the semi-finished parts and of the joint.

Construction principles during joining (left: spot welding, right: plug-slot joint)



Laser remote welding processes perform the welding of the plug-slot joints. The lateral width of the melting zone is adjusted by beam scanning. In coordination with the remaining parameters this process can make a complete connection in mono material design (e.g. steel-steel) and it can also selectively melt the plug material for mixed material joints (steel-aluminum, Fig. 3b).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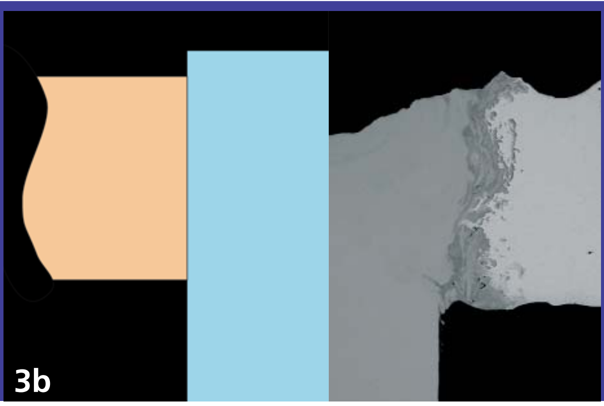
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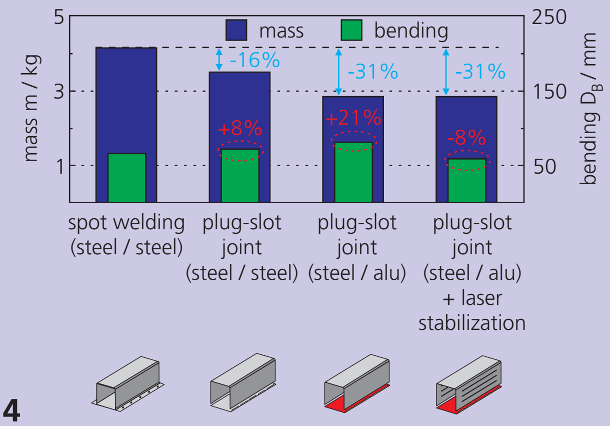
RESULTS

FE crash simulations (PAM CRASH, Shell model) were used to optimize a demonstrator part (Fig. 1 and 2) for minimum weight and maximum strength. The integral plug-in design eliminates the welding flanges leading to a weight reduction of 16 % compared to a spot welded reference part. If the steel cover sheet would be replaced by aluminum the total weight reduction could be 31 %.

Fig. 4 shows the results of the crash simulation of a 3-point bending load for various designs. The plug-slot profiles in steel-steel configuration have comparable structure deformation as the spot-welded reference profile. The steel-aluminum (plug-slot / steel-alu) design has reduced stiffness, which can be compensated by adding local stabilizing structures placed in the plates of the steel U profile (plug-slot/steel-alu + laser stabilization).

Simulation results for component weights and crash deformations in a 3-point bending test



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The addition of the stabilizing structure is accomplished using laser hardening. The material strength in the plastic deformation zone is locally increased (see annual report 2009, pages 38/39).

Laser welded integral mixed designs open manifold opportunities for savings. The elimination of welding flanges does not only reduce weight but also saves space. Due to the implementation of linear joints the specific strength increases compared to spot-welded designs. Accessibility limitation to only one side of the part is sufficient for laser beam welding. Part designs can be very compact and thus cost effective manufactured.

1 Laser welded lightweight profile of integral mixed design

3 Cross section image and principle sketch of plug-slot joints,
a) steel-steel,
b) aluminum-steel

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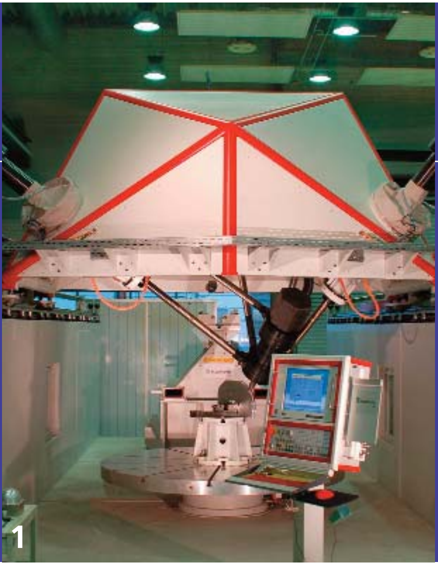
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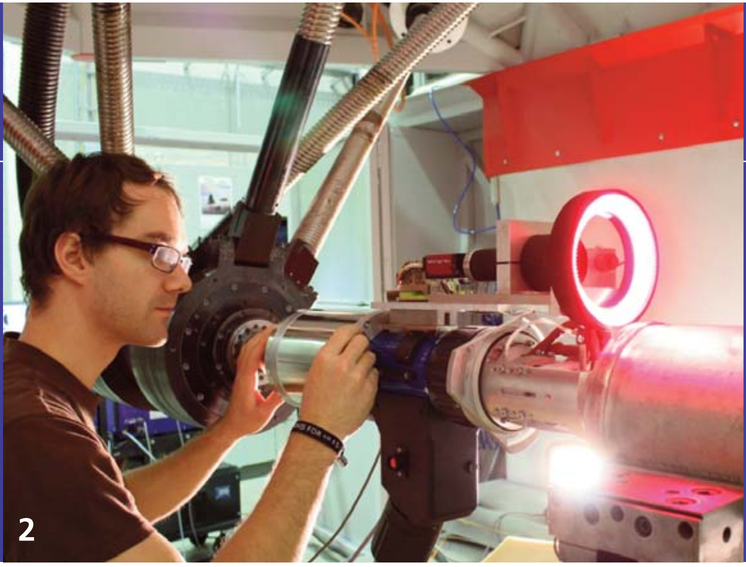
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FLEXIBLE MACHINE CONCEPTS FOR JOINING PROCESSES IN CONTAINER CONSTRUCTION

THE TASK

An important step during the manufacturing of heat exchangers is the joining of tubes to tube sheets. Typical industrial heat exchangers require several thousands of such welds. The selection of an appropriate joining technology therefore has a substantial influence of the overall manufacturing costs. In particular the customer specific manufacturing of small series component is still dominated by many manual steps. Manual processing is often needed because of changing weld geometries, difficult to ascertain positioning tolerances and the selected material combinations. This implies great cost savings potential with automation. High volume series are produced using specialized machines, which have a very limited application range. Therefore a machine concept is required that helps small and medium sized companies to cost effectively automate the orbital welding steps for heat exchanger pipes and is suitable for other tasks such as milling, rolling or welding.

OUR SOLUTION

As the basis system we selected a parallel kinematic Pentapod machine tool. This machine is commercially available in form of CNC and friction stir welding configurations (Fig. 1). Then a customary orbital welding pistol was modified to be integrated into the machine.

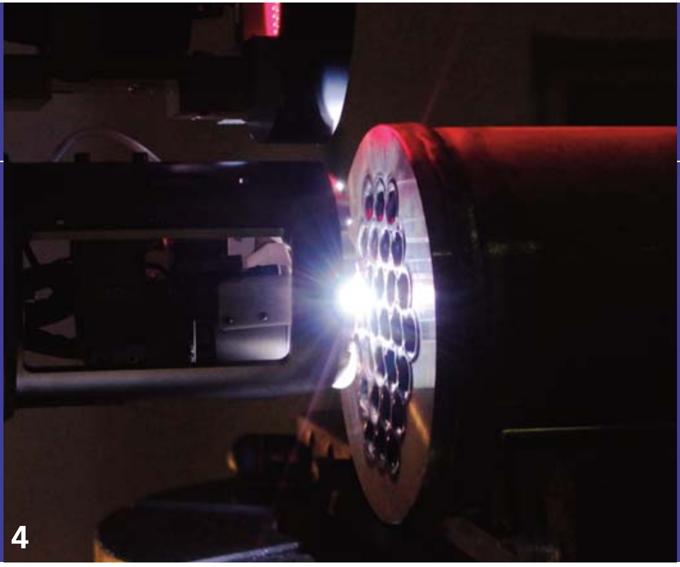
The next step was the integration of an image recognition system. This system is capable of aligning the machine coordinate system with the actual real position of the heat exchanger tube sheet. This avoids the need to position the heavy heat exchanger itself. The alignment of the coordinate systems is relatively easy due to the 3D capability of the Pentapod machine. Welding is performed based on available CAD data. The approximate location of all tube - tube sheet connections is known.

Warpage or position deviations are detected with the image recognition system. The welding process is automatically corrected based on these data. The accuracy is ± 0.03 mm. Each tube is welded under optimum conditions.

A positive side effect of the image based part recognition and alignment is a simplified quality management. Each weld seam is automatically photographed and documented. A suitable algorithm analyzes the photos for optically recognizable imperfections.

RESULTS

The Fraunhofer IWS developed extension of the Pentapod machine concept was experimentally tested on industrial heat exchangers provided by industry customers (Fig. 2 - 4). The system's 3D and image recognition capabilities were successfully demonstrated avoiding the elaborate manual positioning of the components. The results show a significant simplification of the manufacturing process due to automation of positioning and welding steps. It was also shown that the system is capable of documenting the welded joints and that it can optically monitor the weld seams.



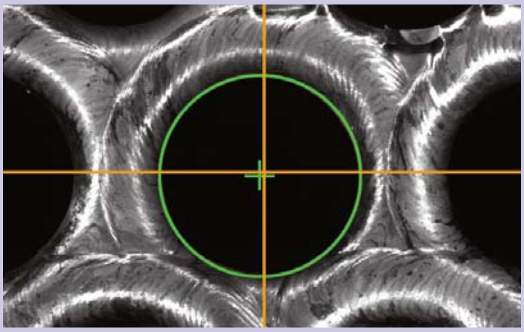
During the development we made sure that the machine program can be generated from CAD data independently of the welding task. Set-up times for such welding tasks were extremely reduced compared to the current state-of-the-art.

An additional advantage of the solution is its flexibility. The same machine can be used to perform pre- and post machining operations. This saves the user the cost of additional machines, set-up times and space. All it requires is a simple tool exchange. The orbital welding head is removed and replaced by a milling tool. This can also be automatically performed. The Pentapod system is easily expanded and is capable of performing force controlled operations. This makes it suitable for friction stir welding or deep rolling operations.

The investment costs are comparatively low. This makes the system especially interesting to small and medium sized companies that want to cover various applications with only one basis machine.

Parts of this work were funded by the European Union and the Free State of Saxony.

Component geometry recognized by software



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1 *Pentapod parallel kinematic with laboratory system*

2 *Novel system for welding tube sheet joints consisting of combined sensor and welding head*

4 *Process image of the welding process on a heat exchanger*

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1

IMPROVED PROCESS STABILITY THROUGH HIGH FREQUENCY BEAM OSCILLATION

THE TASK

Solid-state lasers are easily integrated in an industrial environment, which is a substantial advantage over conventional welding lasers. In particular the introduction of high brilliance solid-state lasers a few years ago has clearly influenced the market. The power increase of available lasers in combination with high quality beams led to the development of completely new processes. The task was to overcome some disadvantages in terms of the process stability associated with the high beam quality. These include strongly varying welding depths (spiking) and increased droplet emission. An improved process stability would open important application areas for welding with high brilliance solid-state lasers as well as increase manufacturing efficiency.

OUR SOLUTION

The welding seems produced with high brilliance solid-state lasers are very deep and narrow due to the high power density. However, the evaporation temperature and the resulting pressure in the vapor capillary are also much higher if compared with CO_2 laser welding. The vapor capillary is extremely steep and narrow. Subsequently the laser radiation arrives at the capillary front at large incident angels. This leads to unstable conditions. High speed imaging at welding speeds of 1 - 4 m min^{-1} show (for aluminum and steel) a strong fluctuation of the capillary opening, resulting in melt flow rate variations and droplet emissions.

The observed motion of the melt bath itself is another reason for increased droplet emission. Irregularly escaping metal vapor is highly dynamically scattered along the laser axis. Strong interactions between laser beam and metal vapor cause spatially and timely inhomogeneous coupling conditions, which explains the strongly fluctuating welding depths.

The process stability was significantly improved by introducing high frequency beam oscillation during welding with high brilliance solid-state lasers (Fig. 3). This Fraunhofer IWS technology utilizes fast oscillating mirrors to project the beam onto the part.

Comparison of the process stability and tendency for droplet emission for steel and aluminum during welding with high brilliance solid-state lasers, left: without (left) and with high frequency beam oscillation (right),
(V_s = 1 m/min, P_L = 1800 W, circle = 200 µm, f = 4 kHz)

3

2

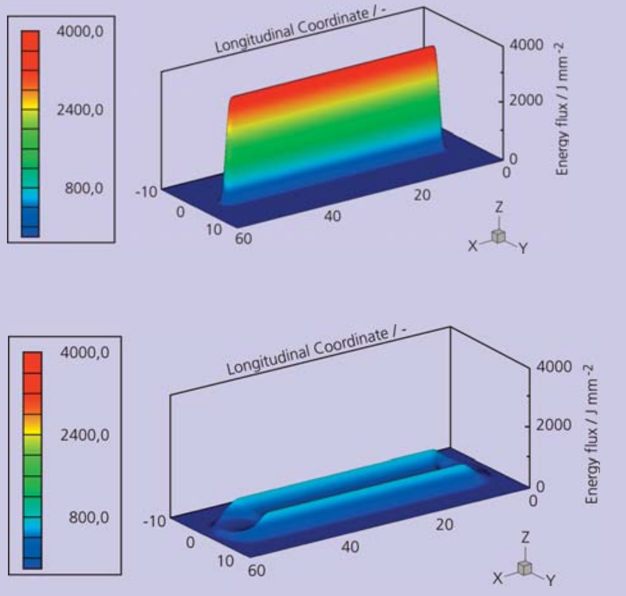
RESULTS

A 2D scanner was developed in the BMBF funded project WELDIMA. The optical device achieves a dynamic working area of 1 mm^2 with a maximum oscillation frequency of 4 kHz. The scanner is controlled via special software that includes automatic amplitude correction. Correcting the amplitude is especially necessary when working at high frequencies. Scanners typically suffer from a frequency depending amplitude attenuation as a consequence of inertia. Without the correction algorithm the actual amplitude of the oscillation would change with increasing frequency and thus deviate from the set values.

High frequency beam oscillations in the shape of Lissajous figures proved to be very suitable to improve the process stability during welding with high brilliance solid-state lasers. The oscillation amplitudes are 200 - 400 µm and the frequencies range from 3 - 4 kHz. These parameters yielded welding velocities of 1 - 4 m min^{-1} and droplet emission could be nearly completely suppressed. In addition the visual quality and porosity of the weld seams improved substantially.

The process stabilization due to high frequency beam oscillation can be explained based on two effects. First, the deposited energy density reduces due to the shortened interaction time between laser and surface material. This reduces the evaporation temperature (Fig. 4). The second effect relates to the widening of the vapor capillary. Thus the capillary vapor pressure reduces which calms down the melt bath dynamics.

Calculated energy deposition during welding with high brilliance solid-state lasers (top) without and (bottom) with high frequency beam oscillation
(V_s = 1 m/min, P_L = 1800 W, circle = 200 µm, f = 4 kHz)



4

1/2 Optical appearance of aluminum welds without (1) and with (2) beam oscillation

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QUALITY WELDING OF THICK HARDENABLE ALUMINUM SHEETS

THE TASK

Precipitation-hardenable high strength aluminum alloys are very important materials for lightweight construction. It is required to weld sheets up to 8 mm thick, which can be accomplished using lasers. However, beam based welding techniques face limitations for larger weld depths. Difficulties include

- missing technical solutions
- insufficient process safety due to crack formation
- high investment costs.

Welding metallurgy and process safety require the use of filler materials to avoid hot crack formation and to reduce the strength differences between component material and weld metal. So far this has been possible for sheet thickness of up to 5 mm. Laser and electron beam sources to weld thick sheets are also very expensive. These disadvantages were overcome with a new multilayer narrow gap welding process. Thus Fraunhofer IWS offers a new solution to weld thick sheets.

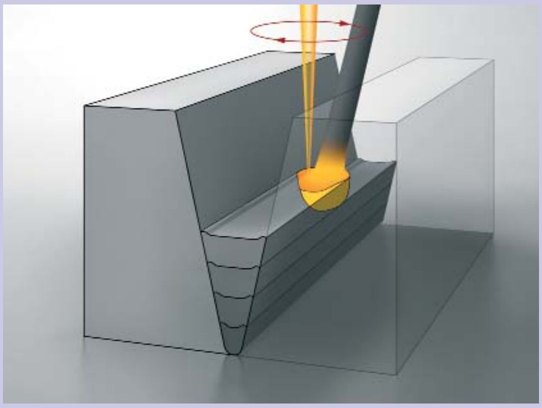
OUR SOLUTION

The process utilizes a single-mode fiber laser of high brilliance (BPP: 0.4 mm mrad) and comparatively low power ($P_L \leq 5$ kW). The beam can be very well focused and completely reaches the bottom of the high aspect ratio narrow gap joint. High frequency beam oscillation is applied across the joint to homogenously disperse the alloying elements (Fig. 1).

RESULTS

Very narrow (3 mm) weld seams with very high aspect ratios (depths up to 30 mm) were created with a multilayer process that relies on the extremely well focusing laser characteristics (Fig. 2). The process is very stable. Reproducibility was demonstrated even for a large number of layers. The risk of hot crack and defect formations is low.

Process principle of laser welding with beam oscillation



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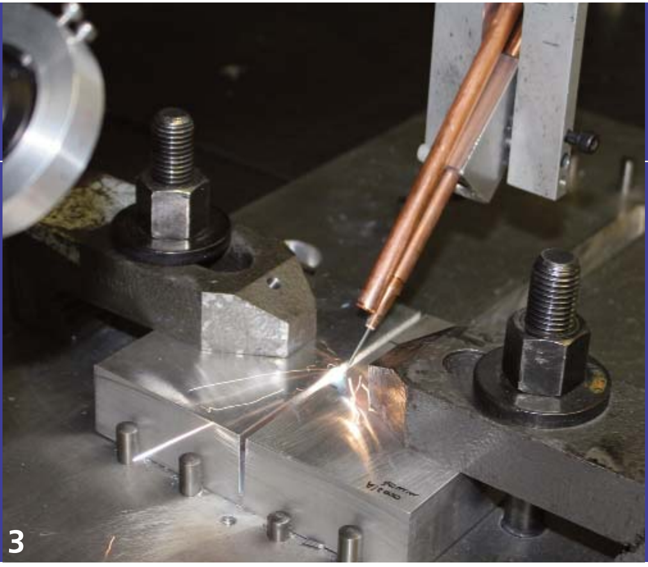
An advantage is the moderate energy input due to the low laser power (smaller than 5 kW) if compared to conventional thick sheet laser welding (Fig. 3). Aluminum has a high thermal conductivity, large heat capacity and a large coefficient of thermal expansions. These physical properties are limiting the possible process window compared to other materials. However, the oscillation laser beam controls the sizes of the melt bath, which reduce the relevance of the physical properties in the multilayer process compared to classic deep welds.



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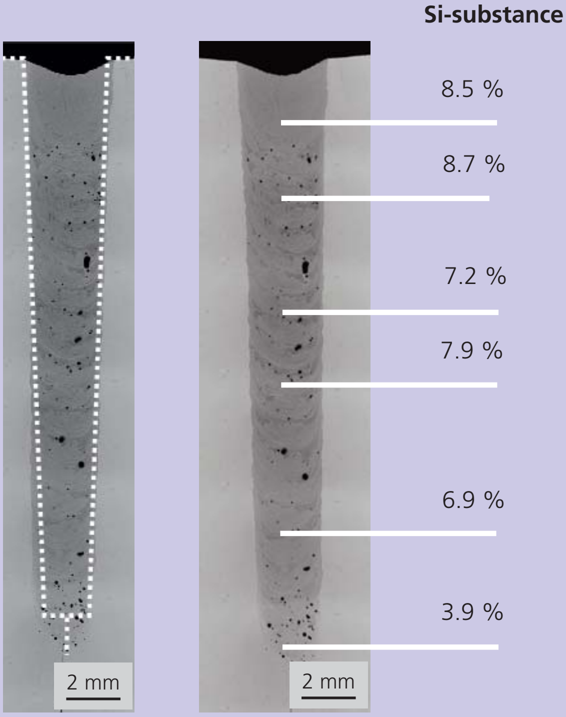
The filler material is added to the gap and leads to a chemical composition, which prevents hot crack formation along the entire depth of the weld. The silicon distribution is very homogeneous from the weld surface down to the weld root (Fig. 2).

On average the silicon concentration is about 7 % above the depth of the seam. It is several times higher in comparison to conventional butt joints. The melt is a very thin liquid with improve outgassing. This reduces the porosity, which is normally typical for aluminum. Large pores as seen in deep welds done by high power lasers are completely avoided. The joint has a very high weld seam quality at minimum warpage.

The research work is funded through AiF (project "Laser Message" No 17404 BR). Future efforts will aim at further reducing pore size, increased welding depths and adapting the process to more materials. The current project results overcome the principle limitations for the thick sheet laser welding of precipitation-hardenable aluminum.

