Fraunhofer

IWS Dresden

FRAUNHOFER INSTITUTE FOR MATERIAL AND BEAM TECHNOLOGY IWS

ANNUAL REPORT 2016

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CERTIFICATE

Fraunhofer IWS

ISO 9001:2008

DEKRA Certification GmbH hereby certifies that the company

Fraunhofer- Institut für Werkstoff- und Strahltechnik IWS

Scope of certification:

Research and development in the field of Surface Engineering / Coatings and Laser Materials Processing with the research areas PVD- and Nanotechnology, Chemical Surface and Reaction Technology, Thermal Coating and Build-up Technologies, Surface Treatment and Joining, Laser Ablation and Cutting, Microtechnology

Certified location:

D-01277 Dresden, Winterbergstraße 28

has established and maintains a quality management system according to the above mentioned standard. The conformity was adduced with audit report no. A15101061.

This certificate is valid from 2016-02-01 to 2018-09-14

Certificate registration no.: 91297819/7

Lothar Werhofen
DEKRA Certification GmbH Stuttgart, 2016-02-01

FOREWORD

"Innovations give the future a future"

Hans-Jürgen Quadbeck-Seeger

2016 saw a stable economic situation for Germany, and it was successful and profitable for the IWS, as well.

This year was also characterized by far-reaching political and technological changes. In politics, the challenge was to try to integrate large numbers of refugees into society. In technology, 2016 was marked by the Industrial Revolution 4.0. The Internet of Things is based on autonomous networked systems that draw data from the Internet and act independently. A key example for Industry 4.0 is 3D printing. The component CAD data can be downloaded from the Internet, the information is sent to a printing machine and the fabricated part is picked up a short while later. Process monitoring and system sensors, as well as process control are essential in this process. Our activities in this business unit are explained in this report in detail.

Laser buildup welding with powder and wire has shown an ever-growing market potential, and the IWS has gained an internationally unique selling point with this technology. Activities and experience in this and other technologies and systems are being concentrated in the "Fraunhofer Center for Thermal Surface Technology".

In the field of energy efficiency, IWS colleagues were awarded with important prizes for PVD-coatings for low friction and wear, battery development and laser interference structuring of surfaces.

There are a number of industrial highlights to report, in which solutions developed by the IWS were implemented in series production. Selected examples of implementations are described in the annual report.

The appointment of Prof. Dr. Christoph Leyens as a member of the institute's management in 2016 was an outstanding event. We will head the institute together until my retirement.

The 25-year-long success story of the IWS continues: we are embarking upon new R&D topics based on our comprehensive expertise in materials know-how and process and systems technologies – learn more about them in this report.

We would like to thank all our project partners for trusting in us and for the excellent collaboration. We hope that you will find inspiration and new ideas in this annual report, and we are looking forward to supporting their implementation.

Prof. Dr.-Ing. E. Beyer   Prof. Dr.-Ing. C. Leyens

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THE FRAUNHOFER IWS

BUSINESS UNITS

CENTERS, NETWORKS, AWARDS

FROM THE BOARD OF TRUSTEES

The Board of Trustees consults and supports the institute’s management and the bodies of the Fraunhofer-Gesellschaft. The 26th Board of Trustees meeting occurred on March 18th, 2016 at the Fraunhofer IWS in Dresden. The Board of Trustees during the reporting period consisted of the following members:

2016 was a year characterized by major changes in politics and technology.

Changes occur at ever shorter intervals, and the knowledge is always increasing. We must stand our ground in this ever-changing world, which is only possible if we proactively shape the future. This applies to both business organizations and a research institutes. The changes, in turn, result in the growing demand of the economy for application-oriented research.

Series of alterations and trends can be reported also for the Fraunhofer-Institut für Werkstoff- und Strahltechnik IWS in 2016.

In addition to Professor Eckhard Beyer, director of the institute and long-time guarantee of success, Professor Christoph Leyens was appointed to join the institute's management, a strategic measure designed to set the course for the future.

There is remarkable progress in technical subjects to report.

The potential for laser application has not yet been exhausted, either in cutting of electrical steel, laser welding of mixed material joints or in surface structuring.

The importance of additive manufacturing is growing as a function of its level of technological maturity. Here, again the IWS has gained a unique position.

Strategic changes in German energy policy continue to advance. Electricity produced from renewable sources accounted for 32 percent of the German energy use in 2016. There is more and more pressure to develop energy storage devices because the amount of electricity that can be produced from renewable energy sources largely depends on volatile, natural processes – the duration and radiation of the sun or intensity of the wind.

The optimization of lithium-ion batteries is far from its limits, and the development of lithium-sulfur batteries is already in full swing. The IWS is contributing to the development of the lithium-sulfur technology, aiming at a cost reduction of below 100 Euro per kW h^{-1} while maintaining high cycle stability.

Carbon coatings have become an effective means of reducing friction and consequently wear, which makes this technology very interesting for industry.

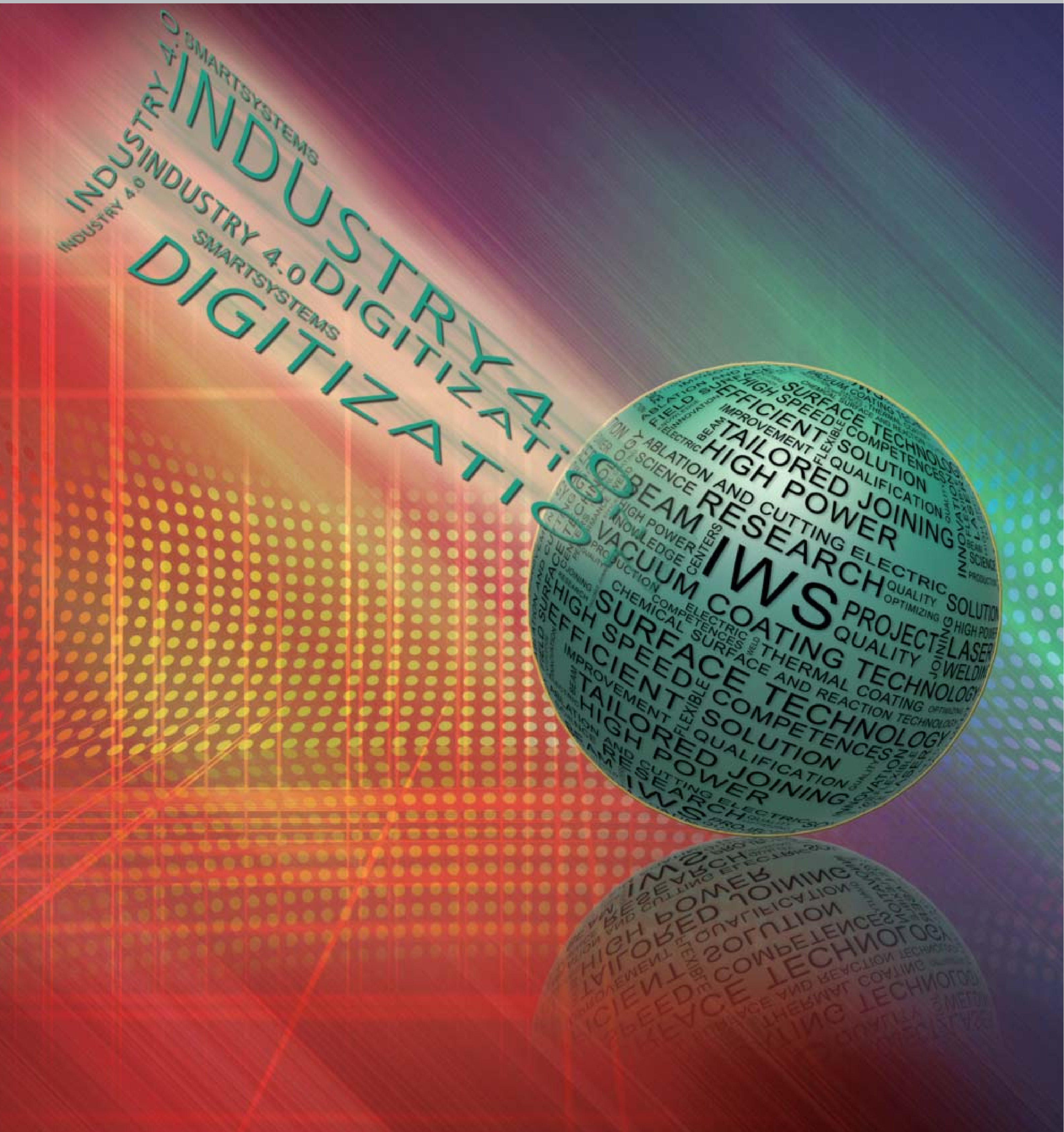
The researchers of the Fraunhofer-Institut für Werkstoff- und Strahltechnik IWS think creatively to advance their technologies to applications, so the financial success of the institute in 2016 is no surprise.

The Board of Trustees thanks the customers for their trust, and is grateful to the members of the institute's management and all partners for the collaboration, commitment, and the results they have achieved. We wish you ongoing success and health in the future.

Yours

Dr. Reinhold Achatz

CORE COMPETENCES



"It is always striking when one speaks of things one understands."

Helmut Käutner

Our research projects are primarily driven by the implementation of current research results into industrial practice. For this reason, we have developed and continue to extend our expertise in the following fields:

LASER MATERIALS PROCESSING

Our laser materials processing knowledge includes understanding of integrated value added chains, from analyzing the component stresses, material considering loads, and component-related process development, up to implementation in industry. The material and component characteristics are our top priority, because they are the basis for the process and system parameters, which ultimately determine the system design. Process monitoring and control round out the portfolio.

SURFACE FUNCTIONALIZATION AND COATINGS

One key task is to improve surface functionality. At the IWS, a wide range of functionalization and coating techniques is available to produce coatings from only a few nanometers to several millimeters using various materials and material combinations. In many cases, the system hardware – such as plasma sources – has to be refined for optimal component processing or coating.

SPECIAL JOINING TECHNIQUES

Joining is a demanding technique to be run in production and incurs significant costs. Current joining developments can essentially contribute to improvements and ideas. With a sound understanding of materials, the IWS has collected experience and knowledge in the fields of electromagnetic pulse joining and 3D friction stir welding, as well as adhesive bonding by laser and plasma pre-treatment and thermal direct joining of thermoplastic composites.

SYSTEMS TECHNOLOGY

Sensors for process monitoring and information processing in networks are necessary to ensure and document process quality. The systems layout has to be modified in many cases. Due to considerable industrial implementations, the IWS has gained detailed knowledge of systems technology and contributed the procedural know-how to the development, design and manufacturing of components, devices and the respective software suitable for industry.

PROCESS SIMULATION AND ANALYSIS

Our simulation expertise involves the development of simulation modules for thermal surface technologies, additive manufacturing, cutting, welding and vacuum arc coating. It also involves the calculation of the optical properties of nanolayer systems. Commercial simulation modules are used to optimize the gas and plasma flow in coating processes and processing of materials by laser.

MATERIALS SCIENCE AND NANOTECHNOLOGY

The IWS has developed comprehensive expertise in the analysis of surfaces, surface-treated and coated, welded, cut and micro- or nanostructured materials and components. This know-how offers the base for the development of specific materials and components. The technologies involve quality assurance, as well as design for materials, manufacturing and calculated stresses and loads.

DEVELOPMENT PROSPECTS

Knowledge of the customer's requirements, long-term research and maintaining a competitive innovation potential are necessary preconditions for the sustainable success of the IWS. The strategy audits are essential milestones in the IWS' continuous improvement process. In these audits, which are performed regularly, the goals of research, the budget and the technical-scientific development aims are assessed by notable representatives from industry and science. These experts attested to the clarity of the IWS strategy and its outstanding development prospects in 2016 as well.

DIGITAL MATERIALS SCIENCE

In almost every field explored at the IWS, in-depth knowledge of materials science in conjunction with process and production engineering know-how is a key factor in solving complex problems. Consequently, increasing digitalization of production technology must be followed by its "digital twin" in materials science. Thus, in the sense of a closed digital loop, it is easier to connect the "material world" with the "production world". Digital materials science also reduces development time for new materials and enhances both material and component properties.

Digital materials science is gradually implemented, since the task is complex and the human resources and research services have still to be provided. Currently, the methods belonging to Integrated Computational Materials Engineering (ICME) are being applied to specific production technologies with which the IWS is familiar, primarily in additive manufacturing. Methods for Integrated Computational Materials and Process Engineering (ICMPE) are engineered in a subsequent step.

DIGITAL LASER MATERIALS PROCESSING

The integrated digitalization of procedures for laser materials processing provides substantial customer benefit in industrial use. Based on the comprehensive systems technology experience of the IWS, cyber-physical systems for laser materials processing were developed with new hardware and software systems. Depending on the case of application, these systems assist the machine operator in performing complex manufacturing tasks, effect an increase in product quality and enhance the reproducibility of results with constant or continually changing production runs.

The platform strategy is crucial for the refinement of the IWS systems technology towards all-digitized systems. Specific hardening, cutting, joining, coating and additive manufacturing solutions have been emphasized and launched on the market step by step.

MACHINE LEARNING

Machine learning, this is the technical system's ability to learn from experience as humans do, is an essential building block for Industry 4.0. Machine learning, as a rule, relies on information in the form of data being captured online and connected with other data that are available offline and have already been analyzed. Machine learning methods applied to surface, coating and laser materials processing are being explored at the IWS. With each new or repeated process, additional information ("experience") is collected. The information must be linked to create an integrated digital data flow among material, systems technology, process and component. As a result, huge, complex and ever-changing data volumes have to be processed.

Expert systems for intelligent systems for laser materials processing were engineered linking the results from the fields of digital materials science and digital laser materials processing. The methods used can also be transferred to the central fields of surface and coating technology.

CENTERS AS STRATEGIC SUCCESS FACTORS

The establishment of centers focusses IWS' experience on the key topics of research (see pages 138 - 149), thus using in-house synergies and enhancing outside perceptions. In 2016, the **"Center for Thermal Surface Technology"** was added to the IWS centers as intersection of various business units aiming at **energy efficiency**, **battery research**, **tailored joining**, **additive manufacturing**, as well as **materials analysis and testing**.

The IWS **"Center for Thermal Surface Technology"** has a wide technical scope and is unequalled in innovations within the Fraunhofer-Gesellschaft itself and throughout Europe. Its experts explore new layer systems, their production technologies and functionalization of surfaces. They combine several techniques into new processes, providing even better coating properties at lower cost. These surfaces are also analyzed in terms of the user requirements.

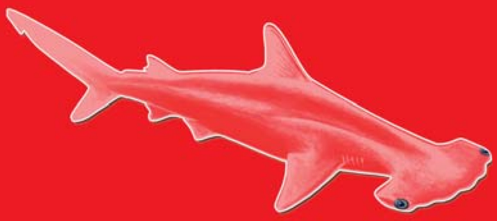
The shareholding company Thyssen-Krupp Steel AG (TKS) concentrates its surface technology research capacities and knowledge at the **"Dortmunder OberflächenCentrum DOC®"** (Surface Technology Center in Dortmund, Germany), where the Fraunhofer-Gesellschaft also has a presence.

The **"Application Center for Optical Metrology and Surface Technologies (AZOM)"**, located at the campus of the University of Applied Sciences (WHZ), links the activities of the Fraunhofer IWS in Dresden with those of West Saxon companies.

The **"Fraunhofer Project Center for Laser Integrated Manufacturing"** was established at the Wrocław University of Technology. In partnership with the IWS, it extends the existing network of cooperation to Eastern Europe and pioneers the collaboration of scientists from Germany and Poland.

The Fraunhofer IWS also collaborates with two autonomously operating research facilities in the USA, the **"Center for Coatings and Diamond Technologies CCD"** and the **"Center for Laser Applications CLA"**. The projects executed in these centers are representative of the IWS' main activities in laser and coating technologies on the US and Northern American market.

HIGHLIGHTS 2016



1

LASER-ARC TECHNOLOGY FOR SERIES PRODUCTION

Super hard ta-C coatings (Diamor®) are suitable for many industrial applications due to their excellent wear resistance and their potential to significantly reduce losses due to friction. The Laser-Arc technology developed at the IWS is unique in productivity and reproducibility.

With the VTD Vakuumtechnik Dresden GmbH in the Federal-Mogul Powertrain group, the IWS built three Laser-Arc modules for coating components and implemented them into series production (Fig. 1).

Scaling up the technology enables to increase the system's productivity and to reduce the coating costs. Consequently, the IWS designed a Twin-Laser-Arc module, in which two modules work simultaneously on one receiver. After successful qualification, the Twin-Laser-Arc module was delivered to the customer in partnership with the VTD Vakuumtechnik Dresden GmbH.

DIGITIZING HISTORICAL PRINTS

Restoring and conserving historical prints from the 16th – 18th centuries, which are often decorated with paint and gold leaf, is extremely complicated. Material data that can be obtained in non-contact manner using hyperspectral imaging are used for conservation purposes. The IWS designed a portal mechanism on behalf of the Polytec GmbH company, by means of which the highly sensitive prints were digitized spectrally using HSI; the setup was implemented at the Bavarian State Library.

HIGH SPEED MATERIAL ANALYSIS

The IWS, together with its partner, the Rubotherm GmbH, is using optical calorimetry in a new product line (InfraSORP) to assess the performance potential of porous materials. With this measuring method, the relevant parameters of porous materials can be ascertained within 5 minutes. Previously established methods analyzed up to 3 samples per day. The Rubotherm GmbH and the IWS installed together an optimized optical calorimeter at the Defence Science and Technology Laboratory (DSTL) in Great Britain (UK). The system investigates porous materials in terms of their absorbability for hazardous substances and also provides quality control in the process (Fig. 2).

FURTHER INDUSTRIAL IMPLEMENTATIONS OF THE REMOTE TECHNOLOGY FOR THE CUTTING OF AIRBAG

A system for flexible laser cutting of airbag materials, created by the Fraunhofer IWS and the company Held Systems, was delivered to industry customers in 2016. The Fraunhofer IWS was responsible for improving and controlling the software modules. The systems can be used for highly flexible laser remote cutting of single and multilayer fabrics.

LAYER ANALYSIS BASED ON SOUND WAVES – LAWAVE 2G

The IWS-developed device, which measures Young's modulus, hardness, layer thickness and the depth of manufactured or interference layers, was completely upgraded in 2016. The newly designed hardware is now available as a compact table-top unit. The software was upgraded with a new model able to analyze a maximum of five layers (see pages 104/105).

2


3


4

5

100 PERCENT CONTROL FOR VIAL TIGHTNESS IN THE PRODUCTION OF PHARMACEUTICALS

Pharmaceutical products must be hermetically sealed to keep the contents germ-free. For hermetic sealing of high value freeze-dried products, the IWS designed a "Head-Space Analyzer" for contact-free control of pharmaceutical vials. The pharmaceutical products are subjected to the sealing test after having been filled under vacuum. Potential leakage can be detected by spectroscopic measurement of the oxygen concentration. A high velocity O_2 laser diode spectrometer was designed to accommodate an enormous throughput of up to 600 vials min^{-1} for 100 percent control at a predefined rate of accuracy. The spectrometer was introduced into the pharmaceutical production by the IWS, together with its industry partner, Seidenader Maschinenbau GmbH (Fig. 4).

ADVANCED LASER WELDING PROCESS FINDS ITS WAY INTO TURBO CHARGER MANUFACTURING

An existing system for laser beam welding of dissipation lattices for turbochargers was redesigned for higher process and energy efficiency and welding seam quality for the compressor manufacturer Kompressorenbau Bannewitz. A 2D device for optical beam scanning and a camera, which positions the laser beam at the joint, were integrated into the system. The energy input during the welding process of crack-prone mixed material joints is significantly reduced by integrating specific control and image processing software. Furthermore it is now possible to do without the previously necessary filler material. The Fraunhofer IWS is responsible for process design and software engineering, as well as the installation of the individual components on the customer's premises.

COAXIAL LASER WIRE BUILDUP WELDING IN ENERGY PRODUCTION AND AIRCRAFT ENGINE TECHNOLOGY

COAXwire, the optical device for laser wire buildup welding developed at the IWS, is increasingly requested by the industry. Five of these systems were installed on CNC machines and robots in 2016 (Fig. 5). Companies and research facilities in Turkey, the USA, India and Finland work with laser heads for buildup welding in all directions, with coaxial wire supply, among them GE with 2 locations, and GKN. The IWS and the Fraunhofer CLA in Plymouth, MI, USA, developed and supplied system components, process modules and supported system commissioning up to the start of production.

TRANSMISSION MEASUREMENT DEVICES ARE REQUESTED WORLDWIDE

The transmission measurement system HiBarSens, developed together with the company Sempa Systems GmbH, which can quantify even the slightest water vapor transmission in barrier materials, is now available for a temperature range from 50 °C to 85 °C. Higher temperatures conform to the requirements of standard tests for organic electronics and also significantly reduce the measurement time, resulting in a substantially higher sample throughput and respectively lower measuring costs. Continuous system refinement and the establishment of HiBarSens device family have ensured a worldwide reputation, so the HiBarSens devices have been implemented in the USA, Germany, Italy, Korea and Taiwan.

COMPONENT MANUFACTURING WITH FINISHED PART QUALITY

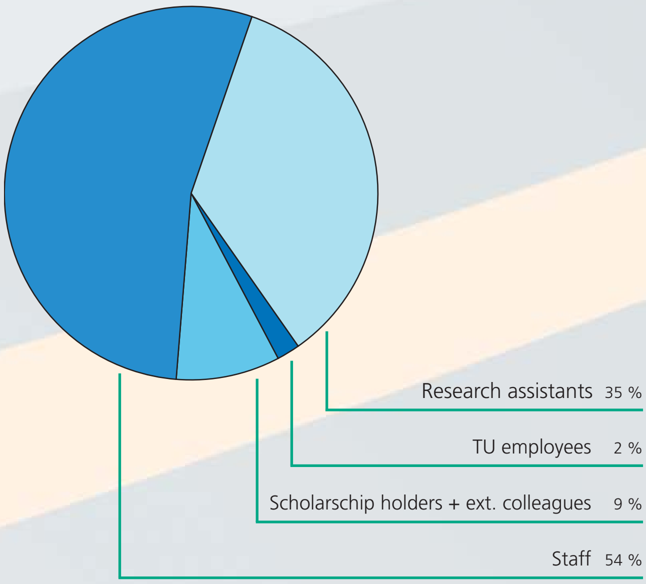
The latest IWS powder nozzle generation COAX14V5 for laser buildup welding and additive manufacturing was implemented at the SAUER Lasertec Company. The powder is better focused in the new nozzle, media supply is embedded, and the nozzle is more user-friendly (Fig. 3).

INSTITUTE DATA

IWS AND GERMAN BRANCHES

EMPLOYEES

	Number
Staff	**231**
- Scientists / Engineers (TU, FH)	158
- Skilled workers with technical or mercantile education	64
- Trainees	9
TU Dresden Employees (working at the IWS)	**37**
Scholarship holders and external colleagues	**7**
Research assistants	**152**
TOTAL	**427**



"Impossible is not a fact. It's an opinion."

Muhamed Ali

HEAD OF ADMINISTRATION

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IWS PUBLICATIONS

	Number
Dissertations	**17**
Diploma theses	**33**
Master's theses	**8**
Journal papers	**149**
TOTAL	**207**
PATENTS (first filing)	**17**

A list of all scientific IWS publications of 2016 can be downloaded from the bibliography database "Fraunhofer-Publica" at:

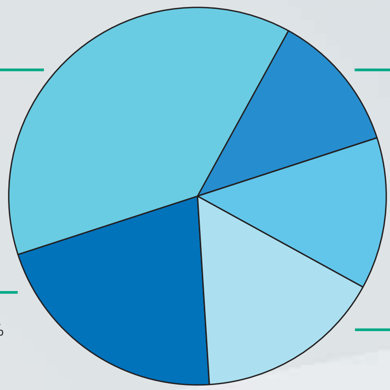
http://publica.fraunhofer.de/institute/iws/2016

Status January 2017

Revenues IWS and German branches 2016 (million €)	Operation	Investments	Total
Project revenues from industry	12.0	0.1	12.1
Project revenues from federal, state and European sources	8.2	0.4	8.6
Base funding and Fraunhofer internal programs	7.6	1.6	9.2
Special investments from federal, state and European sources	0.2	0.9	1.1
	28.0	**3.0**	**31.0**

Fraunhofer Industry ρ_{Ind} = 42.7 %

ORIGIN OF PUBLIC REVENUES, STATE AND EUROPEAN SOURCES



Federal Ministry of Education and Research 38 %

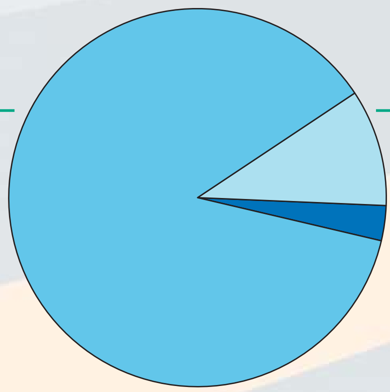
Federal Ministry for Economic Affairs and Energy 21 %

State Saxony 12 %

EU 13 %

Other 16 %

GEOGRAPHICAL ORIGIN OF INDUSTRIAL REVENUES



Germany 87 %

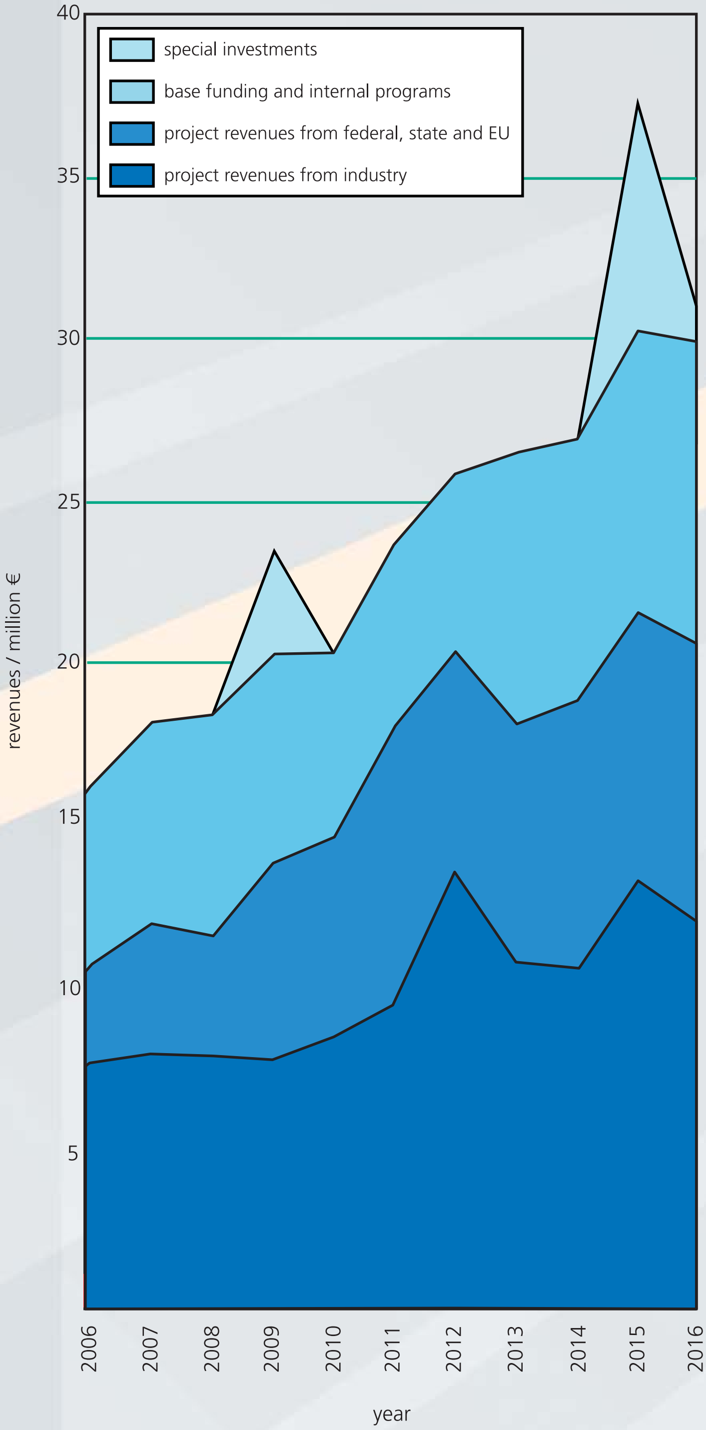
Europe 10 %

Asia 3 %

Status January 2017

Expenditures 2016 (million €)	
Personnel costs	14.9
Material costs	13.1
Investments	2.1
Special investments from federal, state and European sources	0.9
	31.0

Laboratory space	6800 m^2
Office space	3200 m^2



ORGANIZATION AND CONTACTS

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- **Coating Technology** – DI G. Englberger, ext.: 3562
- **Coating Properties** – DI S. Makowski, ext.: 3192
- **Nano Coatings** – Dr. S. Braun, ext.: 3432
- **EUV and X-ray Optics** – DP P. Gawlitza, ext.: 3431
- **Energy Storage Coatings** – DI G. Dietrich, ext.: 3287

Chemical Surface and Reaction Technology

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ext.: 3242

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- **Laser Cladding** – Prof. Dr. S. Nowotny, ext.: 3241
- **Heat Treatment and Plating** – Dr. S. Bonß, ext.: 3201
- **Heat Treatment Systems** – DI J. Hannweber, ext.: 3360
- **Mechanical and Thermal Processes** – DP M. Seifert, ext.: 3204

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ext.: 3242

- **Additive Manufacturing** – Prof. Dr. F. Brückner, ext.: 3452
- **Image Processing a. Data Management** – Prof. Dr. K. Kozak, ext.: 3717
- **Printing** – Dr. A. Roch, ext.: 3415

*"Coming together is a beginning,
keeping together is progress,
working together is success."*

Henry Ford

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- **Process Design and Analysis** – Dr. A. Mahrle, ext.: 3407
- **High Speed Laser Processing** – Dr. J. Hauptmann, ext.: 3236
- **Laser Cutting of Non-Metals** – Dr. J. Hauptmann, ext.: 3236
- **Laser Systems Engineering** – DI P. Rauscher, ext.: 3012

Joining

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ext.: 3212

- **Bonding and Composite Technology** – DI A. Klotzbach, ext.: 3235
- **Special Joining Technologies** – Dr. S. Schulze, ext.: 3565
- **Laser Beam Joining** – Dr. A. Jahn, ext.: 3237
- **Laser Beam Welding** – Dr. D. Dittrich, ext.: 3228
- **Component Design** – Dr. A. Jahn, ext.: 3237

Microtechnology

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ext.: 3252

- **Micro Materials Processing** – DI V. Franke, ext.: 3254
- **Micro- and Biosystems Engineering** – Dr. F. Sonntag, ext.: 3259
- **Surface Functionalization** – Prof. Dr. A. Lasagni, ext.: 3007

IWS Centers

- **Center Thermal Surface Technology** – Prof. Dr. C. Leyens, ext.: 3242
- **Center Battery Research** – Dr. H. Althues, ext.: 3476
- **Center Tailored Joining** – Dr. J. Standfuß, ext.: 3212
- **Center Energy Efficiency** – Prof. Dr. E. Beyer, ext.: 3420
- **Center Additive Manufacturing** – Prof. Dr. F. Brückner, ext.: 3452

Competence Field Materials Characterization and Testing

Prof. Dr. M. Zimmermann
ext.: 3573

- **Materials and Failure Analysis** – Dr. J. Kaspar, ext.: 3216
- **Materials and Component Reliability** – Prof. Dr. M. Zimmermann, ext.: 3573

Status January 2017

ADDITIVE MANUFACTURING AND PRINTING

Editor: Prof. Leyens, the development of additively manufactured products has really accelerated in recent years. What are the contributions of the IWS in this field?

Prof. Leyens: Additive manufacturing, a flexible manufacturing process, is becoming more popular in industry, because effective products were launched that demonstrate the huge technical and economic potential of this innovative technology on the market. The IWS, following a multi-process and multi-material R&D approach, has provided essential contributions across the whole process chain. This helps newcomers to enter into additive manufacturing and experienced customers to find promising approaches for further development.

Editor: What part does the process chain play in additive manufacturing?

Prof. Leyens: The additive manufacturing process itself is only a part of a longer process chain with preceding and subsequent steps. Additive manufacturing is not fundamentally different from other manufacturing techniques in this respect, but rather in the details of the individual steps. The CAD data record for layer-by-layer material buildup must be conditioned first. If necessary, support structures for complex components must be added and later removed. After the buildup process, the manufactured part frequently must be heat treated and finished to meet high accuracy or surface quality requirements. Consequently, the IWS considers not only the buildup process itself, but the entire process chain – this is the only way to get a product with defined properties.

"In science, the credit goes to the man who convinces the world, not to the man to whom the idea first occurred."
Sir Francis Darwin

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Editor: Stories about 3D printing appear frequently in the press. What are the IWS's activities in the field of printing?

Prof. Leyens: The term 3D printing is commonly used as synonym for additive manufacturing in general, although 3D printing, narrowly defined, represents only one specific process. In the field of printing, the IWS is developing innovative solutions to manufacture planar or three-dimensional structures and functional elements. Dispenser printing with pastes, aerosol printing, and fused deposition modeling are available technologies. Printing technologies can integrate functional elements into structures – printed electronics, thermoelectric elements, sensors – that generate entirely new functionalities in the component. The IWS is not only experienced in the manufacturing processes, but also in the development of printing materials, such as inks and pastes.

Editor: Data management is a new focus for the IWS's research. What is being emphasized in this field?

Prof. Leyens: Processing of huge data volumes – Big Data –, both in real time or "offline", is of ever increasing importance for process control and quality assurance. We are currently working on a so-called process data viewer, software that helps to detect process irregularities. With this software, we are delivering exactly what many customers need, since troubleshooting in a huge data pool is currently time-consuming manual labor. In the future, this can be done by the computer much faster and more reliably. The algorithms for automated diagnostics still need to be developed.

COMPETENCES AND CONTACTS

Dr. Aljoscha Roch, group manager printing
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»New, integrated 2D and 3D printing solutions are realized by combining printing technologies.To offer one stop solutions, the group develops materials, printing processes and post-treatment processes such as sintering methods. A focus is on functional printing, which integrates and expands the functionalities of the printed product beyond just creating its shape. It is, for example, possible to integrate electrical conduction paths into 3D bodies during the printing process. One area of research addresses the printing of thermoelectric materials in form of pasts and inks. This enables the industrial use of printing technology to produce thermoelectric generators. The goal is to create flexible thermoelectric generators for use in sensorics, such as "Structural Health Monitoring" and other low power applications in the mW to W power range.«

Prof. Dr. Karol Kozak, group manager image processing and data management
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»"Big Data" means amounts of data (image or alphanumerical data), which are too huge or complex or which may quickly change, so that they cannot be analyzed with common data processing methods. Classic visual image processing software, relational databases as well as statistics and visualization software are often incapable to process such large amounts of data. Thus Big Data handling requires new platforms, data storage and machine learning methods which can run in parallel on up to hundreds or thousands of processors or servers. Companies hope that the analysis of Big Data will open possibilities to obtain competitive advantages, to find cost savings and to create new business fields.«

Prof. Dr. Frank Brückner, group manager additive manufacturing
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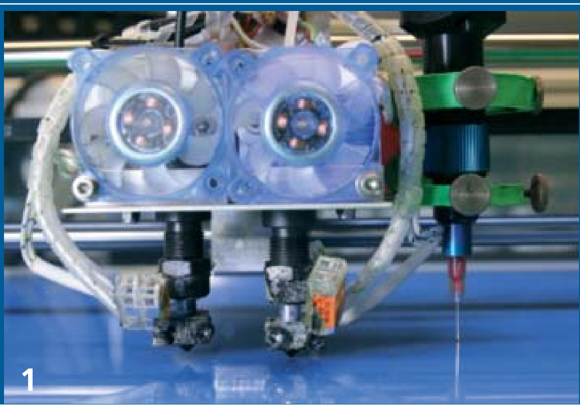
»The group Additive Manufacturing develops generative fabrication technologies for the flexible and efficient fabrication of individualized products which are based on functional components and structures made from modern metallic and nonmetallic construction materials. The processes serve for repair tasks as well as the creation of new parts, which often have to meet complex performance criteria. The unique selling point is a fabrication approach that spans broad ranges of scale and materials. Thus customers from a diverse portfolio of industry branches can benefit from tailored solutions.«

2016 PROJECT EXAMPLES



1

3D PRINTING OF POLYMERS WITH INTEGRATED ELECTRONICS AND SENSORS

THE TASK

Additive manufacturing provides a freedom of design and styling like nothing before. Component geometry can be modified for function, which was impossible before in terms of material use and efficiency. A wider variety of materials and technologies adds value to parts made by additive manufacturing. The additional integration of functionalities, such as integrated sensors or printed electronic components, can expand the functional range and add value to the components.

Many electronic functionalities can be manufactured using printing technologies. These include, for instance, sensors in the form of RFID antennae or other sensors for strain, temperature or pressure measurement. Printed sensors for chemical-physical analysis, detection of humidity, radiation or special chemical components are the state of the art.

Combining techniques from classical additive manufacturing with printing technologies, such as dispenser printing or aerosol printing, is a popular and economical way to produce complex multifunctional components in one step.

OUR SOLUTION

The combination of fused filament fabrication (FFF) and dispenser-printing (see information box) makes it possible to equip the components as they are being processed with additional functions during structure building. Mainly thermoplastic structural materials are FFF-printed, whereas the electronic materials can be dispenser-printed. To implement the combination of techniques, an open source FFF printer was equipped with an additional dispenser printing head. Because of the layer-by-layer part building in additive manufacturing with the FFF printer, functional pastes can be applied in each component plane.

