Fraunhofer

IWS Dresden

FRAUNHOFER INSTITUTE FOR MATERIAL AND BEAM TECHNOLOGY IWS

ANNUAL REPORT 2011

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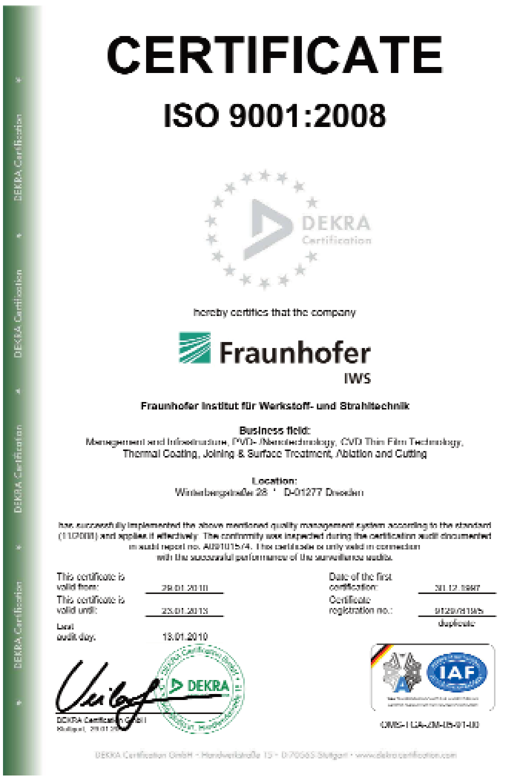

CERTIFICATE

ISO 9001:2008

DEKRA Certification

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: 29.01.2010
This certificate is valid until: 23.01.2013
Last audit day: 13.01.2010

Date of the first certification: 31.12.1997
Certificate registration no.: duplicate

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FOREWORD

Fantasy trumps knowledge,
because knowledge has its limitations.
Albert Einstein

In 2011 the German economy recovered and grew by more than 3%. This positive development drove IWS revenues, which increased by 17%. Industrial revenues accounted for 46% of the institute's operating budget.

The growing concentration of research and development efforts in the areas of energy efficiency and energy technologies had a positive effect. For example, successfully finished projects focused on battery research, friction reduction and the optimization of electrical steel. Simultaneously numerous projects were started in the area of energy research, which will dominate IWS work during the coming years. In addition we transferred IWS technologies to our industrial partners across various sectors. Some of these innovations are highlighted in this Annual Report.

DRESDEN-concept is an initiative of non-university institutions collaborating with the Technische Universität Dresden. The Fraunhofer IWS fully supported the University initiatives to obtain the status of excellence. This effort helped our Fraunhofer institute to establish very successful collaborations with the Helmholtz Center Dresden Rossendorf and the Leibnitz institutes. The IWS network with its subsidiary in the United States and the project groups in Dortmund and Wroclaw was successfully expanded with continuing growth planned for 2012.

A particular highlight was the German-Dutch workshop on photovoltaics, which was attended by the Dutch Royal family. Dr. Lasagni and his team received the German High-Tech Champions award for their efforts in solar photovoltaics.

In 2011 the institute was subjected to a special technology audit. Representatives from industry and science institutions audited the institute's technology profile. The external auditors confirmed the excellent organization and work performed at the IWS. They concluded that the institute is dynamically structured and able to effectively respond to constantly changing requirements. Work areas are well aligned with key technologies and megatrends. The auditors also honored the successful development of the institute through the past 15 years. They appreciated that the institute's work and strategies target those challenges that our society is actually facing.

The audit results are just one of the reasons why we are very positively looking toward the year 2012, for which we anticipate even more success.

CONTENTS

THE FRAUNHOFER IWS

BUSINESS FIELDS

NETWORKS, NAMES, DATA

FOCUS
ENERGY RESEARCH

ENERGY RESEARCH AT THE IWS

The development and industrial implementation of modern technologies in the areas of energy transformation, storage and efficiency is of substantial importance to the Fraunhofer IWS. In 2011 the Institute solicited €5 million from industry and other sources for research projects in these areas. Additionally the institute spent €1 million on internal and basic research projects on energy topics. A substantial part of the funding was used to acquire equipment for roll-to-roll coating, post-processing and testing of battery and supercap materials (see page 84 through 85). These investments enable the institute to offer projects to industry supporting the manufacturing, processing and evaluation of coating materials. The institute is now capable of fabricating sample electrodes for testing purposes.

PRODUCTION TECHNOLOGY DEMONSTRATION CENTER FOR LITHIUM ION CELLS - DELIZ

Starting in 2010 the IWS participated in the large collaborative research project DeLIZ. We focused on production technology issues related to the manufacturing of lithium ion cells. This project was successfully finished in 2011. Numerous results were obtained that are of great interest to our industrial partners. Results include for example the energy-efficient roll-to-roll coating of electrodes, the low-cost remote laser shape cutting, the fixturing of individual foils and the welding of foil packages with minimal contact resistance as well as the laser preprocessing of current collector sheets.

RESEARCH FOCUS PHOTOVOLTAICS

Research in photovoltaics is of increasing importance at the IWS. Many of the related research topics require various areas of IWS competences. These include for example plasma and reaction technologies, surface functionalization, micro processing, print technology applications and process monitoring. So far we have addressed manufacturing aspects in the areas of coating generation and processing (deposition, etching, texturing, metalizing), laser-based ablation and laser interference structuring (efficiency increase of solar cells). Additional work was performed in process monitoring (gas phase characterization) and coating evaluation.

THE DRESDEN CONFERENCE "FUTURE ENERGY"

Fraunhofer IWS employees organized the Dresden conference "Future Energy". This first-time event was held from May 11th-13th, 2011. During the three-day conference representatives from industry and science presented their results, products and experiences in the areas of energy transformation, energy storage and efficient energy utilization. These technology areas represent a worldwide growing market with enormous economical potential. Material systems and manufacturing concepts were introduced and innovations were discussed. The 280 participants were excited about the quality as well as the scope of the event.

The next "Future Energy" conference is scheduled for May 28th-29th 2013. http://www.zukunftenergie-dresden.de

THE DRESDEN INNOVATION CENTER ENERGY EFFICIENCY DIZE^{EFF}

The project DIZE^{EFF} was initiated in 2009 under the umbrella of the DRESDEN-concept initiative. In 2011 the project performance was evaluated and successfully granted more funding for the next period. The cooperatively achieved research results are marketed for additional revenue acquisition from third parties. Selected results are presented on pages 30/31, 46/47 and 94/95 of the Annual Report. http://www.innovation-energieeffizienz.de

2011 HIGHLIGHTS

1

SCANNER TECHNOLOGY IN ACTION

The reduction of power losses is critical to manage energy consumption and heating dissipation in devices such as electro motors, transformers and converters. New laser technology is capable of reducing the magnetization losses in grain oriented electro steel sheets by about 10%. Partners Rofin-Sinar, the Machine Factory Arnold and the Fraunhofer IWS jointly developed the laser system and manufacturing processes (Fig. 1). The machine has a unique arrangement of scanner mirrors, which, combined with fast laser control, achieve excellent beam quality and so far unmatched dynamic capabilities. Simultaneously these systems are highly flexible and guarantee constant processing parameters. So far 4 systems were installed at global customers and 3 additional units are ready for production release in 2012.

THE SIXTH AIRBAG LASER CUTTING MACHINE INSTALLED IN MANUFACTURING

The Fraunhofer IWS and the company Held Systems have jointly developed a compact machine for the flexible laser cutting of airbag material. Such a system was sold to a new customer in 2011. The specialty of this particular machine is the capability to cut "OPW" (one piece woven) material using camera-based pattern recognition. The machine is installed at an automotive supplier in Japan and boasts highest productivity and flexibility.

INDUSTRIAL IMPLEMENTATION OF CONTIWELD TECHNOLOGY

The company Held Systems and the Fraunhofer IWS have partnered to develop and commercialize a new laser machine concept for the manufacturing of large area heat exchanger plates. These "pillow plates" require up to 800 welds per m^2. The new machine couples fast laser scanning technology with conventional kinematics to substantially reduce laser positioning cycle times. Enormous productivity gains were achieved when using more efficient pneumatic chucks. Specifically for this application Fraunhofer IWS engineers developed the CAD-CAM software "CAS.optWELD" for process planning and to program the "pillow plate" welds. Detailed information is provided on pages 50 and 51 of the Annual Report.

LASER TAILORED MICROREACTORS – THE MINIATURIZED LABORATORY

The Capitalis Technology GmbH teamed up with the Fraunhofer IWS to develop a closed process chain for the efficient manufacturing of customized microreactors. These microreactors are fabricated from multilayer systems of silicone, glass and metal or polymer. The fabrication process is fast and very flexible. So far 7 customized versions were made for the market. These include for example microreactors for:

- the standardized wet chemical photometric nitrate detection
- the electrochemical detection of environmentally relevant substances using a yeast cell sensor
- the testing of surface biocompatibility
- the sample preparation for SPR biochips and
- a fluorescence and chemiluminescence sensor platform based on living cells.

ROBOT SYSTEM FOR HARDENING AND BUILDUP WELDING OF TOOLS

Fraunhofer IWS engineers support the fixture construction division of Volkswagen AG to build a robotic machine for laser hardening and buildup welding. The IWS engineers deliver components and perform special training for Volkswagen employees. The machine is particularly tailored for the fabrication of new car body tools. System components for beam delivery, process control and powder delivery as well as complete and automatically interchangeable process modules are part of the support package. The system installation for laser processing various cutting and forming tools at Volkswagen AG in Wolfsburg was completed in 2011. The

2

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system startup and the VW employee training are planned for early 2012.

AUTOMATED LASER SYSTEM FOR THE GENERATIVE FABRICATION OF METALLIC COMPONENTS

The Fraunhofer IWS collaborated with the Machine Factory Arnold to implement a machining center for the generative fabrication of metallic components of complex shapes. The system (Fig. 2) is installed at the Center for Advanced Manufacturing Technologies (CAMT) in Wroclaw. It is based on a 5-axes CNC milling center, which is equipped with a fiber laser and an inert gas chamber. The functionality of the machine is highly complex and allows long-term automatic operation capability and stability. Advanced IWS system components were installed and networked:

- COAXn family processing heads
- E-MAqS camera system for process control
- DCAM software system for 3D data processing and offline programming
- material specific process parameters.

EXPANSION OF INDUSTRIAL APPLICATIONS OF TEMPERATURE MEASUREMENT AND CONTROL SYSTEMS "E-MAQS", "E-FAQS" AND "LOMPOCPRO"

These temperature measurement and control systems were originally developed for laser beam hardening processes. In recent years Fraunhofer IWS engineers have worked continually on expanding applications for these systems. They were adapted to work with manufacturing processes such as laser buildup welding, induction hardening and heat treatment of materials for photovoltaics. Today such processes are safely controlled by IWS temperature measurement and control technology similar to the original laser hardening processes. Some examples for commercial implementations are discussed as follows:
"E-MAqS" is a camera-based temperature data acquisition system and "LompocPro" is a temperature control system. Fraunhofer IWS engineers collaborated with the Machine Factory Arnold Ravensburg to implement both systems in a machine for repairing jet engine components at General Electric in Shanghai. Similar measurement and control system combinations were installed in machines for the generative fabrication of finest metallic structures at the CAMT in Wroclaw, at the System S.A. Katowice and at the Volkswagen AG for their universal tool making machine.

The "LompocPro" measurement and control system is also used at the company EMA Indutec. Here the unit monitors and controls inductive surface hardening processes. The company Sitec Industry Technologies in Chemnitz applies the extremely fast control system "E-FAqS" to explore new possibilities in solar cell manufacturing.

ION BEAM TECHNOLOGY FOR THE MANUFACTURING OF X-RAY OPTICS

For many years IWS engineers have used sputter technologies to develop and produce high performance X-ray mirrors. Magnetron sputter deposition is meanwhile used in several commercial coating machines to manufacture optical precision components. In 2011 the institute transferred ion beam technology to commercial partner AXO DRESDEN GmbH. This technology is implemented in the IonSys 1600 system (Fig. 3) made by Roth & Rau MicroSystems. In addition to the deposition of precision coatings the machine can also remove material from surfaces using tailored ion currents. The capability of cleaning, polishing or structuring of X-ray optical surfaces open new opportunities for customers to fabricate improved and even completely novel optical components.

FROM THE BOARD OF TRUSTEES

The Board of Trustees consults and supports the institute's management and the bodies of the Fraunhofer-Gesellschaft. The 21st Board of Trustees meeting occurred on March 24th 2011 at the Fraunhofer IWS in Dresden. The following members were active in the Board of Trustees during the reporting period:

Did the economy improve better than generally expected?

The GfK group is a global market research company that I personally know very well. They appear to confirm this. And so does the German industry, which thrives primarily on export and is still very optimistic in December 2011. However, market researchers expect a slowdown for 2012.

The best predictions are made for innovative areas that come up with the latest technologies. Many of these areas are still small, and thus are currently at the beginning of the industrial growth wave. However, this requires skilled personnel. Research and education have to become more of a focus for many. Established knowledge has to be strengthened and more quickly expanded. This will secure Germany's economic strength in the future. The predictions are not that bad or perhaps even good. The weak economy of many EU countries only marginally affects the Germany economy. Bad financial news did not curb the optimism of the German industry.

The research and development sector showed a much better performance in 2011 than expected. The Fraunhofer-Gesellschaft was very competitive. I was personally convinced of this when I attended the Fraunhofer-Symposium "Netzwert 2011" during November $28^{th}/29^{th}$ 2011 in München. More than 250 scientists and Board of Trustees members met to discuss Fraunhofer research results and evaluated the potential for future research collaborations. It also became clear that it is necessary to achieve a broader international penetration. The networking between Fraunhofer institutes, the Max-Planck Society and universities was evident at the symposium. The Fraunhofer Institute for Material and Beam Technology successfully follows this orientation. The success of the IWS is reflected in the highlights of 2011, which are based on core competences in surface and laser technologies and strategically aim at topics in energy, mobility, materials and health. This orientation leads the institute to perform research of high scientific and innovative quality resulting in important economic and political consequences.

The very successful cooperation with the Technische Universität Dresden strengthens research and education at the university. Well-trained and university educated employees are critical for the future of Germany's industry. The cooperation of the Technische Universität with external research institutions is also strengthening the university's participation in the competition for excellence status.

The Board of Trustees members are excited about the developments at the IWS in 2011 and support the strategic orientation of the institute.

The Board of Trustees thanks the colleagues, the institute's management and all partners for the achieved results and their effort. We send best wishes for health and success in the future.

Dr. Frank Junker

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

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

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

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

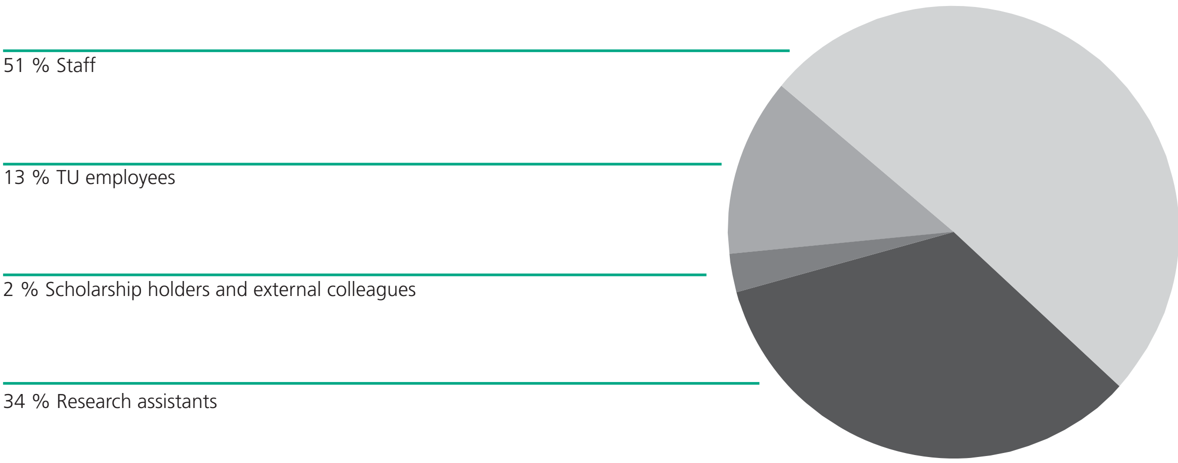
Business fields \ Core services	Laser materials processing	Surface functionalization and coating	Materials / nanotechnology	Systems technology	Process simulation
Ablation / cutting	■	□	□	■	□
Joining	■		■	□	□
Surface technology					
Surface layer technology	□	□	■	■	□
Thermal coating technology	□	■	□	□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

■ core competence
□ additional competence

INSTITUTE DATA

IWS EMPLOYEES

	Anzahl
Staff	**160**
Scientists / engineers (TU/FH)	121
Skilled workers with technical or mercantile education	30
Trainees	9
TU Dresden employees (working at the IWS)	**40**
Scholarship holders and external colleagues	**8**
Research assistants	**107**
TOTAL	**315**



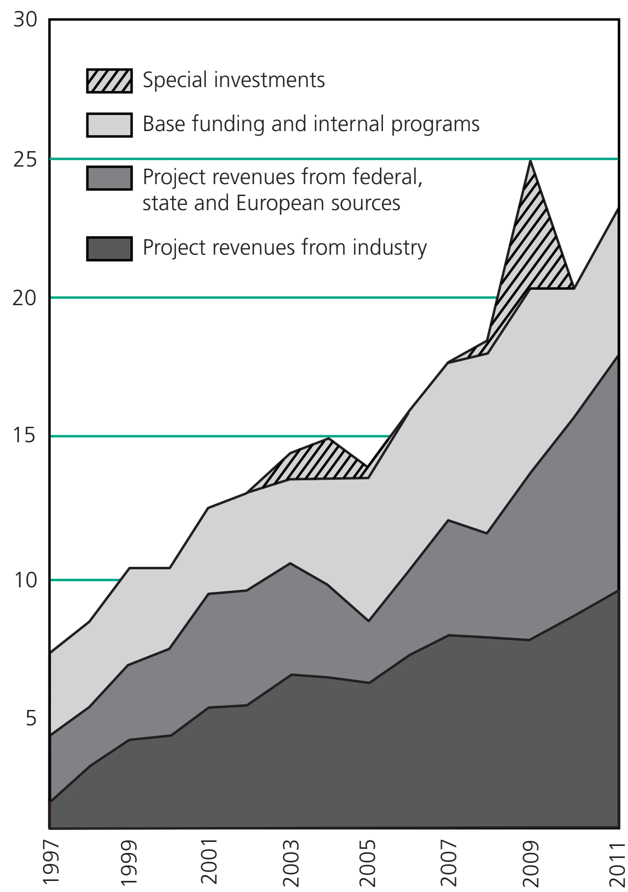
EMPLOYEES AT THE FRAUNHOFER CCL (USA) **14**

"All beginnings are easy; but the last steps are the most difficult and most seldom to be climbed."
Johann Wolfgang von Goethe

Revenues 2011 (Mio €)*	Operation		Investments		Total	
Project revenues from industry	9.2	45 %	0.2	6 %	9.4	40 %
Project revenues from federal, state and European sources	6.7	33 %	1.9	56 %	8.6	36 %
Base funding and Fraunhofer internal programs	4.4	22 %	1.3	38 %	5.7	24 %
	20.3		3.4		23.7	

Expenditures 2011 (Mio €)*		
Personnel costs	9.3	39 %
Material costs	11.0	47 %
Investments	3.4	14 %
	23.7	

*FEBRUARY 2012



IWS PUBLICATIONS

	number
Dissertations	5
Diploma theses	38
Patents	14
Journal papers	103
TOTAL	**160**

EXECUTIVE TEAM

ORGANIZATION AND CONTACTS

External Project Groups

CCL - USA
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Laser Applications
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Coating Technology
Dr. T. Schülke

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

PCW - Polen
Prof. Dr. E. Chlebus
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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 Nanotechnology
Prof. Dr. A. Leson
ext.: 3317

- **X-Ray and EUV Optics** – Dr. S. Braun, ext.: 3432
- **Nanotubes and -particles** – Dr. O. Jost, ext.: 3477
- **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
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

Network Nano ICP + NCC
Prof. Dr. A. Leson, ext.: 3317
Dr. O. Zimmer, ext.: 3257

Laser Materials Processing

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

- **Surface Treatment** – Dr. S. Bonß, ext.: 3201
- **Materials Characterization** – Dr. J. Kaspar, ext.: 3216
- **Welding** – Dr. J. Standfuß, ext.: 3212
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- **Special Joining Technologies** – Dr. G. Göbel, ext.: 3211

Ablation and Cutting
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- **Laser Cutting** – Dr. A. Wetzig, ext.: 3229
- **Microprocessing** – Dr. U. Klotzbach, ext.: 3252
- **Surface Functionalization** – Dr. A. Lasagni, ext.: 3007
- **High Speed Laser Processing** – Dr. J. Hauptmann, ext.: 3236

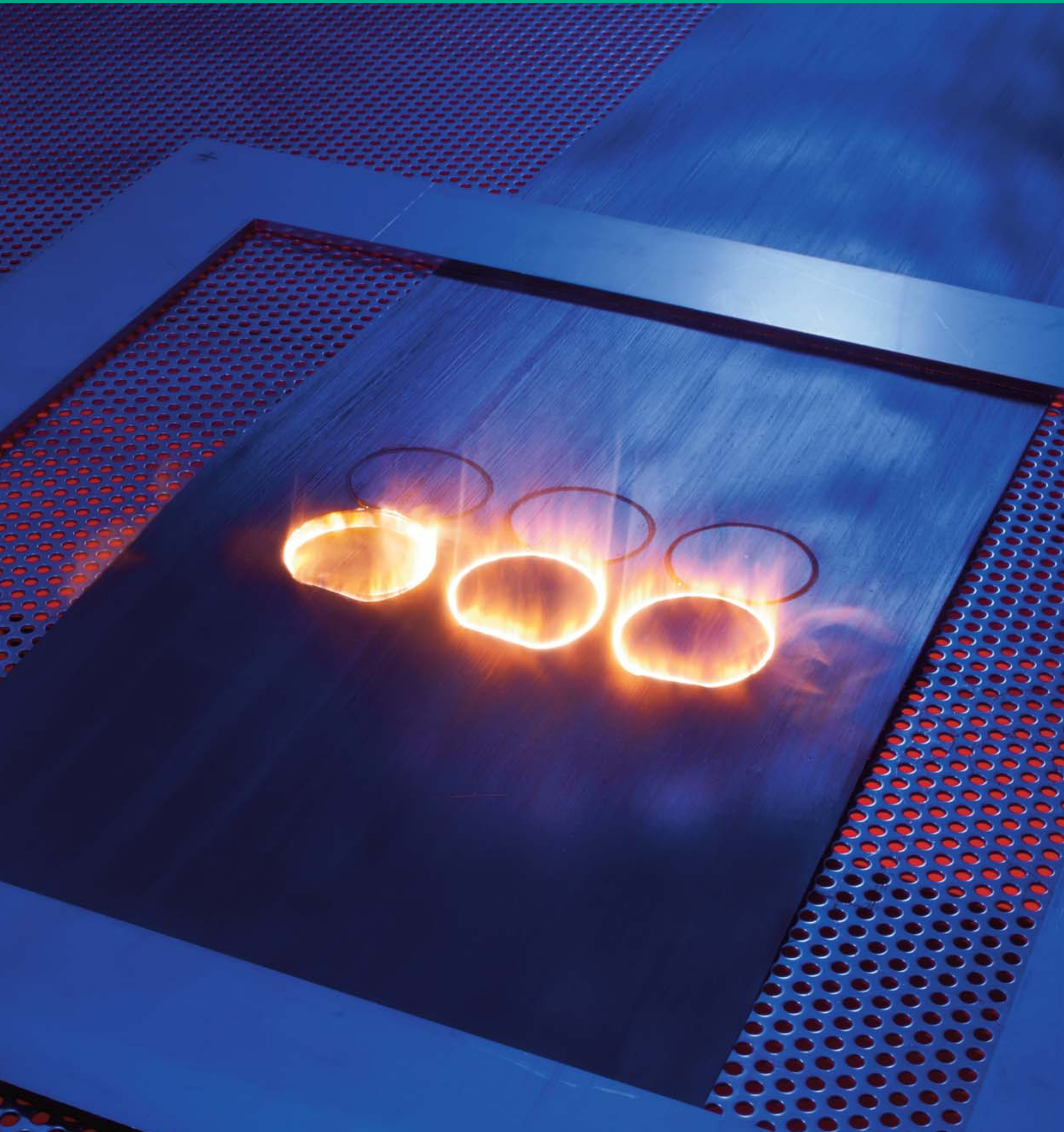
Network Laser LiFt
Dr. S. Bonß, ext.: 3201
C. Zellbeck, ext.: 3332

TECHNISCHE UNIVERSITÄT DRESDEN

Institute of Surface and 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



Enjoying the task yields excellent work
Aristotle

BUSINESS FIELD ABLATION AND CUTTING

Editor: Dr. Wetzig, by now you have been leading the laser ablation and cutting department for three years. How do you see the development of your department and especially the progress that was made after the economic crisis?

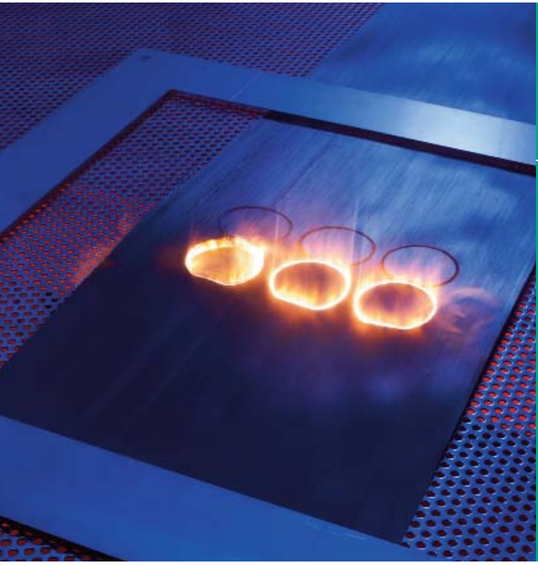
Dr. Wetzig: The economic crisis in 2009 did not hit us as hard as it did some of our customers. Back than we experienced only a slight reduction in industrial contract research revenues. I suppose that a Fraunhofer department needs to strategically position itself within its area of core competence so that it can sustain business during varying economic cycles. This requires maintaining a balance of current industrial projects and look-ahead research to maintain a competitive edge, which is the basis for future project acquisition from industry. In recent years we managed to achieve this for the business fields of ablation and cutting.

Editor: Electromobility became a very important topic. What are the resulting research foci in your department?

Dr. Wetzig: We are developing interdisciplinary technologies and indeed contribute solutions to the field of electromobility. One of our research topics is the cutting of battery foils. Here we deploy remote cutting processes using high brilliance cw fiber lasers as well as pulsed solid-state lasers. A strategic project was launched jointly with an industrial partner to determine the effect of laser cutting on the magnetic properties of electro steel sheets. Low loss electric drives for electric vehicles are an important component of electromobility. Electromobility is just one aspect of the "markets of the day after tomorrow", which the Fraunhofer-Gesellschaft anticipates in the field of "low loss generation, distribution and utilization of electrical energy". Our research on optimizing generator and transformer metal sheets using lasers is aligned with this vision and so are projects addressing the friction reduction of vehicle powertrain components using laser interference structuring.

Editor: How much can you publish about research results in the field of optimizing organic and thin film solar cells?

Dr. Wetzig: Since quite some time we are interested in photovoltaics. However, so far we did not have the appropriate laser sources and processes. Ultra short pulse lasers are just now becoming available. We recently acquired powerful picosecond and femtosecond lasers. These lasers, in combination with the development of a new laser interference process for large area surface structuring, provide the conditions necessary to successfully perform projects in this field. At this point we have started first projects but need to treat them as confidential to protect our industrial partners. In the area of structuring organic solar cells we are submitting a project proposal to a public funding agency. Here we will be able to publish our results in the future.



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.

HEAD OF DEPARTMENT

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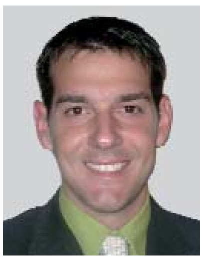
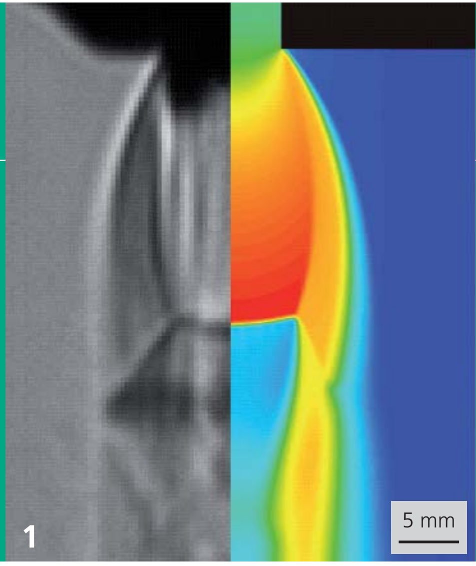


2011 PROJECT EXAMPLES



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INVESTIGATION OF THE GAS DYNAMICS DURING LASER BEAM CUTTING

THE TASK

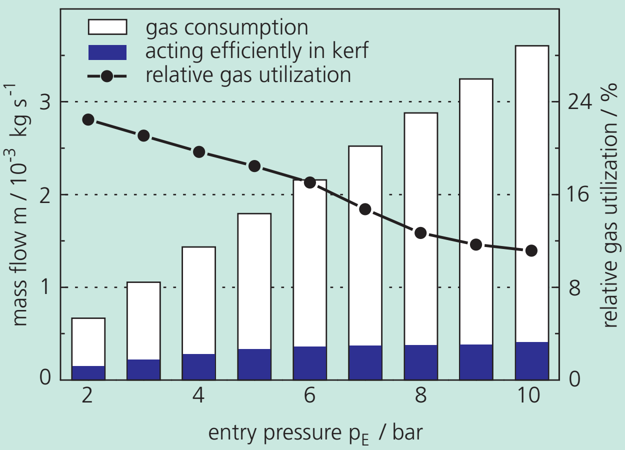
Laser beam cutting is a proven technology to separate metallic materials over a wide range of sheet thicknesses. Laser beam fusion cutting typically involves a laser beam and a cutting gas jet, which are guided along a predefined cutting contour. The laser beam heats the material exceeding the melting temperature and the gas jet ejects the molten material away thus generating a cut. The gas jet driven material ejection results from the large pressure gradient between the jet/melt interation zone and the surrounding atmosphere. Physically the gas jet can be described as a compressible flow with friction, which contains both super- and subsonic flow regions. The location and amplitude of associated compression shock waves substantially affect the gas flow and the resulting shear stresses at the cut front and edge regions. Currently our understanding of process variables and interactions of major effects is mainly empirical and based on experience. Studying the gas dynamics will help to more completely and fundamentally understand the process. In addition the simulations offer the opportunity to also study those process effects that are not directly observable. This will add to a better process understanding.

OUR SOLUTION

Fraunhofer IWS engineers have developed a simulation model to systematically study basic interactions between process parameters and the resulting cutting gas jet flows. The compressible process gas and its coefficient of friction is modeled using continuity equations for mass, momentum and energy and describing it as an ideal turbulent gas flow. Solving the resulting equation system requires special strategies since the equations are strongly coupled and nonlinear.

To validate the model the simulations were compared with experimental Schlieren flow visualizations. The results were in good agreement with respect to the location and dimensions of the supersonic regions and the associated compression shock waves in the free gas flow (Fig. 1) and in the modeled cut kerf (Fig. 3 and 4).

Gas consumption and relative gas utilization as a function of gas pressure for conical nozzles with 3 mm diameter (kerf width 0.4 mm, sheet thickness 6.0 mm)



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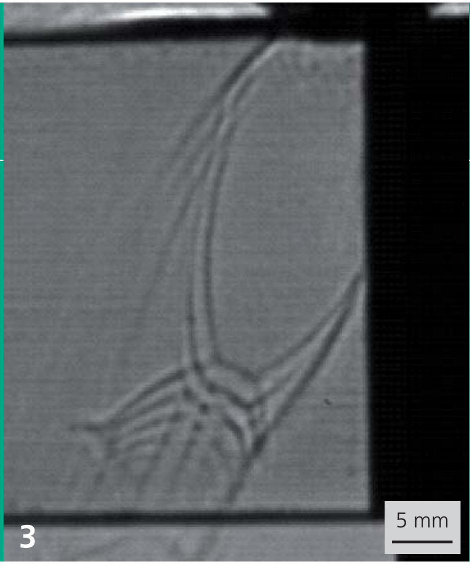

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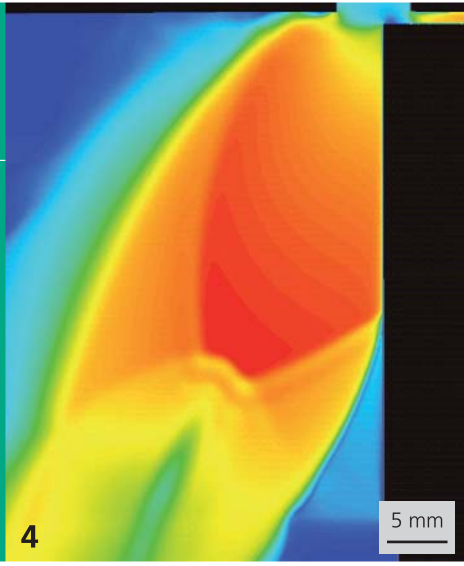

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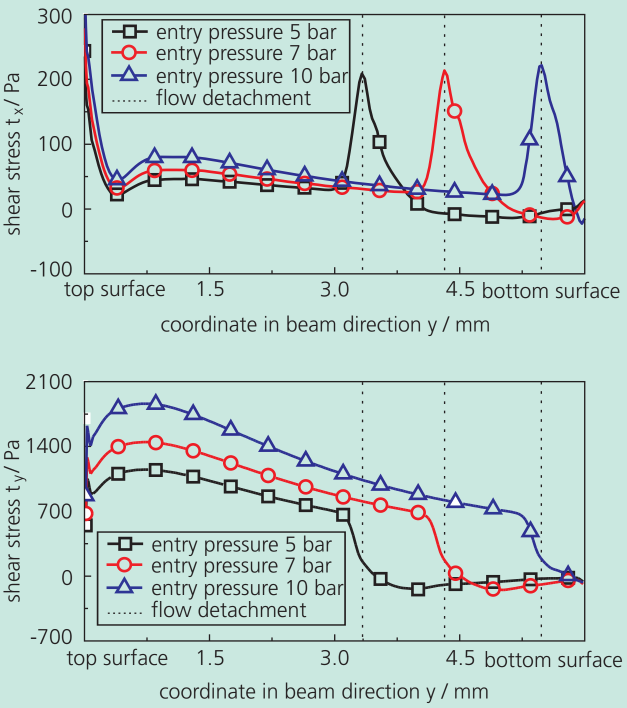
RESULTS

The developed model allows the study of fundamental interactions of the process based on parameter variations. Such parameter studies were performed to quantify the effect of cutting gas pressure, nozzle distance, nozzle diameter, sheet thickness, cut kerf width and shape on the resulting cutting gas jet flow. The model accurately predicts gas consumption and the actual gas fraction that acts in the cut kerf as a function of the cutting gas pressure (Fig. 2). The structure of the supersonic flow affects the forces acting upon the melt surface. This interaction can be analyzed by studying the shear stresses at the cut front and edges in the direction of flow propagation as well as backward in the kerf (Fig. 5). This simulation predicts the ejection behavior of the gas jet during laser cutting.

The application of the model helps to develop novel nozzle concepts for achieving optimal processing conditions during laser beam cutting. The experiences obtained from developing the cutting model are also useful to implement similar models for other laser material interaction processes whose results substantially depend on process gases.

Shear stresses at the transition between front and edge depending on the distances to the material's top surface and the gas pressure (kerf width 0.4 mm, sheet thickness 6.0 mm)

t_x shear stress backward in the kerf
t_y shear stress in propagation direction



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1 *Comparison of Schlieren analysis and simulation for the free jet flow of a conical nozzle at 15 bar of gas pressure*

3 *Schlieren image of the gas flow of a conical nozzle in a cut kerf at 15 bar of gas pressure*

4 *Simulation of the cutting gas flow with parameters obtained from the Schlieren analysis in Fig. 3*

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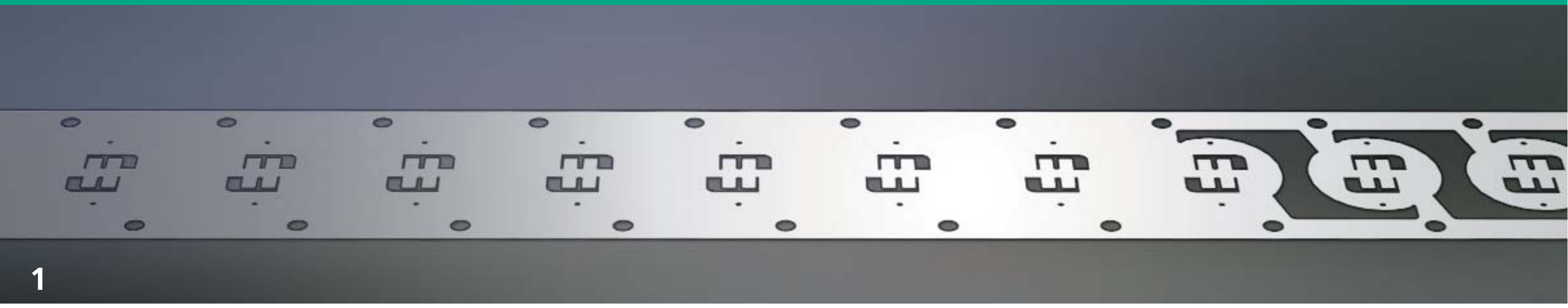


1

"LASER REMOTE PUNCH" – ALTERNATIVE MANUFACTURING PROCESS FOR TECHNICAL APPLICATIONS IN STAMPING AND BENDING

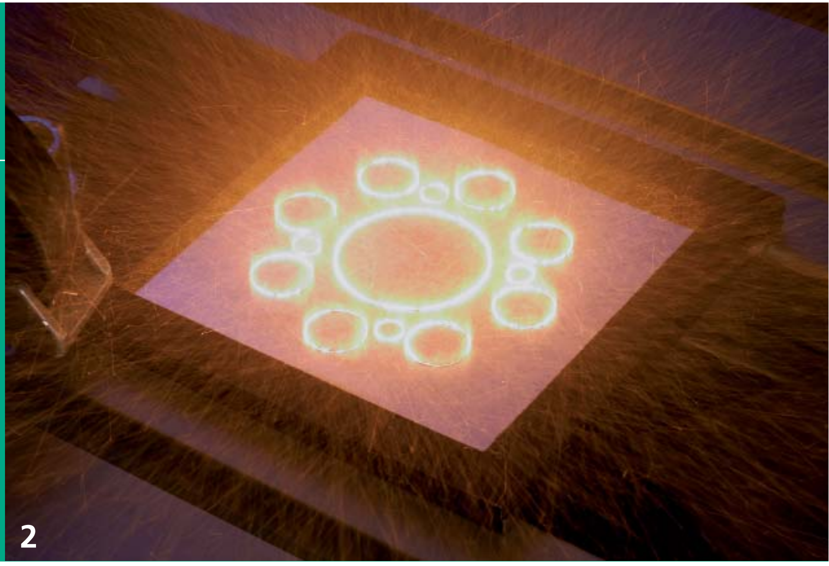
THE TASK

Many industry branches use metallic parts that were fabricated by bending or stamping. In high volume manufacturing these parts are currently produced in an automated environment using progressive dies. These dies typically consist of a cutting and a bending module. Increasingly manufacturing development is driven by three goals: the functionalization of the used materials, cost reduction and delivery time reduction. An example is the trend to use CrNi spring steel bands with mechanical strengths exceeding 1350 MPa even for materials as thick as 0.5 mm. Processing such material may result in unpredictable tool failure and production shut down. This trend also increasingly limits the degree of freedom with which these parts can be manufactured. To address these challenges in the future the project "Laser Remote Punch" was launched. Laser remote cutting offers an alternative manufacturing process for stamping. The objective of this project is to identify a concept for substituting the stamping module of a conventional progressive die tool with a remote laser cutting module.