Multilayer weld seam for the example of an aluminum alloy (left: white dots show the seam preparation), distribution of the silicon concentration in the weld seam (right)



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3 *Multilayer welding process of a 30 mm thick aluminum plate*

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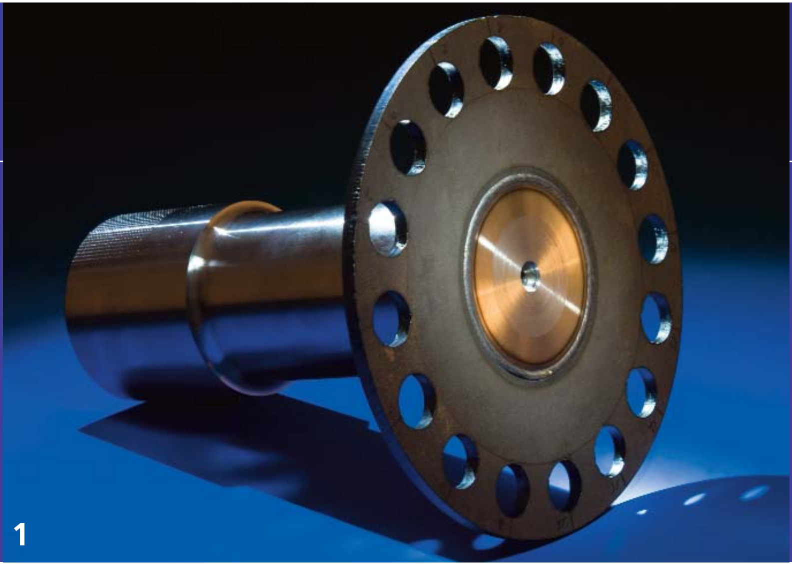


IMPROVEMENT OF THE FATIGUE STRENGTH OF LASER BEAM WELDED PARTS UNDER MULTI-AXIAL LOADING

THE TASK

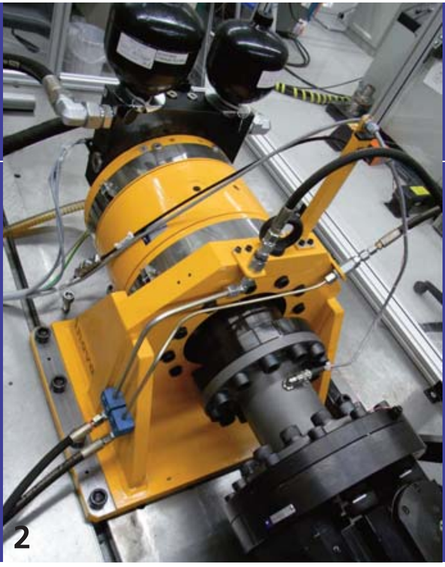
Current strategies to combine lightweight design with modern joining technologies call for detailed knowledge of the mechanical strength of the structural parts to be joined. A typical example is a shaft-hub joint, where the driving force is transmitted through laser beam welded radial or axial circular weld seams. Challenges regarding design as well as process development are manifold. Thus, welding processes must produce reliable and reproducible joints meeting toughness and strength requirements. Appropriate material selection and process optimization by reducing seam lengths and depths are the main parameters to guarantee a resource efficient design. Current design recommendations do not offer solutions to account for cyclic strength under torsional loading for welded structures. Hence, the evaluation is restricted to experimental fatigue results. An experimental evaluation of the cyclic strength of welded prototypes or even whole units of a transmission joint under operation-relevant loading conditions is very time and cost consuming. Hence, strategies have to be developed to evaluate the fatigue strength of the critically loaded welded joints under laboratory conditions. In this respect a simulation of the realistic loading conditions is essential to optimize the welding technology at a very early stage of product design.

OUR SOLUTION

In order to bridge the gap between cost and time consuming prototype testing and laboratory tests of basic homogeneous material samples, a test system was developed and implemented at the Fraunhofer IWS that is capable of combining axial and torsional loading with maximum torque of ± 8 kNm and axial forces up to ± 40 kN at frequencies up to 50 Hz. Superimposing these loads allows for simulating realistic loading conditions as they occur in powertrains. Current research aims to develop a sound basis for the evaluation of the fatigue strength and reliability of welded structures under torsional as well as multi-axial loading conditions. Since an adaptation of laboratory test systems to simulate the exact loading conditions of real parts such as a shaft with a gear is limited, distinctive sample geometries have to be developed to minimize this area of conflict (Fig. 1).

Application oriented test parts are designed to mimic the weld seam geometry, stiffness and heat dissipation conditions of the real structural part at its best. The specimens are then mounted in the testing machine and axial and/or torsional loads are applied in such a way that the multi-axial stress/strain state in the critically loaded weld seam corresponds to that in the real application. Finite element analysis allows to adjust the testing conditions with the true loading conditions in the prototype. Test parameters such as forces, torques, in- or out-of-phase loading and stress ratio are combined in such a way that the load maxima in the specimens correspond to those in the real components.

The test system at IWS (Fig. 2) allows single stage as well as step-load testing with superimposed tensile or compressive mean loads. Hence, in order to reduce time and efforts to evaluate the fatigue strength for a wide range of process parameters of laser beam welded joints, a test design corresponding to the staircase method or the boundary technique can be realized.



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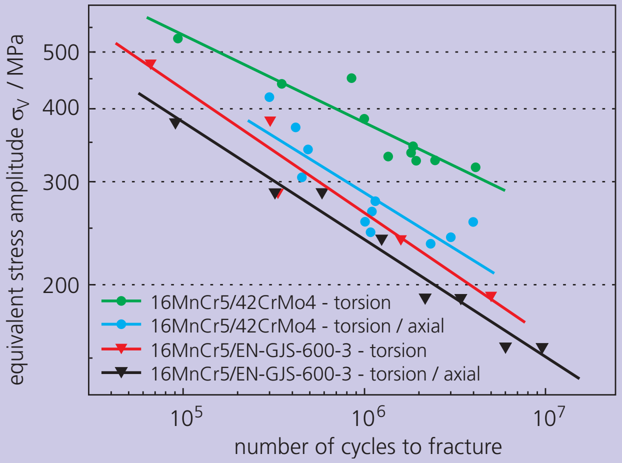
RESULTS

A series of fatigue tests was performed for specimens representing a typical shaft-flange welded joint as shown in Fig. 1. A torque was superimposed by an additional (in-phase) axial force resulting in a combined torsional and bending load in the weld seam allowing an evaluation of the fatigue strength of the shafts base material as well as the welded joint. Two material combinations were tested: heat treatable steel/case hardened steel and cast iron with spherical graphite/case hardened steel. The material combinations were laser beam welded with similar geometries and filler material for the circular weld seams. Fig. 3 depicts the S-N curves obtained in the experiments. The dissimilar welded joint with its poor weldability due to the combination of the cast iron GJS-600-3 with the case hardened steel 16MnCr5 shows remarkably high fatigue strength in the high cycle fatigue regime under pure torsional loads. With 42CrMo4 as shaft material only a minor increase of the fatigue behavior can be achieved. A systematic optimization of the laser beam welding process resulted in similar results comparing the fatigue strength under multi-axial loading conditions - with fatigue strength of the cast iron/case hardened steel combination still meeting the strength specification required. The results presented demonstrate the successful IWS strategy to closely dovetail process optimization with test routines related to realistic loading conditions.

Correlation between equivalent stress amplitude and number of cycles to fracture (S-N-curve for the HCF regime) under torsional and superimposed torsional and axial loading for specimens with circular laser beam weld seams of dissimilar joints (16MnCr5/42CrMo4 and 16MnCr5/EN-GJS-600-3)



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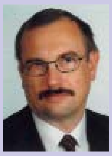
1 Test part with axial round seam

2 Torsional/axial load tester

CONTACT



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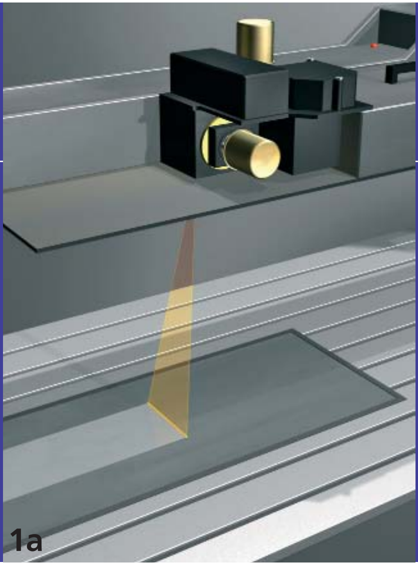

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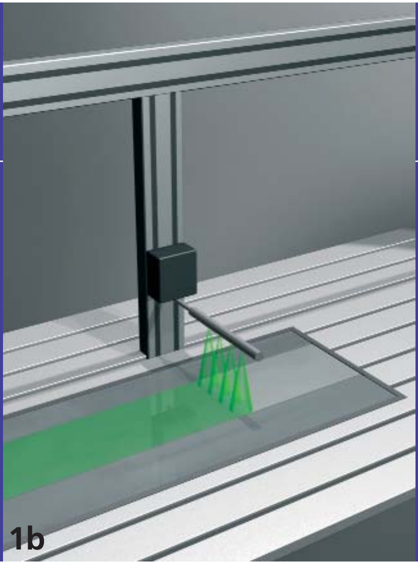

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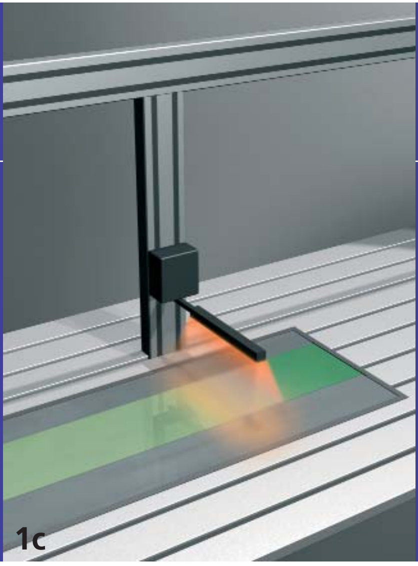

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ORGANOPHILIC STRUCTURED METAL SURFACES FOR REPRODUCIBLE AND LONG-LASTING ADHESIVE BONDING

THE TASK

Many manufacturing industry branches strive for lightweight designs, energy efficiency and environmentally friendly processes. Examples include the automotive and aerospace industries which require the increased used of aluminum and titanium alloys to achieve their lightweight construction concepts. Adhesive bonding technology needs to achieve high initial bonding strengths but also enduring stability; especially when using cold curing adhesives. Reproducible bonding processes require surface preparation.

Conventional preparation processes for lightweight alloys are wet chemical techniques. More recently plasma and also laser processes are gaining momentum for this purpose in industry. Laser treatments are localized, work on nearly all materials and are scalable. Desired roughnesses and topographies are easily manufactured. The process is also dry and operates at high speeds in automated processing environments. As opposed to other techniques, no additional pre- and post cleaning steps are necessary.

Sometimes shipping, storage and other manufacturing processes introduce a delay between pretreatment and adhesive bonding. During this time the freshly cleaned metal surface interacts with environment and may get contaminated again. Thus the pretreatment effect is partially lost, and action is required.

OUR SOLUTION

A polymer film is deposited to preserve the quality of laser treated surfaces. Since the surface is laser treated the polymer film adheres very well. It interlocks mechanically with the surface but also chemically interacts with the metal oxide via functional groups.

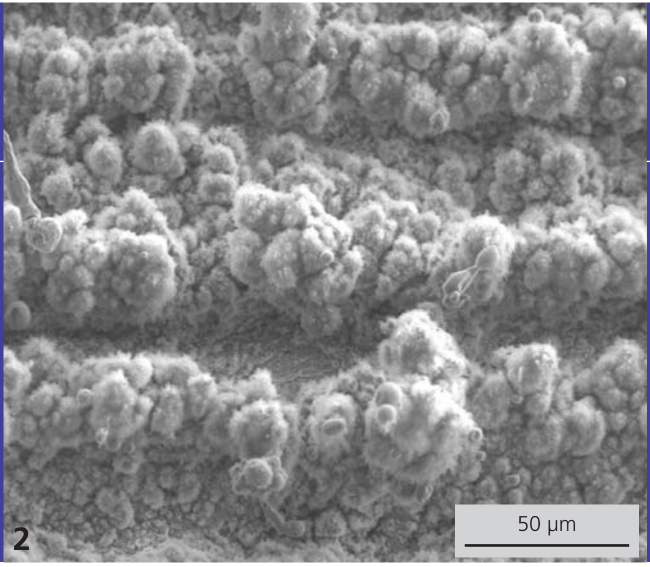
The reactive metal surfaces are dip-coated in or sprayed with water-soluble polyelectrolyte solutions. These consist of polyamines, -imines or carbonic acids. They dry quickly and protect the metal surface from atmospheric impact. The functional groups of the polymer later benefit the adhesive bonding process.

The complete process can be applied in series manufacturing as well as for manifold individual pieces.

RESULTS

The experiments were performed with various aluminum alloys. AW 5457 (AlMg3), a typical wrought alloy was used. Adhesives were energy saving 2K epoxy systems as well as hot curing 1K epoxies and epoxy bonding foils.

An Yb doped fiber laser was used in combination with a 2D scanner system and F-Theta optics to generate defined roughnesses on the aluminum surfaces (Fig. 2). The structuring increases the effective surface area and forms a fresh, thicker and structured oxide layer, which is ideal for adhesive bonding.



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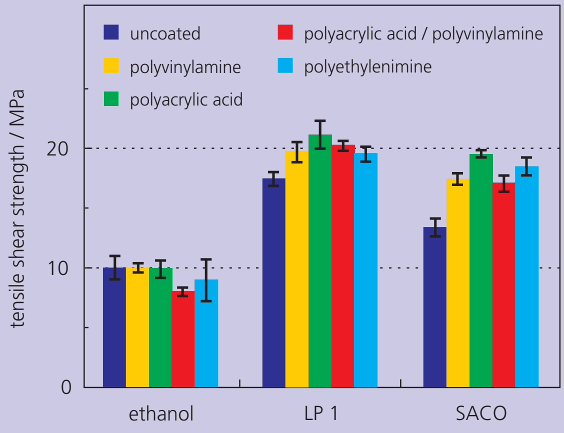
The coating is applied immediately after laser processing. Subsequent adhesive bonding increased the mechanical strength of the compound by up to 20 %, when compared to only laser processed samples (Fig. 3).

Tensile strength versus pretreatment conditions



LP 1: laser parameter - high energy density

3

The coating effect becomes especially obvious when the samples were exposed to a 1000 h aging test. The coated samples show less strength reduction and a larger cohesive fraction when cross sections were examined. The increased cohesive fraction is caused by mechanical interlocking of the coating with the macroscopically roughened surface as well as the microscopic oxide structures in the metal surface. The chemical interaction of the coating with the functional groups of the adhesives plays a role as well. To simulate a storage process coated samples were aged for half a year under typical conditions. Then the samples were bonded. The coated samples showed an increase of mechanical strength compared to coated samples that were not aged.

We also studied potential reactions between amine groups with the carbon dioxide in air. Coated samples were exposed to CO_2 for a longer period. No loss of mechanical strength was observed.

The two-stage pretreatment process is environmentally friendly, energy efficient and has no health risks associated with it. Lightweight metals and other materials can therefore be prepared for adhesive bonding without the risk of losing surface quality due to time delays.

AiF funded this project (No. 16532 BR), which was performed jointly with Dr. Simon from the IPF Dresden.

1 Process schematics of the developed method (laser surface pretreatment, polyelectrolyte deposition and drying)

2 SEM image of a fiber laser structured AlMg3 surface

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HEAD OF DEPARTMENT DR. ANDREAS WETZIG

"Every success has its secrets, every failure its reasons"
Joachim Kaiser (*1928), German critic

BUSINESS FIELD ABLATION AND CUTTING

Editor: Laser ablation and cutting is a wide-ranging business field within laser materials processing. It stretches from classic laser cutting to micromachining with ultra short pulse lasers. Do you see trends for new development, which affects the entire business field or even laser materials processing as a whole?

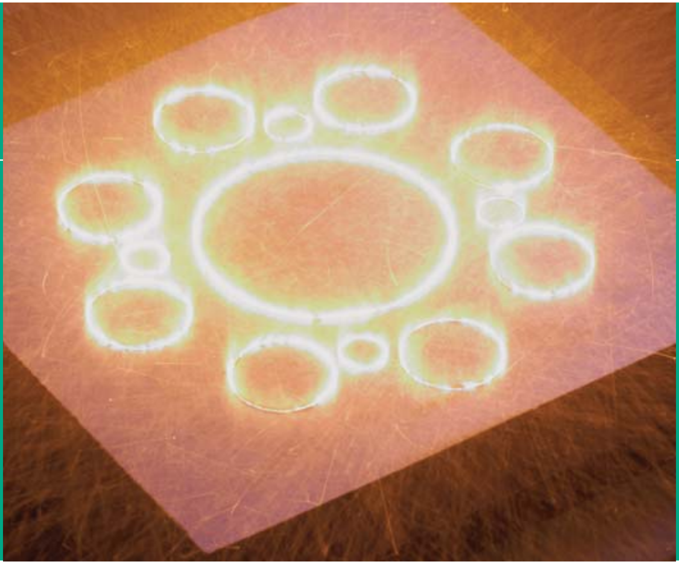
Dr. Wetzig: I think there is a substantial research need to address quality control issues overarching entire process chains. The current state-of-the-art is that quality control is typically performed after laser materials processing and subsequently at the end of the entire process chain. In a worst-case scenario a quality control part has to be destructively tested. We need novel approaches to establish comprehensive in-situ quality control while the part is being processed. Outputs should be monitored such as cutting width, dimensional accuracy, edge roughness, feathering, welding depth or even material texture. Observing these quantities would enable real process control that goes far beyond what is done today. We collaborated with our colleagues who work on joining technologies to develop industrial grade controls for laser welding processes. Currently we transfer the experiences to laser cutting processes. The goal is to detect process cutoffs and gross cutting errors, however we are planning much more. The keyword here is "self learning laser processing system".

Editor: Are there any other trends that you will pursue in your business field?

Dr. Wetzig: Another trend is the need to further develop beam shaping tools to catch up with application requirements and also to make use of the possibilities offered by modern laser beam sources. Currently we very successfully use beam shaping systems that are based on galvanometer scanners. Jointly with two other Fraunhofer institutes we were awarded an internal grant to pursue an entirely different approach. The core concept is based on micromirror arrays to modulate light and on vacuum encapsulated MEMS scanners for laser material processing applications. By the end of the program we will have beam shaping modules not only for micromachining and laser cutting but also for laser welding and surface refinement.

Editor: As we all know recent years saw a very dynamic development of high brilliance solid-state lasers. Will this development continue or do you see new laser types on the horizon, that could be relevant to materials processing?

Dr. Wetzig: I expect that the further development of classic high brilliance cw solid-state lasers will eventually face technical limits. We realize however that there are increasingly more vendors of such lasers. This will be in any case advantageous to the end user in particular with respect to costs, reliability and performance. Ultra short pulse laser development is certainly still strong. We expect to see within a few years ultra short pulse lasers with average powers in the kW range. Our knowhow and expertise will be in high demand to develop process and systems technology solutions. I surmise that it will remain interesting!



COMPETENCES

HIGH SPEED LASER PROCESSING

Research addresses process and system technologies for high speed applications. A detailed process understanding is the basis for the successful industrial implementation of the technology. Our solutions offer the highest processing speeds. The spectrum includes remote welding, cutting and surface treatment processes for metals and non-metals. It also covers the development, setup and qualification of highly dynamic processing systems. A wide range of scanner system technology is available, which is partially in-house developed and can be customized to meet the needs of our clients.

CUTTING

Research focuses on process development in the field of laser melt cutting. Topics include, for example, the improvement of the cutting quality with solid-state lasers or the optimization of electro metal sheet laser cutting without affecting the magnetic properties of the material. Another area is the qualification of novel cutting processes such as the remote laser cutting for manufacturing integration. Lasers of various wavelengths, powers and beam qualities are available. The processing results are characterized including roughness measurements at the cutting edge and detailed texture analysis in the vicinity of the cut using SEM and TEM.

MICROPROCESSING

An extensive and modern equipment pool and the associated know-how enable us to perform research for laser beam microprocessing applications. The purpose is the miniaturization of functional elements used for the design of machines, plants, vehicles and instruments as well as in biological and medical products. Examples include the generation of 3D structures of sub-mm dimensions and surface area structures in polymers, metals, ceramics or quartz-like and biocompatible materials and cleaning processes using laser technology.

SURFACE FUNCTIONALIZATION

New methods are used to fabricate 2- and 3-dimensional micro- and nanostructures on polymer, metal and ceramic surfaces and coatings. These generated structures span macroscopic dimensions and provide micro- and nanoscopic properties over large areas. In addition to modifying topographies, it is also possible to periodically change the electrical, chemical and mechanical properties. Such structured surfaces can be used in biotechnology, photonics and tribology.