The dispenser-printed structures can be quickly and efficiently dried and sintered by means of the plasma technique at atmospheric pressure or with radiant heaters. Functions can be added by dispenser printing on the surface of components made by the FFF technique, on the one hand. On the other hand, the structures can also be completely integrated in the component. This technology can also be combined with other additive manufacturing techniques.

Conductors printed on uneven FFF surface

2

3

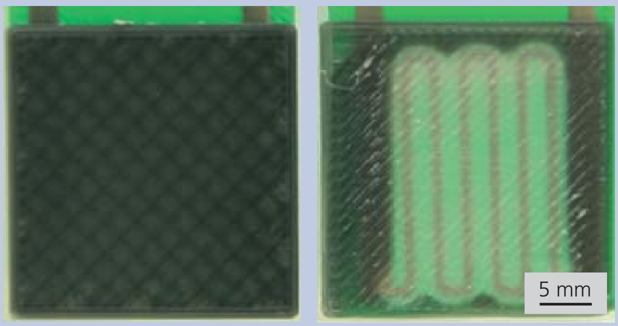
RESULTS

To demonstrate the combination of these techniques, heating structures made of silver paste were integrated into an FFF-printed ABS component by dispenser printing. These heating structures can be used to heat near-surface regions in various systems. Figure 4 shows the working principle with a thermochromatic filament that is black at room temperature and white to transparent at temperatures above 40 °C.

Printed conductors can also be directly applied to sculptured or uneven component surfaces (Fig. 2) to implement near-surface functions in components.

Even more complex functionalities, such as interdigital electrodes for chemical measurements, can be placed at a desired point on a component. Figure 3 shows an interdigital electrode configuration used in Li-ion cells. The electrodes are made of lithium iron phosphate and lithium titanate.

FFF component with integrated heating elements



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The Fraunhofer IWS has developed pastes for the specific electronic functionalities and integrated them into additively manufactured components as well.

Infobox: Fused Filament Fabrication (FFF) and dispenser printing

Fused Filament Fabrication (FFF)

A fused plastic filament is printed layer by layer to build up the structure in 3 dimensions. Filaments are typically thermoplastics, but can also be made as composites, filled with metallic particles, natural fibers, glass fibers, etc.

Dispenser printing

A viscous paste or ink is printed. The paste is dispensed as a line in an x,y,z axis motion with a needle dispenser or drop by drop (jet dispenser) to the desired point. The paste ingredients are metals, ceramics, plastics or nanoparticles.

1 FFF printer with integrated dispenser unit

3 Printed interdigital electrode for Li batteries (dispenser printing)

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1

PROCESS MONITORING FOR ADDITIVE MANUFACTURING PROCESSES

THE TASK

Minor deviations in a technological parameter significantly affect the additive manufacturing process result. Not only key parameters, such as laser power or buildup strategy, are varied; the users also aim to monitor the manufacturing process as a whole. The task is to offer new tools able to predict the resultant component quality in-situ.

Buildup defects are cumulative and continuing due to the process-specific layered structure, whereas the boundary conditions are ever-changing. These variations must be reliably detected and controlled. In additive manufacturing with difficult-to-use materials, such as titanium aluminides or nickel-based super alloys, the range of adjustable process parameters is extremely narrow, so that the process can only be performed reliably by using suitable process control systems.

Laser-based additive manufacturing faces special requirements; for many process parameters, adequate data acquisition must be adapted for these conditions or newly developed altogether. Measurement of the thermal load and scattered radiation in the vicinity of the processing zone is extremely challenging.

OUR SOLUTION

Many measuring tasks can be performed by temperature acquisition systems. Camera-based systems can record temperature gradients on the component surface, as well as geometric process parameters, rather than only temperature and are thus superior to measurements by pyrometer or temperature sensors. These systems are also convenient because they measure indirectly, making process feedback unnecessary.

Functions to record states are provided by integrated sensor elements (see Fig. 3). Detailed monitoring makes the equipment more reliable, assesses the state of the equipment, and enables quality assurance. The objective is to detect a faulty process state without having directly affected it.

RESULTS

Using cameras in conjunction with powerful image processing systems to record, process variables can be captured by means of customized software tools (Fig. 1). The controlling functions for higher process reliability are based on feedback to the process.

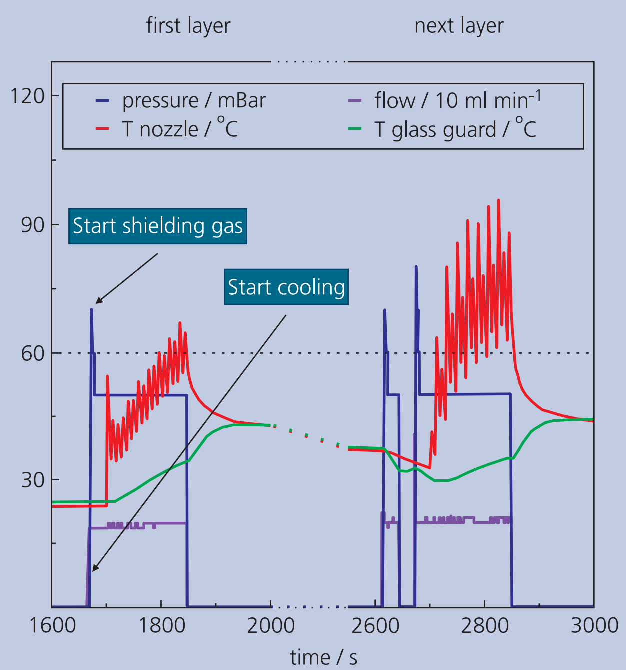
2

An image processing system based on data acquired by a camera can make induction-based laser powder buildup welding significantly more reliable. The systems developed at the Fraunhofer IWS measure and control component temperature and geometry features as well. The part temperature necessary for defect-free manufacturing is adjusted by automated adaptation of the inductively-coupled power. Thanks to the image processing system, even crack-prone alloys can be processed. The measured values are immediately fed back to the additive manufacturing system and adjusted. Stable process conditions and thus uniform manufacturing results are achieved even if environmental conditions change (Fig. 2).

The information gained from the process zone is extended by the data about the state of the laser head for purposes of documentation and saved in a standardized data format. The equipment state is monitored in-situ in parallel to parameter control in the process. Adequate setting of the process limits makes it possible to recognize critical states and switch off the systems in time to avoid damage.

Finally, these measuring devices also validate the process models developed at the Fraunhofer IWS and enhance the process knowledge.

Monitoring of state variables in the laser powder buildup welding process



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1 *Geometry of a turbine blade made of titanium aluminides in comparison; left – built up without and right – built up with process control*

2 *Image processing tool to control laser powder buildup welding (hybrid process)*

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BUSINESS UNIT
ADDITIVE MANUFACTURING AND PRINTING

1

INTEGRATING FUNCTIONALITIES USING 3D PRINTING: NATURE AS A MODEL

THE TASK

Nature provides ingenious solutions for many shapes and geometries with an almost perfect balance of strength, light-weight construction, and functionality. These structures optimized by nature inspired Leonardo da Vinci to translate them into engineering and to draft and design wings for flying machines.

Nature frequently uses recurring elements, such as networks of veins or the cellular structure at the core of bones, which in detail are distinct in terms of shape and size. Elements that are so rich in detail and geometrically indefinite, pose enormous challenges for technical design and manufacturing.

The variety of shapes found in nature and in existing components can be produced by means of advanced additive manufacturing techniques and optical reverse engineering tools. This not only lends freedom in design, but also allows for the integration of functions, such as hinged joints, and for changes in size by scaling.

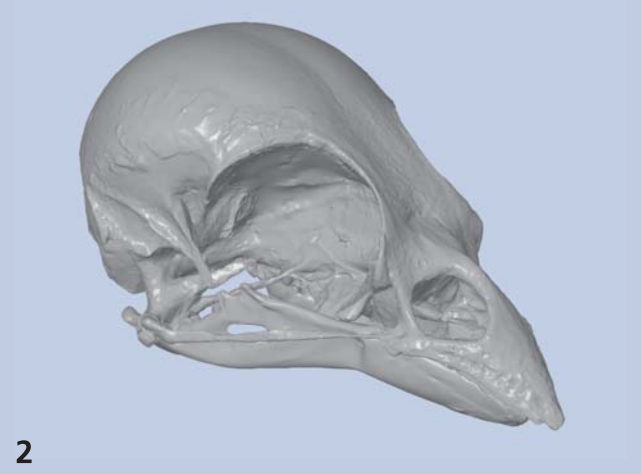
OUR SOLUTION

For additive manufacturing, the Fraunhofer IWS Dresden utilizes powder bed or nozzle based techniques to directly replicate natural and technical objects flexibly and without tools. The IWS is also equipped with various instruments for reverse engineering, used to digitally reconstruct objects through the generation of geometric data. Laser buildup welding with powder or wire, and laser and electron beam melting, can be used for additive manufacturing. Design engineering can be simplified and sped up by reverse engineering thanks to the optical measurement systems for 3D scanning.

An object consisting of several components is to be buildup in one build job with minimal post-processing, i. e. without additional joining operations for hinges or spring elements.

The Fraunhofer IWS creates solutions to implement the process tailored to object size and complexity, considering all of the steps of the process holistically: geometry data acquisition, analysis of technology and strategy, CAD-/CAM manufacturing, process monitoring and control, post-processing and component inspection or analysis, etc.

3D scan of a bird skull, data base for additive manufacturing



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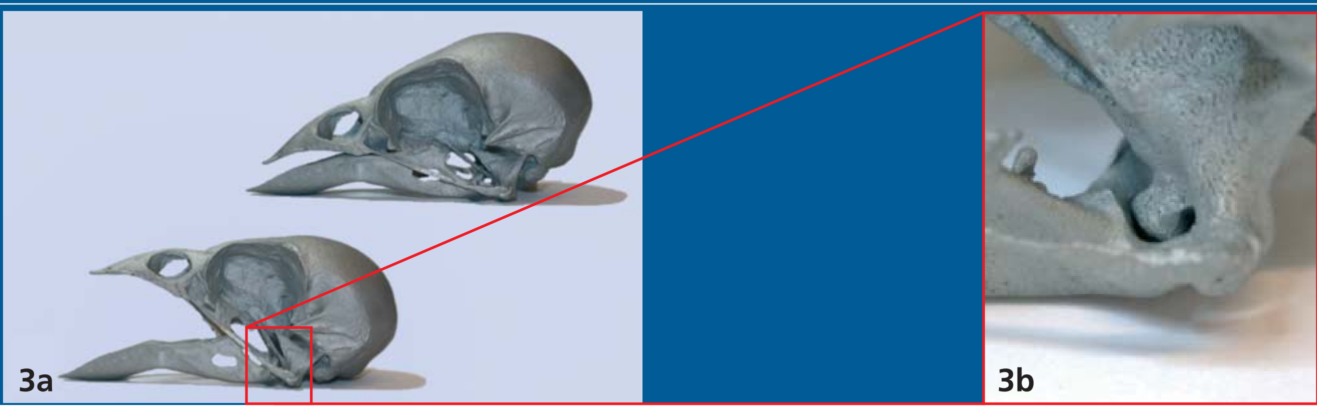


RESULTS

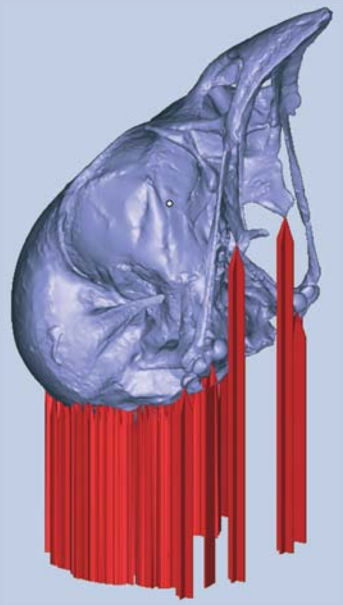
The process chain for the integration of functional elements by 3D printing is demonstrated for the replication of a common swift's cranial bone (Fig. 1). The original skull has cavities – eye sockets and the brain cavity –, as well as two hinges between the skull and the beak.

The replica, or the metal common swift, was laser melted in 1:1 and 4:1 scale. The building strategy was derived from the polygon-based 3D scan of the original skull (Fig. 2). The building direction and required support structure are illustrated in Figure 4.

Mobility of the beak hinge is shown in Figure 3. The hinge consists of an articulated cavity and head. These interlinked elements were built in one print cycle. As in the original, they make it possible to open and close the beak.

The replication of natural structures and functional elements by making use of technical materials can extend component design with many approaches optimized by nature. This also opens up potential applications in the field of rail transport and the aerospace sector, where highly stable, low weight components are needed.

Data conditioning for laser beam melting, positioning and building direction



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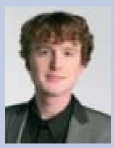
1 Original and replica of a bird skull

3a Functional integration, moveable beak

3b Detailed image of the printed hinge

CONTACT



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PROCESS DATA VIEWER FOR VISUALIZATION OF COMPLEX DATA

THE TASK

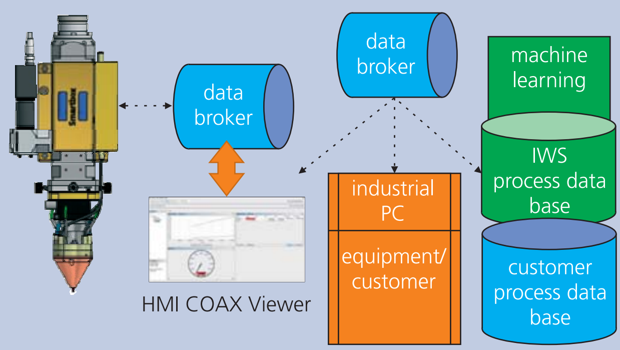
The Data Management Excellence Center is collaborating at the IWS with the TU Dresden and the University Hospital Dresden in the development of interactive visualization systems and methods to process huge data volumes. Research is focused on sensor data, digital image data, process parameters and patient data. Research and development issues include sensors, statistics, automated pattern recognition, image acquisition via image processing, modeling and visualization, design of user interfaces and application.

Data management and confidential data handling are also important for laser processes. The management of the process data, such as process parameters, takes final users up to one quarter of their time. The system sensors generate data of various types, of which it can be difficult to keep track. The digital revolution has also found its way into production equipment. Processes, products, resources and production facilities, and employees are linked by cyber systems and communicate via Internet. The term "big data" describes the handling of data structures whose volume, diversity and complexity demands for new data processing and analysis methods to extract hidden significance. This experience, in turn, is introduced into processes enabling "machine learning". Such big data solutions are being tested in laboratory operations at the Fraunhofer IWS Dresden.

OUR SOLUTION

The power and pressure values, position data, images, video data and bus signals that are collected in laser processes, need to be analyzed. Reasonable compression of process data and representation simplifies interpretation and decision-making. Automated analysis of process data is possible by means of interactive visualization. Correlations and patterns can be found rapidly and easily; process failures and exceeded limits are identified. Visualization techniques can be used for interactive data exploration. They provide a general overview of the collected data, the definition of limits and the detection of deviations from specifications even under real time conditions (Fig. 1).

Process data viewer function for laser processes at the IWS



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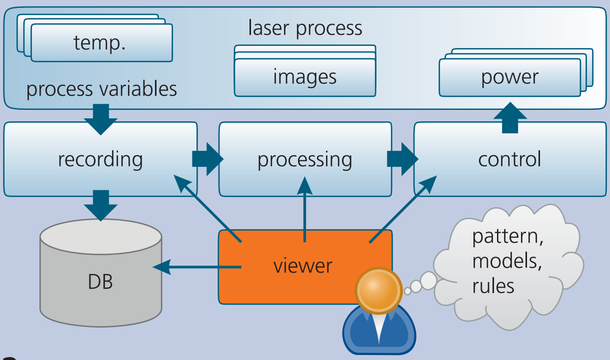
RESULTS

The process data viewer can identify useful correlations among the recorded data records of a finished process to analyze and control it. All parameters can be captured during manufacturing and used for tracking & tracing seamlessly. For laser welding, deposition or cutting, the essential parameters are melt pool and component temperature, laser power, process gas pressures, the distance from component to the optical processing unit, and the image of the processing zone.

Data workflow and data processing phases in the laser process. The process can be controlled and adjusted as a function of the state by means of process data monitoring.



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The user can view the process (Fig. 2) and is given the curves for pool temperature, laser power, and the process image as a function of time.

The Fraunhofer IWS Image Processing and Data Management group has the following competences:

- exploring Industry 4.0 technologies for process data
- data management and data analysis
- development of image databases and technologies
- image processing and interactive visualization of process data
- software engineering for data analysis and data modeling

The additional competence profiles of the collaboration partners include:

- professional software engineering and consulting:
  - object-oriented programming languages: J2EE, .NET, Python
  - professional project management: scrum agile model
  - IT & software architecture modeling
- data management and analysis:
  - development of technology and data standards to manage digital images and meta data
  - automated real-time data processing and management,
  - multi-parameter and statistical data analysis, visualization, management
  - visual analytics

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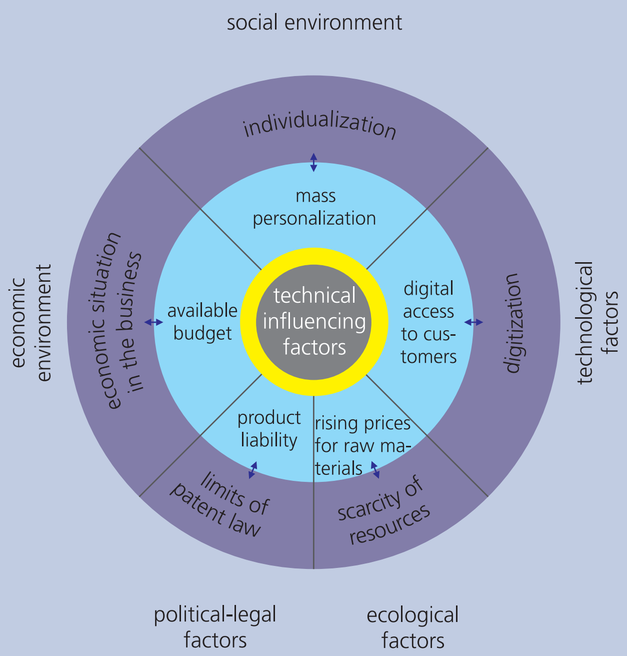
AGENT-3D – FRAMEWORK FOR ADDITIVE MANUFACTURING

THE TASK

The market for additive manufacturing techniques and additively manufactured products is rapidly growing, as well as the number of companies interested in new manufacturing technologies. The Fraunhofer IWS evaluated the additive manufacturing potential with more than 100 partners in the "AGENT-3D" project funded by the Federal Ministry of Education and Research (BMBF). Growth must be generated by pointing out the existing technological and economic limits and the ways how to bypass them.

Overall system to create future scenarios, subdivided into fields of exploration and outside factors



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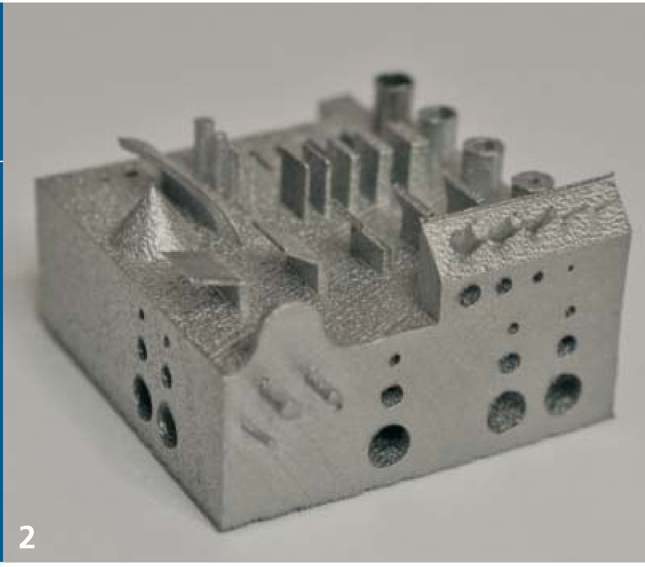
OUR SOLUTION

Twelve research institutes and more than 45 companies under the auspices of the Fraunhofer IWS Dresden launched the strategic alliance entitled "AGENT-3D – Die 3D-Revolution zur Produktherstellung im Digitalzeitalter (The 3D revolution for product manufacturing in the digital age)" in the innovation partnership "Zwanzig20 – Partnerschaft für Innovation" program funded by the BMBF. After successful completion of the strategic phase, 111 partners are now involved in the alliances's two basic projects and seven technology projects. The team, which represents various disciplines and in which 82 percent of participants come from industry, has established a powerful network open to large-scale industry, small- and medium-sized companies, and research institutes in Germany, and is further developing additive manufacturing to make it a key technology.

The sociopolitical, economic, managerial, technological, and legal framework was defined and options to influence it were presented in the basic project "Rahmenbedingungen für die Additive Fertigung (Framework for additive manufacturing)". This framework is based on detailed results obtained by analyzing external real-world factors in the strategic process. Basic findings from various disciplines will be introduced into the AGENT-3D technology projects. The following topics are explored in detail in the basic project:

- consequences of socio-economic factors for development opportunities for additive manufacturing
- copyright/patent rights, product liability, anti-trust regulations
- new design and construction methodologies
- process safety, materials, quality assurance
- interfaces and standardization



RESULTS

The socio-economic studies above all focus on future scenarios with potential development scenarios for additive manufacturing application and a changing organization of value adding systems. Relevant influencing factors for the use of additive manufacturing have to be anticipated (Fig. 1).

The system of the environmental system, subdivided into the fields of politics/law, economy, society, ecology and technology, surrounds the field under consideration and affects it through specific factors. The players in the field to be explored (such as companies or research institutions) have little or no influence on this. The relevant technical factors, such as material availability and productivity, have been identified in addition to the available capital/budget or rising prices for raw materials – non-technical factors that are specific to additive manufacturing.

The legal framework was qualified in a central information platform for legal issues to be contacted online via www.agent-3d.de dedicated to proprietary rights, product and data protection and liability in conjunction with additive manufacturing techniques. Current use cases can be discussed with experts via the platform to find solutions.

Opportunities and limitations of new design approaches in additive manufacturing were analyzed based on technology-specific design options.

Intricate geometric features, such as overhangs or lattice structures, were identified, shown in technology demonstrators (Fig. 2) and checked for quality. As a result, the geometric limitations of the manufacturing techniques can be evaluated.

Significant progress was achieved in quality assurance. Additive product manufacturing at low cost and with high quality demands that the quality standards for each step in the process chain be maintained. Specific parameters and error frequencies of various technologies are identified in the new additive manufacturing measurement and test center, capable of performing computer tomography, 2D X-ray radiography and ultrasonic testing. Quality assurance is enhanced by process modeling and analyses of consequences. The measurement and test center at the Fraunhofer IWS Dresden is a central contact point for testing and measurements in additive manufacturing in Germany.

“AGENT-3D“ is funded by the Federal Ministry of Education and Research (BMBF) in the program “Zwanzig20 – Partnerschaft für Innovation (Twenty20 - Partnership for innovation)“ (registered under the numbers FKZ 03ZZ0201 to FKZ 03ZZ0211).

2 Demonstrator manufactured by selective laser melting (SLM) with demanding geometries

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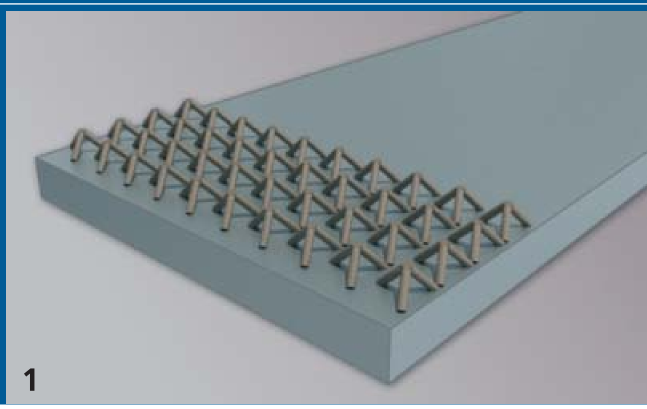

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MICRO-GENERATED CLAMPING STRUCTURES

THE TASK

Low weight and costs, as well as integrated functionalities, are major objectives for product optimization in many fields of research and development. Multi-material design is a global trend. Placing the right material in the right place means saving weight, e. g. by the use of lightweight plastics in component areas under less stress. Ceramic insulation layers in zones subject to high thermal load, where high strength is contributed by the metal components, permit an increase in the operational temperatures of turbo-jet engines.

Material combinations enable to integrate functions that would be impossible through metal design alone: daming of vibrations, thermal and electrical insulation, and protection against corrosion.

Changing over from a classical single-material to a multi-material design approach is challenging and requires, for instance, a joining process to join different materials permanently and robustly.

OUR SOLUTION

Both delicate and large components of several meters can be made on a multi-scale through additive manufacturing. For the change from plastics to metal or ceramics to metal, weld beads can be built up in several layers with a tailored profile to be interlocked with the plastic or ceramic. To reproducibly build delicate microstructures with varying cross sections in large quantities, all processes must be performed carefully with high accuracy using precise equipment.

Microstructures can be tailored for individual tasks, e. g. even with strong undercuts (Fig. 1). The latter yields a strong compound made of the metallic substrate and the join partner, which withstand heavy mechanical loads.

For profound adhesion of the melted plastic, as well as for fiber-reinforced plastic, the CAD / CAM tools were modified and used to optimize the manufacturing process.

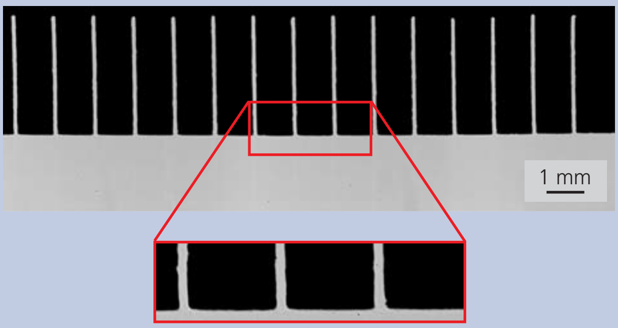
RESULTS

Precise structures can be laser powder cladded on rotationally symmetrical or planar substrates and free-formed surfaces as well in a reproducible, reliable, rapid and economical procedure, with a wide design variety.

In the transition area developed, the force is introduced into the volume of the plastic, which is better than an interface in conventional joining, such as adhesive bonding. Critical transition areas are sealed, or an intermediate layer is applied before joining by means of layer structures. These layers are important for medical and dental applications where they prevent bacterial impairment due to a defective joint.

It is also possible to combine different metals, adapted to the loads and stresses for each case. Even the material compositions can vary (for gradients and others) in size in a two-digit micrometer range. Functional elements can also be applied to the structures made by additive manufacturing.

Transverse microsection of a web-like interlocking structure without pores with strong metallurgical adhesion on the substrate



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As can be seen in Figure 4, metallurgical material compounds can be built layer by layer and without pores even in small sizes. The technology is successfully in use in the latest generation of turbo-jet engines for civil use thanks to consistent process and system refinement and quality assurance measures in parallel.

2-3 Structure to join metal and plastic

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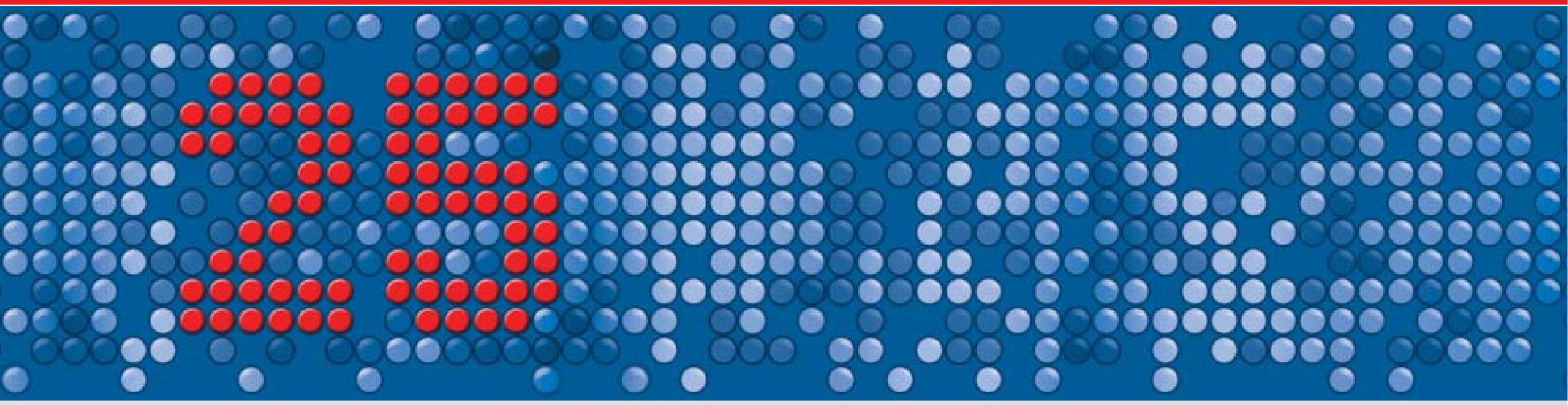

SMALL STRUCTURES – GREAT EFFECT

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PROF. DR. FRANK BRÜCKNER
Group manager additive manufacturing
Fraunhofer IWS

Editor: Dr. Roth-Fagaraseanu, Rolls Royce placed its first research orders with the IWS in 1993 and has consistently collaborated with the institute since 1997. What was crucial to your decision to collaborate with the IWS?

Dr. Roth-Fagaraseanu: We have been collaborating with institutes of the Fraunhofer-Gesellschaft for many years. The option to combine experience in materials and process design with in-depth knowledge of laser process simulation – above all in laser hardening and laser buildup welding – guided us to the IWS Dresden. The institute’s process simulation expertise inspired us.

Editor: What were the goals of the projects with the IWS?

Dr. Roth-Fagaraseanu: We had to deliver better and more cost-efficient protective coatings for gas turbine engines to make aircraft engines more efficient and reduce the CO_2 emissions. The interface between the nickel-based alloy and the ceramic heat insulation layer turned out to be the key to solving the problem. Understanding of the procedures at the interface was incomplete at that time. We were able to analyze bottlenecks and find solutions by simulating thermal conduction and heat transfer from layer to substrate at the Fraunhofer IWS. We had to enhance the strength with which the layer adheres to the substrate. Simulation also showed that intentionally induced segmentation cracks in the ceramic layer can contribute to controlling thermal layer expansion under the influence of temperature and counteract flaking of layers.

Editor: What were the most difficult milestones in the collaboration?

Dr. Roth-Fagaraseanu: It was difficult to define the optimal surface structure for strong adhesion of the thermal insulation layers that are subjected to continual temperature changes. It was even much more difficult to implement this structure on the surface: the laser buildup welding process had to be extremely precise to generate a defined three-dimensional surface morphology. The sprayed ceramic coating adhered better to the substrate then, and many segmenting cracks were induced at the same time.

Prof. Brückner: It took a lot to manufacture the surface structure in the IWS lab. The process parameters were optimized, the equipment for powder supply and process control was developed. The greatest challenge was the industrialization of the technology and the knowledge transfer from the IWS to the Rolls Royce subcontractor. A special surface morphology had to be laser buildup welded, and spraying had to be optimized so that the segmentation cracks could be induced in a controlled and reproducible manner. The particles were monitored online, the substrate temperature was carefully inspected at high temperatures, and a new APS spraying technology was employed. It was hard work for us all to match the influencing variables on an industrial scale and to establish a profitable procedure within two years.

Editor: What do you particularly appreciate in your collaboration with the IWS?

Dr. Roth-Fagaraseanu: The colleagues from Dresden were extraordinarily committed, and we were impressed by the intensity with which the team accepted and dealt with the task. The commitment to implement the designed solution in production was obvious. This convinced us that we would achieve our ambitious goal together with the IWS.

Prof. Brückner: We learned a lot about technology and management in the collaboration with Rolls Royce. It was exciting for us to transfer a technology, with all the certifications required, to the aircraft industry. Our teamwork was always inspiring and a partnership.

Editor: Are there future joint research projects planned?

Dr. Roth-Fagaraseanu: The IWS will remain our research partner in laser processes. The combination of material and process know-how with the simulation and development of equipment suitable for industry and of software for process monitoring and quality assurance are convincing arguments for ongoing cooperation. The developments in the field of additive manufacturing are particularly important for us.

LASER ABLATION AND CUTTING

Editor: The Process Design and Analysis group became a part of your business unit in 2015. How did the group find its place in the business unit? How do your business unit's research foci correspond to those of the institute?

Dr. Wetzig: The Process Design and Analysis group models and simulates laser material processing of all kinds for tasks within and outside the business unit. About 50 percent of our activities are focused on laser cutting. Moreover, the group supports researchers from other business units with its knowledge of laser-assisted plasma welding or modeling of re-melting metallic surfaces.

Editor: What classical laser cutting modeling approaches do you currently use?

Dr. Wetzig: In industrial projects, immediate customer benefit is usually the top priority; this could be, for example, the optimization of an inner geometry of cutting gas nozzles by flow simulation. The projects with public funding, such as by the DFG, however, are clearly more focused on basic research. A grant has just been given to a DFG project on the evaluation of dynamic approaches to optimize inert gas cutting of thick metal sheets by high-quality lasers. Ideally, we can directly utilize the findings from these projects to laser cutting problems in practice, and optimize the laser power distribution or the cutting gas flow.

Editor: Could you explain that in detail?

"It is better to pack imperfectly than to hesitate perfectly."
Thomas A. Edison

BUSINESS UNIT MANAGER
DR. ANDREAS WETZIG
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Dr. Wetzig: Let me describe a current development. The use of dynamic beam shaping to cut thick metal sheets goes back to a DFG project finished about 2 years ago. The options of static beam shaping vs. dynamic beam shaping were compared. Finally, the results clearly demonstrated that dynamic beam shaping is a promising way to increase both quality and process efficiency in the cutting of thick metal sheets.

Editor: Since 2016, your business unit has also included the Laser Cutting of Nonmetals group. What is the background and purpose for establishing this new group?

Dr. Wetzig: We have very successfully analyzed the laser cutting of nonmetals for a long time. For example, we implemented remote laser cutting of airbag material into series fabrication together with industrial partners several times. In the meantime, laser cutting of fiber-reinforced plastics has become a major part of our research. We bundled all our activities in the new group so that our customers are now better informed about our services. We are currently focusing our research on the cutting of films and adhesive tapes and the laser processing of composite materials, such as fiber-reinforced plastics, metal-plastic composites, and composites based on natural materials. We also concentrate on the cutting of isolator materials with or without cutting gas. Another emphasis is on laser processing of glass materials. As you see, the new group is facing many fascinating tasks.

COMPETENCES AND CONTACTS

Dr. Jan Hauptmann, division manager high-speed laser processing
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»Research foci are process and system technological developments for high speed applications. Profound process understanding forms the basis for the successful implementation of the different tasks in technology and system development for industrial applications. The offered processes and solutions are characterized by highest processing speeds. The portfolio includes technology development of remote processes for cutting, ablation, surface treatment and joining of metals and nonmetals as well as the designing, building and qualifying of highly dynamic processing systems.«

Dipl.-Ing. Peter Rauscher, group manager laser systems technology
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»The group's competence is the development of new, and improvement of existing, system technology with a focus on laser cutting, surface treatment and welding. Software and hardware components are being developed for applications that require fast beam scanning and shaping. A process development focus is the laser structuring of grain-oriented electrical sheets for highly efficient transformers.«

Dr. Jan Hauptmann, group manager laser cutting of nonmetals
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»The group focuses on classic polymer cutting and the laser processing of composite materials. Under development are remote cutting processes for fiber-polymer composites. The specialty of these processes is the simultaneous application of different laser wavelengths. Laser cutting process development also addresses other nonmetallic materials such as novel hybrid materials and high performance textiles.«

Dr. Patrick Herwig, group manager laser cutting
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»Research in the area of laser cutting focuses on obtaining a better understanding of the process and on process developments in the areas of laser melt and flame cutting. Topics include the improvement of the cutting quality with solid state lasers or the optimization of the laser beam cutting of electrical sheets without disturbing magnetic properties. Beyond this we qualify novel cutting processes such as the remote laser cutting and its integration into productions processes. To work on these topics, we have at the IWS all typical lasers with various wavelengths, powers and beam qualities, which can be combined with highly dynamic 2D and 3D cutting machines.«

Dr. Achim Mahrle, group manager process design and analysis
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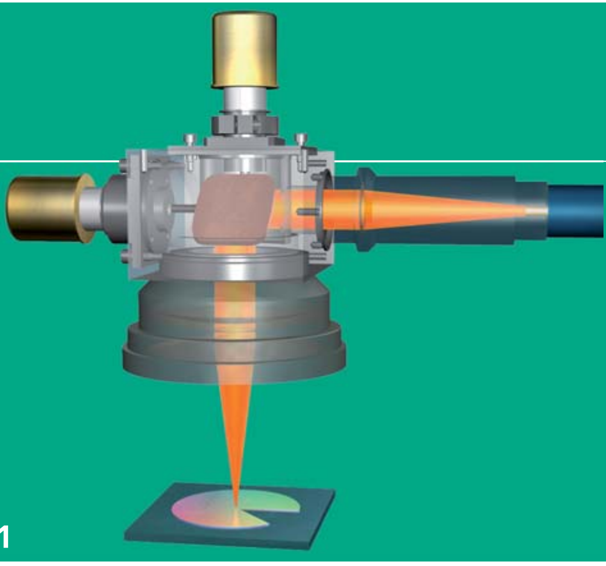
»Based on the laws of thermodynamics and state equations we evaluate the principle energy balance of the studied laser material processing technologies. By comparing the real process and competing technologies we draw conclusions with respect to energy efficiency and obtainable process efficiencies. An additional focus is process analysis. The aim is to describe the functional dependencies between control variables, influencing factors, disturbance variables and target quantities of a given laser material treatment process. Numerical as well as experimental methods are being applied.«

2016 PROJECT EXAMPLES



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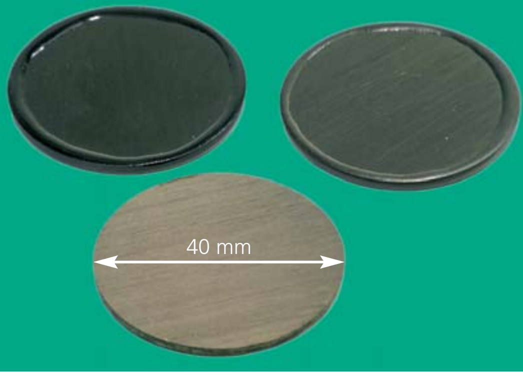

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EDGE SEALING OF REMOTE LASER CUT FIBER-REINFORCED POLYMERS

THE TASK

For the cutting of fiber-reinforced polymers, remote laser cutting using beam sources with continuous emission offers several advantages compared to classic mechanical cutting technologies, such as milling, drilling or water jet cutting. High hardness and brittleness of the glass and carbon fibers, in conjunction with the viscoelastic properties of the polymeric matrices, usually result in high tool wear. The forceless and non-contacting laser beam makes it possible to cut edges with continuous manufacturing quality, without delamination, with high productivity; furthermore, the technique makes the technology a good candidate for automation (Fig. 1 and 2).