OUR SOLUTION

This task requires overcoming the technical challenge of cutting high-strength metallic materials with thicknesses of up to 0.5 mm. Quantitative and qualitative requirements are derived based on the part spectrum, which is defined by project partners. Cycle times are very important. But it is also critical to achieve the required part tolerances.

To evaluate whether or not remote laser cutting can be used for this application we tested laser beams with high power density but moderate power levels. This approach required laser beam sources of highest brilliance, which have beam diameters in the order of less than 50 µm. In addition we use fast beam scanning systems. This is necessary to achieve the required cycle times for manufacturing the stamped and bent parts. The targeted cycle times are also the reason why it is necessary to work with a beam source that can continuously deliver power in cw mode. As part of the project we also aimed at consequently reducing moving masses. This helps to better achieve the desired part geometry.



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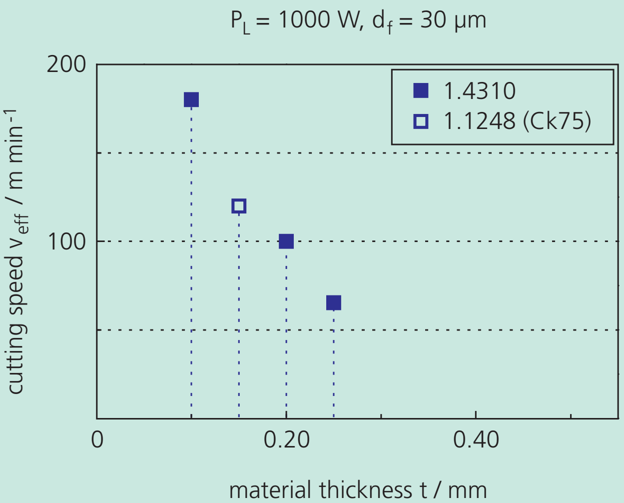
RESULTS

The cutting speeds and cycle times of the remote laser cutting process are comparable to those achieved with the current stamping process. They meet the production targets and unveil the substantial potential of the alternative manufacturing process, "Laser Remote Punch", for the fabrication of stamped-bent parts. The investigation shows that it is possible to cut materials of up to 0.25 mm thickness with a laser power of 1000 W. The achievable cutting speeds are primarily determined by the material thickness and range between 70 m min^{-1} and 180 m min^{-1} (Fig. 3). That means that a typical part is manufactured within a few tenths of a second. Thus several hundred parts can be manufactured per minute. Additional research also showed that it is possible by selecting appropriate system components to accurately fabricate complex geometric elements such as angles, line lengths and bridge contours.

Achievable effective cutting speeds as a function of material thickness, plotted as the ratio of processing speed and number of removal cycles



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Fraunhofer IWS engineers permanently continue to develop the software "PathControl". This tool is useful to accurately project critical elements such as circular geometries with diameters of less than 1 mm and processing speeds of more than 10 m s^{-1} while simultaneously meeting the required tolerances of less than 0.05 mm.

In summary the project results clearly demonstrate the potential of remote laser cutting as an alternative manufacturing technology for stamped-bent parts. Part cycle times and cutting precision meet the manufacturing requirements. The process can be commercially applied in high-volume manufacturing.

1 *Stamped and bent strip (pattern from Scheuermann + Heilig GmbH)*

2 *Process image during remote cutting*

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1

CUTTING OF ELECTRODE MATERIALS WITH SHORT PULSE LASERS

THE TASK

Electro-mobility represents a central development focus for the global automotive industry. Electric vehicles drive emission free and thus embody the future of our mobility. Achieving this goal requires overcoming many challenges. An example is the need for cost-effective high-volume manufacturing technologies to produce the required energy storage devices. A partial aspect of the development work addresses the cutting of the sheet materials for the three elementary components of lithium ion cells: the cathode, the anode and the separator. The active electrodes are built from multilayer metal foil (aluminum or copper) stacks, which are coated on both sides with graphite or lithium metal oxide. This combination of different materials causes challenges for the cutting process.

The state-of-the-art electrode materials cutting processes are highly productive stamping technologies. Their primary disadvantage lies in the low flexibility of static tools and permanent tool wear caused by the cutting of ceramic materials. The quality of the cutting edges continually decreases. Laser beam cutting is a contact and wear free technique and thus presents an alternative. This laser technology is also highly flexible in particular if varying cutting contours are required. However, so far there has been one critical disadvantage of this technology and that is the higher cycle times.

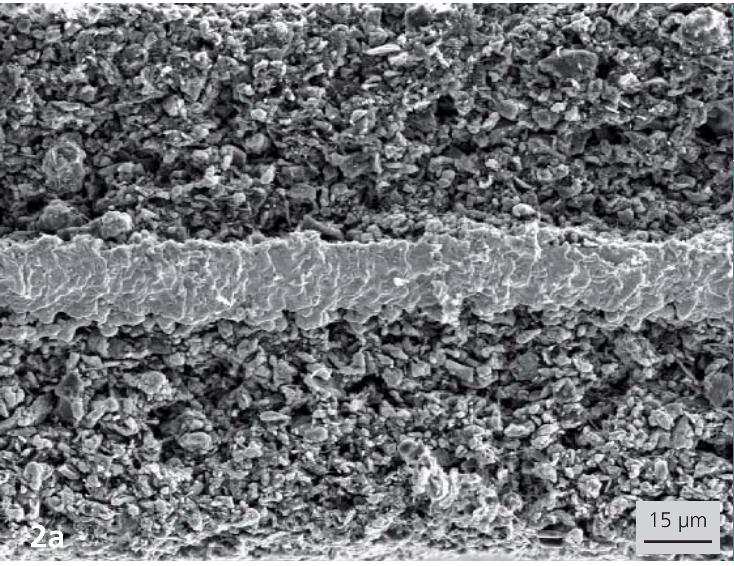
This project aims at overcoming this limitation. The concept is the utilization of laser beam sources of highest beam quality in combination with dynamic remote cutting processes.

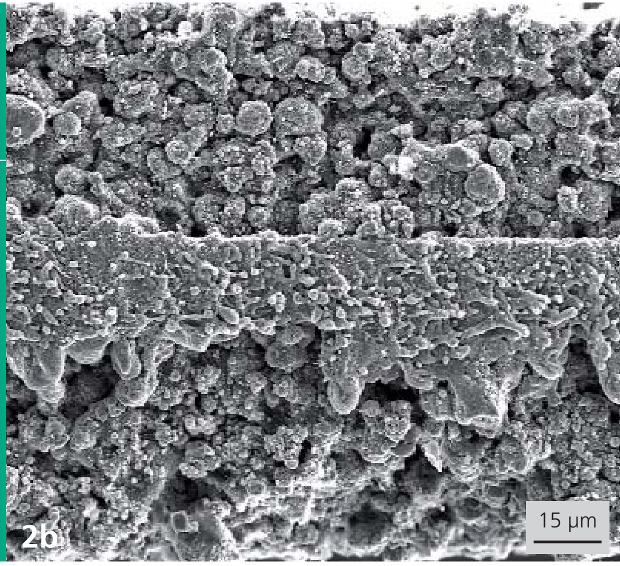
OUR SOLUTION

The laser remote cutting with dynamic beam scanning allows very high path velocities. This process purposely avoids process gases as used in conventional laser beam cutting. Therefore the laser beam can be scanned quickly over the surface using galvanometer scanners following the desired cutting contour. The use of laser sources with high quality beams achieves in particular for pulsed lasers very high intensities in the processing spot. Under such conditions the cutting occurs as material ablation in vapor form.

The service life of the lithium ion cells depends on the quality of the cuts. The cutting process has to avoid heat dissipation into the sheet material to suppress undesired ablation and to avoid the modification of the active coating material along the cutting edges. Another concern is the redeposition of ablated material, which could cause electrical shorts in the cell.

Fraunhofer IWS engineers performed numerous experiments to develop and optimize cutting processes for anode and cathode materials. Key process parameters were analyzed such as the pulse length and how it affects the cut quality.





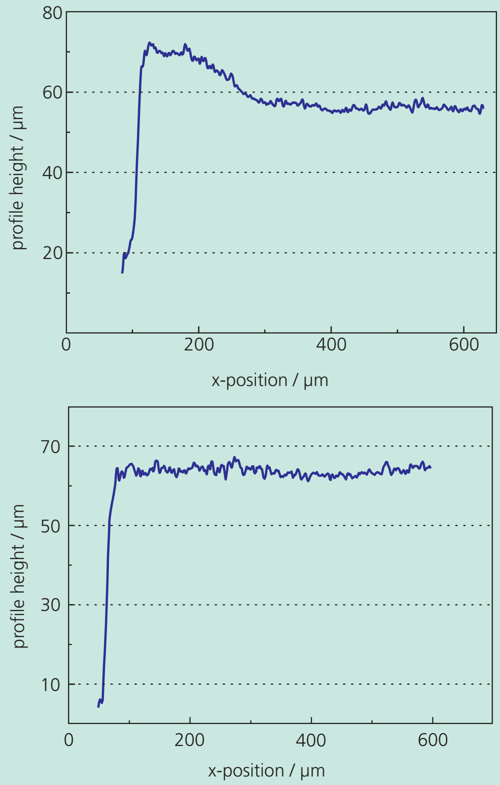
RESULTS

Figures 2a and 2b show SEM pictures of the typical cutting-edge during processing with short pulse solid-state lasers. The size and amount of particles that remained on the surfaces is so little that they do not present any limitation to further processing. Anode and cathode foils could be separated with high quality under identical conditions (40 W average power, wavelength 1 µm, spot diameter 25 µm). The influence of two pulse lengths (30 ns and 10 ps) on the processing results was studied. Both pulse lengths lead to almost identical cutting speeds up to 30 m min^{-1} when using equal power. Cutting speeds on the order of 60 m min^{-1} require laser powers exceeding 100 W.

The focus diameter and intensity or pulse energy was optimized to minimize the removal of active coating material from the metallic carrier foils along the cut edge. Transitioning to ultra short laser pulses has a measurable influence on the impact of heat dissipation and redeposition along the separated edge surface. The surface profiles shown in Figure 3 clearly show this for the anode material, which can increase in volume due to heating. Due to the minimal interaction time during ps pulses there is no thermal effect visible.

These results were obtained as part of a BMBF funded project DeLIZ (02PO2640; 02PK2641/2642). This project also addressed the test of high power cw fiber lasers for cutting such electrodes with speeds of up to 700 m min^{-1}.

Comparison of surface profiles of cut edges:
a measurable increase in surface height due to heat impact is observed for the process using nanosecond pulses (upper graph);
in the case of picosecond pulses (lower graph) the profile remains flat and does not show measurable thermal effects.



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1 Example electric car

2 SEM image of the cut edge of a laser cut electrode

a) cathode

b) anode

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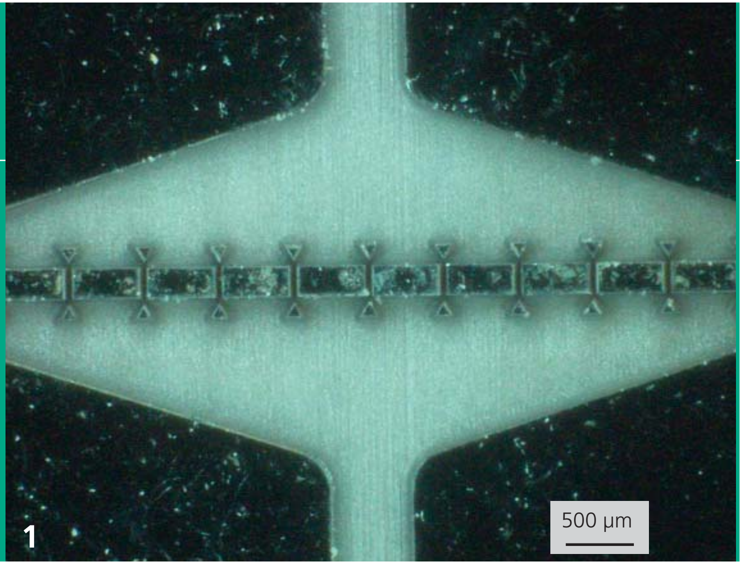
BUSINESS FIELD
ABLATION AND CUTTING



DYNAMIC MICROREACTOR PLATFORM WITH INTEGRATED MICROPUMPS AND MICROSTRUCTURES

THE TASK

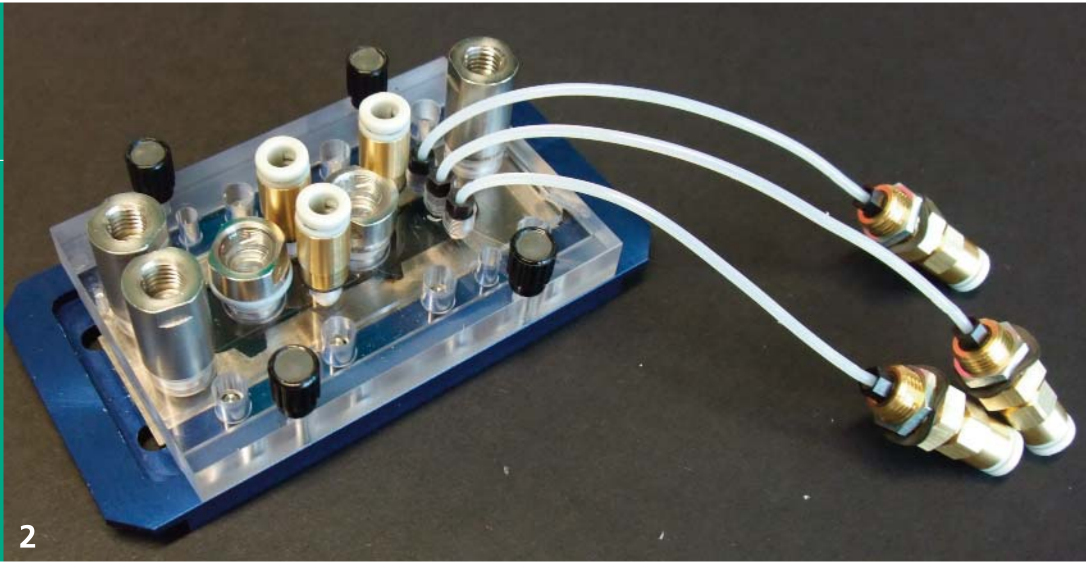
Microreactors are highly miniaturized and automated. They implement complex chemical and biological processes with minimal technical and personnel effort. These systems require low investment and operational costs. They have a compact design, high functionality and are easy to handle. Short information paths enable short reaction times. The miniature design reduces wiring and thus increases reliability. Heat and mass transport are intensified. This implies reaction technological advantages such as improved product cleanliness, improved yields and selectivities, higher process stability as well as access to new processes and applications. The integration of complex microstructures enables the realization of defined microenvironments.

Microreactors are becoming increasingly important in many areas of chemical and pharmaceutical synthesis, environmental analysis, molecular biological diagnostics, and general substance research. A dynamic microreactor platform is required to develop new processes and to transfer existing processes to a microreactor. The platform would provide necessary basic components such as pumps, valves, reaction chambers, mixers and heat exchangers and allows them to be quickly combined with each other. The resulting reactors have to be chemically, mechanically and thermally stable to handle a wide range of process parameters.

OUR SOLUTION

Fraunhofer IWS engineers have achieved very good results with customized microreactors. These are made from multilayer systems of material combinations from silicone, glass and metals or polymers. To build the microreactor, a polydimethylsiloxane flow cell is molded onto a metallic or polymeric connector plate and protected by a cover plate. The connector and cover plates contain microstructures, connectors, sensors (electrodes, microlenses, optical fibers) and actuators (heaters, electromagnets, piezovibrators). The flow cell contains the microfluidic system, which consists of channels, micromixers, pumps and valves as well as optional sensors and actuators. The cell is cast from a master die. The master die is fabricated using IWS laser micro material processing techniques or lithographic processes. The thickness of the pump and valve membranes is adjusted by changing the position of die elements.

The microreactors are very modular, which makes them easily adaptable to specific applications. Reaction chambers are made optically accessible but electrically insulated by using glass, polymers and silicone materials. Processes can be optically monitored. Photo and electrochemical functionality can be integrated. A metal connector plate provides efficient thermal transport.



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RESULTS

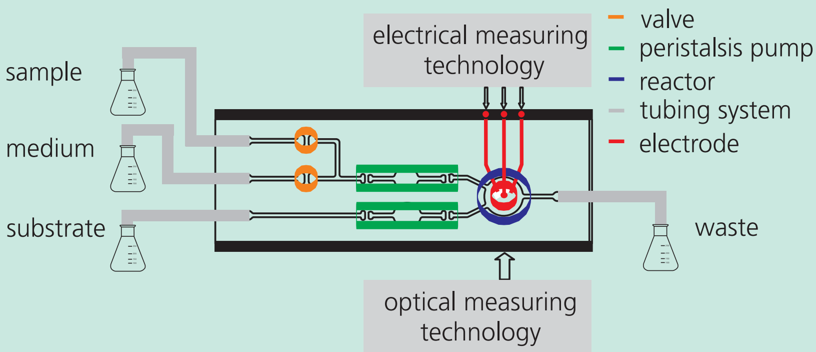
Customized microreactors with integrated micropumps and microstructures were successfully built and characterized based on an established dynamic microreactor platform.

Example 1:
A microreactor was developed and successfully tested to analyze environmentally relevant substances using a yeast cell sensor with optical and electrochemical detection mechanism. The microreactor selectively supplies the yeast cells with nutrition, sends a defined sample volume to the cells or adds a defined amount of reactive ingredients for the enzymatic reaction (Fig. 1). The cells form enzymes, which are monitored optically via fluorescence or electrochemically via amperometry using microelectrodes. Microstructures are integrated to trap genetically modified cells in specifically designed compartments.

Example 2:
Another microreactor was developed to implement a standardized wet chemical nitrate quantification process via photometric detection. The reactor was successfully tested. A defined sample volume of an aqueous solution can be precisely and accurately injected into the carrier flow. The carrier flow transports the sample while reactants are added for the chemical reaction. The sample then travels through a micromixer into a photometric flow through detector (Fig. 3).

The developed dynamic microreactor platform serves as a tool for the fast and flexible implementation of existing processes on microreactors and also for the development of new processes (Fig. 2).

Schematic setup of a microreactor for the electrochemical detection of environmentally relevant substances



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1 Microscope image of a microstructure to trap genetically modified yeast cells inside of the microreactor

2 Dynamic microreactor with integrated micropumps, valves and microstructures

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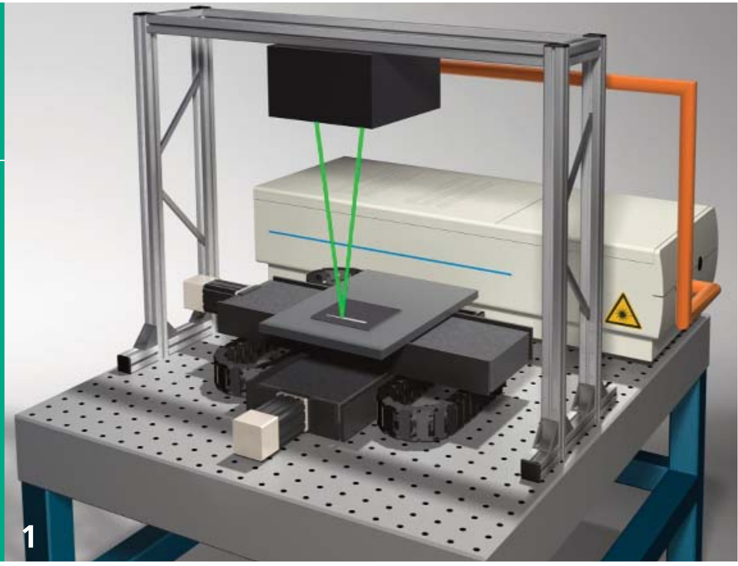
BUSINESS FIELD
ABLATION AND CUTTING



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LARGE AREA FABRICATION OF NANOSTRUCTURES FOR MORE EFFICIENT ORGANIC SOLAR CELLS

THE TASK

In recent years the photoelectric efficiency of organic photovoltaics has made enormous progress. The technology offers the scaling potential to large and flexible photovoltaic substrates. Further efficiency improvements are expected from optimizing the intrinsic properties of the organic materials. But it is also necessary to optimize the optical properties of the solar cells. Other thin film technologies have already demonstrated the advantages of periodic structuring or roughening of the surface.

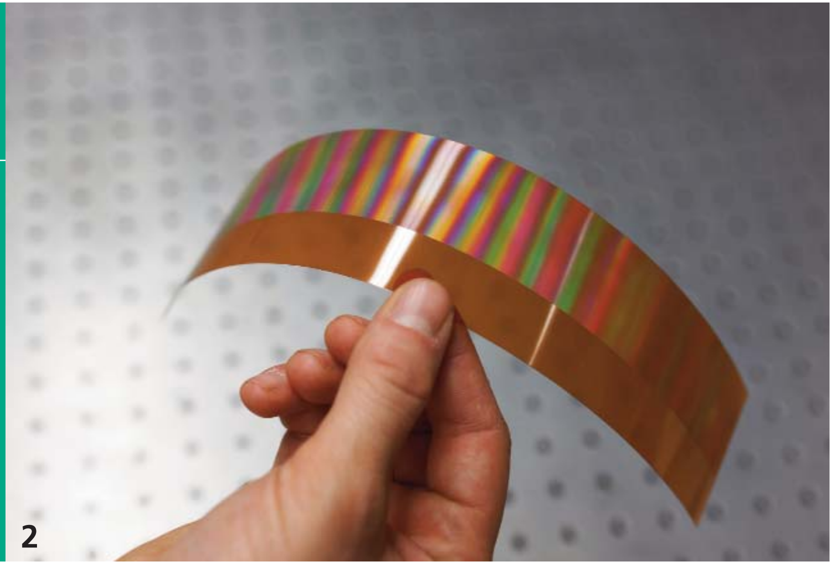
Surface structures may improve the efficiency of solar cells based on Bragg diffraction on photonic crystal structures. So-called light trapping geometries increase the path length for the incoming light within the photoelectrically active material. Thus, micro- and nanostructured surface are advantageous for organic solar cells.

Structured surfaces were already used for various thin film solar cells based on Si, GaAs and organic materials. Typical structuring processes use lithographic, molding and stamping techniques. Lithography methods often use electron or ion beams to fabricate structures smaller than the optical resolution limit. However, the industrial scaling of these techniques is challenging. For example, many technologies require several complex processing steps or contaminate the substrate surface. Often long processing times are required, which lead to substantial production costs.

OUR SOLUTION

Fraunhofer IWS engineers achieved drastically shortened processing times at increased resolution by using direct laser beam interference patterning (DLIP) method (Fig. 1). The method transfers nanostructures in one step into metals, ceramics or polymers (Fig. 2). Making an periodic structure requires at least two collimated and coherent laser beams, which superimpose on the substrate surface. Interference occurs throughout the entire superposition volume of the beams. A single laser pulse can process a surface area of up to several square centimeters, which leads to an effective structuring speed of several square centimeters per second.

DRESDEN concept

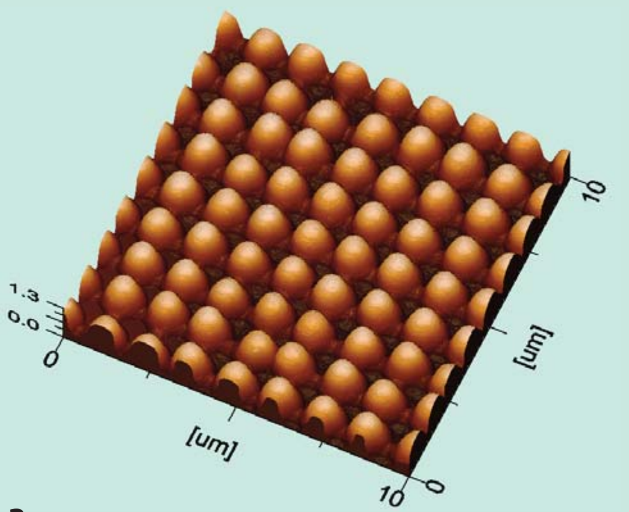


2

RESULTS

Fraunhofer IWS engineers collaborated closely with the Institute for Applied Photo Physics (IAPP) of the Technische Universität Dresden to improve the efficiency of solar cells by DLIP structuring PET foils. The superposition of two laser beams results in a linear structure. Furthermore, using three laser beams or more, permits the direct fabrication of 2D patterns. The structuring period is defined by the angle between the laser beams and their wavelength. Crossed structures as shown in Fig. 3 are made in a two-step process. First a linear structure is imprinted and then the substrate is rotated by 90° prior to repeating the same structuring step. A compact laser interference system was built that can be installed in an industrial setting as an inline process tool (Fig. 1). Following the structuring process the PET substrate was coated with a transparent PEDOT electrode, which in turn is coated with active organic material. The solar cells were characterized using a Steuernagel SC1200 Sun Simulator. The experiments showed improved performance when the solar cells were fabricated on structured substrates. This was in particular true for low current densities (Fig. 4). Hexagonal structures are especially efficient with an improvement of 21 %. In comparison to a reference solar cell on glass the efficiency increased by 12 %.

DLIP grid structure on polymer (scanning force microscope image)



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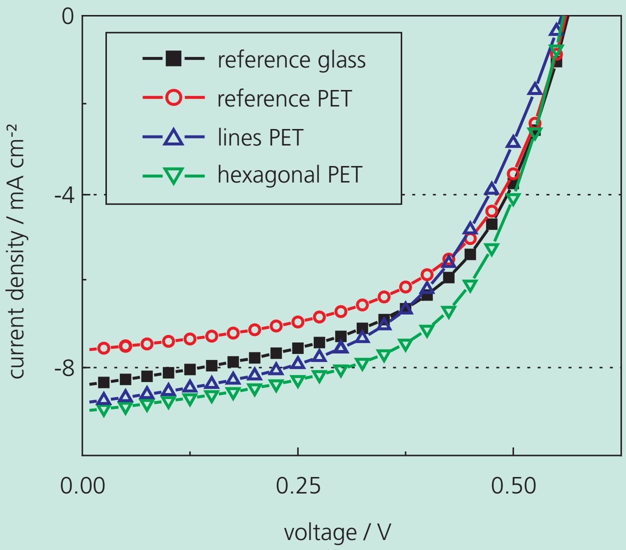
Current density versus voltage for a lighted organic solar cell on structured PET and reference cells on PET and glass



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1 *DLIP system (schematics) at the Fraunhofer IWS*

2 *DLIP structure polyimide foil*

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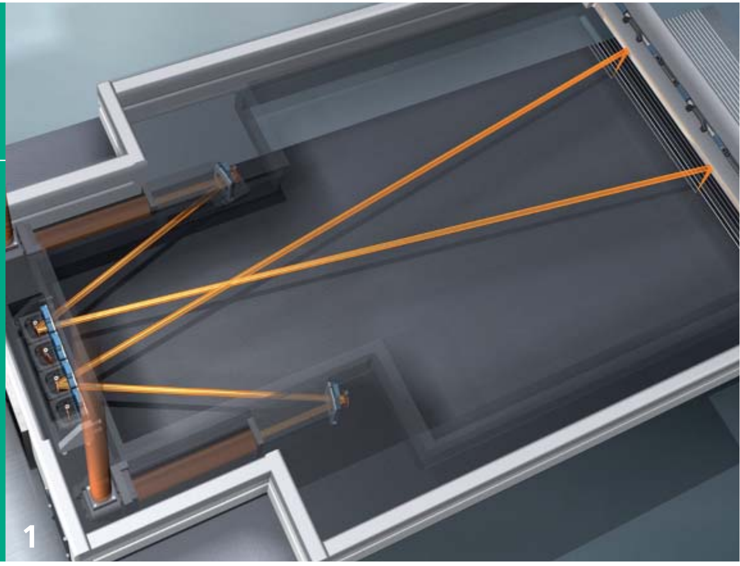

1

LASER PROCESSING OF GRAIN ORIENTED ELECTRO METAL SHEETS

THE TASK

The global increase of energy consumption, the decentralization of power grids due to utilization of renewable energy sources and the efforts to improve energy efficiency lead to an increased demand for high quality low loss transformers for electrical energy distribution. Power and distribution transformers are using grain oriented electro sheets whose magnetic properties can be improved by laser processing. A brief spatially confined heat treatment of the transformer core material refines its magnetic domains and reduces magnetization losses.

The industrial implementation of such a process requires a system technology, which can be easily integrated into existing manufacturing processes and lines. A technology with the highest possible impact on the magnetic properties should be applied to save costs. Energy losses could be reduced and power transmission improved.

OUR SOLUTION

Fraunhofer IWS engineers have developed a laser beam scanning system lasertronic® SAO for the magnetic domain refinement of a continuously moving band of grain oriented electro sheet metal. The laser radiation originates from two laser beam sources and is focused onto the metal sheet surface using a patented optics (Fig. 1). The laser spot processing the material moves at speeds of up to 250 m s^{-1} perpendicular to the direction of band motion. The laser radiation interacts with the material with well-defined spatial and temporal parameters and induces thermal stresses. These refine the magnetic domains in the sheet material and reduce the losses.

The beam scanning system lasertronic® SAO consists of 6 fast galvanometer scanners to deflect the beams. The two lasers can be independently used and cover the entire material width during processing.

Industrial partners joined IWS engineers to set up a **L**aser **M**agnetic **D**omain **R**efinement (LMDR) test system (Fig. 2). The machine is used to treat grain oriented electro sheet metal under conditions similar to production processes. The coil handling system is replaced by a moving axis so that individual sheets of sizes up to 1 m x 1 m can be processed. This axis can be removed so that the LMDR test system can be installed in an existing production system by placing the beam scanning system above the moving electro sheet metal band. The LDMR test system is also equipped with an open interface, which allows the connection of various laser beam sources (CO_2 lasers, solid-state lasers) for electro sheet metal processing.

2

RESULTS

The LMDR test machine with lasertronic® SAO beam scanning system achieves a significant reduction of magnetization losses in core materials. Specific results depend on materials and process parameters. A special control system was developed to keep the adjustable process parameters independent from the band speed. The parameters are automatically adjusted leading to constant processing conditions.

The galvanometric scanners are controlled by especially developed modules directly connect to a fieldbus (EtherCAT). The digital transfer of position data occurs within a cycle of 10 µs enabling performance and process stability increases. The further developed beam scanner in the LMDR test system reaches spot velocities of up to 300 m s^{-1}. The LMDR test system provides the opportunity to study laser induced domain refinement under production-like conditions. Customized optimizations are possible.

LMDR test system specification

processing width	≤ 1000 mm
band- or axis velocity	0.5 – 90 m min^{-1}
spot velocity	≤ 300 m s^{-1}
laser beam sources	2 beam sources, independently selectable (CO_2-Laser, Faserlaser)
max. laser power	1 kW – 5 kW (independent from laser beam source)
line distance	2 – 20 mm (adjustable)
material dimensions	metal sheet up to 1 m x 1 m

3

1 Beam scanning system lasertronic® SAO

2 LMDR test system

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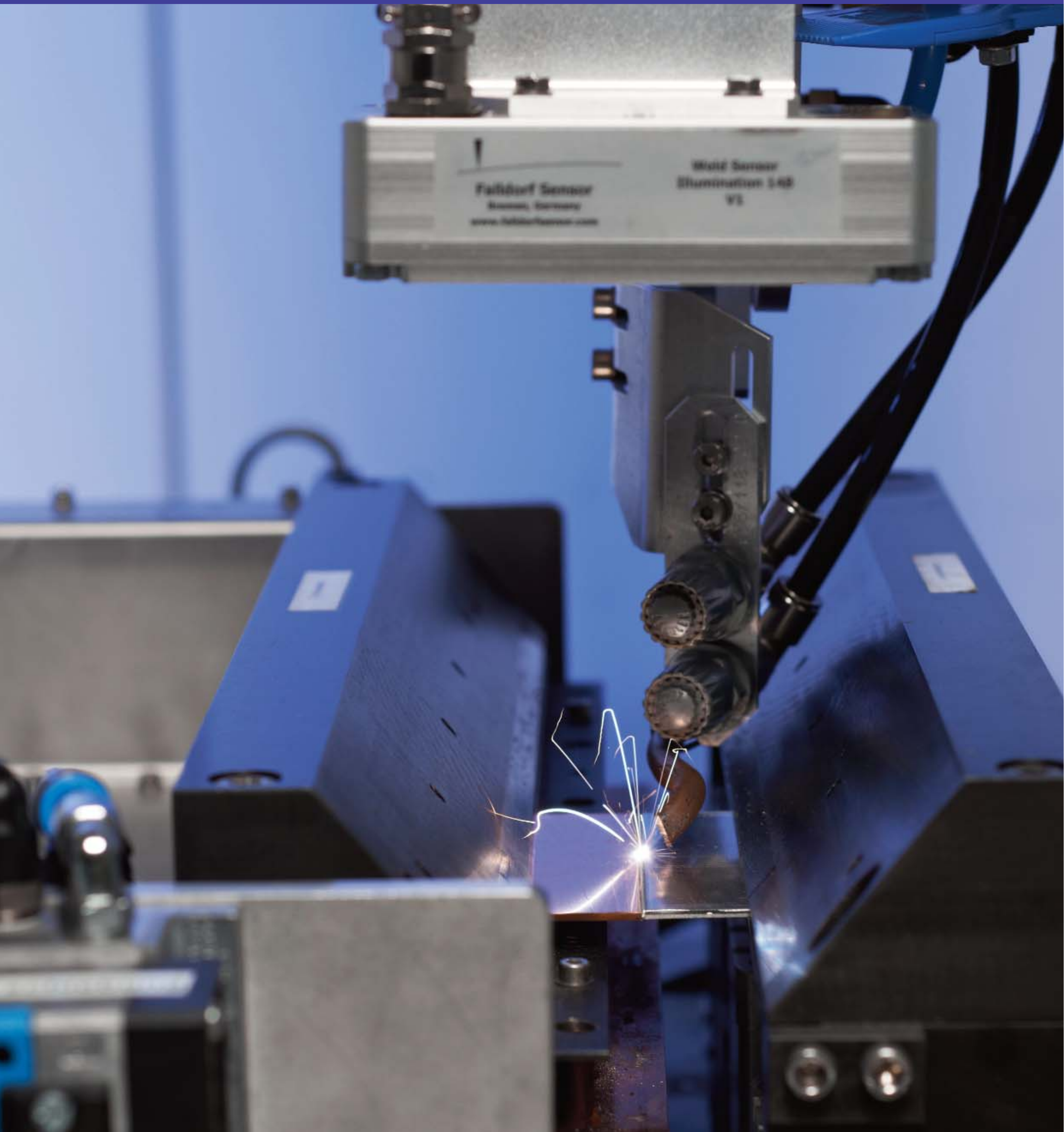

The critical part of knowledge is to take it to heart and apply it.

Confucius

BUSINESS FIELD JOINING

Editor: The automotive industry is currently experiencing a rapid paradigm shift with respect to powertrain technologies. Your past activities in this industry were focused on automotive powertrain related research and development of welding processes. How are you prepared for the change?

Prof. Brenner: The paradigm shift is indeed leading to major challenges for welding process and technology development. However, we are very well prepared for this change. We follow a broad research and development approach in laser beam welding technology and early on we worked on new processes such as adhesive bonding, friction stir welding and electromagnetic pulse welding. One challenge is the need for high performance; crash safe, and yet still affordable, auto body structures. These are constructed from high strength multiphase steels. To join such materials we continued to develop a laser welding process with integrated tempering. This process leads to a more homogenous hardness distribution. Subsequent forming operations of the materials are improved as well as their capacity to absorb energy in case of a crash.

Another focus area is the manufacturing of lithium ion batteries. Today we have solutions for three manufacturing challenges. An effective and stable laser welding application is the joining of aluminum or copper foil stacks with themselves as well as with the current collector. The cell stacks also need to be hermetically sealed. Here the current collector needs to be sealed with plastic casing. A selective laser processing prior to the adhesive bonding step makes the cell less expensive and longer lasting. Laser induction roll plating is a process to fabricate Al-Cu cell connectors with excellent mechanical and electrical properties. The BMBF project DeLIZ funded work to design, develop and build a completely novel type of laser induction roll plating machine. This unique machine will be used to very efficiently join material combinations that are not weldable with conventional melt based welding processes such as Cu/Al, Al/Ti, steel/Cu and steel/bronze. Meanwhile we made 22 mm wide Cu/Al bimetal strips with very high peel strengths in a single joining and forming process without additional heat treatment processes.

Editor: During the year you performed the first welding of longitudinal seams of aircraft fuselage panels using friction stir welding. How satisfied are you with the results?

Prof. Brenner: In recent years we developed laser welding processes for stringer-skin, clip-skin and skin-skin joints. The development of friction stir welding for large 3D parts represents the fourth stage of replacing riveting processes in the manufacturing of metallic primary structures in passenger aircraft. Compared to laser beam welding, the friction stir welding offers some improvements of the properties of the weld seams. The process causes less weld seam undermatching. The intense deformation of the welding and heat affected zones occurs below the melting temperature and causes a thermomechanical strengthening of the material. Friction stir welding is especially attractive, also from a manufacturing viewpoint, due to a new machine concept that includes a pentapod that enables a cost effective process for large 3D parts. Welding experiments were very successful with sample parts at 1/4 scale, demonstrating the concepts for large component assembly of fuselage segments. We are very satisfied with the results.

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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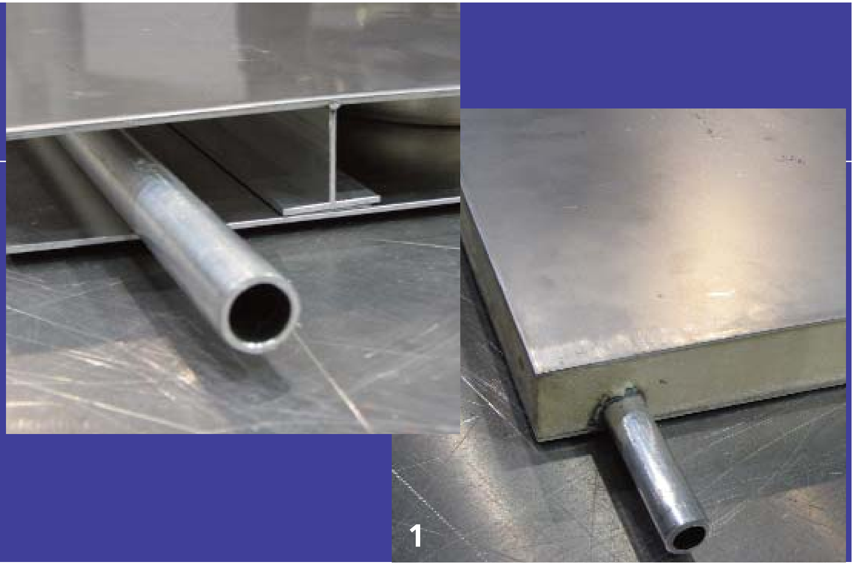

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APPLICATION OF BRILLIANT LASERS FOR STRUCTURALLY INTEGRATED LIGHTWEIGHT CONSTRUCTION

THE TASK

The use of alternative powertrain concepts in the field of electromobility requires new approaches to function integration and lightweight construction. An example is the integration of heat exchangers into the vehicle structure as they are required for the temperature management of electrical energy storage devices.