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2012 PROJECT EXAMPLES


1

EFFICIENT FABRICATION OF HOLOGRAPHIC EMBOSSING TOOLS

THE TASK

Large area microstructuring of material surfaces presents one of the most demanding technology challenges to today's surface engineering community. Application fields for such technologies are manifold. Of special interest are possibilities to provide product protection applying holographic embossing techniques as they are used for copyright protection of banknotes and credit cards. An increasing number of manufacturers of high value products needs to be protected from counterfeit and replicas made in low-wage countries. The authenticity of the product should be easily verifiable to the end user. One of the most cost effective and flexible methods is to emboss a product logo in holographic microstructure technology. The associated light scattering effects are especially obvious and appealing. And the technology is by far too complex to allow for easy copying.

A special process is required to provide sufficient and affordable protection for mass products at high speeds and constant quality. Such technology would also have great application potential in photovoltaics, optics and other manufacturing areas. Currently available technologies for large area structuring are essentially limited to embossing and stamping techniques. The pattern is transferred by pressure and/or rotation from the stamp to the part.

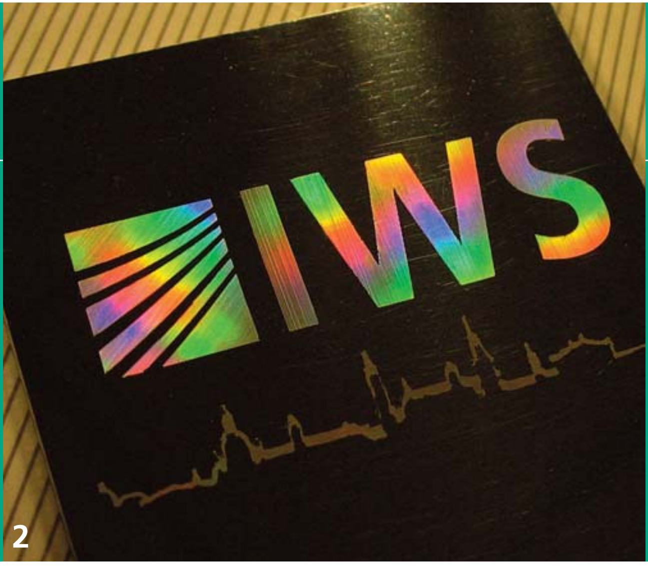
One of the largest issues is the high cost associated with the fabrication of the stamp. The process is also not very flexible. Complex lithography techniques require the use of matrix sheets. Due to the seam in the sheets the roll-to-roll process suffers from interrupted pattern continuity.

OUR SOLUTION

We use the process of direct laser interference structuring (DLIP), which can apply periodic microstructures from 200 nm – 50 μm directly onto large areas without the need for interim steps or masks. With CAD technology any graphic design can be transferred to the part surface.

In DLIP, different optical elements are used to split laser beam into several sub-beams, which are later superimposed to form an interference pattern, which transfers the periodic laser energy distribution into the exposed surface. The structure period depends on the superimposition angle of the partial beams and on the wavelength of laser radiation.

Direct laser interference structuring is able to treat an area of several square centimeters per second and is applicable to various technologically relevant materials.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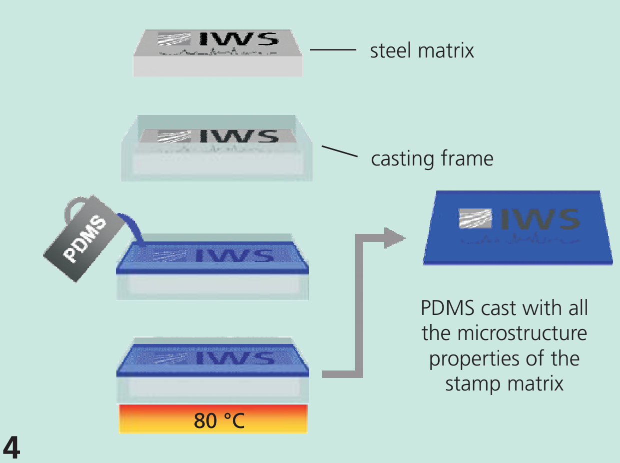
RESULTS

Several patterns were transferred into polymers (Fig. 1) as well as polished steel substrates (Fig. 2) using a pulsed Nd:YAG laser. Polyimide and numerous other polymers can be structured with a wavelength of 355 nm. The best results on metals were achieved with 532 nm or 1062 nm.

To demonstrate the method a steel stamp with the microstructured IWS logo was placed into a frame and cast with PDMS. The PDMS was then cured at 80 °C. The last step separates the cast from the stamp. The pattern embossed in the stamp including the microstructure was thus transferred to the liquid state PDMS and completely reproduced.

Direct laser interference structuring significantly reduces production costs for holographic embossing with submicron resolution. The process is also much more flexible. For example, it is possible to use the same method to fabricate flat stamps and embossing rolls.

The casting process



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1 *Stamp matrix on polyimide foil, thickness 125 µm*

2 *Stamp matrix on polished stainless steel*

3 *PDMS cast*

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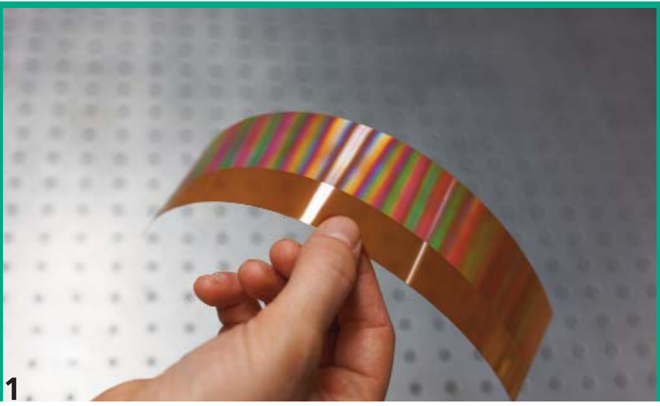


1

ANTIBACTERIAL SURFACE THROUGH LASER INTERFERENCE STRUCTURING

THE TASK

Properties and performance of technical products are not only depending upon the material but also on surface characteristics. Special topographies transform surfaces from being mere boundaries into functional elements.

Current R&D projects aim at making antibacterial surfaces. These can be used in medical devices (e.g. implants), in hospitals or in the food processing and related industries (e.g. packaging, kitchen surfaces). Various periodic and aperiodic structures were studied on different materials with respect to their non-stick properties. The fabrication of such topographies can be accomplished with numerous manufacturing technologies. Examples are casting techniques, E-beam lithography and optical lithography.

All these manufacturing methods are suitable to structuring in the µm and sub-µm range. However, they are typically sequential processes or they require an enormous and costly technical effort (e.g. fabrication of masks, etching, development).

OUR SOLUTION

The Fraunhofer IWS offers a fast and cost effective solution called Laser Interference Lithography (LIL). A small number ($N \leq 4$) of coherent laser beams are forming an interference pattern above the substrate surface. The intensity distribution is projected into a light sensitive layer on the substrate and induces thermal or chemical transition processes. Just like in optical lithography the process uses positive and negative photoresists. When using high power lasers, it is also possible to directly ablate materials such as metals, ceramics and polymers (Fig. 1).

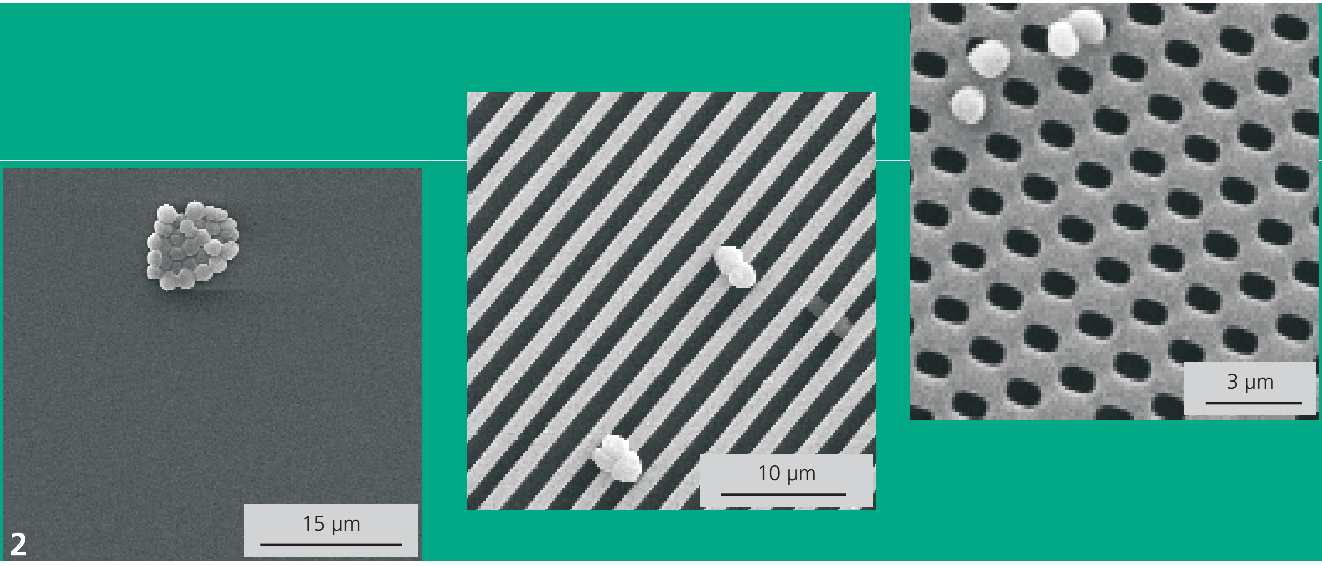
The laser interference process creates periodic surface structures, which can be defined by the number of used laser beams, the laser wavelengths and the angle between the interfering beams. No masks or master patterns are required. A single ns laser pulse can expose an area of some cm^2. These Fraunhofer IWS methods offer a high degree of flexibility and fast processing speeds.

RESULTS

The influence of laser structured polymer surfaces on the bacteria adhesion behavior was studied in close cooperation with Leibniz IPF and MBC for Biomaterials in Dresden.

Line, hole and column structures with periods of 500 nm – 5 µm were fabricated in commercial photoresist SU 8 on single crystalline silicon substrates (Fig. 2). Lines and columns were produced with two and three interfering laser beams.

The holes were also made in two beam configuration but with two exposures between which the substrate was rotated at a certain angle. After structuring the samples were colonized with bacteria of the type *Staphylococcus epidermidis*.



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This is a microbe that occurs on human skin and mucosal tissues. It can cause serious infections during medical surgeries such as transplantations or implantations.

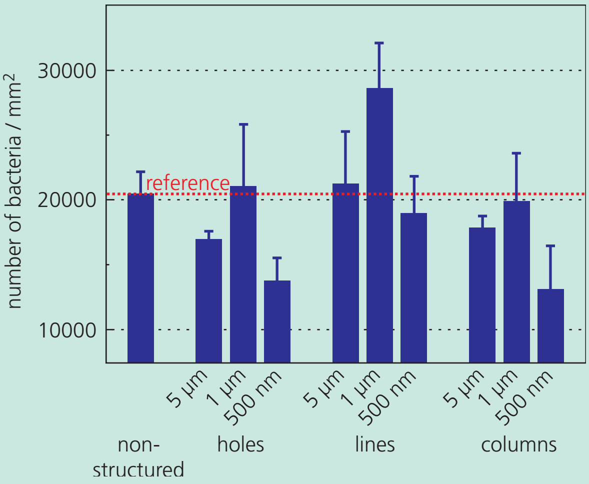
The samples were contaminated by dripping a liquid with the bacteria onto the surface. Finally fluorescence microscopy was performed to count the number of bacteria that remained on the surface, which were fixated and dyed.

Fig. 3 shows the trend of bacteria colonization as a function of the structural properties (period, geometry) and compares them with a reference sample (non-structured SU 8). It is evident that a smooth surface as well as a line structure positively affects the settling behavior of *S. epidermidis*.

The initial adhesion of the bacteria was reduced on the 5 µm and 500 nm hole and column-like structures. The least amount was counted for 500 nm structure period with 13000 bacteria per mm^2 (holes) and 12000 bacteria per mm^2 (columns).

The main reason for the reduction of the initial adhesion is the size of the period. In particular submicron structures significantly minimize the contact area between bacteria and substrate. Thus the cells find few contact points and cannot develop a strong network.

S. epidermidis bacterial count per mm^2 on structured photoresist SU 8 as a function of the structure period and geometry



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1 *DLIP structured polyimide foils*

2 *Scanning electron microscopy image of non-structured and structured photoresist after colonization to S. epidermidis*

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LOW LOSS ELECTRIC DRIVES WITH LASER CUT ELECTRICAL SHEETS

THE TASK

The lifetime energy costs for running electromotors and generators exceed the initial equipment investment multiple times. The number of installed electrical machines is huge and thus will be a significant increase of energy efficiency if electrical energy losses is reduced.

Generators and electromotors convert kinetic into electrical energy and vice versa. Conversion losses need to be minimized. This optimization begins with the proper design and efficient manufacturing technologies. But the used materials are also of great importance. For example, often these energy conversion devices use non-grain oriented electrical metal sheets. This area is an important research topic also pursued at the Fraunhofer IWS. Laser cutting instead of punching makes it possible to improve the efficiency of electrical drives and simultaneous benefits application oriented manufacturing with varying geometries and flexible lot sizes.

OUR SOLUTION

By the nature of the process, conventional mechanical fabrication such as die cutting of non-grain oriented electrical sheets, introduces stresses into the material (Fig. 2). Such internal stresses negatively affect the magnetic properties. This is in particular true for the often-used high-grade electrical sheet material, which is very sensitive to mechanical degrading in the edge region. Iron and copper losses increase and subsequently reduce the efficiency of the electrical machine. In some cases these negative effects can be corrected with additional heat treatment steps, which contradicts the objective of energy efficient manufacturing.

Laser beam fusion cutting, mechanically speaking, is a manufacturing process that does not additionally damage the cut sheets. Thermal damage could be possible but is minimized with modern processes. Fraunhofer IWS engineers create the processes using thermography and optimized the beam source and optical configuration. Based on these results further process development was performed to optimize it for soft magnetic materials. Material properties (hysteresis losses) were measured with normalized inductive techniques (Fig. 4). Varying sample widths sufficiently well represent real part contours as they are used in stators of electrical machines.

Depending on the final application, were simulated different magnetic flux densities and field frequencies to obtain insights into process related damage.

Such damage has different effects on the magnetic properties depending on beam source and process selection. The data are used for numerical simulations of component damage, which in turn is used to improve product development and helps to select suitable materials.

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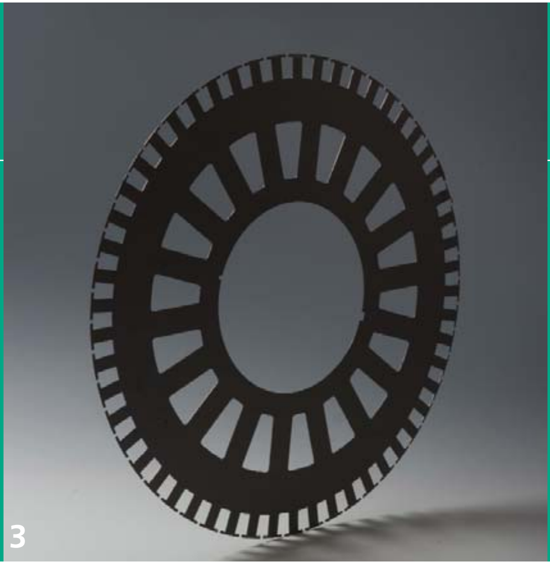

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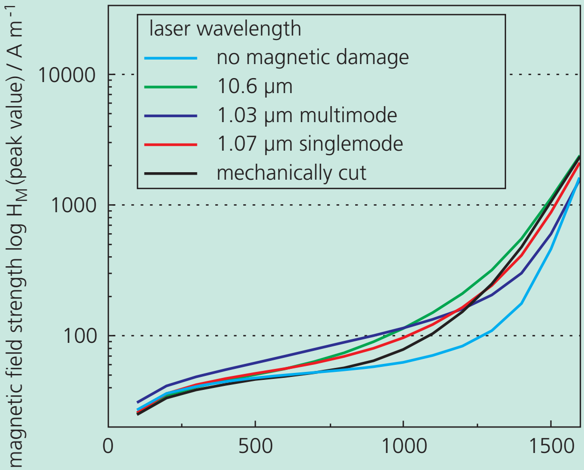
RESULTS

An ever-increasing diversity of product variants comes along with decreased lot sizes. Laser beam cutting is a well-suited process for these conditions due to its flexibility. The process also directly and locally influences the magnetic properties of the sheets, which improves the overall performance of the material.

Using appropriate process conditions minimizes thermal damage to the part. This in turn increases the magnetic efficiency of the later part. The focus is also on cost effective manufacturing to meet defined energy efficiency requirements. The process design is typically oriented based to the material grade, the design parameters and magnetic requirements. The latter depends on the operating point of electrical machine.

Possible tools are various beam sources. These can process conventional electrical sheet but also material grades with high silicon content and alloys. Laser beam cutting is the ideal process to develop prototypes and to manufacture small and medium quantities, when high magnetic performance of the electrical machine is critical.

Example of an analyzed electrical machine: Selection of the laser beam source according to the lowest required field strength as a function of a defined magnetic flux density, material: electrical sheet of 0.35 mm thickness



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1 *Application of laser beam fusion cutting of electrical sheets*

2 *SEM image of a mechanically separated sample (left: damage of the insulating layer and feathering, right: damage-free laser cut sample)*

3 *Generator applications: Laser beam melt cutting of a sample contour*

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1

HIGH FLEXIBILITY LASER SCRATCHING AND CUTTING OF DIGITALLY PRINTED OUTER PACKAGING

THE TASK

Digital printing of packaging materials is a cost effective alternative to conventional printing in particular for small sized goods in small lot sizes. Digital printing does not require print forms. Therefore the process is acceptably cost effective, fast and easy to print packages even for individual pieces. The technology is very attractive considering a future market growth of individualized packaging.

Outer packaging is manufactured from cardboard sheets fed to a stamping machine, which performs scratching, embossing and stamping operations. The process is tied to specific tools, which limits flexibility and productivity for small lot sizes. Here laser technology offers new possibilities to cost effectively substitute mechanical scratching and stamping.

OUR SOLUTION

Conventional scratching of cardboard delaminates material from the sheet where it is to be folded for packaging. The scratch line defines the shape but is also a zone allowing for material compression and stretching.

Fraunhofer IWS' laser scratching process weakens the material and reduces the thickness by ablation. The cardboard material absorbs the focused laser energy to locally evaporate.

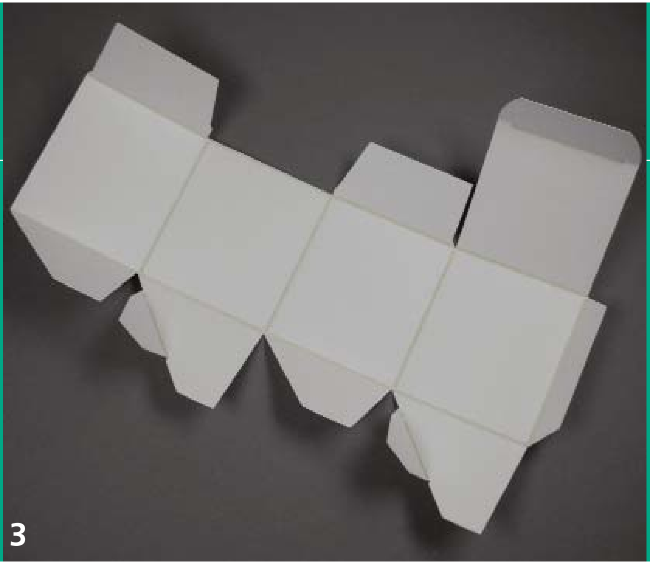
The ablation depth is very well reproducible with the controllable laser process. The theoretically determined scratch geometry can be exactly generated. Experimental and analytical investigations help to optimize geometry and location of individual scratch lines.

Folding result with optimized scratch geometry

2

The stringing together of several v-type lines minimizes the required material ablation. This directly influences the strength and stability of the packaging. The design affects the stretching of the upper side of the material and prevents damage (e.g. tearing of the printed image).

Laser assisted stamping is also based on evaporative ablation. Laser power and processing speed are adjusted so that the same system that scratches also performs the cutting of the packaging.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RESULTS

The sublimation process does not require a cutting gas and achieves scratching speeds of several meters per second with only a few hundred watts of power. Thus remote processing is suitable for its industrial implementation. The laser beam is rapidly scanned over the surface using mirror projection. Since only small masses are moved the beam motion is highly dynamic and extremely precise.

An on-the-fly process demonstrated laser assisted scratching and cutting. The cardboard sheet was continuously moved. Laser beam and cardboard motion were superimposed to first perform scratching and then cut the contour. To prove the suitability of the technology for industrial use we built a demonstrator (Fig. 4). The system was designed (laser and scanner selection) based on the results of initial concept reviews. We carefully considered the interconnection between optical imaging (focus requirements), laser power and cutting speed.

Laser based scratching and cutting has a cost advantage compared to conventional cutters with respect to required flexibility, small lot sizes and a large number of different orders. In contrast to the conventional approach, laser scratching and cutting treats the packaging from the inner side. The characteristic appearance of the scratches becomes visible only when the packaging is opened. It does not affect the graphics. The further processing in folding and gluing machines is not different from the conventional method.