A heat affected zone occurs in this technology. As a result of the thermal laser impact, the matrix material moves away from the cutting edge, because the decomposition temperatures of the polymers and the reinforcement fibers are clearly different (Fig. 3). There remain exposed fiber ends with a capillary effect and an irregularly structured plastic component margin. The large surface broken through by filaments means that more water can be absorbed, which, in turn, negatively affects the material properties.

Independent of the cutting method, corrosion primarily of carbon fiber-reinforced plastics (CFRP) starts at and propagates from the exposed fiber ends. Graphite is a noble material according to the electrochemical properties. This requires countermeasures, when the less noble lightweight material aluminum is used in structural joint connections.

OUR SOLUTION

We at Fraunhofer IWS Dresden studied the extent to which the remote laser cutting of fiber-reinforced plastics in general results in higher water absorption. We also considered the extent to which edge sealing by the deposition of plastics on laser cut near-net-shape machined structural CFRP components enhances the characteristics in a humid environment.

For this purpose, comprehensive experiments on laser cut and milled CFRP multilayer composites of orthogonal structure were performed. Fine-weighing of the circular test specimens, which have been aged in water bath at 60 °C for a longer period, makes it possible to quantify the absorbed humidity, so that the processing techniques can be compared.

The sealing capabilities of several thermoplastic and thermoset plastics were assessed. Here, not only the barrier's effect on water input, but also handling of the un-crosslinked one- or two-component polymers were important for an automated post-treatment of edges. Low-viscosity epoxy and unsaturated polyester resins were studies as thermoset sealing systems, with polypropylene as the processed thermoplastic. The base material is a CFRP with epoxy matrix and high-strength HT fibers, which was pressed into a prepreg.

3

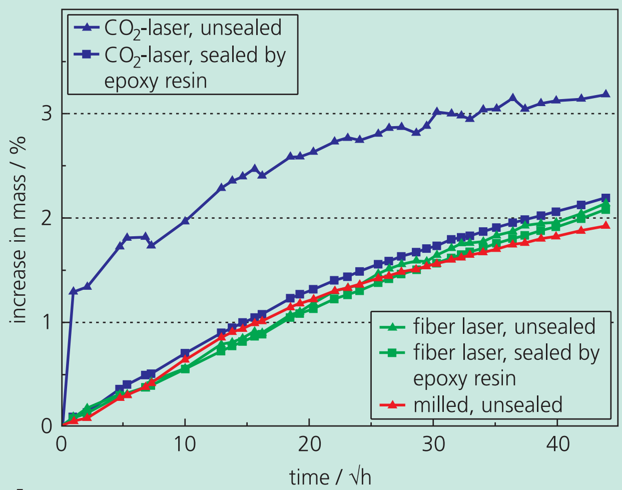
RESULTS

Heat affected zones of up to 500 µm emerge in the CFRP multi-layer composites during CO_2 laser cutting. This phenomenon is caused by the wavelength that offers rather poor focusability in comparison to fiber lasers, so that interaction between the laser and the material takes a long time. The long ends of the filaments, which are exposed, are capillaries with a substantial storage capacity.

The fiber composite weight significantly increases during the aging of the specimens in a water bath (Fig. 4). After the first weighing, the free water absorbed through the capillaries is included in the measurement. Under operating conditions, it is conceivable, that free water is constantly present on the edges and can thus diffuse into the plastic matrix. Consequently, cutting of CFRP by means of the CO_2 laser is not suitable.

Subsequent edge sealing of the CFRP material processed by the CO_2 laser has a great impact. Such post-treatment avoids sudden water absorption by the material and shifts the saturation curve into the range of mechanically machined, unsealed CFRP material (Fig. 4).

Saturation curves of CFRP with various edge states



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Clearly better results are achieved when cutting CFRP by fiber laser. Water absorption is commensurable with the results gained for milled specimens. When the wavelength of the laser in use is changed, the processed material absorbs less water. Subsequent edge sealing does not provide essential improvements in the water absorption properties.

Epoxy resin provides the best processing characteristics for post-treatment of the cutting edges; it reliably adheres to the CFRP base material. Moreover, there are available fast curing systems that can be activated by ultraviolet light or another energy source, which are suitable for an automated process with short cycle times. However, subsequent deposition of polypropylene is not useful. The melt deposited neither adheres to the CFRP nor offers any barrier effect. Neither is the use of polyester resin an alternative, since the strong vibration in conjunction with curing causes the sealing to delaminate.

1 *Remote scanner for cutting of fiber-plastic composites – principle structure*

2 *CFRP specimens cut by fiber laser, without post-treatment (bottom), and post-treated by epoxy resin (top left) and polyester resin (top right)*

3 *Microscopic image of a CFRP edge, remote laser cut (cross section)*

CONTACT

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SIMPLIFIED CONTROL OF HIGHLY DYNAMIC SCANNING MIRRORS

THE TASK

Highly dynamic galvanometer scanners, which, as a function of their optical design, can generate lateral spot velocities of several meters per minute, are used to implement rapid motions of a laser beam. These scan systems are applied in a wide variety of ways in the laser machining of materials, in which specific manufacturing tasks must be executed through rapid contour motion capacities. Recently, galvanometer scanners have also been used more and more for high-frequency beam oscillation processes to influence the dimensions and dynamics of the molten bath. To implement and direct more and more complex technological techniques in the fields of remote laser cutting, welding and cladding, it is necessary to link the trajectory of the scan systems with the machine control, the laser beam sources, and, if applicable, available sensors and actuators. Furthermore, the demands of efficient production, short manufacturing cycles and automatic chaining of sequential manufacturing steps, make it necessary to develop paradigms for holistic interconnections that include the control of galvanometric scanners.

OUR SOLUTION

At the Fraunhofer IWS Dresden, the so-called ESL2-100 modules (see Fig. 1) were developed for the integration of highly dynamic galvanometer scanners into machine controls. The real-time capabilities, the open structure and the flexibility of available field bus systems are used to extend the control of the galvanometer scanners. The ESL2-100 module functions as a gateway between the Ethernet-based field bus system EtherCAT and the SL2-100 report to trigger scanners. This setting ensures cyclical and synchronous communication between the scan system and the machine control, as well as the sensors, in the process. Furthermore, the flexibility of the field bus system makes it possible to distribute the scan systems in space in almost any chosen position. As a result, scanners can be employed in various positions in production equipment and can be synchronized with one another. Not only are Ethernet-based field bus systems (EtherCAT) in use, but also additional industrial Ethernet standards, such as Profinet. It may also be possible in the future to support the XY2-100 protocol for control of scan systems.

Modules for digital control of galvanometer scanners (scanner report: SL2-100) via EtherCAT (left) or Profinet (right)

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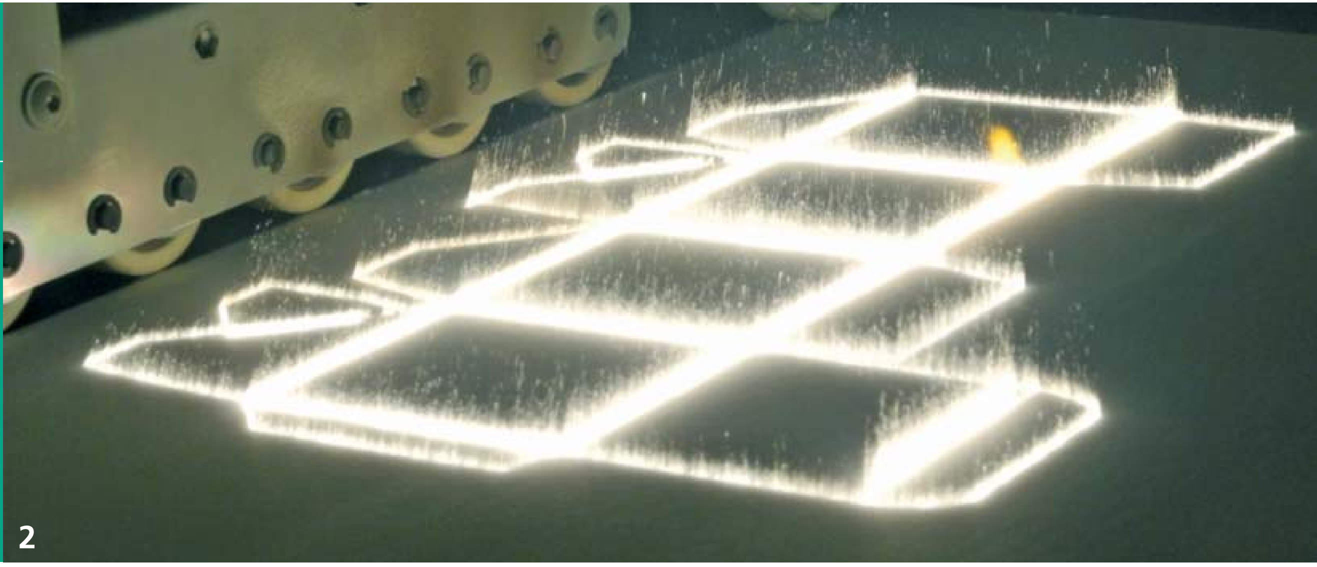

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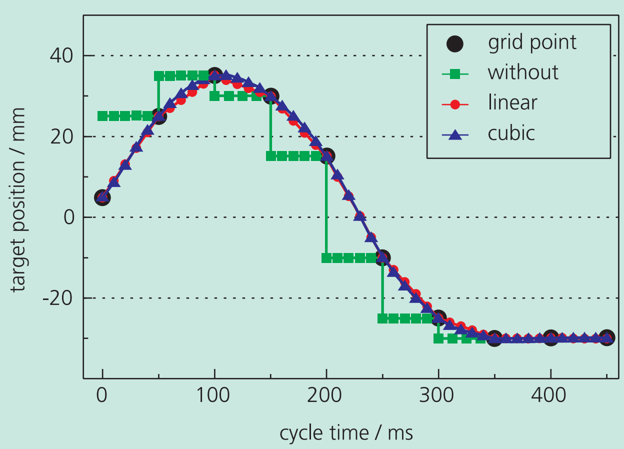
RESULTS

Scan systems for laser materials processing can be integrated into existing field bus systems by means of the ESL2-100 modules (see Fig. 4). Discrete nominal position values are cyclically transmitted to the scanner for control. The position values are calculated in a programmable controller (PLC) and can be connected with various sensors installed in the process. Additionally, the dynamic characteristics of the scanner, analogously to an NC axis, are either considered when selecting the position or chosen as a function of the manufacturing process.

The ESL2-100 module provides the option of choosing among several types of interpolation, which enable fine interpolation (without, linear, cubic) depending on the PLC cycle time (see Fig. 3). An oversampling function is implemented to improve the time resolution; as a result, several grid points can be transmitted with each EtherCAT cycle.

4-fold oversampling function and fine interpolation of ESL2-100 modules, which can be selected depending on the task



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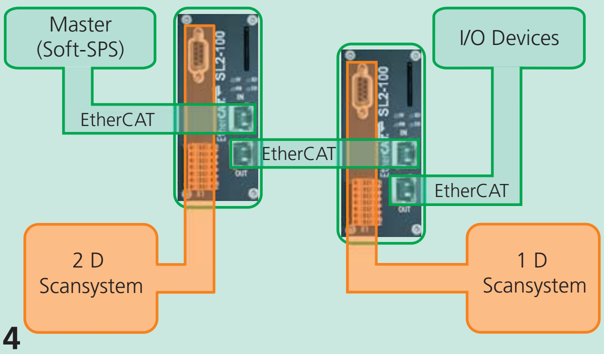
Principle for integration of several scanning systems in the machine control (Field bus system EtherCAT)



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The required image field correction is calculated in the ESL2-100 module and can be loaded via SD card. The system created by the IWS is in use 24/7 for laser processing of electrical steel. Thanks to the high coil speed feed rate of max.150 m min^{-1}, up to 12 individual axes are in use. The control of all scanners is performed as a function of the coil speed. For this purpose, the machine control synchronizes the manufacturing process including the scanner motion related to the coil speed. Other ranges of application include technologies in which the scanner motion must be directed in real time, such as in high-frequency beam oscillation.

2 *Highly dynamic remote laser cutting of fiber reinforced composites and cardboard*

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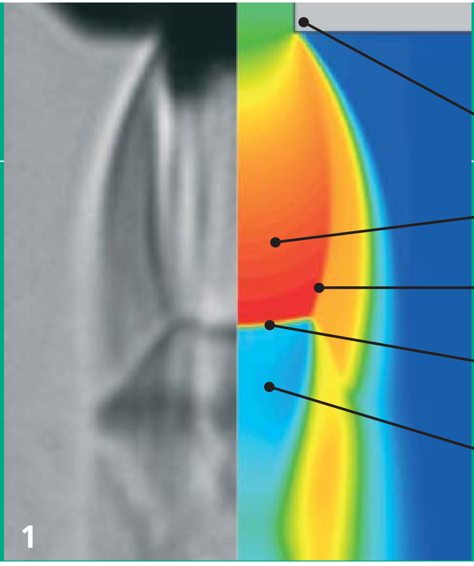


CFD SIMULATION FOR FLUIDIC COMPONENT OPTIMIZATION

THE TASK

Gases are used in many ways in laser materials processing. As primary gases, they blow out material in thermal cutting procedures, such as laser fusion cutting. In joining processes, shielding gases protect the process zone from the surrounding atmosphere. In cladding, gas functions as the carrier of the powder material. As secondary gases in a widest range of processing techniques, they have many other applications, including:

- shielding optical components,
- limiting disturbing influences from process emissions, in the form of vapor or smoke, which can impair both process reliability and processing quality due to interactions with incident laser beams,
- keeping the air in production compartments clean to fulfill the labor safety requirements.

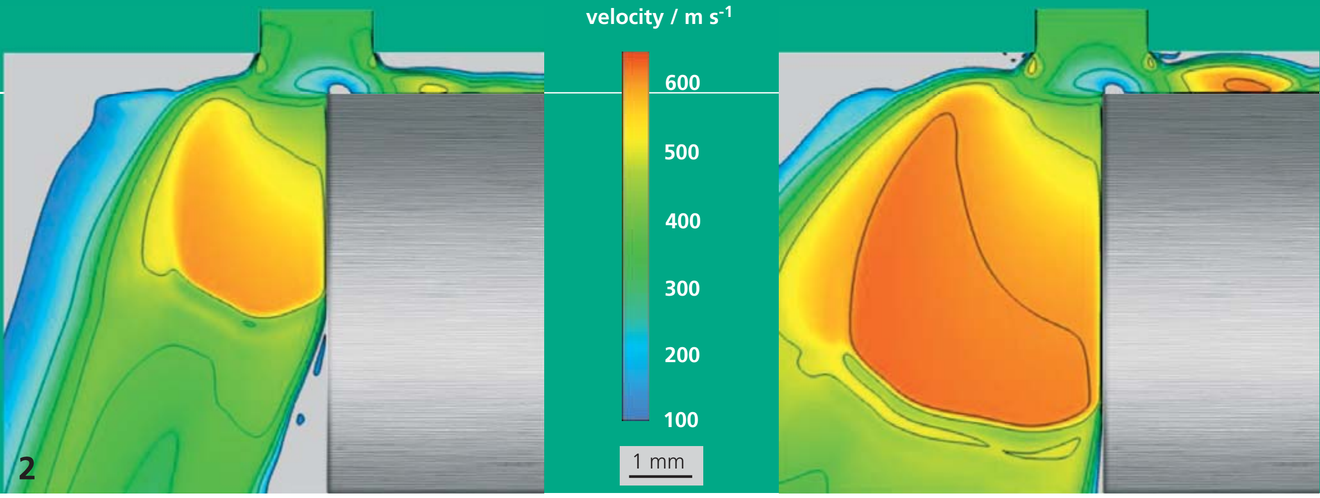
With reference to dimensioning, favorable design, and the configuration of the fluidic components to be used, several problems with practical relevance frequently emerge, which have to be solved to maintain both an optimum effect and economical gas application and consumption.

OUR SOLUTION

When examining how to utilize the primary and secondary gases for laser materials processing more efficiently, the spatial and sometimes even the temporal flow characteristics of the gases have to be characterized. For this purpose, at IWS, we have developed particular CFD models that make it possible to simulate gas flows under near-real conditions. These models were created at our customers' demand and in projects with public funding. Here, as a rule, excellent predictive accuracy, as well as a sound coincidence with the experimental results, was achieved (Fig. 1). In contrast to experimental testing methods, the gas flow can also be characterized in regions outside the visually observable range.

Parameterized models are the base for well-founded parameter studies and sensitivity analyses, which – together with statistical design and analysis of experiments – make it possible to identify the essential influencing factors, as well as relevant interactions.

As a result of these investigations, it is not only possible to immediately deduce specific recommendations aimed at constructive changes in the design of individual components, but also to identify optimal parameter settings under predefined conditions of application.



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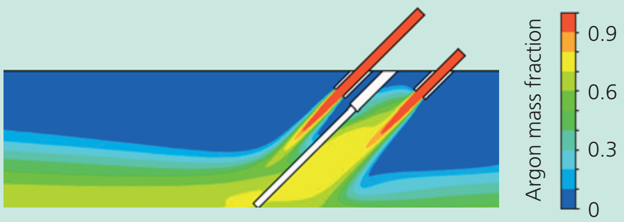
RESULTS

As varied as the ranges of application are the models that were and are being developed for gas flow simulation at the IWS. Current research topics are mainly focused on user problems arising from laser welding and laser cutting. Figure 3 illustrates a calculated shielding gas distribution (Argon) for narrow gap laser welding of multilayers with filler metal (wire). Based on the simulation results, one can analyze and assess different variants of shielding gas supply.

Simulation of shielding gas coverage in narrow gap laser welding



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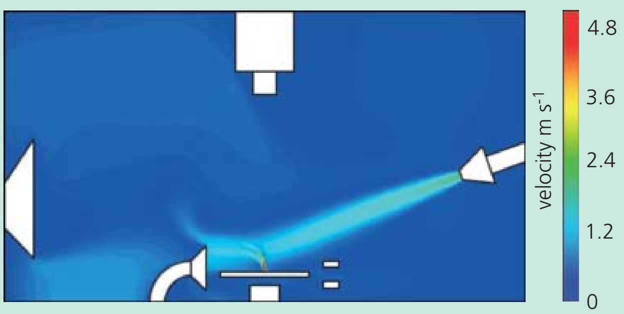
Global air flows were simulated for remote laser welding. Figure 4 shows the calculated velocity distribution in a model processing chamber with local and global inflow and outflow air components.

Air flow (calculated) in a processing chamber for remote laser welding



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The purpose of the project is to evaluate concepts of optimized air flow guidance, which, on the one hand, eliminate disturbing welding vapors in the laser beam path. On the other hand, they also guide the process emissions intentionally into the designated exhaust units to minimize the contamination both of workpieces and optical components. Flow characteristics of individual components were found to be a specific challenge and have usually to be analyzed separately in submodels.

In laser cutting, our customers are mostly interested in the analysis of nozzle concepts and flow characterization of entire processing heads. For laser fusion cutting, the efficiency of the cutting gas coupling into the cut kerf is analyzed as an objective criterion for an intended optimization, and the cutting gas flow within the kerf is examined (see Fig. 2).

1 *Comparison of experimental and numerical results for a free jet from a gas nozzle. Left: density distribution found in experiment (schlieren method). Right: calculated flow field.*

2 *Simulation of the cutting gas flow as a function of gas pressure in laser fusion cutting (left: 5 bar, right: 10 bar).*

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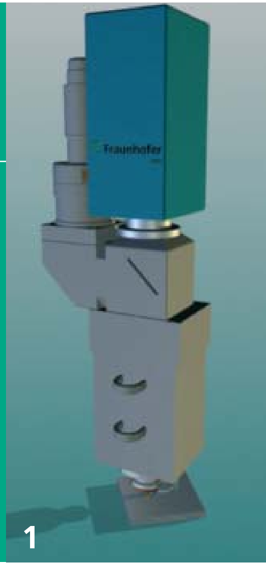
BUSINESS UNIT LASER ABLATION AND CUTTING



TEMPERATURE-BASED PROCESS MONITORING FOR LASER CUTTING

THE TASK

End users are focusing more and more on process monitoring and control sensors for laser cutting. The desired functionality ranges from simple quality assurance systems to smart solutions with online optimization of the cutting parameters. The sensors currently commercially available are mostly limited to the control of individual cutting parameters or monitoring of individual incidents. These systems are not capable of providing a general assessment of the process state or the current cutting quality or, if they are, only to a low extent. Furthermore, these systems have always to be calibrated to the nominal cutting quality or the requested parameter.

To create acceptable solutions for process automation in industry, we need a system that is able to reliably distinguish the greatly varying cutting processes and states. The system should be able to detect both unacceptable parts and continuously diminishing cutting qualities.

Consequently, we strive for a sensor system that depicts a correlation between characteristic measured values and the cutting result in the cutting process. The system should not only "digitally" classify as "ok/not ok", but also detect further graduations that indicate the process state more clearly. Ideally, the analysis system can also intervene in the cutting process and adjust the nominal cutting quality via suitable controlling parameters.

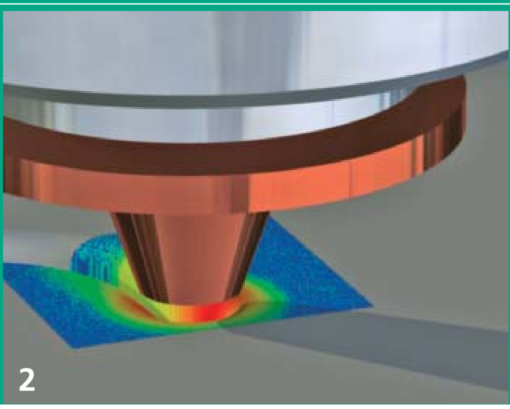
OUR SOLUTION

Basically, laser cutting is a thermal process connected with emissions in the electromagnetic spectrum. It could be verified by various optical measuring methods that these emissions correlate with the current process state both in a quantitative – as to be seen in laser density – and a qualitative way, observed for the assignment to spectral ranges.

What is state of the art for other thermal techniques, such as laser hardening, can also be applied to laser cutting: the cutting process can be characterized by means of the thermally induced emissions.

This characterization was implemented at the IWS Dresden by means of the camera-based temperature recording system "E-MAqS" and the controlling system "LompocPro". The measuring and control system originally developed for power-controlled temperature guidance in laser hardening, is successfully in use in build-up laser welding, laser soldering, induction hardening and other specific heat treatment techniques.

The system is designed for demanding industrial measurement tasks and makes available surface temperature values at a lower measurement threshold of 600 °C and a frequency of max. 200 Hz.



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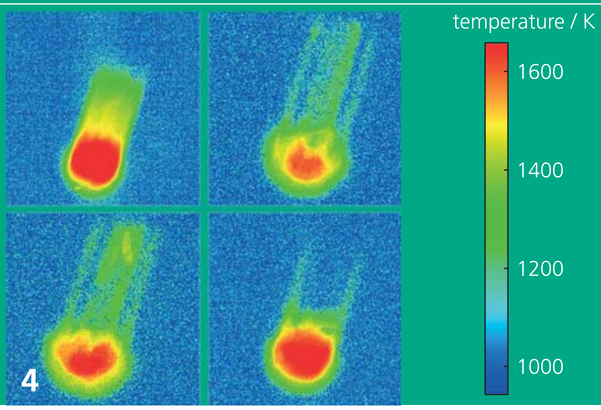

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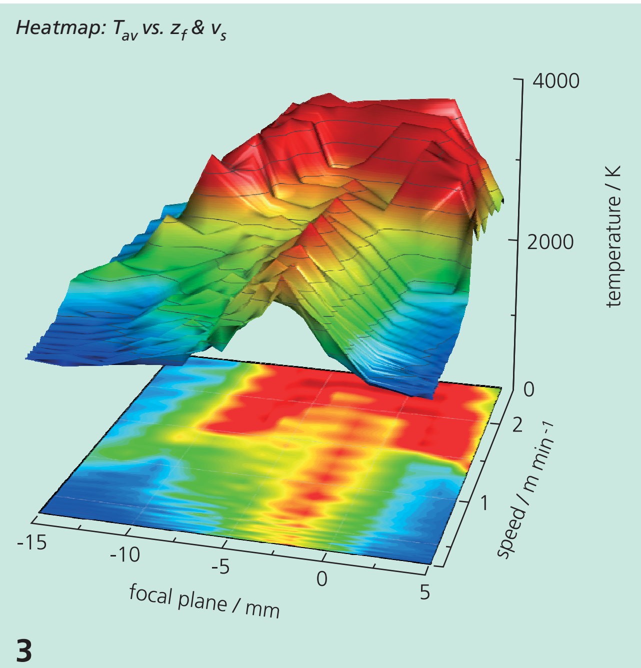
RESULTS

The examinations were run on commercially available hardware, equipped with an E-MAqS system of Fraunhofer IWS. A 5 kW solid state laser was used as the beam source, and standard optical components modified specifically for the coaxial coupling of the E-MAqS system into the laser beam, were used for cutting. The signal curves were correlated with the cutting results achieved to evaluate the process characteristics. The results shown in Figures 3 and 4 depict fusion cutting of CrNi steels.

The cutting process can be evaluated and characterized by means of various parameters. Since the measurement is spatially and temporally resolved, the melt pool temperature at discrete positions and the melt pool size or spatial and temporal temperature gradients can be considered. Analysis of the gradients simplifies the measuring methodology, because it is not necessary to exactly know the emissivity of the cast.



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The melt pool characteristics depend on many factors, with various effects. The melt pool characteristics are strongly influenced by the sheet metal thickness, the laser power, and the resultant cutting clearance geometry.

The mulitdimensional correlation between the maximal temperature and the speed and focal plane as the two cutting parameters ($T_{max} = f(v_S, z_f)$) is shown as an example in Figure 4.

Current research is aimed above all at designing purposeful analysis strategies, which can be based spatially and temporally. Various effects can only be detected in the cutting process. Thus, a clear increase in the melt pool temperature indicates an imminent breakdown of the process. Other goals are online characterization of the resultant edge roughness and burr formation and the validation of the measurement system for additional cutting techniques.

The “E-MAqS“ temperature measurement system is suitable for monitoring flame cutting processes, since here spatially based signal analysis plays a role in detecting instabilities in the cutting process. Under certain conditions, for instance, so-called “self-burning“ or “side-burning“ effects may occur, which can be detected by means of “E-MAqS“ and compensated with the help of the “LompocPro“ complementary control.

1 Cutting head with E-MAqS

2 Measuring position (sketch)

4 Snapshots

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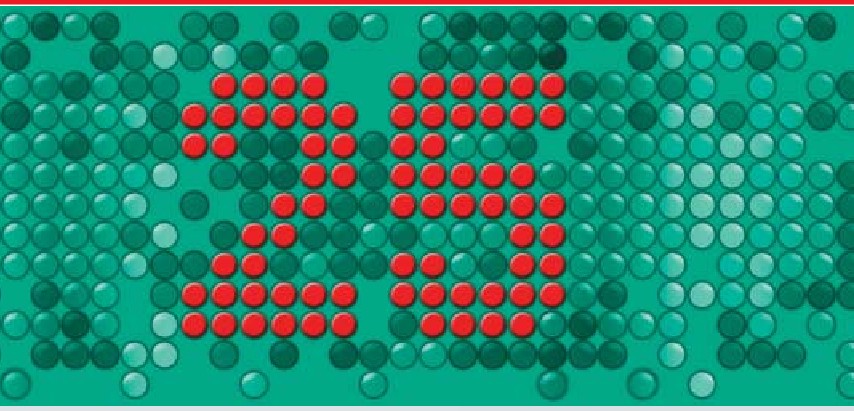

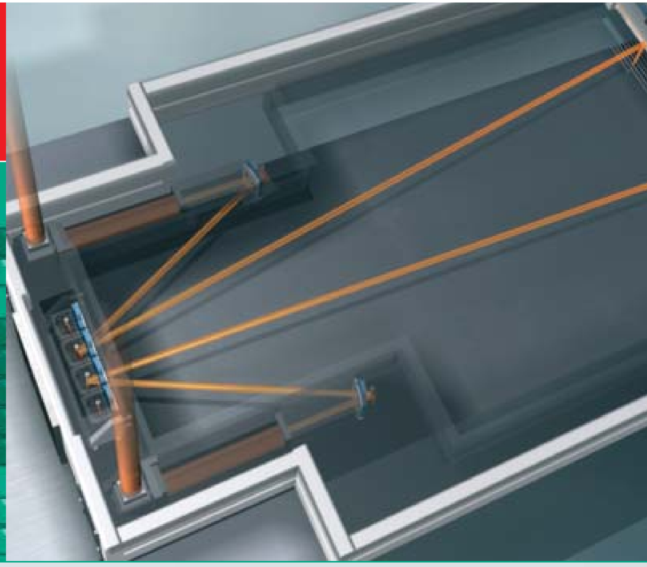

LASER MAGNETIC DOMAIN REFINEMENT – A SUCCESS STORY

ERIC MÜLLER
Key account manager LDRS
Rofin Sinar Laser GmbH

DR. JAN HAUPTMANN
Division manager high-speed laser processing
Fraunhofer IWS Dresden

Editor: Your company has collaborated with the institute for many years. When and how did you begin working together on Laser Magnetic Domain Refinement (LMDR)?

Mr. Müller: The close and comprehensive collaboration in cutting, welding, and surface treatment between the ROFIN company and the IWS goes back to the beginning of the 1990s. From this time onwards, projects for industry were successfully executed and implemented in products for customers from the automotive, aircraft and other industries. In our projects for the automotive industry, the focus was on gear parts, speed change gears, airbags, etc. With the turn of the new century, we obtained the first detailed project requests for "Domain Refinement of grain-oriented Electrical Steel" from Asia. Drawn by the reputation and preliminary studies of Professor Beyer in domain refinement by laser dating from the 1980s and 1990s, we contacted the IWS for support.

Editor: Can you describe how you began to solve the problem?

Mr. Müller: First, we established a system for R&D to gather process expertise in the latest equipment and to determine whether the system could be transferred to a production line. At that time, many steel producers had already studied the subject of domain refinement in detail and engaged in developments in their own laboratories and/or institutes. The findings in the fundamentals were very advanced, but there remained a need for hardware providing technical solutions within production lines.

Editor: Which challenges did you have to meet?

Mr. Müller: The main problem was to reliably control the process in the complicated surroundings of the steel industry. Harsh environmental conditions, instable processes, high productivity and availability requirements with short downtimes for the systems within the production line demanded a lot from the laser system. Thanks to profound and professional preparation and execution, it was possible to deliver all systems to the customers after the installation stage and a short training phase. The users were then able to operate and run the systems for production.

Editor: What is the position now? Can you explain the latest results?

Mr. Müller: Over the last 15 years, a total of 10 systems for electrical steel treatment have been successfully sold and delivered to customers in the steel industry. All systems are run in production and/or production lines, mostly in 3 shifts. Close cooperation with the IWS and the companies ARNOLD and ROFIN provided the consortium with a global reputation and made it the biggest current provider of this solution. We expect further projects in this field in the short and longer term, because we are continuously refining the process for an extended application, aimed at the treatment of heat-resistant electrical steels.

Editor: What, from your point of view, made the collaboration with the IWS particularly pleasant?

Mr. Müller: We appreciated the well-structured, professional and reliable cooperation – from project preparation to delivering the systems to the customers, as well as subsequent assistance if necessary.

The reason why our customers have chosen this consortium was, among others, the process know-how of the IWS and the option to perform preliminary experiments. The experience we have collected in various contexts is another driver for an increasing number of successful installations in industry.

Dr. Hauptmann: For the IWS it is always very pleasant to be involved very early by our partner ROFIN in technical collaborations for individual customer projects. Moreover, for five years, we have continuously worked on an R&D project with three partners: the companies ARNOLD, ROFIN and the IWS. So we have been able to do industrial exploratory research independent of individual customer projects.

Editor: What are your next goals for development?

Mr. Müller: The conventional thermal conduction-based process has been established and implemented. Depending on global needs, further projects are expected, while the number of new systems will be limited. Refinement of processes, in turn, means that they can also be used in the "heat-resistant" treatment of electrical steel ("heat proof" LMDR) and in so-called magnetic flux-adapted LMDR. The "heat proof" LMDR would permit the use of laser treated electrical steel, even for wound core transformers. The flux-adapted LMDR allows for another reduction of the hysteresis losses during the transformer operation. New environmental laws and regulations, as well as the general demand for energy savings in the future, will certainly result in additional requirements and application fields.

THERMAL SURFACE TECHNOLOGY

Editor: Prof. Leyens, the IWS offers customized systems engineering solutions for thermal spraying processes with suspensions. What are their particular features?

Prof. Leyens: A crucial precondition for thermal spraying with suspensions is the homogeneous, controllable supply of the materials being sprayed. For this reason, we developed a suspension feeder equipped with three tanks enabling the precise supply of the mostly ceramic suspensions. One of the containers is filled with cleaning liquid applied to the injection nozzles, while the others hold the appropriate suspension. Thus highly productive coating processes can be implemented with no interruption in the supply of the medium, and new coating systems and structures are rendered feasible through mixing or gradient deposition of two different suspensions. We offer our customers injection systems in combination with the retrofitting of existing or the development of new spraying systems with suspensions.

Editor: The IWS plays a leading role in laser hardening. What is the secret of your success?

Prof. Leyens: The laser as a precise energy source can be used for local heat treatment, which, in turn, improves the wear resistance of the material used. In contrast to conventional hardening techniques, in which generally the properties of the surface of the entire component are changed, laser hardening allows for customized solutions. The technique can be applied to components with complex geometries and to materials that tend to build up high thermal stresses, as well. Our customers benefit from the IWS's comprehensive understanding of the development of customized solutions, as well as our experience, recognized worldwide, in materials and systems engineering.

"First doubt, then inquire, then discover!"

Thomas Buckle

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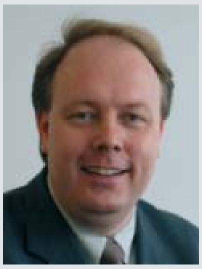
Editor: Laser buildup welding is one of the most important thermal surface technologies. What is the goal of future developments?

Prof. Leyens: Regardless of whether the filler metal is supplied as a powder or wire, we obtain the highest quality layers with perfect metallurgical bonding to the component through laser buildup welding. We make use of these advantages when coating large components that have to be protected against wear or corrosion, or for other purposes.

The advantages in terms of quality are obvious. Productivity plays an important role in the technique's profitability. Here we are developing innovative systems for customized solutions. Currently we can deposit single traces 45 mm wide with a laser power of maximally 20 kW – with extraordinarily constant layer thicknesses across the whole trace. The wire-based laser buildup welding techniques also offer excellent profitability. The advantages of the wire are derived, among other things, from the full uti-lization of the material employed. Our COAXwire technology has recently become well established in industry; new prospective customers arrive almost daily.