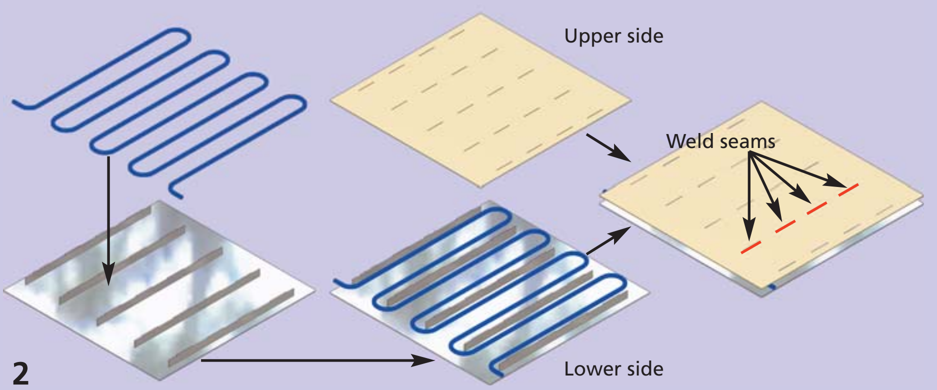
Fraunhofer internal advanced research projects were performed with institute partners IVI, IFAM, LBF and IBP. The work investigated the fabrication of structurally integrated heat exchangers for hybrid busses. The specification for the heat exchanger required that the module would simultaneously perform heat management and structural functions. The following tasks were to be accomplished:

- selection and design of structurally integrated functional elements for areal cooling and heating systems,
- design of a demonstrator concept unit made from a paintable outer layer sheet metal, an insulating layer and a heat exchanger unit with paintable inner layer sheet metal,
- investigations with laser based manufacturing processes to make functional heating and cooling areal elements and laser based welding experiments to test the implementation of the concept.

OUR SOLUTION

Structurally integrated lightweight designs often include thin walled elements, which need to be supported by welded stiffeners. Welding such stiffeners to the thin structures requires precise energy control. This can be achieved by laser beam welding with brilliant beam sources (e.g. DC-CO_2 laser, fiber or disk laser). Using such lasers with extremely low line energy minimizes the heat deposition and the warpage of the thin walled structures.

Design variation for a laser welded heat exchanger



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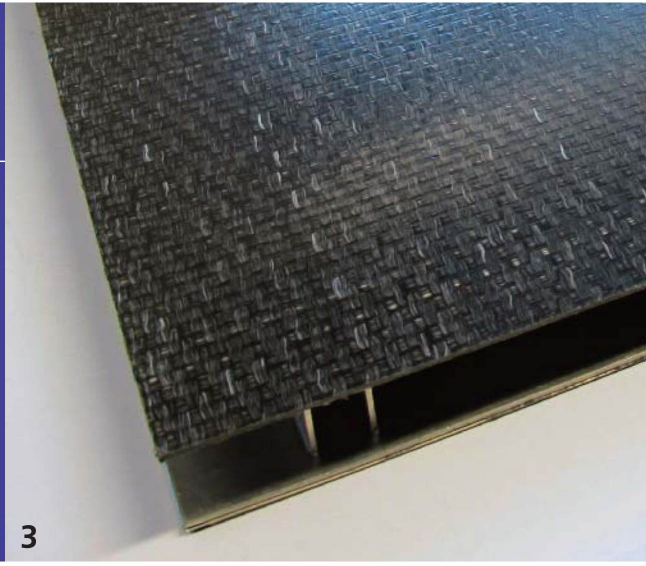

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The BMBF funded a project named "FSEM Fraunhofer System Research Electromobility". One of the research outputs is a multifunctional heat exchanger module based on a double wall Al structure with laser welded stiffeners and a S curved pipeline (Fig. 1 and 2).The longitudinal strips were welded with a CO_2 laser. The special achievement here is that the stiffeners were welded using two lasers simultaneously from both sides with filler wire. This parallel welding process completely eliminates warpage, which cannot be avoided when welding just from one side. The filler wire (AlSi12) prevents the formation of hot cracks by overalloying with silicon. Hot cracking can occur when welding material combinations such as AlMgSi 0.5 and AlSi1MgMn.

RESULTS

The laser welded structures were bend tested for stiffness as well as thermally characterized in collaboration with the Fraunhofer IFAM Dresden.

Laser welding experiments were also performed on adhesively laminated sheets in addition to developing structurally integrated heat exchangers. Such laminated sheets allow the use of different metallic materials and thus expand the material selection for various applications. An example is a laminate of 0.5 mm stainless steel and 2.0 mm thick aluminum. This sheet fulfills different requirements such as:

- corrosion resistance and high quality optical finish for the outside (stainless steel),
- sound proofing (laminate sheet) and
- lightweight construction due to aluminum of GFC on the inside.

These different requirements are of interest as outer wall structures for railroad vehicles for example. To ensure structural integrity it is necessary to add stiffening elements such as aluminum profiles to the aluminum side of the laminate. This was accomplished by laser beam welding with brilliant laser sources and extremely low line energy. This process almost completely avoids thermal damaging of the laminated sheets. Adhesive bonding is used for joining the inner lining of aluminum stiffeners or GFC.

The described results were developed within a project funded by the BMBF (13N11426), "FSEM Fraunhofer System Research Electromobility".

1 *Laser welded heat exchanger from aluminum, left: prior to foaming, right: after foaming*

3 *Variation of a mixed design outer wall structure: laser welded Al profile stiffener on stainless steel/Al laminated sheet, GFC (adhesively bonded) for inside*

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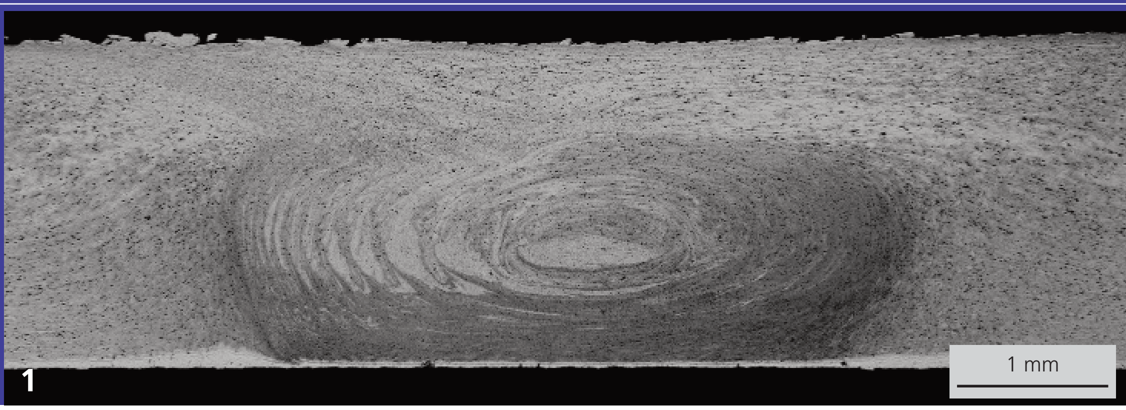


1

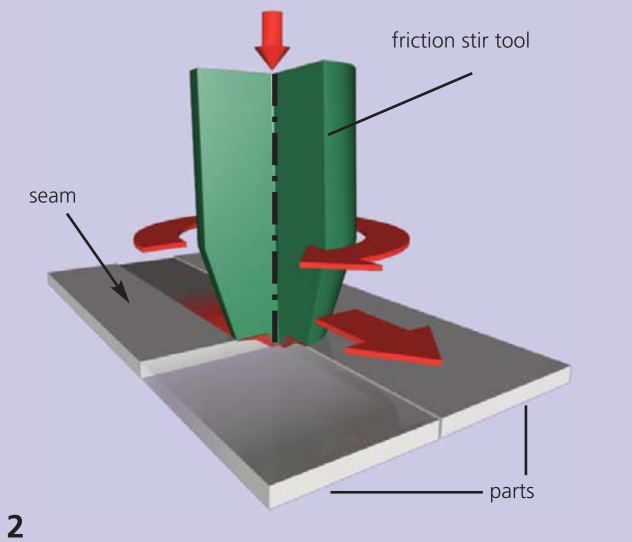
FRICTION STIR WELDING OF AIRCRAFT FUSELAGE TEST STRUCTURES

THE TASK

The lighter the better! Since the beginning this motto is the driving force in the aerospace industry. Fraunhofer IWS engineers have been working since more than a decade on joining technologies and industrial concepts to make aircraft fuselages lighter. A prominent customer is the Airbus Group. Since 2009 the choice of joining technologies has been expanded beyond laser welding to include the still lesser known friction stir welding (FSW, Fig. 2). This process avoids the melting of the involved material surfaces and consequently is capable of welding previously unweldable alloys.

In some niche areas of aircraft manufacturing this technique is already established. However, experiences and concepts for the cost effective industrial implementation of FSW in high volume manufacturing are still missing. Equally uncharted is the field of welding certain large 3D parts that lose stiffness when bent. An example is an aircraft fuselage segment.

Schematics of friction stir welding (FSW)



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OUR SOLUTION

At the Fraunhofer IWS we work on machine concepts to efficiently join such parts. The new welding process requires significantly increased forces but should not warp the aircraft skin beyond specified tolerances. Since 2009 IWS engineers have worked with Airbus on advancing industrial concepts within a technology project MERGE (next generation metal fuselage), which is part of the larger Aerospace Research Program IV. This project is funded by the Federal Ministry BMWi (FKZ 20W0606A), which supports the research and development of advanced technologies in the field of civil aviation in Germany.

A novel IWS approach to develop cost efficient joining technologies lies in the machine selection for the fabrication of test structures: In collaboration with an equipment manufacturer IWS engineers converted a parallel kinematic 3D milling center into a fully functional friction stir welding machine. The machine is a so-called pentapod, which achieves similar stiffness and precision but weighs only 10 % of conventional Cartesian motion systems. This offers new degrees of freedom when designing machines for the processing of large parts. In addition our engineers investigated adapted control strategies to increase the robustness of the welding process for the industrial production of the described parts. Airbus suppliers were involved early on so that these new technologies will find their way into production as soon as possible. Some of the welded test

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structures we provided by RUAG Aerospace Structures GmbH. The test structures have the identical geometry of typical real fuselage sections but are reduced in size by a ratio of 1:4. This size reduction is required by Airbus as a standard procedure to determine the technology readiness level.

RESULTS

Fraunhofer IWS engineers collaborated with partners from the aerospace industry to use a new process to weld aircraft fuselage segment test structures. Fig. 3 shows the machine and Fig. 4 shows the finished cylindrical test structure. The process is completely controlled. The integrated force control mechanism is designed for short latency and ensures uniform process conditions even if the process window shifts. Such shifts may occur when the clamping fixtures deform under process loads.

Seam quality was tested with metallographic analysis methods. A cross section of the weld seam is shown in Fig.1.

Since these results are very promising, the next step will be to move to larger real sized parts. This will help to refine welding concepts and will also improve conclusions with respect to the technology readiness level. The latter is of great importance to our aerospace industry customers. Thus we have come a step closer to implementing the vision of efficiently friction stir welding complete aircraft segments in the future.

1 *Cross section of a FSW seam microstructure, material Al 2024*

3 *"Pentapod" parallel kinematic machine for 3D friction stir welding (workspace 6.5 x 2 x 1.5 m^3) with welded test structure in front of the machine*

4 *Detail of a longitudinal seam on the test structure*

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1

FLEXIBLE PROTOTYPE MACHINE FOR THE INDUCTIVELY ASSISTED LASER ROLL PLATING

THE TASK

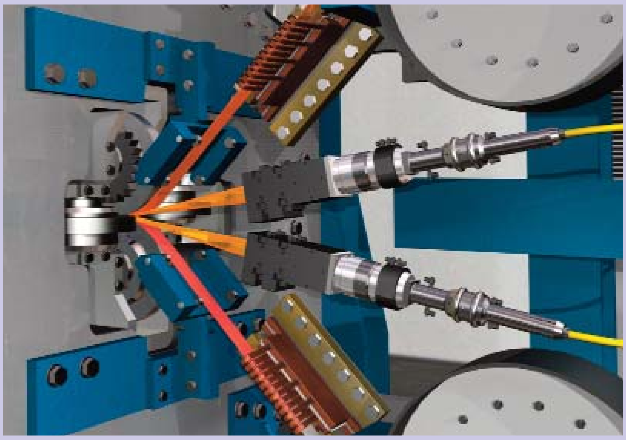
The current development trends in the automotive industry are electromobility and lightweight construction. These trends address issues such as the drastic increase of costs of important metals. They also lead to an increased demand for semi-finished products of metal composites. An example is the need for Al-Cu parts for the cost effective manufacturing of lithium ion batteries.

In collaboration with industrial partners, Fraunhofer IWS engineers developed a special inductively assisted laser roll plating process and build a laboratory machine to join narrow strips of Al and Cu. As opposed to the conventional hot roll plating this new process inductively preheats the precut strips to the required temperature for joining them in a roll tool whereas the inner surfaces are heated by laser. The laboratory machine was originally limited to a fixed strip geometry and limited band length. To further develop the inductively assisted laser roll plating as an industrial process it was necessary to expand the machine's capabilities.

OUR SOLUTION

Fraunhofer IWS engineers designed a unique inductively assisted laser roll plating machine with the flexibility to process varying strip geometries. An industrial partner built and installed the machine in a very short time. The machine was completed with the induction generators, the laser and a specialized beam shaping optics. The first tests were performed.

Arrangement: inductive and laser heating of the bands



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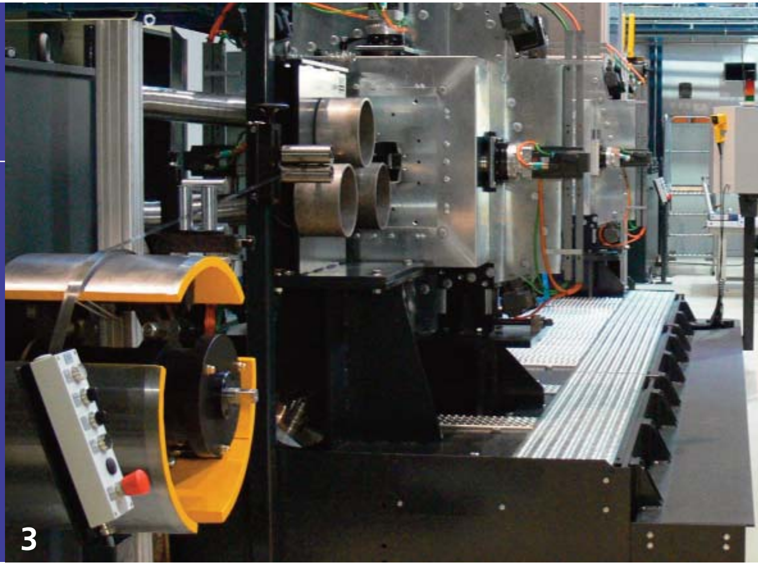
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RESULTS

The core of the machine is a rolling frame, which works on the principle of the so-called "flexible Turks head". The method uses 4 staggered rolls to provide the necessary roll gap and can change the gap geometry without having to change the rolls. Immediately in front of the roll gap is the heating zone. Two disk lasers are used to provide the heating energy though linear foci on the inner side of the bands.

Two HF generators with 50 and 100 kW power inductively preheat the bands. The maximal width is 150 mm for bands of up to 4 mm thick. The achievable roll plating width depends on the laser power. The machine also includes mechanisms for handling the band coils, which can carry up to 1 ton. Additional elements are included for alignment and brushing. The machine also houses a second Turk head roll frame, which is used for calibration and final shaping of the plated strips. Both roll frames are mounted to the same machine stage, which also holds the movable panel of the NC machine controller. The system is completed with a special protective gas enclosure for those regions where the band is warm and at the roll gap. The plated band is gas cooled. Several cameras and pyrometers are used for process observation. The new machine has an overall length of 18.5 m.

The machine design is such that it is possible to plate band-to-band but also band-to-profile. The total physical deforming during laser roll plating is relatively small. Thus it will be also possible in future to join materials in overlapping configuration, which is useful to optimize components for reduced material use.

In addition to the mentioned material combinations the technology is also suitable to roll plate different steels as well as steel and aluminum, titanium or copper alloys.

The research was funded by the BMBF with the project DeLIZ (02PO2640; 02PK2641/2642).

1 Machine schematics

3 Roll plating machine at the IWS

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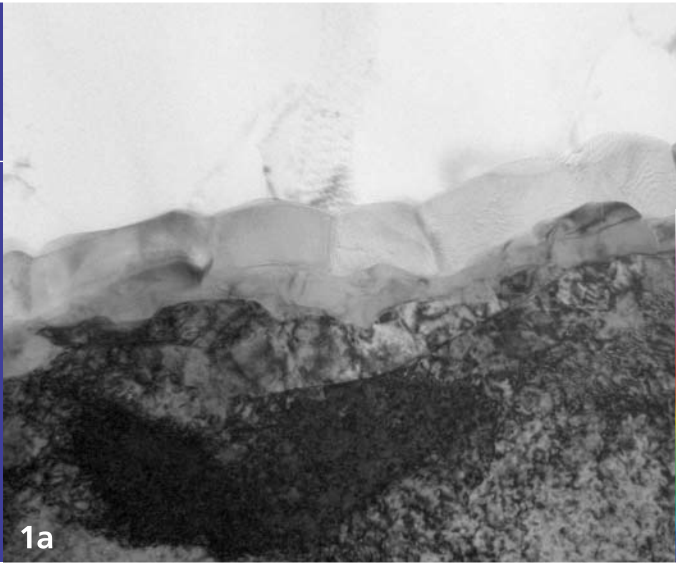

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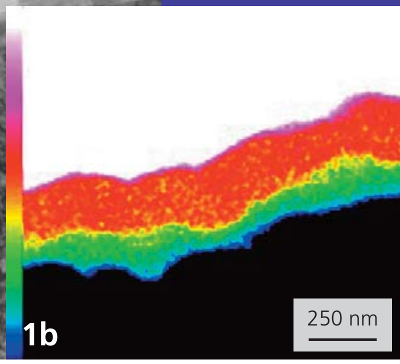

1b

HIGH RESOLUTION CHARACTERIZATION OF THE INTERFACE BOUNDARY SURFACES OF MIXED METALLIC JOINTS

THE TASK

The term “multi materials design” implies that such parts are constructed from mixed materials to provide properties exactly where they are required. The consequent use of mixed materials construction offers new material and processing challenges for joining technologies. One of the most critical issues related to using mixed materials is the formation of brittle intermetallic phases in the welding zone. Such brittle phases lead to significant performance degradation of the welded component. This is the reason why Fraunhofer IWS engineers develop processes such as laser induction assisted roll plating, electromagnetic pulse joining and friction stir welding in parallel to laser beam welding solutions.

A substantial limitation for the development of these new joining technologies is the insufficient knowledge about the joining mechanisms. Conventional metallographic preparation techniques and characterization methods are only suitable to a limited degree, which complicates the research. The goal is therefore to develop and apply appropriate preparation techniques and high resolution characterization methods to fully understand the processes in the boundary region of the joining interface.

OUR SOLUTION

Typical Fraunhofer IWS characterization methods for mixed metallic joints include metallography, scanning and transmission electron microscopy (SEM, TEM) and energy dispersive X-ray microanalysis (EDX). The methods are complementary to each other. All electron microscopy imaging techniques are used. Ion beam based preparation techniques are applied to prepare sharp edges for analysis with minimal artifacts. Procedures are available to prepare samples of various material combinations.

RESULTS

Fraunhofer IWS engineers successfully produce mixed metallic joints of different material combinations (Al-Cu, Al-steel, Steel-Cu) using laser induction roll plating, electromagnetic pulse joining and friction stir welding. The various joining technologies generate very different process conditions (e.g. pressure, temperature, interaction times, degree of deformation). However, there are many and sometimes even surprising analogies between the processes with respect to the actual material joining mechanism. Here we describe the results obtained from a mixed metal Al-Cu joint.

Even with brilliant lasers in the kW power range used at high welding speeds it is not possible to reduce the thickness of the intermetallic interface layer to much less than 10 µm. Subsequently the strength of the mixed joint is always lower than that of the original Al material.

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On the other hand, laser induction roll plating and electromagnetic pulse joining lead to seam thicknesses of less than 1 µm (Fig. 1a and 1b). Consequently, mechanical tests show that the component will fail in the aluminum material rather than in the seam. Thus the joining zone has at least the strength of the weaker partner.

In comparison to the other joining processes, friction stir welding causes significantly higher mixing of copper and aluminum (Fig. 2). The interaction time is relatively long and therefore the formation of intermetallic phases cannot be as effectively suppressed as during laser induction roll plating or electromagnetic pulse welding.

So far the research led to the hypothesis that a very thin but continuous phase-seam benefits the fabrication of Al-Cu mixed material joints. Mechanical clamping only, i.e. no mixed material boundary region is formed, is insufficient to provide adhesion between aluminum and copper.

The detailed structural and analytical investigations showed that the properties of mixed material joints are also significantly influenced by thermally and mechanically induced structural changes in the boundary regions. Typical induced changes can be recrystallizations, phase changes, deformation hardening as well as the dissolution or reformation of segregations.

Current research aims at identifying the correlations between structure and properties for the various mixed metal multi material systems. The results provide the basics for process optimization and for the design of multi material systems in automotive, railway and aerospace industries.

1 TEM image of an interface of an Al-Cu mixed joint, which was produced by laser induction roll plating (LIWP). The image is used to identify the submicroscopic phase seam

a) TEM bright field image

b) Al element distribution (EDX mapping)

2 Cross section through a friction stir welded Al-Cu butt weld (light microscopy overview)

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1

CNT CONTAINING ADHESIVES

THE TASK

Adhesive bonding is a joining technology, which has step-by-step advanced into high-tech industry branches. The original purpose of the adhesive joint is to transmit mechanical forces. However, new functional requirements such as electrical and thermal conductivity are emerging. The desired properties can be achieved with nanoscale filler materials, which are added to the adhesives.

A very promising group of filler materials are carbon nanotubes (CNT). They have extraordinary properties. The electrical conductivity of CNTs depends on their structure and can vary between conductive and semiconductive. Industrial applications require electrically conductive adhesives for large area adhesive joints in components to eliminate electrostatic charging. The application of CNTs in adhesives can also be imagined in electrode materials for actuators in optical systems or in medical technologies.

Already at low densities CNTs provide higher mechanical strength than steel. Mechanically optimized adhesives are especially useful for making high strength joints in multi material applications for the aerospace industry. The thermal conductivity properties can be used in microelectronics to provide protection from overheating of sensible components.

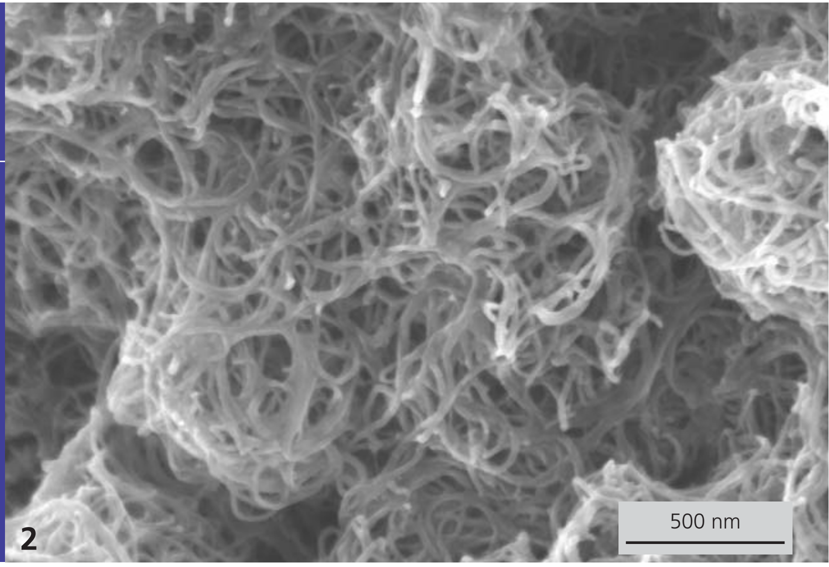
Our research objective is to integrate additional functionality into adhesives.

OUR SOLUTION

The dispersion quality, the type and the quantity of CNTs in adhesives are critically affecting the resulting properties.

Several dispersion techniques were studied to optimize the breakup of CNT agglomerates and to achieve a homogeneous distribution. These techniques allow the processing of melt adhesives (with dual auger extruder) and also of single or multi component adhesives (with three roll mill, high pressure disperser, speed mixer, ultra-turrax or ultrasonic sonotrode). The effects on the adhesives as well as the CNT distribution and the degree of their destruction vary from method to method. The modified adhesives are characterized with respect to the resulting property changes.

The project is performed as part of the "Dresden Innovation Center Energy Efficiency". Energy efficient surface treatments prepare the surfaces prior to applying the specially developed CNT modified adhesives. The goal is to develop high strength, long-term stable and reproducible adhesive joints. The desired properties are individually adjusted and it is possible to generate multi functional layers. The matrix material was a dual component low additive containing epoxy resin based on bisphenol A. This material was also chosen as a reference for comparison with other epoxy based adhesives.



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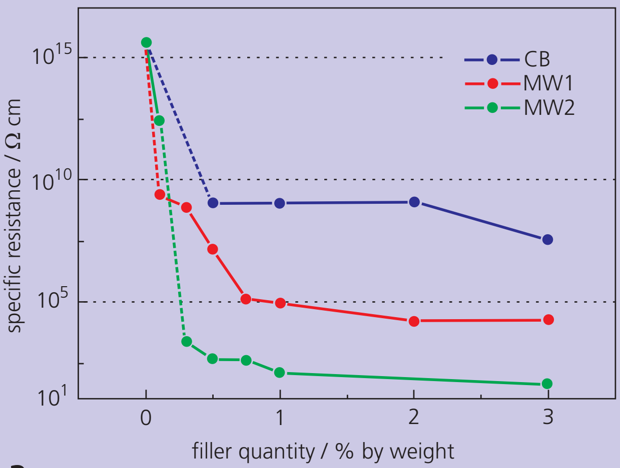
RESULTS

The specific electrical resistance of the epoxy resin without additional CNT filler is 10^{15} Ω·cm. The addition of multiwalled CNTs (MW2) substantially reduces this resistivity to 8 Ω·cm. Measurable electrical currents (percolations) were already detected at 0.01wt-%. The percolation threshold with multiwalled CNTs from another manufacturer (MW1) is at 0.3 wt-%. Soot particle (CB) filled adhesives show a much higher resistivity of 10^{8} Ω·cm at 3 wt-%.

Tensile testing showed an increased elongation for functionalized nanotubes. The tensile strength remained unchanged.

It was also possible to substantially increase the conductivity of thermoplastic adhesives. The elasticity of the melt adhesive decreases with increasing CNT content. Adhesive bonding experiments showed a small increase in tensile shear strength with increasing CNT content.

Dependence of the specific volume resistance from filler quantity and type



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1 Sample for different test methods

2 SEM image of CNTs

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1

ONLINE SPECTROSCOPY FOR QUALITY ASSURANCE

THE TASK

Industrial manufacturing is continually striving to improve quality control and process documentation. Process monitoring techniques that can be integrated online into the manufacturing flow are of critical importance to quality assurance efforts. Laser welding is increasingly applied in the area of powertrain component manufacturing. Newest design concepts are based on joining dissimilar materials; a challenge for which Fraunhofer IWS engineers have already developed proven welding process solutions. Frequently these welding processes apply a filler material to tailor the properties of the weld to the requirements of a given application and to reduce manufacturing costs. Quality control requirements demand process monitoring and documentation.

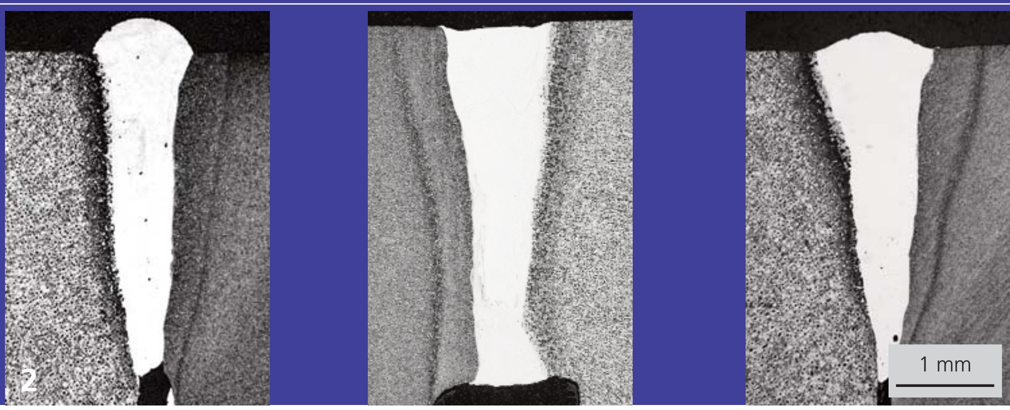
Laser beam welding with filler materials depends critically on the accurate reproducibility of process parameters. These parameters exactly determine the metallurgical properties of the weld seam, which directly relate to part performance. The structural composition of such seams is typically analyzed with destructive methods. These take a long time and are costly. It is also evidently not possible to test 100 % of manufactured products with destructive methods. Here we looked for an alternative technique, which can perform 100 % testing and can be seamlessly integrated into the manufacturing flow.

OUR SOLUTION

Laser beam welding is a high power density process involving plasma formation in the metal vapor that fills the keyhole region. The optical emission form such plasma is characteristic for the interaction between laser beam and material. The emitted secondary radiation can be detected and spatially, temporally and spectrally analyzed. The interesting wavelengths are in the UV and Vis spectral ranges. The analysis can focus on discrete wavelengths, which are characteristic emission lines for specific chemical elements.

Measured spectra are evaluated by comparing them to reference spectra. The latter are previously recorded, processed and stored in the measurement system. For each manufactured part the recorded spectrum is compared with the reference spectrum. The difference between measured and reference spectra holds information that is relevant to various process parameters. These data are documented and also used as feedback information to adjust process parameters. Thus online spectroscopy provides the means for documentation as well as information for process control.

Spectra are recorded for a wide range of process parameters and than analyzed for correlating features, which can be used for process monitoring.



RESULTS

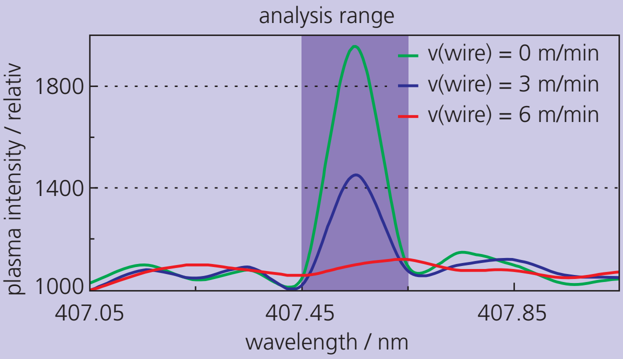
Online spectroscopy of the optical plasma emissions during laser beam welding is used to continuously monitor the process and quality properties of the welded products. The high temporal resolution of the intensity measurements allows correlating the data spatially throughout the entire welding process. The data therefore provide information about the change of processing conditions along the weld.

Fraunhofer IWS engineers have qualified this method for the typical conditions of laser welding processes with filler materials. The critical process parameters are the amount of filler material and the laser spot position with respect to the welding location.

When welding dissimilar materials in overlapping configuration, additional parameters become important such as the follow-through weld and the depth of the weld seam. The parameters can also be detected by online plasma spectroscopy.

Dependence of the emission intensity from the amount of filler material during laser beam welding

Weld of a differential transmission component (6 kW CO_2 laser)



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The developed online spectroscopy techniques for monitoring welding quality have been deployed in industrial environments since several years and have a proven performance record. However, the system technology is continually being updated and tailored for many different applications. The current development stage of the system uses new spectrometer modules with extended wavelength ranges. This reduces the number of required modules form two to one. The increased spectral resolution also improves the information that can be derived. These improvements also increase reliability and validity of the results.

1 *Typical transmission components with mixed material joints*

2 *Cross sections of weld seams of mixed material joints*

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1

INNOVATIVE MACHINE CONCEPT FOR ON-THE-FLY WELDING OF PILLOW PLATES

THE TASK

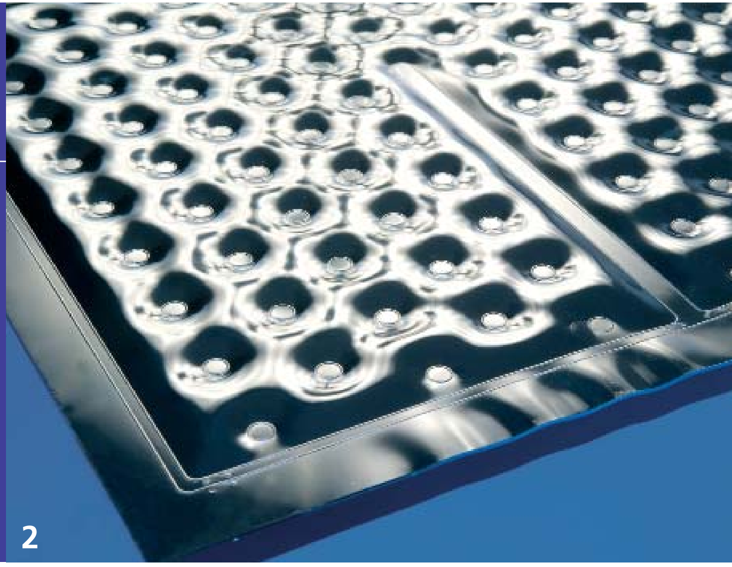
Heat exchangers are becoming increasingly important for carefully tailored thermal energy management applications. The market for plate heat exchangers is growing since they offer a flexible design, good thermal transport and a limited number of required manufacturing steps. Pillow plates are produced by overlap welding of two stainless steel sheets and a subsequent hydroforming step (Fig. 2). This processing sequence sounds relatively simple but proves to be a challenging technology for mechanical engineers. The immense number of required welds leads to thermal stresses that have to be absorbed by the clamping fixtures. Conventional machine concepts have hydraulic clamping fixtures and a laser head that moves in two dimensions. The laser has to be positioned to the numerous welding locations, which takes up valuable production time. Ultimately the achievable welding speed of such a system is limited by the machine dynamics and complex seam geometries.

Previously Fraunhofer IWS engineers had developed the so-called contiLAS technology for the remote cutting of continuously moving material. The task here was to adapt this technique to work for a welding process as well. The goal was to implement a remote welding process utilizing overlaying axes and to develop the necessary software components. The solution had to be highly flexible and easy to use. It should be efficient to even make economic sense for processing single items.

OUR SOLUTION

The remote welding experiments lead to first heat exchanger prototypes. Scanner technology was used that couples to axes “on-the-fly” and increases the dynamics of the system. Combined with adapted laser power the scanner technology increases the welding speeds. Positioning times are nearly eliminated. The process also significantly reduces the heat impact and thus thermal warping of the part. The prototypes performed convincingly during hydroforming and burst testing.

After successfully testing the concept, the development aimed at implementing the process for series production. The overall system was jointly developed with the company Held Systems Deutschland GmbH (Fig. 1). The concept involves segmented pneumatic fixtures and welding cycles. During the welding process the scanner is moved over the part to be welded to optimize speed. Its position with respect to the part is calculated in real time. The protective gas is switched on only in the segment where the head is positioned. Segmented welding requires a special strategy with an overlapping region when welding circumferential seams. Plate heat exchangers may require as many as 800 individual weld contours per m^2. This requires a substantial programming effort, which necessarily calls for CAM software. The special programming system CAS.optWELD was developed based on previous IWS laser process control know-how. The weld geometries in DXF format and the desired process parameters are transferred to a processing program. During data import the software distinguishes between part and welding contour. Based on database records the software selects the optimal segment width and overlap for a given pair of sheet metal.



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Similarly the system also establishes the optimal processing parameters (welding speed, laser power and the amount of protective gas flow). The overlapping range can be defined for the individual contour groups using another database with numerous configuration options. The user can customize and expand the technology data tables. The software offers various automated processes but can also be used in a manual mode. The latter is in particular useful when setting up new products for the process.

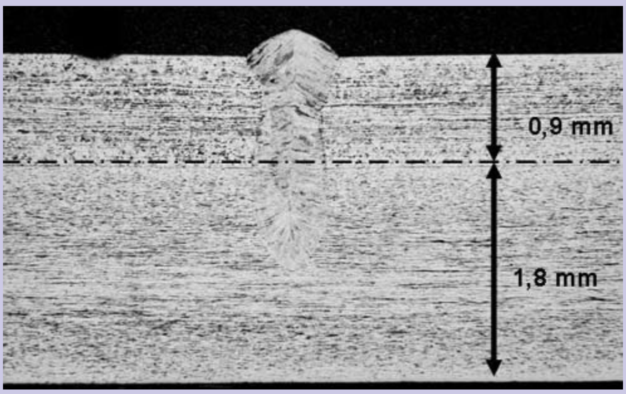
The software calculates an optimized welding process. The algorithm takes into account the formed region for calculating overlapping regions outside of the contours. It only takes a few seconds for the software to establish scanner, laser and machine programs. The resulting system control file package is sent to the machine controller and stored in a database. The machine operator can access various program parts and execute them according to the required production flow. The program can be created directly on the machine but also offline during job preparation.

RESULTS

The consequent implementation of our know-how on overlaying axes control algorithms led to the development of a highly productive manufacturing machine. The performance improvements are based on an increased welding speed, an increased positioning speed of typically 12 m s^{-1} and a fast pneumatic clamping fixture. IWS engineers developed the programming system CAS.optWELD. This program is very flexible and enables the individual and fast implementation of customized processes. Thus the users can efficiently adapt their manufacturing process flows to varying customer requirements.

The contiWELD technology also offers so-called "aesthetic" welding, which implies a solid mechanical connection without a visible through weld. This process is particularly used in the food processing industry (Fig. 3). The first user of the contiWELD system is impressed. Additional system implementations are in progress.