The results offer decisive progress in the field of digital printing, which increases the acceptance of the process in industry. Small jobs down to individual pieces can be more efficiently processed with respect to material and energy consumptions as well as costs.

The European Union and the Sächsische Aufbaubank are funding this research and development project.

1 Laser based scratching and cutting process
3 Packaging blank
4 Demonstrator system

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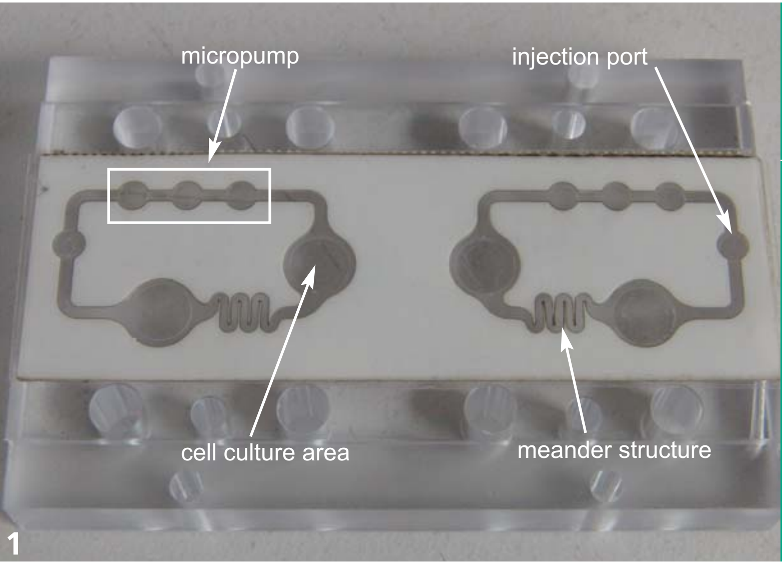

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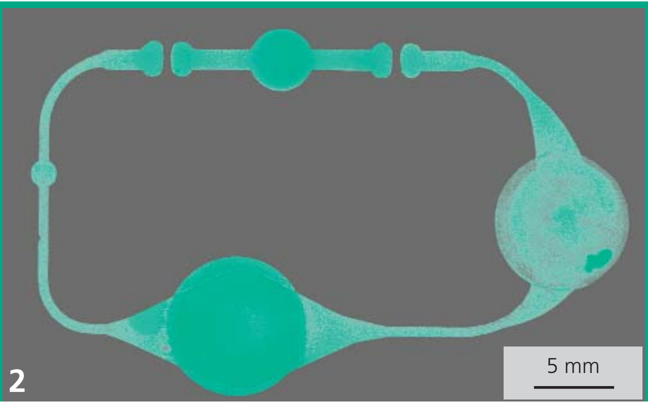

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INEXPENSIVE LAB-ON-A-CHIP SYSTEMS WITH MULTILAYER DESIGN FROM LASER MICROSTRUCTURED FOILS

THE TASK

Miniaturization, fast prototyping and automation are increasingly important in the field of lab-on-a-chip technologies. These systems are used in medical diagnostics and to replace animal testing in pharmaceutical and cosmetic industries. Multi organ chips (MOC) are well suited to mimic processes in living organisms.

Testing substances on a chip require the implementation of closed circulatory systems. These consist of several cell culture segments, storage chambers and a micropump. So far the fabrication was accomplished by casting a silicone flow cell to a connector plate. This process is complicated, expensive and difficult to automate. It also limits the microfluidic system to be designed in a single layer.

OUR SOLUTION

Fraunhofer IWS engineers are developing a closed process chain to cost effectively (automated) manufacture inexpensive chips. The new system is a multilayer design made from laser microstructure foils.

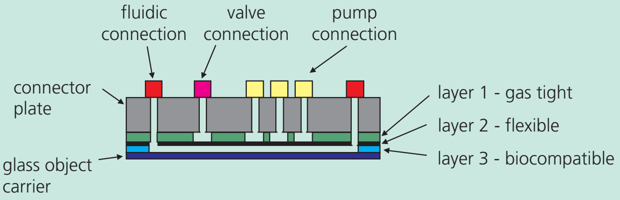
The first step is to slice the microfluidic system design into individual layers so that later each layer can be fabricated on a separate foil. The next step is to select the desired properties (e.g. hydrophilic, hydrophobic, transparent, …) for each foil, which depends on the functional requirements. In the third step these foils are laser processed on both sides, i.e. they are microstructured and functionalized. The final fourth step is laminating these individual foils into a multilayered system via adhesive or plasma bonding.

The multilayer technology is also applied to fabricate pneumatically powered pumps and valves. The associated peristaltic pump is a reciprocating and rotary pump, which operates as a membrane pump. The pump chambers are connected in series and (with suitable control) accomplish a directed transport of the liquid. Under excess pressure a thin polymer membrane bulges and displaces liquid in the underlying chamber.

Under lowered pressure however the membrane withdraws and increases the chamber volume. To make valves the membranes are equipped with addition seal lips.

Fig. 3 shows a representation of the established microfluidic platform. It consists of a connector plate with fluidic and pneumatic connections, the multilayer flow cell with integrated micropump and a glass cover plate. This plate

Schematic design of a multilayer lab-on-a-chip system with integrated micropumps and valves



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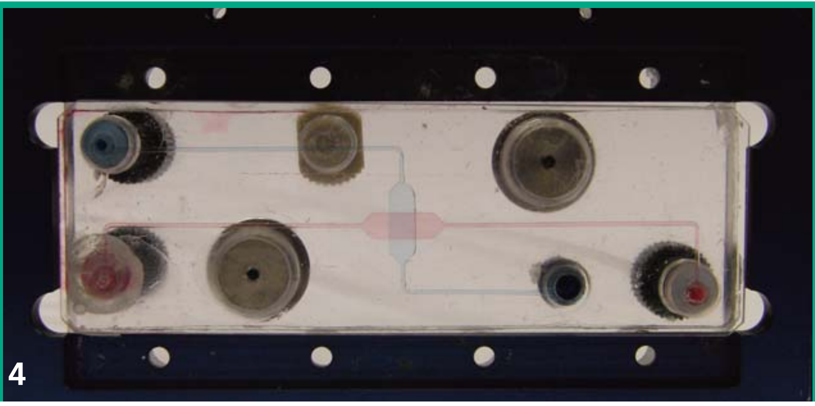

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provides the seal on the bottom of the chip and serves as the optical access port.

RESULTS

A closed technology chain was established at the IWS Dresden to automatically manufacture inexpensive lab-on-a-chip systems based on multilayer designs made from laser microstructured foils. Different industrial lab-on-chip-systems can be built.

A particular system was made from polycarbonate foils and Teflon. The foils were structured and functionalized with a ps laser system at wavelengths of 532 nm and 355 nm. Finally they were laminated in a special holder. Fig. 1 shows the prototype of a fluidic system with two closed circuits, two cell culture areas, one injection port and a 3-point peristaltic pump as well as meander structure as a damper. Fig. 4 shows a prototype with intersecting channels, which run at different levels. The chip was filled with two different dyes to make the fluidic separation of the two channels visible.

Microfluidic structures can be placed at different levels in the multilayer design, which results in greater functionality per chip area. Wettability can be tailored by using foils with different properties (hydrophilic, hydrophobic, functionalized). This enables the implementation of new functions such as capillary stop valves and the tailored occupation of areas with cells. Foils can also be used to integrate thin film electrodes.

1 Prototype with two circuits
2 Dye filled circuit
4 Prototype with intersecting channels

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1

LASER INDUCED TEXTURING OF PLASTIC MONOFILAMENTS

THE TASK

Numerous texturing technologies are used to refine textile materials. The texturing induces curling of the smooth fibers. The effect is mostly based on the thermoplastic behavior of the material. It significantly changes the character of the textile. Properties such as haptic, heat insulation capability, water adsorption and elasticity can be tailored.

Most classic texturing processes create a geometrically random curling, which is tied to mechanical damage of the monofilament's surface. Industrial applications require to create geometrically defined curling. The process should be energy efficient and work for various monofilament materials.

OUR SOLUTION

Fraunhofer IWS engineers developed a rapid thermal treatment process of moving polymer monofilaments. The material heats up close to the melting temperature and is simultaneously formed. Its polymer structure and orientation is changed. These changes are frozen through rapid cooling so that the curling geometry is retained.

The process makes use of several advantages associated with laser technology. Fast control and local heat input allow, for example, treating several filaments simultaneously. The beam of the CO_2 slab laser is very quickly controllable with galvanometer scanners to perform "multi spot" processing. The use of fast radiation pyrometers made it possible to achieve an independent control of adjusting and stabilizing the temperatures of each monofilament.

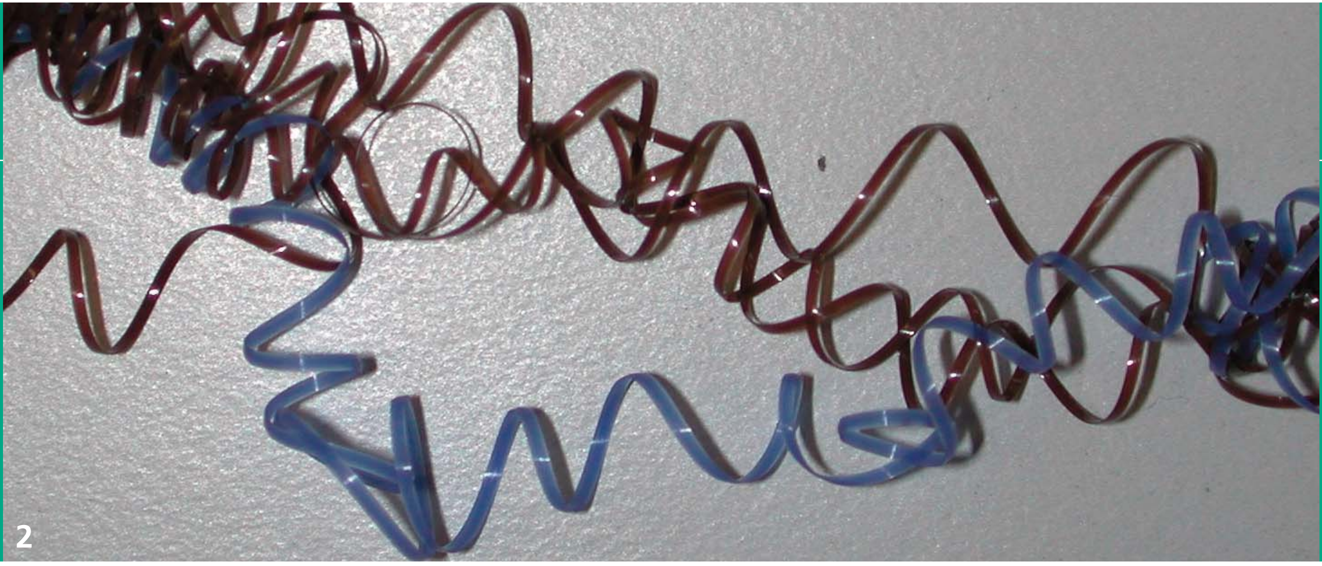
The IWS laboratory system is made up of the following components:

- monofilament unwinder for up to 8 individual filaments
- 400 W CO_2 laser
- galvanometer scanner for fast beam positioning
- filament forming unit with a transport velocity of up to 60 m min^{-1}
- cross winder for winding up of monofilament strands
- radiation pyrometer to control the monofilament temperatures at the processing spots
- thread tensioning sensors
- machine controller with integrated laser software

RESULTS

Various thermoplastic monofilaments were successfully structured during process development. Temperatures and pull forces were modified to affect the physical properties of the textile fiber such as remaining shrinkage, curl and tensile strength. Mechanical damage and melting was avoided.

The technology generates geometrically defined curling (e.g. spiral geometry) in an in-line process. Depending on the feed rates up to 8 individual monofilaments can be processed simultaneously. Multi spot irradiation with online temperature



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Evaluation criteria of texturing methods

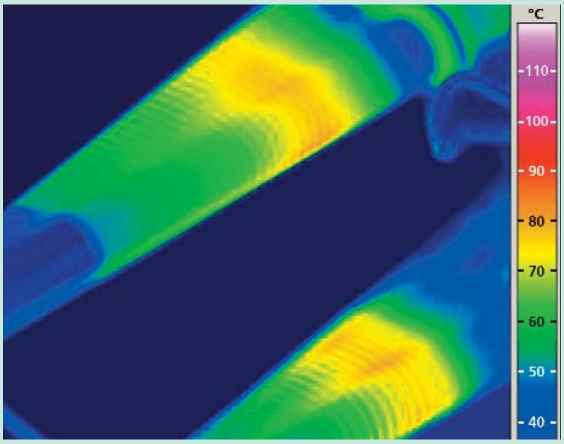
	compression chamber curling	knit de knit process	laser texturing
form of texture	undetermined	omega geometry	determined
curling	limited	high	high, variable
system footprint	low (right after yarning)	high (integrated knitting)	low (separately installed)
output	high	low	low (for single laser operation)
energy consumption	high	very high	low

3

control could also be used in different applications such as artificial lawn manufacturing, damping structures and medical textiles.

Funding for this project comes from the European Union and from the Sächsische Aufbaubank.

Thermographic image of two thread forming units with double spot laser irradiation and continuously moving monofilaments



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1 *Sample carrier for the laser induced texturing of polymer monofilaments*

2 *Curled polymer monofilaments*

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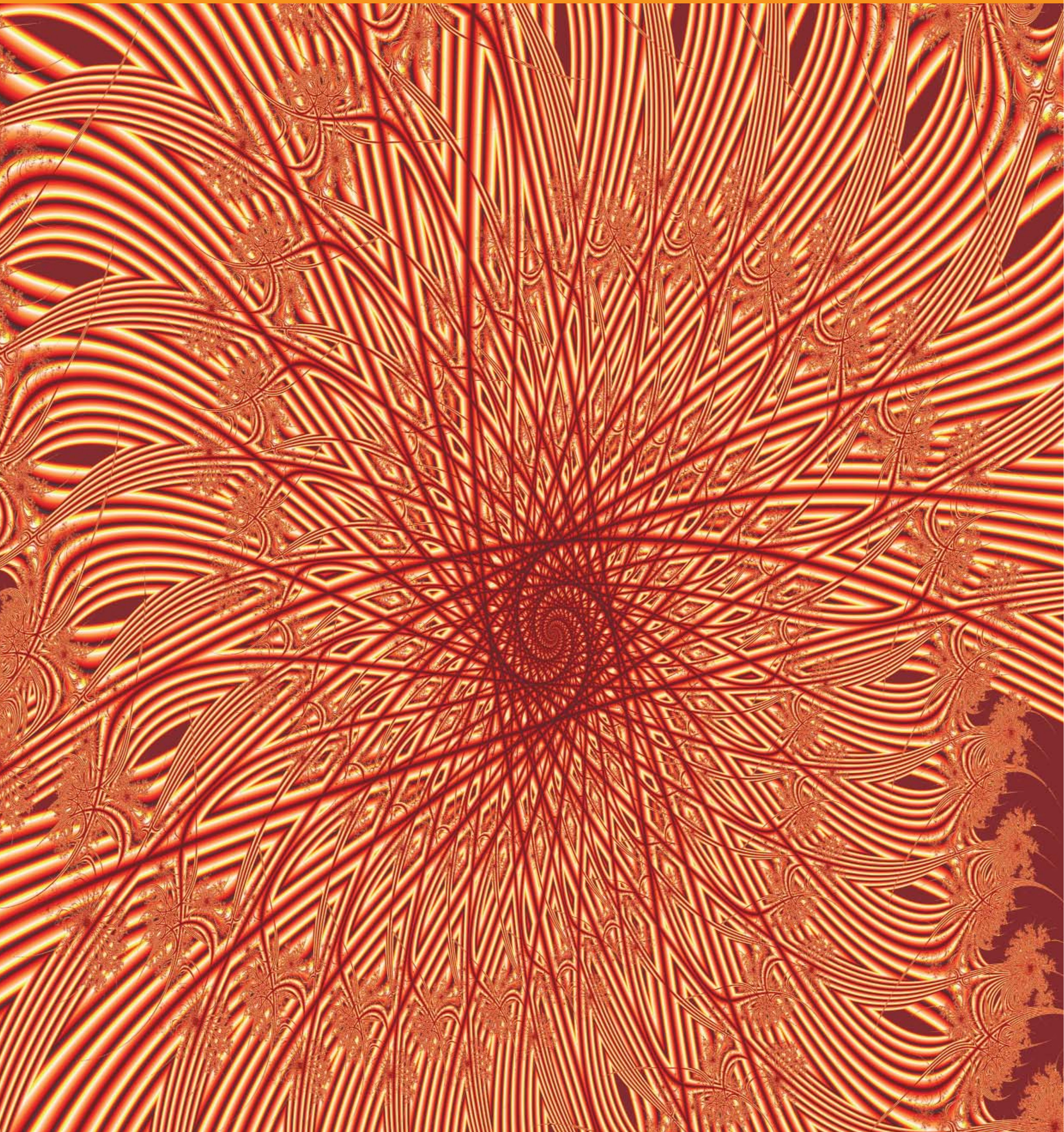
CENTERS



IWS BATTERY CENTER TECHNOLOGIES FOR NEW ENERGY STORAGE SYSTEMS

Research in the areas of electromobility as well as stationary energy systems is a central theme at IWS in Dresden. Important contributions can be provided to battery fabrication processes based on the numerous IWS technology developments. In order to offer solutions to industry, the IWS is establishing a center for battery research. The EU and the Free State of Saxony fund this project with 4 million Euros. IWS internal and Fraunhofer funds add 3 million Euros. BMBF project funds contributed another 1 million Euros for equipment. This offers the best conditions to work on numerous public industry projects. A selection of these is listed here:

N2P (EU: CP-IP 214134-2)
Nano To Production
Timeframe: 06/2008 – 11/2012

DeLIZ (BMBF: KIT 02PO2640)
Production technology demonstration center for lithium ion cells
Timeframe: 05/2010 – 06/2011

AlKaSuSi (BMBF: FZJ 03X4618A)
Material concepts for alkaline metal sulfur batteries
Timeframe: 05/2011 – 04/2014

DryLIZ (BMBF: KIT 02PJ2302)
Dry fabrication of lithium ion cells
Timeframe: 01/2012 – 12/2014

MaLiSu (EraNET/BMWi: DLR 01MX12009A)
Nanomaterials for future generation Li-S-batteries
Timeframe: 01/2012 – 12/2014

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CryPhysConcept (BMWi/BMU/BMBF: FZJ 03EK3029B)
With crystal physics to future concepts of electrochemical energy storage systems
Timeframe: 10/2012 – 12/2015

BaSta (BMU: FZJ 0325563A)
Battery – Stationary in Saxony
Timeframe: 11/2012 – 10/2015

BatCon (BMWi: DLR 01MX12055C)
Functionally integrated high current connectors for battery modules
Timeframe: 1/2013 – 12/2015

A 2012 Fraunhofer IWS highlight was the workshop “Lithium sulfur batteries”. Prestigious experts from industry and science presented and discussed the latest development trends in the field of Li-S batteries. The next workshop will be held on November 6th and 7th 2013.

www.iws.fraunhofer.de/en/events.html

JOINING TECHNOLOGY CENTER CONCENTRATED COMPETENCE IN DRESDEN

Joining is a central production challenge and also a significant cost factor. In many cases current joining technology developments offer significant improvements and impulses. Therefore the Fraunhofer IWS in cooperation with the TU Dresden and other partners established the joining technology center "Tailored Joining". The center is designed to provide an overview to users of joining technology, to show the different processes, their advantages and limitations. New developments will be presented and industrial solutions will be shown.

The basis of the center is formed by the enormous variety of available joining technologies in Germany and the world. IWS performs research into all of these methods:

- laser beam welding
- laser hybrid processes (plasma, arc, induction)
- laser soldering (hybrid)
- magnetic pulse welding (forming + welding)
- friction stir welding
- press welding (laser, induction roll plating)
- adhesive bonding
- process combinations

Additional joining processes are subject to research at the TU Dresden.

Special effort is spent on presenting a fair comparison of the various solutions. The goal is to provide the user with assistance to find the best suitable technology.

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A first activity of the Joining Technology Center was the Fraunhofer IWS Dresden organized symposium "Tailored Joining" held in October 2012. The conference focused on laser beam and arc welding. In addition the topics included friction stir welding, magnetic pulse welding, mechanical joining and adhesive bonding. The relevance of joining technology was apparent by the fact that this symposium was a newly created event, which immediately attracted more than 200 participants.

The IWS also managed the technical organization of the "Welding and Joining" workshop in Schaumburg, Illinois, USA. This was a two-day event focusing on laser beam processes. It was held in combination with the LME (Laser Manufacturing Event). More events are planned addressing the topics of "Tailored Joining".

LASER INTEGRATION CENTER

For many years the Fraunhofer IWS has aimed at increasing the competitiveness of Germany's machine and plant building industry by providing laser technology. Dresden's researchers have already delivered numerous innovative technologies and systems to industrial customers. A special brochure compiled a selection of such successes, which was issued for the 20th anniversary of the institute.