COMPETENCES AND CONTACTS



Dr. Steffen Bonß, division manager heat treatment and plating
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» For part geometries, wear scenarios and materials where conventional hardening technologies fail, alternative surface technologies such laser beam hardening and laser beam remelting often offer new approaches to generate wear resistant surfaces. This is especially relevant for the selective hardening of parts with multidimensional curved surfaces, inner surface or hard-to-reach areas, bores or notches as well as for those parts that are prone to distortion. «

Dipl.-Ing. Jan Hannweber, group manager heat treatment systems
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» The successful transfer of a technology toward industrial implementation is essentially depending on the technological maturity of its individual components. The group's core competence is the development of new and the improvement of existing laser materials processing systems technology with a focus on laser beam hardening. The conception and development of systems ranging from individual devices to complex machinery during the project performance, follows consequently current European guidelines. The project "Industry 4.0" provides important guidance. «

Dipl.-Phys. Marko Seifert, group manager mechanical-thermal processes
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» The group's core competence is the development of processes and customer-specific processing concepts in the field of laser-assisted mechanical-thermal materials processing. Main work areas are laser hardening of steel materials and laser induction roll plating to create complex mixed metal joints. Furthermore, we offer special technical solutions for soldering, remelting and gas alloying. Tools are multi kilowatt high power lasers up to 9 kW. A focus in all developments is the realization of precise temperature controls to provide the basis for reproducible industrial processes. «

Dr. Filofteia-Laura Toma, group manager thermal spraying
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»Atmospheric plasma spraying (APS) and high velocity oxygen fuel (HVOF and HVAF) spraying technologies are available for thermal coating process development with powders and suspensions. Metal, hard metal and ceramic coatings are deposited on components made from steel, lightweight metals or other materials. Core competences include the development of tailored coating solutions, of system components and their integration into adapted machine concepts. Supporting the technology deployment on-site at the customer installation is an important aspect of know-how transfer.«

Prof. Steffen Nowotny, division manager buildup welding
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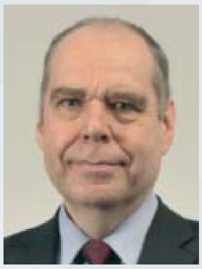
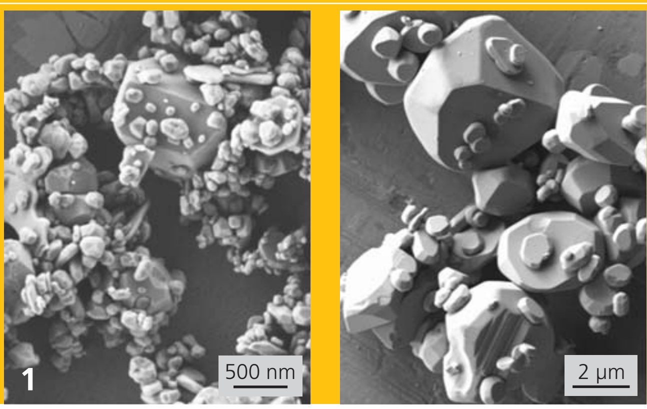


»The competence field encompasses the application of laser buildup welding technology with powders and wire for the purposes of surface coating and surface functionalization. An important focus is the development of processing heads, component technologies and CAM software. To use the technology in production we support our customers with expertise in process development, systems technology and on-site consulting. We also offer consulting, education and training programs.«

2016 PROJECT EXAMPLES



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CR_2O_3 HIGH PERFORMANCE COATINGS BY THERMAL SPRAYING WITH SUSPENSIONS

THE TASK

Chromium(III)oxide (Cr_2O_3) is a widely used coating material, in particular for printing, paper, pump and textile industries, as well as in mechanical sealing systems. Cr_2O_3 coatings are very hard and highly resistant to wear and corrosion; they also have good frictional and sliding properties and can be well structured by laser.

Cr_2O_3 coatings are mainly made by atmospheric plasma spraying (APS). Deposition efficiency ranges from approximately 30 to 40 percent. The APS coatings show a porous structure, which is unfavorable for some applications. Denser coatings can be produced by high velocity oxygen fuel (HVOF) spraying. Since this spraying technique achieves only a low deposition efficiency (< 10 percent), it is not widely used in industrial coating spray jobs. Consequently, the Fraunhofer IWS is developing high density Cr_2O_3 coatings with higher deposition efficiency.

OUR SOLUTION

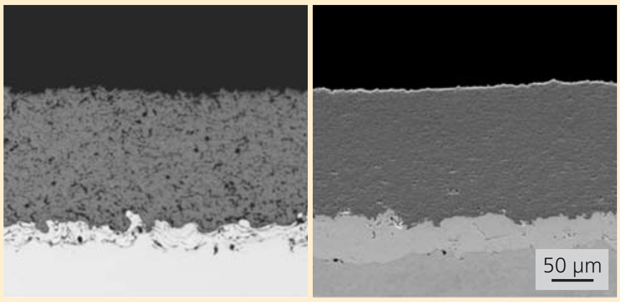
The scientific-technical approach is based on thermal spraying techniques with suspensions. The coatings are sprayed with suspensions made of submicro- or nanopowders (Fig.1), which are finely dispersed in liquid, instead of coating powders with particles from 5 to 50 µm size. Using stable suspensions with a low viscosity is crucial for the long-term reliability and efficiency of the processes. For this purpose, concentrated aqueous Cr_2O_3 suspensions with a solid content of up to 40 weight percent were developed and tested in collaboration with the Fraunhofer IKTS.

The hardware components specifically needed to spray the suspensions were engineered at the IWS and customized for conventional APS and HVOF spraying systems. The suspension HVOF spraying tests were performed by means of a Top Gun HVOF using ethylene as fuel. The suspension was supplied by means of a pressurized suspension feeder (Fig. 2) and axially injected into the modified combustion chamber. During spraying, the suspension feed rate and pressure are continuously controlled and monitored.

RESULTS

The SHVOF coatings microstructures (Fig. 3) are denser than those of traditional APS coatings. The typical crack-like structure of conventional coatings could not be observed in the SHVOF coatings.

Cross-section micrographs of an APS-Cr_2O_3 coating (left) and a SHVOF-Cr_2O_3 coating (right)



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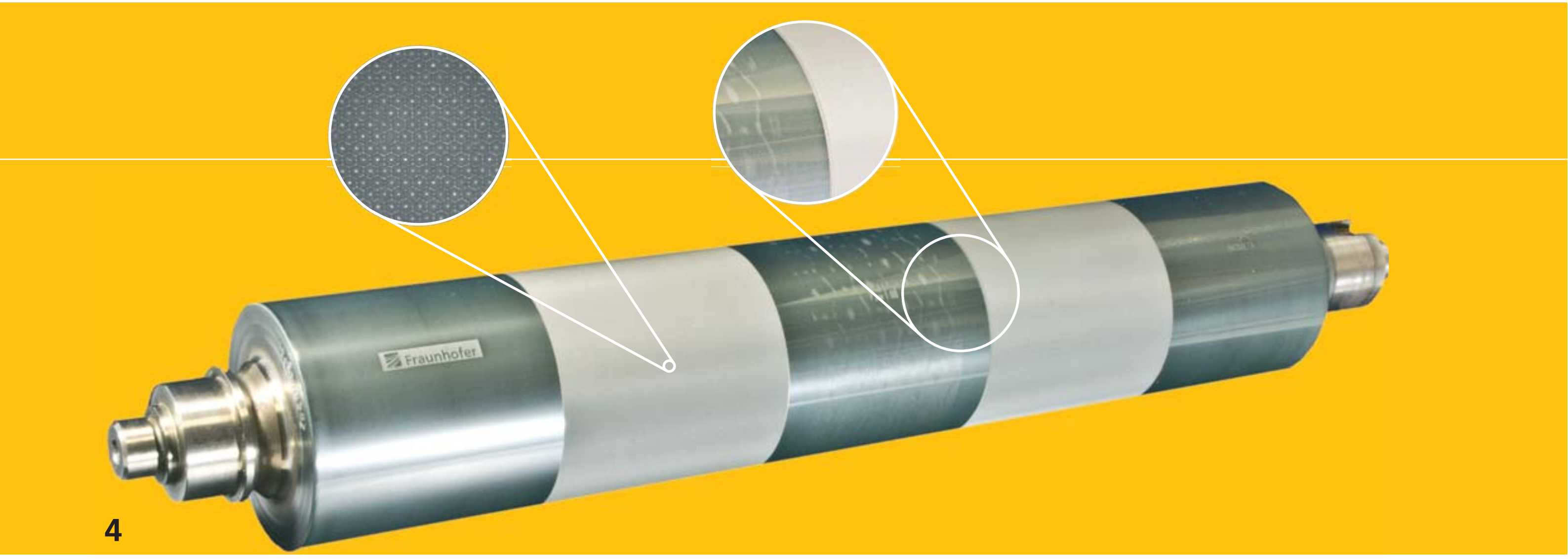

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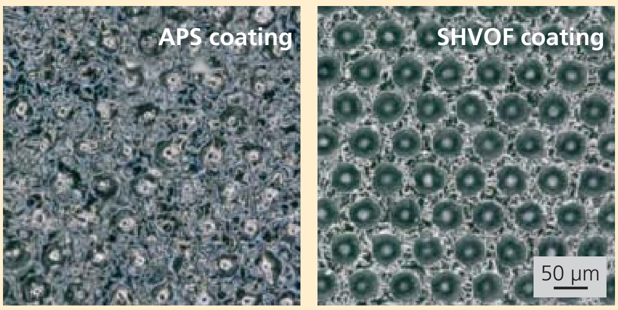
For suspension coatings, hardness values from 1200 to 1500 HV 0.3, which outperform the values of conventional APS coatings, were measured. Using finer particles clearly enhances the mechanical properties. The Young's moduli of the SHVOF coatings exceed 135 GPa, whereas those of the APS coatings lie just at approximately 75 GPa. SHVOF coatings provide similar wear coefficients, but lower roughness values than conventionally sprayed coatings. The SHVOF coatings show higher resistance to corrosive media thanks to the higher density of the microstructure. When Cr_2O_3-based surfaces using the SHVOF technique are sprayed, deposition efficiencies from 30 to 35 percent were achievable, which corresponds to an improvement of more than 300 percent in comparison with Cr_2O_3- HVOF powder coatings. Another advantage of the SHVOF coatings is the smooth surface. Roughness values (R_a) of suspension-sprayed coatings of 1 - 3 µm were clearly below those of the powder-sprayed coatings (R_a > 5 µm). This makes subsequent grinding and polishing of the suspension coatings cheaper and saves time. Figure 4 depicts the surface topographies of the laser-structured APS- and SHVOF coatings. In comparison with the conventional coatings, the SHVOF coatings provide excellent, finer laser structuring even without subsequent machining. The fine patterns also serve as a lubricant reservoir for tribological applications.

Topography images of a laser structured APS coating (left) and a SHVOF coating (right). Laser structuring was carried out on as-sprayed coatings.



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SHVOF-Cr_2O_3 coating on an aluminum shaft, polished, laser structured and laser engraved

6

The superior coating properties make the SHVOF-Cr_2O_3 coatings ideal for application on components subject to heavy corrosion and wear, such as printing rollers and shafts (see Fig. 4 and 6).

The findings introduced here were developed in collaboration with the Fraunhofer IKTS in the IGF project 18.154B / DVS-No. 02.094, which was funded by Forschungsvereinigung Schweißen und verwandte Verfahren e.V. of the DVS.

1 Morphology of fine Cr_2O_3 powders for suspension fabrication

2 Suspension feeder with three pressure tanks

4 Printing roller (demonstrator): SHVOF-Cr_2O_3 coating, polished, laser structured and laser engraved

CONTACT

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COAXIAL LASER WIRE BUILDUP WELDING WITH EXTENDED MATERIAL RANGE

THE TASK

Laser wire buildup welding – a material-efficient and clean process – is being used more and more in addition to classical wire and powder-based spraying technologies and arc welding techniques in the field of thermal surface technology. Figure 1 elucidates the connection and adaption of the robot and a wire optical unit COAXwire thus engineered. In this optical unit developed at the IWS, a beam coupled in through an optical fiber cable is coaxially split into three partial beams. Arranging them symmetrically around a central wire supply allows for many degrees of freedom in process guidance, as well as ideal preconditions for process automation.

Reproducible and reliable process conditions are required for the processing of demanding wire material for aerospace applications. For the implementation of the process, not only the laser processing optical unit itself, but also the peripheral systems, such as the laser beam source, process monitoring, wire supplier and CAM software, had to be qualified.

When processing reactive materials, such as aluminum and titanium, an inert environment is an additional necessity, wherein the residual oxygen content should not exceed 50 ppm. Typically used nozzles with annular gap or as trailer-type for local melt pool shieldings cannot maintain this value. Thus, a new protection concept based on shielding gas had to be engineered: it had to ensure quick and easy-to-perform adaption to the optical unit, as well as high gas quality and the processing of free formed surfaces in 5 axes, and be suitable for the additive manufacturing of large-sized components.

OUR SOLUTION

The principle of the COAX technology can be applied to almost any commercially available massive and cored wires on spool. The alloy range comprises light metals, iron and nickel-based alloys, as well as hard materials-binder filler metals. They are used for the coating of surfaces that are tribologically loaded, changes in dimension and shape or repairs to forming dies and cutting tools, as well as for the generation of complex components.

The COAXwire processing optics was refined for the use with the latest generation of diode lasers. Existing lasers have a socket efficiency of more than 30 percent and function in a wavelength range from 940 nm to 1060 nm.

The use of repeatable, highly dynamic wire feeding units was explored. Increased process reliability is achieved by low-friction guideways, sensors for real value capturing, a buffer system to decouple primary and secondary drives, as well as the use of four-roll drives.

The new development of a flexible shielding gas chamber makes it possible to guide the process in a highly clean shielding gas atmosphere. The chamber is designed so that it can be quickly mounted on the CNC machine table or the turn-tilt axis of a robot system. The design mainly consists of a compact basic frame and a flexible foil cap. Defined tool mounting can be performed inwardly using clamping devices. A new head adapter was installed for quick and leak-proof assembly with the optics.

2

RESULTS

The diode laser with a beam parameter product of 30 mm mrad makes possible the optimal illumination of the optical elements over the entire path of the laser beam by the processing optical unit. The resultant focus diameter is 2 mm at a fiber diameter of 600 µm. Having been adapted to this laser type, this coaxial laser wire processing optical component is now compatible with all laser beam sources generally used in material processing.

The shielding gas chamber can be used for these lasers. This chamber can be filled to a residual oxygen content of 20 ppm within 30 minutes by applying pure argon or a mixed gas supply adapted to the welding application on the bottom. This inert atmosphere is kept constant in the chamber constant even if the adapted optical components are moved, enabling especially stable process conditions (Fig. 3). During welding, a gas supply of only 10 l min^{-1} is sufficient due to the system's high permeability.

Coaxial laser wire buildup welding process

3

The refinement of the systems components makes it possible to implement new welding strategies and to extend the manufacturing possibilities for aluminum, titanium and nickel-based alloys as bulk wire, as well as for other alloy compositions as cored wires.

Figure 2 shows an example of a buildup welded pattern part with an external cylindrical shell, whose inner core tapers off, with connecting webs made of Inconel 718. The building rate is 120 cm^3 h^{-1} for a layer thickness of 0.8 mm and a 2.2 kW laser power. It takes 2.5 hours of process time to produce the component of 1.9 kg weight; pure welding time – excluding positioning and idle times – is only 2 hours.

1 Laser wire processing optics COAXwire with flexible shielding gas chamber

2 Welded sample part made of Inconel 718

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BUSINESS UNIT
THERMAL SURFACE TECHNOLOGY

1

AUTOMATED MEASURING SYSTEM FOR POWDER FLOW ANALYSIS

THE TASK

Metrological standardization and qualification of powder gas flows in different cladding nozzles is for the laser powder cladding technology (LPC) a long-term R&D focus at the Fraunhofer IWS. Since the requirements of the users from industry and projects with public funding are ever growing, it is necessary to develop automated and, for specific functions, also standardized measuring equipment able to replace previously typical analog photographic documentation (Fig. 1). The goal of the metrological qualification of a cladding nozzle is to derive quantitative information about the powder beam including the real position and dimension of the powder focus.

OUR SOLUTION

The groups of Additive Manufacturing (Sensors & Software Implementation), Buildup Welding (Design & Development), in collaboration with other departments, such as PLC and Electronics, engineered an automated, completely autonomous powder nozzle measuring device to obtain quantitative data for the valuation of powder flows in powder processing heads.

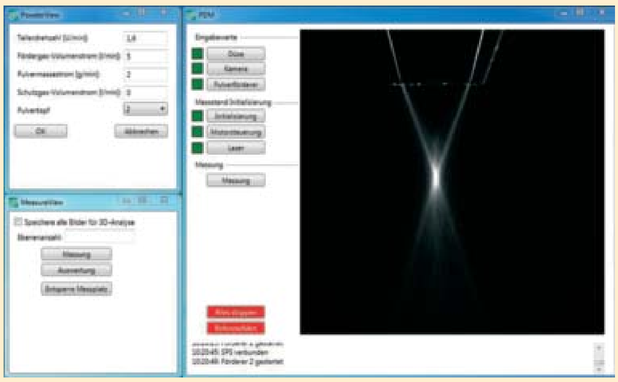
This powder nozzle measuring device (Fig. 3) consists of three main assemblies:

- a powder gas flow measuring device, in robust, lockable housing, with exhaust and collection bucket,
- a standardized powder feeder and
- a PC workplace with the newly developed "PDM" software to analyze the powder-gas flow.

The central "measuring device" component consists of high-precision linear units, which are moving through the powder cladding nozzle in XYZ direction with a vertically aligned line laser in automated mode. Figure 4 explains the internal measuring setup with the carrier rotating unit, on which the line laser and the camera – offset by 90 ° in cladding nozzle direction – are positioned. This rotating unit makes it possible to measure the powder beam path of nozzles with annular gap, multi beam and, in the future, also nozzles for wide beams in various throw-on positions.

During the laser light section measurement the powder is collected in a bucket fixed approximately 900 mm below the nozzle and can be recycled; it can be randomly exchanged depending on the grain fraction. An exhaust for the finest powder particles in the room is run constantly. An automatic door lock, inserted laser protection windows and a machine traffic light indicating the equipment status, as well as a complex switch cabinet with emergency-stop function are fully integrated.

PC-based analysis software "PDM" to measure powder flow in powder nozzles for laser powder cladding



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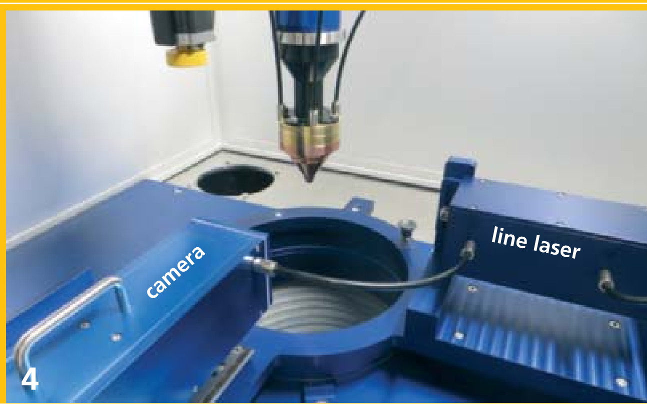

4

RESULTS

Intelligent image processing algorithms are used to analyze the specific working distance of the nozzle and the extension of the powder focus. The distribution of the particles in the powder focus can provide conclusions regarding the powder beam's homogeneity and symmetry. During measurement, the PC-based analysis software "PDM" (Fig. 2) communicates with the test stand control via powerful Ethernet-based field bus technologies. In this communication, in addition to the data exchange itself and transfer of control commands, diagnostic functions are also made available. The measurement consists of several steps, including

- input of nozzle parameters,
- transfer to the test stand and its periphery,
- fully automated adjustment of system components,
- calibration of brightness,
- measuring in a parametrizable resolution and
- documentation of measured values in a standardized data format.

The "PDM" software can be used to input and test several variants of cladding nozzles, camera objectives and the associated powder feeder parameters, such as powder mass flow, carrier gas flow and shielding gas flow (Fig. 2). With the automated initialization of the system, the corresponding cladding nozzle is positioned by the linear axes in XYZ so that the powder density distributions are measured by means of brightness intensities.

The measured results of the powder feeder parameters are stored in standardized image and table formats and can be represented and optimized in the form of a histogram (2D curve diagram) and 3D powder intensity distributions for detailed analysis and diagnostics. The recorded diagrams consider the powder intensity distributions with the working distances from nozzle tip- bottom edge to the powder focus diameter.

1 Powder flow of a COAX14-V5 powder nozzle - closeup

3 Powder nozzle measuring device QM-COAXn developed by the IWS Dresden to characterize powder nozzles for laser powder cladding

4 Rotating table unit with line laser, as well as camera and linear unit with COAX14-V5 powder nozzle

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BUSINESS UNIT
THERMAL SURFACE TECHNOLOGY

NEW CALIBRATION SYSTEM FOR THE "E-MAQS" TEMPERATURE MEASURING SYSTEM

THE TASK

The "E-MAqS" temperature measuring system has been successfully used for various procedures in laser material processing for more than ten years. In comparison with a conventional pyrometric solution, this system offers enormous improvements in process control and guidance, mainly in laser hardening and buildup welding.

Precise measurement of the surface temperature is the basis for optimal process control. It requires exact system calibration to be performed by the user on site because the "E-MAqS" system can be used flexibly and depending on the application. For this purpose, a simple, small and function-adapted calibrating radiation emitter is required. A classical black radiator is too complicated for applications in industry and is also fault-prone.

The intuitive operation of the specific radiator should be controllable both manually and by PC software. Some customers even demand triggering per remote maintenance via Internet, since calibration can thus be offered as a low-cost service worldwide. A self-diagnosis function for automated detection of system or fault states and their representation is also desirable.

OUR SOLUTION

The functional core of the IWS system is a high-power LED array with an optical initial power of 1 W. This LED array irradiates a diffusor disk in a narrow wavelength range, and the disk is limited by a mechanical aperture. The temperature measurement system "E-MAqS" to be calibrated uses the identical narrowband range of the electromagnetic spectrum for temperature measurement.

A programmable current generator is used as the driver stage for the LED array. This integrated circuit is triggered via a bus interface and makes possible current changes with 0.3 mA resolution over a setting range of 600 mA. The master module of this communication is an advanced microprocessor with many communication interfaces. The microprocessor not only makes it possible to communicate with the sensors, but also includes field bus interfaces and provides an adequate Ethernet and thus Internet connection.

A specially adapted highly integrated printed circuit with low space requirements and weight, low susceptibility to faults and optimal energy consumption was developed (Fig. 1). The basic functions are enhanced by circuit functions for self-diagnotics. This way, relevant parameters, such as power, temperature or maximal current and voltage are constantly monitored. Ageing processes, damage to the LED array or other circuit components, and faulty operations can be detected reliably.

The user is informed of the regular calibration cycles by a highly precise real-time clock, while error messages are assigned a timestamp. A position and an acceleration sensor that function as integrated spirit levels, or an angulometer, are additionally installed. An advanced graphic touch screen with intuitive menu guidance functions serves as the human-machine interface (HMI).

2

RESULTS

The LED array at the IWS is calibrated in a temperature range from 800 ° to 1450 °C to the standard of the National Metrology Institute of Germany and is designed as a customized calibrating device for the "E-MAqS" temperature measuring system developed at the IWS. All calibration data are immediately stored by the relevant sensor. Maloperations through loading and use of incorrect calibration data by the user are excluded.

The high power LED array is switched on automatically just for the calibration measurements lasting a few seconds. This prevents ageing of the components, is energy-efficient and allows energy to be supplied by the 24 V connector socket, battery or power-over-Ethernet. The calibration irradiator can be monitored and the calibration itself can be performed by remote maintenance. The system user is responsible for the mechanical setup of all components. After remote access to the network of the respective equipment and single systems, calibration can be performed as a service or, together with the customer, in the form of training. The individual calibration projects are managed via a software module.

The recording of two suitable characteristic lines is sufficient for complete calibration of an "E-MAqS" temperature sensor. A factor describing the specific properties of each configuration, such as aperture, exposure time, binning mode of the camera, as well as measuring distance, attenuation (damping) of the laser optical components and many other influences, may be calculated according to Planck's radiation law. Except for the gray value signal of the camera and the temperature, the mathematical relationship consists only of simple or natural constants. Having found the factor, all the other characteristic lines can be exactly calculated for any arbitrary temperature range.

During a measurement, within a few microseconds, the measuring range of the "E-MAqS" temperature measuring system can be switched, and the exact temperature can be calculated as a function of the measurement and camera parameters. Precise temperature calculations well beyond the calibration range can be performed by means of the exact timer components of the camera. For high temperature processes, temperature measurements can be carried out at 3000 °C with minimal measuring errors. Characteristic curves calculated this way are generated by the software automatically and stored in a format compatible with the control software.

For precise calibration, as wide as possible a perpendicular radiation of the "E-MAqS" systems should be addressed by the calibration irradiator. The angular error should not exceed +/-3 ° ; this requirement can be met easily even in the industrial environment by means of the integrated location sensors and spirit levels.

The different housing shapes of the irradiator were 3D printed. This technology makes possible robust and flexible mechanical designs, both as a portable device and machine component with stationary installation (see Fig. 2).

1 Contact wafer of the LED array for temperature calibration

2 Housing design, housing 3D printed

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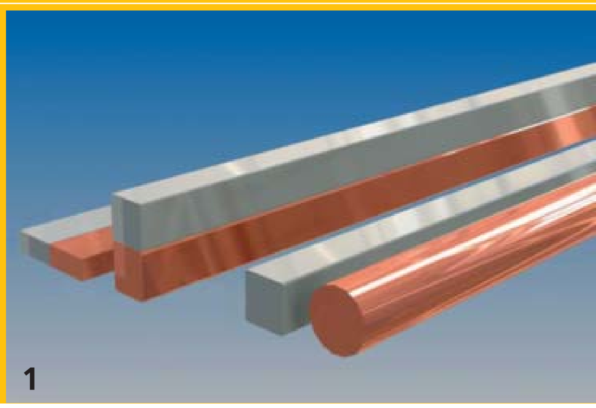

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WIRE-SHAPED LASER ROLL PLATED BIMETALS

THE TASK

Several fields of engineering would have been unthinkable for decades without bimetals. They can be made by cold or hot roll bonding, extrusion of composites or centrifugal composite casting, and are used as contact or connecting elements, fasteners, or as bearing materials. With suitable material compounds, properties can be combined in a semi-finished product, which could not be achieved with a single material, on the one hand. On the other hand, high quality materials can be used more efficiently and thus more economically. Both aspects currently play important roles.

Most bimetal semi-finished products are produced as strips or sheets. This results in labor-intensive machining and is thus costly for applications that demand very slim geometries and thus comprehensive subsequent machining, such as for semi-finished products for electrical contact or connection elements or transition joints. Thin, wire-shaped bimetals are commercially available only as fully coated round wire (for instance Cu/St). Rectangularly shaped wires and profiles for small final sizes would be much more favorable, both in terms of manufacturing engineering and economy.

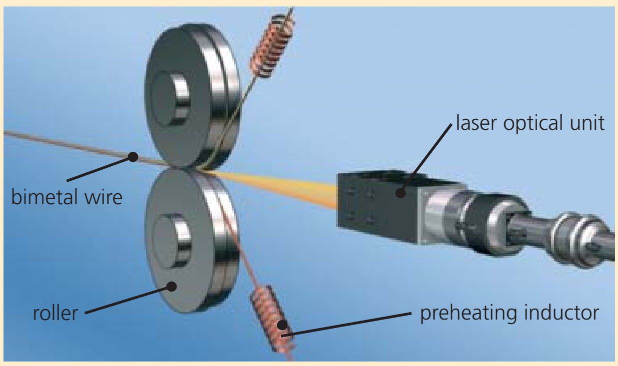
OUR SOLUTION

Manufacturing rectangularly profiled bimetal wires by means of laser roll bonding, a process developed by the Fraunhofer IWS and subsequently patented, is a low-cost alternative to produce thin bimetal semi-finished products. The basic principle of this technique is shown in Figure 2.

In contrast to conventional plating technologies, in laser roll bonding, both semi-finished products (square or rectangular wires with an edge length of up to 5 mm) are guided to the pass at an angle of 45 ° (Fig. 2). In this procedure, the internal wire surfaces can be heated to process temperature immediately before going through the pass by means of a linear or rectangular laser beam. Laser power values of maximally 3 to 4 kW are sufficient for the most wire geometries. The highly concentrated and localized heat input means that forming occurs only in these areas.

If necessary, both initial wires can be individually tempered by preliminary inductive heating. The conditions in the pass can thus be optimally adapted to the specific material combination and geometric requirements. The heated regions and the laser contact zone situated directly in front of the pass are protected against oxidation by a shielding gas enclosure.

Basic principle: inductively supported laser roll bonding of wire-shaped semi-finished products



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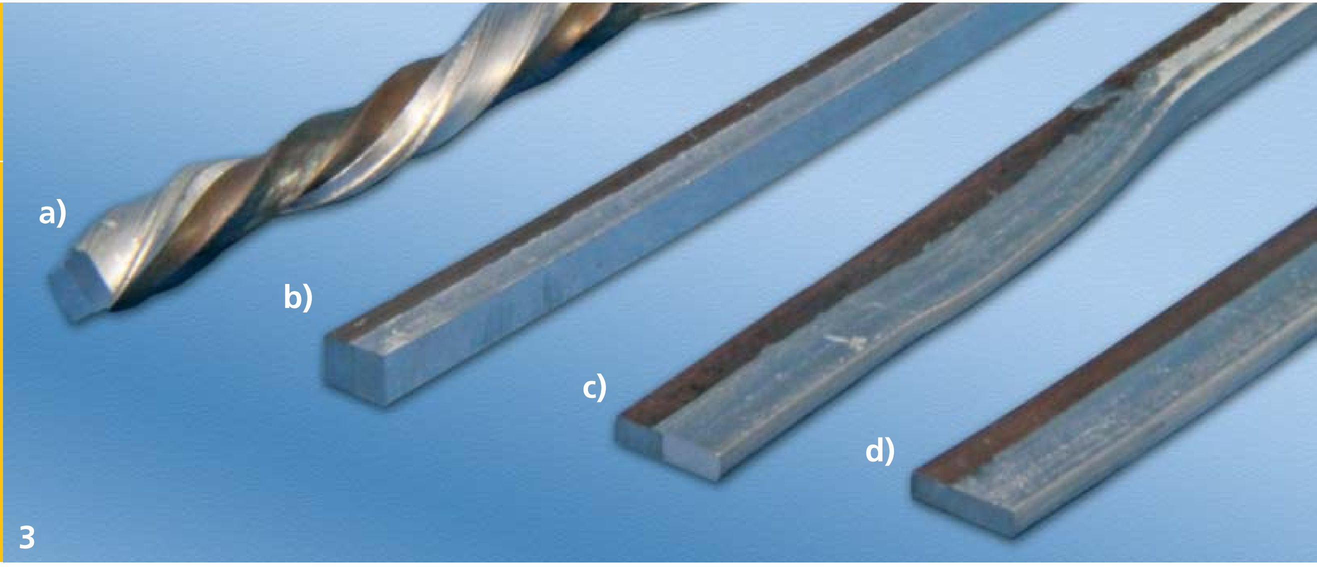

RESULTS

The conditions of the technology (local energy input and local deformation) allow for very small total deformation ratios in order to generate highly loadable bimetal wires. Thus, near-net-shape plating is possible. Greater degrees of freedom arise in the thickness combination of the semi-finished products being joined in comparison with conventional roll plating methods. To guarantee a homogeneous deformation across the entire cross section for wires with narrow rectangular cross sections as well, a roller couple designed as a "closed gauge" is used. The rolls form the desired bimetal contour in the pass.

When the materials are available as wires, many material compounds can be made by laser roll bonding. In addition to several combinations of steels and copper or copper alloys with aluminum or its alloys, steels can also be combined with copper alloys, or bimetals can be made of several steels and contact materials.

Depending on the deformability of the bimetal compound, narrow butt joints of approximately 1 mm thickness are also feasible (Fig. 3). They can be used as transition joints in car assembly or for several electrical engineering/electronics applications.

The combination of laser roll bonding and subsequent cold or semi-hot rolling (see Fig. 3) expands the range of application. A preliminary contour is made by laser roll bonding; then it is swiveled by 90 ° to the rolling plane and rolled to the final contour afterwards. At the IWS, the second roll mill of the laser roll bonding equipment is applied for this step. In this roll mill, the required pass is shaped by 4 mutually offset rollers enabling various rectangular cross sections without tool change.

In principle, suitable initial semi-finished products of square or rectangular contour can also be manufactured from commercially available round wires in the calibration mill in a preliminary operation.

In laser roll bonding, brittle phases are either non-existent or only partially formed which is quite advantageous and provides high-strength material composites with good cold formability – even for material combinations which traditionally strongly tend to form intermetallic phase borders at material transitions such as combinations of steel or copper with Al materials. In laser roll bonding, the deformation of the materials to be combined immediately at the joining zone generates a material flow contrary to the feed direction. Thus the diffusion-controlled formation of intermetallic phase seams at material transitions is prevented.

1 Representation of the initial and final products (simulation), from right: round initial wire, rolled to four-edged wire, rectangular bimetal wire, flat rolled

3 Laser roll plated Cu/Al bimetals a) laser roll bonded and twisted, b) laser induction roll plated, c) transition of laser induction roll plated and rolled, d) rolled to final contour

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SOFTWARE SOLUTIONS FOR INTEGRATED PROCESS CHAINS WITH LASER

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Managing Director
S.K.M. Informatik GmbH

PROF. STEFFEN NOWOTNY
Division manager buildup welding
Fraunhofer IWS

Editor: Mr. Schroeder, how long has the collaboration between the company S.K.M. Informatik GmbH and the IWS been going on, and what was its origin?

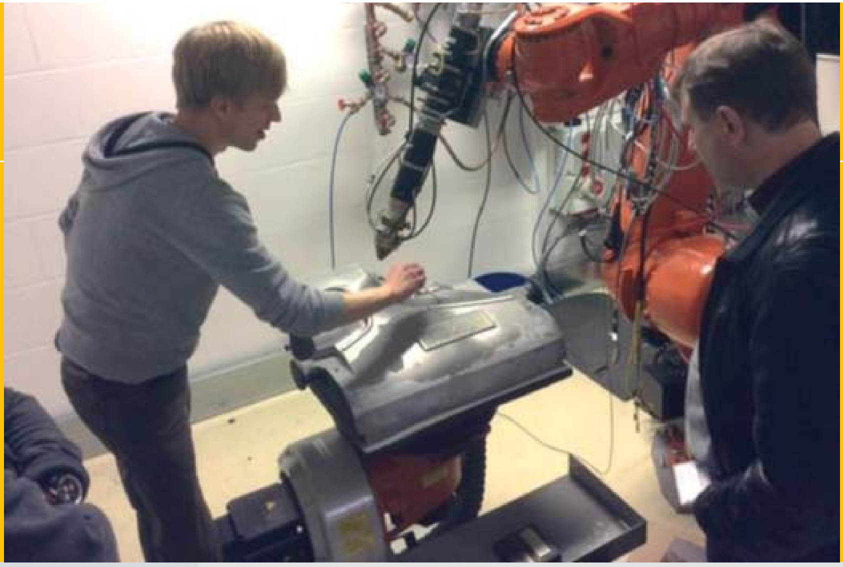
Mr. Schroeder: The collaboration began with a project consulting for the BMBF project PROLAS in Dresden in 1997 by our CAM director Thomas Heptner. Thus, we can celebrate our 20th anniversary this year! In the meantime, the DCAM system by S.K.M. has become a leading platform for individual CAD/CAM solutions in material processing by laser and is used worldwide.

Editor: What are the advantages of your software solutions in comparison with other programming systems?

Mr. Schroeder: From my point of view, our solution is particularly flexible. This results from the sophisticated configuration of our technology modules and the related interfaces. After many years of development by our engineers and software developers, our software is now used to generate programs for CNCs and robot controls, controlling not only path geometries, but also the periphery (laser, powders, gases, sensors) very precisely. The IWS has challenged us again and again.

Prof. Nowotny: What we appreciate in the S.K.M. software module is mainly the efficient CAM planning function and the simulation of continuously path controlled processes with extremely demanding kinematic systems. It is possible to control up to 9 axes in parallel, not only for CNC equipment, but also, and more importantly, with robots equipped with additional axes, external positioners, etc.

Editor: How did laser technology inspire DCAM? What is the role of the IWS here?



Mr. Schroeder: Laser technology and the variety of application scenarios for tools and materials, as well as the geometries and kinematic mechanisms, were great stimuli for the DCAM platform as an offline programming system. This can be seen in the process-specific DCAM technology modules we developed. Numerous functions for CAM-compatible geometry conditioning, efficient strategies for trajectory planning and complex simulation tools were and are constantly under development so that the planning process itself can be simplified and sped up due to a high level of automation. The early collaboration with the IWS in research projects was to a certain extent the "boost", in particular for CAM software technologies dealing with laser buildup welding.

Editor: In what areas of material processing by laser is DCAM currently applied?

Mr. Schroeder: DCAM provides integrated technology modules for laser-based coating, hardening, generative manufacturing, welding and cutting by means of CNC machines and robots. Soon we will also be able to offer solutions for additive manufacturing. The solutions implemented with these modules are today the core CAM business of S.K.M. Our customers are technical colleges, universities, institutes, equipment and system manufacturers, and end users worldwide in almost every industry.

Editor: What was S.K.M.'s motivation for this extraordinarily long-term collaboration – 20 years – exclusively with the IWS?

Mr. Schroeder: Particularly the available market access of the IWS via nozzles technology and the related technology partners, such as laser manufacturers and robot or equipment manufacturers, was and is still strategically important for S.K.M. We are in a top position on the world market thanks to these long industrial partnerships. Intensive collaboration with the IWS in industrial networks, such as AGENT-3D, in demanding customer projects, as well as in ambitious research projects is clearly a real success story.

Prof. Nowotny: What we appreciate at S.K.M. is mainly the great competency and the commitment to address every demanding task, no matter how complicated it is, and offer proposals for its solution.

Editor: What are your predictions for the future?

Mr. Schroeder: S.K.M. has excellent connections with industry, institutions and technical colleges. This is mainly the case for the current environment for additive manufacturing techniques. On the horizon are almost unlimited applications, not only for metal materials, but also in combinations with ceramics and plastics. These are bright prospects – but without question they also place great pressure for development on all of the engineering partners at the same time. In any case, we can state that the signs for us in this area clearly point to growth. S.K.M. is involved in many research projects up to 2020, in three alone with the IWS. S.K.M. also serves as a board member in the AGENT-3D initiative steered by the Fraunhofer IWS.