Stainless steel (1.4301) weld, 0.9 mm on 1.8 mm



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1 *Laser system concept contiWELD technology*

2 *Plate heat exchanger, remote laser welded (after hydroforming)*

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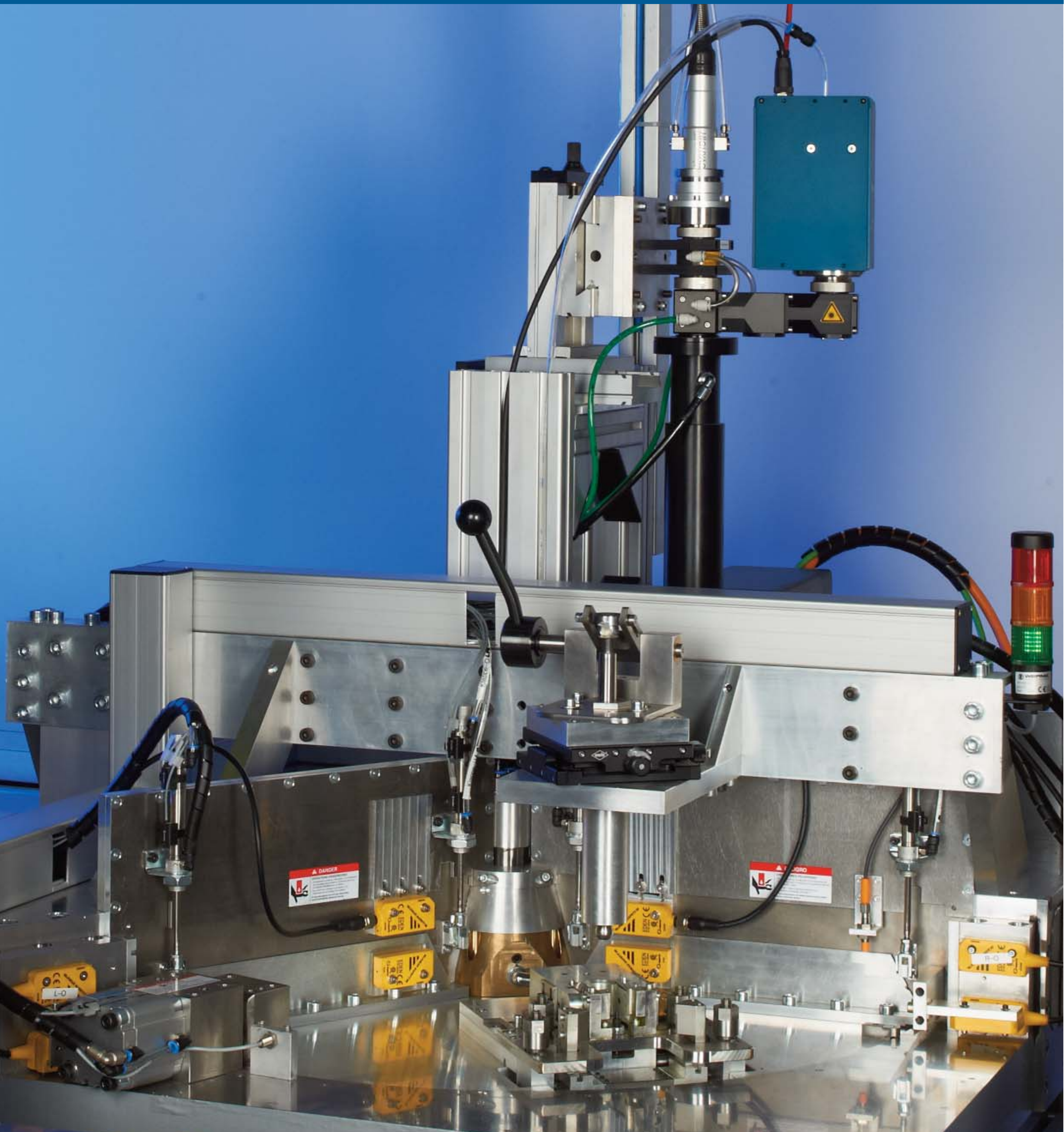

It is the unsolved rather than solved problems that are keeping the mind alive.
Erwin Guido Kobenheyer

BUSINESS FIELD SURFACE TECHNOLOGY

Editor: In recent years you have developed several system components to improve the control and quality of industrial laser hardening processes. What will be developments in the future?

Prof. Brenner: We have responded to market demands at a time when the process basics were understood and simultaneously efficient beam sources such as the fiber coupled high power diode lasers became available.

Today all system technological components are developed for deploying industrial scale laser beam hardening processes. These components include robot integration, beam shaping (our LASSY system) and process and quality control modules (temperature measurement system E-MAqS, E-FAqS, temperature control system LompocPro). Now we have the know-how and the opportunity to explore other applications for these system components.

Editor: Which applications do you have in mind?

Prof. Brenner: Several applications come to mind. For example, the temperature control of localized liquid phase processes for laser buildup welding, soldering and in particular laser beam soldering, heat conduction welding or rapid thermal processing such as the induction hardening or the laser tempering. We are excited that we managed to develop a control concept that enables more reproducible laser buildup welding processes.

The first step was to analyze the influences of laser power, spot size, power density distribution, powder mass flow and processing speed on the welding behavior of the substrate. The data were then used to develop a control concept that is based on the online detection of the melt bath size to derive information about substrate melting.

A robust process control algorithm was developed and already installed at 6 international customer sites.

Editor: Last year you reported about a new laser beam unit with rotating mirror optics for the temperature controlled laser beam hardening of inner surfaces in semi-spheres. What happened to this technology?

Prof. Brenner: We had a customer contract to demonstrate the long-term reliability of this system. The positive test results were then used to design and test a rotary table machine with integrated rotating mirror optics. This configuration helped to further reduce the cycle times to 60%. Thus this interesting beam shaping concept is now ready for industrial implementation.

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.

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SOFTWARE DEVELOPMENT AS A FLEXIBLE TOOL FOR SURFACE HARDENING

THE TASK

There is a general trend in the industry to integrate more and more functions into individual machine components. The laser beam hardening technology is benefitting from this trend. New applications are explored and it rapidly becomes an established and accepted manufacturing process. Consequently existing systems and components require further development and adaptation. A particular area of interest is the improvement of process monitoring and control capabilities. Process control is especially important for applications such as the hardening of valve seats and the soldering of solar cells. In addition to hardware improvements it is also necessary and beneficial to improve software components. To guaranty highest flexibility we implement the latest advancements of advantageous software design patterns. In the area of software adaptation it is especially important to use flexible hardware interfaces. The software/hardware design has to be flexible and open to allow the seamless and quick integration of additional components, which may be required for a particular process.

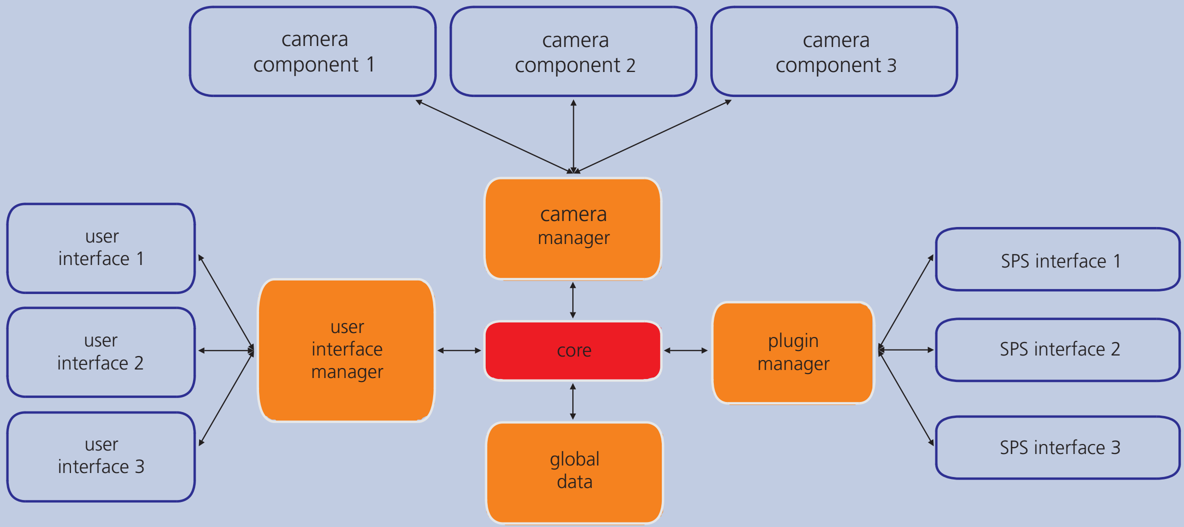
OUR SOLUTION

Software

Our frequently deployed process controller “LompocPro” and the dynamic beam shaping software “LASSY” provided the basis for a completely new implementation of their proven functionality. Particular goals of the new implementation were to improve scalability, data throughput and modularity. The software used to be implemented as a single monolithic block. Now it consists of functionally separated modules, which communicate via interfaces. It is now possible to dynamically call additional core components during runtime (Fig. 2). Such functionalized modularity also offers the possibility to use individual modules in other software products. Following industry trends the data transport was implemented on fast bus systems. The implementation uses unified SPS modules. As such the software is implemented much closer to the machine and can be more easily integrated into existing machine control systems. But it is not only the internal separation into functional blocks that is of importance. We also completely reorganized data flow and processing. For example, modern industrial process cameras deliver more than 600 frames per second with a resolution of 120 x 112 pixels. This is an enormous data volume. To accommodate high frame rates and resolutions it was necessary to redesign the core of the process controller “LompocPro”. Data streaming rates had become so demanding that they could negatively impact the actual control function of the manufacturing process.

Hardware

A similar modular structure was implemented for the camera manager. Each process uses a set of optimized cameras, which are controlled via a unified software interface. Initially this concept requires additional implementation effort. However, the effort pays off when manufacturing processes require a variety of different camera systems with varying hardware specifications such as wavelengths, frame rates, frame resolutions and bits per pixel. In this case any camera model can be integrated without having to adapt the accessing process controller. Even complex InGaAs (indium gallium arsenide) cameras can be incorporated in addition to the conventional CCD cameras.



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RESULTS

A new system implementation was developed for the process controller "LompocPro" and the dynamic beam shaping software "LASSY". The new software conforms to modern industrial requirements with respect to flexibility and modularity.

The "LompocPro" software is for example used to control laser beam hardening processes. It is now equipped with a new camera library to us a broader spectrum of available camera based temperature acquisition systems. It is now also possible to use several detection channels in parallel with different or dynamically adapting sampling frequencies. Data are stored in a format to enable further data processing.

The specialty of "LASSY" is to dynamically oscillate mirrors that are positioned in the laser beam path. The mirror oscillation spreads the beam and thus adapts the beam width to cover the desired hardening zone. Oscillation frequencies may range from 100 Hz to 1 kHz and are driven by an output signal of ±10 V. The intensity distribution of the laser beam can be locally adjusted even without interrupting the laser processing. The new software also measures the actually performed oscillations of the mirror in real time. The data can be visualized and used for analysis.

The new software systems integrate high performance input/output hardware components with wide variety of industrial bus system interfaces. This concept enables flexible system integration into customized machine systems.

1 Integration of "LompocPro" and "LASSY"

2 Schematic representation of the core components of modern control systems

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EFFECTIVE HARDENING OF SURFACES WITH ROTATIONAL SYMMETRY

THE TASK

Over the past decade laser beam hardening with high power diode lasers became an established industrial surface treatment process. Advantages of the process include the precise control of the hardening zone location, the possibility to treat hard to reach surfaces (e.g. in bores) and the low heat impact of the process, which leads to minimized part warpage.

The typical process hardens tracks on the surface with widths from 1 millimeter to several centimeters. It is difficult to generate closed loop tracks such as rings because tempering effects may occur at the location where start and end points of the track meet. These effects may reduce the hardness at that location and also cause critical stress distributions.

However, surface wear protection is in particular critical for parts of rotational symmetry in the automotive industry and other branches.

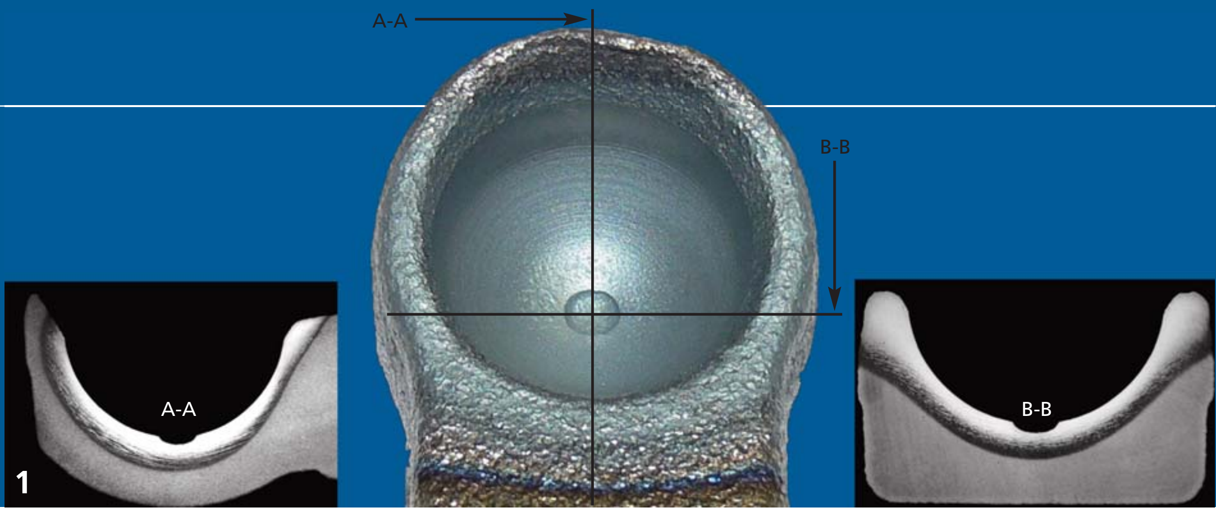
Consequently IWS engineers addressed the development of beam shaping units and process variations to achieve the tempering free surface hardening for such rotationally symmetric parts and other complex surface shapes.

OUR SOLUTION

Large parts of complex shape with 3D hardening zones are, for example, forming tools, turbine blades, angular rings and others. Such parts are processed with two cooperating robots. Each of the robots is equipped with the 1D beam shaping system "LASSY" with integrated temperature controller (also see Annual Reports 2009/2010). In addition the following process variations and corresponding beam shaping systems were developed, tested and implemented in production:

1. Fast part rotation with temperature controlled laser power adjustment
2. Part adapted ring beam optics
3. 2D scanner
4. Rotation mirror optics

The developments provide our customers with specific solutions for a wide selection of parts that can be surface hardened. This capability then enables new designs and products using such parts. In addition the new process variations and system components also help to reduce manufacturing cycle times, costs and energy consumption during surface hardening.



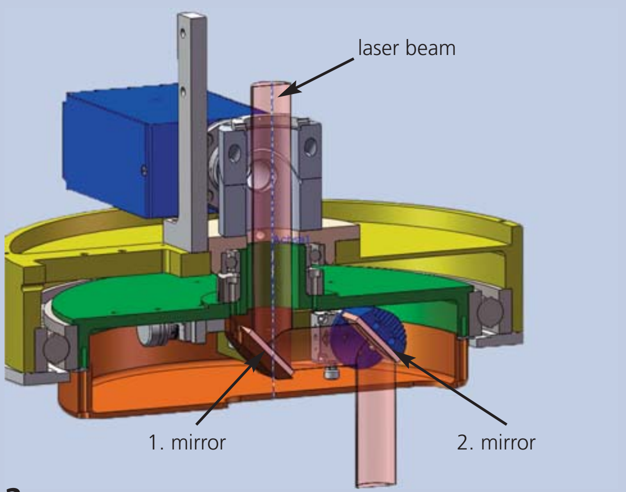
RESULTS

1. A ring shaped region of austenitic steel can be generated by fast rotation of parts such as shafts, shaft shoulders, ring grooves, leading edges or similar. After a brief heating period the glowing ring can be moved along the part using the NC feed.
This simple process variation is very flexible. The NC controller is used to adapt the process to different materials, part diameters, hardening zone depths and transition radii.

2. Especially designed ring optics were developed to perform the hardening of a ring shaped path on flat parts in one shot. This setup is practical for nuts, thrust washers, seat surfaces, valve seat rings or similar and requires only a very simple part fixture. However, the required laser power increases over-proportionally with increasing ring widths.

3. 2D scanners on the other hand allow virtually any shape of closed hardening zones on flat or slightly curved surfaces. Compared to the ring optics approach the 2D scanners require different limits with respect the achievable hardening depths. Typically the required power is substantially lower.

Rotation mirror optics



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4. Rotationally symmetrical parts with strongly curved, convex or concave surfaces require special optics for hardening. This optical system was developed based on rotating mirrors with integrated temperature control. The laser beam is guided by two mirrors, which are rotating around laser beam axis (Fig. 2).

The speed is continuously variable and adaptable to the application. The angle of the second mirror can be adjusted to achieve a sufficiently steep beam impact not only on flat and slightly curved surfaces but also on strongly curved surfaces and even on cylindrical shaft zones. The flexibility of this rotating mirror approach is optimal but it is intrinsically limited to the hardening of rotationally symmetrical surfaces only.

An industrial application example for using the rotating mirror optics is the hardening of ball calottes in suspension components. Here the process has to uniformly harden the entire inner surface of the calotte (Fig. 1). This is in particular difficult due the varying material thickness throughout the desired hardening zone. A compact processing chamber was developed for using the rotating mirror optics in an industrial environment. Due to its compactness it can be easily integrated into existing production lines. It is also possible to use it as a stand-alone unit with its own controller and manual or automated part feed.

1 Longitudinal and cross sections of a laser hardened ball calotte

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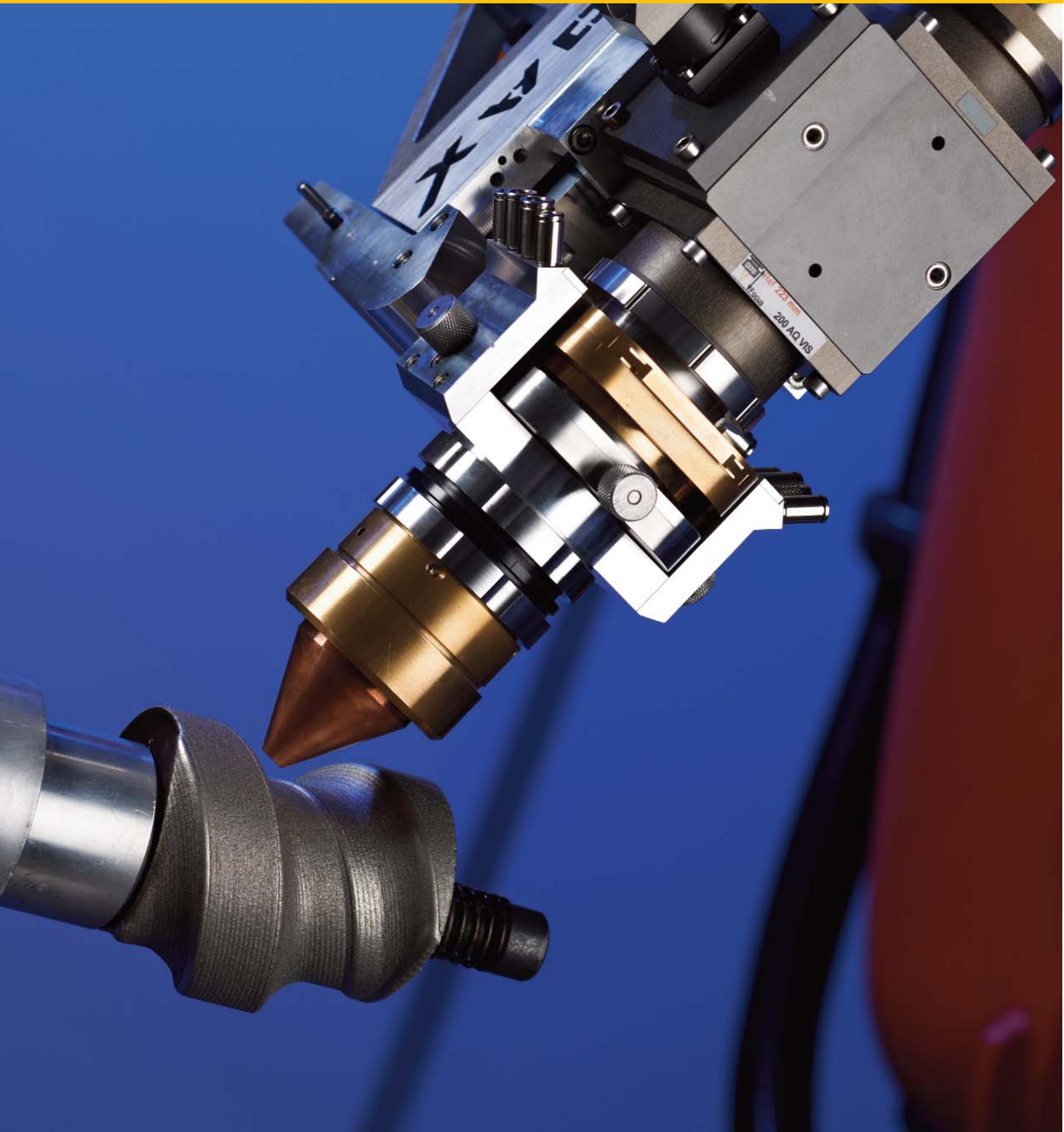
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The only way to predict the future is to build it.
Alan Kay

BUSINESS FIELD THERMAL COATING

Editor: This year your department expanded by forming a new group. What was the motivation to build competence in the area of printing technologies?

Prof. Leyens: Printing as a technology to fabricate 2D coatings and 3D structures perfectly complements our existing competences in these areas and opens access to completely new application fields. The high precision of today's printing technology makes it possible to produce very fine structures. Additional advantages are the high printing speeds and the broad selection of available inks. Our printed coatings and structures are intended for applications in electronics, batteries, photovoltaics, energy harvesting with thermoelectric generators and microsystem technical components.

Editor: That sounds interesting. But isn't printed circuit board technology already well established in the electronics industry? What is so special about the IWS activities?

Prof. Leyens: Indeed, printing technologies are well established in the industry. However, we are aiming at entirely new approaches by cleverly leveraging our materials know-how and process understanding. For example, we attempt to combine printing and heating processes to drastically reduce the ink drying times. This leads to the capability of printing even finer structures at higher speeds. But the precise thermal control of our special inks is not only intended to dry them faster. We also try to adjust critical material properties such as thermal conductivity, magnetic and mechanical properties.

Editor: Thermal spraying is more and more using suspensions. What are the advantages?

Prof. Leyens: Powders have to have a minimal particle size to be reliably transported and fed to the process. Smaller particles such as nanoparticles are problematic since they tend to agglomerate. However, suspended in aqueous or alcohol solutions even smallest particles can be thermally sprayed. This implies enormous technological advantages. By selecting the right process parameters it is possible to customize dense or porous coatings over a wide range of thicknesses. Due to the small particle sizes, these can even be evaporated so that the resulting coating structure is similar to those made by vapor deposition processes but at significantly lower costs. Suspension spraying for example allows the fabrication of thermal barrier coatings with morphologies comparable to those of electron beam evaporated coatings.

Editor: What is the development focus in the field of buildup welding?

Prof. Leyens: Buildup welding process developments with wire and powders pursue two main directions: Buildup welding with high productivity and generating with highest precision. Energy sources such as laser beams and inductive heating are combined to achieve high deposition rates and to make the process more economical. This is of great interest to the oil and gas industry to protect large and heavy parts from wear. On the other hand the aerospace industry requires generative structures of highest precision. Whether the requirements are productivity or highest precision, our materials and process know-how can be applied to address nearly any customer request.

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 + 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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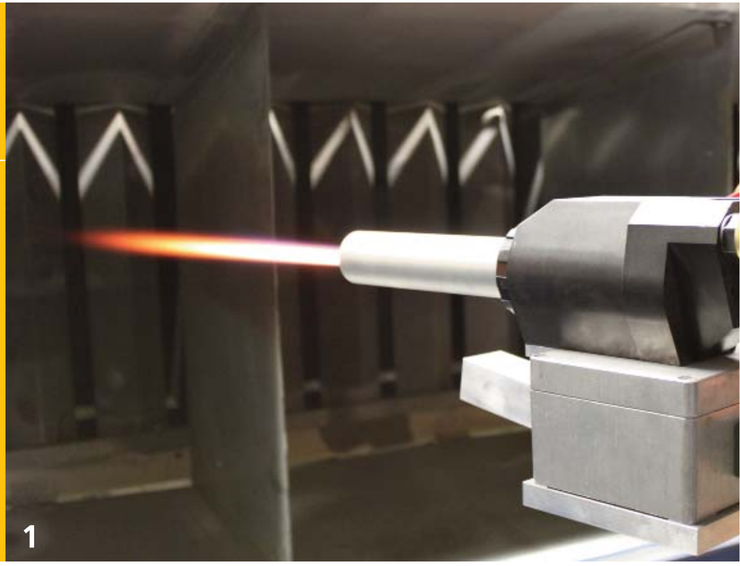
2011 PROJECT EXAMPLES

BUSINESS FIELD
THERMAL COATING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HVAF – AN ALTERNATIVE PROCESS FOR HIGH VELOCITY FLAME SPRAYING

THE TASK

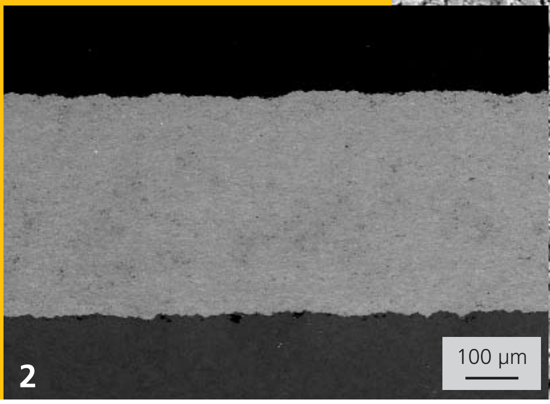
High velocity oxygen fuel flame spraying (HVOF) is a reliable and established industrial thermal coating process. HVOF sprayed metallic and hard metal coatings have the advantage of being very dense. In particular hard metal coatings are highly wear and fatigue resistant.

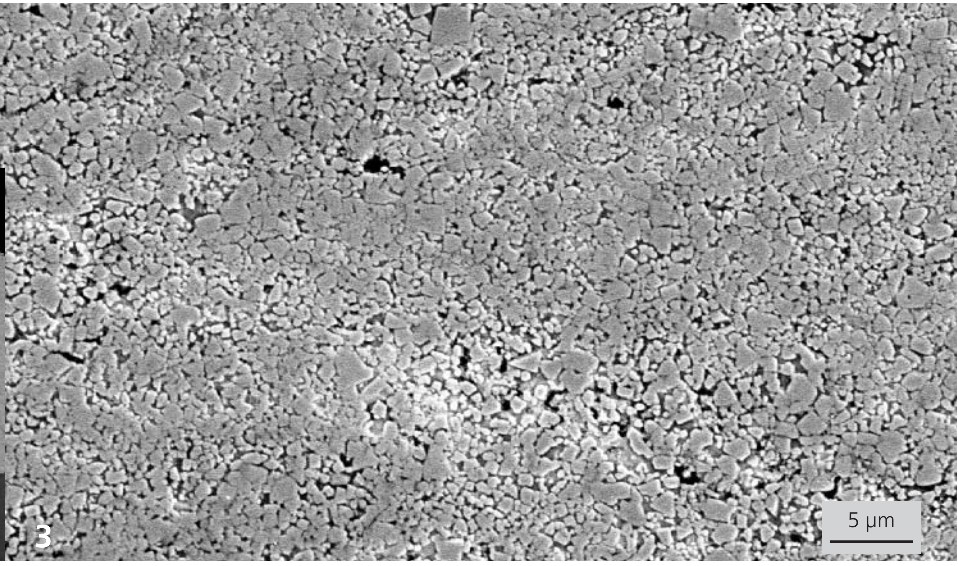
However, to address new industrial applications for metallic and hard metal coatings it is necessary to reduce the costs of high velocity flame spraying processes. The goals are to improve the deposition efficiency, to reduce the heat impact of the process on the parts and to reduce the equipment investment and operational costs. Using air instead of oxygen (high velocity air fuel) for combustion is a new method used in particular outside of Europe. Therefore Fraunhofer IWS engineers decided to evaluate this technology with respect to its possibilities and limitations.

OUR SOLUTION

Since 2010 we have had a M2^{TM} AC-HVAF coating system in operation at the Fraunhofer IWS. This machine complements other existing thermal spray technology. The new process achieves particle velocities of Mach 2, i.e. 600 – 700 m s^{-1}. The spectrum of coating materials includes low melting point metals, hard alloys and hard metal powders. The machine is equipped with a special powder delivery system and uses compressed air instead of oxygen. It also does not require water cooling. Subsequently operating costs are reduced. Methane, propane or natural gas is used for fuel.

The process temperatures and higher particle velocities form coatings of increased toughness. The heat transfer into the substrate is lower compared to the HVOF process. This allows to coat thinner substrate materials without additional time consuming cooling phases during the deposition process.





RESULTS

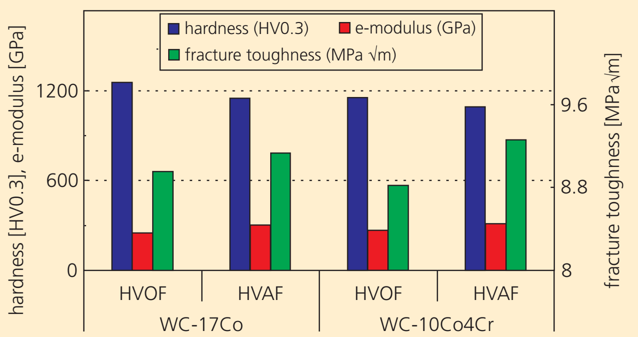
In practice the M2[TM] system was convincingly demonstrating the efficient and robust capability of depositing high quality coatings.

Hard metal and metal deposition processes achieved coating efficiencies of up to 80 %. Compared to HVOF the particle velocities are higher and thus require lower temperatures. The very high kinetic energy of the particles leads to a compact microstructure of the coatings with improved adherence to the substrate. The lower particle temperatures also reduce oxidation during the processing of metals. Undesired phase transformations (decarburization) are avoided during the processing of hard metals.

The coatings were analyzed with respect to their mechanical properties including hardness (HV0.3 in cross section), E-modulus and fracture toughness. HVAF coatings of the same porosity typically show a lower hardness but higher E-modulus and higher fracture toughness than HVOF coatings (Fig. 4).

Currently we are investigating how these modified mechanical properties affect the wear resistance of HVAF coatings. First results allow the assumption that HVAF coatings may be suitable for new applications such as parts exposed to rolling contact fatigue wear.

Properties of HVAF deposited coatings



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1 M2[TM] AC-HVAF spraying system at the Fraunhofer IWS

2 Overview image of the WC-17Co hard metal coating on a steel substrate

3 Microstructure of a HVAF deposited WC-17Co hard metal coating

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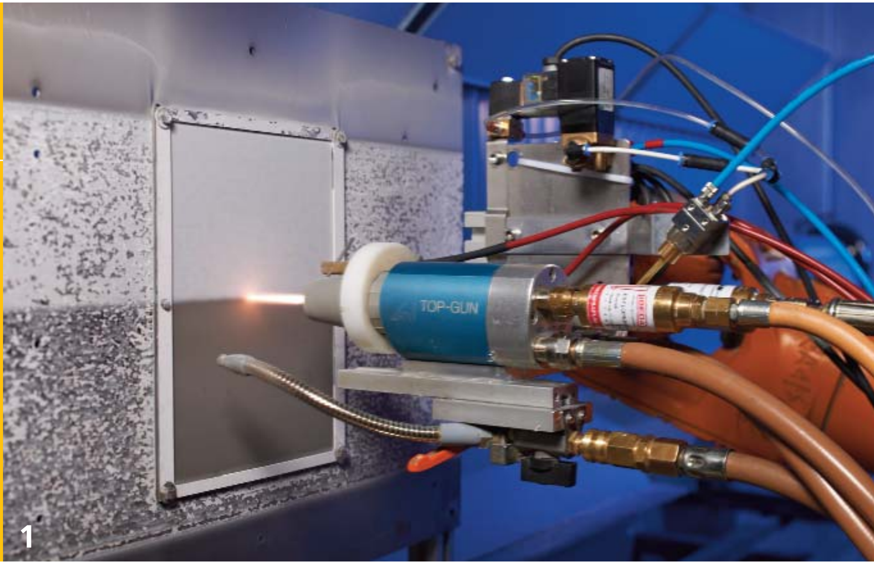


THERMAL SPRAYING WITH SUSPENSIONS – INNOVATIONS IN COATING ARCHITECTURE AND QUALITY

THE TASK

Thermal spraying is an established surface technology used in numerous industrial applications. Atmospheric plasma spraying (APS) and high velocity oxygen fuel spraying (HVOF) are the most commonly used processes. They offer a degree of flexibility when engineering coating solutions based on oxide ceramics, hard metals and metals over a wide thickness range from 100 µm up to several millimeters. Across the entire materials palette the used powder particle sizes range from 10 µm to 100 µm. Developing new applications continually requires to improve coating properties, reliability and cost efficiency.

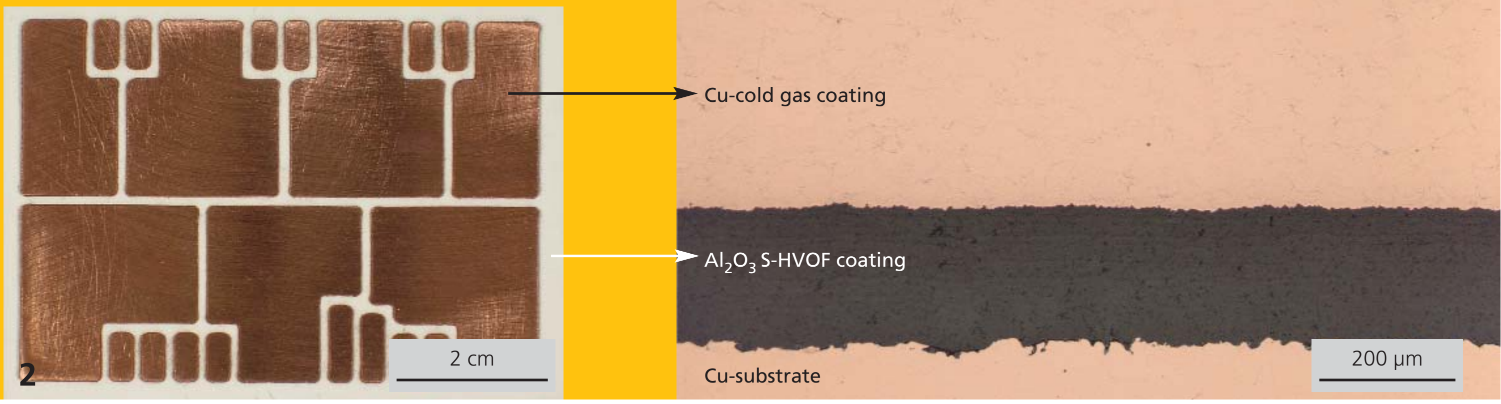
OUR SOLUTION

Using suspensions instead of conventional powders offers new possibilities. For example, it is possible to use finely dispersed powders with particle sizes in the range of nanometers to a few micrometers. Subsequently the resulting coatings can be as thin as a few tens of µm. The cost effective production of coatings with new property profiles and qualities becomes a reality, which is not achievable with conventional powder spray methods.

Thermal suspension spraying requires suitable suspension delivery systems, which can be integrated into existing spraying machines. At the Fraunhofer IWS we adapted a suspension spraying process to work on a F6 plasma spray machine as well as a TopGun HVOF machine (Fig. 1).

The suspension feeder achieves a constant feed rate of up to 100 ml min^{-1} at high process stability. Deposition efficiencies of up to 70 % are feasible. The injectors spray the suspension depending on the machine axially (internal) or radially (external and internal) into the flame or plasma.

Suspensions with a solid particle content of 5 to 50 wt-% are produced by mixing finely dispersed powders into solvents. Typical solvents are distilled and deionized water, alcohols and water-alcohol blends. The homogeneity and long-term stability of suspensions are of critical importance to the spraying process and the quality of the resulting coatings. The development of suitable suspensions is performed in cooperation with the Fraunhofer IKTS.



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RESULTS

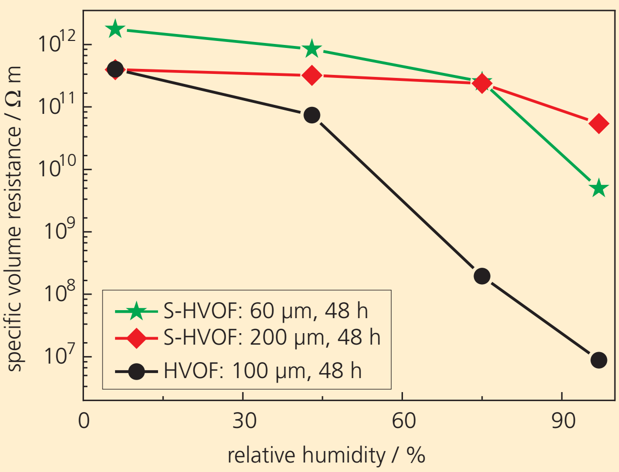
Suspension spraying allows the fabrication of ceramic coatings with tailored microstructure. Coating thicknesses from a few micrometers to several millimeters are possible from dense to porous structures.

The mechanical properties (hardness, E-modulus) of suspension sprayed coatings range from equal to substantially better than those made by powder spraying. Simultaneously the process generates smoother surfaces and fewer anisotropies in the coatings. Economic parameters such as the deposition efficiency and coating thickness per pass are attractive.

Suspension sprayed coatings are substantially different from conventional coatings with respect to phase composition and coating architecture. When deposition aluminum oxide coatings (Al_2O_3) it is possible to avoid the undesired transformation from the α to the γ phase without the addition of stabilizers. Suspension HVOF sprayed Al_2O_3 coatings combine a specific microstructure with a higher α-phase content and show a better long-term stability of dielectric properties compared to conventional coatings. As shown in Fig. 3, the specific resistance of conventional HVOF Al_2O_3 coatings drastically reduces in humid environments. Al_2O_3 suspension coatings (S-HVOF) on the other hand show better electric properties even at very high humidity.

Fraunhofer IWS engineers collaborate with researchers at the Helmut-Schmidt University in a BMBF funded research project (BmWi-Innonet, id 16INO696) to investigate the performance of suspension HVOF sprayed coatings as insulators for high power electronics applications. An example is shown in Fig. 2.

Dependence of the specific volume resistance from the relative humidity for conventional HVOF Al_2O_3 layer (thickness: 100µm) and S-HVOF Al_2O_3 layer (thickness 60 and 200 µm). Ageing time: 48 h each



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1 *Suspension HVOF spraying machine at the Fraunhofer IWS*

2 *Circuit board for high power electronics: cold gas sprayed copper coating on suspension HVOF Al_2O_3 coating on Cu heat sink*

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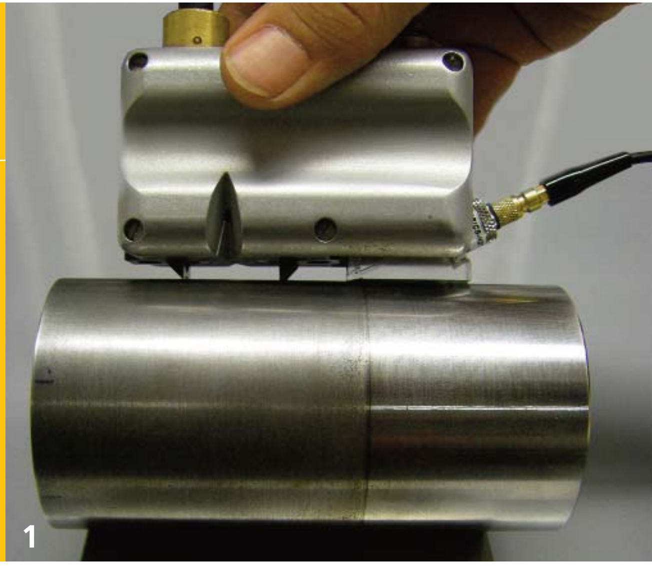

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NON-DESTRUCTIVE TESTING OF THERMALLY SPRAYED COATINGS

THE TASK

Thermal spraying is a highly efficient technology to deposit wear resistant and functional coatings on diverse parts. Modern thermal spray processes produce nearly pore free coatings. However, some micro defects and residual porosity cannot be avoided. For some applications a defined amount of porosity may even be useful. However, in most cases porosity and increased defect densities decrease the mechanical integrity of the coating reducing strength and adherence. A fast and non-destructive testing method is very useful for materials development and quality control of thermal spray coatings.

OUR SOLUTION

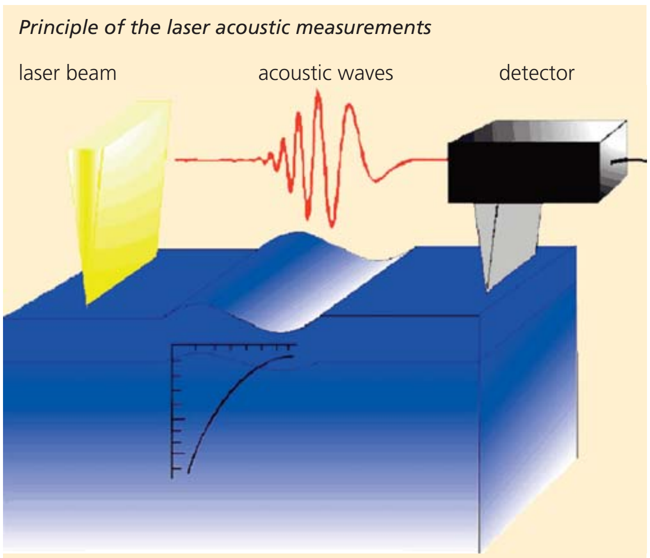
The Young's modulus is an important mechanical property of thermal spray coatings. It is also a sensible indicator for increasing porosities and micro crack densities in the coatings.