The institute's activities continue to be driven by branch overarching applied research for industry. IWS networks and collaborations with other research institutions and industrial partners are concentrated within the center for laser integration in manufacturing. The goal is to offer customer "one stop" solutions.

The advantages for machine and plant builders as well as for manufacturers are evident:

- cost savings due to reduced process chains,
- higher efficiency of the manufacturing processes and products,
- higher quality and market relevance of the products,
- competitive advantages at the highest technical level.

Public relations and knowledge dissemination are important components of technology transfer. This is the reason for many Fraunhofer IWS exhibitions at numerous annual trade shows. In 2012 the institute exhibited at the Hannover tradeshow, the Euroblech show, the hardening congress and the Euromold.

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In 2012 the workshop "Industrial applications of high power diode lasers" was held for the 9th time. The annual symposium "Thermal coating with laser based manufacturing processes" is also a solid component in the event schedule of the laser community. This symposium is jointly organized with the Technical Academy Wuppertal. Of great popularity is also the "International laser symposium fiber & disc (FiSC)". In 2012 this symposium was combined with the joining technology symposium "Tailored Joining" and an "Innovation Evening" for companies from the region of Central Germany. A big success!

By the way, the 8th International Laser Symposium will combine the previous events "Industrial applications of high power diode lasers", the joining technology symposium "Tailored Joining" and the "International laser symposium fiber & disc (FiSC)". This event will be held in the International Congress Center in Dresden on February 27th and 28th 2014.

www.lasersymposium.de

NANO IN FOCUS
THE NANOTECHNOLOGY CENTER

Nanotechnology offers innovation and delivers important contributions to energy and resource efficiency. It is a cross sectional technology overarching many branches. A close cooperation between research organizations and companies is required to faster and better utilize nanotechnologies in applications. The Fraunhofer IWS has been actively participating in this effort for years. Activities include internal research work as well as the coordination of and participation in numerous initiatives.

Research work at the IWS in this field in particular:
- the fabrication and processing of nanoparticles and nanotubes (pages 50/51, 52/53)
- the deposition of thinnest films (pages 40/41)
- the fabrication of nanostructures on surfaces (pages 100/101)

These works are of increasing interest for industrial applications.

The 9th International Nanotechnology Symposium "Nanofair – new ideas for industry" was held on June 12th and 13th 2012 in Dresden. The event was jointly organized with the state capital Dresden. The program included more than 40 presentations and contributions from participants from 23 countries. Topics included nanomaterials for lightweight construction, electronics, optics, energy applications, nanoanalytics and special process aspects. As part of the symposium the VDI issued for (the 4th time) their Junior Scientist Award. This year the award was presented to Dipl.-Phys. Andreas Tittl from the university of Stuttgart for his work on developing novel hydrogen sensors.

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The Fraunhofer IWS is actively engaged in transferring research results to manufacturing. For years the institute has been participating in the "nano tech" fair in Tokyo, Japan. Also, the participation at the PSE in Garmisch-Partenkirchen addresses the topic.

On December 4th 2012 the initiative "Nano in Germany" elected Prof. Andreas Leson as their spokesman. Prof. Leson is the deputy director of IWS Dresden and also head of a department at the institute.

The IWS Dresden coordinates the nanotechnology competence center "Ultrathin Functional Coatings" (Nano-CC-UFS). The center's membership includes 51 companies, 10 university institutes, 22 research organizations and 5 associations. Members collaborate in the areas of public relations and technology transfer. The IWS is also a member of the Fraunhofer Alliance Nanotechnology and in Dresden's cluster for nanoanalytics.

CENTER FOR CARBON TECHNOLOGY UNIQUE VARIETY AT FRAUNHOFER IWS

Carbon is a special element with extraordinary versatility. Its various modifications and compounds anable a broad property and application spectrum. For years carbon has played a central role in Fraunhofer IWS research. Here are some examples:

Diamond-like carbon coatings (ta-C) to reduce friction and wear are an important research focus in the business field PVD and Nanotechnology. For many years the research has addressed the link between coating properties and deposition process. Now Fraunhofer IWS developed systems technology to deposit ta-C has found its way to industry.

Graphite-like carbon (GLC) has predominantly graphitic bonds and the associated high electrical conductivity. IWS engineers use a modified deposition technology to synthesize these coatings. A special laser structuring process is also used to locally graphitize diamond-like coatings.

Porous carbons in the form of coating on metal foils serve as electrodes for double layer capacitors. The device performance is mainly depending on the specific surface and pore geometries of the carbon (pages 26/27).

Carbon nanotubes (CNT) are another research focus at the institute. Vertically aligned carbon nanotubes serve as conductive and binder free matrix for contacting sulfur in lithium sulfur batteries. IWS engineers produce single-walled carbon nanotubes, which are increasingly used in sensor and actuator applications (page 50/51).

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Carbon black is a byproduct of solar thermal processes to produce hydrogen from methane (pages 32/33). Carbon black particles are 50 – 150 nm in size and very pure. They can be used as conductive Carbon black or filler material in the rubber and dye industries.

Carbon fibers are another, highly topical issue. IWS scientists concentrate on the modification of carbon fibers to achieve a cost-efficient fabrication. Furthermore they investigate cutting and joining process steps for carbon-reinforced polymers.

Mono- and polycrystalline diamond is of great interest for optical, X-ray optical and electronic applications. At Lansing, MI, USA subsidiary Fraunhofer CCL, IWS produces diamond from the vapor phase by homoepitaxial chemical vapor deposition (pages 34/35).

SURFACE TECHNOLOGY CENTER DORTMUND (DOC®)

Surface technology is key to many steel products. ThyssenKrupp Steel Europe AG (TKSE) has concentrated its surface technology research and development efforts in Dortmund. The "Dortmunder OberflächenCentrum" (DOC® for Surface Technology Center Dortmund) is a globally leading research institution addressing the development of surface technologies for steel products. The DOC® develops tailored coatings, which are deposited in a continuous manufacturing process onto moving steel band substrates. Customer oriented development goals are the implementation of novel surface concepts leading to superior properties such as improved corrosion resistance, scratch resistance, electrical conductivity, forming capability or cleaning properties. Flat steel products with completely new functional properties and thus increased value are also part of the current research, which for example includes work on solar thermal and photovoltaic properties.

The Fraunhofer IWS cooperates directly with DOC® by supporting a project group on site. This group works primarily on surface coatings using PVD, PACVD and spraying processes and on laser materials processing.

Current main foci in the thin film technology:

- development of conductive carbon coating systems (GLS: Graphite Like Carbon) for electromobility, e.g. for steel bipolar plates in fuel cells as well as Al and Cu electrodes for batteries and super capacitors,
- Diamor® coating systems (ta-C: tetrahedral amorphous carbon) for wear protection based on a short pulsed arc processes (spArc®),
- novel PVD procedures for metal band coating processes and developments of corrosion protection properties. They base on zinc alloy coatings, e.g. for highly corrosion-resistant metallic coatings and for metallic coatings in hot forming processes.

Laser materials processing and spray coating projects include:

- development of joining processes based on laser MSG hybrid welding for lightweight construction, e.g. for the welding of mobile crane components made from high strength fine grain construction steel,
- high speed laser welding with high beam quality solid-state lasers and low melt particle emission,
- wire arc spraying,
- combination process of joining and wire arc spraying, e.g. for the post galvanizing of weld seams,
- development of prototype welding processes with solid-state laser.

MANAGER OF THE PROJECT GROUP AT DOC® IN DORTMUND

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The Fraunhofer project group offers a selection of complementary surface refinement technologies, which is available at its 1100 m^2 laboratory space. The latest system technology is used to make spray coatings with the cost effective wire arc process, which can also be performed in an oxygen-free environment (vacuum chamber) and in combination with solid-state lasers. Surface areas of parts and tools exposed to high wear conditions can be clad with millimeter thick wear protective coatings using laser buildup welding. Even in vacuum it is possible to coat meter-sized and ton-heavy parts with nano- and micrometer thin high performance coatings including Diamor® films that are deposited with the cost effective and robust spArc® process. These coatings have an exceptional hardness and excellent low friction properties. They are deposited at high rates and at temperatures below 150 °C. New coating material systems are under development to provide additional corrosion protection properties.

The spectrum of system technology available at the Fraunhofer DOC® project group includes:

- modular spArc® evaporator technology with industrial PVD large chamber system with a usable diameter and height of 1.2 m each (batch load up to 2 tons),
- in-house developed high performance PVD technology for the metal band coating under rough vacuum conditions,
- latest wire arc spray technology with spraying cabin, vacuum chamber and the possibility to support the process with laser power,
- 3D capable laser and laser-MSG hybrid welding system (gantry portal system, robot systems) with mobile 8 kW fiber and 4 kW Nd: YAG-lasers.

Additional systems from Fraunhofer IST and TKSE are available for joint projects. TKSE, IST and IWS jointly operate the DOC®'s modular and 80 m long sheet metal band coating pilot machine. The team offers research and development on vacuum coating processes for the continuous surface refinement of thin metal sheets.

The broad selection of offered processes and systems can also be efficiently combined in many instances. In combination with Fraunhofer IWS know how we ensure that we provide TKSE, TKSE's customers and other industrial customers with technically and economically optimized solutions. New, compact and mobile solid-state lasers offer the possibility to perform process development as well as trouble shooting directly onsite and on short notice for our industrial customers.

PROJECT CENTER LASER INTEGRATED MANUFACTURING IN WROCŁAW (PCW)

The Fraunhofer Project Center was established in 2008 and actively establishes the Fraunhofer model in the Polish research market. 2012 was another successful year. S.A. Katowice has been using a laser buildup welding system since 2011. In 2012 the company received several additional powder nozzles from the Fraunhofer IWS Dresden. The installed technology is very successful and the development of new applications required the expansion of the systems.

Another success was the sale of systems for the laser cutting of airbag materials to a Polish customer. This technology was jointly developed with a medium sized German company. In 2013 the system and the process will be implemented in production. IWS engineers support the company in system design, technology implementation and onsite employee training.

In 2012 several research projects were performed in the following areas:
- laser materials processing
- generative manufacturing
- biotechnology
- industrial image processing and contour capture.

The project "RemCoVis" aims at developing solutions for observation and visualization of remote processes. It has meanwhile moved to the application phase. The basics for the optical design of the observation unit and the software algorithm were previously developed. In 2012 the individual components were integrated and tested with concrete tasks in the area of laser materials processing.

The results demonstrated the desired alignment capability of a programmed geometry with respect to the real workpiece orientation as well as the generation of motion paths, which correspond to the workpiece contour. The test and application of the jointly developed solution was done at the IWS Dresden with the support of a Polish colleague.

This implementation of the solution, the joint development and know-how generation elevated the international and interdisciplinary collaboration to a new level.

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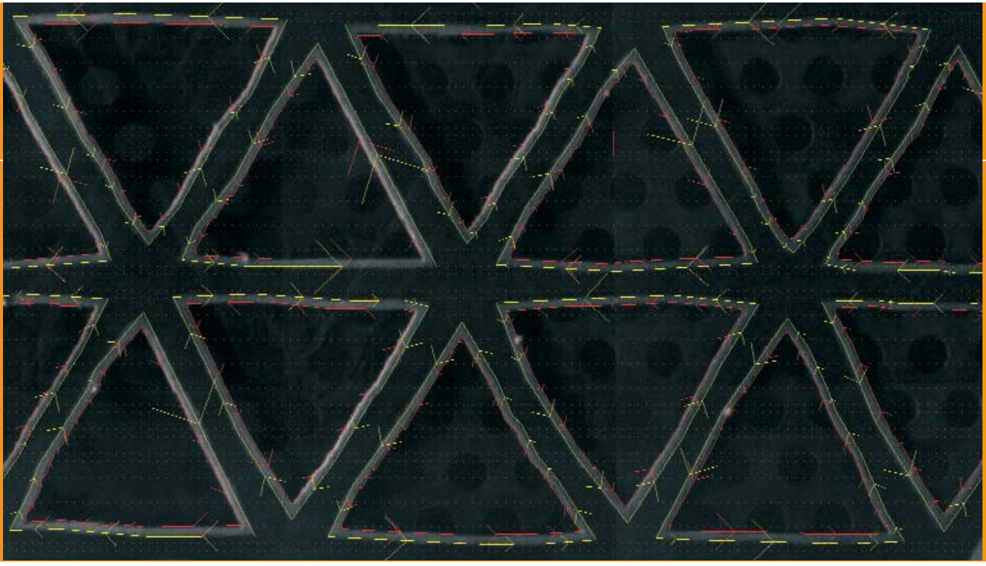

The goal of the "Bioreactor" project is the development of dynamic micro bioreactor systems with integrated artificial supply vessels. Such systems create a biocompatible complex 3D microenvironment. Hollow fibers offer one possibility to make biofunctional vessel systems. They are fabricated via rapid prototyping and then connected to microfluidic components to supply artificial tissues with oxygen and nutrients. One of the challenges is the biocompatible and tight connection between the two components. Particle image velocimetry is applied to characterize fluidic properties. Fluorescence and radiological contrast methods determine the permeability. The project combines the microfluidic competences of Fraunhofer IWS engineers with the rapid prototyping expertise of the Polish colleagues to address new applications.

Another project is titled "Bioimplants for regeneration of bone tissue in oncological patients". The goal was to develop a therapy for patients after tumors are removed from the jaw region. The developed solution integrates novel implants to repair facial bones. These implants have a scaffold structure covered with stem cells, bioactive substances and antibiotics. The implant grows into the bone and regains the normal function of the damaged region. The geometric design of the parts derived from the obtained computer tomography data.

The development work focuses on the process development to selectively laser melt titanium alloys as well as subsequent processes to build parts matching the requirements.

"LasTech – laser technologies for manufacturing functional 3D and surface structures" is a new endeavor addressing the identification of micro metallurgical parameters for laser generated parts. One of the results was a substantial porosity reduction of the parts from1.53 % to 0.04 % pore fraction. Additional research aims at minimizing the structure size, reducing the post processing requirements and improving the surface quality. Basic parameters with respect to strength and porosity were developed for lightweight construction applications. The project results were implemented in "ready to use" sample components in apparatus construction and medical device technology.

Industrial image processing and spectroscopy competences were further developed in the project "2D spectral methods for technical documents investigation". Various spectroscopic methods were applied and analysis algorithms were optimized to provide a tool for forensic tasks. In the studied case it was necessary to identify the correct sequence of signatures placed on documents.

The method is also useful for numerous other applications such as the detection of undesired contaminations in food products.

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 $5 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.

www.ccl.fraunhofer.org
www.ccl-laser.fraunhofer.org
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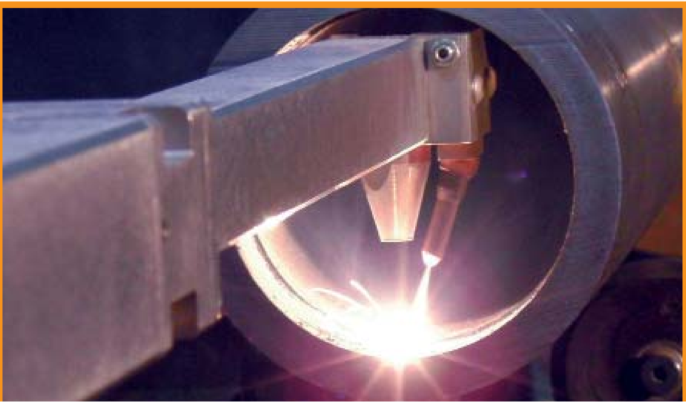


Laser Applications Division

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.

Coating Technology Division

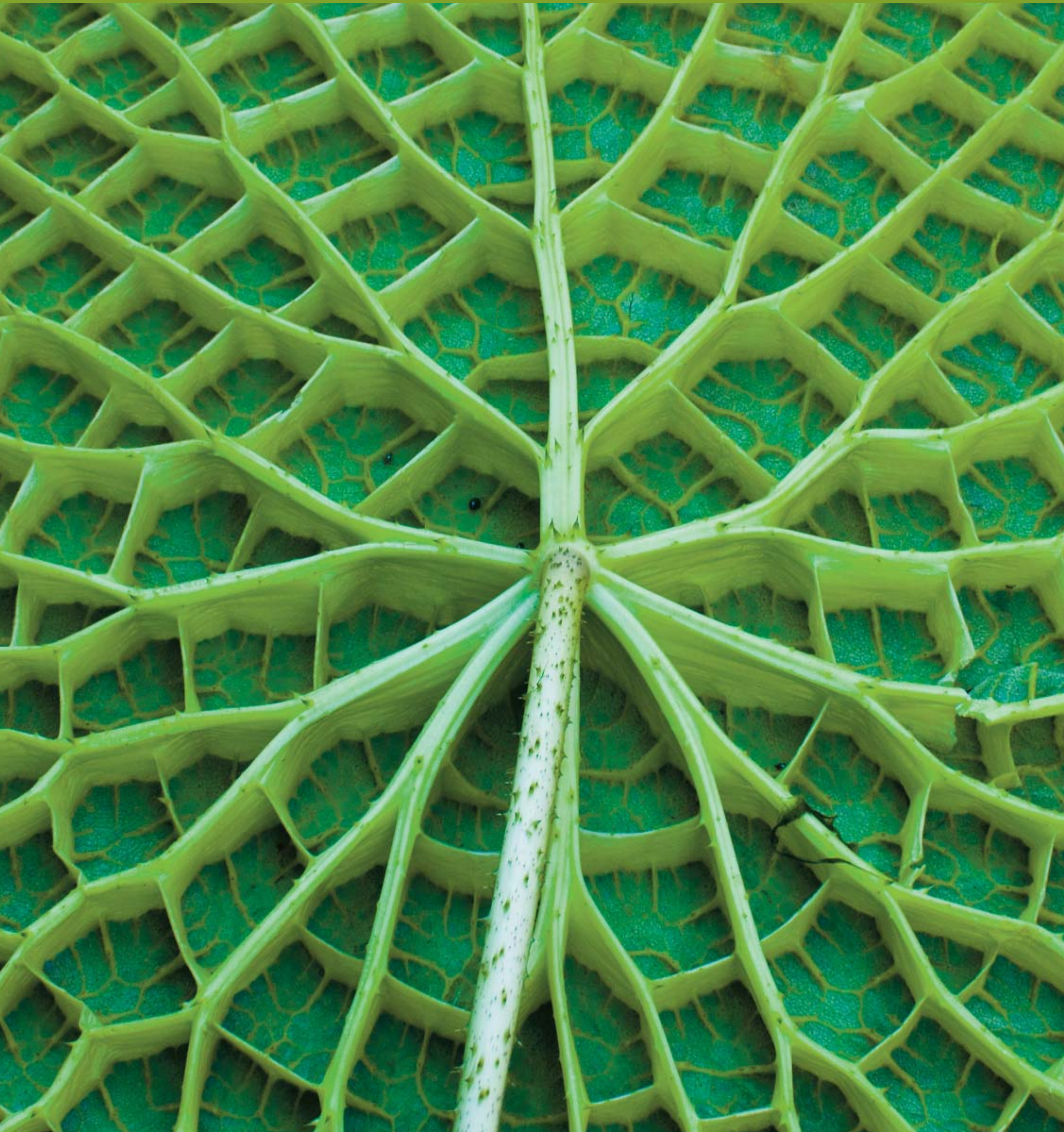
Prof. Jes Asmussen and Dr. Thomas Schuelke lead a group of experienced Fraunhofer researchers and German students in collaboration with faculty members and students of the Michigan State University. The team works in the following research areas:

- 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 Laser Arc 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.

NETWORKS



Joseph von Fraunhofer

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.

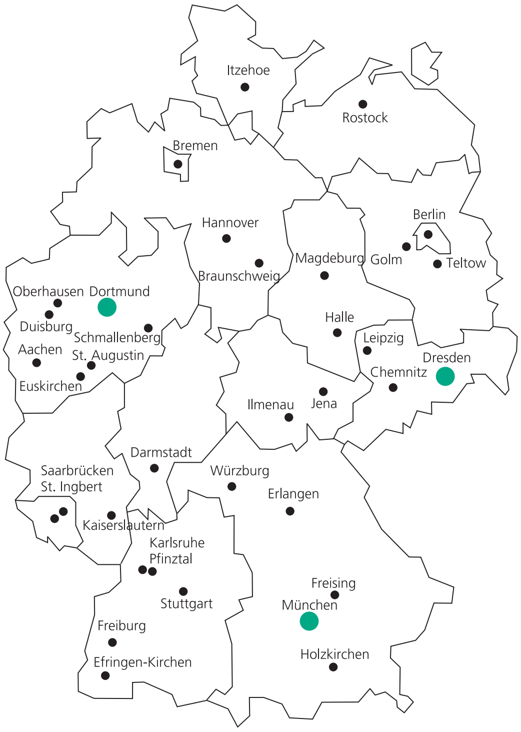
At present, the Fraunhofer-Gesellschaft maintains 66 institutes and independent research units. The majority of the more than 22,000 staff are qualified scientists and engineers, who work with an annual research budget of 1.9 billion euros. Of this sum, more than 1.6 billion euros is generated through contract research. More than 70 percent of the Fraunhofer-Gesellschaft's contract research revenue is derived from contracts with industry and from publicly financed research projects. Almost 30 percent is contributed by the German federal and Länder governments in the form of base funding, enabling the institutes to work ahead on solutions to problems that will not become acutely relevant to industry and society until five or ten years from now.