JOINING

Editor: Dr. Standfuß, laser beam welding – as is known – is the joining technique the Fraunhofer IWS has focused on for many years in its materials-related research. What new challenges do you anticipate?

Dr. Standfuß: Materials-related process engineering at the IWS primarily aims at laser welding processes of multilayers consisting of aluminum and hot crack prone nickel-based alloys, as well as brazing applications. Our experience has shown that holistic solutions in this field demand not only a process engineering view, but also a systems engineering one. For this reason, we have intensively developed and tested the system hardware in recent years. Thus, for instance, we use high-speed camera systems with customized process illumination and image recognition to efficiently develop applications for laser beam brazing and welding by means of scanners. In the future, we will increasingly be able to offer our customers a combination that is both, process systems- and engineering-oriented. To give an initial successful example in this field, we implemented laser beam welding in the production of dissipation lattices for turbochargers for the compressor manufacturer Kompressorenbau Bannewitz (near Dresden) in 2016.

Editor: Are you faced with similar challenges for other joining technologies performed at the IWS as well?

Dr. Standfuß: Of course! For example, we apply our knowledge of laser-based techniques and systems to adhesive bonding and fiber composite technology solutions that are ready for industrial implementation. These developments are relevant to businesses such as aircraft industry, in laser-supported surface pre-processing to fabricate adhesively bonded fiber-metal laminates. Our solutions expand the materials portfolio for aircraft. Working with our partners from industry, we have designed

"Curiosity is always the first step to solving a problem."
Galileo Galilei

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and engineered multi-functional equipment for efficient processing of large surfaces by means of several laser beam and plasma sources to support the process engineering activities of our customers, up to prototype applications and components. This flexible equipment concept is not only optimal for pre-processing of surfaces before adhesive bonding, but also for other manufacturing technologies, such as welding, cutting, ablation and structuring. Metals, plastics and textiles can be processed.

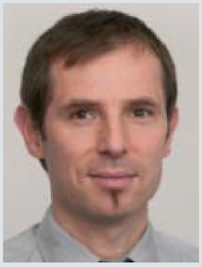
Editor: What is new in friction stir welding?

Dr. Standfuß: An extraordinarily successful multi-year collaboration with the Airbus Group gave us new projects in the joining of fuselage structures. In addition to process and system engineering developments for laser beam welding of skin-stringer joints for metallic fuselage shells, the Special Joining Techniques team concentrates on solutions for a completely welded metallic fuselage. In-depth understanding of the friction stir welding process is required to develop and test a technology suitable for joining demonstrators with aircraft-typical dimensions. Specific system engineering know-how is needed here.

Editor: And what about the design of the components?

Dr. Standfuß: Our studies and knowledge of this domain are becoming increasingly important for our customers. We can offer a complete solution: in addition to the aspects already named – process and systems engineering – component design plays a growing role, particularly for lightweight design applications. For this reason, the team is involved in almost every project of the business unit.

COMPTENCES AND CONTACTS



Dr. Axel Jahn, division manager laser beam joining
☎ *+49 351 83391-3237* / ✉ *axel.jahn@iws.fraunhofer.de*

»The application field of laser beam joining technologies is increasingly broadening. Laser based processes are especially advantageous when the application demands a combination of high precision, component quality and economics. There are rapidly mounting challenges in terms of the increasing range of desired materials and their combinations. The simultaneously increasing demands for higher part strengths lead to the development of ever more complex joining technology solutions. The department "Laser Beam Joining" performs comprehensive tasks. These range from the design of the parts to meet processing and strength requirements and include welding process development for specific materials as well as the evaluation of the part quality and process efficiencies.«

Dr. Dirk Dittrich, group manager laser beam welding
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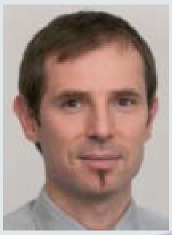
»Process understanding and metal physical background knowledge provide the basis to adapt laser beam welding processes. Processes with integrated short-term heat treatment, with material specific filler materials as well as high frequency beam manipulation enable new approaches to produce crack-free welded joints made from hardenable high strength steels, cast iron, lightweight metal pressure casts and hot-crack prone Al or Ni materials, mixed joints as well as parts of high stiffness. The group follows the credo of "One Stop Solutions", develops tailored welding technologies and supports customers all the way to industrial applications.«



Dr. Axel Jahn, group manager component design
☎ *+49 351 83391-3237* / ✉ *axel.jahn@iws.fraunhofer.de*

»Increasing demands for parts, innovative materials and material combinations as well as novel manufacturing processes typically require new design approaches. The group offers structure-mechanical FE simulation tools, thermo-mechanical modeling and experimental verification. The goal is to design parts with the capability to meet the process needs and application requirements requested by the customer. The solutions are developed in close collaboration with in-house process development and materials characterization.«

Dipl.-Ing. Annett Klotzbach,
group manager adhesive bonding and fiber composite technology
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»The group bundles competences which address industrial demands for joining technologies of fiber composite materials in lightweight constructions. Modern laboratories and efficient systems technology are available for example to develop new pre-treatment process for the large area bonding of metals and polymers. Plasma as well as laser pre-treatment processes are deployed. The group also researches the basics of direct thermal bonding of thermoset composite materials. To prove that a produced joint will be sufficiently strong in real-world environments, we apply ageing studies such as climate and spray tests in addition to mechanical testing.«

Dr. Sebastian Schulze, group manager special joining processes
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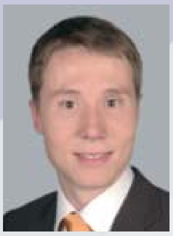
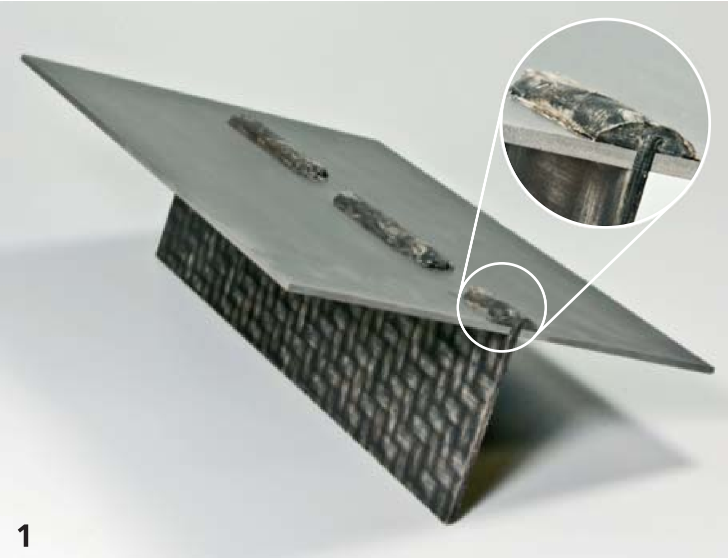


»Often fusion based welding processes are limited in their capability to join modern functional materials. For metals for example, this is so for high strength aluminum alloys. If mixed metal joints are needed, such as welding aluminum and copper, difficulties become even greater since the melt forms intermetallic phases, which strongly reduce strength. The group aims at developing joining processes, which avoid melting and the associated problems. The primary focus is on friction stir welding and electromagnetic pulse welding. We offer process development, prototype welding and system technology developments.«

2016 PROJECT EXAMPLES



1

THERMOMECHANICAL JOINING OF METAL AND FIBER-REINFORCED PLASTICS

THE TASK

Both the automotive and aircraft industries tend to use material composites. Various materials are combined to use their specific advantages depending on the load situation. In many innovative designs, either mixed metallic materials (such as a mix of steel and aluminum) or hybrid structures made of dissimilar materials (such as metal and fiber-reinforced plastics) are in use.

A big challenge in hybrid design is to connect the join partners, which is much more complicated than for monolithic structures. Each material match demands its own customized joining concept based on the requirements of the material, production and design, so that joints of sufficient quality and resilience can be created and reproduced.

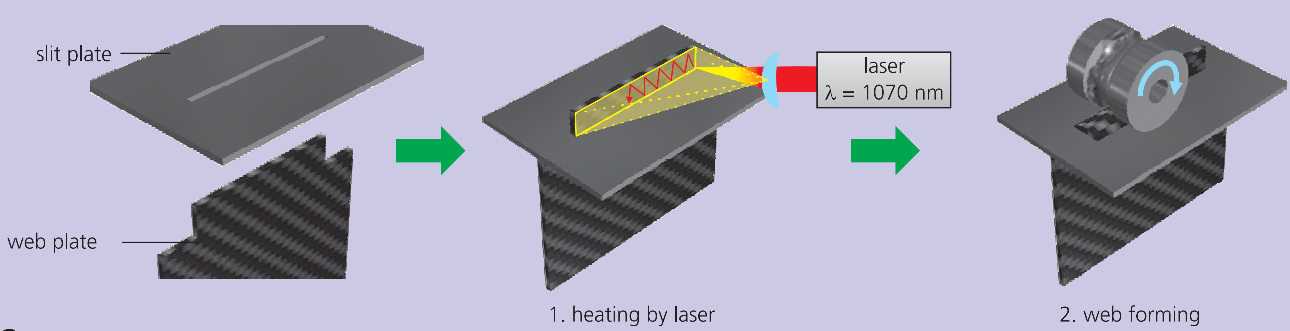
The Fraunhofer IWS Dresden was faced with the challenge of engineering a laser technique capable of joining metal and fiber-reinforced plastics in a T-joint configuration and examining the joint strength.

OUR SOLUTION

The Fraunhofer IWS Dresden developed a self bridging deck-plate connection registered as patent (Patent No.: DE1020111 20269 A1), which has already been used to join two form fitting metal sheets. This principle was applied to join an organosheet (fiber-reinforced thermoplastic) as web plate with a metal sheet as slit plate (Fig. 1).

Once the sheets are fitted together, the projecting part of the fiber-reinforced thermoplastic web plate is heated by means of a fiber laser (wavelength l = 1070 nm). The fiber laser makes it possible to locally precisely position, adjust and control the heat input. Two-dimensional and high-frequency beam ejection by means of a scanner system guarantees homogeneous plastic heating. The heating temperature is paid special attention; for subsequent forming, it must remain in the range between the plastics' melting and decomposition temperatures. Forming the heated plastic web into the desired geometry with a specific forming die finally generates a stable form fit in all 3 spatial directions (Fig. 2).

Web-slit principle



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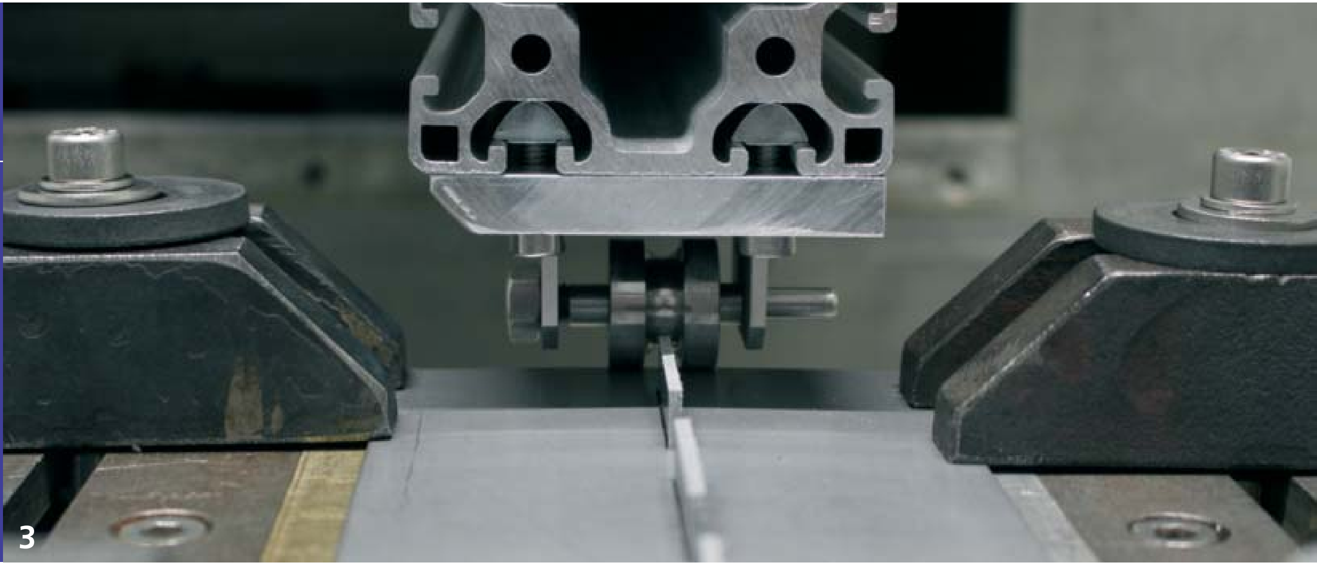

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RESULTS

A specific heating period is required for the greatest homogeneous fusion of the fiber-reinforced plastic web both in terms of the thickness and across the length and height, and in consideration of the low thermal conduction of the plastic. This heating period varies as a function of the chosen material (PP, PA, PE etc.), material thickness and heating strategy (web heating on one or both sides).

The roller tools proved to be particularly suitable for web forming, because their use can largely avoid fiber damage due to low bending radii during forming. Thus, for instance, the groove-roller tools (Fig. 3) create cross section geometries from the molten web projects that are similar to rivet joints (Fig. 4), and are highly reproducible and promise outstanding joint properties.

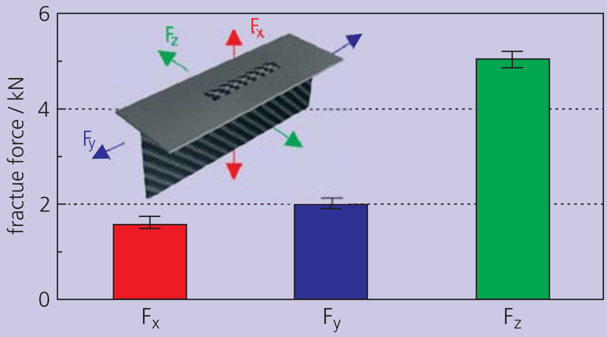
Cross section images of two formed fiber–reinforced plastic webs

4

The hybrid joints were mechanically tested in three load directions for strength assessment and to analyze failure characteristics. Maximal fracture forces of the hybrid joint can be absorbed in the tensile shear direction, transversely to the web (in Fig. 5: Z-direction), which is crucial for the design of the components with these hybrid joints.

The fracture forces for a web length of 20 mm shown in Figure 5 were measured for the joint of a steel slit plate (S355; 1.5 mm thick) with a plastic web reinforced by a fiberglass fabric (E-glass / PA6; 2 mm thick) and a forming geometry similar to that of a rivet are given in Figure 4 (right).

Fracture forces in 3 loading directions of a web-slit joint, material combination steel-GRP



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Further research and investigations at the Fraunhofer IWS Dresden were aimed at improving adhesion and tightness between the plastic and the metal sheet. Pre-treatment by means of laser structuring on the metallic join partners allows significantly higher combined tension and shear forces to be transferred.

The examinations were executed within the scope of the joint project "LaserLeichter" (Laser-Lighter), funded by the BMBF (Federal Ministry for Research and Technology), registered under the code 13N12878.

1 Fiber-reinforced plastic = metal composite

3 Groove roller tool to form geometries similar to those of a rivet joint

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1

EFFICIENT PROCESSING OF LARGE SURFACES BY LASER AND PLASMA TECHNOLOGIES

THE TASK

Efficient solutions for lightweight design in the automotive and aircraft industries demand flexible production and processing technologies for sheet-like semi-finished products made of several materials. This, in turn, requires new and flexible equipment concepts for a combination of different manufacturing technologies, such as welding, cutting, ablation and structuring. These technologies should be equally applicable to processes and technologies for metal, plastics and textiles. To fulfill the conditions mentioned, laser-remote processes with radiation sources adapted to the material properties offer a promising approach.

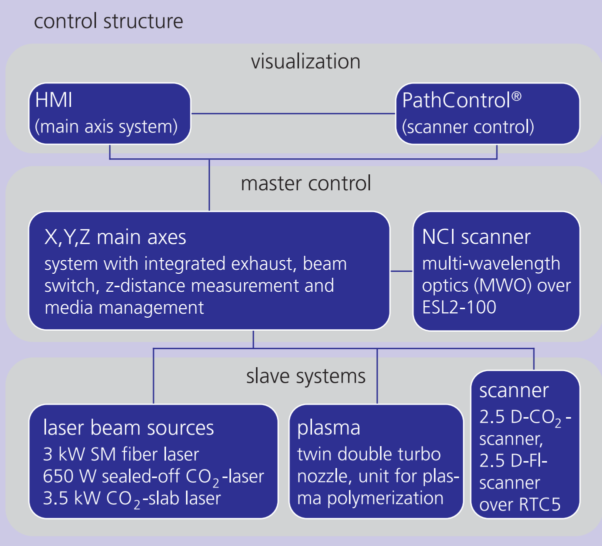
The availability of extremely bright cw radiation sources of different wavelengths opens up new opportunities for remote applications. The scanner working ranges used for beam scanning currently limit the applications. Extensions of the working range can be implemented by combining scanners with Cartesian kinematic systems. The two-dimensional on-the-fly coupling of scanner and axis system has already shown the potential of an optimized axis superposition in practice. The combination of large field scanners with highly dynamic spindle drives promises high-precision and high-speed manufacturing.

The Fraunhofer IWS intends to offer the systems and process engineering potential of these field extensions prospective customers from industry. Together with industrial partners, the IWS is developing a multifunctional prototype system for high-speed manufacturing of plane, moderately shaped, sheet metal and textile prepregs.

OUR SOLUTION

The equipment concept is based on a single column design with a travelling Z axis carrier, holding a platform for the optical devices (Fig. 1). The setup consists of a fixed positioned scanner system, which is linked with a highly dynamic XY travelling unit for on-the-fly material processing. To this setup were added different laser beam sources and equipment for plasma processing at atmospheric pressure. To guarantee reliable processing of fiber-reinforced composite materials, such as CFRP, both the laser and the electrical components of the machine axis system are encapsulated to make them dustproof. A suction chamber that can be adapted to the work distance efficiently removes the by-products from the workspace; the by-products are sub-sequently filtered by means of special equipment and are separated out.

Flexibly expandable control structure of the multifunctional remote system (based on Beckhoff-SPC and PLC)



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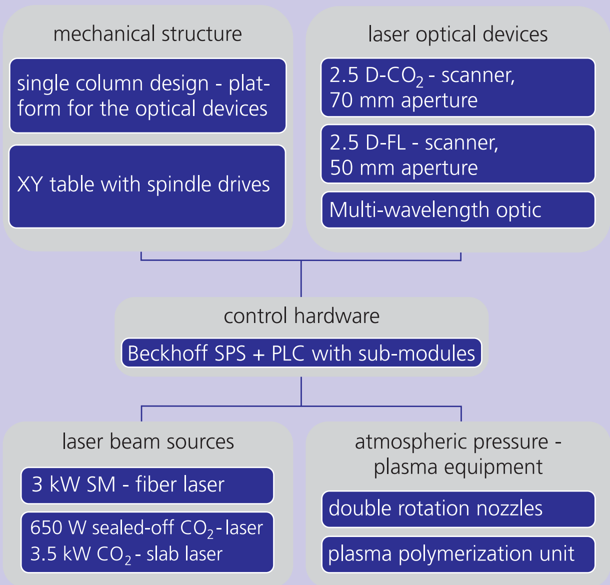
A flexible controlling structure enabling user-friendly programming of all components and embedding of the sensor units was designed for highly dynamic triggering of the driving unit and the coupling with the scanner systems (Fig. 2). The details of the functional components are summarized in Figure 3.

RESULTS

The laser remote processes, which can be implemented by means of the prototype system, are profitably used in multi-material lightweight design for direct thermal joining of metal with thermoplastic fiber-reinforced compounds. Thus, laser macro-structuring by means of a fiber laser allows flexible pre-processing of the metallic joint partners. In the joining step itself, the parts, which overlap one another, are adhesively bonded by laser-induced heating of the metallic joint partner on the rear side, from which heat is conducted into the metal-thermoplastic interface.

System component overview of the multifunctional remote system for laser and plasma processing of large surfaces



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If the task is to produce hybrid laminates from metals and thermoplastics or organosheets continuously, then heating by the laser directly occurs in the joining gap between the two prepregs. The surface of the locally molten thermoplastic is bonded to the metal between pressing rolls (Fig. 4). Using the remote technology with integrated laser power control, depending on the scanner position, sheets up to 0.5 m width can be joined.

The equipment can also be used for pre-processing of surfaces before adhesive bonding. In aeronautics, GLARE® composite sheets – a mulitlayer structure of aluminum films and fiberglass-reinforced resin layers are regarded as an alternative to pure aluminum alloys. The individual metallic layers, each a few tenths of a millimeter thick, are conventionally pre-processed on both sides in chemical solutions and subsequently adhesively bonded with the fiberglass rovings or fabrics. Similar adherence strength values can be obtained if chemical pre-processing is replaced by laser pre-processing, which enables an increase in surface and boosts oxide layer growth. Laser-remote processing is one way to replace chemical pre-processing and can significantly contribute to a higher level of resource efficiency and environmental protection.

1 *Multifunctional remote system at the Fraunhofer IWS*

4 *Experimental setup for continuous joining of metal and organosheet*

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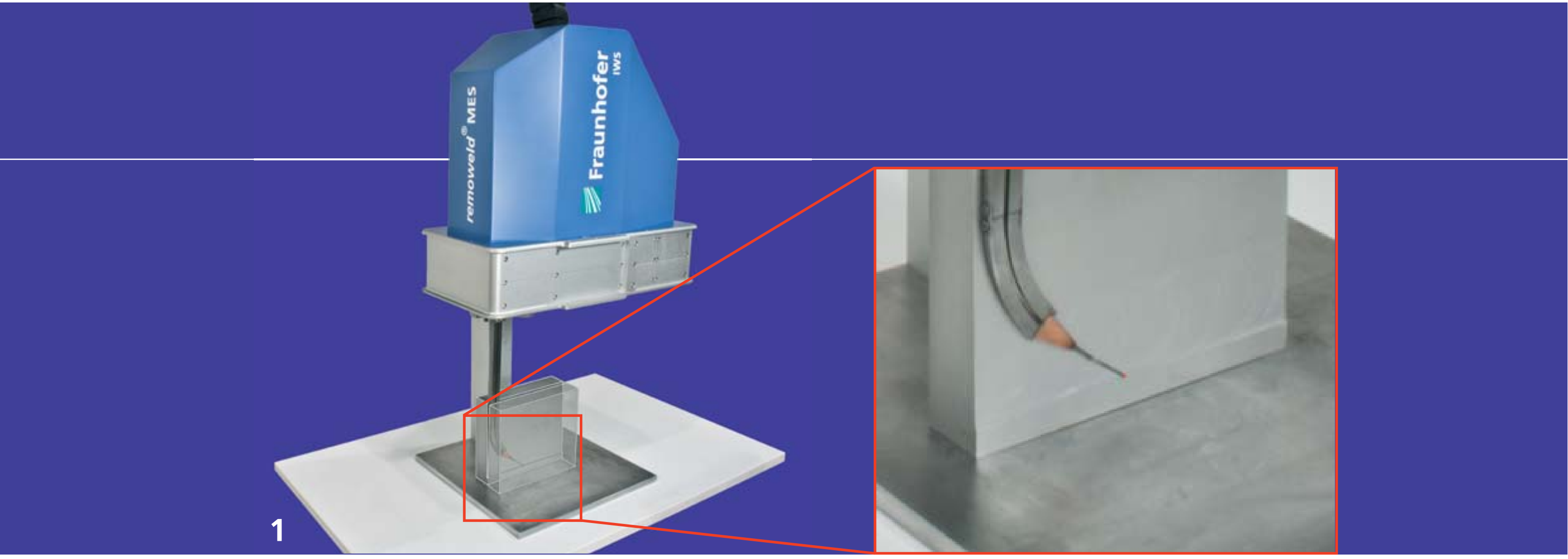

1

JOINING OF NICKEL-BASED SUPER ALLOYS BY LASER-MULTI-PASS-NARROW-GAP WELDING

THE TASK

Policy changes related to renewable energy sources that aim both to protect the environment and to conserve resources are undoubtedly the only choice. In future, it will thus be very important for energy generation to operate powerfully and highly efficient thermal power stations to guarantee the basic energy supply.

With nickel-based super alloys, global power station manufacturers can achieve an increase in energy efficiency of both existing and planned thermal power stations of up to 50 percent by increasing the vapor temperature to 700 °C. The nickel-based super alloy 617occ is a promising material for use in the so-called 700 °C power station. Joining of thick-walled components made of nickel-based super alloys, in particular of the alloy 617occ, in high-temperature processes is a major challenge. Conventional welding techniques can significantly impair the high-temperature characteristics of hot crack prone alloys (for instance in creep behavior and creep rupture strength) due to the unacceptably high heat input.

To cope with current materials developments and to maintain the huge potential for adding value to the manufacturing of thick-walled components (> 30 mm) made of the nickel-based super alloys that are popular in Germany, the Fraunhofer IWS Dresden developed laser-multi-pass-narrow-gap welding (Laser-MPNG)- a laser-based welding technique for low-damage and hot crack-free joining of nickel-based super alloys.

OUR SOLUTION

The Laser-MPNG technology developed at the Fraunhofer IWS offers great potential for joining nickel-based super alloys thanks to its technological specifics. In general, the technique is characterized by very low energies per unit length, which, in turn, reduces angular distortions and thermal damages of the joining parts' base material. The consumption of filler metal is drastically reduced, because the seams can be made in a very narrow manner, with gaps from 2 to 3 mm width and a minimal side opening angle of less than 2 °.

The welding technology was developed by means of the *removeld*®MPNG welding head prototype (Fig. 1). The modular structure of the welding head allows the configuration of the optical unit to be flexibly adapted to the materials to be welded and their specific properties. Thanks to the optical and mechanical design, components of maximum 250 mm wall thickness can be welded in the future.

Welding process engineering was consequently based on the profitability of the technique's application. Nickel-based super alloys were joined by using extremely bright fiber laser sources up to a power of 5 kW. An advantage of these lasers is the reasonable investment for equipment manufacturers. With these lasers, extremely small gap sizes during welding are feasible due to the low beam parameter product.

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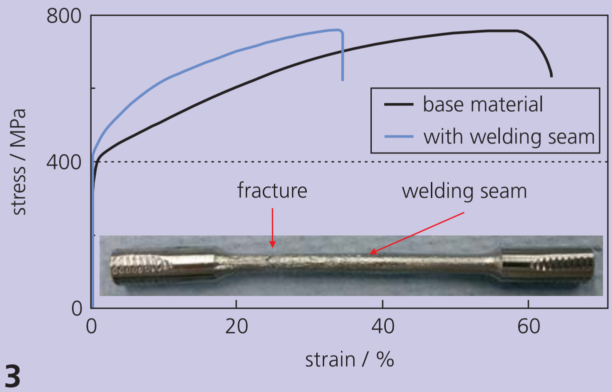
4

RESULTS

Welding tests on component-like cylindrical alloy 617occ samples after solution heat treatment (Fig. 2) have demonstrated that it is possible to generate sufficiently adhered welding seams free of cracks by laser MPNG and using a similar filler metal (Fig. 4). Using high-frequency beam oscillation minimizes the occurrence of pores and guarantees that the filler material is molten off reliably. As a result, quasi side-parallel welding seams of homogenous structure are formed.

Examinations of the mechanical welding seam strength values in a direction lateral to the welding direction showed – in comparison with the base metal – higher yield strength values and the same tensile strength values (Fig. 3). The samples with weld material failed throughout in the base material, but not in the weld material or the heat-affected zone. Melting losses of the alloying elements were not found in the weld material.

Strength characteristics of tensile test items made of base metal and test items with welding seam – in comparison



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The next goal of the project is to increase welding seam depth incrementally beyond 100 mm to maximum 200 mm. These studies were accompanied by the determination of the creep and fatigue characteristics of the welds created, as well as the development and implementation of an inline-capable non-destructive testing procedure.

The results introduced were gained by the research-oriented, strategic alliance of the Fraunhofer institutes IWS, IWM and IKTS. They include excerpts from the project entitled "Laser-multi-pass-narrow-gap welding applied to key components of future energy-efficient and resource-saving high-temperature processes", funded internally by the Fraunhofer-Gesellschaft.

1 Welding head (prototype) removeld®MPNG

2 Component-like cylindrical sample of 50 mm wall thickness

4 Microscope detailed image of the welds of a welding seam, alloy 617occ

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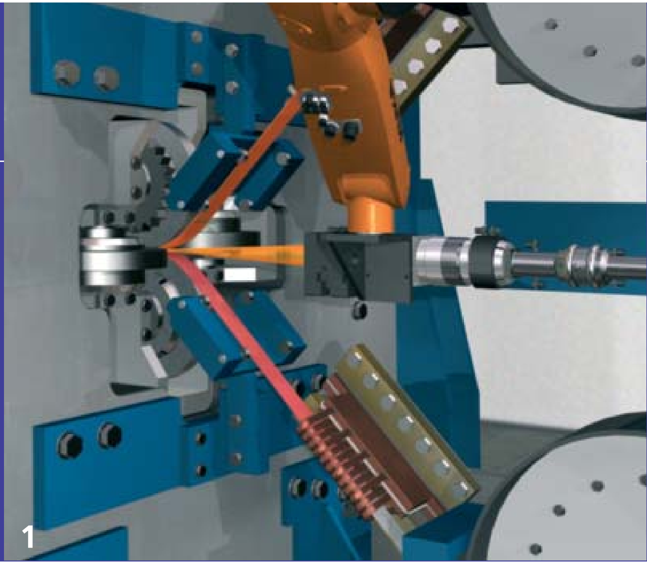


MATERIALS ENGINEERING STUDIES FOR THE FABRICATION OF AL/CU CONNECTIONS

THE TASK

Energy storage devices that can be produced in large quantities and put on the market at reasonable prices are an essential precondition for electric mobility. The interconnection of cells by means of so-called high-current cell connectors is a key process in the configuration of battery modules from individual battery cells. This process has been hitherto implemented mechanically by screwing with all of its disadvantages in terms of costs and reliability over the duration of the battery life. The joint project "BatCon" was aimed at replacing the screwing solution. Function-integrated high-current connectors for battery modules had to be developed by means of cost-optimized manufacturing technologies in a holistic approach.

The most difficult challenge in the use of thermal joining techniques is the limited solubility of the associated metals with one another (Al, Cu) in the solid state, tending to form brittle, intermetallic phases. At the beginning of the project, the fabrication of fusion-welded joints of aluminum and copper was not state-of-the-art because brittle intermetallic phases emerged. Consequently, the aim of the project was to develop process technologies and a fundamental understanding of the material behavior related to the joining of aluminum with copper, and to engineer new joining technologies for the manufacturing of semi-finished products for cell connectors optimized in terms of function and costs.

OUR SOLUTION

Making use of the IWS' expertise in joining materials or material composites for which fusion-welding either requires special conditions or cannot be done at all, the innovative special joining techniques of laser induction roll plating (see also ps. 64/65) and friction stir welding were refined to make them applicable in the production of Al/Cu cell connectors as semi-finished products. During this process the required reproducibility, efficiency and functionality was also taken into account.

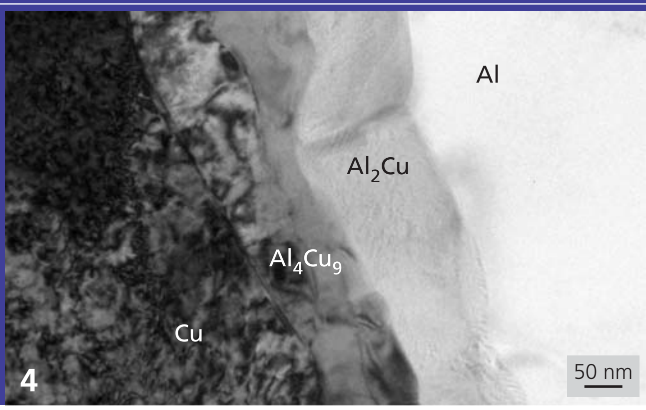
Other core competencies used within the project are material development strategies accompanying the process development, materials characterization and materials testing. They are used in the project, for example, to understand the predominant joining mechanisms and to test the joint connections reliability.

RESULTS

The first project stage was focused on the comparison of different joining approaches for bi-metallic Al/Cu composite fabrication of semi-finished products. Laser beam welding, friction stir welding and laser induction roll plating were examined in this technological assessment.

In terms of materials engineering, friction stir welding and laser induction roll plating can be considered most suitable for joining Al and Cu sheets because they guarantee a thin and continuous phase seam, sound adhesion and low contact resistance values. As a result of the technology itself the joint areas (intermetallic phase seam) through friction stir welding are clearly smaller than in laser induction roll plating. However, this phenomenon can result in low strength, especially under cyclic load.

Due to its high productivity laser induction roll plating is the most economical technology by far for the production of large quantities, despite the high investment costs. Since laser induction roll plating has hitherto been performed only to join completely overlapping strips, a hardware concept intended for



partial overlapping strips was developed (Figures 1, 2). The goal was to fabricate the Al/Cu cell connector whose bonding zone is located not symmetrical as shown in Figure 3.

The implementation of this complex and novel solution for laser induction roll plating included design, fabrication and use of special calibrating rolls, as well as the integration of a diode laser with specific line optics. It also demanded comprehensive process development to achieve the necessary speed, quality and reliability of the joining process. The feasibility of the fabrication of the semi-finished products of bimetallic Al/Cu cell connectors could be demonstrated in the project.

In comparison with the state-of-the-art, represented by screwing of the cell connectors, welding of the cell connectors fabricated by laser induction roll plating offers the following advantages:

- higher level of automation with clearly reduced production costs,
- significantly reduced contact resistances and thus lower electrical losses,
- enhanced long-term reliability and mechanical stability as well as
- less weight and more freedom of design to reduce the installation space.

The Al/Cu connections produced by means of various joining techniques were subject to comprehensive comparative structural analyses. Apart from friction stir welding and laser induction roll plating, the examinations also involved the techniques developed by the project partners: laser beam welding, ultrasonic welding and electromagnetic pulse welding. The formation of the intermetallic phases Al_4Cu_9 and Al_2Cu in the joint zone is characteristic for all of the joining techniques (Fig. 4). During laser beam welding, the thickness of the intermetallic intermixture zone cannot be reduced below 10 µm, which results in relatively high embrittlement and thus risk of cracking and breakage. In general, for this material combination, laser beam welding shows better suitability for thin films (thickness < 1 mm) than for sheets of higher thickness and thus stiffness.

However, with the other techniques investigated, it is possible to limit phase seam thickness to approximately 1 µm, which is not critical for the electrical properties and mechanical stability. The phase seam necessary for the actual joining do not show any ageing characteristics even at maximal temperatures of 100 °C relevant for use over more than 500 h.

Research performed from 2013 to 2015 was funded by the Federal Ministry for Economic Affairs and Energy (BMWi) within the scope of the "Elektro Power" funding initiative in the project "BatCon", registered under FKZ 0101X12055C.

1 Process principle – laser induction roll plating (with laser beam (middle) and the Al and Cu strips fed into the rolls)

2 Detail of the roll stand

3 Al/Cu cell connector welded by laser beam

4 TEM image: intermetallic phase seam

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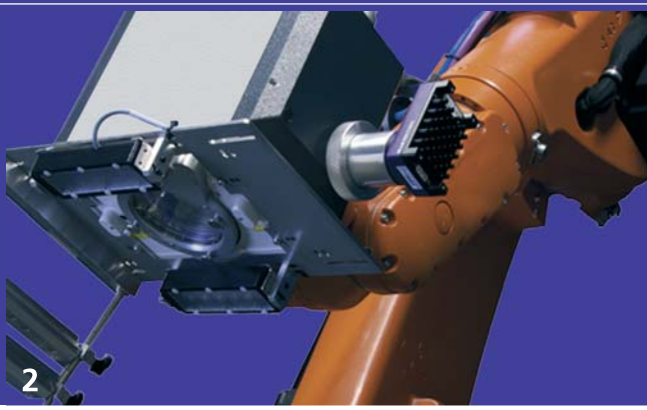

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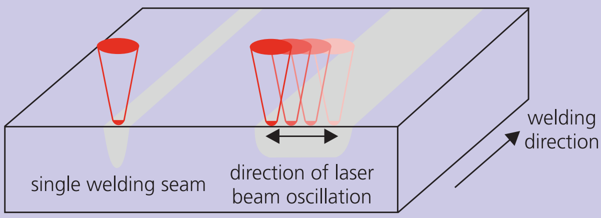
IMPROVED JOINT CONNECTION THROUGH BRAZING WITH LASER BEAM OSCILLATION

THE TASK

Joining by laser is still of interest to automobile manufacturers and provides the impetus to develop joints of lightweight materials, such as aluminum, high-strength steels, and mixed materials. Many assemblies, including doors, lift-gates and other car body sheet parts can be joined using laser processes. An advantage of the laser arises from the focused and controlled heat input, which, in turn, results in less part distortion.

Oscillation of the laser beam in welding or brazing (Fig. 1) can contribute to improving the seam quality. A high-speed camera system for process monitoring can be used to enhance understanding and optimization of the technique.

Laser beam oscillation principle



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OUR SOLUTION

A laser technique for brazing aluminum-aluminum- and steel-aluminum joints was developed and intentionally engineered with a high-power 3D galvo scanner for manipulation of the laser beam (Fig. 2) at the Fraunhofer Center for Laser Applications (CLA) in Plymouth, Michigan, USA. Based on typical requirements from the automotive industry, two different joint types were examined. Zinc coated steel (dual phase steel) and aluminum sheets made of a 6000 series AlMgSi alloy (thickness from 1.2 mm to 1.5 mm) (see Fig. 3), were used for the development. Wires of various aluminum alloys were supplied as filler metal to achieve defect-free brazing joints. Real-time process visualization and monitoring were performed by means of a high-speed camera system engineered at the Fraunhofer CLA in cooperation with Fraunhofer IWS (Fig. 4).