The measurements are performed using the LAwave® method, which is based on laser induced acoustic surface waves. Acoustic surface waves are small amplitude vibrations, which propagate along the surface region and do not affect the material structure. The propagation velocity of the acoustic surface waves is measured as a function of the frequency. The data are then evaluated to determine the Young's modulus of the coating. A special handheld tester was developed for the fast and non-destructive testing on a part surface (Fig. 1).

RESULTS

Laser induced acoustic surface waves are successfully applied to determine the Young's modulus of sprayed single and multilayer coatings made from ceramics and hard metals. The fast and non-destructive method samples a larger volume than an instrumented indentation tests. The result is the effective Young's modulus throughout the testing volume, which is substantial influenced by micro defects in this region (Fig. 2).

The analyzed coating volume is at least 5 mm x 5 mm x coating thickness. The penetration depth of the acoustic wave generally depends on the wavelength but reaches down to the substrate for all typical coating thicknesses.



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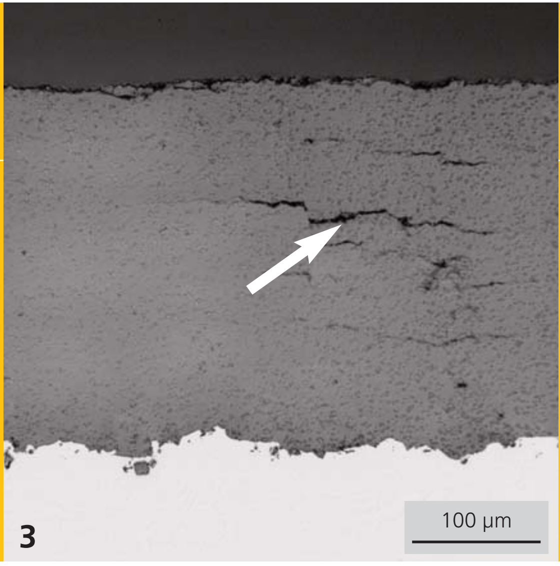

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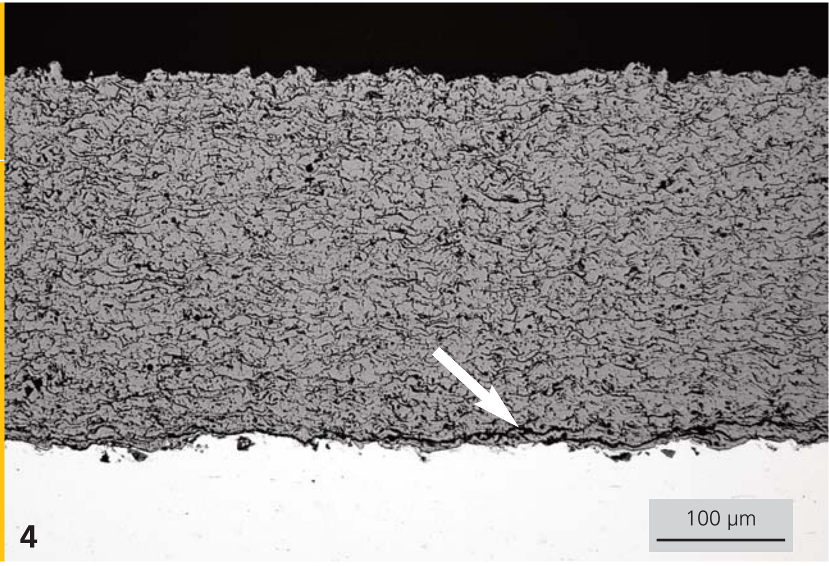

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The laser acoustic testing method LAwave® was applied to determine the Young's modulus of coatings made by different spraying processes: Atmospheric plasma spraying (APS), high velocity oxygen fuel spraying (HVOF), spraying with suspensions.

coating material	spraying process	e-modulus, GPa
Al_2O_3	APS	68 ± 1
Al_2O_3	HVOF	113 ± 2
Al_2O_3	suspension	101 ± 6
TiO_2	APS	76 ± 1
TiO_2	HVOF	111 ± 1
TiO_2	suspension	88 ± 4

5

APPLICATION EXAMPLES

Crack detection

The dramatic influence of cracks on the Young's modulus is shown in Fig. 3. The image shows the metallographic cross section of a suspension sprayed Al_2O_3 coating. The coating has lateral cracks. Compared to flawless coatings such cracks reduce the modulus of elasticity from 101 GPa to 46 GPa.

Adhesion failure detection

APS sprayed Cr_2O_3 coatings have a typical Young's modulus of 50 GPa. LAwave® measurements on the coating shown in Fig. 4 yielded 23 GPa. Therefore a defect was suspected in the coating. To localize the defect it was for calculation purposes assumed that the coating consists of two layers. The interface layer to the substrate was supposed to be 10 µm thick. For such a layer the derived Young's modulus was only 4 GPa. The top layer was assumed to be 290 µm thick and yielded a modulus of 52 GPa, which is a reasonable result for the material. Subsequently we concluded that there must be a defect in the coating located close to the substrate interface, which could be an adhesion failure. This assumption was then confirmed by microscopic imaging (Fig. 4).

The table shows that the Young's modulus of oxide ceramic coatings strongly depends on the deposition process.

1 Laser acoustic handheld tester

3 Al_2O_3 coating with lateral cracks, Young's modulus: 46 GPa

4 APS sprayed Cr_2O_3 coating with adhesion failure, Young's modulus in interface layer (10 µm thick): 4 GPa, Young's modulus in top layer (290 µm thick): 52 GPa

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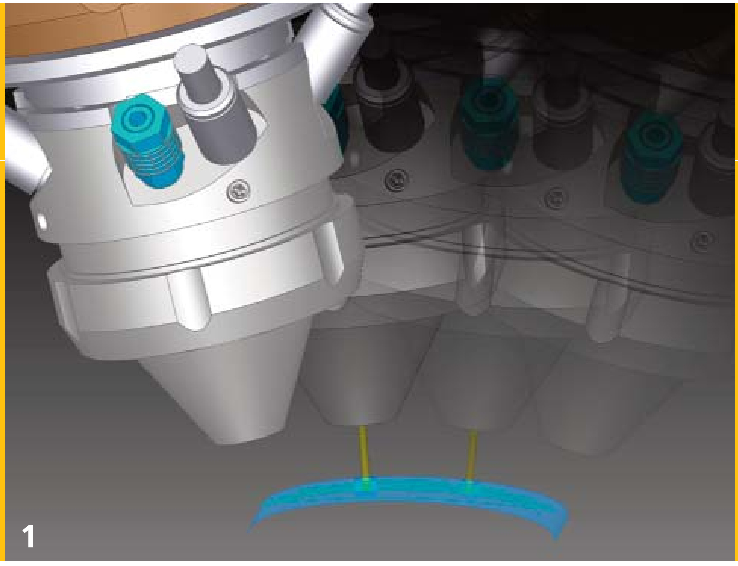

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EFFICIENT LINKING OF PROCESSES FOR PRACTICAL LASER BUILDUP WELDING

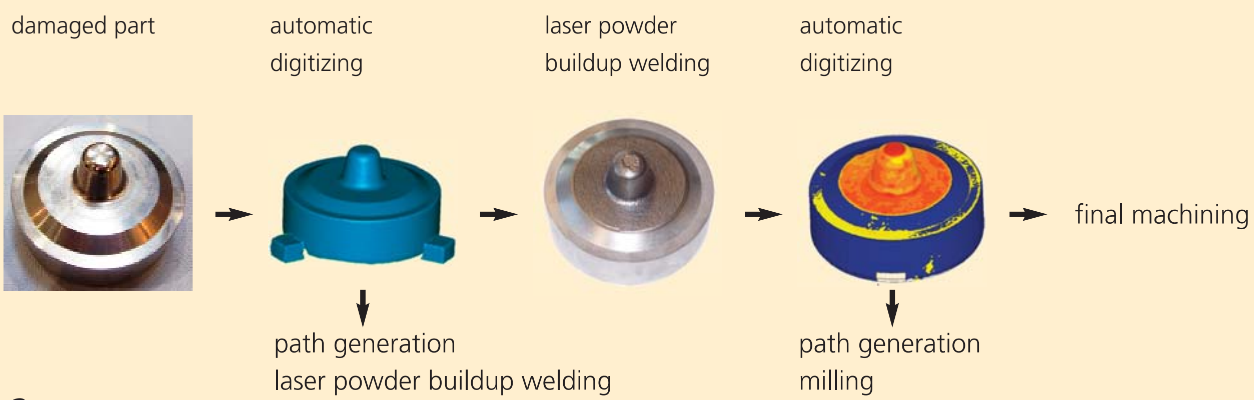
THE TASK

Laser precision buildup welding is an established manufacturing method and implemented in modern industrial production settings. The excellent performance and cost effectiveness of the laser sources and the process itself are the criteria for selecting the method over alternative buildup welding methods. In addition to surface coatings the current main application area is the generative buildup welding for repairs, design changes and the direct generation of tools and parts. In particular for industrial repair and shape change it is necessary to precisely know the given state of wear and damage of a part prior to processing it. Knowing the differential volume between damaged and desired geometries is critical for designing the repair process.

These data need to be acquired in relation to the position and orientation of the part and they need to be early on obtained to develop the welding strategy. Thus the complete generative process includes several steps prior to and after the buildup welding process. The success of the overall process is primarily determined by the coupling of the additional steps with the parameter controlled metallurgical process of three-dimensional metal deposition.

The cost effectiveness and quality of a real industrial application is therefore determined by the performance of the entire process chain from data generation and processing to buildup welding and final machining.

Stages of part processing in the closed process chain



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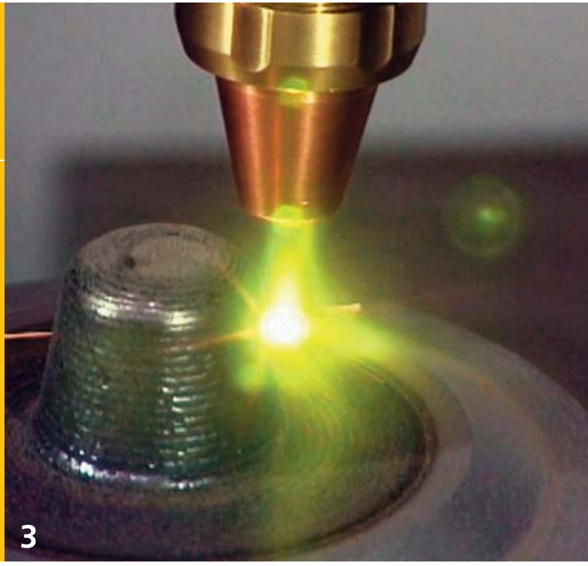

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OUR SOLUTION

The modern CAM software IWS/SKM DCAM 2011 uses the geometry data to generate NC machine code for laser buildup welding and final machining steps that make up the manufacturing process (Fig. 1). The code contains the path coordinates of the tools but also the processing strategies. At predetermined part locations the laser beam generates material volume close to the final contour (Fig. 3). Subsequently a directly integrated milling process shapes the part to its final geometry using the same machine setup. The acquisition of the required geometry data can principally be performed by commercially available fully automated measurement systems. However, these systems are expensive because they come with high precision axes drives, detectors and a separated controller. All these components are already available in a modern laser CNC or robot machine. It is possible to combine a CNC laser machine with a 3D areal scanner, which effectively provides a laser milling center with a 3D digitizer. This solution provides the quality of a commercial measurement system at significantly reduced costs.

RESULTS

The result is an industrially deployable technology module that creates CAD data of the part at every processing step and performs the execution of the complete processing chain in a single machine setup. The CNC machine integrates the laser system, the machining technology and the 3D digitizer. The processing machine moves the digitizer, the laser buildup welding head and the mill for final machining. An advantage is the modularity of the 3D digitizer since it can be universally used. Individual hardware components can be exchanged without having to rework the complete system. The hardware specific software components of the 3D digitizer as well as the motion system are intelligently linked via libraries.

All individual processing steps are united in a single machine. This offers a very attractive production technology solution for generative laser buildup welding and machining. A typical application is the repair of jet engine components. The technology is also used to change the geometry of large tools for automotive body making. A current example is a laser processing center for the generative fabrication of titanium parts and other high performance materials as shown on page 9.

1 Generating the processing strategy for laser powder buildup welding using DCAM

3 Deposition process with laser powder buildup welding

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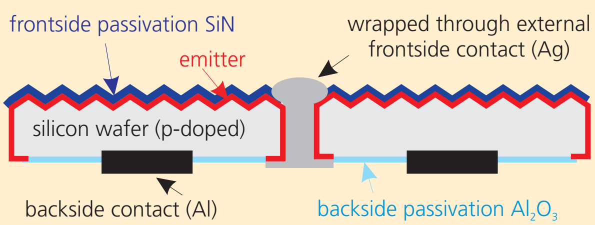
BACKSIDE PASSIVATION OF CRYSTALLINE SILICON SOLAR CELLS

THE TASK

The BMBF funds the project "Saxony Photovoltaics Automation Cluster" S-PAC (id 03WKBW03C). A task in this project is the development of flexible and compact automated modules for the fabrication of metal wrap through solar cells (MWT solar cells). In MWT cells the external frontside contact is moved to the backside of the cell (Fig. 1). The advantage is reduced shading losses on the front side and thus an improved efficiency of the solar cell. As part of the S-PAC project we attempt to combine this concept with a backside passivation of the solar cell.

Schematic representation of a MWT solar cell



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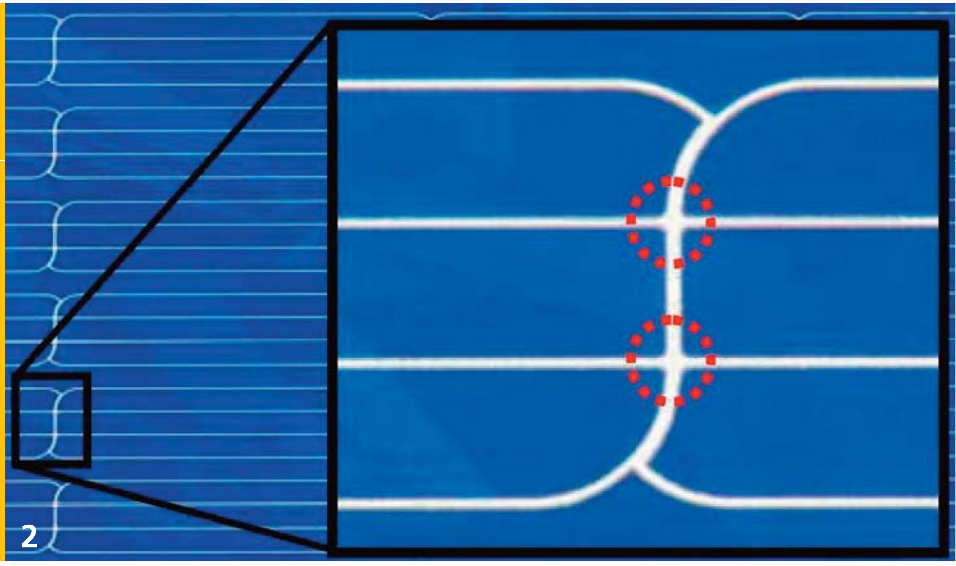
Fraunhofer IWS engineers have developed an atmospheric pressure process to deposit AlO_x passivation layers. The module can be integrated into a laser machine for processing MWT cells. To make this work the high throughput potential of the system requires matching high deposition rates for the passivation layer. Additional requirements address the use of easy to handle precursors and low concentrations of environmentally damaging and toxic waste gases.

OUR SOLUTION

The selected deposition method was ultrasonic spray pyrolysis. This process works at atmospheric pressure and can be integrated as an inline process. The precursors are stable aqueous or organic aluminum solutions. These are sprayed through an ultrasonic nozzle onto the preheated wafer. A first step was the evaluation of the precursor chemistry by wet chemical deposition with spin coating.

The precursors were aluminum triisopropoxide and aluminum sec-butoxide. Aluminum triisopropoxide is a solid powder that was dispersed in water. Adding a drop of nitric acid created a stable sol. The sol particle size (X_{DLS} value) was 17 nm. The fabrication of the sol based on aluminum sec-butoxide was performed using ethyl acetoacetate and isopropanol. Both were spun onto boron-doped 4" silicon wafers (1 - 5 Ω·cm, thickness 525 µm ± 20 µm, frontside polished). Subsequently the wafers were heated at atmospheric pressure. Varied parameters included the synthesis conditions of the sols, the wafer pretreatments, the coating thickness and the heat treatment regime.

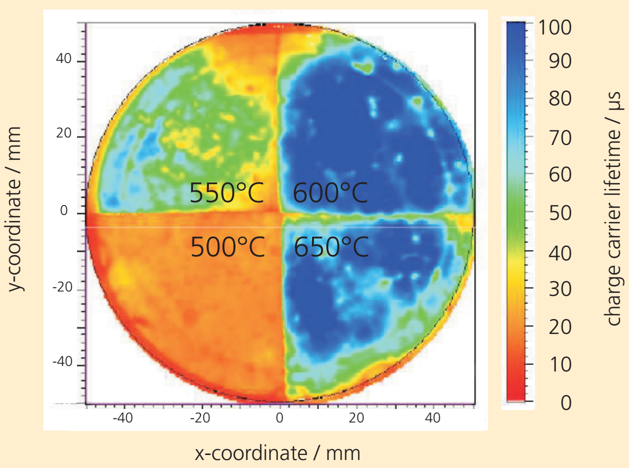


RESULTS

The thickness of the studied coatings was 33 nm – 45 nm. After heat treatment the coatings have a stoichiometry nearly identical to Al_2O_3. Aluminum oxide films made from a sol based on an aqueous solution of aluminum triisopropoxide had an EDX measured Al/O ratio of 58.5/41.5 at-%. The organic sol from aluminum sec-butoxide yielded a ratio of 60.4 /39.6 at-%.

XPS was applied to search for carbon and nitrogen contaminations in the coatings. None were found up to a sputtering depth of 10 nm. FTIR transmission spectroscopy was performed to detect organic groups in the coatings after heat treatment, which may originate from the sols. No traces were found. At a wavelength of 630 nm the measured refractive index was in the range from 1.52-1.55. The average roughness of the coatings (R_a) was 2 nm (aluminum triisopropoxide sol) and 0.5 nm (aluminum sec-butoxide sol).

Mapping of the charge carrier lifetime of differently heat treated microelectronic wafers with AlO_x passivation layer based on aluminum triisopropoxide sol



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Charge carrier lifetimes (CCLT) were determined using microwave detected photoconductivity. The coatings made from the aluminum triisopropoxide sol achieved up to 97 µs. We found that the CCLTs depended significantly on the selected heat treatment. The best CCLT was reached at a heat treatment temperature from 600 °C to 650 °C (Fig. 3).

In the future these coatings will be deposited on 156 mm x 156 mm and 180 µm thin solar wafers. Research will focus on increasing charge carrier lifetimes and on the influence of the deposition process on the laser produced vias.

2 *Metal wrap through solar cell overview and detail*

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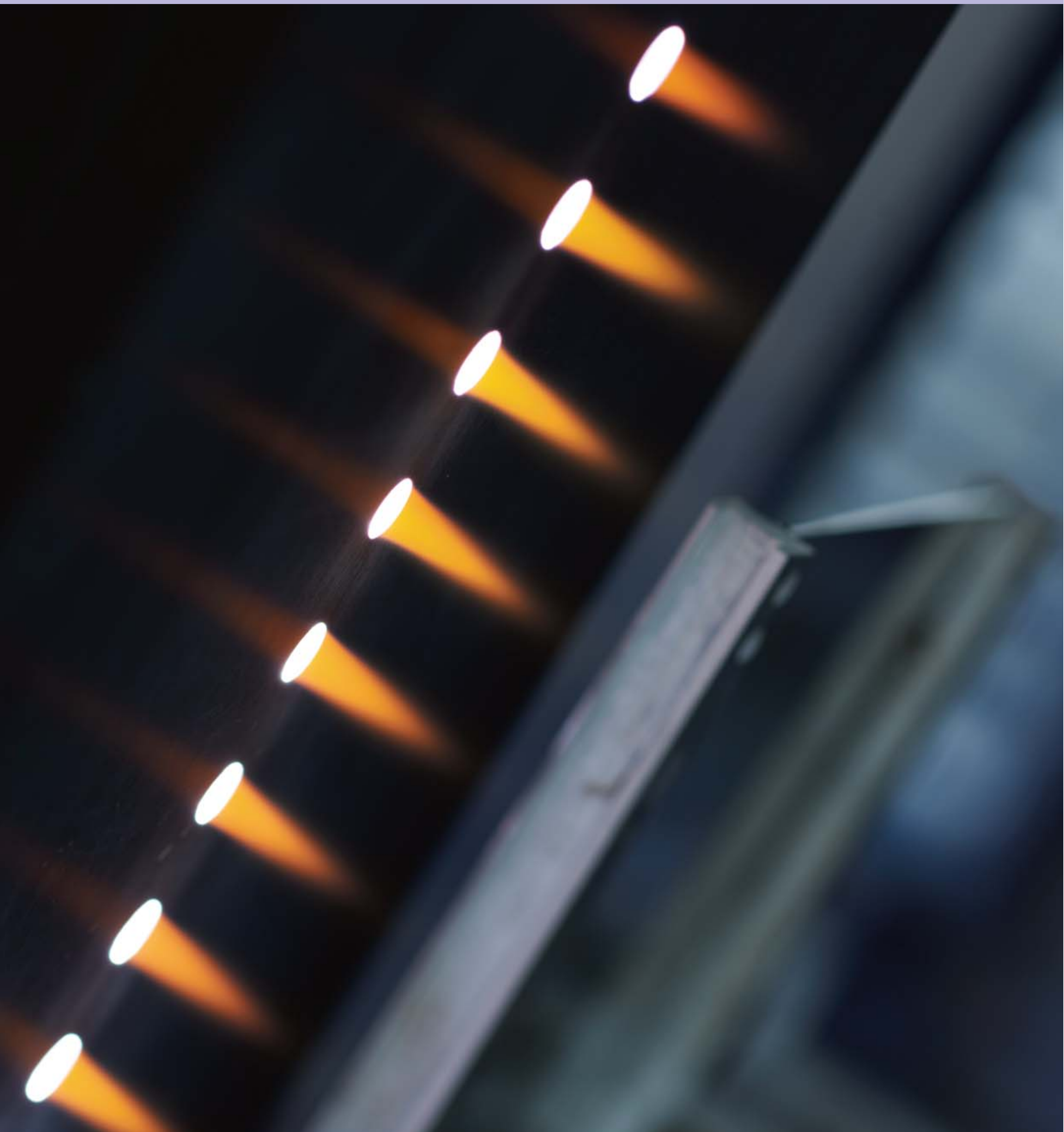

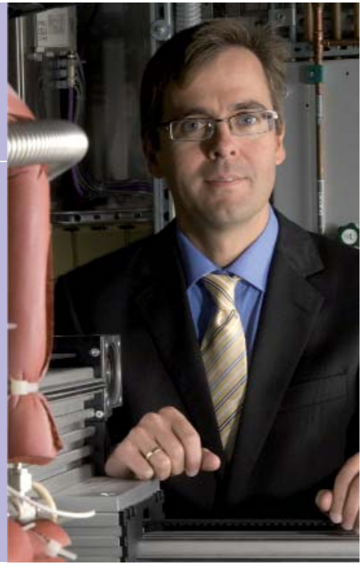

A new invention creates more jobs than ten new laws.

Norbert Bluem

BUSINESS FIELD CHEMICAL SURFACE AND REACTION TECHNOLOGY

Editor: The recent economic crisis caused strong turbulences. Entire industry branches stumbled. In which future field do you see growth potential?

Prof. Kaskel: Coating development in the coming years will see an emphasis in the area of electromobility. Here we anticipate substantial challenges to establish the manufacturing of electrode materials in Germany. Currently there are only a few companies involved (e.g. Evonik). Germany is missing a supplier base for the necessary machine technology as well as the raw materials. The processed materials come almost exclusively from Japan. The recent natural disaster in Japan showed the dangerous consequences that such dependence can have for Germany. Therefore we see in this area a great potential to collaborate with medium sized industry exploring new markets based on the manufacturing of raw materials (e.g. carbon materials) and the implementation of roll-to-roll system technology. It will be absolutely necessary to understand the dependencies between material performance, process and function of the batteries. Therefore we added equipment for battery cycle testing and processing of electrodes this past year.

Editor: The media report about all kinds of battery types such as lithium ion batteries or metal hydride batteries. Which battery will win the race?

Prof. Kaskel: As a contract research service provider we have to follow a healthy mix. In terms of future performance lithium sulfur batteries have certainly the largest potential. On the other hand, lithium ion batteries will dominate the market for many years. There is still a great cost savings potential to exploit during the production of large format lithium ion batteries. Monitoring humidity plays here an important role. In this area we developed numerous automated systems. An example is the controlled freeze-drying process (pages 82/83). Essentially such a control mechanism shortens the drying process and reduces energy costs. Similar effects are possible during the manufacturing of the batteries where humidity causes failures.

Editor: A central issue, which is frequently ignored when enthusiastically discussing electromobility, is the question of from where the electricity comes to charge the batteries. Currently it is mainly generated from fossil sources.

Prof. Kaskel: You are absolutely right. Electromobility only makes sense in combination with using regenerative energy sources. It is true that wind and water generated electricity will be better utilized when all electric cars charge during the night. But that is only a partial solution. In addition to photovoltaics it will be necessary to push solar thermal efforts. Solar thermal power plants are highly efficient and have made great progress in recent years. It is an illusion to hope that CO_2 emissions will be reduced based on non-committal declarations of intention. Just like it was in the 70ies, when SO_2 emissions were responsible for acidic rain and killed massive amounts of forests, issuing appropriately restrictive laws will be required to solve the issue.

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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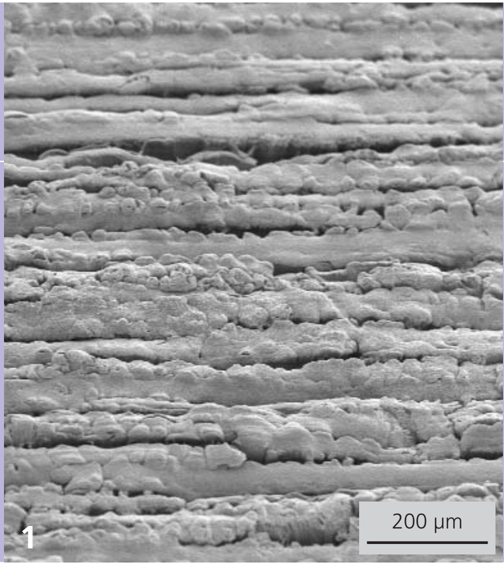

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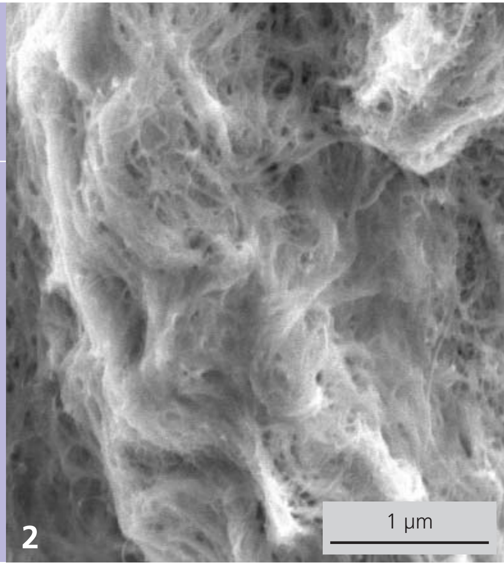

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NOVEL COMPOSITE MATERIAL FOR LITHIUM SULFUR BATTERIES

THE TASK

The currently used cathodes for lithium ion batteries are made from metal oxides and phosphates. Their capacity of 150 – 200 mA h g^{-1} limits the energy density to a maximum of 200 Wh kg^{-1}.

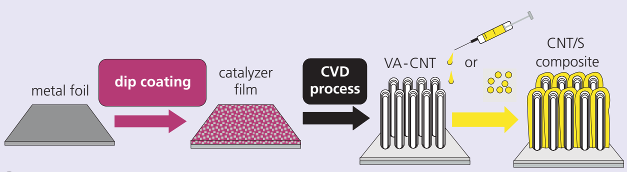
Compared to this state-of-the-art, sulfur cathodes have remarkable advantages. The theoretically determined capacity of elemental sulfur is 1672 mA h g^{-1}. This implies energy densities exceeding 350 Wh kg^{-1}. Sulfur is also a less expensive, non-poisonous and unlimitedly available raw material. However, sulfur also has a low conductivity of $5 \cdot 10^{-30}$ S cm^{-1}. Therefore carbon is added to improve the conductivity and to exploit the electrochemical properties of sulfur. The current approach is to make electrodes using pastes consisting of sulfur, a polymer binder, a conductive carbon material and a solvent. Using squeegee processes the paste is applied to an aluminum current collector, dried and calendered. Such paste systems allow for a high degree of sulfur utilization and stabilization. But the overall composite energy density suffers due to the high carbon (30 wt-%) and binder (5-10 wt-%) content.

Properties can be improved by replacing the carbon with carbon nanotubes (CNT). CNTs have high intrinsic conductivities, unique structures and make an excellent additive to improve conduction. During charging and discharging cycles they provide a stable matrix for the sulfur. CNT containing electrodes are highly stable but also contain binders and other additives so that the sulfur content is limited to maximal 70 %. The highest capacity calculated based on the total mass of the electrode is currently below 600 mA h g^{-1}. Increasing the sulfur content and utilization is currently one of the greatest challenges to exploit the potential of lithium sulfur batteries with respect to energy density.

OUR SOLUTION

The IWS approach is to use vertically aligned carbon nanotubes (VA-CNT) as the conductive and binder free matrix that contacts the sulfur. As opposed to the conventional paste and binder process, the IWS electrode fabrication is based on the chemical vapor deposition (CVD) of VA-CNT directly onto a conductive substrate (nickel, aluminum, carbon fiber web). The substrate is first wet chemically coated with a thin catalyzer film. The next step is the CNT synthesis at 650 – 730°C from an ethene precursor. Subsequently the sulfur is infiltrated from solution in an organic solvent or directly melted in.

Schematics of the fabrication of binder free VA-CNT/sulfur composite electrodes



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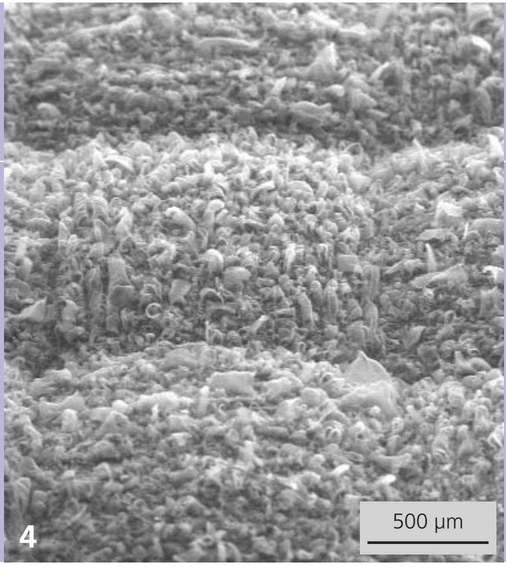
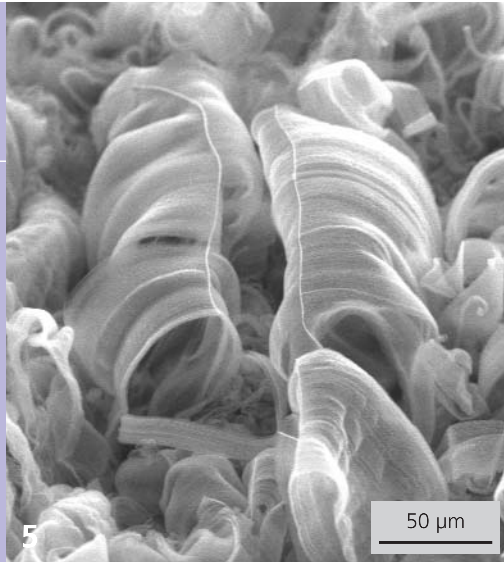




RESULTS

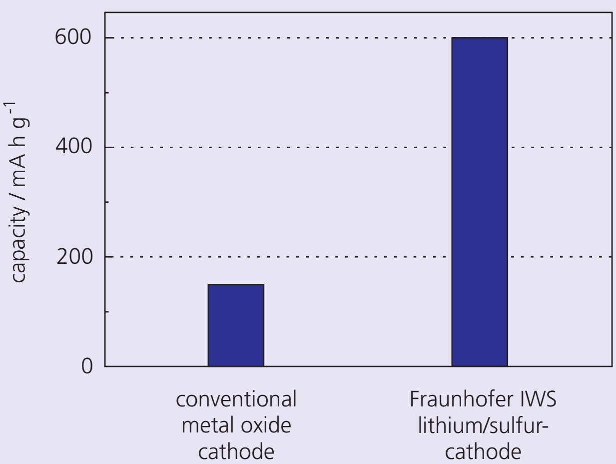
The thickness of the CNT coatings depends on the substrate. It is typically between 50 to 200 µm with a corresponding density of 0.06 to 0.13 g cm^{-3}. The individual CNTs are mostly multiwalled and have diameters from 4 to 30 nm. The CNTs directly contact the substrate. The material forms a stable and conductive network with an accessible porous structure, which is formed by the spaces between the CNTs.

SEM analysis shows a homogeneous infiltration of the sulfur into the open CNT film structure. The capillary forces cause a contraction of the CNT films. The sulfur content can reach up to 90 wt-%. Stable discharge capacities of at least 600 mA h g^{-1} based on total electrode mass are possible (Fig. 6). First cycle tests demonstrated discharge capacities between 800 and 900 mA h g^{-1} (based on total electrode mass) with electrodes of a lesser sulfur content (69 wt-%) and without electrolyte additives.

The discharge capacity per surface area is significantly increased when using a three-dimensionally structured substrate (e.g. a carbon fiber web) for the VA-CNT deposition instead of a metal foil. Here the wet chemical coating of the catalyzer is especially useful enabling a gap free CNT growth on weaved carbon fibers. It is also possible to fabricate freestanding sulfur electrodes with CNT as a conductive additive and a polymer binder.

CNT sulfur composite materials are further developed and new cell concepts are being tested in collaboration with Fraunhofer ICT and CAU Kiel. Funding is provided by the BMBF in a project AlkaSusi (funding id 03X4618A). The research goal is to develop cells with energy densities exceeding 400 Wh kg^{-1}, which would more than double the energy densities of conventional lithium ion batteries.

Discharge capacities (averaged from 10th to 20th cycle) of a VA-CNT/sulfur composite coated nickel foil as a cathode compared to state-of-the-art



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1/2 VA-CNT sulfur composite on nickel foil

4/5 carbon fiber web with VA-CNT

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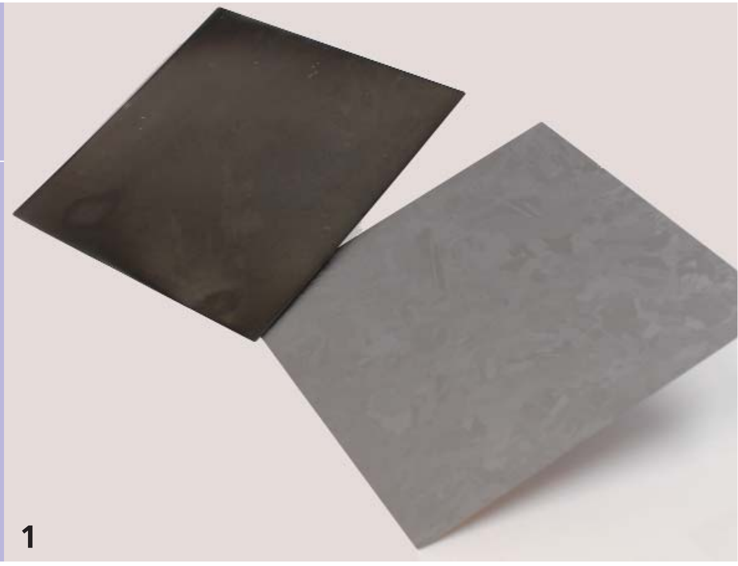


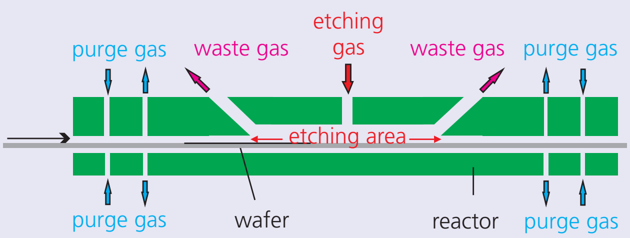
1

DRY ETCHING AT ATMOSPHERIC PRESSURE – COST EFFECTIVE AND CLIMATE FRIENDLY

THE TASK

Most of the etching steps during the manufacturing of crystalline silicon solar cells are performed wet chemically. The deposition of antireflection and passivation layers occurs with plasma assisted chemical vapor deposition in vacuum. This combination of very different manufacturing processes is the reason for the high processing costs due to the need for massive deployment of wafer handling robots. A continuous production process with few handling steps would require unified processing technologies for most of the steps. Atmospheric pressure gas phase processes offer flexible use, compact system designs and continuous inline processing capabilities. Thus they are very well suited for such a production line. The task was therefore to develop an atmospheric pressure gas phase dry etching process for the manufacturing of silicon based solar cells. This work was funded by Nines Photovoltaics, Dublin, Ireland.

Principle of the function of an atmospheric pressure dry etching system



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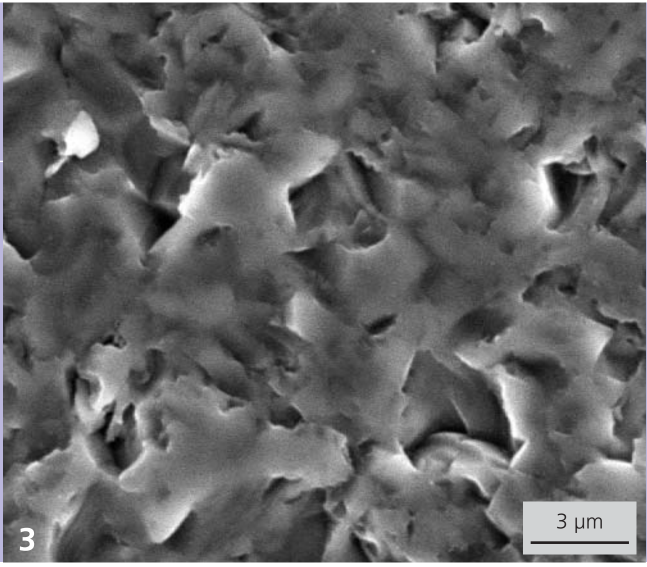
OUR SOLUTION

IWS engineers use the high reactivity of an 0-GWP (global warming potential) gas to develop a dry etching system for silicon solar wafers. The process works by thermal activation of these gas. The typical etching processes in photovoltaics manufacturing use fluorine containing gases. The big advantage of our solution instead is that it does not contribute to global warming (GWP = 0).

Previously the use of an non plasma activated etch gas as an industrial etching gas was inhibited due to the limited storage capacity of the highly toxic substance. However, technical progress led to the development of 0-GWP gas on-site generators. These generators electrolytically break down an acid to the etch gas on demand directly at the etching system. Thus it is not necessary to have a plasma source to generate the etching radicals.