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

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

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

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




IWS


IPM


ILT


IST

FRAUNHOFER-GROUP LIGHT & SURFACES

COMPETENCE BY NETWORKING

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

CORE COMPETENCES OF THE GROUP

- surface and coating functionalization
- laser-based manufacturing processes
- laser development and nonlinear optics
- materials in optics and photonics
- microassembly and system integration
- micro and nano technology
- carbon technology
- measurement methods and characterization
- ultra precision engineering
- material technology
- plasma and electron beam sources

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FRAUNHOFER INSTITUTE FOR ELECTRON BEAM AND PLASMA TECHNOLOGY FEP, DRESDEN

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

www.fep.fraunhofer.de

FRAUNHOFER INSTITUTE FOR LASER TECHNOLOGY ILT, AACHEN

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

www.ilt.fraunhofer.de

FRAUNHOFER INSTITUTE FOR APPLIED OPTICS AND PRECISION ENGINEERING IOF, JENA

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

www.iof.fraunhofer.de

FRAUNHOFER INSTITUTE FOR PHYSICAL MEASUREMENT TECHNIQUES IPM, FREIBURG

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

www.ipm.fraunhofer.de

FRAUNHOFER INSTITUTE FOR SURFACE ENGINEERING AND THIN FILMS IST, BRAUNSCHWEIG

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

www.ist.fraunhofer.de

FRAUNHOFER INSTITUTE FOR MATERIAL AND BEAM TECHNOLOGY IWS, DRESDEN

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

www.iws.fraunhofer.de

EXCELLENT COOPERATION PARTNER TU DRESDEN

The cooperation with the TU Dresden began in 1997. Since then the Fraunhofer IWS has continuously expanded the cooperation with various university chairs. Such collaboration enables the combination of the broad basic science knowledge of the university with the applied development work performed at the IWS. Professors and coworkers at the TU Dresden are closely involved in IWS research projects and have access to the technical equipment and infrastructure at the institute. IWS management and coworkers support the university in educating students and graduate students. Junior scientists emerge from this pool. This effort is driven by these scientists:

FACULTY OF MECHANICAL SCIENCE AND ENGINEERING INSTITUTE OF MANUFACTURING TECHNOLOGY

CHAIR OF LASER AND SURFACE TECHNOLOGY
PROF. DR.-ING. HABIL. ECKHARD BEYER

Topics:

- laser systems technology
- laser machining processes
- plasma in manufacturing
- surface technologies
- laser robotics

FACULTY OF MECHANICAL SCIENCE AND ENGINEERING INSTITUTE OF MATERIALS SCIENCE

CHAIR OF MATERIALS SCIENCE
PROF. DR.-ING. CHRISTOPH LEYENS

Topics:

- metallic and intermetallic high temperature materials
- ferrous and nonferrous materials
- surface and coating technologies
- relationships between microstructure and properties of metallic materials

FACULTY OF MATHEMATICS AND NATURAL SCIENCES DEPARTMENT OF CHEMISTRY AND FOOD CHEMISTRY

CHAIR OF INORGANIC CHEMISTRY
PROF. DR. RER. NAT. HABIL. STEFAN KASKEL

Topics:

- synthesis, characterization and application of porous materials
- inorganic nanoparticles
- nanocomposites and hybrid materials

DRESDEN concept

"We all must discern, that we all must learn."

Wilhelm Busch

FACULTY OF MECHANICAL SCIENCE AND ENGINEERING INSTITUTE OF MANUFACTURING TECHNOLOGY

PROFESSOR FOR LASER STRUCTURING IN MANUFACTURING TECHNOLOGY

PROF. DR.-ING.
ANDRÉS-FABIÁN LASAGNI

Research focuses on the development of new methods to fabricate large area 2- and 3-dimensional micro- and nanostructures on flat and curved surfaces. Structure size and geometry periodically affect electrical, chemical and mechanical properties of surfaces in various materials. These surfaces can be used in biotechnology, photonics and numerous tribological systems.

FACULTY OF MECHANICAL SCIENCE AND ENGINEERING INSTITUTE OF MATERIALS SCIENCE

PROFESSOR FOR MATERIALS TESTING AND CHARACTERIZATION

PROF. DR.-ING.
MARTINA ZIMMERMANN

Her expertise in high frequency fatigue testing and the associated measurement technologies in combination with high-resolution analytics provide the basis for research at the highest scientific level. Prof. Zimmermann focuses on basic research but also wants to use high frequency testing methods in terms of short-run analysis for the characterization and prevention of materials damage in industrial applications.

FACULTY OF MECHANICAL SCIENCE AND ENGINEERING INSTITUTE OF MANUFACTURING TECHNOLOGY

PROFESSOR FOR NANO- AND COATING TECHNOLOGY

PROF. DR. RER. NAT.
ANDREAS LESON

Topics:

- nanotechnology
- thin film technology

FACULTY OF MECHANICAL SCIENCE AND ENGINEERING INSTITUTE OF MANUFACTURING TECHNOLOGY

PROFESSOR FOR PRODUCTION TECHNOLOGY

STEINBEIS UNIVERSITY
PROF. DR-ING.
ULRICH GÜNTHER

Topics:

- surface cutting
- production design

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

The Dresden Innovation Center Energy Efficiency originates from the very successful cooperation between the Technische Universität Dresden and the Fraunhofer-Gesellschaft with the DRESDEN-concept.

The goal of the innovation center is to strengthen academic education, research and innovation competency of both institutions through close scientific collaboration. The results shall benefit the Dresden research region.

The competences of 4 Fraunhofer and 8 university institutes are bundled to collaborate on research relevant to energy efficiency:

- high performance solar cells,
- fuel cells,
- high temperature energy technology,
- lightweight construction and energy efficient manuffacturing,
- energy saving displays.

These topics are of substantial interest to industry in terms of research and development services and education of scientists and engineers.

Within this innovation center the TU Dresden and Fraunhofer-Gesellschaft particularly focus on the promotion and support of the next generation of scientists and engineers. They offer attractive working conditions to junior researchers.

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The Dresden Innovation Center Energy Efficiency achieves a high performance level because it tightly connects basic research at the Technische Universität Dresden with Fraunhofer's competences to transfer technologies and innovations to industry. Thus the implementation speed for industrial innovation increases. The university and Fraunhofer strengthen Germany's economy.

The Fraunhofer-Gesellschaft funds the innovation center with six million Euros. The Free State of Saxony contributes another four million Euros. The funding secured numerous highly qualified science and engineering jobs between 2009 and 2013.

DIZE^{EFF} is scientifically as well as economically a full success. DIZE^{EFF} scientists were, for example, participating in research on organic electronics, which was honored with the German Future Award in 2011. Prof. Dr. Lasagni, Dr. Müller-Meskamp and their research teams received the German High Tech Champions Award in Solar/PV for their overarching project research on rapid large area nanostructure fabrication for high efficiency solar cells.

An important performance measure for DIZE^{EFF} is the amount of third party revenues. Already after three years in operation the innovation center acquired more then 10 million Euros from third parties. These additional funds will establish and secure more science jobs in the following years.

The consortium also presented results in the education of junior scientists. Since the winter semester of 2011 the TU Dresden has offered the discipline "Regenerative Energy Systems" as a field of study. Several DIZE^{EFF} professors are involved. Furthermore, Fraunhofer institute employees are increasingly involved with teaching at the TU Dresden.

The Dresden conference "Future Energy" will take place for the second time in 2013. This conference is another result of the successful cooperation in the research region Dresden.

Further information:
www.innovation-energieeffizienz.de

DRESDEN concept

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

9 institutions of the TU Dresden collaborate with 4 Fraunhofer institutes in Dresden on 23 scientific projects in 6 subject complexes related to energy efficiency.


Fraunhofer IWS


Dresden


Fraunhofer
IWS


Fraunhofer
THERMISCHES BESCHICHTEN
FÜGEN


Girls'Day
Mädchen-Zukunftstag
Fraunhofer IWS
26.04.2012

SPECIAL EVENTS

MARCH 2nd, 2012

20 Years Fraunhofer in Dresden, Gala ball at the Dresden Airport (Co-organizer: Fraunhofer IWS Dresden)

MARCH 14th-15th, 2012

TAW-Symposium "Thermal Coating with Laser Based Manufacturing Processes" of the Technical Academy Wuppertal e.V. in collaboration with the Fraunhofer IWS Dresden and FriBa Lasernet Holzkirchen in Dresden

MARCH 27th-28th, 2012

9th Workshop "Industrial Applications Of High Power Diode Lasers" (Organizer: Fraunhofer IWS Dresden)

APRIL 26th, 2012

Participation of the Fraunhofer institute center in the federal "Girls Day"

JUNE 11th, 2012

"5th Nanofair Junior Scientists Forum", event at the "Nanofair 2012" (Organizer: Fraunhofer IWS Dresden)

JUNE 12th -13th, 2012

"9th International Nanotechnology Symposium Nanofair – New Ideas For Industry", held at the International Congress Center Dresden
(Organizers: Fraunhofer IWS Dresden and the state capital Dresden)

JUNE 14th, 2012

Workshop "Nanocomposites For Industrial Applications", event at the "Nanofair 2012"
(Organizer: Fraunhofer IWS Dresden)

JULY 6th, 2012

Participation of the Fraunhofer institute center at the "Long Night Of Sciences" of the state capital Dresden

AUGUST 23rd, 2012

Visit by Prof. Sabine von Schorlemer, State Minister for Science and Art, at the Fraunhofer IWS

AUGUST 27th-31st, 2012

1st International Summer School – "Trends and New Developments in Laser Technologies"
(Organizer: Fraunhofer IWS Dresden)

OCTOBER 16th-17th, 2012

"FiSC 2012 – International Laser Symposium Fiber & Disc" at the International Congress Center Dresden (Organizer: Fraunhofer IWS Dresden)

OCTOBER 17th, 2012

"Industry @ Fraunhofer IWS – Innovation Evening For Companies From The Central German Region"
(Organizer: Fraunhofer IWS Dresden)

OCTOBER 17th-18th, 2012

"Tailored Joining 2012 – Joining Technology Symposium" at the International Congress Center Dresden (Organizers: Fraunhofer IWS Dresden und TU Dresden)

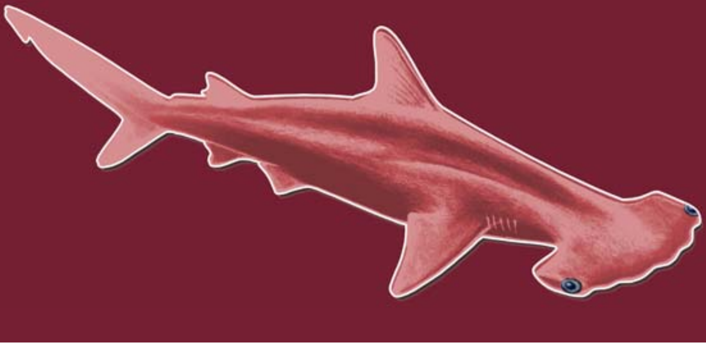
NOVEMBER 9th, 2012

Theme day "Tool And Die " (Organizer: Carbon Composites e.V., co-organizer: Fraunhofer IWS Dresden)

NOVEMBER 15th, 2012

Workshop "Lithium-Sulfur Batteries " at the Fraunhofer-Institute for Materials and Beam Technology (Organizer: Fraunhofer IWS Dresden, Institute for Inorganic Chemistry TU Dresden)

AWARDS AND HONORS



20 Years Fraunhofer in Dresden

This year the Fraunhofer institutes and institute subsidiaries in Dresden celebrated the 20th anniversary. Currently these institutes generate a combined annual turnover of more than 130 million Euros. Dresden is one of the major sites of the Fraunhofer-Gesellschaft with more than 1300 employees.

The Fraunhofer-Gesellschaft awarded **Prof. Dr.-Ing. habil. Eckhard Beyer** the Fraunhofer Medal during the celebration "20 Years Fraunhofer Dresden". Prof. Bullinger's laudation especially prized Prof. Beyer's intensive engagement in the growth of the IWS and the successful establishment of the institute in the scientific and economic community. He also underlined the close and very fruitful collaboration with the TU Dresden and Prof. Beyer's tireless work weaving a close network with non-university research organizations.

The Joseph-von-Fraunhofer Prize 2012 went to **Dr. Stefan Braun** (Fraunhofer IWS Dresden) as well as to Dr. Klaus Bergmann (Fraunhofer ILT Aachen) and Dr. Torsten Feigl (Fraunhofer IOF Jena) for their strategic collaboration in the area of EUV Technologies. Jointly they create essential elements for German industry active in the field of EUV lithography. Dr. Stefan Braun and his team optimized reflective coatings for illumination and projection mirrors, which are required for the exposure of microchips. The developed magnetron sputtering process achieves the highest precision without the need for additional polishing or verification steps. A system for large area precision coating deposition is already deployed in industrial manufacturing.

Dr. Matthias Lütke of the Fraunhofer IWS Dresden received this year's award from the Scientific Society for Laser Technology e.V. (WLT). Dr. Lütke was honored for developing remote laser beam cutting processes. His work received international recognition. Remote laser beam cutting is an alternative process for the separation of parts, which previously were manufactured primarily by stamping. Seals for motor components or electrodes for lithium ion cells are good examples. The process also allows the use of highest strength steels for the parts and offers higher flexibility in terms of design. The WLT award is bestowed annually for outstanding accomplishments in the field of applied laser research.

At the second international conference and exhibition "Aluminum 2D Welding And Brazing" in Moscow, **Dr. Jens Standfuß and Dr. Dirk Dittrich** received the prize, sponsored by ALCOA Russia, for their contribution on laser welding of aerospace structures.

On December 14th the 2012 IWS award recipients were honored.

Dr. Slavcho Topalski, Dr. Axel Zwick and Klaus Kratzenberg received the prize for the best scientific technical achievement. The award was given for the development of a novel high performance source for the deposition of corrosion protective coatings, which can be economically and technically operated in a band coating line. The process is characterized by very high deposition rates and is especially suitable for the cathodic corrosion protection of highest strength steels.

The research works of Mr. **Moritz Greifzu** on "Investigation Of Carbon Nanotube Based Thin Films For Space Applications" received honors as an outstanding student performance. He researched the electrical resistances of CNTs as a function of the chemical environment and he tested CNT based polymer foils with respect to shielding effect against electromagnetic radiation.

Ms. **Vicky Tröger** was also honored for an outstanding student performance. She developed a new method for nanoplotting proteins onto surface plasmon resonance chips. This technique enables the automated fabrication of biochips for clinical laboratories. The chips can also be stored for at least 4 weeks and can even be regenerated.

Mr. **Teja Roch** received the award for the best scientific achievement of a junior scientist. He delivered an important contribution to nano- and microstructuring of amorphous carbon coatings. Direct laser interference structuring reduces the coefficient of friction of amorphous carbon coating by up to 30 %. The areal processing speed is about 60 $cm^2\ s^{-1}$.

The prize for the best innovative product idea to start a new business field went to **Dr. Axel Jahn** and Mr. **Markus Wagner**. Jointly they investigated the possibilities for laser hardening to improve the crash strength of metal sheets (Page 82/83). The localized laser hardening in highly stressed regions allows the use of low strength steel sheets of minimized thickness while maintaining the crash strength. The layout of the hardened zones is optimized via simulation and adapted to the loading exposure. The failure mode of crash structures such as beams, columns, sills and seat components can be tailored. Studying automotive engineering, materials and components, Mr. **Markus Wagner** wrote a masters thesis on this topic, which received the Bernhard-von-Cotta prize for outstanding theses. The TU Bergakademie Freiberg (VFF) issued the award.

The special prize of the institute went to Ms. **Antje König** for her extraordinary engagement during application and administration of EU projects.

Dr. Axel Jahn, Dr. Anja Techel, Teja Roch, Vicky Tröger, Markus Wagner, Dr. Axel Zwick, Prof. Andreas Leson, Klaus Kratzenberg, Prof. Eckhard Beyer, Moritz Greifzu, Dr. Slavcho Topalski (f.l.t.r.)

PUBLICATIONS

PRP = peer-reviewed papers

[L01]
L.-M. Berger

»Metallurgische Vorgänge beim thermischen Spritzen von Hartmetallen und deren Auswirkungen auf die Schichteigenschaften«

Tagungsband zum 15. Werkstofftechnischen Kolloquium in Chemnitz, 20.-21. September 2012, Schriftenreihe »Werkstoffe und Werkstofftechnische Anwendungen«, Band 47, S. 16-28
Herausgeber: B. Wielage
ISBN: 978-3-00-039358-7,
ISSN: 1439-1597

[L02] PRP
L.-M. Berger, D. Schneider, M. Barbosa, R. Puschmann

»Laser Acoustic Surface Waves for the Non-Destructive Characterisation of Thermally Sprayed Coatings«

Thermal Spray Bulletin 5 (2012), No. 1, P. 56-64
ISSN 1866-6248

[L03]
L.-M. Berger, M. Barbosa, H.-P. Martin, R. Puschmann, S. Scheitz, S. Thiele, C. Leyens, E. Beyer, A. Michaelis

»Potential of Thermal Spray Technologies for the Manufacture of TEG«

Thermoelectrics Goes Automotive II (Thermoelectrics III), Proc. Conf., 21.-23. November, 2012, Berlin, Germany, D. Jänsch (ed.). Renningen: expert Verlag, 2013, S. 260-272
ISBN 978-3-8169-3169-0

[L04]
L.-M. Berger, J. Spatzier, C. Hochmuth, R. Georgi

»Milling of Thermally Sprayed Hardmetal Coatings«

Thermal Spray Bulletin 5 (2012), No.1, p. 33-37
ISSN 1866-6248

[L05]
E. Beyer, A. Mahrle, M. Lütke, J. Standfuß, F. Brückner

»Innovation in High Power Fiber Laser Applications«

Proc. Of SPIE, Vol. 8237, 823717 (2012)

[L06]
E. Beyer, P. Herwig, S. Hunze, A. Lasagni, M. Lütke, A. Mahrle, S. Nowotny, J. Standfuß, S. Thieme

»High-Power Laser Materials Processing«

31th International Congress on Applications of Lasers and Electro Optics (ICALEO), 23.-27. September 2012, Anaheim, CA (USA), paper OP2 (2012), S. 1-10, Tagungs-CD, ISBN 978-0-912035-96-3

[L07]
S. Bonß

»Systemkomponenten sorgen für zuverlässige Prozesse«

9. Workshop »Industrielle Anwendungen von Hochleistungsdiodenlasern«, 27.-28. März 2012, Fraunhofer IWS Dresden, Tagungs-CD

[L08]
S. Bonß, J. Hannweber, U. Karsunke, S. Kühn, M. Seifert, E. Beyer

»Laser Heat Treatment with Latest System Components«

SPIE Photonics West 2012, 21.-26. Januar 2012, San Francisco, California, USA, Tagungs-CD

[L09]
S. Bonß, J. Hannweber, U. Karsunke, S. Kühn, M. Seifert, E. Beyer

»Laser Heat Treatment with Latest System Components«

31th International Congress on Applications of Lasers and Electro Optics (ICALEO), 23.-27. September 2012, Anaheim, CA (USA), Tagungs-CD
ISBN 978-0-912035-96-3

[L10]
L. Borchardt, M. Oschatz, M. Lohe, V. Presser, Y. Gogotsi, S. Kaskel

»Ordered Mesoporous Carbide-derived Carbons Prepared by Soft Templating«

Carbon 50 (2012), Nr. 11, S. 3987-3994

[L11]
S. Braun, A. Kubec, M. Menzel, S. Niese, P. Krüger, F. Seiboth, J. Patommel, C. Schroer

»Multilayer Laue Lenses with Focal Length of 10 mm«

SRI 2012
Journal of Physics: Conference Series (in Druck)

[L12]
B. Brenner, V. Fux, J. Standfuß, J. Kaspar, G. Göbel

»New Laser-Assisted Joining Technologies for Meeting the Demands of Electric Vehicles«

EALA 2012 - European Automotive Laser Applications, Bad Nauheim, 7.-8. Februar 2012, Tagungs-CD

[L13]
B. Brenner, G. Göbel, J. Standfuß, D. Dittrich, V. Fux, A. Grimm

»Neue Verfahren für das Fügen nicht oder schwer schweißbarer Werkstoffe und Mischverbindungen für luftfahrttypische Anwendungen«

Tagung »Schweißen im Luft- und Raumfahrzeugbau«, 11.-12. September 2012, Berlin, DVS-Berichte Band 287

[L14]
P. Bringmann, M. Kolb, D. Raps, I. Jansen

»APP-CVD as Pre-Treatment for Structural Bonding in Aircraft Industry – a Potential Alternative to Anodising or Silane Treatments?«

Euradh 2012, 9th European Adhesion Conference, 16.-20. September, 2012, Friedrichshafen/Germany, S. 64 und Tagungs-CD