A special test program was designed and executed for a better understanding of the influence of wire positioning and alignment, as well as of the most important process parameters. Brazing tests were performed with and without laser beam oscillation and with different oscillation patterns; the test samples were analyzed afterwards by microscopy. During the experiments high speed video data of the process was captured and processed using software.

Aluminum-aluminum joint, brazed with the help of laser beam oscillation

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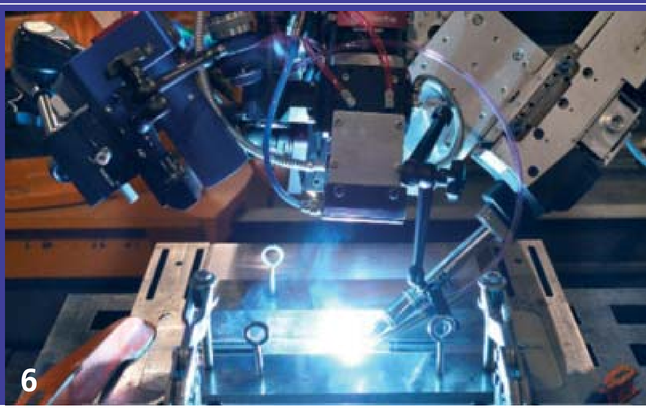

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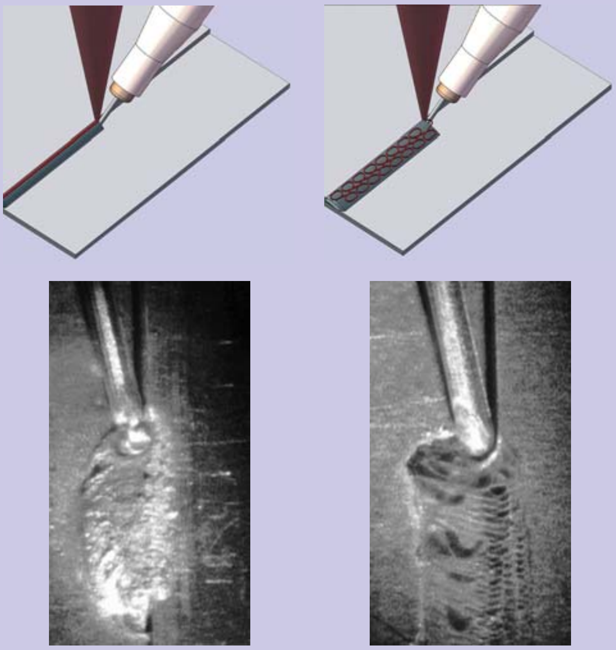
RESULTS

Laser brazing with beam oscillation provided higher quality and wider brazing joints. The results demonstrated that the horizontal beam oscillation transverse to the feed direction (Fig. 5 right) led to the optimal brazing profile. The brazing profile can also be well controlled in terms of laser beam oscillation and seam position by process monitoring and keeping wire feeding constant.

Images recorded by means of the high-speed camera of the laser brazing process, without (left) and with beam oscillation (right)



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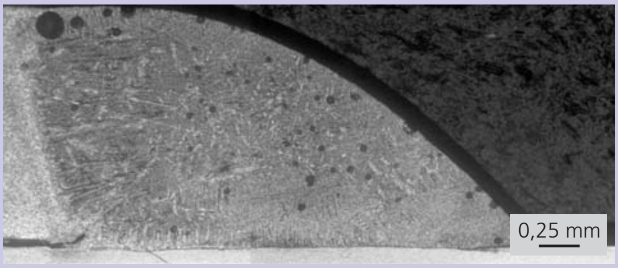
The steel-aluminum joints brazed by laser with beam oscillation achieved higher strength and toughness values than joints brazed without beam oscillation. This can be attributed to the fact that heat supply to the steel sheet is better controlled and the formation of brittle intermetallic phases is minimized through beam oscillation.

The high-speed camera system significantly enhances the monitoring of both wire position and welding seam, simplifying process development and optimization of brazing processes (Fig. 6).

Examining the aluminum-aluminum joint, it was discovered that the brazing wire can either be located at the seam or at a position on the bottom base material at a certain distance to the seam. Nevertheless, the wire melts in a controlled manner, and the substrate material only minimally affects the process (Fig. 7).

Cross-section of aluminum-steel joint brazed by means of beam oscillation and aluminum filler wire



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2 Scanner system for laser beam oscillation

4 Process monitoring system created by the Fraunhofer CLA

6 Brazing process with process monitoring

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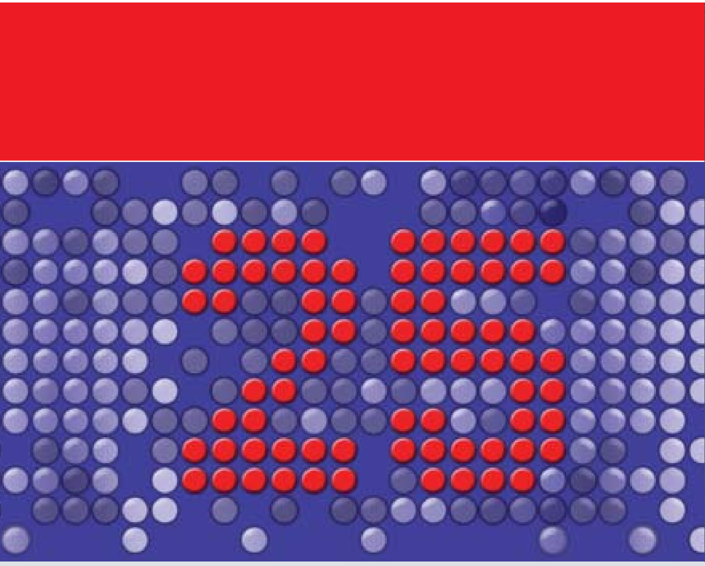


JOINING IN THE AIRCRAFT INDUSTRY – MORE EFFICIENCY DUE TO LIGHTWEIGHT DESIGN

DR. JENS HACKIUS
Fuselage Structure Research&Technology
Architecture&Integration
Centre of Competence Structure
Airbus

DR. JENS STANDFUSS
Business unit manager joining
Fraunhofer IWS Dresden

Editor: Dr. Hackius, the aircraft industry is known for continuous innovation management. What issues did Airbus research together with the IWS? And why did you choose this Dresden institute?

Dr. Hackius: The initiative of Prof. Berndt Brenner (IWS) was crucial to the collaboration with the IWS. As head of the Joining department, during a colloquium, he contacted Mr. Brenneis from Airbus and discussed numerous ideas for enhancing the manufacturing technology in aeronautics. At that time, Airbus was just looking for a development partner able to support the start of production in laser beam welding of stringer-skin joints in the Nordenham manufacturing plant. Their in-depth materials engineering knowledge, manufacturing background, and equipment concepts for laser beam welding convinced the Airbus representative. They helped out with a laser in the short term and started the first test series in Dresden. The results were impressive, and thus the foundation was laid for a long term partnership.

Editor: Dr. Standfuß, what does this step mean for the IWS?

Dr. Standfuß: To cope with the needs of Airbus in the short and medium terms, we needed larger test equipment for laser beam welding as soon as possible. The approach was entirely new. Two lasers, wire supply and clamping fixture had to be triggered simultaneously for 3D machining of sheets up to 10 m long and 3 m wide. The system is equipped with 26 axes, and the greatest precision is required for synchronization and matching.

Financing the equipment was also a challenge. Prof. Brenner did a lot of persuading of the Saxon ministries, so that the investment permit for the so-called XXL hardware was finally obtained by the IWS in July 2002. In 2004, the system was ready and could be launched at the IWS.

Editor: What development steps did the Fraunhofer IWS support?

Dr. Hackius: They began with laser welding of stringer-skin joints for new aluminum alloys. Given that several kilometers of stringer length are installed in an aircraft – where the stringers have to stabilize the skin fields longitudinally and are fixed with tens of thousands of riveted joints – the greatest effect regarding lightweight construction and reduction of manufacturing costs was expected just here. The Dresden researchers tested the welded components in-house, analyzed the influencing parameters and occurrence of damage and, subsequently, proposed new stringer geometries optimized in terms of stresses and loads. Both partners registered for a patent for this. The next project stage was focused on clip welding, that is the connection between the longitudinal and circumferential weld. The Fraunhofer IWS developed a concept for automated clip welding and implemented it in the XXL system. In this process, another idea to be protected by patent was born: pre-deposition of a tape-like filler metal. Finally, laser welding of the longitudinal seam to join several panels was examined. The IWS had good ideas for this as well, and followed up on several concepts for damage tolerant design. But the laser welded material was not yet able to withstand the component testing requirements. Other technological concepts were needed.

Editor: Was the IWS able to help you here?

Dr. Hackius: The IWS was not deterred by the initial failure and embarked upon an examination of friction stir welding technology. Together with a medium-sized Saxon enterprise, the institute surprised us with an entirely new, extremely low-cost machine concept for the technique and implemented it in practice. The structure of the parallel kinematic mechanism created by the company Metrom is currently used as the basis for investigations in friction stir welding at the IWS, as well as the development of innovative clamping solutions.

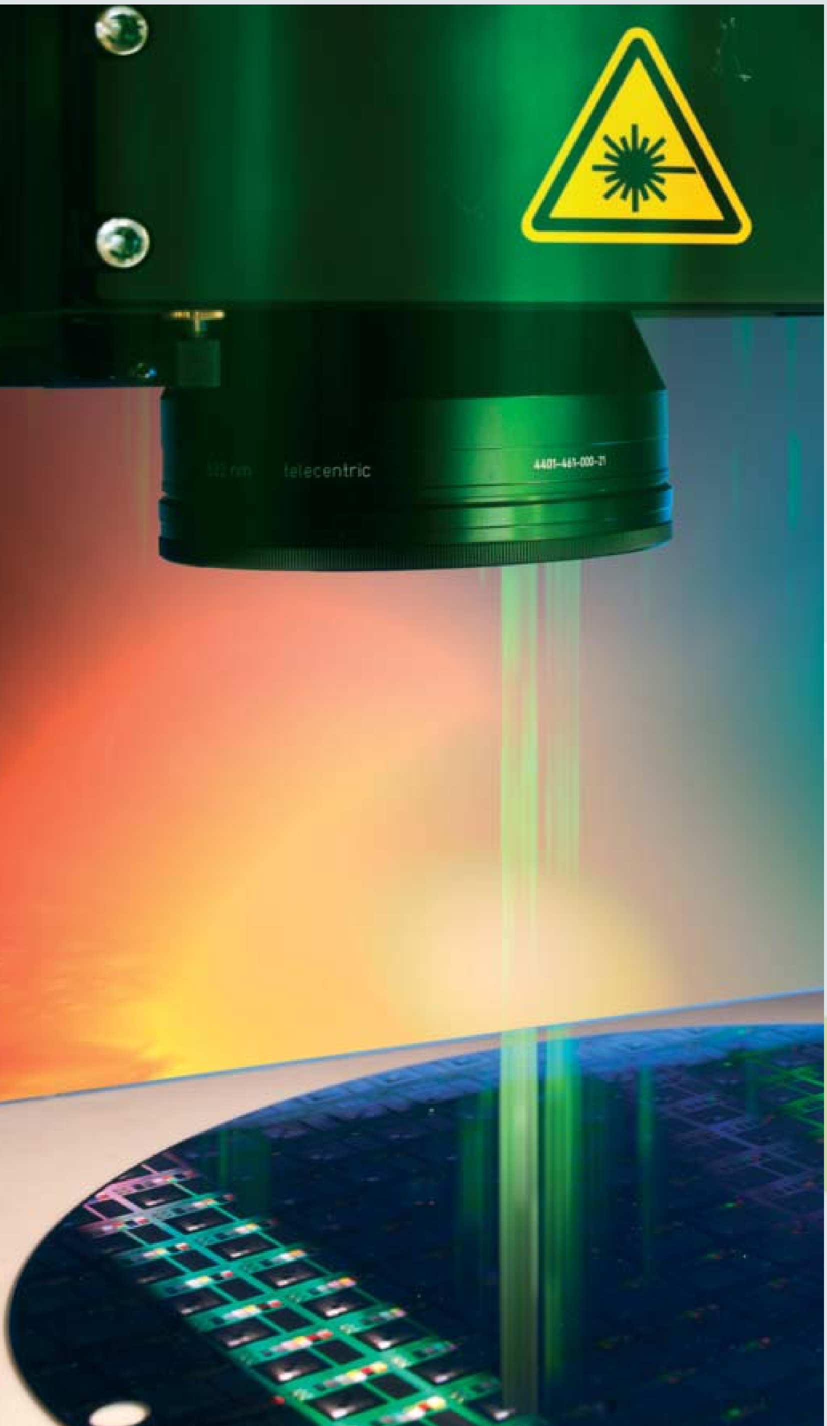
Editor: What, from your point of view, made the collaboration with the IWS particularly pleasant?

Dr. Hackius: As a rule, the IWS follows a holistic approach, seeing materials, techniques, hardware systems, operational stability and damage tolerance always as a whole and in terms of their interactions. Comprehensive work packages are implemented reliably and in a forward-looking manner. The excellent infrastructure in the field of lasers and equipment, as well as in materials engineering, provides numerous opportunities for collaboration.

Editor: Are there new development goals?

Dr. Hackius: Friction stir welding of the longitudinal seam has just been demonstrated for A320 shells in their original size. The industrial implementation of this technology is just under preparation. New, promising material concepts, so-called fiber-metal laminates, have already been tested at the Fraunhofer IWS for their processability. Applied to surface pre-processing before adhesive bonding, laser technology with laser remote techniques offers enormous potential in comparison with the current wet-chemical processes in terms of manufacturing costs and environmental protection.

MICROTECHNOLOGY



Editor: Dr. Klotzbach, how do you see the current microtechnology market?

Dr. Klotzbach: The medical industry and the healthcare market are the strongest drivers of microtechnology innovations in Europe. In Germany, the automotive industry – influenced by electric mobility for low-emission drive concepts- has given subcontracting industries as a whole a push toward innovation, which manifests itself strongly in microtechnological developments. We can offer solutions for a wide range of demands, both for process technologies by means of micro materials processing and systems engineering.

Editor: What opportunities are there for the IWS in microtechnology?

Dr. Klotzbach: We have aimely considered the use of the laser as an outstanding tool for microtechnology. Its material selectivity and precise controllability offered significant progress in the customized manufacturing of microfluidic structures and, thus, of microphysiological systems for various applications. Our focus is mainly on systems with integrated pneumatic pumps and sensors. Novel microphysiological systems with integrated membrane technology to be used as scaffolds have been developed to examine biological barriers, such as in the kidney. Thus, we are able to offer a microphysiological "starter kit" for medical and biological applications in 2016.

New materials, such as high performance ceramics, fiber-reinforced plastics or layered material composites (laminates) are widely used in the field of mobility, as well as in energy generation and storage. The microtechnology business unit, with comprehensive expertise in ultrashort pulsed laser processing, is well positioned.

"All modern thought is permeated by the idea of thinking the unthinkable."

Michel Foucault

BUSINESS UNIT MANAGER

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Editor: Which of your business unit's achievements in 2016 would you like to draw attention to?

Dr. Klotzbach: Having continuously developed the technology of direct laser interference patterning (DLIP), we can now generate functional microstructures over large areas quickly. Our new optical concepts make it possible to structure 2 to 5 m^2 areas per minute. Various industrial applications demand different DLIP optical strategies. Thus, we offer the "DLIP-High-Speed", "FlexDLIP" and "R2R-DLIP" variants to our customers. The team headed by Professor Andrés Lasagni took the second place in the 2016 Berthold Leibinger Innovation Competition for its work "Laser beams stamp microstructures" in direct laser interference patterning.

Editor: Your business unit frequently takes an interdisciplinary approach – what does that mean for the various technologies?

Dr. Klotzbach: Our interdisciplinary strategy is based on our employees communication with one another, which is conducive to multi-technological approaches. Take, for instance, the microstructured surfaces for reduced friction and wear, or the enhancing of surface properties for medical implants. We were able to demonstrate two techniques and that they can be combined in one process. In this hybrid process, multiply functional, hierarchical structures can be manufactured on the surface, while maintaining the individual advantages.

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Dipl.-Ing. Volker Franke, group manager micro materials processing
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»The institute has a comprehensive modern pool of laser processing equipment and offers a wealth of know-how in laser micro processing. Applied research focuses on micro machining to miniaturize functional elements in mechanical engineering, equipment, vehicle and device manufacturing as well as bio and medical device industries. Examples include the generation of 3D structures with feature sizes in the sub-mm range. Structures are formed on the surfaces of polymers, metals, ceramics, quarzites and biocompatible materials. Laser technology is also applied to clean such surfaces. Diagnostics is equally critical to understand processes and process results. Thus the group has special foci to use high speed camera technologies for optical laser process analytics and to use terahertz radiation for non-destructive analytics of materials.«

Dr. Frank Sonntag, group manager micro- and biosystems technology
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»Research in the field of micro- and bio systems technologies includes the design, simulation and rapid manufacturing of microfluidic structures, micro reactors and complex lab-on-chip-systems. Our scientists rely on their comprehensive know-how with regard to the implementation of integrated functional elements such as pneumatically and electrically powered micro pumps or optical and electrical sensors. These systems are completed with automation and periphery concepts (hardware and software) for laboratories in biomedical engineering. Based on design technology, additive manufacturing of 3D scaffolds and micro perfusion systems we are able to develop tailored platforms for diagnostics, non-animal testing and tissue engineering.«

Prof. Andrés-Fabián Lasagni, group manager surface functionalization
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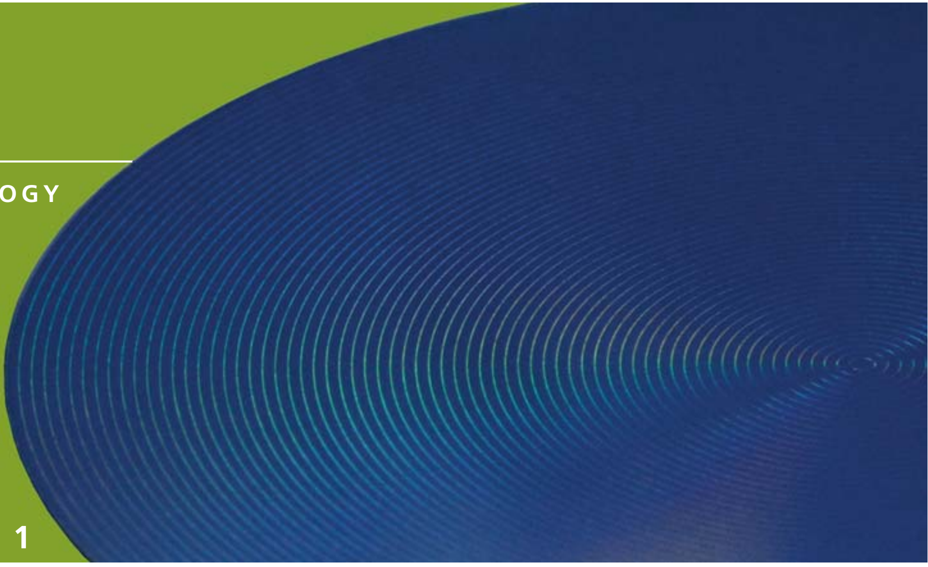
»As a result of evolutionary processes, we find today structures on plant and animal surfaces, which provide unique properties, such as low friction or antibacterial effects. Following these biological structures it is nowadays possible to implement their properties in technological surfaces. New methods are able to create two and three dimensional micro and nanostructures over large macroscopic areas on surfaces of polymers, metals, ceramics and coatings. By the help of these methods, we are able to generated structured surfaces with significantly optimized properties. Thus technological modifications of chemical, optical or mechanical material properties enable the decisive advancement of products in the field of bio technology, photonics and tribology.«

2016 PROJECT EXAMPLES



1

MICROSTRUCTURED SURFACES TO CONTROL FRICTION AND WEAR

THE TASK

Losses due to friction represent energy quantities that go unused when two moving surfaces interact. Wear on these surfaces reduces the life time of components or the entire system. It is estimated that an average economic loss of approximately 2 to 7 percent of the annual gross domestic product is due to friction and wear.

Significant savings potentials in energy and materials arise for systems that are otherwise technically mature when the tribological, i. e. friction- and wear-related, parameters of mechanically interacting surfaces are influenced by patterning. Prominent examples are common in vehicle manufacturing.

Power train components subjected to endurance stress, such as piston rings, have to be modified on their surfaces on a microscopic scale, without impairing their macroscopic functionality, such as their impermeability to oil and dissipation of heat. Since, as a rule, friction and wear influence one another, in almost all cases the influence of the lubricant has to be considered. An optimal solution for the customer has to be developed.

OUR SOLUTION

The characteristics of metallic surfaces in the automotive industry are modified using several strategies. Functional structures can be generated in partial areas by several laser techniques, but also over entire surfaces, whereby super hard, diamond-like coatings are deposited. The two variants have different goals. Patterning super-fine pocket structures with pulsed laser systems extends the functionality; reservoirs for lubricant emerge, and components sliding across the surface float. Thus, dry friction or mixed friction phases, as well as wear, are minimized. Coating entire surfaces with low roughness and hardness also aims at minimal wear and offers per se less frictional resistance, which, in turn, saves lubricant.

What is fascinating in this approach is the combination of functional microstructures with the advantages of a functional layer over the entire surface. These coatings frequently are subject to high internal stresses and are optically transparent (i. e. lower absorption to laser irradiation). To be able to process them at all in a defined manner and with minimal damage, ultrashort pulsed laser systems with highly flexible beam deflection were used. Customized manufacturing strategies were engineered for each application.

RESULTS

The group of technologies known as "Laser texturing of power train components with hard material coatings, subjected to friction" is consistently focused on (ultra) short pulsed laser systems. Longer pulsed lasers typically result in thermal influences that are hard to avoid, such as the formation of throw ups, increased hardness, and flaking. Another disadvantage is the risk of insufficient absorption. The range of base and layer materials to be addressed can be extended when using (ultra) short pulses and laser wavelengths that are shorter than the infrared wavelength widely in use.

Cavities without burr, of defined component-constant depth with minimal tolerances (Fig. 1), are generated when brittle-hard materials are impacted by laser pulses with pulse durations of 500 fs to10 ps. Diameter and depth, as well as functional layout, are designed for each purpose: piston rings, for example, were functionalized radially with an offset point lattice, with an approximately 2 µm thick diamond-like carbon coating. Point-to-point distances ranged from 50 to 150 µm, the diameters from approx. 15 to 50 µm, and the depth values from approx. 2 to 5 µm (Fig. 2 and 3). Laser structuring in this way retains the sealing capabilities of the piston rings and significantly contributes to minimizing friction by floating on a lubricant film that is dynamically generated. The frictional coefficient can ultimately be diminished by up to 25 percent (as a result of laser structuring).

Life time was significantly increased for other vehicle components without additional sealing functionality, by introducing cavities in a rotationally symmetrical configuration down to a depth of approximately 1 µm (Fig. 1).

Comparing unstructured or conventionally structured and coated components with laser structured and coated ones under the influence of a lubricant, is very complicated. Tests with (ultra) short pulsed laser systems, combined with highly flexible beam deflection devices, demonstrated that customized functional microstructures positively and controllably affect wear characteristics, as well as the frictional parameters of the hard-material-coated components.

1 Rotationally symmetrical laser functionalized surface

2 Laser microstructured piston ring coated with hard material

3 Detail of structure - "piston ring functionalization"

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2

SCANNER-BASED DIRECT LASER INTERFERENCE PATTERNING

THE TASK

Functionalization of a technical surface by means of natural, biologically inspired structures is an innovation driver of the 21st century. The functionalities achieved are suitable for tribological applications in the automotive industry, for improved biocompatibility in medical and biotechnological industries, and for optical applications, such as product and trademark protection.

Established manufacturing techniques for structures in the nano- and micrometer range are either too expensive or time-consuming (electron beam lithography) or provide low structure resolution (direct laser writing). The Fraunhofer IWS has been and is developing the direct laser interference patterning (DLIP) technology to generate complex structures with high resolution and high process velocity and customizing them for industrial requirements.

OUR SOLUTION

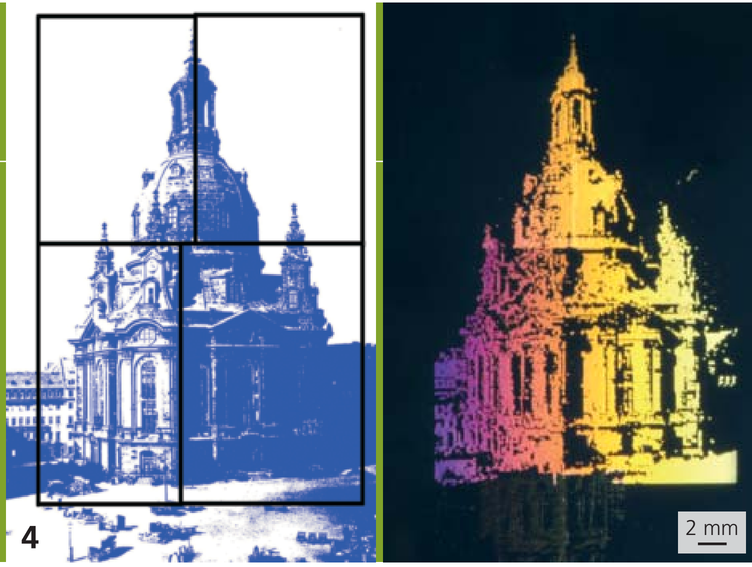
In direct laser interference patterning, a coherent laser beam is split into two or more sub-beams, which are superposed on the component surface. Defined structures can be applied to components due to interference (as periodic modulation of laser intensity) resulting from superposition.

Fraunhofer IWS scientists were able to fabricate constant structure geometries on large areas at rates of up to 1 $m^2 min^{-1}$ by means of the DLIP technique. However, the generation of variable structure geometries at high process velocities makes it necessary to develop advanced solutions.

The Fraunhofer IWS has succeeded for the first time in developing a structuring procedure able to fabricate these variable structures in short process times. The solution arises from combining a DLIP processing head with a galvanometer scanner system (Fig. 1). The newly developed DLIP scanner system is compatible to the µFab systems of the Fraunhofer IWS, which are suitable for industrial use (Fig. 2).

Dimensioning the optical device to control several partial beams using the galvanometer scanner system and engineering of a holistic patterning concept was demanding. However, we were successful, so that high-power laser sources with frequencies up to the megahertz region can be applied to fabricate variable surface structures "on-the-fly".

In addition to the increase in possibilities for rapid prototyping, in-line structuring in roll-to-roll processes, as well as the processing of 3D geometries, all the advantages of the DLIP technique – such as direct processing of metals and polymers, without using expensive cleanroom conditions – are maintained.



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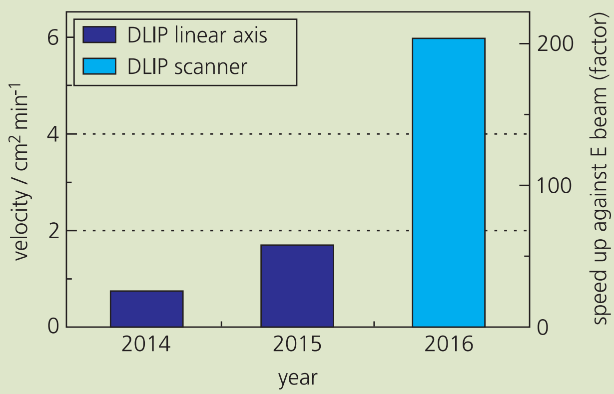
RESULTS

Comparing the process speeds of a DLIP system with linear axes and the newly developed DLIP galvanometer scanner system shows the obvious innovation potential for the reduction of process times (Fig. 3). We were only able to achieve low process speeds of approximately 1.5 cm² min^{-1} by means of a DLIP system with linear axes up to 2015.

The DLIP galvanometer scanner system enables significantly higher area rates of approximately 6 cm² min^{-1} (with 1 kHz pulse repetition rate of the laser system) due to its low inertia. Process speed, which is in general only limited by the pulse repetition rate of the laser system used (Fig. 3), can thus been increased.

A significant growth of the area rate from 60 cm² min^{-1} (@ 10 kHz) to 1500 cm² min^{-1} (@ 250 kHz) can be expected from more powerful laser sources in combination with the DLIP scanner system. This results in shorter process times (in many applications such as rapid prototyping) and thus competitive advantages.

Process speeds of various DLIP concepts



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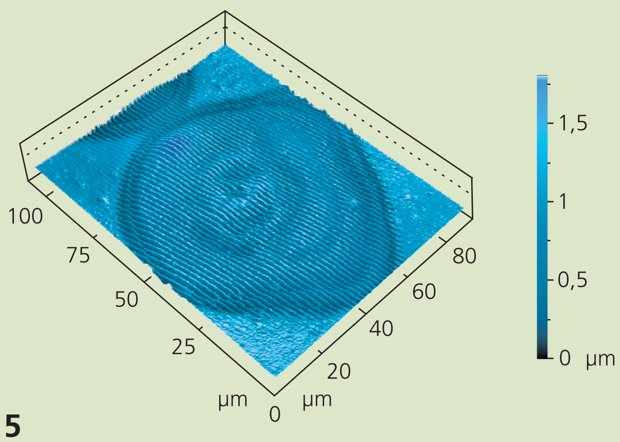
Larger sized surface regions are structured by means of optimized stitching methods: the regions to be structured are divided into several surface segments and are structured sequentially. This strategy can be used for the fabrication of decorative elements for product and trademark protection (Fig. 4).

The structures generated by the DLIP scanner system can be varied in their spatial periods and fabricated on several materials, such as polymers (Fig. 5).

Confocal microscopy image of a structured PET surface



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1 DLIP scanner head
2 DLIP-µFAB industrial system
4 Decorative theme: Dresden Church of our Lady

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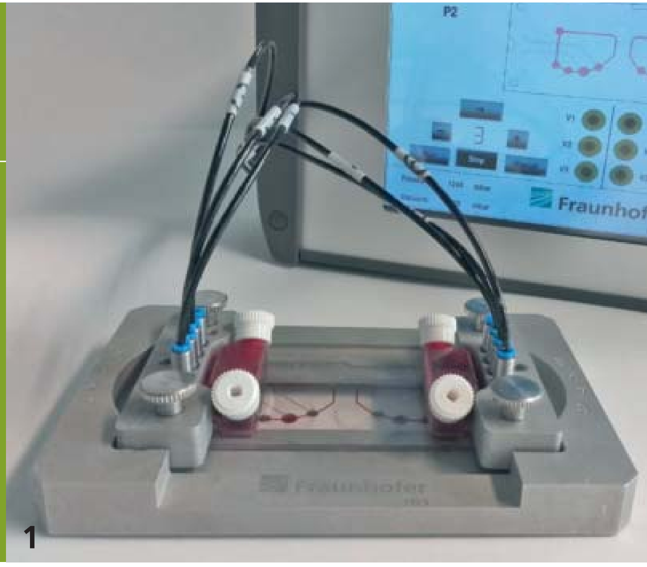


1

LASER-BASED CELL MANIPULATION IN MICRO PHYSIOLOGICAL SYSTEMS

THE TASK

Many diseases of human blood circulation and its associated organs, such as the kidney, result from damaged individual endothelial cells, which line the vascular system from the inside. Cell regeneration in interaction with the immune system plays a key role both in understanding and in curing these diseases.

Cell culture experiments in microphysiological systems are very suitable for the scientific exploration of both the underlying regeneration mechanisms and the interaction of the various cell types. Essential processes of the human body – such as blood flow of the cardiovascular system – are simulated by combining a technical pump system with the co-culture of human blood and vascular cells. The examination of the cell regeneration mechanism in such a system is carried out on vascular cells whose inner walls are damaged. Up to now the cells have been artificially damaged by means of a cannula or by chemical stimulation. These methods, however, cannot be applied to a closed cell culture system; one reason is the required high precision of the damage.

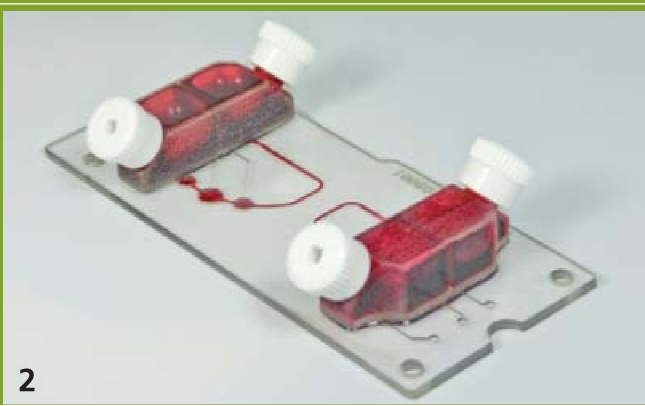
The Fraunhofer IWS Dresden had to manipulate – if possible, only partially – or damage selected cell regions in a defined manner in a closed microphysiological system that was inaccessible mechanically and from the outside. The course of the damage and the subsequent regeneration mechanisms had to be documented in parallel with images and videos.

OUR SOLUTION

A microphysiological basic platform (Fig. 1) for simultaneous cultivation of various cell types under conditions similar to those of the human body was developed at the IWS. This platform consisted of a controlling unit and a multilayer microfluidic system made of polymer films. A pump similar to the heart, cell culture segments and media reservoirs were integrated. The microfluidic platform was flexibly designed and can be adapted to several problems depending on the cell culture requirements.

A microphysiological system with a pump similar to the heart channels in which the inner surface is lined by endothelial cells, and circulating immune cells – so-called monocytes – was developed (Fig. 2) to examine the regeneration mechanisms of the human vascular system and its interactions with immunological cells. The damage induced by the laser can be traced easily by means of laser patterned position markers in the polymer film near the cell culture segments.

Laser sources with constant power were coupled into the beam path of a passing light microscope for defined selective damaging of cells. The setup developed makes it possible to optically inspect defined segments of microphysiological systems and to manipulate them intentionally by laser irradiation and monitor them on-line.



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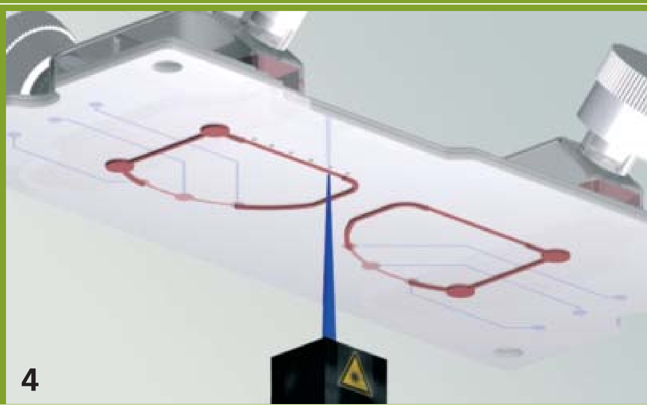

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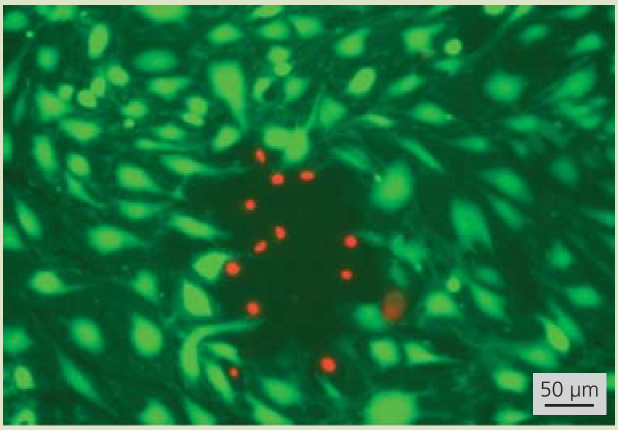
RESULTS

A defined cell structure in the closed vascular cell layer was damaged at several points by the microphysiological system in combination with the laser-based optical manipulation system. Based on the design of the microphysiological system, several points in the systems, which were marked before, can be damaged in a defined way (Fig. 4). The selective damage in a closed cell layer is shown in Figure 3.

Subsequent regeneration and the impact of the immune cells during this process were studied by means of time-lapse microscopy. The processes underlying the regeneration – proliferation of endothelial cells and the migration to the place of damage – can be examined with the setup and documented, and thus contribute to a better understanding of the complex interaction between immune and endothelial cells.

Selective damage (red) in a closed cell layer (green) of endothelial cells and monocytes



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As a next step, the developed system can be used to analyze how medications affect the regeneration process. These comparative studies may be based on reproducible intentional cell damaging in a defined way, by means of the technology developed.

1 Microphysiological basic system

2 Adapted microphysiological system for the co-culture

4 Laser-based damaging on a marked position in the micro-physiological system

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1

FOCUSED ION BEAM (FIB) ANALYSIS AND MICROSTRUCTURING

THE TASK

To take full advantage of the mechanical strength potential is an essential goal in the development of advanced materials, layer systems and manufacturing techniques. Detailed knowledge of the microstructures is very important here; the heterogeneities intentionally induced in the material, such as grain boundaries and precipitations, must be studied, on the one hand. On the other hand, the consequences of material defects, such as discontinuities, microcracks or delaminations must also be known. In this classical field of materialography and materials testing, there is a need to obtain data in greater resolution for the observation of ever-smaller structural lengths and to analyze representative or intentionally selected volumes. The established cross section preparation method with its planar images must be extended into a 3D tomography imaging and analysis for the exploration of anisotropic structures in composite and gradient materials, as well as in layer systems.