Etching radicals are formed by the thermal decomposition of the 0-GWP gas and subsequent reactions with the silicon atoms. The reaction product is volatile silicon tetrafluoride (SiF_4), which is cost effectively recycled using conventional washers. In the future silicon will be recycled from the waste gas. The discussed approach combines the advantages of cost effective thermal dry etching processes at atmospheric pressure with climate neutral etching gases. This new process also offers advantages for the manufacturing of future high performance cells. It can treat only one side of the wafers. It can also be used for etching and structuring smooth silicon wafers.



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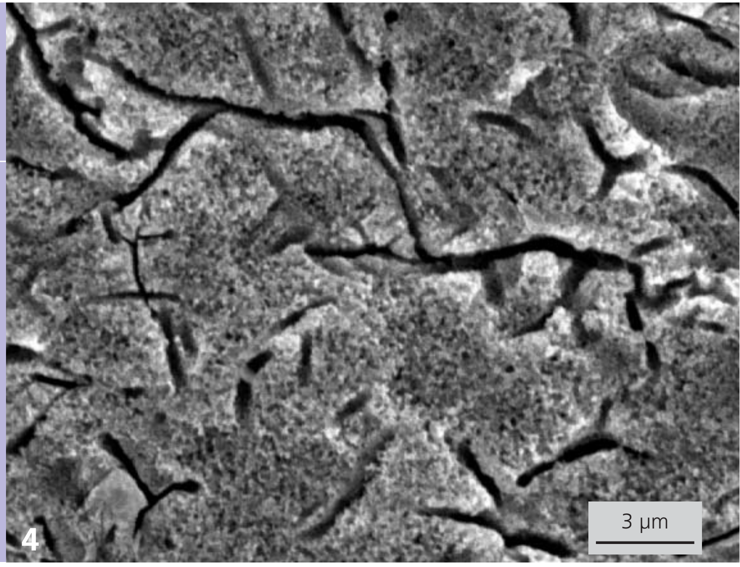

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RESULTS

The IWS engineers collaborated with an irish company to develop an inline capable demonstration system was built to dry etch 156 x 156 mm² silicon solar cell wafers. Initial testing was performed with strongly diluted 0-GWP etching gas. Even though the system is not yet optimized, it achieved a dynamic etch rate of 0.38 µm m min^{-1} and 80 % of the etch gas contributed to the etching of silicon. Processes run with higher gas concentrations are expected to achieve or even exceed the etch rates obtained with conventional gases. The system will also be further optimized to improve etch gas utilization. Thus the use of the 0-GWP gas to dry etch silicon achieves sufficiently high etch and utilization rates, which are the necessary conditions for the industrial deployment of the technology.

Comparison of various studied etch gases and etch gas mixtures with respect to silicon etch rates, gas utilization and global warming potential

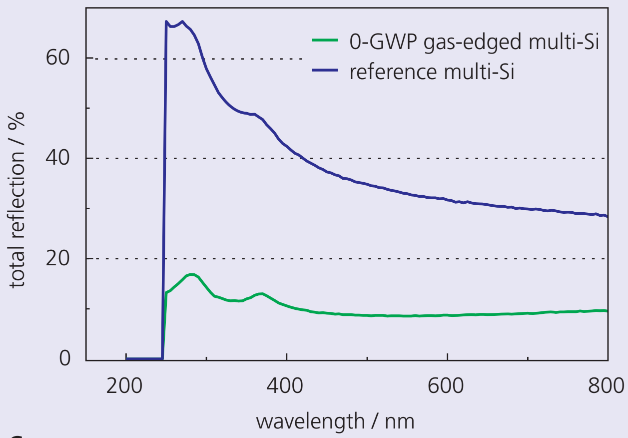
etch gas	dynamic silicon etch rate µm m min^{-1}	utilization %	global warming potential(GWP)
SF_6	0.55	15	22800
$SF_6 + O_2$	1.74	80	22800
NF_3	1.34	90	17200
$NF_3 + O_2$	1.38	99	17200
10 % 0-GWP gas in N_2	**0.38**	**80**	**0**

5

The 0-GWP gas can also be used for texturing silicon wafer surfaces. A textured solar cell wafer frontside (Fig. 1) reduces reflections and thus increases light utilization leading to higher solar cell efficiencies. The largest reduction of diffuse reflections is achieved with porous nanostructures (Fig. 6).

This work is continuing and funding is being provided under SOLNOWAT contract 286658.

Comparison of total reflection of multicrystalline silicon wafers prior to and after dry etching with 0-GWP gas (2 % in N_2)



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1 Multicrystalline silicon wafer, grey: unetched reference, black: after dry etching with 0-GWP gas

3/4 SEM image of a surface of a multicrystalline silicon wafer, left: unetched reference, right: after dry etching with 0-GWP gas

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1

MOISTURE BASED CONTROL OF FREEZE-DRYING SYSTEMS

THE TASK

The pharmaceutical industry has to meet strong requirements to maintain aseptic production. Therefore such production processes are implemented in a well-controlled cleanroom environment. Any changes to components in contact with the product or to drying processes require time-consuming recertification and requalification protocols. Thus the goal is to avoid such changes.

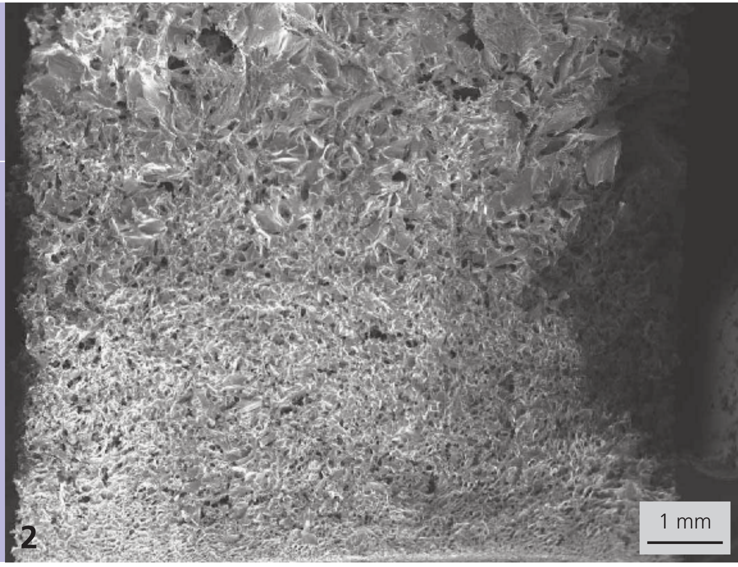
Despite these rules, the PAT initiative "Quality by Design" (2004) requests that the product quality is being controlled during the process and not, as typically done, by testing samples after the production process. An online control scheme for freeze-drying processes is desired. Such a capability would allow reducing the safety time buffer of current recipes. It would also detect and rectify process parameter and product quality deviations. Overall the processing time could be significantly reduced while ensuring a constant and high product quality level.

OUR SOLUTION

The characteristic quantity of a drying process is the achieved degree of dryness. Water is used as a solvent for more than 90% of the products. What matters here is the residual moisture after a drying process. The residual moisture is hard to measure during production in vacuum chambers. Online samples are difficult to obtain and not representative. Thus the residual moisture is determined based on the total gas composition above the product. All samples contribute to this gas composition, which makes it representative.

Laser diode spectroscopy (LDS) is very sensitive and capable of accurately measuring the small water vapor partial pressures from 1 mbar down to 10^{-3} mbar. It is possible to measure either the water vapor partial pressure or the water content of the atmosphere in the freeze dryer.

The sensors can be easily integrated by using an existing chamber window or an additional adapter flange with a reflector. Only very few components could come in contact with the product and would require requalification. The adapter flange was designed with aseptic production goals in mind. The cleanability of the entire system as well as potential shadowing effects due to sensor integration were considered. In addition to monitoring the gas concentration it is also possible to follow the progress of the drying process by monitoring removed water amount. A laser line is monitored with and against the flow direction. The Doppler shift is determined from these data. With Doppler shift, water vapor concentration and the flow cross section one can calculated the gas velocity and water mass flow or, by integrating the latter, the total removed water amount. The developed solution enables gas velocities of 0.15 m s^{-1} to > 500 m s^{-1}. This is a first for so-called "Integrated Freeze Dryers".

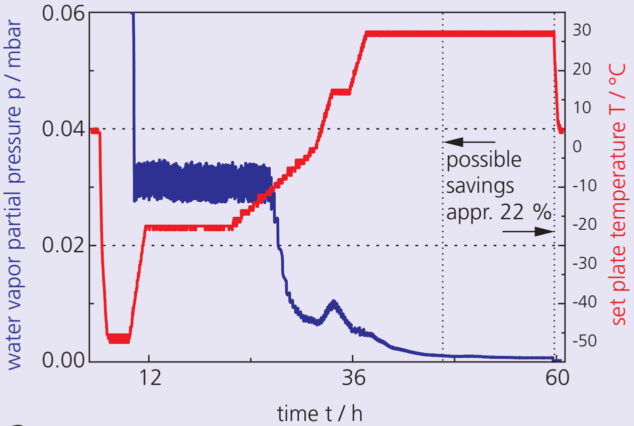


RESULTS

Based on measuring the gas concentration it is possible to reliably determine the endpoints of main and post drying steps. Once reaching of the endpoints is detected the system can automatically advance to the next process step as opposed to the fixed setup that was previously used. The process control recipe uses criteria such as concentration thresholds or concentration changes, which are independent from the product type and load in the chamber.

The sensor was not only sufficiently tested in laboratory systems, but was also implemented for the moisture based process control in production machines in the pharmaceutical industry. An immediate savings potential of 20 % was achieved just by reducing the safety buffer times (Fig. 3).

Savings potential during freeze drying of a live virus vaccine



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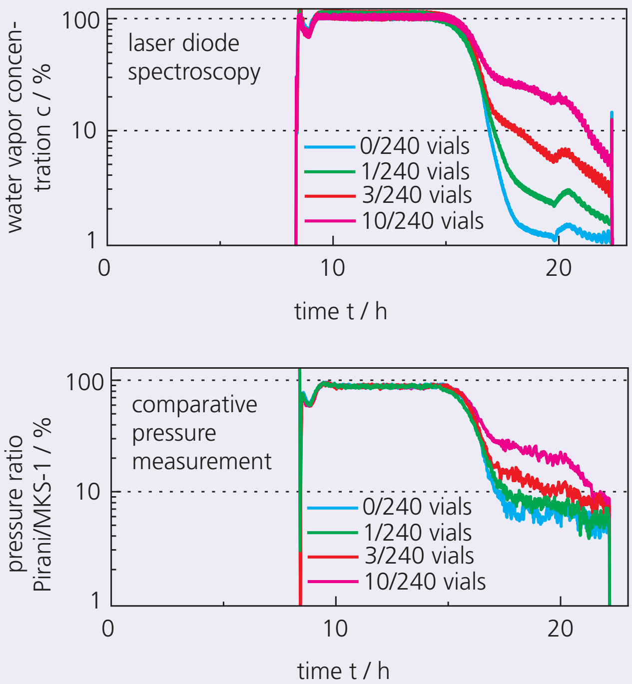
The sensor technology also supports the development of new concepts and the scaling of laboratory systems to production machines by reducing the number of experiments and required testing substances. The solution is robust, stable, can be vapor sterilized and is much more sensitive than alternative methods such as comparative pressure detection. The maximal chamber load is 240 vials. Already a single vial with an insufficiently dried product can be safely detected (Fig. 4).

Influence of the number of insufficiently dried vials on measured signal



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1 Vials with pharmaceutical product

2 SEM image of a freeze-dried vaccine

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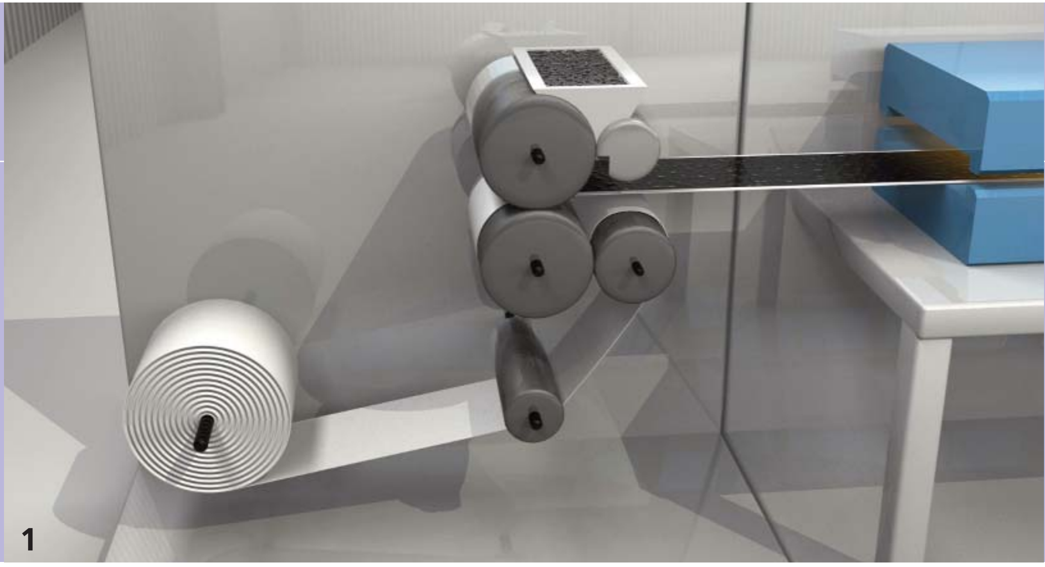

ELECTRODE DEVELOPMENT FOR BATTERIES AND SUPERCAPS

THE TASK

The electrode is the heart piece of batteries and supercaps. Its composition and structure determine lifetime and performance of the electrical energy storage device. Therefore each electrode fabrication step, from materials selection to packaging, demands careful attention. The selected processing steps do not only determine the properties of the electrodes but also the overall costs. Expensive raw materials and complex processing steps often contain the largest fraction of the added value during electrode manufacturing. One of the cost drivers during the production of lithium ion batteries is the deposition of coatings from organic solvents (typically *N* methyl pyrrolidone NMP). These solvents have to be removed and recycled during expensive drying steps. The use of organic solvents is also a safety risk for employees and the environment.

Since the performance requirements are very tough for electrodes, any potential process change implies an immense development effort. Process development includes time-consuming electrochemical testing of the product. Thus developing battery and supercap electrode manufacturing processes that avoid organic solvents for cost reduction is a big challenge.

OUR SOLUTION

Fraunhofer IWS engineers have developed cost reducing solutions for battery and supercap electrode manufacturing processes. A particular BMBF project (DeLIZ, id 02PO2640) funded the development of aqueous processes for making anodes and cathodes for lithium ion cells. Graphite anodes and lithium iron phosphate cathodes were produced using aqueous binders and suitable additives. Squeegee processes applied the materials onto metal foils (current collectors). In a next step procedures were developed to transfer the process to a roll-to-roll coating machine. The coatings were then densified and smoothed by calendaring.

The residual moisture is removed in a post-drying step. Then the electrodes are mounted in test cells for electrochemical characterization. The results are very promising. Even the sensitive cathode materials show their full performance potential after aqueous processing. Capacities of up to 140 mA h g^{-1} (at 0.2 C charging rate) and 50 mA h g^{-1} (at 16 C charging rate) imply good adhesion and no damage in the active material as a result of the coating process. Experiments to test cycle stabilities of complete cells are in preparation.

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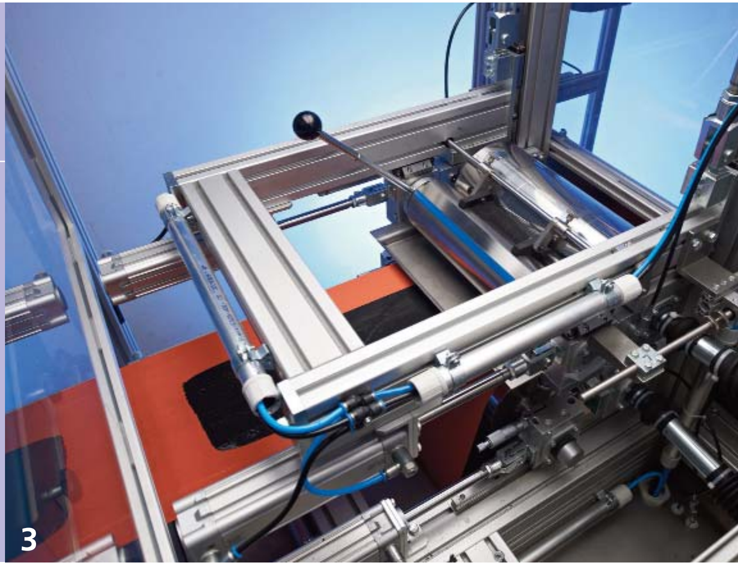

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RESULTS

The Fraunhofer IWS offers equipment and know-how to develop electrodes for electrical energy storage devices. The following equipment is available:

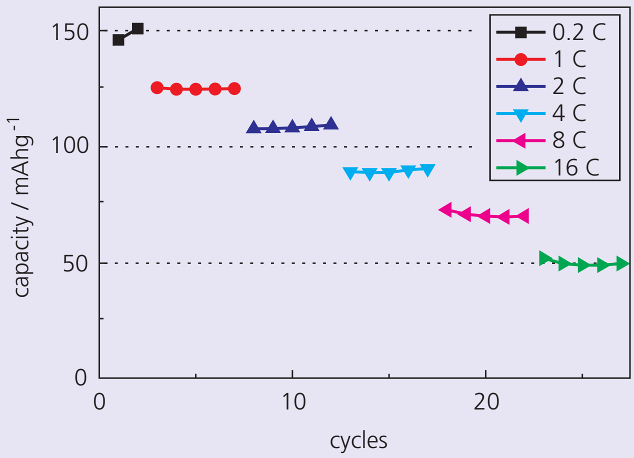
- roll-to-roll coating on foils with deposition via roll squeegee,
- 3 m drying stage and alternative drying possibility,
- densification and smoothing by calendaring (250 kN) up to a width of 280 mm.

Several systems and are available for electrochemical testing of battery and supercap electrodes:
- temperature test chamber,
- 2-channel battery tester (large cells),
- 4-channel potentiostat,
- 32-channel battery tester (test cells).

Our services include:
- evaluation of active and coating materials as well as components for their suitability in battery and supercap electrodes including electrochemical characterization,
- providing electrodes and sample coatings (Li ion, supercap) for testing purposes,
- process development for electrode manufacturing based on new materials.

Research work is continued to develop new electrode materials funded by the DryLIZ project (id 02PJ2302). This work focuses on the aqueous and dry processing of anodes and cathodes for lithium ion cells and their further processing by cutting and joining.

Capacities of a $LiFePO_4$ electrode as a function of the discharge rate.



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1 Schematics of the roll-to-roll coating process
2 Coated foil
3 Coating system at the IWS

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APPLICATION POTENTIAL OF METAL ORGANIC FRAMEWORKS

THE TASK

The process of adsorption increases the concentration of a certain material on the surface of a substrate. Adsorption is a critical effect in numerous industrial processes such as gas purification and separation processes. The processes rely on porous materials such as activated carbon or zeolites, which have very large inner surface areas for adsorption to occur.

Metal organic frameworks (MOF) are a new class of porous materials with very promising adsorption properties. They consist of inorganic nodes connected by organic ligands. This modular principle implies nearly unlimited possibilities to combine and tailor the MOFs for specialized adsorption tasks. MOFs by far outperform the adsorption properties of conventional materials when selecting appropriate functional nodes and ligand systems. A goal is to make these novel materials accessible to industrial applications and to offer solutions tailored to numerous adsorption processes.

nano MOF

OUR SOLUTION

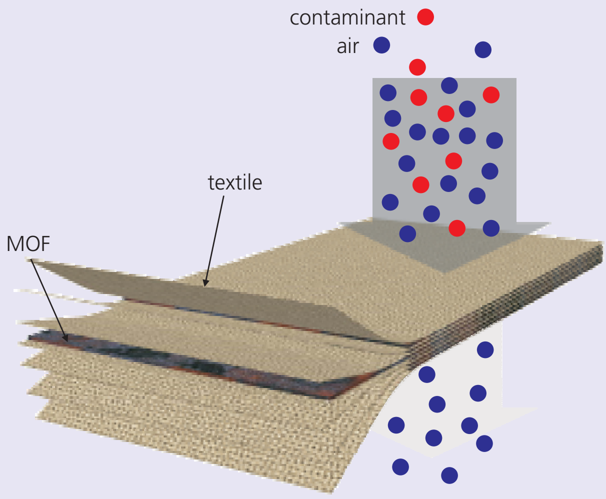
Scientists from 9 research institutions and 8 companies from 10 countries collaborated within the European project "nanoMOF". The goal is to accelerate the transition of MOFs from the research state to industrial application. The focus is on potential applications such as gas purification, gas storage and catalysis.

The project nanMOF is funded as part of the seventh European Framework Program (id CP-IP 228604-2).
Project partners are:
- Fraunhofer IWS, Germany
- Johnson Mattheu PLC, UK
- Katholieke Universiteit Keuven, Belgium
- Universidad de Granada, Spain
- Technische Universität Dresden, Germany
- Stiftelsen SINTEF, Norway
- Università di Torino, Italy
- Centre National de la recherchéscientifique Lyon, France
- Ouvry SAS, France
- Norafin Industries GmbH, Germany
- Oleon NV, Belgium
- Ben-Gurion University of the Negev, Israel
- Innovatext Textile Engineering and Testing Institut Co, Hungary
- Società Italiana Acetilene e Derivati S.p.A, Italy
- TDL Sensors Ltd, UK
- Blücher GmbH, Germany
- Hollomet GmbH, Germany

MOF GAS PURIFICATION

MOFs offer significantly increased performance compared to conventional materials for gas purification applications. The project aims at desulfurization of gases in fuel cells and at the development of filter components in breathing masks for the protection of members of civil forces.

Textile filter for the separation of pollutants from air



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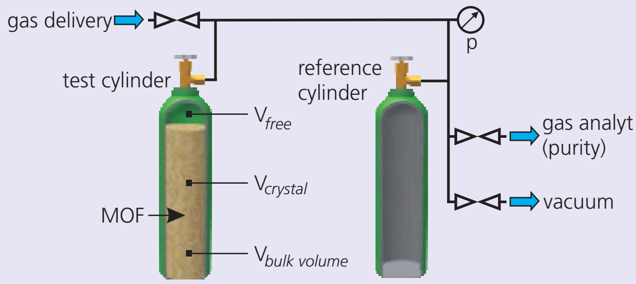
MOF CATALYZER

MOFs find oleo chemical applications for the selective esterification of fatty acids to make mono glycerides. The need for complex processes to separate undesired byproducts can be avoided. This improves the energy and environmental efficiency of the process.

MOF GAS STORAGE

The adsorptive storage of gases is accomplished at significantly reduced pressures compared to normal pressurized gas bottles without reducing the stored capacity. This improves the safety when dealing with toxic gases.

Simplified schematics to test adsorptive gas storage



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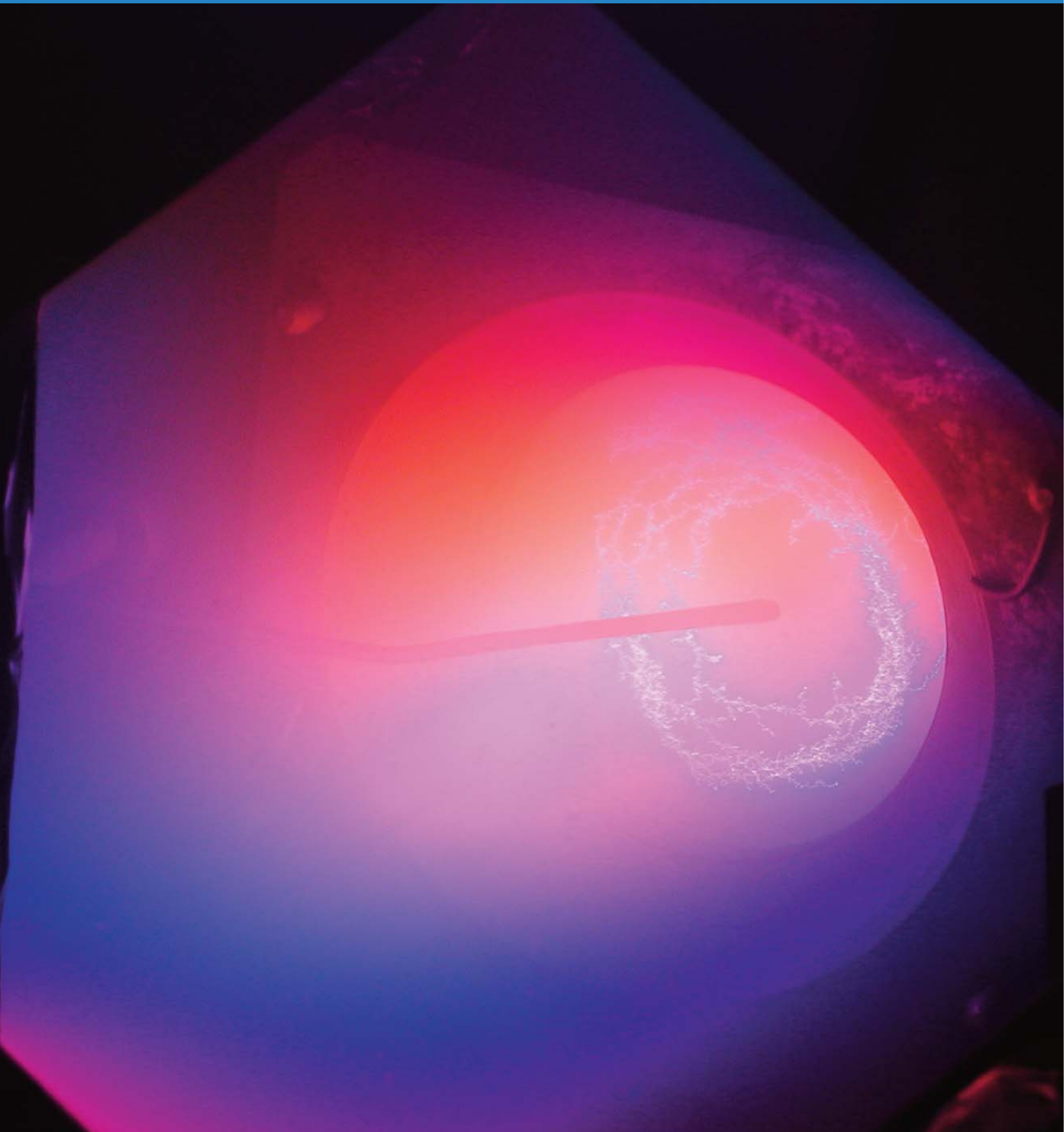


The biggest enemy of creativity is not error but lethargy.

Henry T. Buckle

BUSINESS FIELD PVD VACUUM COATING TECHNOLOGY

Editor: Coatings are increasingly applied to tools, parts and components. Often these are amorphous carbon or so-called DLC coatings. Your department focuses research primarily on hydrogen-free carbon coatings and their applications as well as the related deposition technology. Which advantages do you expect from this?

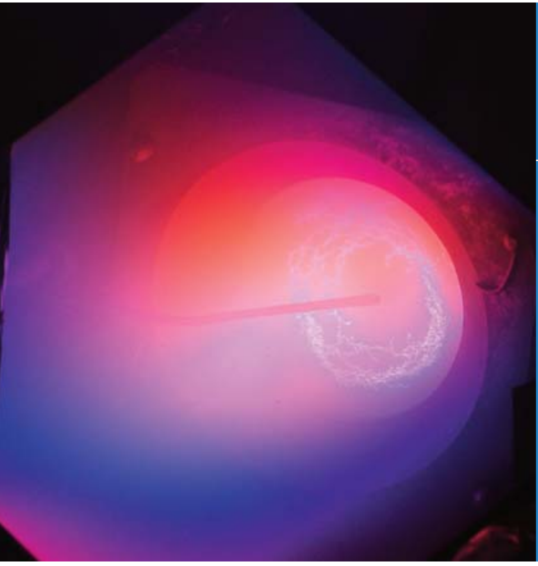
Prof. Leson: Hydrogen-free carbon coatings indeed offer a number of advantages compared to classical DLC coatings. For example, the hardness of our Diamor® coating is significantly higher. These coatings also offer a great potential to minimize friction, which is of interest for example to the automotive industry. We have also developed a productive process for manufacturing these coatings. The Laser-Arc process deposits smooth super hard carbon coatings. Currently we collaborate with a number of companies on transferring Diamor® coating technology to industrial applications.

Editor: For a long time the fabrication of high precision multilayer coatings has been an important topic in your department. Are there any new developments to report?

Prof. Leson: In recent years we have developed much competence in using ion beam technology. We use this for precision deposition as well as material removal and polishing of substrates. This way we achieve a completely new quality level for X-ray optical components. Currently we are in the process of transferring important technology elements to our spin off company AXO GmbH Dresden.

Editor: Since several years your department has been capable of producing larger quantities of single-walled carbon nanotubes. These materials are highly interesting. Are there already applications which could benefit from their unique properties?

Prof. Leson: Initially we aimed at scaling the manufacturing process. Now we are focusing on developing applications. We have already demonstrated the fabrication of flexible transparent electrodes with excellent electrical properties due to the incorporation of single-walled carbon nanotubes. Another example is an actuator element based on a dielectric elastomer, which receives its functional properties from dispersed nanotubes. This successful development demonstrates the possibility to make low cost polymer based actuators. Here we hope for numerous applications, which we want to explore in the coming years.



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.

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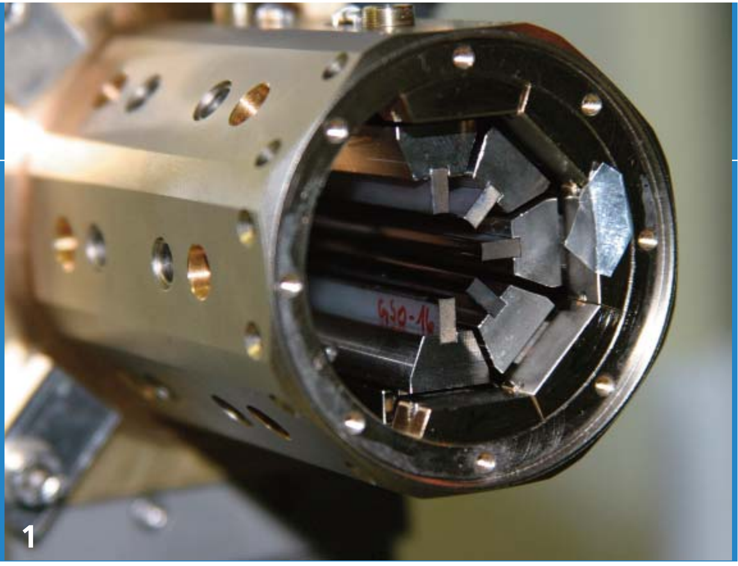
BUSINESS FIELD PVD VACUUM COATING TECHNOLOGY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HIGH PERFORMANCE X-RAY OPTICS FOR SPECTROSCOPY

THE TASK

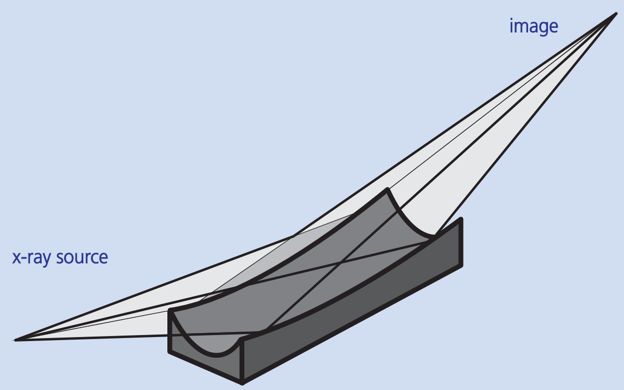
The imaging quality and efficiency of X-ray optics is primarily determined by the built-in components. Shaping beams in the wavelength range from $\lambda \approx 0.01 - 1$ nm usually requires reflecting mirrors or diffractive structures such as single crystals, gratings and zone plates. The bandwidths of the allowed incident angles or photon energies are relatively narrow, which limits the transparency of the used systems. Imaging or spectroscopic applications in this wavelength range have to always strike a compromise between transparency and lateral or energy resolution. Innovative optical systems are required to improve the sensitivities (detection limits) and imaging quality. An example is a component that increases the entrance aperture and thus provides a better utilization of the source radiation.

OUR SOLUTION

Reflective multilayers on two-dimensionally curved mirror surfaces offer a number of advantages compared to conventional flat or one-dimensionally curved X-ray optics. Compared to crystals or gratings, the multilayer coating accepts a larger energy bandwidth or divergence of the entrance angle. It is also possible to achieve larger reflection angles than total reflection mirrors. This results in larger apertures and better beam utilization. Two-dimensionally curved mirrors also focus the X-rays with only one reflection, which increases the transparency of the optical system.

The fabrication of two-dimensionally curved X-ray optical components is very challenging due to the extreme requirements for the surface roughness ($\sigma_{rms} \approx 0.1$ nm) and coating thickness precision. Ion beam technology proved to be indispensible to process such optical surfaces. The ion beam is used for material removal to shape contours and to polish the surface and for ion beam assisted deposition.

Principle sketch of two-dimensional focusing X-ray optics



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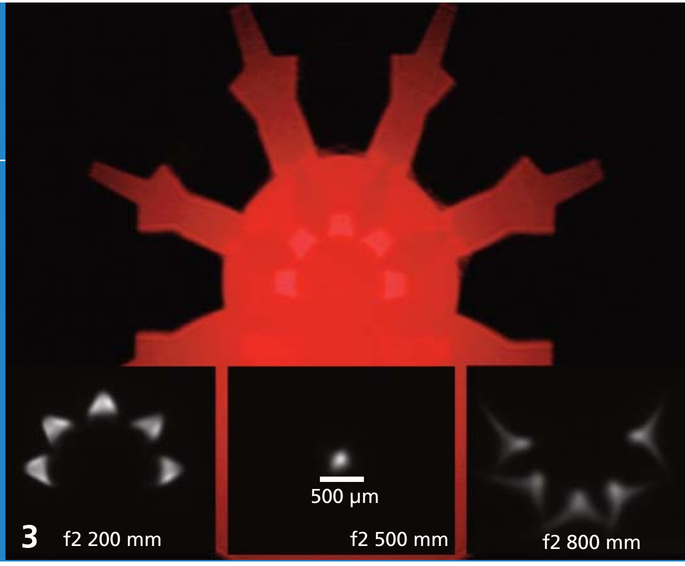
The ion beam system “IonSys 1600” is installed at the Fraunhofer IWS. The machine can perform all the mentioned ion beam processes. If possible these processes are performed sequentially without having to vent the system in between steps to avoid undesired surface modifications. The system uses a linear ion source and is able to process large substrates with optical areas of 500 x 200 mm^2. Alternatively several smaller substrates can be homogeneously and reproducibly processed simultaneously.



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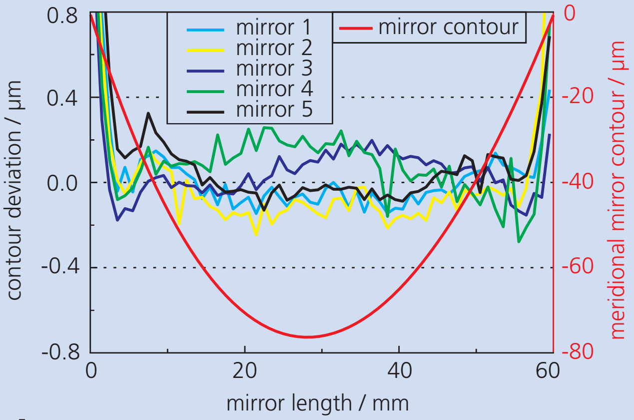
RESULTS

Fraunhofer IWS engineers built an X-ray optical system for a high-energy electron spectroscopy (HEES) experiment. The experiment uses X-rays generated by an ultra short pulsed laser plasma source and requires five individual mirrors placed around the optical axis of the setup (Fig. 1). The surface of each mirror is shaped as an elliptically curved torus. The source spot (∅ ≈ 10 …20 µm) is focused onto the image plane at a distance of 600 mm. The specialty of the 2D curved surface is the relatively small sagittal radius (r ≈ 4 …6 mm) at mirror dimensions of 60 x 2 mm^2.

Ion beam removal was applied to cylindrical substrates to form elliptical contours and to polish the final shape (removal of about 80 µm). After shaping the substrates were coated with a reflecting multilayer (150 x [Ni/B_4C]; d_p = 2.5 …3.2; lateral gradient).

Deviation of ion beam fabricated 2D curved X-ray optics (5 individual optical components) from the targeted (red) contour



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The achieved imaging accuracy of the five individual optical components is shown in Fig. 4. Tangential angle errors in the order of $\Delta\Theta < 35$ µrad are easily tolerated by the multilayer. The optics is placed in close proximity to the plasma source (f_1 = 100 mm) in order to capture a large solid angle of radiation, which is emitted in 4 π direction. The system was directly compared with conventional 2D curved single crystals. A photon yield increase of more than one order of magnitude was demonstrated at the sample location.

1 *Focusing X-ray mirror arrangement consisting of five two-dimensionally curved individual mirrors*

3 *Beam projection of the adjusted 5-fold optics: upper: rough adjustment with laser radiation, lower: foci of the Cu Kα X-ray radiation at different distances*

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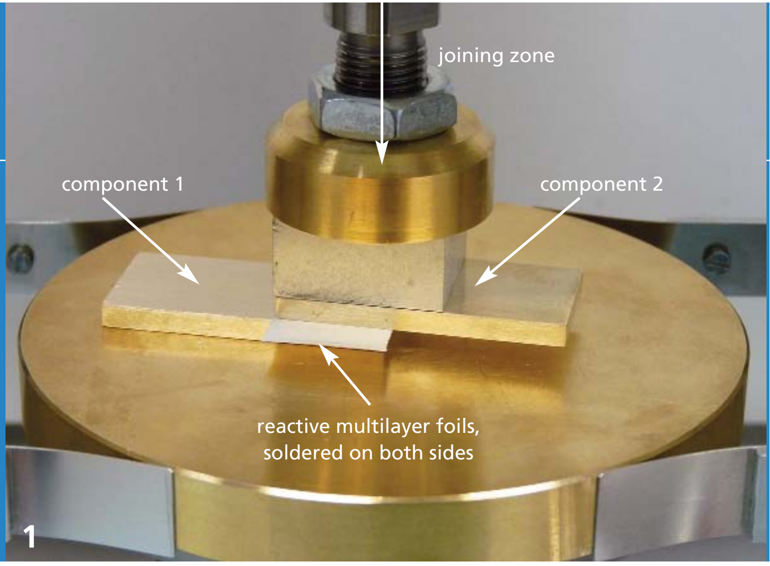


REACTIVE NANOMETER MULTILAYER SYSTEMS ARE TAILORED HEAT SOURCES

THE TASK

Reactive multilayer systems (RMS) can generate heat directly in the joining zone of two parts. The effect is used in reactive soldering applications, which require very sensitive, low stress and material safe processing. RMS are tailored as heat sources for specific soldering tasks. They consist of exactly defined coating stacks, which are designed for optimal energy content and propagation velocity of the reaction zone.

OUR SOLUTION

RMS consist of at lease two different reactive materials, which are deposited to form a stack of several hundreds to thousands of individual layers. This stack of different material films is a metastable reactive system. Introducing activation energy, for example with an electric spark, triggers the rapid atomic interdiffusion of the materials.