[L15]
F. Brückner

»Modellrechnungen zum Einfluss der Prozessführung beim induktiv unterstützten Laser-Pulver-Auftragschweißen auf die Entstehung von thermischen Spannungen, Rissen und Verzug«

Fraunhofer Verlag, Stuttgart, 2012
Zugl.: Dresden, TU, Diss., 2011
ISBN 978-3-8396-0451-9

[L16]
F. Brückner, M. Riede, S. Nowotny, E. Beyer

»Herstellung hochpräziser metallischer 3D-Strukturen durch Auftragschweißen mit brillanten Strahlquellen«

5. TAW-Symposium »Thermisches Beschichten mit laserbasierten Fertigungsverfahren«
14.-15. März 2011, Dresden, Tagungsband

[L17]
F. Brückner, S. Nowotny, M. Riede, H. Hillig, C. Leyens, E. Beyer

»Generative Manufacturing by Use of High Brightness Lasers«

FiSC 2012 - Proceedings of the International Laser Symposium Fiber & Disc, 16.-17. Oktober 2012, Dresden, Germany

[L18]
F. Brückner, D. Lepski, S. Nowotny, C. Leyens, E. Beyer

»Calculating the Stress of Multi-track Formations in Induction-assisted Laser Cladding«

31th International Congress on Applications of Lasers and Electro Optics (ICALEO), 23.-27. September 2012, Anaheim, CA (USA), S. 176-182

[L19]
W. Bundschuh, S. Volk, A. Wetzig, M. Lütke

»Laser Remote Punch: Inline High Speed Laser-Cutting of Punching-Bending «

FiSC 2012 - Proceedings of the International Laser Symposium Fiber & Disc, 16.-17. Oktober 2012, Dresden, Germany

[L20]
L. R. X. Cortella, D. Langheinrich, E. F de Sá, H. T. Oyama, I. A. Cestari, A.. Lasagni, I. N. Cestari

»STEM Cell Adhesion and Proliferation on Polyurethane Treated with Direct Laser Interference Patterning«

Proceedings XXIII Congresso Brasileiro em Engenharia Biomédica, P. 1-7

[L21] PRP
L. Daniele Scintilla, L. Tricarico, A. Mahrle, A. Wetzig, E. Beyer

»A Comparative Study of Cut Front Profiles and Absorptivity Behavior for Disk and CO_2 Laser Beam Inert Gas Fusion Cutting«

Journal of Laser Applications 24 (2012), Nr. 5
Doi: 10.2351/1.4755980

[L22] PRP
C. Demuth, M. Bieda, A. Lasagni, A. Mahrle, A. Wetzig, E. Beyer

»Thermal Simulation of Pulsed Direct Laser Interference Patterning of Metallic Substrates Using the Smoothed Particle Hydrodynamics Approach«

Journal of Materials Processing Technology, 212 (2012), 689-699
Doi:10.1016/j.jmatprotec.2011.10.023

[L23]
G. Dietrich, M. Rühl, S. Braun, A. Leson

»Hochpräzise Fügungen mittels Reaktiven Nanometermultischichten: Entwicklung einer kontrollierbaren, lokalen und kurzzeitig wirkenden Wärmequelle zum Fügen von wärmeempfindlichen Bauteilen«

Vakuum in Forschung und Praxis 24 (2012), Nr. 1, S. 9-15

[L24]
D. Dittrich

»Verbesserung der Belastbarkeit von Haut-Haut-Schweißverbindungen für metallische Integralrumpf-Strukturen«

Stuttgart: Fraunhofer Verlag, 2012
Zugl.: Dresden, TU, Diss., 2011
ISBN 3-8396-0375-7
ISBN 978-3-8396-0375-8

[L25]
S. Dörfler, M. Hagen, H. Althues, J. Tübke, S. Kaskel, M.J. Hoffmann

»High Capacity Vertical Aligned Carbon Nanotube/Sulfur Composite Cathodes for Lithium-Sulfur Batteries«

Chemical communications 48 (2012), Nr. 34, S. 4097-4099

[L26]
S. Dörfler, I. Felhösi, I. Kék, T. Marek, H. Althues, S. Kaskel, L. Nyikos

»Tailoring Structural and Electrochemical Properties of Vertical Aligned Carbon Nanotubes on Metal Foil Using Scalable Wet-Chemical Catalyst Deposition«

Journal of power sources 208 (2012), S. 426-433

[L27]
B. Dresler, D. Köhler, G. Mäder, S. Kaskel, E. Beyer, L. Clochard, E. Duffy, M. Hofmann, J. Rentsch

»Novel Industrial Single Sided Dry Etching and Texturing Process for Silicon Solar Cell Improvement«

PVSEC, 9. Februar 2012, Frankfurt, Tagungsband

[L28]
V. Franke, J. Latokartano

»Application Potentials of New Pulsed Fiber Lasers of the LIFT Project«

FiSC 2012 - Proceedings of the International Laser Symposium Fiber & Disc, 16.-17. Oktober 2012, Dresden, Germany

[L29]
R. Frenzel, I. Jansen, T. Schiefer, F. Simon

»Organophile strukturierte Metalloberflächen für reproduzierbare und langlebige Klebungen«

12. Kolloquium Gemeinsame Forschung in der Klebtechnik, 28.-29. Februar 2012, Frankfurt/Main, S. 26

[L30]
R. Frenzel, I. Jansen, T. Schiefer, F. Simon

»Polyelektrolyte für das Kleben laserstrukturierter Aluminiumfügeteile«

Tagungsband 20. Neues Dresdner Vakuumtechnisches Kolloquium »Beschichtung, Modifizierung, und Charakterisierung von Polymeroberflächen NDVaK«, G. Blasek (Herausgeber), Leibniz-Institut für Polymerforschung Dresden e.V, 25.-26. Oktober 2012, S. 54-57
ISBN 978-3-98125-504-1

[L31]
R. Frenzel, I. Jansen, T. Schiefer, F. Simon

»Adhesion Promotion by Polyelectrolyte Coatings at Laser Structured Aluminum Surfaces«

Euradh 2012, 9th European Adhesion Conference, Friedrichshafen/Germany, 16.-20. September 2012, S. 27 und Tagungs-CD

[L32]
A. Fürst, A. Klotzbach, R. Zocher, T. Blum, F. Kretzschmar, K. Zenger

»Laser Induced Heat Setting of Thermoplastic Monofilaments«

6. Aachen-Dresden International Textil Conference 29.-30. November 2012, Dresden, Tagungs-CD (2012)

[L33]
G. Göbel, E. Beyer

»Bearbeitung größerer Bauteile mit dem Laser – Schweißen, Schneiden und Beschichten«

LASYS 2012 Stuttgart, 12.-13. Juni 2012

[L34]
G. Göbel, J. Standfuß, E. Beyer

»Welding of Mixed Materials Using High Brightness Lasers«

Welding and Joining Workshop, October 23-24, 2012, Schaumburg, Illinois, USA

[L35]
G. Göbel, B. Brenner

»Fügen mit Feldern – Hintergründe und Entwicklungen«

Fügetechnisches Symposium »Tailored Joining« , Dresden, 17.-18. Oktober 2012

[L36] PRP
G. Göbel, J. Kaspar, B. Brenner, E. Beyer

»Dissimilar Metal Joining: Macro- and Microscopic Effects«

5th International Conference on High Speed Forming, Dortmund, 24.-26. April 2012

[L37]
M. Graudenz, M. Heitmanek

»Laser Tools in the Manufacturing Process: Joining Technology Trends in Body Manufacturing at Audi«

Laser-Technik-Journal 9 (2012), Nr. 4, S. 24-27

[L38]
A. Grimm, G. Göbel, B. Brenner, E. Beyer

»Friction Stir Welding of 3D-Structures and Flexible Components«

9th International Friction Stir Welding Symposium, 15.-17. Mai, 2012, Huntsville, Alabama, USA

[L39]
S. Günther, R. Siebert, E. Beyer, W. Hofmann

»Einfluss der Bearbeitung von Elektroblechen auf die Verluste elektrischer Fahrmotoren«

EMA-Nürnberg 2012 Elektromobilitätsausstellung und Fachtagung

[L40]
Y. Gu, J. Lu, T. Grotjohn, T. Schuelke, J. Asmussen

»Microwave Plasma Reactor Design for High Pressure and High Power Density Diamond Synthesis«

Diamond and Related Materials 24 (2012), S.210-214

[L41]
M. Hagen, S. Dörfler, H. Althues, J. Tübke, M.J. Hoffmann, S. Kaskel, K. Pinkwart

»Lithium-Sulphur Batteries - Binder Free Carbon Nanotubes Electrode Examined with Various Electrolytes«

Journal of power sources 213 (2012), S.239-248

[L42]
J. Hauptmann, A. Klotzbach,
J. Sykora, S. Pieper

»Hochflexibles Laser-Rillen und -Stanzen bei der Herstellung von digital gedruckten Umverpackungen«

Tagung Verarbeitungsmaschinen und Verpackungstechnik 2012. Praxis trifft Wissenschaft! Tagungsband, S. 461-470, 22./23. März 2012 Dresden

[L43]
J. Hauptmann, A. Klotzbach,
K. Zenger, T. Schwarz, P. Rauscher,
F. Klenke

»High Speed Processing - Applications and Systems«

FiSC 2012 - Proceedings of the International laser Symposium Fiber & Disc, 16.-17. Oktober 2012, Dresden, Germany

[L44]
A. Jahn, M. Wagner

»Steigerung des Leichtbaupotenzials von Crashprofilen durch den Einsatz lasergeschweißter Mischbaustrukturen«

3. Freiberger Crashworkshop, 28. September, 2012

[L45]
I. Jansen

»Innovations in Adhesive Bonding Technology«

Fügetechnisches Symposium »Tailored Joining«, Dresden,
17.-18. Oktober 2012, S. 28

[L46]
I. Jansen, T. Schiefer, F. Simon,
R. Frenzel

»Herstellung organophiler klebbarer Metalloberflächen durch Laserbehandlung und Beschichtung«

6. MATERIALICA Surface Kongress, 24. Oktober 2012, München

[L47]
F. Kaulfuß, O. Zimmer

»Wie Nanostrukturierung die Grenzen der Hartstoffbeschichtung erweitert: Dicke Hartstoffschichten, hergestellt mit einer PVD-Dünnschichttechnik«

Jahrbuch Oberflächentechnik 2012

[L48]
A. Klausch, H. Althues,
T. Freudenberg, S. Kaskel

»Wet Chemical Preparation of YVO_4:Eu Thin Films as Red-Emitting Phosphor Layers for Fully Transparent Flat Dielectric Discharge Lamp«

Thin solid films 520 (2012), Nr. 13, S. 4297-4301

[L49]
A. Klotzbach, A. Fürst,
J. Hauptmann, E. Beyer

»Remote Processing of Tailored Fiber Reinforced Lightweight Structures«

31th International Congress on Applications of Laser and Electro Optics (ICALEO) 23.-27. September 2012, Anaheim (CA), USA, paper 401 (2012)

[L50]
A. Klotzbach, J. Hauptmann,
U. Klotzbach, A. Mahrle, A. Wetzig,
E. Beyer

»Remote Processing of Carbon Fiber Composite Materials with Brillant cw-Laser«

International Symposium on Laser Processing of CFRP and Composites (LPCC), 26.-27. April 2012, Yokohama, USA, Tagungs-CD (2012)

[L51]
A. Klotzbach, J. Sykora, M. Boden,
J. Hauptmann

»Scannersysteme für die Laser-Makromaterialbearbeitung: Klassifizierung und Systemvergleich«

8. Jenaer Lasertagung, 15.-16. November 2012, Jena, Deutschland (2012)

[L52]
A. Klotzbach, A. Zinke, T. Schwarz,
A. Fürst

»Automated Cutting of Non-Crimp and Woven Fabrics Using the Laser Remote Technology«

6. Aachen-Dresden International Textil Conference 29.-30. November 2012, Dresden, Tagungs-CD (2012)

[L53]
U. Klotzbach

»Status and Progress of European FP7 Project of LIFT – Leadership in Fibre Laser Technology«

FiSC 2012 - Proceedings of the International Laser Symposium Fiber & Disc, 16.-17. Oktober 2012, Dresden, Germany

[L54]
U. Klotzbach, M. Panzner,
G. Wiedemann

»Verfahrensgrundlagen und Gerätetechnik für die Laserreinigung von Kunst und Kulturgut«

Patitz, G.:
Natursteinsanierung 2012 : Neue Natursteinrestaurierungsergebnisse und messtechnische Erfassungen sowie Sanierungsbeispiele; 16. März 2011, 18. Fachtagung Natursteinsanierung
Stuttgart: Fraunhofer IRB Verlag, 2012, S.37-49

[L55]
T. Köckritz, E. Roch Talens,
R. Luther, G. Paschew, U. Keitel,
I. Jansen, O. Jost, A. Leson

»Dielectric Elastomer Actuators Based on Single Walled Carbon Nanotubes«

9th International Nanotechnology Symposium »New Ideas for Industry« Nanofair 2012, 12.-13. Juni, 2012, Dresden

[L56]
T. Köckritz, I. Jansen, R. Luther,
A. Richter

»Material Platform for Dielectric Elastomer Actuators - Important Properties of the Investigated Material and Long-Term Stability Characteristics of the Actuator Layers«

Euradh 2012, 9th European Adhesion Conference, Friedrichshafen/Germany, 16.-20. September, 2012, S. 120 und Tagungs-CD

[L57] PRP
J. Körner, G. Göbel, B. Brenner,
E. Beyer

»Numerical Simulation of Magnetic Pulse Welding: Insights and Useful Simplifications«

5th International Conference on High Speed Forming, Dortmund, 24.-26. April 2012

[L58]
L. Kotte, G. Mäder, J. Roch,
B. Leupolt, S. Kaskel, J. Wielant,
T. Mertens, F. Gammel

»Großflächige Plasmavorbehandlung und PECVD bei Atmosphärendruck mittels LARGE-Plasmaquelle«

Jahrbuch Oberflächentechnik 2012, Band 68
ISBN 978-3-87480-274-1

[L59]
M. Langer, R. Rechner, M. Thieme,
I. Jansen, E. Beyer

»Surface Analytical Characterisation of Nd:YAG-Laser Pre-Treated AlMg3 as a Preparation for Bonding«

Solid State Sci. 14 (2012)7,
S. 926-935

[L60]
D. Langheinrich, S. Eckhardt,
A. Lasagni

»Direct Fabrication of Periodic Patterns on Polymers Using Laser Interference«

Plastic Research Online,
10.1002/spepro.004281

[L61]
D. Langheinrich, S. Doerfler,
H. Althues, S. Kaskel, A. Lasagni

»Rapid and Scalable Method for Direct and Indirect Microstructuring of Vertical Aligned Carbon Nanotubes«

Surface and Coating Technology, 206, Nr. 23, S. 4808-4813

[L62]
D. Langheinrich, E. Yslas,
M. Broglia, V. Rivarola, D. Acevedo,
A. Lasagni

»Control of Cell Growth Direction by Direct Fabrication of Periodic Micro and Submicrometer Arrays on Polymers«

Journal of Polymer Science, 50,
Nr. 6, S. 415-422

[L63]
A. Lasagni, D. Langheinrich

»Direkte Fabrikation periodischer Muster auf Polymeren mit Hilfe von UV-Laserinterferenzstrukturierung«

Blasek, G., Leibniz-Institut für Polymerforschung -IPF-
Beschichtung, Modifizierung, und Charakterisierung von Polymeroberflächen, 20. Neues Dresdner Vakuumtechnisches Kolloquium 2012, Tagungsband, 25.-26. Oktober 2012, Dresden, S. 73-78

[L64]
A. Lasagni, T. Roch,
D. Langheinrich, M. Bieda,
H. Perez, A. Wetzig, E. Beyer

»Large Area Direct Fabrication of Periodic Arrays Using Interference Patterning«

Laser-based Micro- and Nanopackaging and Assembly VI, 24. Januar 2012 San Francisco, California, USA Proc. SPIE 8244, 82440F (2012);
DOI: 10.1117/12.906758

[L65]
A. Lasagni, D. Langheinrich,
T. Roch

»Fabrication of Circular Periodic Structures on Polymers Using High Pulse Energy Coherent Radiation and an Axicon«

Advanced engineering Materials, 14, 107-111

[L66]
B. Lehmann

»SWCNT des Fraunhofer IWS und ihre Weiterverarbeitung zu Nanosensoren wie z. B. piezoresistive Sensoren«

14. Chemnitzer Seminar für Nanotechnology, Nanomaterials and Nanoreliability, September 2012, Chemnitz

[L67]
B. Lehmann, E. Roch Talens,
A. Roch, O. Jost, A. Leson

»Nano- and Microfibers From Single-Walled Carbon Nanotubes«

9th International Nanotechnology Symposium »New Ideas for Industry« Nanofair 2012, 12.-13. Juni, 2012, Dresden, Tagungsband, S. 32

[L68]
B. Lehmann, T. Endmann,
A. Augustow, A. Roch,
E. Roch Talens, O. Jost, A. Leson

»Piezoresistive Sensors Based on SWCNTs Produced by Unique Pulsed Arc Discharge«

Paper-no. 1569543555. SSD12/SCI 2012: Session SCI8. März 2012, Chemnitz

[L69]
B. Lehmann, O. Jost

»Elektrospinnen – eine textilorientierte Technologie zur Mikro-/Nanofaserherstellung auf Basis von CNTs. Modernste Carbon-Nano-Technologie - Anwendungsbereit für Smarte Textilien.«

Workshop des SmartTex Netzwerkes. Mai 2012, Weimar

[L70]
C. Leyens, S. Nowotny, F. Brückner

»Innovations in Laser Cladding and Direct Metal Deposition«

SPIE Photonics West 2012, 21.-26. Januar 2012, San Francisco, California, USA

[L71]
C. Leyens, F. Brückner, S. Nowotny

»Latest Development Work on Induction Assisted Laser Cladding Processes«

Proceedings of the Laser Additive Manufacturing Workshop,
LAM, 29. Februar - 1. März 2012,
Houston, TX (USA)

[L72]
Y. Luo, A. Lode, A.R. Akkineni,
F. Sonntag, B. Nies, M. Gelinsky

»Well-Ordered Calcium Phosphate/alginate Biphasic Scaffolds Containing Designed Hollow Fibers for Bone Tissue Engineering and Regeneration«

Journal of tissue engineering and regenerative medicine 6 (2012), Supplement 1, Abstract 61.P20, S. 372

[L73]
R. Luther, M. Tietze, G. Paschew,
T. Köckritz, I. Jansen,
E. Roch Talens, O. Jost,
F. Schlenkrich, L. Seffner, U. Keitel,
A. Schönecker, A. Richter

»Full Polymer Dielectric Elastomer Actuators (DEA) Functionalized with CNTs and High-k Ceramics«

CIMTEC International Conference »Smart Materials, Structures and Systems«, 10.-14. Juni, 2012, Montecatini Therme, Italy, S. 88, C:P13

[L74] PRP
M. Lütke, J. Hauptmann, A. Wetzig

»Energetic Efficiency of Remote Cutting in Comparison to Conventional Fusion Cutting«

Journal of Laser Applications 24 (2012), Nr. 2, 022007-1 - 022007-7

[L75]
M. Lütke, F. Bartels, J. Hauptmann,
A. Wetzig, E. Beyer

»Relative Efficiency of Remote Laser Cutting.«

The Laser User (66)

[L76]
M. Lütke, A. Wagner, A. Wetzig,
E. Beyer

»Identification and Characterization of Analogies of Remote Fusion Cutting Processes Using Different Beam Sources«

31th International Congress on Applications of Lasers and Electro Optics (ICALEO), 23.-27. September 2012, Anaheim, CA (USA)

[L77]
A. Mahrle, S. Rose, M. Schnick,
T. Pinder, E. Beyer, U. Füssel

»Prozesscharakteristik des Laserstrahl-Plasmaschweißens von Stahl und Aluminium«

Tagungsband Dresdner Fügetechnisches Kolloquium 2012,
TU Dresden

[L78]
A. Mahrle, M. Schnick, S. Rose,
T. Pinder, E. Beyer, U. Füssel

»Development and Experimental Analysis of Laser-Assisted Plasma Arc Welding«

31th International Congress on Applications of Lasers and Electro Optics (ICALEO), 23.-27. September 2012, Anaheim, CA (USA), paper 1302, p. 435-444

[L79]
A. Mahrle, S. Rose, M. Schnick,
T. Pinder, E. Beyer, U. Füssel

»Improvements of the Welding Performance of Plasma Arcs by a Superimposed Fiber Laser Beam«

Photonics West, High-Power Laser Materials Processing:
Lasers, Beam Delivery, Diagnostics, and Applications
24.-26. Januar 2012, San Francisco, California, USA
Vol. 8239 82390D
ISBN: 978-0-8194-8882-4

[L80]
S. Makowski, V. Weihnacht,
F. Schaller, A. Leson

»Diesel Lubricated Ta-C-Coatings«

18th International Coloqium Triboloy, Technische Akademie Esslingen, Tagungsband S. 95, 10.-12. Januar 2012,
ISBN 3-924813-97-3