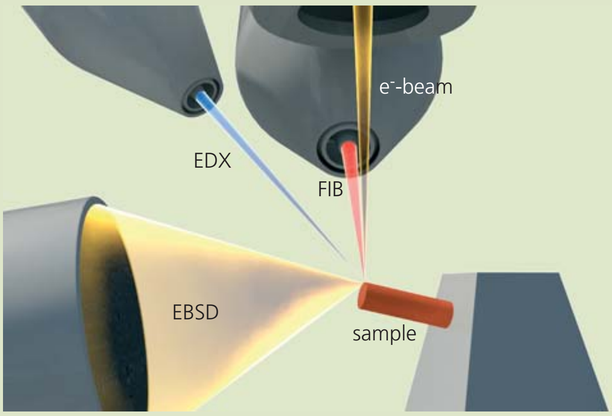
OUR SOLUTION

The application of the focused ion beam (FIB) has been established for high-precision, low-damage, pinpoint and efficient preparation of the material structure in a volume element that determines the properties. When combined with a scanning electron microscope (SEM) in a so-called dual-beam device, the samples can be fabricated and analyzed in linked process steps.

For the requirements of the Fraunhofer IWS Dresden and its cooperation partners, a special FIB/SEM dual-beam system is used. It is equipped with detectors for secondary, backscattered and transmitted electrons and with systems for the analysis of chemical composition (energy dispersive X-ray spectroscopy, EDX), as well as crystal orientation analysis (electron back scattered diffraction, EBSD), and with a micromanipulator (Fig. 1).

One advantage of the system setup is that the detectors and the EDX and EBSD analysis systems are aligned to the ion and electron beam in a way that works without moving the sample from the preparation to the measuring processes and vice versa (Fig. 2). Thus, complex analyses, such as tomography measurements, can be performed with simultaneously high geometric accuracy in an automated mode. Moreover, miniature components whose dimensions with sizes in the micrometer range and accuracies below 100 nm can also be fabricated.

Geometry of ion and electron beam, EDX and EBSD analysis systems and the sample



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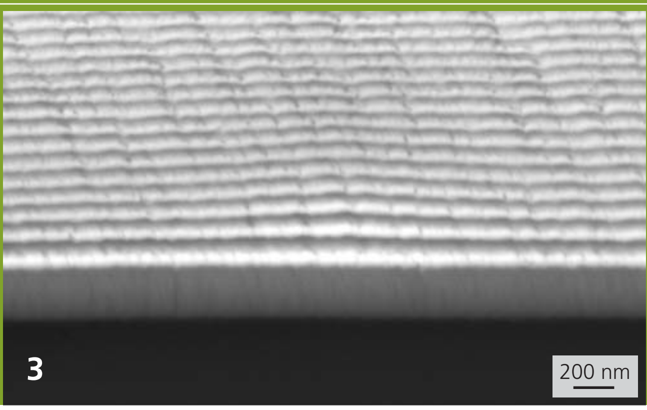


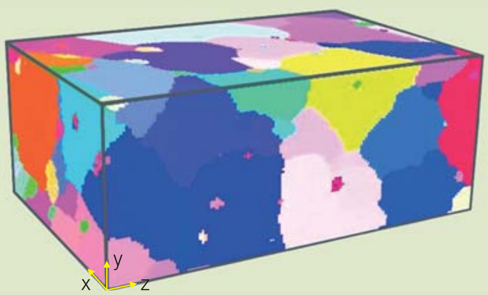
RESULTS

When analyzing layer systems, the advantages of the FIB preparation, mainly for highly accurate and low-damage sample preparation, take effect. A cross-section of a stack of silicon oxide/hafnium oxide coatings on an aluminum substrate with an adhesive coating (nickel) is depicted in Figure 3. The coatings with hafnium content appear brighter, whereas the coatings with silicon appear darker. The high resolution at thickness values of approximately 40 nm is apparent.

The microstructure of a Sn-Cu-Ag alloy is represented in Figure 4, with color coded distribution of the grain orientations. It was prepared and analyzed by combined ablation of material slices in z-direction and mapping of orientations in x-y planes by means of electron backscatter diffraction (EBSD). The 3D model of the examined volume is generated by stacking the planar mappings in z-direction.

A great deal of information can be derived from the 3D structure analysis with resolutions in the order of 10 nm, such as how the manufacturing processes influence the formation of the structure and the resulting characteristics. This analysis can also be used as a basis for the modelling of microstructures in a simulation model (for example, to forecast the deformation characteristics of a structure).

Color coded 3D representation of crystal orientations in a Sn-Cu-Ag alloy



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The FIB technology is particularly suitable to generate geometric structures in the micro- and nanoscale. To fabricate special X-ray optical components (multilayer Laue lenses), thin slabs with parallel surfaces and predefined thickness must be precisely cut out from very detailed small preforms. This precision together with the prevention of damage by amorphization is only feasible when using focused ion beams with optimized process steps in preparation. The example from Figure 5 depicts the smooth surface and homogeneous geometry achieved in the FIB cut. Slab thickness is 1 µm.

FIB technology offers many options for better understanding the structure property correlations of the heterogeneous structure of the materials and layer systems generated at the IWS and opens up new potentials for the fabrication of micro- and nanoscale components.

1 FIB/SEM dual-beam device

3 Layer stack of SiO_2 and HfO_2

5 Micro-component for a multilayer Laue lens

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MEASUREMENT WITH LIGHT – MULTI-SPECTRAL PROFILOMETRY

THE TASK

Structuring of technical surfaces by means of laser systems is crucial for industry. The equipment for the precise manufacturing of micro and submicrostructures for surface functionalization and the generation of falsification-protected features is extremely complicated. New and task-specific measurement techniques must be developed to fulfill these requirements.

In laser surface structuring, it is very important to inspect material ablation in the running process. Ablation of material changes during processing as a function of the material properties of each surface and the machine parameters. Ablation of single microcoatings also changes the substrate material locally. These alterations in the material make it nearly impossible to calculate the ablation level for deeper layers in advance, and a special measurement technique is needed. Ablation volume quality and measuring rate are essential criteria for suitability for industrial use.

An industry-proof technique for material ablation measurement in laser micro structuring was developed at the IWS application center AZOM, Zwickau. The project is focused on precise and quick recording of coating properties during the process to implement the technology in the production environment.

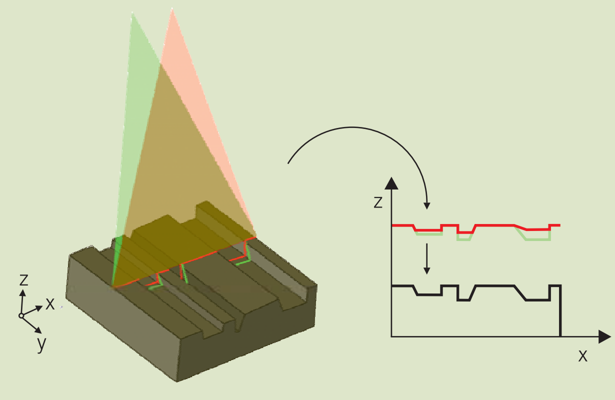
OUR SOLUTION

The task was solved by modifying and installing a measurement system based on light section technology (Fig. 1). Three different wavelengths are integrated in the setup. Lasers of 455 nm, 532 nm and 638 nm wavelength were focused linearly on the relevant sample region by cylinder lenses and separated into R(red), G(green) and B(blue) channels by camera.

The three wavelengths were radiated onto the sample at various angles to avoid shadows on three-dimensional surface structures, which would otherwise limit the potential range for height measurement. Using three different wavelengths also expands the range for dynamic detection in terms of the material properties.

The specific absorption of the various substrate materials relevant for laser materials processing means that conventional measurement systems are limited in their detection capability. Using several spectral ranges for surface analysis, one can

Principal multi-spectral measurement setup (two spectral ranges)



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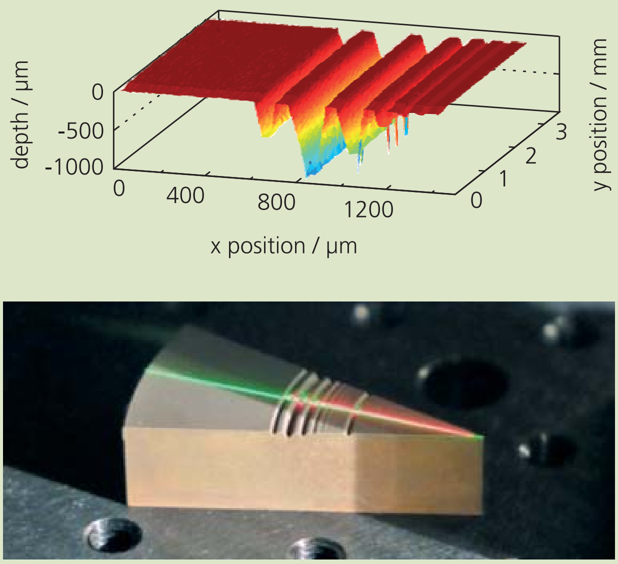
compensate for absorption effects by illumination with other spectral ranges that are more suitable here, thereby enhancing the measurement dynamics.

RESULTS

Extensive studies to refine optical components, such as measuring lasers and cameras, were performed in the project. The results showed that expensive special lasers are not necessary to achieve measurement accuracies in the low, two-digit µm range. A high-resolution camera, in combination with sophisticated software analysis, proved adequate to provide the required values. The AZOM project team contributed its expertise above all in analysis software engineering.

Representation of a calculated altitude profile (top) of a surveyed object (bottom)



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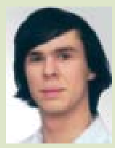
The use of precise filtering algorithms and the correct calibration of the measurement system made it possible to calculate high-resolution altitude profiles from data gained in test structure measurements (Fig. 3). The dynamics could be enhanced by analyzing all the three wavelength ranges.

The measurements and results were executed and verified both on height-setting normals (PTB TEN 900) and typical samples. The results gained in laboratory measurements are currently being implemented under real production conditions for an industrial partner. Therefore, the measurement setup was miniaturized and customized for laser materials processing equipment.

The use of this technology in other ranges of application, such as the packaging industry, extrusion of profiles, and in the textile industry, is being prepared.

2 *Adjustment of the measurement setup*

CONTACT



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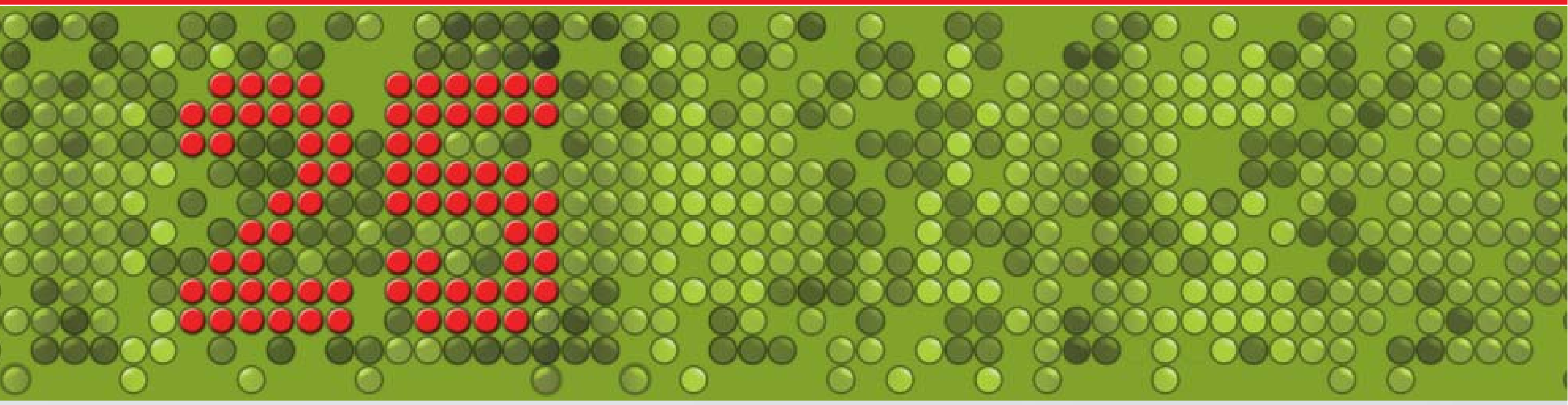


MICROSYSTEMS TECHNOLOGY AND LABORATORY AUTOMATION

DR. STEFFEN HOWITZ
Managing Director
GeSiM society for silicon microsystems mbH

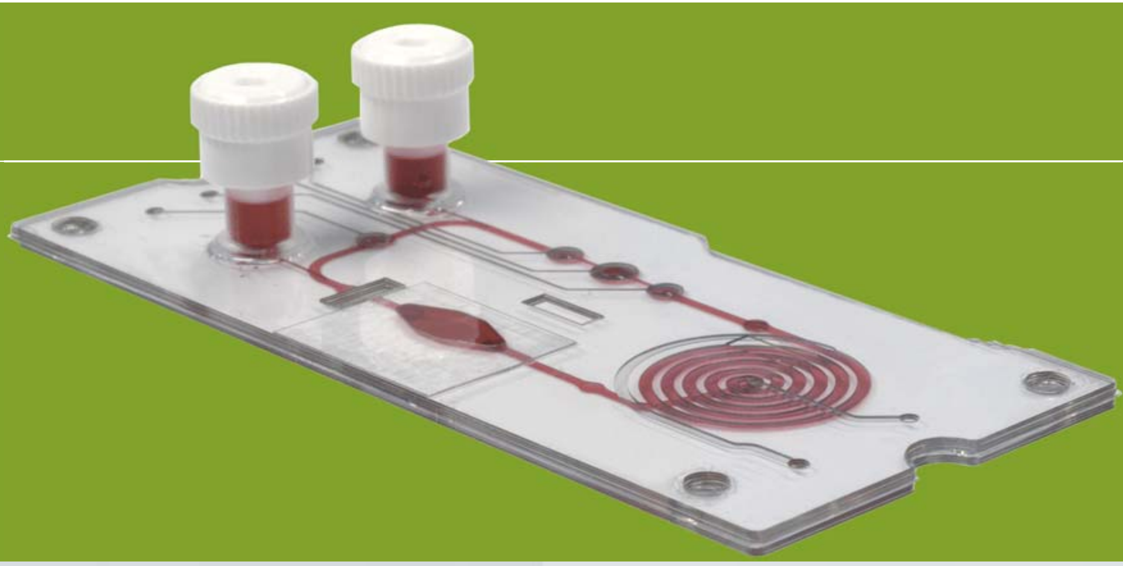
DR. FRANK SONNTAG
Group manager micro- and biosystems technology
Fraunhofer IWS

Editor: Dr. Howitz, your company has been collaborating with the Fraunhofer IWS for many years. When did you start your collaboration in microsystems technology? How did it begin?

Dr. Howitz: The close and comprehensive collaboration between the society for silicon microsystems GeSiM mbH and the IWS goes back to 2005. We developed and established a universal microfluidic platform for biosensors in a joint project. This research was based on the technologies for laser micro materials processing available at the IWS.

Editor: What stages of development did you go through together? What were the challenges?

Dr. Howitz: We started with examining the technological limits for laser structuring and functionalizing materials, such as polymers, silicone, glass, silicon, that are relevant to microsystems technology. We found that processing by ultra-short pulse lasers is a low-cost and flexible alternative to lithography techniques. Many microsystems equipment manufacturers had already studied laser structuring in detail, but not specific technology process chains for the manufacturing of microsystems. The most demanding task was to integrate laser micro material processing into existing sequences of technologies. Laser processes had to be optimized to reduce microcracks and depositions, as well as to minimize the heat-affected zone, and new technologies for cleaning and joining of the structured substrates had to be developed and established.



Editor: What has already been achieved?

Dr. Howitz: In the meantime, laser based technologies have become the technological backbone to fabricate highly flexible multilayer based microsystems based on polymers (see also page 92/93). Today micropumps with pneumatic control and valves can be produced by means of integrated membranes. We have succeeded in entering new business fields in micro-physiological systems and multi-organ chips. At the same time, our cooperation has extended to the System Technology department, in which we succeeded in the developing several modules and hardware platforms; the multi-channel 3D printer and the 2-level laboratory automation platform are good examples.

Editor: What made, from your point of view, your collaboration with the IWS particularly good?

Dr. Howitz: Let me emphasize the successful products we were able to launch from these joint projects, such as multi-organ chips. The multi-channel-3D printer we developed together is, for instance, used as the basis for our bio-scaffolder platform.

Dr. Sonntag: The IWS benefits from GeSiM technologies and experience and from in-depth idea exchange and communication, as well. Our partner GeSiM involves us very early in technical project agreements. We look back on ten years of joint R&D projects by the GeSiM and the IWS that have given us the chance to engage in forward-looking industrial research independent of customer projects.

Editor: Where do you stand today and what are the next development goals?

Dr. Howitz: We will strive for further innovations in the future. Together with the IWS, we intend to add further functionalities, such as plasmonic structures, to multilayer-based microsystems. For this purpose, we have to integrate our nano-imprint-lithography technology into the existing process chain. Another goal is to create a universal platform for substance testing without animal experiments and for basic medical research. Multilayer-based microsystems, 3D printing technologies to produce defined test tissues and a 2-level laboratory automation platform for automated handling are included as well.

Dr. Sonntag: We also intend to continue and extend our joint strategy to enter Asian markets. We gave successful presentations together at tradeshows and conferences in China in 2016, where we saw considerable interest. For this reason, we think we will present the multilayer-based microsystems, the 3D printing technologies, and the 2-level laboratory automation platform, in the GeSiM application lab in Shanghai from 2017 onward.

PVD- AND NANOTECHNOLOGY

Editor: Prof. Leson, after some delays, it seems that EUV lithography will finally succeed in being used for high-volume production of integrated circuits in the next few years. How can the IWS expertise contribute to this?

Prof. Leson: EUV lithography's time does indeed seem to have come – for both technical and economic reasons. The development of this technology is motivated by significant progress in the productivity of current EUV wafer steppers, on the one hand. On the other hand, it results from the fact that traditional wafer steppers are ever more complex, which makes them much more expensive. At the IWS, our activities are focused on a key component, the optical devices, where we can contribute our many years of experience in depositing ultra-precise nanometer multilayers optimally. We were able to increase the reflectivity of EUV optical devices to well above 70 percent, which is really a terrific value. This results in important advantages for the throughput and the productivity of the steppers.

Editor: The R&D activities of your business unit dealing with carbon coatings were particularly in demand last year. Can you tell us the reasons for this great interest?

Prof. Leson: In terms of hardness and wear resistance, our ta-C coatings are more advantageous than the classical DLC coatings widely in use. They also evince extremely low coefficients of friction under specific conditions of loading and stress. In practice, these coatings are useful for almost any application in which friction and wear occurs. The focus is currently on the automotive industry, because the use of our ta-C coatings significantly contributes to higher energy efficiency and thus CO_2 emissions reduction. In addition to

"Whoever stops getting better has stopped being good."
Philip Rosenthal

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coating development, we also have the process technology for the deposition of ta-C coatings. The laser-arc process developed at the IWS is the only such technique in the world for productive manufacturing of smooth ta-C coatings suitable for industrial use. This combination is a major reason that our R&D services are strongly in demand. It was a special pleasure for us to be awarded with the Innovation Award by the EARTO (European Association of Research and Technology Organizations) for this development in 2016.

Editor: In your business unit, you not only examine carbon coatings, but also other hard coatings that are frequently used to increase the performance of tools. Are there any new developments in this field?

Prof. Leson: Many industries are unimaginable without the multiple advantages of hard coatings. That said, there remain many applications where the properties of hard coatings are not yet satisfactory for industrial use. To address this market, we have developed very thick multilayer hard coatings that are particularly suitable for forming dies subjected to extreme forces and thermal cycling or shock stresses. We have also found new ways to avoid the edge roundings that frequently occur in thick layers, by adequate process control. We are hopeful that the range of applications can be significantly expanded with these innovations and intend to implement this approach with our industrial partners in the coming years.

COMPETENCES AND CONTACTS

Dr. Otmar Zimmer, group manager PVD coatings
☎ *+49 351 83391-3257* / ✉ *otmar.zimmer@iws.fraunhofer.de*

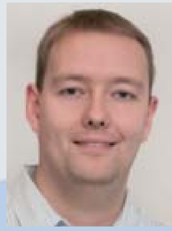
»Physical vapor deposition (PVD) processes deposit high quality tribological and functional coatings. Coating thicknesses range from few nanometers to several hundreds of micrometers. Available technologies range from high-rate evaporation to highly activated plasma processes. A focus is, among other things, the deposition of very thick PVD coatings for various applications.«

Dr. Stefan Braun, division manager nano coatings
☎ *+49 351 83391-3432* / ✉ *stefan.braun@iws.fraunhofer.de*

»Since several years, industry has been using precision coatings of nanometer thickness. Current research and development foci are single- and multilayer coatings for optical and joining applications. The optics field includes reflective coatings for EUV and X-ray mirrors as well as multilayer Laue lenses to focus X-rays. Reactive multilayer coatings are researched for joining applications. They provide temporal and spatial control of the heat source based on self-sustaining exothermic chemical reactions.«

Dipl.-Phys. Peter Gawlitza, group manager EUV and X-ray optics
☎ *+49 351 83391-3431* / ✉ *peter.gawlitza@iws.fraunhofer.de*

»For the deposition of nanometer single- and multilayers for EUV and X-ray optics, we utilize the methods of magnetron and ion beam sputter deposition as well as pulse laser deposition. The coating systems meet the highest standards with regard to coating thickness accuracy, roughness, chemical purity, lateral homogeneity and reproducibility. Furthermore we focus our research on ion beam processes for contouring and polishing X-ray optical substrates.«



Dipl.-Ing. Georg Dietrich, group manager energy storage coatings
☎ *+49 351 83391-3287* / ✉ *georg.dietrich@iws.fraunhofer.de*

»Through the use of reactive-multilayer-systems (RMS), metals, ceramics, semiconductors and polymers can be joined effectively. A RMS is inserted between both of the components being joined, and activated. The activation causes a brief chemical reaction generating the heat precisely in the narrow region required for joining the components.«

Dr. Volker Weihnacht, division manager carbon coatings
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» The superhard ta-C carbon coatings (Diamor®) developed in the group are outstandingly suited as friction-reducing protective coatings for lubricated and non-lubricated application conditions. They can be deposited on all kinds of tools and components with very good adhesion over a wide coating thickness range. The coating is applied with the Laser-Arc technology, particularly developed for ta-C coatings. Besides the technology, for the industrial implementation of Diamor® coatings, IWS together with partner companies also supplies the necessary coating sources. «

Dipl.-Ing. Gregor Englberger, group manager coating processes
☎ *+49 351 83391-3562* / ✉ *gregor.englberger@iws.fraunhofer.de*

» The group's competence is the deposition of superhard carbon coatings. A very good understanding of the process enables the adaption of ta-C coatings to various customer requirements. The IWS-developed Laser-Arc technology is an effective plasma source to deposit carbon coatings free of hydrogen, which has been optimized for industrial use. «

Dipl.-Ing. Stefan Makowski, group manager coating properties
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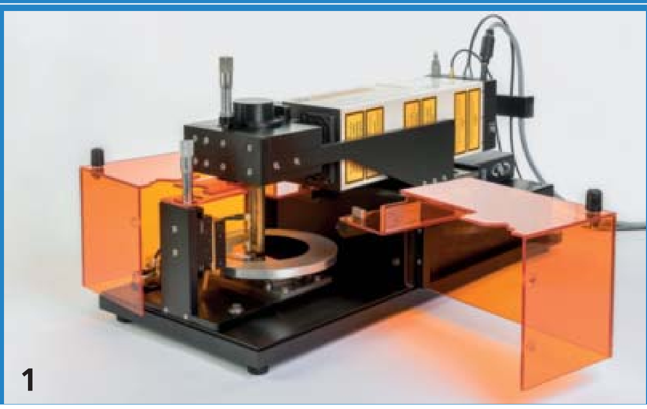
» That coating properties are relevant to applications is ensured by testing their mechanical and structural parameters. In addition to broadly used methods such as nanoindentation and tribological testing, we are also focusing on techniques such as laser acoustics (LAwave®) and adhesion testing. «

2016 PROJECT EXAMPLES



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LAWAVE 2G – A NEW DEVICE FOR TESTING OF SURFACES AND COATINGS

THE TASK

Laser acoustic testing has occupied a prominent position among coating and surface characterization methods for some time. During that time, LAwave devices have successfully come into use worldwide, such as in Japan, China, the USA, Russia and Great Britain (UK). The measuring technique performed using surface waves is non-destructive, works quickly and is extremely sensitive to minor alterations in the surface properties; it is used, for instance, to analyze the Young's modulus, density or layer thickness (Fig. 2). The wide range of application ranges from nanometer thick functional coatings, to thermal spray deposition of coating several hundred micrometers thick, and damage layers caused by wafer processing to hardened steel surfaces.

Greater demands for performance, convenient handling and an option for a flexible integration of the solution into process inspection, as well opening up new fields of applications, motivated the Fraunhofer IWS Dresden to consistently refine the proven measuring technique.

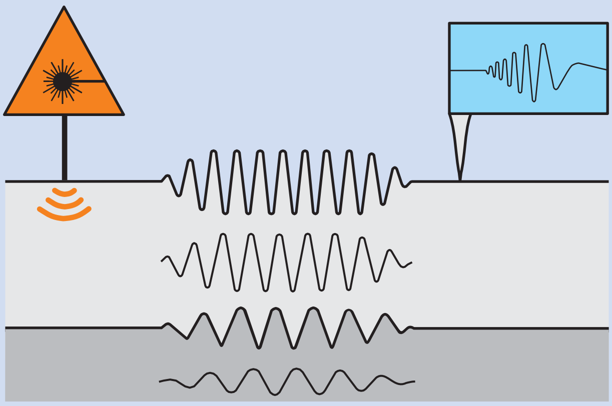
OUR SOLUTION

The new generation of equipment, LAwave 2G, is characterized by improvements in terms of handling, size, technical capability and expanded analysis options. A new equipment configuration with a stationary table for the specimens and a laser that can be positioned minimizes the influence of multiple test specimen weights. Thus, it is possible to flexibly accommodate test specimens and components of any size, which is, in turn, a precondition to integrate the equipment into automated processes (Fig. 1).

New space-saving components permit compact installation with enhanced technical capability. The mass of the new LAwave 2G system is 40 kg in contrast to the 160 kg of the original system. Only one third of the space of the original version is needed, so there is enough space on any table (Fig. 3). For these reasons, transport and installation are much easier.

To cover various ranges of application, measuring heads with a modular design allow for an adjustment to different frequency ranges on demand. The foundation for the analysis of multilayer systems lies in the integration of a new analysis model into the software.

LAwave measuring principle: A laser generates acoustic surface waves (left) that are recorded by a sensor (right). The wave packet includes depth-dependent information allowing for conclusions on the material parameters of both the bulk material and the surface.



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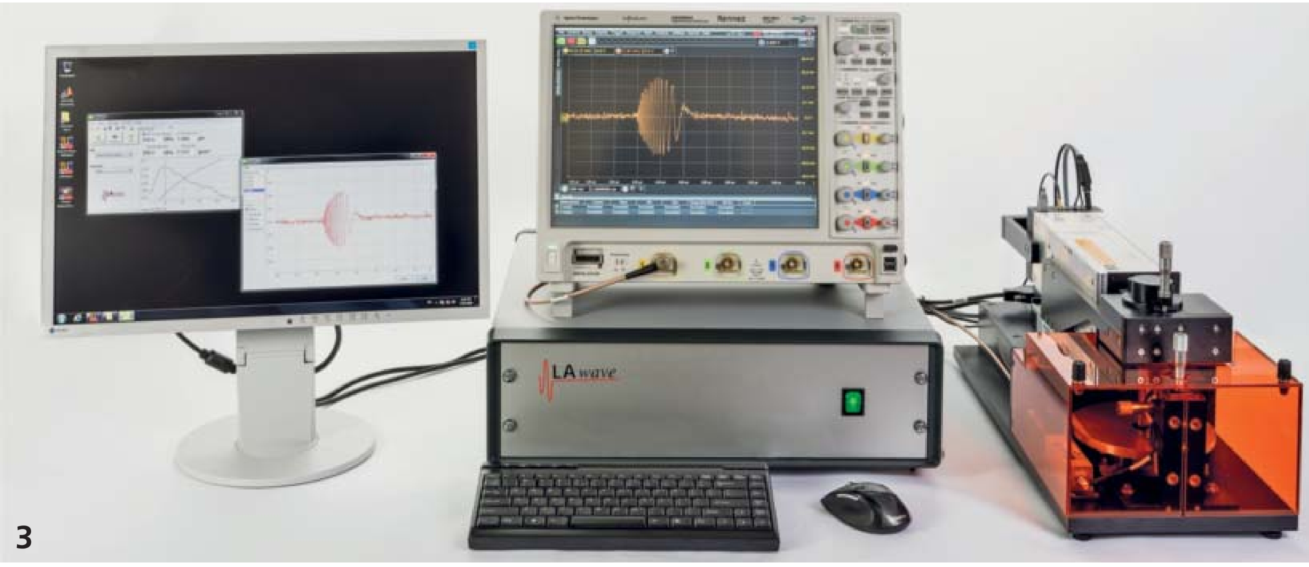

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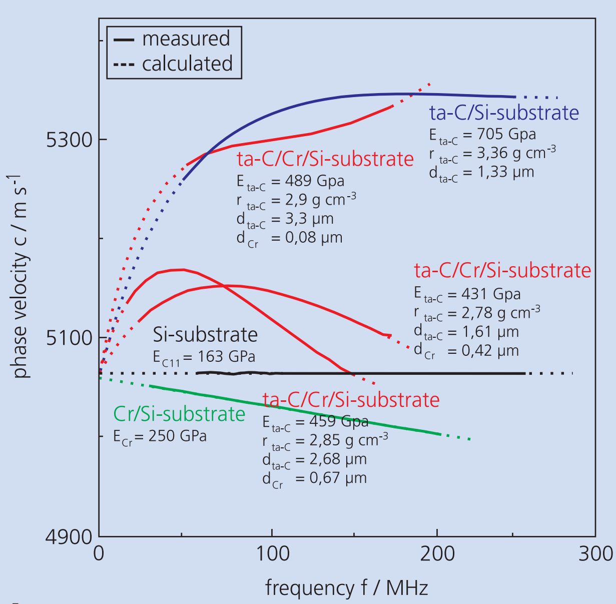
RESULTS

A layer system with a tetrahedral amorphous carbon coating (ta-C) and a chromium interface layer on a silicon wafer was measured in several variants by means of the LAwave method. The curves of the frequency-dependent phase velocities are distinct even with minimal differences in the layer system structure (Fig. 4). The material parameters – Young's modulus E, density r and layer thickness d – determined from the so-called dispersion curves by means of the analysis software are listed next to the curves.

The phase velocity of the uncoated silicon is constant and thus independent of the frequency. If a chromium coating is deposited onto the silicon (Cr/Si), the curve decreases in comparison with the substrate due to the difference in density between chromium and silicon, from which Young's modulus can be calculated.

Measured and calculated dispersion curves for the material systems Si (black), Cr/Si (green), ta-C/Si (blue) and several variants for ta-C/Cr/Si (red), as well as the material parameters determined from them.



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If, instead of chromium, a hard ta-C coating is deposited onto silicon (ta-C/Si), the curve clearly rises as a result of the difference in Young's moduli. Young's modulus, coating thickness and the density of the ta-C coating can be determined simultaneously from the multi-curved curve. When combining a ta-C coating with a chromium interface layer (ta-C/Cr/Si), the influences of both layers lead to a strong, partially multi-curved curve. Four material parameters can be calculated from the curve; in this example, it is also possible to compute the thickness of the different well-defined chromium interface layers.

Many innovations, such as changes in design, adequate component choice and analysis software, make the LAwave method a technique that may be often and flexibly employed for new applications in research, development and production inspection.

1, 3 LAwave 2G, designed as a compact tabletop device for R&D. The setup of the stationary table to hold the specimen also makes it possible to adapt the system for large components and test specimens.

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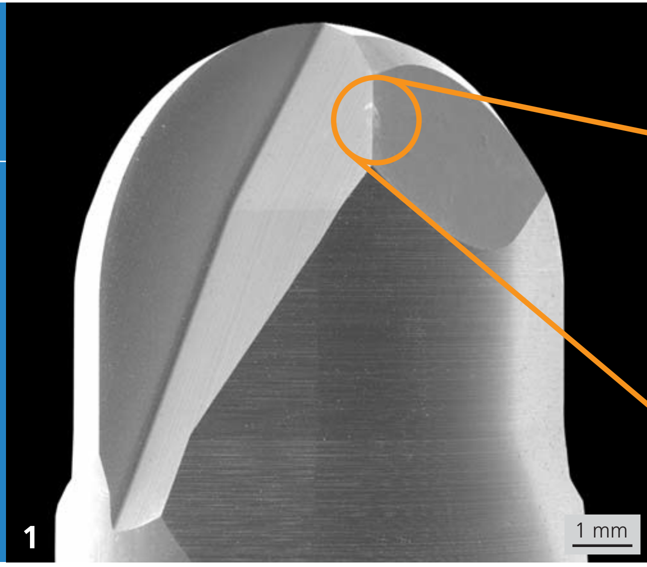

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SHARP EDGES THANKS TO COATING

THE TASK

Deposition of thin coatings on an industrial scale has been widely used for years. Coatings that were produced by means of the PVD and CVD techniques are used, for example, as wear resistance coatings, for decoration, and to diminish friction. Contour-accurate coating of complex geometries, such as of tools (Fig. 1), is still a challenge. Consequently, the coatings generally used in industry are typically deposited to a thickness of just a few micrometers because edge rounding (Fig. 2, top), for instance, is still irrelevant in this thickness range.

If it were possible to coat complex geometries accurately to contour, it would also be possible to use thicker coatings, which would provide far better protection. Monolayer systems, such as of TiN, CrN, AlTiN or AlCrN, are not yet suitable for these coating tasks. The Fraunhofer IWS Dresden is developing and testing new coating approaches and suitable coating procedures for this purpose in collaboration with the TU Dresden.

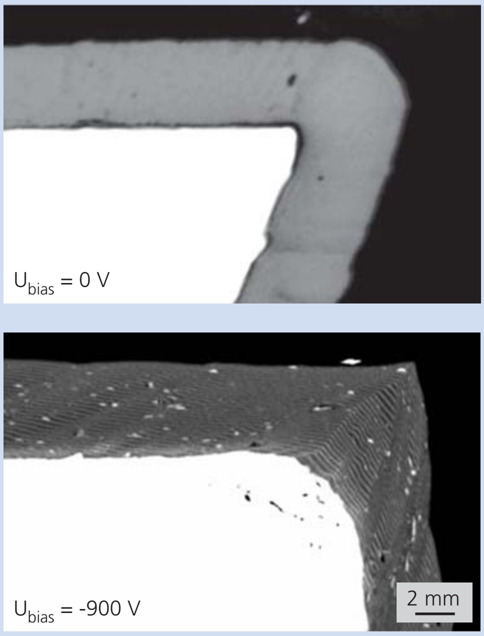
OUR SOLUTION

Research at the IWS is focused on the development of coating processes that provide better protection and with which complex components can be coated accurately following the contour and with constant layer thickness along the component.

The coating properties are typically improved by applying an electrical substrate bias potential. For complexly shaped components, however, the additionally applied electrical substrate bias potential results in heterogeneous electric field distribution, which, in turn, causes different layer thicknesses along the contour.

Optimization of the coating material helps to avoid multiple layer thicknesses caused by different deposition rates. Using the AlCrSiN/TiN coating system developed at the IWS, not only the typical edge rounding effect can be avoided but also, if necessary, edges can be sharpened (Fig. 2, bottom).

Transverse microsection of a monolayer coating, deposited without bias potential (top) and a multilayer hard coating, deposited with high bias potential (bottom)



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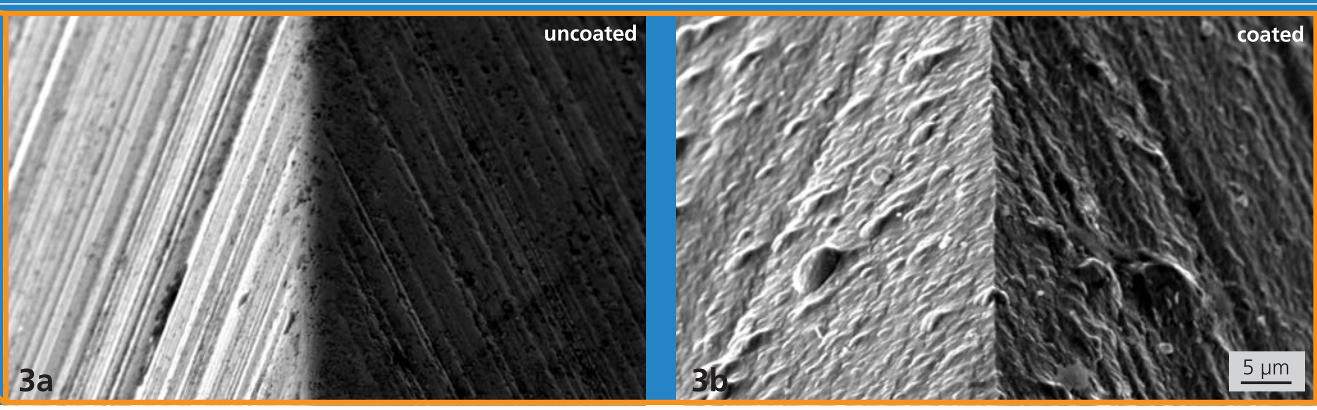
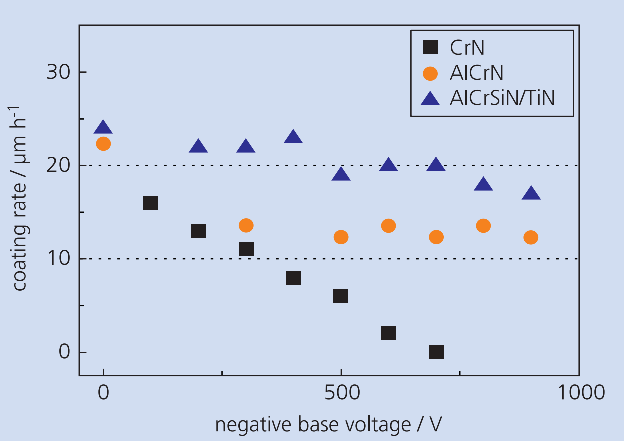


RESULTS

SEM images (Fig. 3) show the cutting edges in uncoated and coated state. Unlike the uncoated fillet-like edge, deposition of the AlCrSiN/TiN coating system sharpens the edge.