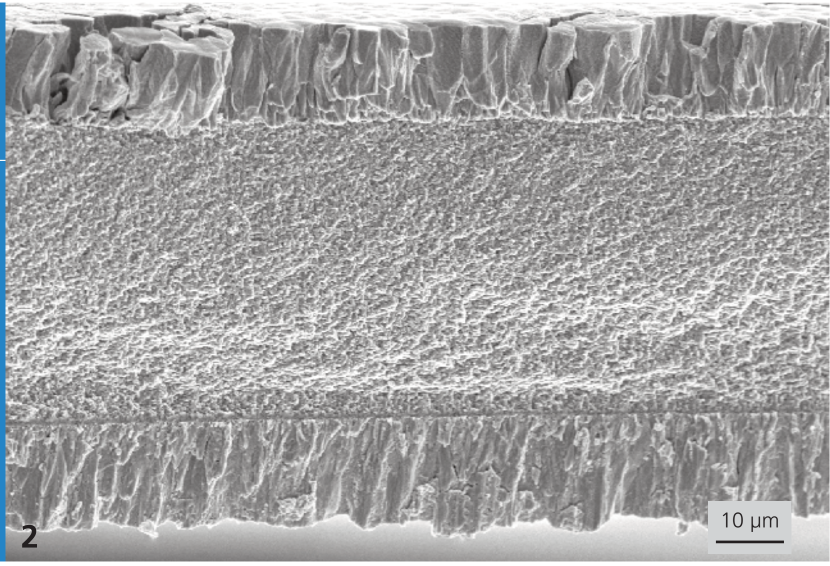
This reaction releases a certain amount of heat, which in turn can melt a nearby solder material. Changing the period thicknesses of the individual layers as well as the stoichiometric ratio of the reactive materials can precisely adjust the process.

Freestanding RMS foils can be fabricated. The energy content and the propagation velocity of the self-moving reaction zone are determined by the coating parameters. The available maximal temperature and the melting time for special solders can be calculated and adjusted. Sample material joints from brass-brass, Ti-Ti and Cu-ceramic are mechanically tested to study the influence of the joining process parameters on the resulting tensile strength.

RESULTS

Fraunhofer IWS engineers have successfully developed reactive multilayer coating stacks of various material combinations. The released heat amount and the propagation velocity of the reaction front are adjusted via the thickness of the films to match the needs of the desired joining task. For example, varying the period thickness from 25 nm to 150 nm resulted in reducing the propagation velocities from 11 m s^{-1} to 3 m s^{-1}. For soft Sn solders this results in an increase of simulated melting times from 0.1 ms to 0.8 ms. Differential thermal analysis (DTA) was performed to measure the released heat in the range from 1.2 kJ g^{-1} – 2.0 kJ g^{-1} as a function of the Ni-Al ratio. RMS can be deposited onto parts or made into freestanding reactive multilayer foils. A freestanding foil can optionally be coated with a solder material and thus represent a mobile variation of the reactive joining technology. Special 40 µm thick Ni/Al reactive multilayer foils were produced and successfully tested to solder various material combinations.

Successful joints were produced from material combinations of metal-metal, metal-ceramic, silicon-ceramic and metal-ultra nano crystalline diamond foils. The strength of the joints depends on many parameters. Fig. 3 shows the tensile strength dependence from solder type, joining pressure and surface pretreatment. The joining pressure has an influence on the quality of the produced joint. Low joining pressures lead to an insufficient wetting of the surface. On the other hand, too much pressure drives the melted solder out of the joining interface region and thus reduces the resulting strength. The surface pretreatment is also of importance. Positive effects were achieved by adding wetting promoters as well as thermal barrier coatings. The latter extend the time for which the



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solder is in its liquid phase, which increases the strength of the resulting joint.

In addition to varying the process parameters, the choice of the solder material itself is important and has potential to increase the joint strength. Typical Sn based soft solders reach tensile strengths in the order of 25 MPa. With alternative solders such as for example $AuSn_{20}$ values exceeding 50 MPa can be achieved. Using reactive multilayers for joining tasks is mostly useful when conventional joining techniques cannot be used. The specific advantages of the RMS based joining find applications in micro systems technology, optics and fine mechanics, power electronics, machine and plant manufacturing and in automotive and aerospace industries.

Tensile shear strength of two reactively joined brass sheets as a function of selected joining process parameters. Stoichiometric 40 µm thick freestanding Ni/Al RMS were used.

strength / MPa	solder	joining pressure / MPa	surface pretreatment
4.3	10 µm Sn	5	none
9.3	10 µm Sn	15	none
15.4	10 µm Sn	15	wetting promoting film
25	10 µm Sn	15	wetting promoting film; thermal barrier
51	15 µm $AuSn_{20}$	15	wetting promoting film; thermal barrier

3

1 *Joining of two brass sheets by using a freestanding solder covered reactive nanometer multilayer foil*

2 *SEM image of the cross section of a 40 µm thick Ni/Al reactive multilayer foil with double-sided 10 µm thick Sn solder cover*

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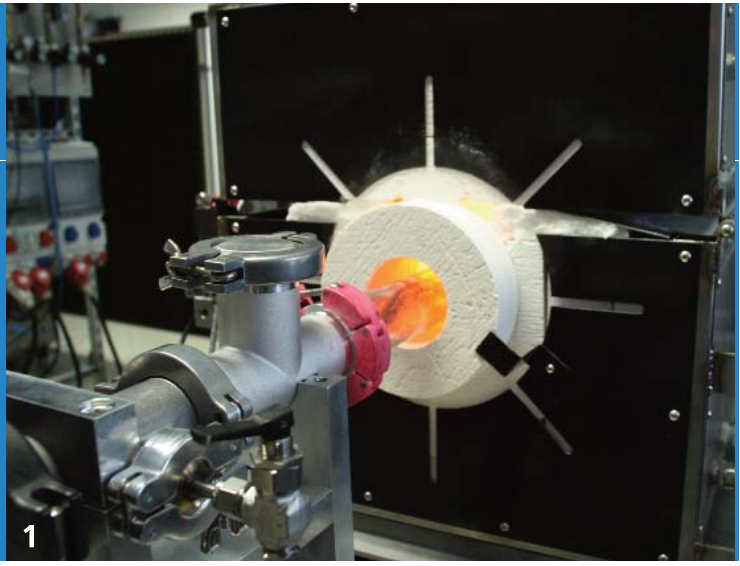


CLEANING OF CARBON NANOTUBE COATINGS

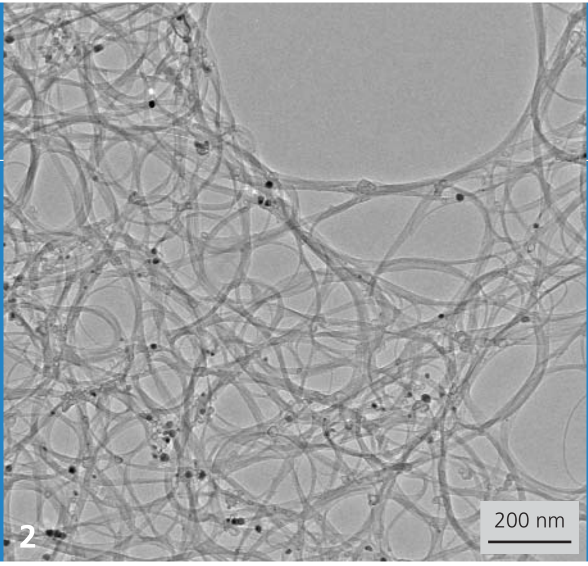
THE TASK

Since their discovery in 1993, single-walled carbon nanotubes (SWCNT) have been considered an important material for the future. Their ratio of tensile strength to density is an order of magnitude higher than that for steel or carbon fibers. They can carry current densities of up to 10^9 A cm^{-2}. The good electric conductivity of SWCNTs is explained based on ballistic electron transport in a one-dimensional crystalline metallic structure with an ohmic resistance of ~ 26 kΩ per conduction channel. In the best case a SWCNT has 4 conduction channels and the resistance is ~ 6.5 kΩ. It is therefore beneficial to have a larger fraction of longer SWCNTs when building a highly conductive SWCNT network.

The SWCNTs also should be metallic. Metallic SWCNTs make up about 33 % in a natural SWCNT distribution. A Fraunhofer IWS process based on pulsed arcs synthesizes a higher fraction (45 - 55 %) of metallic SWCNTs, which is measured by optical absorption spectroscopy. However, in addition to SWCNTs (< 40 wt-%) the process generates a large amount of amorphous carbon. The latter has to be removed by wet chemical processing, which may take several hours. This treatment may also damage, shorten or destroy SWCNTs and ultimately negatively affect the conductivity of the material. Therefore a gentle process is desired to separate SWCNTs from other carbon species.

OUR SOLUTION

Spraying processes can deposit SWCNT material on quartz glass surfaces. The SWCNT films can have various thicknesses and transparencies. The quartz glass plates are furnace tempered in N_2 atmosphere and at temperatures exceeding 850 °C. The temperature leads to desorption of smaller carbon clusters and adsorbents from the hot quartz and the SWCNT surfaces. The long SWCNT bunches remain on the quartz glass surface.



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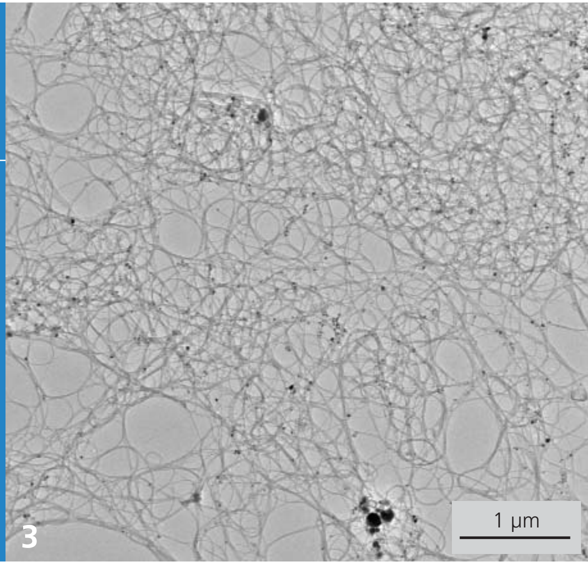

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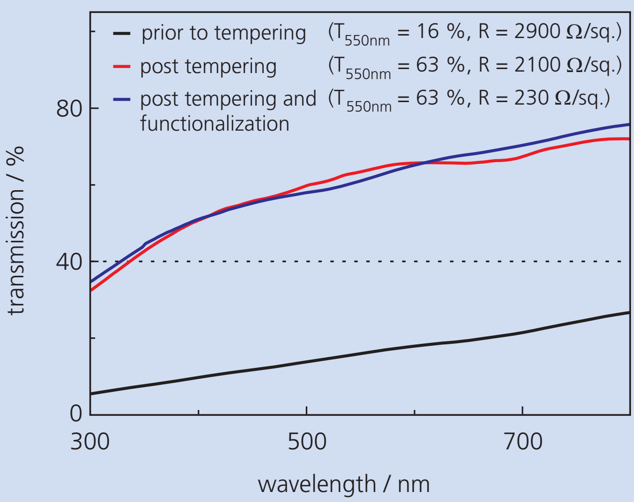
RESULTS

The tempering reduced the carbon contamination by up to 100%. The analysis was performed using absorption spectroscopy and electron microscopy. This cleaning process performs very well for thinly sprayed SWCNT films. It cannot however be used for bulk material. Treated SWCNT films increase their transparency by 15 - 50 %. The electrical conductivity remains constant. In addition to amorphous carbon shorter SWCNT bunches desorb as well. They do not substantially contribute to conductivity. Only after several hours of longer treatment SWCNT bunches begin to desorb.

The temperature also removes adsorbents (e.g. O_2, H_2O) from the SWCNT surfaces. This makes a subsequent functionalization of SWCNTs much more effective. For example, a functionalization of the tempered samples can increase the surface conductivity by more than one order of magnitude.

Extinction curves of a SWCNT film after different treatments, the resulting resistances R and transparencies T



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1 Temper furnace for coatings made from carbon nanotubes

2/3 TEM images of carbon nanotubes

CONTACT

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EXTREMELY LOW FRICTION WITH NEW CARBON COATINGS

THE TASK

Energy losses due to friction occur in all moving mechanical systems such as transmissions, bearings and guides. The objective to minimize friction losses becomes increasingly important in times of resource shortages and climate concerns. A positive example is the attempt to reduce the fuel consumption of cars and trucks. But also stationary machines and plants suffer friction losses.

Design changes and lubricant engineering with complex additives already achieve substantial friction reduction. Nevertheless, some systems still show significant friction losses. A new era of friction reduction was entered with the introduction of diamond-like carbon (DLC) coatings for components in sliding contact. Such coated parts survive significantly higher contact pressures and provide low friction performance in poorly lubricated situations. A disadvantage however is that DLC coatings do not respond to the typical oil additives. In some cases these additives even lead to higher friction coefficients for a coated versus an uncoated part. The task is therefore to identify combinations of coating and lubricants, which do not negatively affect each other's performance and ideally even increase it.

OUR SOLUTION

The chance is provided with the introduction of ta-C coatings (tetrahedral amorphous carbon). The ta-C coatings do not contain hydrogen, which makes them more responsive to lubricant additives, binding them more readily to the surface. This is in particular so for the friction reducer glycerol monooleat (GMO) and all other organic substances that contain hydroxyl and carboxyl groups. In combination with ta-C these substances achieve a very low friction coefficient in mixed friction conditions. On top of that ta-C offers extreme wear resistance since it is by far the hardest type of DLC coatings.

RESULTS

Engineers at the Fraunhofer IWS have developed the Laser-Arc process to deposit three types of ta-C coatings (soft, standard, hard). These were deposited with a thickness of about 2.5 µm on steel samples (100Cr6). The following coating properties were measured:

With nanoindentation measured hardness and Young's modulus of the three coating variations

	a-C soft	ta-C standard	ta-C hard
hardness [GPa]	15.1	48.8	62.9
Young's modulus [GPa]	125	460	606

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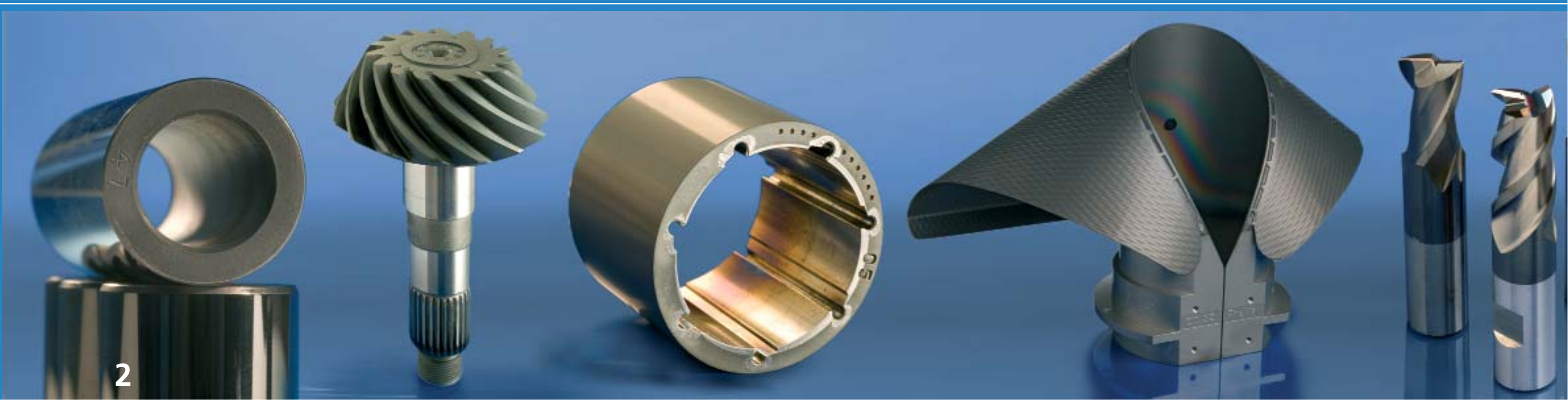
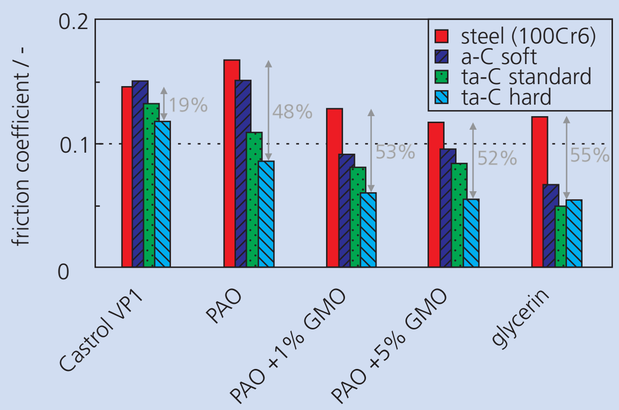


The coated samples were then tested with a tribometer (Optimol SRV® 4). To simulate realistic loads the following conditions were selected: steel ball ∅ 10 mm as counter part, 50 N load, 50 Hz vibration frequency, 1 mm vibration amplitude, temperature 80°C. The lubricant was Castrol VP1 (conventional mineral motor oil), PAO (polyalphaolefin, synthetic oil), PAO with 1 % technical GMO, PAO with 5 % technical GMO as well as pure glycerin.

Friction coefficients were measured three times each and are presented in Fig. 3. The data show a substantial friction advantage of ta-C coatings compared to uncoated steel. The percentage data in the diagram show the maximal achievable friction reduction compared to steel. For the mineral oil VP1 this advantage is still relatively low (19 %). Moving on to the other lubricants the improvement is 48 % or more. Very low friction coefficients are measured for PAO with GMO additives. Glycerin is a chemical relative of FMO and shows as expected the biggest effect (55 %). However, it is evident from the data that already very little amounts of the GMO additive in PAO oil will lead to substantial friction reduction. The effect is immediately useful for technical applications.

SRC test friction coefficient data for various lubricants



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The data also show that the ta-C type and in particular the hardness have a strong effect on the achievable friction reduction. In fact, the hardness should be as high as possible to get the lowest friction.

Systematic investigations show that ta-C can be combined with a number of lubricants to engineer a significant friction reduction compared the uncoated steel/steel pair. This provides ta-C coatings with an additional advantage. Those technical applications for which lubricants can be freely chosen, may benefit directly and immediately from this solution. The Laser-Arc process produces tailored ta-C coatings with the desired hardness.

2 Components and tools with ta-C coating to reduce friction and wear

CONTACT

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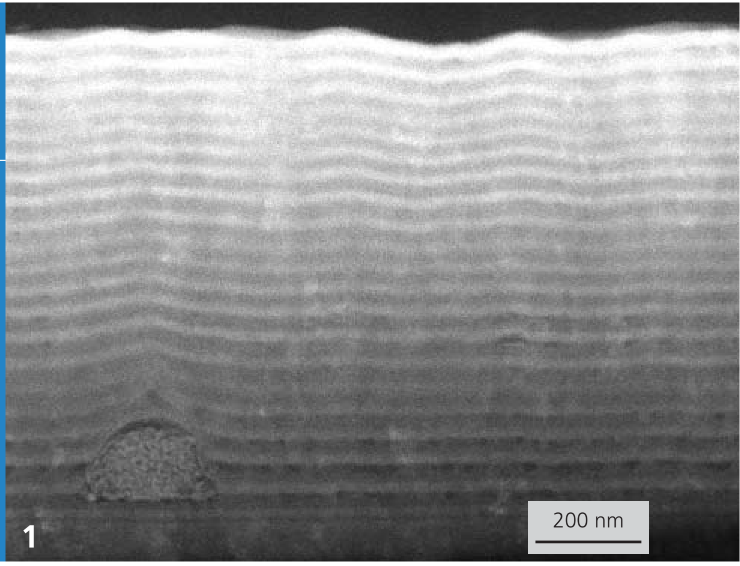


HARD COATINGS FOR SURFACES UNDER EXTREME LOADS

THE TASK

Thin wear resistant nitride coatings (e.g. TiN, AlTiN, CrN) are used in industry for tools and components. The manufacturing processes are PVD (physical vapor deposition) and CVD (chemical vapor deposition) technologies. For some special applications it is desirable to have hard coatings as thick as 50 µm. Such coatings enable much longer lifetimes for tools and machine components. Thicker coatings also offer the possibility for post treatment or surface structuring. However, typical PVD and CVD coatings are limited to 20 µm thicknesses. The most prominent limiting factors are defect growth and intrinsic film stresses.

The vacuum arc technology is a frequently used PVD process. Here the coating source (arc evaporator) emits particles, which are embedded into the coating during the process and form a tiny defect. These particles are typically very small and do not affect the coating performance. However, once embedded in the coating these particle defects will further grow during the subsequent process. They can even reach macroscopic dimensions. The resulting coatings turn rough and inhomogeneous. Subsequently they cannot be used as wear resistant coatings. Another challenge for thicker coatings are intrinsic stresses. These affect the interface between coating and substrate. They can cause cracks or coating delamination. Therefore thicker hard coatings can only be produced if defect growth and stress states can be controlled.

OUR SOLUTION

Continuous defect growth can be interrupted if the defect is covered with a different material. Once covered, the defect microstructure cannot grow further. This implies a great benefit for multilayer structures in coatings consisting of alternating materials. A suitable selection of the material combination suppresses extensive defect growth and levels the surface. Individual layer thicknesses can be limited to nanometers (nanolayer), which improve the homogeneity of the coating structure (Fig. 1).

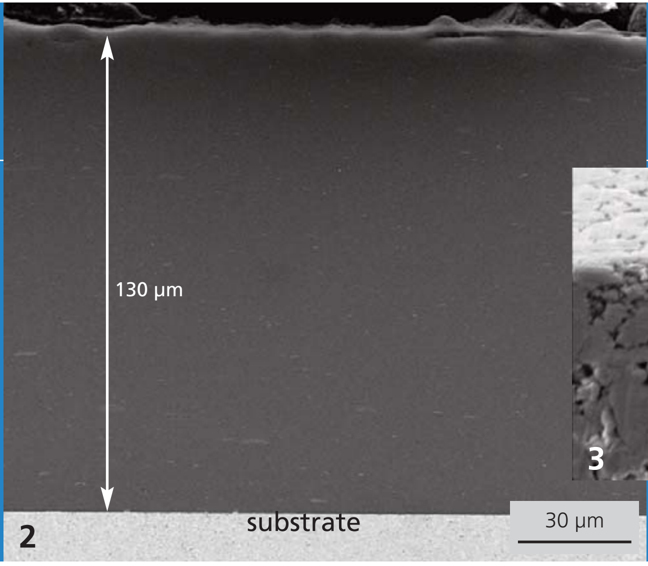
The layered structure is also useful to control intrinsic stresses. Suitably selected layer combinations show lower stress levels than the individual components of the coating.

Another useful approach to improve coating properties is nanostructuring based on self-organization. For example, the addition of minimal amounts of silicon to the coatings improves their hardness and toughness.

RESULTS

Based on multilayer architectures coatings were deposited with thicknesses exceeding 100 µm (Fig. 2). Suitable material selection for the individual layers reduces the intrinsic stresses compared to TiN, CrN and AlCrN coatings (Fig. 4). The thickness ratios of the individual layers are modified to adjust the intrinsic stresses.

The coating structure is mostly homogeneous and very useful for tool applications. In addition to investigating the structural



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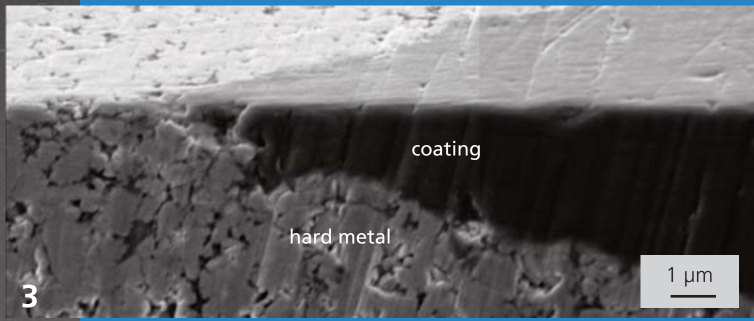

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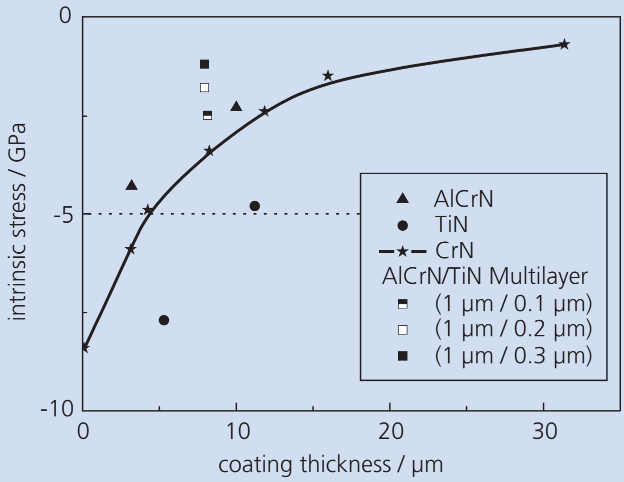
Intrinsic stresses of various coating systems, reducing intrinsic stress by selecting the layer thicknesses in the AlCrN/TiN system



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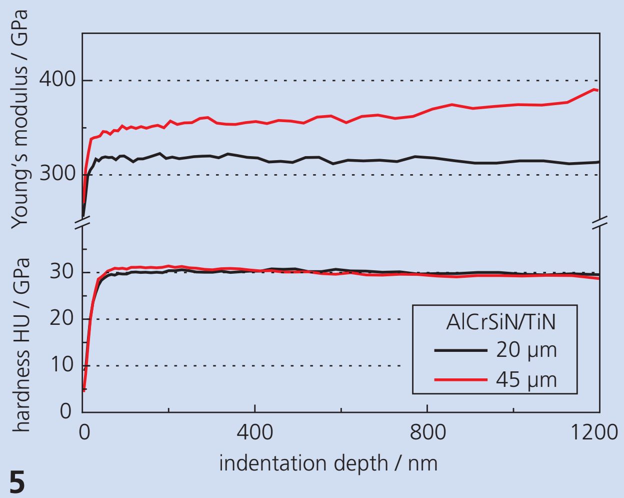
Coating hardness and Young's modulus of AlCrSiN/TiN as a function of coating thickness and indentation depth



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properties with a scanning electron microscope we also measured the distribution of mechanical properties. Fig. 5 plots coating hardness and Young's modulus versus coating thickness and indentation depth during the measurement. The hardness is a homogenous function of the indentation depth.

APPLICATION POTENTIAL

Thick and hard wear resistant coatings offer longer wear resistance compared to thinner coatings. They are therefore especially useful for highly loaded surfaces that need a long service life. These coatings can also be mechanically processed, for example by grinding. Fig. 3 shows an edge, which was cut into a thick hard coating. Clearly visible is the much more homogenous structure of the coating compared to the hard metal substrate. This way it is possible to make very sharp edges or hard and structured part surfaces.

This work was funded by the European Fund for Regional Development (EFRE) 2000-2006 and by the government of the Free State of Saxony.

1 *Defect embedded in a multilayer coating*

2 *AlCrSiN/TiN nanolayered coating, about 130 µm thick*

3 *Preparation of an edge in a thick coating on a hard metal substrate*

CONTACT

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1

BETTER DRILLING WITH DIAMOR®

THE TASK

The machining of metals and alloys prone to cold welding is often problematic. An example is the drilling of deep holes. Offshore pipes (Fig. 1) are subjected to extreme strength requirements. They are manufactured by drilling out forged rod material. BTA deep hole drilling tools (Fig. 2) are used in particular for larger diameters in combination with higher specifications for the sidewall finish after the drilling process.

The cutting inserts located at the tip of the tool perform the actual drilling operation. The outside diameter of the tool holds three polished hard metal guide rails to center the drill. The functional surfaces of the guide rails just slightly extend a few micrometers beyond the inserts and serve a second function to smoothen the bore surface after cutting. This process causes extremely high loads, which separates the lubricant film and leads to abrasive wear of the guide rails.

An additional problem is transfer of smearing materials such as stainless steel and titanium to the surface of the guide rails. This results in a reduced quality of the drilled out surfaces and also causes stick-slip effects and related vibrations. In that case the guide rails have to be exchanged, which interrupts the process and requires machine shut down time. Consequently the overall process becomes less economical. An appropriate coating is required to avoid these problems.

OUR SOLUTION

The guide rails were coated with Diamor®, a carbon based coating that was developed at the Fraunhofer IWS. Tests showed a significant improvement of the BTA deep hole drilling process.

The Diamor® coatings are deposited using pulsed high current arc technology and have a high fraction of diamond bonds resulting in an extreme hardness (depending on the deposition conditions up to 7500 HV). The wear resistance of Diamor® coated guide rails is substantially greater than that of TiN coatings. Abrasive wear is much reduced. The low dry friction coefficient of Diamor® coatings is very advantageous under the processing conditions of extremely high surface contact pressures. Constant processing conditions are maintained. Stick-slip effects and related vibrations are significantly reduced.

The covalent bonding in the coating prevents cold welding of machined part material onto the coated guide rail surface. Thus the functional surfaces of the guide rails do not suffer geometric changes. Subsequently the machined surfaces are of much higher quality. The Fraunhofer IWS coating technology works for various construction materials such as hard metal and produces well adhering Diamor® coatings. This drastically improves the processing safety for applications with very high shear forces such as in the discussed case.

2

RESULTS

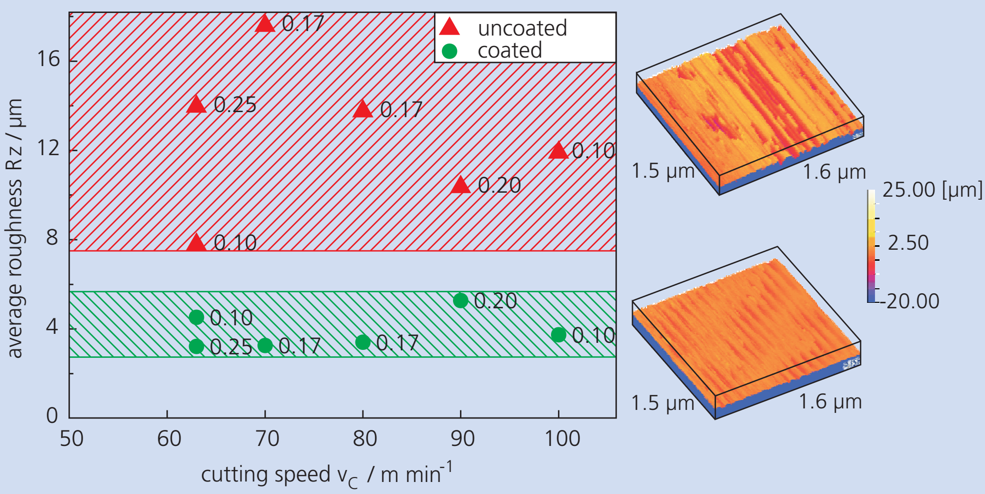
Commercial polished hard metal guide rails (type P20) were coated with 4 µm Diamor® films and then brushed to remove growth defects from the surface. The roughness of the coated and brushed guide rail surfaces was Ra = 0.010 µm and Rz = 0.095 µm and as such significantly lower than the uncoated surfaces as delivered (Ra = 0.023 µm, Rz = 0.185 µm). The coated guide rails were installed in a BTA drill head with a diameter of 57.4 mm. Two AlTiN cutting inserts were installed. The head was used to drill centric holes into rod material from austenitic stainless steel X5CrNi18-10 (1.4301).

Cutting speed and feed rates were varied. Fig. 3 shows that the coating leads for all cutting speeds and feeds to significantly improved surface qualities (lower average roughnesses). In addition the results for the coated parts are less scattered. The analysis of the results proved that the Diamor® coated guide rails indeed generates much smoother surfaces. There was also no material transfer to the coated guide rail surfaces. The current project is therefore continuing to explore the great potential of Diamor® coatings for this application.

Special thanks go to Mr. Dipl.-Ing. Thorsten Upmeier from the Institute of Machining Technology at the TU Dortmund for performing the drilling tests.

Influence of cutting parameters on the surface quality of drill holes for uncoated guide rails (red) and Diamor® coated guide rails (green). Various cutting speeds and feeds were tested. The values are shown right next to the data points.

3D white light confocal microscopy image of drill hole surfaces; upper: drilled with uncoated guide rails, lower: drilled with coated guide rails



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1 Deep hole drilled stainless steel pipes for the offshore industry

2 BTA deep hole drill head with three guide rails distri buted along the outer circumference of the tool

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AWARDS AND HONORS 2011

SCIENTIFIC AWARDS FOR RESEARCH WORKS ON DIRECT LASER INTERFERENCE STRUCTURING


GERMAN HIGH TECH CHAMPIONS
AWARD CERTIFICATE

in the area of Applied Research in Solar/Photovoltaics
for the Business Case entitled

Rapid Fabrication of Nano-Structures

developed by:

Dr. Andrés F. Lasagni, Dr. Lars Müller-Meskamp
(Team Leaders)
Teja Roch, Yong Hyun Kim, Dr. Reinhard Scholz
and **Simone Hofmann** (Team)

Fraunhofer Institute for Material and Beam Technology, Germany
Institut für Angewandte Photophysik, Technische Universität Dresden, Germany

and presented at the
Clean Technology Conference and Expo 2011
in Boston, USA, on June 15, 2011.
The award is endowed with prize money of 10,000 Euros.

On behalf of the Organizing Committee,

Dr. Raoul Klingner
Fraunhofer-Gesellschaft, International Business Development

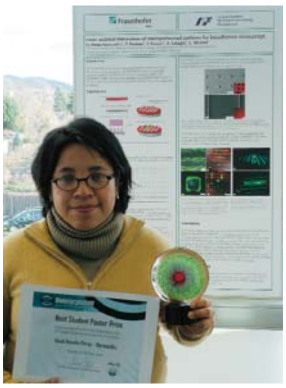
Federal Ministry of Education and Research

Research in Germany
Land of Ideas

The GHTC competition is for university and research institution scientists who develop products or processes with a focus on actual applications of the technology. The Fraunhofer-Gesellschaft "German High Tech Champions" campaign also invites scientist to promote their applied technology developments beyond Germany to an international technical audience.

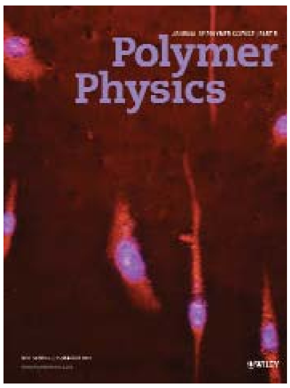
This year's "German High Tech Champions" in the field of photovoltaics come from Dresden. **Dr. Andrés F. Lasagni** (Fraunhofer IWS), **Dr. Lars Müller-Meskamp** (TU Dresden, Institute for Applied Photo Physics) and their teams received the "German High Tech Champion" award in the field of Solar/PV. The award ceremony was performed on June 15th, 2011, during the Clean Technology Conference & Expo in Boston, USA. The event included a presentation at the fair as well as an unconventional "speed dining" event for making individual contacts with interested companies and technology scouts.

Mrs. **Heidi Perez** received the "Biointerphases Award" for 2011 in recognition for her poster contribution at the 24th European Conference on Biomaterials. The poster entitled "Laser Assisted Fabrication of Bioadhesive Microdomains" presented research results on the structuring of hydrogels with micro lens arrays. The Fraunhofer IWS research group "Surface Functionalization" performed this work.



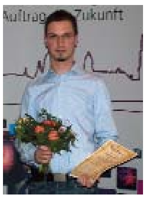
The scientific "Journal of Polymer Science Part B Polymer Physics" also recognized the work of the same research group. D. Langheinrich, E. Yslas, M. Broglia, V. Rivarola, D. Acevedo and A. Lasagani published the article "Control of Cell Growth Direction by Direct Fabrication of Periodic Micro- and Submicrometer Arrays on Polymers", which will appear in the journal in March 2012. The article, discussing how periodic submicron structures affect the behavior of living cells, will also be featured on the cover page of the journal's March issue.

This publication is a result of the cooperation between the Fraunhofer IWS research group "Surface Functionalization" and the *Laboratorio de Investigacíon y Desarollo de Materiales Avanzados* at the University *Rio Cuarto* in Argentina. The Federal Ministry for Education and Research financially supported this collaboration.



The 2011 IWS Awards Ceremony occurred on December 16^{th}, 2011.

Dr. Andrés F. Lasagni, Matthias Bieda and **Teja Roch** (f. l. t. r.) received the "Award for the Best Scientific Achievement" for their research on large area manufacturing of nanostructures for more efficient solar cells. This award honors the development of compact systems for laser interference structuring processes, which can now be deployed in industry. Two demonstrators were built and tested. One solution is suitable for laser systems with high pulse energies and the other for lasers with high pulse frequencies.



Mr. **Mirko Riede** received the "Award for the Best Scientific Achievement of a Junior Scientist". He provided important contributions identifying process parameters and quantifying their influence during high precision laser powder buildup welding. His research led to the modification of several system components and the adaptation of corresponding welding strategies. The resulting precision and reproducibility of welded structures was significantly improved.

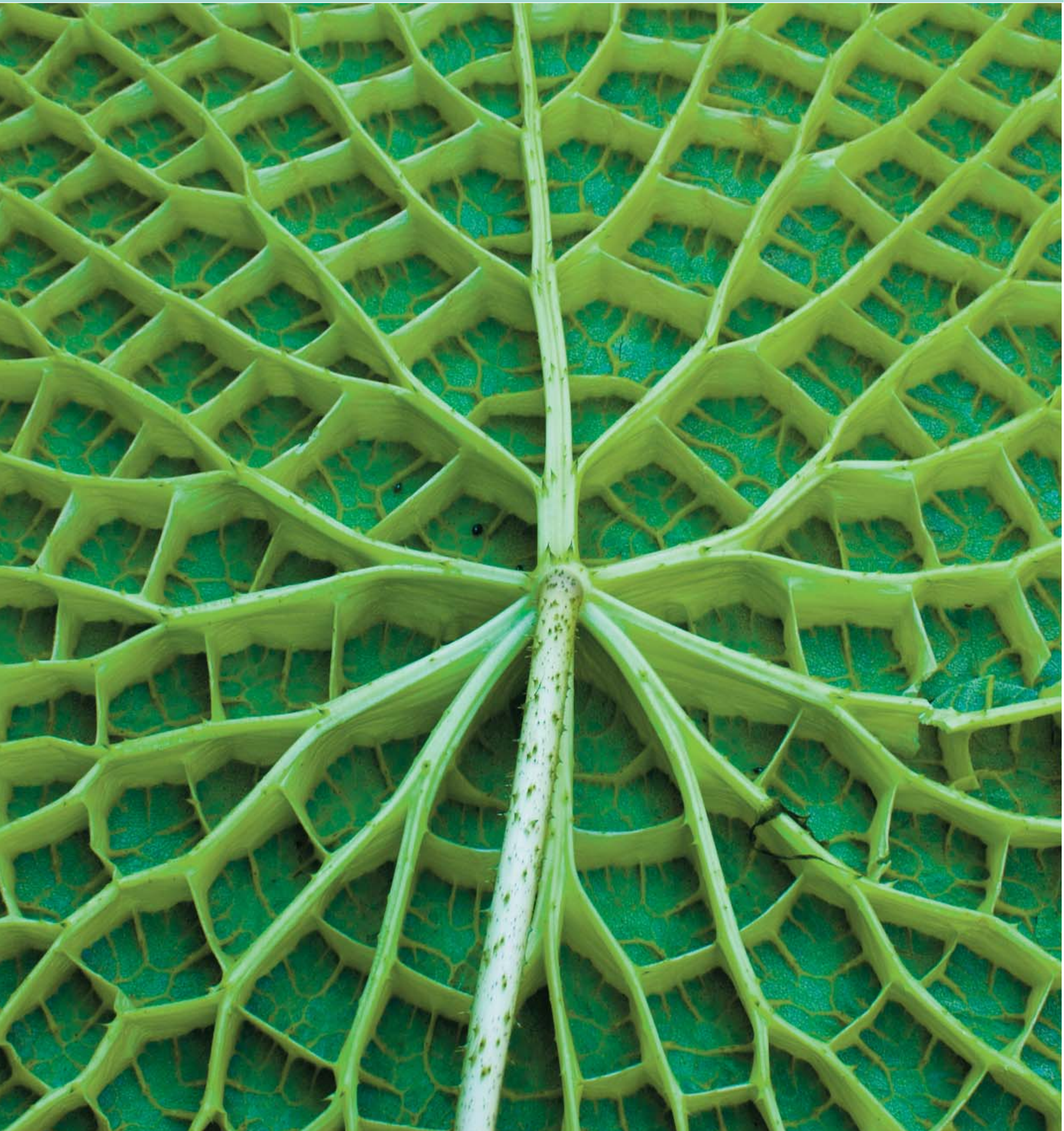
Mr. **Erik Pflug** researched novel reactive multilayer coatings based on Ni/Al material systems. His effort was recognized as an "Outstanding Student Performance". In the past welds produced by Ni/Al reactive multilayers contained intermetallic phases which led to a less than optimal quality of the joint. Mr. Pflug developed an extended reactive multilayer system to avoid the negative influence of the intermetallic phases. The solution improved the mechanical and electrical properties of the joints as well as the fabrication and handling of the reactive multilayer system.