[L81]
D. Mari, L.-M. Berger, S. Stahr

»Analysis of Microstructural Changes with Temperature of Thermally Sprayed WC-Co Coatings by Mechanical Spectroscopy«

Internal Friction and Mechanical Spectroscopy, 16th International Conference on Internal Friction and Mechanical Spectroscopy (ICIFMS-16), 3.-8. Juli, 2011, Lausanne, Switzerland,
Eds.: R. Schaller, D. Mari
Solid State Phenomena, Vol. 184, 2012, p. 313-318
(ISSN 978-3-03785-338-2)

[L82]
T. Mertens, F.J. Gammel, M. Kolb,
O. Rohr, L. Kotte, S. Tschöcke,
S. Kaskel, U. Krupp

»Investigation of Surface Pre-Treatments for the Structural Bonding of Titanium«

International journal of adhesion and adhesives 34 (2012), S. 46-54

[L83]
L. Müller-Meskamp, Y.-H. Kim,
T. Roch, S. Hofmann, R. Scholz,
S. Eckardt, K. Leo, A. Lasagni

»Efficiency Enhancement of Organic Solar Cells by Fabricating Periodic Surface Textures Using Direct Laser Interference Patterning«

Advanced Materials, 24,
S. 906-910

[L84]
J. Musiol, M. Lütke, M. Schweier,
J. Hatwig, A. Wetzig, E. Beyer,
M. F. Zaeh

»Combining Remote Ablation Cutting and Remote Welding: Opportunities and Application Areas«

Photonics West, High-Power Laser Materials Processing:
Lasers, Beam Delivery, Diagnostics, and Applications
24.-26. Januar 2012, San Francisco, California, USA
Vol. 8239 8239 0Q
ISBN: 978-0-8194-8882-4

[L85]
S. Norman, A. Appleyard,
A. Hassey, A. Wetzig, E. Beyer

»Application and Performance of KW-Class Single-Mode Fibre Lasers in the Cutting of Non-Oriented Electrical Steel«

FiSC 2012 - Proceedings of the International Laser Symposium Fiber & Disc, 16.-17. Oktober 2012, Dresden, Germany

[L86]
S. Nowotny

»Hochproduktives Laser-Auftragschweißen mit Pulver und Draht«

Fraunhofer Verlag 2012, ISBN: 978-3-8396-0493-9

[L87]
S. Nowotny

»Oberflächenbeschichten und generativer Strukturaufbau durch Laser-Auftragschweißen«

5. TAW-Symposium »Thermisches Beschichten mit laserbasierten Fertigungsverfahren«
14.-15. März 2011, Dresden,
Tagungsband, S.1-7

[L88]
S. Nowotny, F. Brückner, H. Hillig, C. Leyens, E. Beyer

»Hochleistungs-Auftragschweißen mit Laserstrahlung«

Wt Wekstattstechnik online, Jahrgang 102 (2012) H.6, S. 368-369

[L89] PRP
S. Nowotny, J. Ortner, S. Scharek, J. Spatzier, E. Beyer

»Repair of Erosion Defects in Gun Barrels by Direct Laser Deposition«

Journal of Thermal Spray Technology 21, 2012, S. 1173-1183
DOI 10.1007/s11666-012-9817-3
(online-first publication)

[L90]
S. Nowotny, F. Brückner, H. Hillig, C. Leyens, F. Beck

»Hochproduktives Laser-Auftragschweißen durch Energiequellenkombination«

Schriftenreihe »Thermisches Spritzen«, Band 5, 2012, ISSN 1610-0530, Seiten 77-84

[L91]
M. Oschatz, L. Borchardt, M. Thommes, K.A. Cychosz, I. Senkovska, N. Klein, R. Frind, M. Leistner, V. Presser, Y. Gogotsi, S. Kaskel

»Carbide-Derived Carbon Monoliths with Hierarchical Pore Architectures«

Angewandte Chemie. International edition 51 (2012), Nr. 30, S. 7577-7580

[L92]
H. Pajukoski, J. Näkki, S. Thieme, J. Tuominen, S. Nowotny, P. Vuoristo

»Laser Cladding with Coaxial Wire Feeding«

31th International Congress on Applications of Lasers and Electro Optics (ICALEO), 23.-27. September 2012, Anaheim, CA (USA), paper 124 (2012), P. 169-178,
Tagungs-CD,
ISBN 978-0-912035-96-3

[L93]
J.-S. Pap, I. Jansen

»The Effect of Material Properties on the Strength of Adhesively Bonded Thermoplastic Composites«

Euradh 2012, 9th European Adhesion Conference, Friedrichshafen/Germany, 16.-20. September, 2012, S. 114 und Tagungs-CD

[L94]
H. Perez-Hernandez, A. Lasagni

»Fast and Efficient Manufacturing Method of 1D and 2D Polyethylene Terephthalate Transmission Diffraction Gratings by Direct Laser Interference Patterning«

Polymer Engineering and Science 52, 2012, Nr. 9, S. 1903-1908

[L95]
H. Perez-Hernandez, T. Paumer, T. Pompe, C. Werner, A. Lasagni

»Contactless Laser-Assisted Patterning of Surfaces for Bio-Adhesive Microarrays«

Biointerfaces, Online journal 7 (2012), Nr. 1-4, Art. 35, S.1-9

[L96]
R. Rechner

»Laseroberflächenvorbehandlung von Aluminium zur Optimierung der Oxidschichteigenschaften für das strukturelle Kleben«

Dissertation TU Dresden 2011
Verlag Dr. Hut, München, 2012
ISBN 978-3-8439-0306-6,
ISBN 3-8439-0306-9

[L97]
R. Rechner, I. Jansen, E. Beyer

»Laseroberflächenvorbehandlung von Aluminium zur Optimierung der Oxidschichteigenschaften für das strukturelle Kleben«

DVS-Berichte 292 (2012), S.1-6
ISBN 978-3-87155-599-2

[L98]
R. Rechner, I. Jansen, E. Beyer

»Optimization of the Aluminum Oxide Properties for Adhesive Bonding by Laser Surface Pre-Treatment«

Journal of Laser Applications 24 (2012), Nr. 3,
032002-1 bis 032002-9

[L99]
D.K. Reinhard, D.T. Tran, T. Schuelke, M.F. Becker, T.A. Grotjohn, J. Asmussen

»SiO_2 Antireflection Layers for Single-Crystal Diamond«

Diamond and Related Materials 25 (2012), S. 84-86

[L100]
A. Roch

»Herstellung von defektarmen einwandigen Kohlenstoffnanoröhren in großen Mengen«

Laser Magazin - Neue Werkstoffe Ausgabe 2 (2012), S. 57

[L101]
T. Roch

»Großflächige Herstellung von Nanostrukturen für effizientere organische Solarzellen«

Photonik 44 (2012), Nr. 3, S. 14

[L102]
T. Roch, V. Weihnacht, H.-J. Scheibe, A. Roch, A. Lasagni

»Nano- and Micro-Patterning of Diamond-Like Carbon for Tribological Application«

9th International Nanotechnology Symposium »New Ideas for Industry« Nanofair 2012, 12.-13. Juni, 2012, Dresden, Tagungsband

[L103]
E. Roch Talens, T. Endmann, A. Roch, M. Greifzu, T. Köckritz, B. Lehmann, O. Jost, I. Jansen, E. Beyer, A. Leson

»Highly Elastic Transparent SWCNT-Polymer Electrodes with Excellent Robustness and Long-Term Stability«

9th International Nanotechnology Symposium »New Ideas for Industry« Nanofair 2012, 12.-13. Juni, 2012, Dresden

[L104]
S. Rose, M. Schnick, A. Mahrle, T. Pinder, E. Beyer, U. Füssel

»Plasma Welding with a Superimposed Fiber Laser Beam«

Int. Institute of Welding, Study Group 212 »Physics of Welding« (2012),
Doc.XII-2055-12 / 212-1213-12 / IV-1106-12

[L105]
M. Rühl, G. Dietrich, E. Pflug, S. Braun, A. Leson

»Heat and Mass Transfer in Reactive Multilayer Systems (RMS)«

Comsol Europe
Proceedings of the 2012 Comsol Conference (in Druck)

[L106]
S. Scheitz, F.-L. Toma, L.-M. Berger, T. Hoffmann, U. Klotzbach, M. Fries, S. Thiele

»Entwicklung thermisch gespritzter Beschichtungslösungen für keramische Substrate«

Tagungsband zum 15. Werkstofftechnischen Kolloquium in Chemnitz, 20.-21. September 2012, Schriftenreihe »Werkstoffe und werkstofftechnische Anwendungen«, Band 47, p. 74-83 Herausgeber: B. Wielage
ISBN: 978-3-00-039358-7,
ISSN: 1439-1597

[L107]
T. Schiefer, I. Jansen, R. Frenzel, F. Simon

»Laser Structuring of Aluminum Surfaces and Subsequent Organophilic Coating for Structural Bonding«

Euradh 2012, 9th European Adhesion Conference, Friedrichshafen/Germany, 16.-20. September, 2012, S. 115 und Tagungs-CD

[L108]
N. Schilling, M. Paschke, U. Klotzbach, S. T. Hendow

»Formation of Tribological Structures by Laser Ablation«

Hennig, G. ; Society of Photo-Optical Instrumentation Engineers -SPIE- Bellingham/Wash.:
Laser applications in microelectronic and optoelectronic manufacturing, LAMOM XVII (2012), San Francisco, California, United States; Part of SPIE Photonics West
Bellingham, WA : SPIE, 2012,
Paper 82430X (Proceedings of SPIE 8243)

[L109]
F. Schmidt, H. Klemm, K. Schönfeld, A. Gerds, W. Hungerbach, C.J. van Lookeren Campagne, S. Kaskel

»Novel Composite Spherical Granulates with Catalytic Outer Layer and Improved Conversion Efficiency and Selectivity«

Chemical Engineering and Technology 35 (2012), Nr. 4, S. 769-775

[L110]
F. Schmidt, S. Paasch, E. Brunner, S. Kaskel

»Carbon Templated SAPO-34 with Improved Adsorption Kinetics and Catalytic Performance in the MTO-Reaction«

Microporous and mesoporous materials 164 (2012), S. 214-221

[L111]
D. Schneider, A. Leson, L. M. Berger

»Laserakustik für Schicht- und Oberflächenprüfung: Methoden für die zerstörungsfreie Prüfung von Schichten und Werkstoffoberflächen«

Vakuum in Forschung und Praxis 24 (2012), Nr. 4, S. 17-23

[L112]
D. Schneider, R. Hofmann,
T. Schwarz, T. Grosser, E. Hensel

»Evaluating Surface Hardened Steels by Laser-Acoustics«

Surface and coatings technology 206 (2012), Nr. 8-9, S. 2079-2088

[L113]
M. Schneider, M. Weiser, S. Dörfler,
H. Althues, S. Kaskel, A. Michaelis

»Electrodeposition of Copper on Aligned Multi-Walled Carbon Nanotubes«

Surface engineering 28 (2012), Nr. 6, S. 435-441

[L114] PRP
M. Schnick, S. Rose, U. Füssel,
A. Mahrle, C. Demuth, E. Beyer

»Experimental and Numerical Investigations of the Interaction Between a Plasma Arc and a Laser«

Welding in the World, Vol. 56, No. 03/04 (2012)

[L115]
B. Schuhmacher, S. Puls, J. Schauer-Paß, M. Strack, K. Nikolov,
H. Paschke, T. Stucky

»Plasma Technology for Energy Conversion and Storage: Chances and Challenges for Flat Steel Sheet Products«

13th International Conference on Plasma Surface Engineering, Garmisch-Partenkirchen,
10.-14. September 2012

[L116]
S. Schulze, G. Göbel, U. Füssel,
E. Beyer

»Optimization of FSW Clamping Systems by Utilizing Numerical and Experimental Approaches«

9th International Friction Stir Welding Symposium, 15.-17. Mai 2012, Huntsville, Alabama, USA

[L117]
L. D. Scintilla, L. Tricarico,
A. Wetzig, E. Beyer

»Energy Balance in Disk and CO_2 Laser Beam Inert Gas Fusion Cutting«

Photonics West, High-Power Laser Materials Processing: Lasers, Beam Delivery, Diagnostics, and Applications 24.-26. Januar 2012, San Francisco, California, USA
Vol. 8239 82390N
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[L118]
M. Seifert

»Die Vielfalt der Verfahrensvarianten bei der Laserwärmebehandlung mit präziser Temperaturregelung«

9. Workshop »Industrielle Anwendungen von Hochleistungsdiodenlasern«, 27.-28. März 2012,
Fraunhofer IWS Dresden,
Tagungs-CD

[L119]
R. Siebert, H. Thonig, A. Wetzig,
E. Beyer

»Applicability of Various Beam Sources for High Power Laser Cutting of Non-Oriented Electrical Steel«

Photonics West, High-Power Laser Materials Processing: Lasers, Beam Delivery, Diagnostics, and Applications
24.-26. Januar 2012, San Francisco, California, USA
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[L120]
R. Siebert, M. Lütke, A. Wetzig,
H. Thonig, E. Beyer

»Experimental Findings on High Power Laser Cutting of Non-Oriented Electrical Steel«

5th International Conference Magnetism and Metallurgy WMM'12, Ghent, Belgien
Tagungsband S. 262-271

[L121]
A. Sinibaldi, N. Danz, E. Descrovi,
P. Munzert, U. Schulz, F. Sonntag,
L. Dominici, F. Michelotti

»Direct Comparison of the Performance of Bloch Surface Wave and Surface Plasmon Polariton Sensors«

Sensors and Actuators. B 174 (2012), S. 292-298

[L122]
W.A. Soer, M.M.J.W. van Herpen,
M.J.J. Jak, P. Gawlitza, S. Braun,
N.N. Salashchenko, N.I. Chkhalo,
V.Y. Banine

»Atomic-Hydrogen Cleaning of Sn From Mo/Si and DLC/Si Extreme Ultraviolet Multilayer Mirrors«

Journal of micro/nanolithography, MEMS and MOEMS 11 (2012),
Nr. 2, Art.021118

[L123]
J. Standfuß, E. Beyer

»Innovationen beim Laserstrahlschweißen mit hochbrillanten Strahlquellen«

Fügetechnisches Symposium »Tailored Joining« Dresden, 17.-18. Oktober 2012

[L124]
J. Standfuß, D. Dittrich, B. Brenner,
B. Winderlich, G. Kirchhoff,
J. Liebscher, G. Goebel, A. Grimm

»Laser Beam Welding of High Strength Aluminium Alloys«

The 2nd International Conference and Exhibition »Aluminium-21/WELDING AND BRAZING«, Saint Petersburg, Russland, 20.-22. November 2012, Tagungsband

[L125]
F. Takali, A. Njeh, D. Schneider,
M.H. Ben Ghozlen

»Surface Acoustic Waves Propagation in Epitaxial ZnO/alpha-Al_2O_3 Thin Film«

Acta acustica united with Acustica 98 (2012), Nr. 2, S. 223-231

[L126]
G. Theiler, T. Gradt, W. Österle,
A. Brückner, V. Weihnacht

»Friction and Endurance of MoS_2/ta-C Coatings Produced by Laser-Arc Deposition«

Wear 297 (2013) S. 791-801

[L127]
S. Thieme, R. Kager, S. Nowotny

»Neuentwicklungen zum Laser-Heißdraht-Auftragschweißen«

Schriftenreihe »Thermisches Spritzen«, Band 5, 2012
ISSN 1610-0530, S. 85-92

[L128] PRP
F.-L. Toma, L.-M. Berger, S. Scheitz,
S. Langner, C. Rödel, A. Potthoff,
V. Sauchuk, M. Kusnezoff

»Comparison of the Microstructural Characteristics and Electrical Properties of Thermally Sprayed Al_2O_3 Coatings from Aqueous Suspensions and Feedstock Powders«

Journal of Thermal Spray Technology, 2012, Vol. 21, No. 3-4,
p. 480-488

[L129]
A. Voronov, P. Gawlitza, R. Cambie,
S. Dhuey, E. M. Gullikson,
T. Warwick, S. Braun, W. Yashchuk,
H.A. Padmore

»Conformal Growth of Mo/Si Multilayers on Grating Substrates Using Collimated Ion Beam Sputtering«

Journal of Applied Physics 111 (2012), Nr. 9, 093521, 9

[L130]
M. Wagner

»Belastungsangepasstes Bauteildesign mithilfe lokaler Laserverfestigung«

2. Freiberger Crashworkshop,
03. Februar, 2012

[L131]
F. Wehnert, I. Jansen, J. Heinrich

»Multifunctional Adhesives by Integration of Carbon Nanotubes«

Euradh 2012, 9th European Adhesion Conference, Friedrichshafen/Germany, 16.-20. September, 2012, S. 116 und Tagungs-CD

[L132]
F. Wehnert, I. Jansen, E. Beyer

»Nanopartikel-basierte Klebstoffsysteme«

DVS-Berichte 292 (2012), S. 65-72
ISBN 978-3-87155-599-2

[L133]
V. Weihnacht

»Industrielle Herstellungstechnologie für superharte ta-C Schichten und Anwendungsbeispiele«

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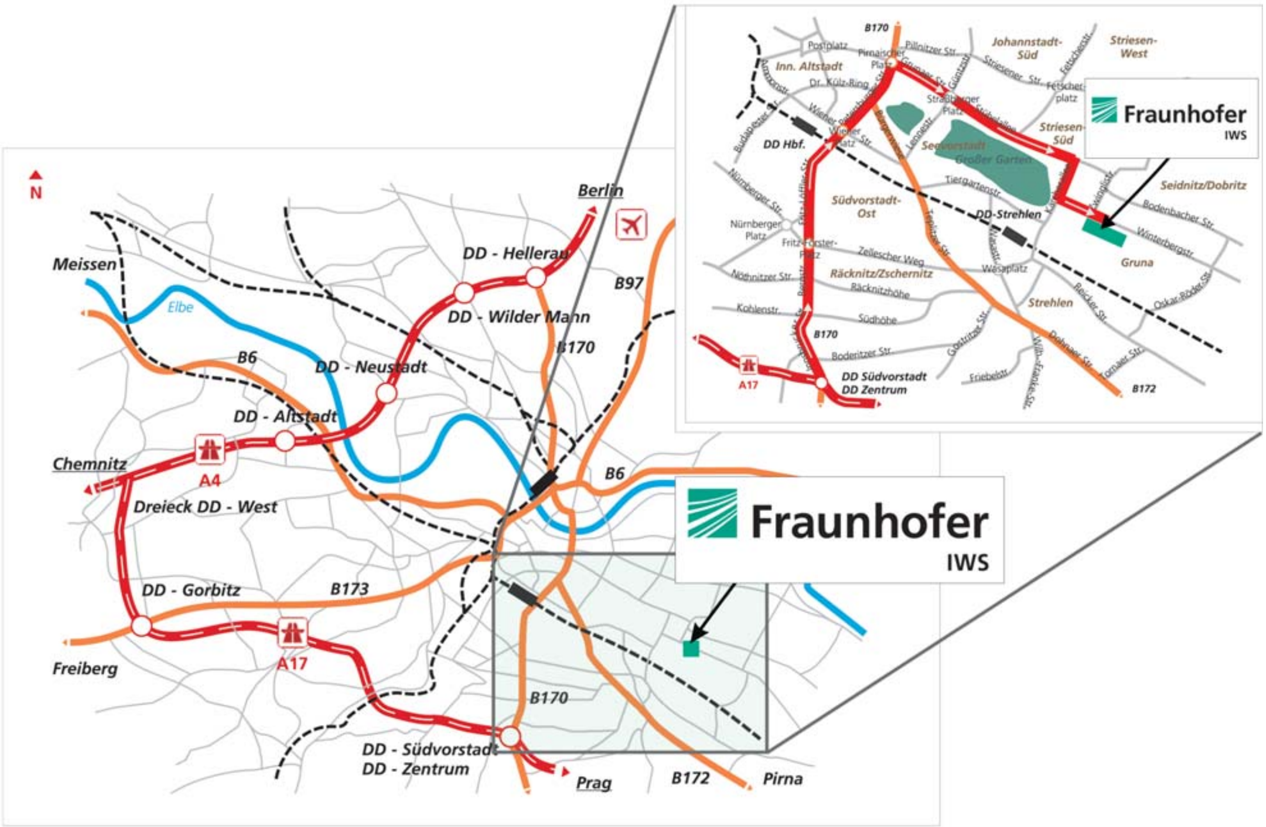

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- follow road B170 in direction Stadtzentrum (city center) to Pirnaischer Platz (about 6 km)
- at Pirnaischer Platz turn right towards "Gruna / VW-Manufaktur"
- continue straight until the end of the "Großer Garten" (Great Garden) and then turn right onto Karcherallee
- at the next traffic light turn left onto Winterbergstraße and continue straight until IWS

by railway and tram

- from Dresden main railway station take line #10 to Straßburger Platz
- change to line #1 (Prohlis) or #2 (Kleinzschachwitz) heading out from the city; exit at Zwinglistraße stop
- 10 minutes to walk from there (in the direction of Grunaer Weg)

by air plane

- from Airport Dresden-Klotzsche with a taxi to Winterbergstraße 28 (about 10 km)
- or with public transportation (shuttle train) to the main railway station (Hauptbahnhof), and continue with the tram

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