Mr. **Sören Thieme's** work was also recognized as an "Outstanding Student Performance". He developed high capacity sulfur/carbon electrodes using powder materials and thus avoiding solvents. His solution is very efficient, scalable and reproducible with high application potential.

A "Special Award from the Institute" was presented to Mrs. **Steffi Wittig** for the swift, competent and uncomplicated administrative project support that she provided to many colleagues.

Another "Special Award from the Institute" was presented to **Dr. Arnhold Luft** for the conception and performance of extensive internal education programs addressing materials sciences.

NETWORKS



THE FRAUNHOFER-GESELLSCHAFT

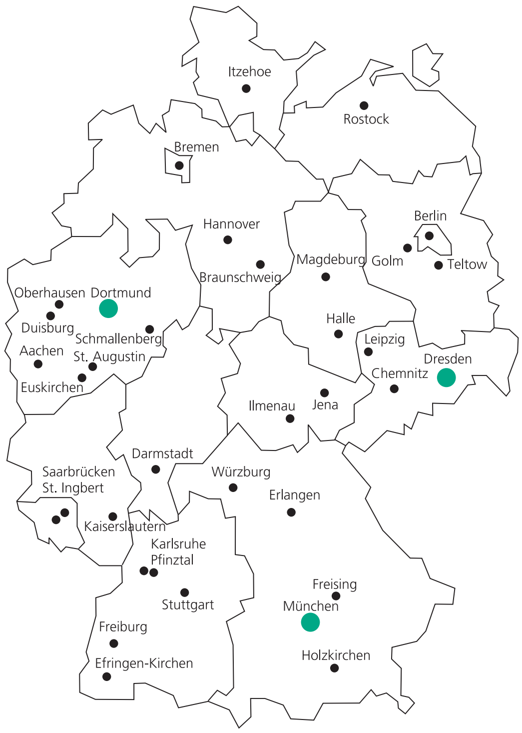
Research of practical utility lies at the heart of all activities pursued by the Fraunhofer-Gesellschaft. Founded in 1949, the research organization undertakes applied research that drives economic development and serves the wider benefit of society. Its services are solicited by customers and contractual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

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

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

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

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



Economic power
determines the present of a country;
its youth determines its future.
Unknown author

CONNECTION TO THE TECHNISCHE UNIVERSITÄT DRESDEN

COOPERATION FRAUNHOFER IWS – TU DRESDEN

A cooperation agreement regulates the collaboration between IWS and TU Dresden. Based on a joint appointment, Prof. Beyer simultaneously holds the positions of Fraunhofer IWS director and a chaired professorship at the TU Dresden. This arrangement is based on the following concept: The emphasis at the university chair is on research and teaching, and applied research and development occur at the IWS. IWS employees are involved in university activities, and vice versa, university employees join IWS efforts. Ultimately, IWS and university chair form a unit with different emphases.

advantages for IWS:
- cost effective basic research
- education of junior scientists for IWS
- access to scientific assistants

advantages for the TU:
- R&D participation in industrial projects
- integration of latest R&D results in education
- education of students using latest equipment

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

topics:
- laser systems engineering
- laser processing methods
- plasma in manufacturing technology
- surface, micro and nanotechnology
- manufacturing technology II
- laser robotics
- rapid prototyping and tooling

Following professors of the TU Dresden work as department heads at the Fraunhofer IWS:

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

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

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

topics:
- metallic and intermetallic lightweight construction materials
- high temperature materials
- thin film systems
- materials testing

PROF. DR.-ING. ULRICH GÜNTHER
CHAIR OF PRODUCTION TECHNOLOGY
STEINBEIS UNIVERSITY

topics:
- chipping surface processing technology
- production design

DRESDEN concept

»DRESDEN-CONCEPT«

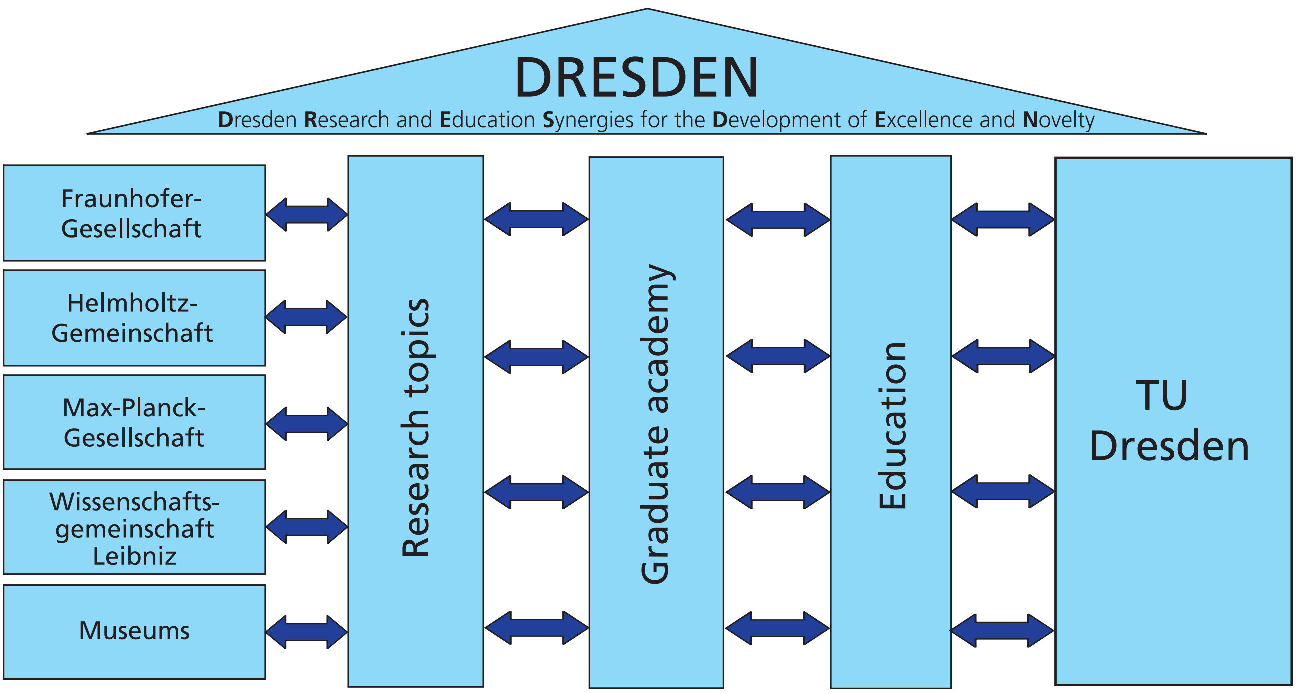
Dresden is among the leading research locations in Germany with a high concentration of scientific institutions: ten universities including the TU Dresden, the university of technology and economy Dresden (HTW), 12 Fraunhofer institutions, three institutes of the Max Planck-Gesellschaft, three institutes of the Leibniz-Gemeinschaft and the Helmholtz-Zentrum Dresden-Rossendorf.

Strong networking activities are pursued in Dresden's scientific landscape to further build on this advantage and to form an excellent research and education region. Since February 2009 the TU Dresden has been forming an elite research alliance with Dresden's research institutions and the museums in the state capital. Such an alliance is unique not only for Germany, but also globally.

The name of the alliance is its program: DRESDEN-concept (**D**resden **R**esearch and **E**ducation **S**ynergies for the **D**evelopment of **E**xcellence and **N**ovelty). The collaboration of non-university and university research and education institutions with the TU Dresden creates synergies benefiting research, graduate education and scientific infrastructure.

The concrete goals of the DRESDEN-concept are:

- definition of joint research emphases,
- establishment of graduate schools in these areas,
- collaboration to attract excellent scientist from all over the world,
- utilization of synergies of existing infrastructure (laboratories, equipment) as well as student education.



"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.

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

The Dresden Innovation Center Energy Efficiency achieves a high performance level because it tightly connects basic research at the University of Technology 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 provides 6 million Euros and the Free State of Saxony commits 4 million Euros to support the innovation center. These funds support numerous highly qualified scientific jobs in the region from 2009 through 2013. Additional industrial financial commitments generate more scientist jobs in the subsequent years.

www.innovation-energieeffizienz.de
www.iws.fraunhofer.de

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

SPEAKER

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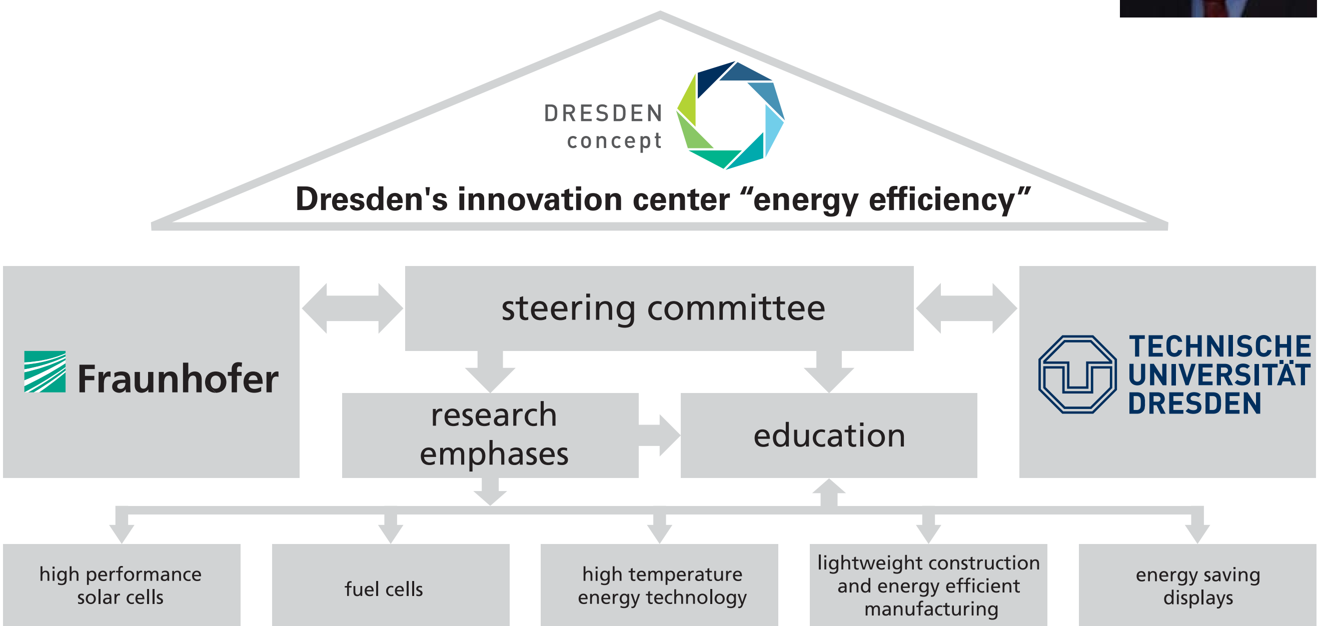

PROJECT GROUP AT THE SURFACE TECHNOLOGY CENTER DORTMUND (DOC®)

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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 Oberflächen Centrum" (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.

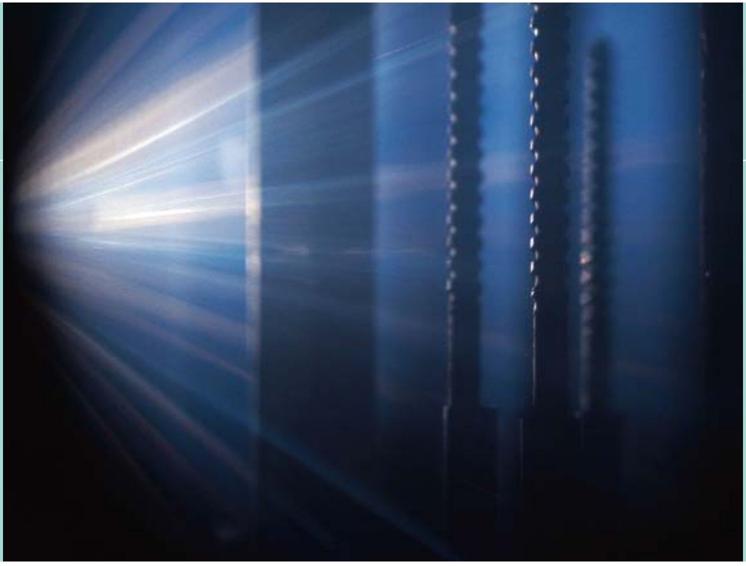
The Fraunhofer IWS cooperates directly with DOC® by supporting a project group on site. This group works primarily on surface coatings using PVD, PACVD and spraying processes and on laser materials processing.

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.



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)

This Fraunhofer Project Center was opened in 2008 and established the "Fraunhofer Model" in Poland's research market. In 2010 the PCW received a substantial selection of equipment from Wroclaw's University of Technology, which was funded by the Polish investment project "Optolas". 2011 saw the final installation and startup of the equipment and its utilization in numerous publicly funded projects such as:

- lastech – laser technologies for manufacturing functional 3D and surface structures,
- bioimplants for the treatment of bone loss in oncological patients,
- rapid manufacturing technologies in low volume production of individualized products,
- laser technologies for structural surface manufacturing – cladding and alloying,
- method development for replication of forensic evidence,
- cax software and measurement equipment for simulation based on opto-mechatronic devices, especially machine vision.

For Wroclaw University, and thus for the Fraunhofer Project Center, the highlight of this year was the conference "ManuFuture 2011" in Wroclaw. Under the management and presidency of Prof. Chlebus, the conference attracted 400 international guests who participated in sophisticated lectures under the theme "West and East Europe in High Added Value Global Manufacturing – Facts of Today and Challenges of Tomorrow". The potential and possibilities of the Fraunhofer Project Center were presented during the conference and a tour was offered to participants. The center also participated in the organization of the "7th International Conference Production Engineering 2011 – Innovations and Technologies for the Future". The effort provided the Center directly with contacts to potential project partners. Latest developments in the area of manufacturing technology were presented to a national and international audience from industry and the sciences.

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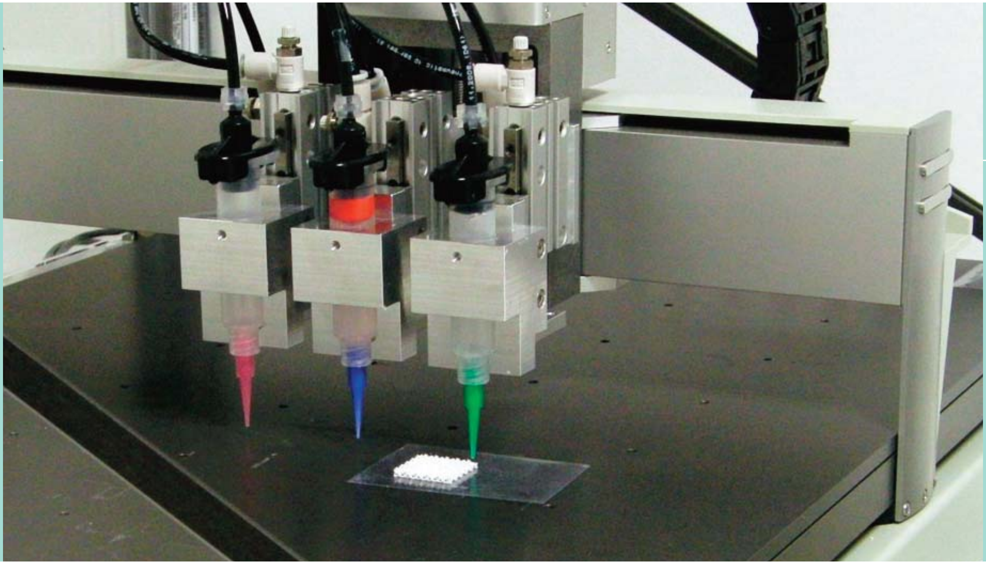


The joint project "RemCoVis" develops observation and visualization solutions for remote processes. The increasing industrial utilization of "laser processes operating from the distance" generates the need for visualization solutions. Systems are already offered for the wavelength range of solid-state lasers. However, there is nearly no solution available for CO_2 laser applications. The challenges arise from the large difference between observation and processing wavelengths if coaxial beam guidance is desired. The Center for Advanced Manufacturing Technologies of the Technical University in Wroclaw has competences in the field of image processing, visual inspection and optics dimensioning. These competences are leveraged with Fraunhofer IWS laser materials processing know how to address the challenges in this project.

The work concentrates on the implementation of monitoring and sensor systems for scanner heads. The goal is to improve quality and optimize processing. Applications include high-speed cutting and ablation of fabrics, non-metals and composite materials. The to-be-developed solutions should improve process implementations by offering "teaching" possibilities and simplifying the setup for new parts. Observation capabilities will lead to a better process understanding and improve stability. Observing the process will also provide the means for quality monitoring and control. The vision is to have self-learning and self-controlling remote processes. The basics are being developed in this project.

A second joint project is called "Bioreactor". Here we leveraged CAMT's rapid prototyping competences with Fraunhofer IWS bio systems technology. Vascularization, the controlled formation of new blood capillaries, is one of the greatest challenges of tissue manufacturing. It is state-of-the-art to place living cells onto and into three-dimensional scaffold structures. Cell culture systems can be kept alive for several weeks. However, after implanting such a construct most of the cells die because the formation of new blood capillaries takes too long and thus oxygen and nutrients cannot be provided. The challenge is therefore to fabricate an artificial tissue structure providing a vessel system that can be directly and easily connected to the body's blood circulation.

The goal of this project is the joint development of an implantable bioreactor that can be directly connected to the blood circulation. The bioreactor consists of a biocompatible case, which houses a scaffold with a cell population. The reactor has two interfaces for connecting a vein and an artery. Initially the case has to be liquid tight so that it is possible to provide the cells inside with nutrients and oxygen without interrupting the blood circulation. With such a technology patients would be able to produce inside the body missing substances such as insulin (diabetes) or dopamine (Morbus Parkinson). The work is focusing on the development of various material combinations and reactor designs.

FRAUNHOFER CENTER FOR COATINGS AND LASER APPLICATIONS (CCL)

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

The Fraunhofer Center for Coatings and Laser Applications mirrors the main activities of the IWS in laser and coating technologies. With an annual turnover of $4.2 Mio the center is one of the strongest Fraunhofer centers in the USA. Since 2003, Dr. Jes Asmussen heads the CCL. He is a professor at Michigan State University and his previous work in diamond coatings and synthesis ideally complement the know-how of the Fraunhofer IWS in the area of Diamor® coatings.

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

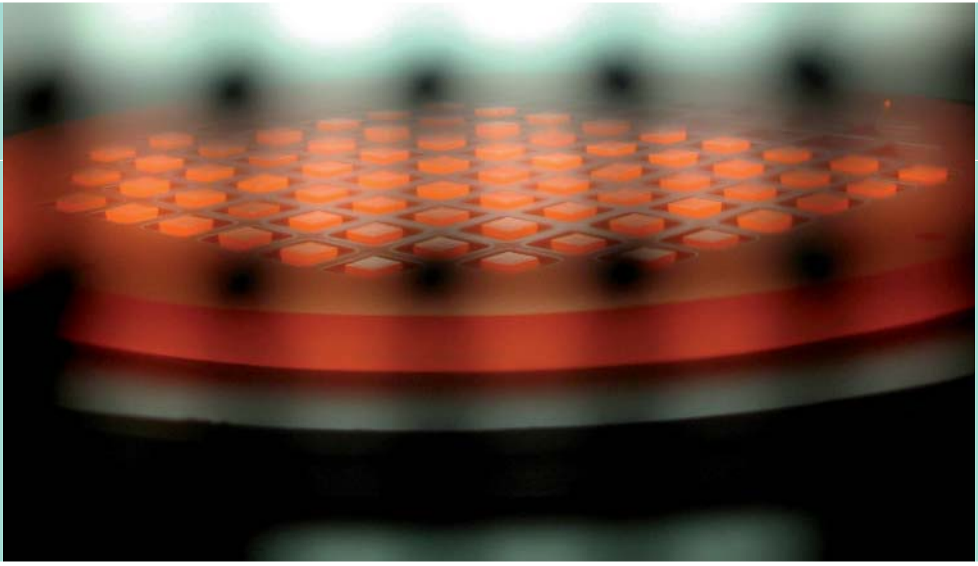
Coating Technology Division

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

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

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

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



Laser Applications Division

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

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

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

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

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NANO TECHNOLOGY ACTIVITIES

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

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

In the nanotechnology field the IWS was organizer of the "Nanofair – International Nanotechnology Symposium", which was held on May 6th - 7th 2010 for the 8th time. Currently the 9th Nanofair is in preparation. The event will be held on June 12th - 13th 2012 at the International Congress center in Dresden under the joint sponsorship of the state capital, the Office for Economic Development and the Fraunhofer IWS.

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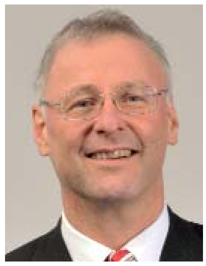

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LASER INTEGRATION IN MANUFACTURING TECHNOLOGY – LIFT INITIATIVE

From 2007 through 2010 the Federal Ministry of Transport, Building and Urban Development funded the **LiFt Initiative**, which had won the Innovation Competition "Industry meets Science". The goal of the initiative was and still is to support Saxony's competitiveness and potential in the field of machine manufacturing and plant construction through laser technology. Additional innovative technologies were continued to be developed after the initial funding phase had ended.

The Fraunhofer IWS cooperates within LiFt with the University of Mittweida and the Institute for Innovative Technologies, Technology Transfer, Education and Continuing Education e. V. (ITW) in Chemnitz. The cooperation advances the transfer of developed laser materials processing technologies toward industrial applications.

The network's goals are to show potentials, to offer services and to demonstrate the advantages to machine builders and plant makers. Such advantages could be:

- time and cost savings through shortening of process chains,
- higher efficiencies of manufacturing processes and products,
- high quality, market capability of the products,
- unique selling proposition at the highest technology level.

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As a technology developer and knowledge provider, the LiFt project partners support small and medium sized companies in Saxony but also in other regions.

There is an increasing demand for laser solutions. Primary 2011 network activities were consulting services at the Fraunhofer IWS and onsite at interested partners, which meets a core objective of the project. Jointly with industry partners we also work on strengthening European contacts.

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

SPECIAL EVENTS

MARCH 2ND-3RD, 2011
Workshop "Laser + Sheet Metal", Carl Hanser Publishing House, Garching by München,
(Co-organizer: Fraunhofer IWS)

MARCH 23RD-24TH, 2011
TAW Symposium "Thermal Coating with Laser Based Manufacturing Processes" in Dresden, Organized by Technical Academy Wuppertal e.V. in collaboration with the Fraunhofer IWS Dresden and FriBa LaserNet Holzkirchen

APRIL 14TH, 2011
"Dutch-German Seminar on Energy Innovations – Connecting PV Industries from Saxony and the Netherlands", special event at the Fraunhofer Institutes Center in Dresden during the visit of Her Majesty the Queen Beatrix of the Netherlands, His Royal Highness Prince Willem-Alexander of Orange, and Her Royal Highness Princess Maxima of the Netherlands.

APRIL 14TH, 2011
Fraunhofer Institutes Center participation in the national "Girls Day"

APRIL 20TH, 2011
Info-Day "MOF – Metal Organic Frameworks" at the Fraunhofer IWS Dresden (in cooperation with Saxony's Economic Development Corporation)

MAY 11TH-13TH, 2011
Dresden Conference "Future Energy" at the International Congress Center in Dresden, (Organizers: Fraunhofer IWS Dresden, DRESDEN-concept, state capital Dresden)

MAY 13TH, 2011
"Technology Day Dresden" – 7th Alumni Meeting of the Fraunhofer IWS and the TU Dresden Chair of Laser and Surface Technologies (LOT)

JULY 1ST, 2011
Participation of the Fraunhofer Institutes Center in the "Long Night of the Sciences", sponsored by the state capital Dresden

OCTOBER 17TH-20TH, 2011
V2011 – Industry fair and workshop week "Vacuum Coatings and Plasma Surface Technology", sponsored by the European Research Society "Thin Film Coatings" (EFDS) e.V.,
(Co-organizer: Fraunhofer IWS Dresden)

NOVEMBER 3RD, 2011
Workshop "Carbon Materials for Electrodes",
(Co-organizer: Fraunhofer IWS Dresden)

NOVEMBER 9TH, 2011
2nd BMBF status seminar "Electromobility" at the Fraunhofer IWS Dresden, this event was part of the BMBF framework concept "Research for Tomorrow's Manufacturing",
(Organizer: Fraunhofer IWS Dresden)

NOVEMBER 17TH-18TH, 2011
Technology audit at the Fraunhofer IWS Dresden

NOVEMBER 23RD, 2011
Workshop "MOF for industrial applications" in Bergamo, Italy,
(Organizers: Fraunhofer IWS Dresden, Institute for Inorganic Chemistry of the TU Dresden)

DECEMBER 6TH, 2011
Workshop "Amorphous Carbon Coatings – Tribological Applications and Industrial Manufacturing Processes" at the Fraunhofer IWS Dresden, sponsored by the European Research Society "Thin Film Coatings" (EFDS) e.V.


VOM ATOM ZUM KOMPLEXEN BAUTEIL


Willkommen
Internationales Congress Center Dresden
Dresden, 11. – 13. Mai 2011

PUBLICATIONS

[L01]
F. Bartels, B. Suess, A. Wagner, J. Hauptmann, A. Wetzig, E. Beyer

»Agility - Complexity Description in a new Dimension Applied for Laser Cutting«

International Conference on Lasers in Manufacturing (LIM), München, Hrsg.: M. Schmidt, Wissenschaftliche Gesellschaft Lasertechnik -WLT-: Lasers in Manufacturing, Proceedings, 23. – 26. Mai 2011, München, Amsterdam, Elsevier (2011), S. 543-547
(Physics Procedia 12.2011, S. 1)

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

»Microstructural Investigation of Thermally Sprayed Ceramic Coatings by Laser Acoustic Surface Waves«

International Thermal Spray Conference & Exhibition ITSC (2011), 27. - 29. September 2011, Hamburg, Conference Proceedings, DVS-Berichte 276 (2011), S. 718-724, Tagungs-CD, ISBN 978-3-87155-268-7

[L03]
E. Beyer

»Fraction-Limited Fiber Lasers for Welding and Cutting«

European Conference on Lasers and Electro-Optics Europe, 12th European Quantum Electronics Conference CLEO Europe/EQEC (2011), 22. - 26. Mai 2011, München, Piscataway, NJ: IEEE, Nr. 2, S. 1241, ISBN 978-1-4577-0533-5, ISBN 978-1-4577-0532-8

[L04]
E. Beyer

»High Performance Laser Cladding«

Laser Insights webpage: https://www.lia.org/laserinsights/2011/05/06/high-performance-laser-cladding/#more-1035, Mai 2011

[L05]
L.-M. Berger

»Thermisch gespritzte Hartmetallschichten – ein Überblick«

Tribologie in Industrie und Forschung: Werkstoff- und Energieeffizienz - Herausforderung und Lösungsansätze, Symposium der Österreichischen Tribologischen Gesellschaft (2011), Hrsg.: F. Franek, A. Pauschitz, 24. November 2011, Wiener Neustadt, Österreich, S. 27-38,
ISBN 978-3-901657-40-5

[L06]
L.-M. Berger, K. Lipp, J. Spatzier, J. Bretschneider

»Dependence of the Rolling Contact Fatigue of HVOF-Sprayed WC-17%Co Hardmetal Coatings on Substrate Hardness«

18th International Conference on Wear of Materials (WOM), Philadelphia, USA,
4. - 7. April 2011, Amsterdam, Elsevier (2011), S. 2080-2088, ISSN 0043-1648 (Wear 271 (2011), Nr. 9/10)

[L07]
E. Beyer, L. Lahn, C. Schepers, T. Stucky

»The Influence of Compressive Stress Applied by Hard Coatings on the Power Loss of Grain Oriented Electrical Steel Sheet«

Journal of Magnetism and Magnetic Materials 323 (2011), Nr. 15, S. 1985-1991

[L08]
E. Beyer, A. Mahrle, M. Lütke, F. Bartels, J. Standfuss, F. Brückner

»Innovation and Invention with High Brightness Lasers«

The Laser User Magazine, Issue 63 (2011), S. 30-33

[L09]
E. Beyer, S. Nowotny, F. Brückner, H. Hillig, A. Techel

»New Industrial Systems for High Performance Laser Cladding«

LIA Today Vol. 19 (2011) 4, S. 18-20

[L10]
E. Beyer, I. Jansen, R. Rechner, F. Wehnert

»Untersuchungen zu nanopartikelbasierten Klebverbindungen«

Konferenz »Zukunft Energie«, 11.-13. Mai 2011, Dresden

[L11]
S. Bonß, J. Hannweber, U. Karsunke, S. Kühn, M. Seifert, E. Beyer

»Laser Heat Treatment with Latest System Components«

30th International Congress on Applications of Lasers and Electro Optics (ICALEO), 24.-27. Oktober 2011, Orlando (FL), USA, paper 905 (2011), S. 463-472, Tagungs-CD, ISBN 978-0-912035-94-9

[L12]
H.-P. Bossmann, F. Brückner, S. Gebhard, S. Hatzl, V. Kochubey, C. Mundt, B. Rittmeister, R. Vassen

»Innovative multifunktionale Schichtsysteme für hocheffiziente Gasturbinen«

WING-Konferenz (2011), 4.-6. Oktober 2011, Berlin, Tagungsband

[L13]
S. Braun, P. Gawlitza, M. Menzel, W. Friedrich, J. Schmidt, A. Leson

»Spiegel für extrem ultraviolette und Röntgenstrahlung«

V2011 Industrieausstellung & Workshop-Woche, Tagungsband, S. 141

[L14]
F. Brückner, S. Nowotny, H. Hillig, F. Kubisch, M. Riede, S. Thieme, E. Beyer

»Industrial Solutions and System Components in Laser Additive Manufacturing«

Conference - Industrial Laser Applications, 29. - 30. März 2011, Pilsen (Cz), Tagungsband

[L15]
F. Brückner, S. Nowotny, M. Riede, E. Beyer

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

4. TAW-Syposium »Thermisches Beschichten mit laserbasierten Fertigungsverfahren«, 23. - 24. März 2011, Dresden, Tagungsband

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

»Stabilitätsverbesserung von Wärmedämmschichten durch strukturierte Substratoberflächen mit Hilfe des Präzisions-Laser-Pulver-Auftragschweißen«

Workshop »Materialien und Prozesstechniken der Turbinenschaufelbeschichtung«,
15. März 2011, Dresden, Hrsg.: V. Kirchhoff, Europäische Forschungsgesellschaft Dünne Schichten e.V. -EFDS-: Materialien und Prozesstechniken der Turbinenschaufelbeschichtung, Tagungsband, S. 10

[L17]
A. Cramer, S. Landgraf, E. Beyer, G. Gerbeth

»Marangoni Convection in Molten Salts : Physical Modelling Toward Lower Prandtl Numbers«

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»Comparative Study of the Electrical Properties and Characteristics of Thermally Sprayed Alumina and Spinel Coatings«

Journal of Thermal Spray Technology 20 (2011), Nr. 1-2, S. 195-204

[L99]
F.-L. Toma, S. Langner, M.M. Barbosa, L.-M. Berger, C. Rödel, A. Potthoff

»Influence of Spray Parameters on the Characteristics and Spraying Parameters on the Properties of Dense Suspension-Sprayed Al_2O_3-Coatings«

International Thermal Spray Conference & Exhibition ITSC (2011), 27. - 29. September 2011, Hamburg, Conference Proceedings, DVS-Berichte 276 (2011), S. 421-426, Tagungs-CD, ISBN 978-3-87155-268-7

[L100]
F.-L. Toma, S. Scheitz, R. Puschmann, L.-M. Berger, V. Sauchuk, M. Kusnezof

»Development of Ceramic Heating Elements Produced by Thermal Spray Technology«

International Thermal Spray Conference & Exhibition ITSC (2011), 27. - 29. September 2011, Hamburg, Conference Proceedings, DVS-Berichte 276 (2011), S. 912-917, Tagungs-CD, ISBN 978-3-87155-268-7

[L101]
F.-L. Toma, S. Scheitz, S. Langner, L.-M. Berger, V. Sauchuk, M. Kusnezoff

»Comparison of the Electrical Properties of Al_2O_3 Sprayed Coatings from Feedstock Powders and Aqueous Suspensions«

International Thermal Spray Conference & Exhibition ITSC (2011), 27. - 29. September 2011, Hamburg, Conference Proceedings, DVS-Berichte 276 (2011), S. 1346-1351, Tagungs-CD, ISBN 978-3-87155-268-7

[L102]
R. Trache, L.-M. Berger, F.-L. Toma, S. Stahr, R.S. Lima, B.R. Marple

»Electrical Resistivity of Thermally Sprayed Cr_2O_3-TiO_2 Coatings«

International Thermal Spray Conference & Exhibition ITSC (2011), 27. - 29. September 2011, Hamburg, Conference Proceedings, DVS-Berichte 276 (2011), S. 1179-1184, Tagungs-CD, ISBN 978-3-87155-268-7

[L103]
F. Wehnert, I. Jansen, P. Pötschke

»Improved Properties of Adhesives by Integration of Carbon Nanotubes«

12th international Conference on the Science and Application of Nanotubes, NT 11, 10. – 16. Juli 2011, Cambridge, P 226, Tagungsstick

[L104]
V. Weihnacht, A. Brückner, G. Theiler, T. Gradt

»Kombinierte ta-C/MoS2-Schichten für vakuumtribologische Komponenten«

V2011 Industrieausstellung & Workshop-Woche, Tagungsband, S. 75

[L105]
V. Weihnacht, S. Makowski, A. Brückner, G. Theiler, T. Gradt

»Tribologie und Anwendung trokken laufender ta-C-Schichten«

52. Tribologie-Fachtagung (2011) in Göttingen, Tagungsband

[L106]
B. Winderlich, A. Jahn, B. Brenner

»Leichtbaupotenzial zyklisch belasteter Laserstrahl-Hybridschweißverbindungen aus S1100QL«

MP materials testing 53 (2011), Nr. 5, S. 256-265

[L107]
P. Wollmann, M. Leistner, U. Stoeck, R. Grünker, K. Gedrich, N. Klein, O. Throl, W. Grählert, I. Senkovska, F. Dreisbach, S. Kaskel

»High-Throughput Screening: Speeding up Porous Materials Discovery«

Chemical communications 47 (2011), Nr. 18, S. 5151-5153

[L108]
P. Wollmann, M. Leistner, W. Grählert, O. Throl, F. Dreisbach, S. Kaskel

»Optical Detection of the Heat of Adsorption for the Determination of Specific Surface Areas«

Microporous, Mesoporous Materials 149 (2011), S. 86-94

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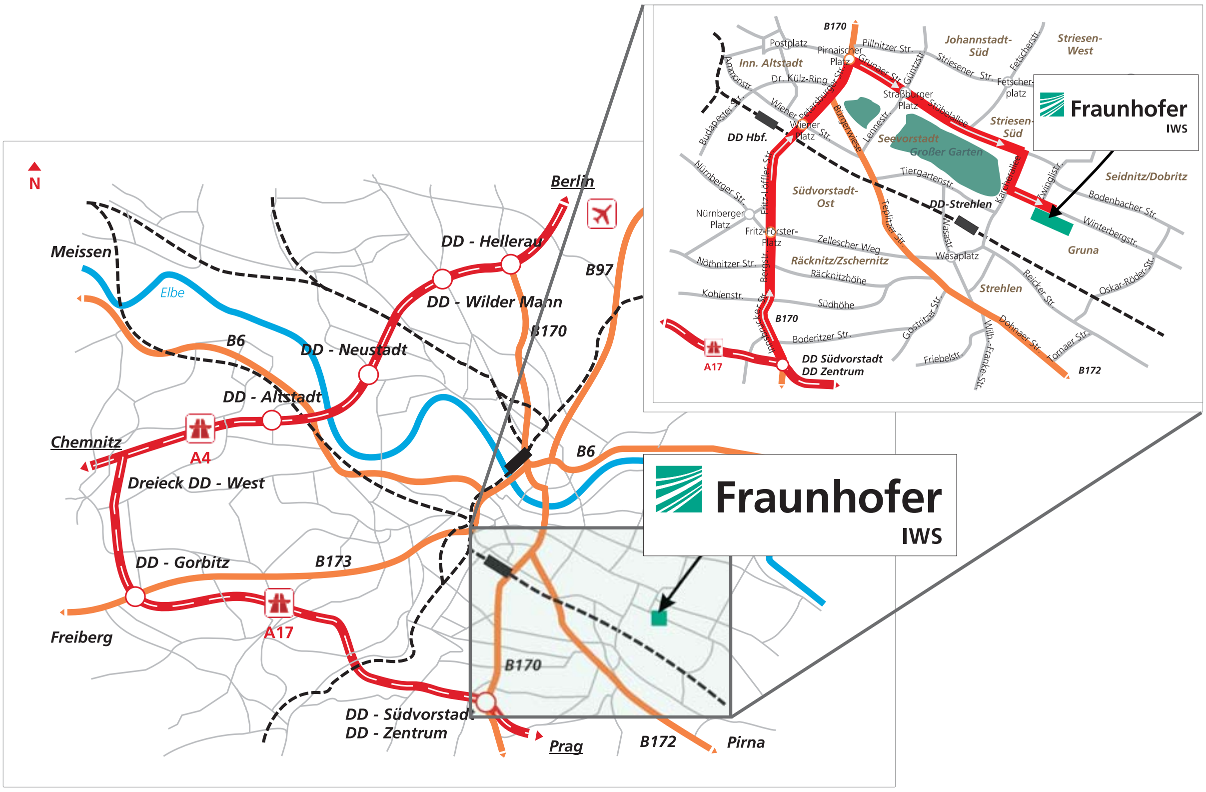

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Photos:	p. 3	Fraunhofer IWS / Christian Hüller
	p. 6	Miklav (fotolia)
	p. 8 (Fig. 2)	Held Systems
	p. 11	Dr. F. Junker (private)
	p. 16	Fraunhofer IWS / Frank Höhler
	p. 26	Marco Becker (fotolia)
	p. 67 (top l. pic.)	Helmut-Schmidt-Universität
	p. 73 (top l. pic.)	Heraeus
	p. 84 (Fig. 1)	GrandeMedia
	p. 102 (Fig. 1+2)	TU Dortmund
	p. 106	Secret Side (fotolia)
	p. 111	Fraunhofer IWS / Bolko Kosel
	p. 114	TU Wrocław
	p. 120 / 121	Fraunhofer FEP, ILT, IOF, IPM, IST
	p. 2, 3, 16, 19, 53, 61, 75, 89	Frank Höhler
	p. 18, 31 (Fig. 2), 33 (Fig. 2+4), 34, 35, 52, 60, 66 (Fig. 1), 74, 82 (Fig. 1), 85 (Fig. 1 a. 2), 88, 104 (top pic.)	Jürgen Jeibmann
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