Due to the complex geometry of a tool's cutting edge, field effects during coating with bias voltage and traditional coating systems frequently result in growth defects at the cutting edges, such as uneven edge cover. The AlCrSiN/TiN coating system shows only slight changes in the coating rate over a wide range of the bias voltage (Fig. 4). This makes it possible to homogeneously coat even complex geometries with field effects occurring during the coating. New possibilities to coat edges subjected to extreme load/stress are opened up.

Coating rates for various layer systems (single-layers vs. multilayers)



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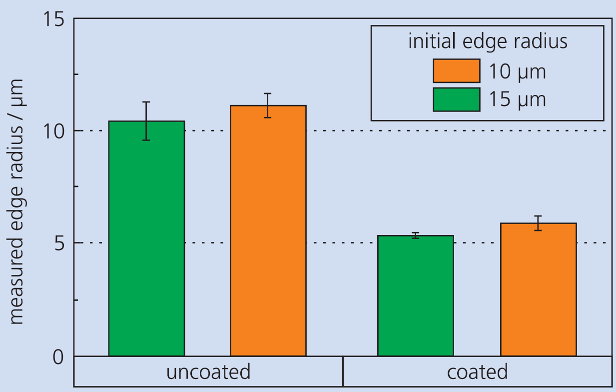
We also succeeded in bypassing edge rounding and even intentional edge sharpening when coating complex geometries (see Fig. 2 and 3).

Optical edge surveillance demonstrated that edge radius can be drastically reduced almost independent of the initial cutting edge radius by means of the coating process engineered at the Fraunhofer IWS (Fig. 5).

Edge radius before and after coating



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As a consequence, edge sharpness can be adjusted by the coating parameters for each application and no longer depends on the initial contour of the uncoated tool. It is also possible to use coatings of much greater thickness than before, since edge radius increases as a function of the layer thickness is no longer important.

1 View of a tool cutting edge

3 Edge of an uncoated (a) and a coated tool (b)

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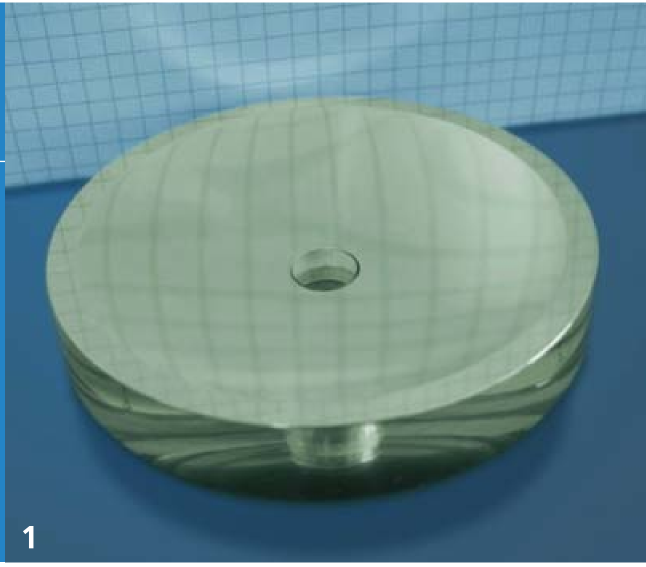
BUSINESS UNIT
PVD- AND NANOTECHNOLOGY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EUV MIRROR LAYERS FOR 7 NM LITHOGRAPHY

THE TASK

Several semiconductor manufacturers currently expose significantly more than 1000 wafers per day by means of EUV lithography. Thus, it makes sense to introduce this "unusual" vacuum technology into microelectronics – not only for technical, but also for economic reasons.

In all photolithographic configurations, the optical device plays a key role. In EUV lithography, the mask structure is mapped on the wafer by means of mirrors (Fig. 1). The reflective layers deposited must fulfill the highest requirements in terms of the reflection coefficient, smoothness, precision of lateral thickness distribution and low internal stresses. The requirements increase still more as a function of further structure reduction so that a continuous improvement of the coating properties is still necessary.

In the SeNaTe (Seven Nanometer Technology) European research project coordinated by the ASML company, the IWS is responsible for the exploration of EUV reflective layers for future optical devices for lithography. The highest priority requirements in terms of layer development consist in:

- reducing stray light from the reflective layers
- engineering high precision coatings on sculptured surfaces
- diminishing internal layer stresses while maintaining consistently high optical performance

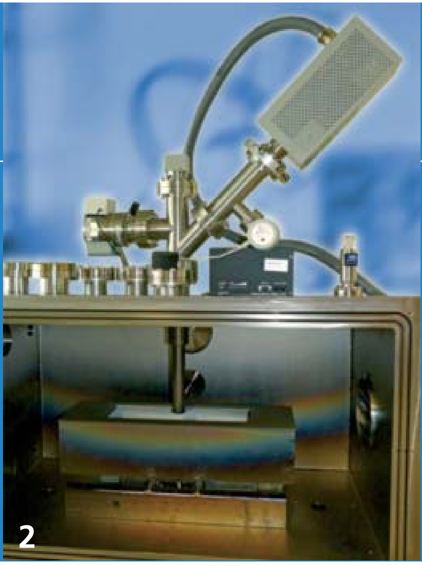
The special challenge is to develop a coating process enabling the production of EUV mirror layers that are highly reflective, with both low stray light and low internal stresses.

OUR SOLUTION

With magnetron-sputter deposition (MSD), the IWS has a technique at its disposal that has been proven in industry and used for the exploration of EUV reflective layers for several years. The coating properties are defined by the vacuum conditions, as well as, above all, the kinetic energy of the particles impinging on the substrate. Thus, reduced coating roughness can be achieved by, for example, an increase in the mean kinetic energy of the particles that form the layer. However, this activation must be exactly measured to avoid any intermixture of the materials at the interfaces, as well as an amplification of the compressive stresses that typically occur.

To obtain precise information about the distribution of kinetic energy as a function of the coating parameters, an EQP 500 plasma monitor was positioned at the point of coating (Fig. 2). This device makes it possible to quantify the energy distributions of both the charged and neutral particles.

Energy distributions, such as those typical for magnetron plasmas, are verified with standard processes, in which coating roughness values of < 0.1 nm rms cannot be achieved. For surfaces that are inclined by more than 30 °, roughness clearly increases and internal stresses change. For this reason, an activation of the coating process was introduced, in which the energy distribution is shifted to levels of higher energies.



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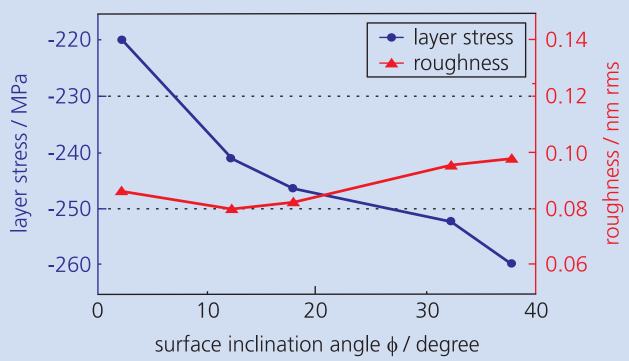
However, when making use of activation processes to obtain the desired smoothing, there is the risk that the coatings will mix thoroughly at their interfaces. By balancing the various above mentioned objective criteria, we found a parameter set involving discharging power, sputter gas pressure and ion activation, for which the coating properties could be substantially improved.

RESULTS

The increased kinetic energies of the particles impinging on the substrate at first resulted in the desired smooth surfaces: roughness surveyed by means of a scanning force microscope ranged now from 0.06 to 0.10 nm rmp. The lower roughness limits were achieved for planar substrate surfaces. Roughness values lay at approximately 0.10 nm rmp for surfaces with concave curvature, with 40 ° angles of slope against the incoming particle flow.

Reduced roughness at first resulted in a reduction of the light diffusely reflected by the mirror. In optical imaging units, this effect improved the signal-to-background ratio, that is to higher image contrast.

Roughness and internal stresses on substrate surfaces of concave curvature as a function of surface slope.



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Plasma activation at first caused stronger intermixture at the interfaces, which we could reduce. The specular reflection of the mirrors could also be increased. The reflection coefficients > 70.5 percent (λ = 13.5 nm, α = 5 °) were reproducibly evidenced both by the National Metrology Institute (Physikalisch Technischen Bundesanstalt (PTB)) and the Berkeley National Lab (BNL) in independent investigations. The previous record value is R = 70.7 percent.

An unintentional increase in the compressive stresses of the layers can be a negative concomitant effect of the plasma activation. This expectation was confirmed in the first investigations: compressive stresses from -200 MPa to -250 MPa, typical in standard coatings, were clearly exceeded and lay in the range from -300 MPa to -650 MPa. Intentional customization of the activation both in terms of intensity and duration avoided a more pronounced formation of properties without reducing the desired smoothing effect. With this configuration, coatings with internal stresses from -220 MPa to -260 MPa and of < 0.1 nm rms roughness can be fabricated. These values are feasible on large substrates of 300 mm diameter and on substrates with strong curvature, with local surface inclinations of up to 40 ° (Fig. 3).

1 EUV mirror (photography)

2 Setup for energy quantification by means of the EQP 500 plasma monitor

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METALLIC BIPOLAR PLATES – COMPACT, LOW COST, LONG-TERM STABLE

THE TASK

The use of renewable energies frequently entails questions regarding energy storage options. Hydrogen production from energy surpluses and the storage thereof could provide a solution. Hydrogen could be directly used for the propulsion of vehicles thereby speeding up the further development of electric mobility, rather be stored or transformed into natural gas in ongoing procedures.

In a fuel cell, hydrogen and oxygen are converted to water, and the electrical energy produced is used for propulsion (Fig. 1). The current driving range of vehicles with fuel cells is approximately 600 km. The fuelling procedure is like that used for a conventional car. A special filling station network would not be needed.

A membrane electrode assembly and a bipolar plate (BIP) are key fuel cell components. The BIP is responsible for hydrogen and oxygen supply, removal of water and cooling. On the hydrogen, the BIP gathers the emitted electrons and transfers them to the oxygen side after they have performed work in moving the vehicle. Thus the BIP material must have excellent electrical conductivity that also does not significantly decrease under the electrochemical conditions in the fuel cell.

The task is to develop a compact, low-cost BIP suitable for mass markets and stable in the long term.

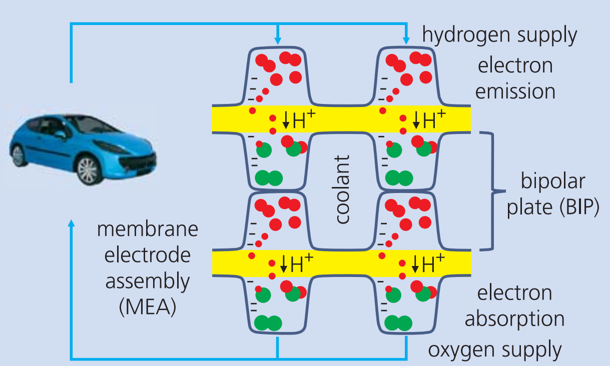
OUR SOLUTION

Graphite is used as the BIP material in applications with sufficient available installation space, whereas deep drawn stainless steel sheets with a thickness of approximately 0.1 mm are preferred in the automotive industry due to reduced installation space and high cost pressure. As a default, these steel sheets have until now been gold plated, because the natural passive coating of the stainless steel is a poor current conductor. At the Dortmund Surface Center (DOC), a branch office of the Fraunhofer IWS Dresden, two alternative coating systems were developed and tested in the miniBIP project, registered under 03ET045A and funded by the Federal Ministry of Education and Research BMBF:

- PNC (plasma-nitrocarburized coatings)
- GLC (graphitic carbon coatings)

The contact resistances of the coatings has to be similar to those of gold. The coating must also adhere sufficiently so that ready coated plain sheets can be formed into BIPs without damage.

Diagram of a fuel cell



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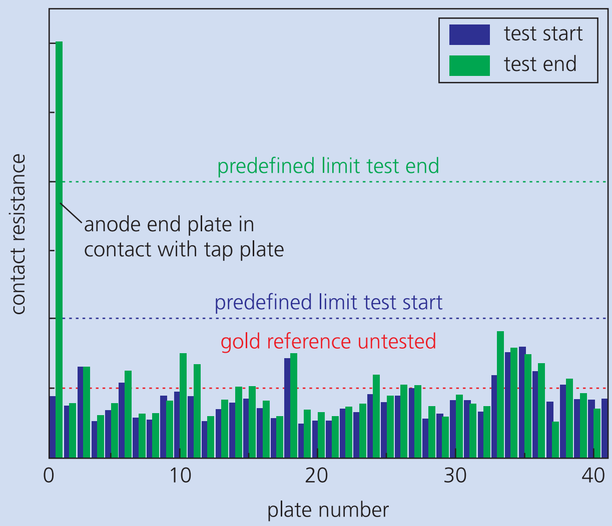
RESULTS

In the project, both surface modification techniques were optimized on various stainless steels in terms of high corrosion resistance and low contact resistance (Fig. 2). Both coating systems achieved the contact resistance of the gold coated sheets. Significantly improved anti-corrosion characteristics in comparison with those of the uncoated material were demonstrated.

The best results for the contact resistance were achieved by GLC coatings of less than 100 nm thickness. They were deposited with pulsed vacuum arc evaporation by twofold substrate rotation within a minute. Similar values could be achieved by sequential plasma-nitrocarburizing in about 15 minutes.

Contact resistance values of the BIP after PNC-treatment, fuel stack with 40 cells, after 1000 test hours (test results of the Daimler AG)



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The thickness of the surface zones enriched with nitrogen and carbon is below 5 µm. Both techniques also offer mass market potential in strip coating machines.

At the end of the project, the project partner Daimler AG assembled a fuel cell stack consisting of 40 cells. Figure 3 elucidates the results before and after the operation of the stack. Apart from the faulty anode plate, the contact resistance values of all BIPs before and after the test lay in the range of the unstressed gold reference. They were 300 percent below the requirements after the end of the test. In tests with former test geometry, GLC coatings proved to be about 200 percent below the required limit at the end of the test.

The requirements could also be achieved for both surface modifications at the end of the stack tests, in which the test sheets were first surface-coated and then formed, as well as locally damaged in a scratch test. The test specimens showed no corrosion, even on damaged surfaces.

2 *Pattern part with forming elements of a metallic bipolar plate*

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BUSINESS UNIT
PVD- AND NANOTECHNOLOGY

ENHANCED TRANSPORTATION SAFETY WITH ANTI-REFLECTIVE COATINGS

THE TASK

Light reflected on glass surfaces can carry serious safety risks in transportation on the street. The windshields of transit and city buses are particularly affected. The vertical windshield installation in conjunction with the interior illumination obscures the driver's vision and creates hazardous situations which can lead to accidents. In the United States of America alone, there are 25,000 to 30,000 injuries every year in accidents involving buses, about 1 percent of which are fatal.

Reflections occur if light is mirrored at the interfaces of media with various refraction indices. Air has a refraction index (n) of approximately 1 in comparison to 1.5 for glass.

By applying thin coatings additional interfaces can be created which may result in phase shift and attenuation or extinguishing of optical waves. Application-related anti-reflective (AR) coatings can be generated based on intentional modification of refractive index and coating thickness.

OUR SOLUTION

Conventional anti-reflective coatings, such as for optical filters, often consist of complex multilayer coating systems. The Fraunhofer USA Center for Coatings and Diamond Technologies (CCD) collaborated with a company in Grand Rapids, Michigan, USA, to develop a more simple and economic thin film stack solution.

The coating concept is based on minimizing glare in the mean wavelength range of visible light (550 nm). For minimal reflection, the coating must have an average refractive index between the adjacent media.

$$n_{AR} = \sqrt{(n_{Medium\ 1} \times n_{Medium\ 2})}$$

The glass-air transition requires a refractive index of less than 1.3. This value can only be achieved by salts which are not suitable as durable thin film coatings. For that reason, a layer with a refractive index greater than that of glass is used as interlayer, followed by a second layer with a medium index to air. The coating system developed at the CCD is based on this approach using aluminum oxide (Al_2O_3, n ~ 1.7) and indium-stannic (ITO, n ~ 2.0) for an incremental increase of the refractive index, followed by a fluorinated diamond-like anti-reflective carbon coating (F-DLC, n ~ 1.4).

Conventional coating techniques were used with the goal of scalability to windshield application. Both metal oxides were produced by means of pulsed DC magnetron sputtering. Aluminum oxide Al_2O_3 was reactively deposited from a metal target (99.99 percent Al), whereas ITO was deposited from a ceramic target (In_2O_3/SnO_2 90/10 weight percent). The F-DLC coatings were generated with a gas mixture of Ar, C_2H_2, H_2 and CF_4 from a linear ion source.

RESULTS

The development of the anti-reflective coating concept based on F-DLC and metal oxides was funded by the Department of Transportation of the USA within a program for small and medium-sized companies. Reflection and transmission of the windshield glass segments coated at the Fraunhofer CCD were measured at the Transportation Research Institute of the University of Michigan (UMTRI).

Portions of reflected (top) and transmitted (bottom) irradiation windshield pane glass, with/without anti-reflective coating

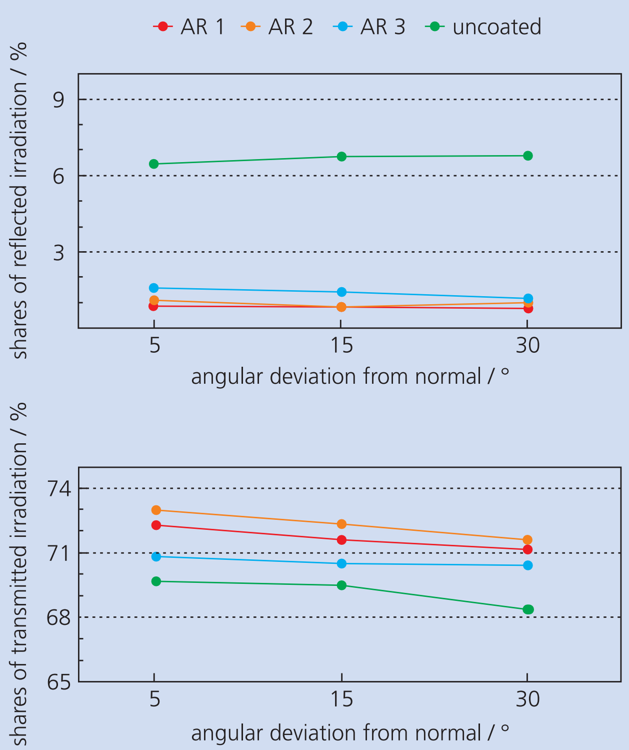

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Figure 2 demonstrates the anti-reflective coating effect with a pane glass coated on one half. The glare from solar radiation is drastically reduced and the details behind the coated half are significantly more visible.

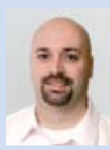
The measurements of UMTRI were performed in a dark room using an electric light source. The data were recorded at angles of 5 °, 15 ° and 30 ° to the normal incident to simulate the field of view of the bus driver under realistic conditions. Coating the windshield with F-DLC reduced reflection from almost 7 percent to less than 1 percent (see Fig. 3, top).

At the same time the transparency of the windshield glass was not affected by the thin film coatings (see Fig. 3, bottom). In fact, a slight increase in transparency was noted, which is due to the decreased refraction. When applied to automotive windshields these coatings increase the driver’s visibility by at least 10 m, helping him to detect hazards and avoiding accidents.

1 *Reduced vision due to reflection on the windshield*

2 *AR coated glass pane, coated on the right half (left side uncoated)*

CONTACT



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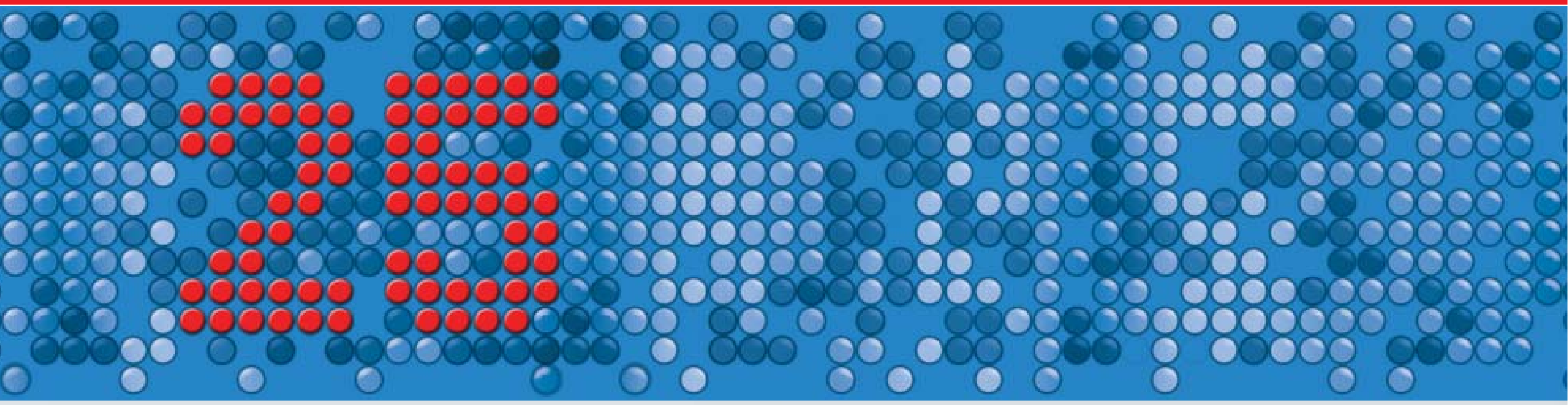

WEAR-RESISTANT AND ENERGY-EFFICIENT CARBON COATINGS BY LASER-ARC TECHNOLOGY

UWE HEYDENREICH
Managing Director
VTD Vakuumtechnik Dresden GmbH

PROF. ANDREAS LESON
Business unit manager
PVD- and Nanotechnology
Fraunhofer IWS

Editor: Mr. Heydenreich, VTD Vakuumtechnik Dresden GmbH and the Fraunhofer IWS can look back on a long history of collaboration. What were the main reasons why VTD decided to cooperate with the institute?

Mr. Heydenreich: Our excellent collaboration with the IWS does indeed go back to the 1980s. For VTD, above all the IWS's obvious expertise, its many years of experience in thin film coating technology, as well as in plasma sources, were essential to our close collaboration.

Editor: What markets are you and the IWS targeting together?

Mr. Heydenreich: Our current joint activities clearly focus on the deposition of super hard carbon coatings, so-called ta-C coatings. These coatings are extremely hard and offer optimal frictional characteristics. These advantages make them the coatings of choice for an application in combustion motors where they clearly reduce fuel consumption and, in turn, CO_2 emissions. Therefore, the automotive OEMs and their subcontractors are generally very interested in these coatings. But they are also extremely attractive for the tool market, and in mechanical engineering in general. Obvious advantages have been observed in the use of ta-C coatings in comparison with the established hard coatings in cutting of abrasive composite materials and nonferrous metals. In this sector, as well, we expect an increasing demand of potential customers for coatings and the equipment required.

Editor: At what stage is the development? Are there other goals you have set for yourselves and in the cooperation with the institute?

Mr. Heydenreich: With the Laser-Arc module whose basis was developed at the IWS, and our own equipment, we have already created a foundation to fulfill customer needs for productive and reliable deposition of super hard ta-C coatings. Together, we currently have the basis to scale up the technology for further implementation in industry, so that the coatings can be fabricated more productively and at lower costs in the future. Filtered coating providing the deposition of smooth ta-C coatings must and will be refined for many applications.

Editor: What do you appreciate above all about working with the IWS?

Mr. Heydenreich: In our joint activities with the IWS, we particularly appreciate the professional and structured approach of the IWS personnel. This includes project scheduling and execution, commissioning for the customer, and support in the event that problems occur. The IWS personnel shows great commitment and flexibility so that it is always a pleasure to collaborate with the institute.

Prof. Leson: Our team mainly appreciates the open and friendly communication we have with the VTD employees. Necessary agreements can be made quickly and easily so that the projects can be executed efficiently. This is the case both for publicly-funded projects, where we have enjoyed more than 10 years of partnership, as well as for industrial projects.

CHEMICAL SURFACE AND REACTION TECHNOLOGY

Editor: Prof. Kaskel, a Federal Council statement explicitly mentions the goal of allowing only zero-emission cars for traffic in the European Union from 2030 on at the latest. Do you see confirmed in your strategy?

Prof. Kaskel: Truly, we are facing a new global challenge. Electric mobility seems to be advancing. Predictions involving specific dates certainly should be made with care, and this forecast hardly seems realistic in Germany. On the other hand, it is obvious that in Asia, above all in China, they are moving from gasoline- or diesel-powered vehicles to electric cars very quickly due to new legislative initiatives. Increasing environmental pollution and unacceptable personal living conditions will necessarily accelerate this trend.

Editor: How does the IWS specifically contribute to solving this problem?

Prof. Kaskel: For many years, the Fraunhofer IWS has focused on the development of sulfur-based batteries. From our point of view, this is the most promising next-generation battery technology, since the gravimetric storage densities achieved in this area outperform traditional lithium-ion batteries by more than 100 percent. However we provide the dry processing technology as a generic technique for other battery technologies.

Editor: That means you also rely on classical lithium-ion batteries?

"Economics is the only field in which two people can share a Nobel prize for saying the opposite thing."

Joseph E. Stiglitz

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Prof. Kaskel: Yes, there is still a tremendous development potential. Look at the more recent developments in silicon anodes. Silicon, as an additive to classical graphite anodes, is becoming more and more important. Furthermore thin protective carbon films play a major role for nanostructured electrode materials.

Editor: Carbon is a particularly light material.

Prof. Kaskel: Yes, it is. Carbon fiber is a classic example that is also employed in lightweight design. The IWS examines carbon materials in many modifications. We not only develop porous carbon electrodes and thin functionalized coatings, but also pre-treat carbon fibers by means of new plasma techniques. These activities contribute to high strength in composite materials. However, we also need new recycling processes that go beyond pure incineration and add value through the recycling of the longest possible carbon fibers.

Fraunhofer IWS has in its portfolio a whole arsenal of various carbon materials, from thin films to carbon fiber, from amorphous carbon coatings to diamond structure, depending on whether electrical, mechanical or other functional properties are most important.

COMPETENCES AND CONTACTS

Dr. Holger Althues, division manager chemical surface technology
☎ +49 351 83391-3476 / ✉ holger.althues@iws.fraunhofer.de

»In the department "Chemical Surface Technology", functional materials and coatings are being developed for a wide range of applications. Besides functional thin films, electrodes put a thematic focus for energy storage. Through the three workgroups, the key processes in the development of next-generation batteries (especially lithium- and sodium-sulfur-batteries) from the material to the coating processes and up to the production of prototype cells, are covered.«

Dr. Susanne Dörfler, group manager battery- and electrochemistry
☎ +49 351 83391-3703 / ✉ susanne.doerfler@iws.fraunhofer.de

»The development of tailored materials (especially carbon and silicon nanomaterials) and the electrochemical characterization of electrodes for battery storage are the focus of this group. Thus the foundations are created to develop new lithium- and sodium-batteries as the next generation of high capacity energy storage devices.«

Dipl.-Ing. Thomas Abendroth, group manager battery technology
☎ +49 351 83391-3294 / ✉ thomas.abendroth@iws.fraunhofer.de

»Methods for constructing prototype battery cells and their testing are the foci of this group. Lithium-sulfur cells with 4 Ah and specific energies of > 300 Wh kg^{-1} are fabricated, tested and improved across groups. A process line to automate production of battery cells in local dry room atmosphere was installed at IWS. Key processes are the remote laser cutting "on the fly", the remote laser welding and the automated cell stacking, which were integrated into the process chain.«

Dr. Benjamin Schumm, group manager chemical coating processes
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»Water-based coatings and solvent-free processes for the manufacturing of electrodes are being developed as a roll-to-roll process for the cost-effective production of double-layer capacitors and batteries. Vapor-phase (CVD) and liquid-phase processes for the deposition of functional thin films for conductive, scratch-proof, optical or self-cleaning surfaces are another focus of the group.«

Dr. Gerrit Mäder, group manager plasma technology and nanomaterials
☎ *+49 351 83391-3262* / ✉ *gerrit.maeder@iws.fraunhofer.de*

»The plasma technology and nanomaterials workgroup develops large area atmospheric pressure plasma sources for custom applications. Application areas are the pretreatment of surfaces for adhesive bonding, the application of adhesion promoters and powder deposition by means of plasma technologies. Another area is the development of gas phase reactors for the production of nanoparticles and metallic conductive carbon nanotubes (CNTs). A flexible, cost-effective high-rate synthesis method was developed especially for the synthesis of single-walled, low-defect CNTs.«

Dr. Wulf Grählert, group manager process monitoring
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»Optical spectroscopy methods are an excellent process monitoring tool in the characterization of industrial production processes, as well as their products, during or after production. Depending on the methods used, relevant information about the process atmospheres (gas composition) and product characteristics (surfaces, layers, composition, porosity, etc.) can be determined. The methods operate in a contactless manner and are highly sensitive. Some of them even offer spatial resolution. The obtained results can be used for the automated monitoring, control and optimization of the processes.«

2016 PROJECT EXAMPLES

NEW ELECTROLYTE SYSTEMS FOR LITHIUM-SULFUR BATTERY CELLS

THE TASK

Lithium-sulfur (Li-S) battery cells are characterized by high specific energy and low material costs in comparison with traditional lithium-ion batteries. This cell chemistry is highly attractive for future lightweight storage, mainly to extend the range of electric vehicles.

However low battery life is a tremendous challenge: although current Li-S prototype cells can achieve a specific energy value of 350 Wh kg^{-1}, they degrade substantially within the first 50 charging/discharging cycles. As a result, their range of application is still mainly limited to aerospace industry. At present it is not feasible to use these cells for electric mobility. In future, however, an increase in cycle stability or another increase in the specific energy to more than 400 Wh kg^{-1} can significantly extend the real application potential of the cell type.

OUR SOLUTION

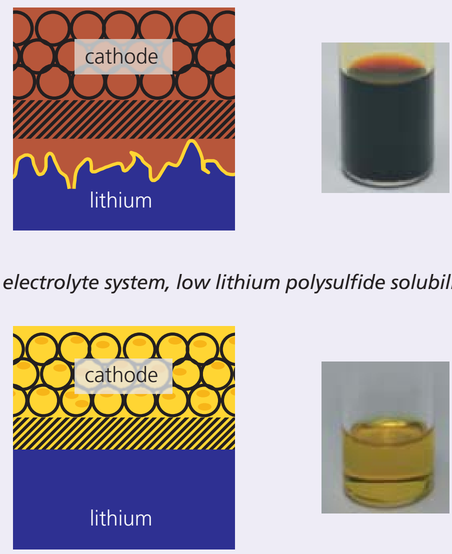
The electrolyte system is a key component for a refinement of the Li-S technology and significantly affects the following cell properties:

- Energy- and power density: In previous prototypes, the electrolyte has represented at least 40 - 50 percent of the cell weight. Since the electrolyte is involved in both dissolution and conversion reactions in the cathode, the kinetics and the completeness of sulfur conversion (specific capacity) immediately depend on the electrolyte share. Values less than 3 ml electrolyte per gram sulfur cannot be achieved by classical approaches.
- Cycle stability: decomposing reactions of the electrolytes on the lithium anode surfaces are the main reason for drying out and degrading.
- Self-discharging and energy-efficiency: Highly soluble reaction intermediary products (lithium polysulfides) result in accelerated self-discharging and low charging efficiency (polysulfide shuttle).
- Temperature and safety: Electrolyte solvents significantly define the thermal range of Li-S cell application and the resistance of the cell against misuse and inflammability.

Electrolyte concepts for Li-S battery cells
left: Principle; right: Electrolyte

E1: Intermediary complete solubility of lithium polysulfides

E2: IWS electrolyte system, low lithium polysulfide solubility



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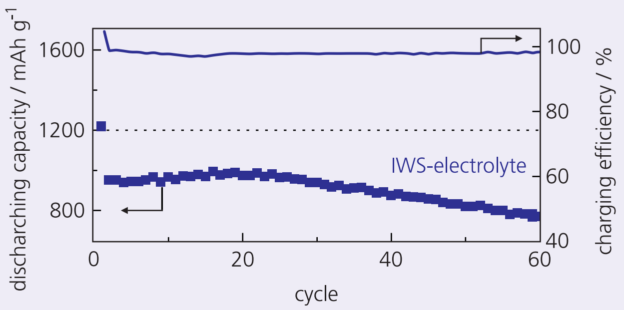
At Fraunhofer IWS, innovative approaches that make it possible to overcome the limitations of these properties are being developed. For this purpose, reducing the polysulfide solubility in the electrolyte system through modified solvent formulations is very promising. This reduction not only restricts the polysulfide shuttles, but also compresses the cathode structure to a wider extent. Stable protective coatings can be formed on the lithium anode and be adapted by electrolyte additives or co-solvents (Fig. 1).

Galvanostatic measurements with IWS electrolyte (5.0 ml g^{-1}-sulfur) in CR2016 button cell indicates high charging efficiency and stable capacity.



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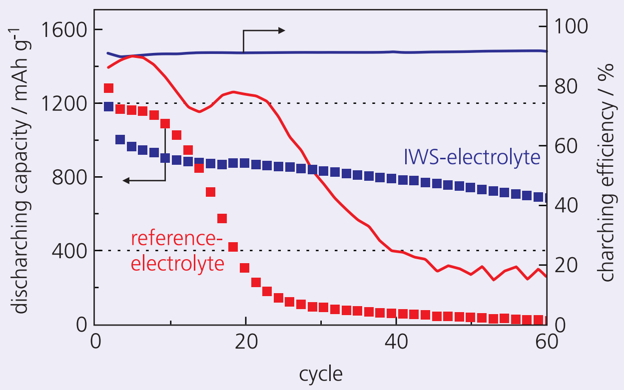
Galvanostatic measurement in IWS prototype cell confirms clear increase in cycle stability and charging efficiency by IWS electrolyte (2.7 ml g^{-1}-sulfur) in comparison with reference electrolyte (3.0 ml g^{-1}-sulfur).



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RESULTS

The non-combustible electrolyte with low polysulfide solubility developed at Fraunhofer IWS causes sulfur to be converted on the cathode's carbon surface in a quasi solid material-solid material conversion. Unlike in the ether based reference electrolyte system, in this approach, the active material is efficiently held back in the cathode. Due to the restricted polysulfide shuttles, the charging efficiency is high, as is confirmed by button cell experiments and tests in multilayer lithium-sulfur prototype cells (Fig. 3).

Corrosion of the lithium anode is prevented by a consistent, in-situ deposited surface coating (solid-electrolyte interphase). For this reason the morphology of the deposited lithium remains smooth and fine-grained for more than 100 cycles. Using the IWS electrolyte, a cell expansion induced by unintentional degradation processes is excluded (Fig. 2). Based on these advantages, the cycles can be made significantly more stable for 40 – 60 cycles. At the first time, the sulfur can be widely utilized even at low electrolyte percentages of 2.7 ml g^{-1}-sulfur (< 40 percent cell weight) or less.

2 *Left: No gas formation to be detected at prototype cell after cell test with new electrolyte; Right: Expansion of the cell with traditional electrolyte by gas formation after cell test*

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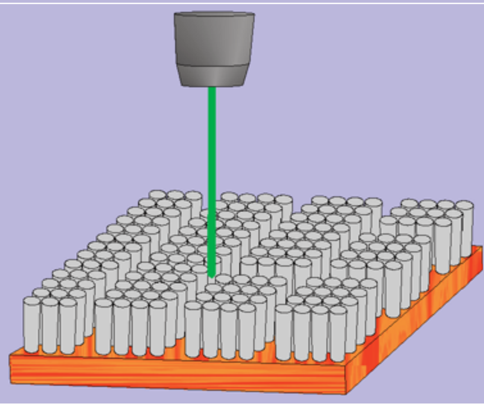

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SILICON ANODES FOR HIGHER ENERGY DENSITY OF LITHIUM BATTERIES

THE TASK

An increase in the energy density of lithium-ion batteries is necessary to extend the driving range of electric vehicles. Since the space in the vehicle is limited, energy density per volume unit has to be given special attention. The substitution of the recently used graphite anodes by silicon ones offers the potential to meet this demand because they can store a higher quantity of lithium ions per weight and volume.

A disadvantage that has hitherto prevented the commercial implementation of silicon-based anodes is their volume expansion by about 300 percent during the lithium insertion. Composite structures consisting of silicon and carbon are regarded as the solution to this problem. However, this combination limits the positive impact of the silicon. The use of compact silicon films has been hitherto avoided, since the active material would lose contact during the volumetric expansion.

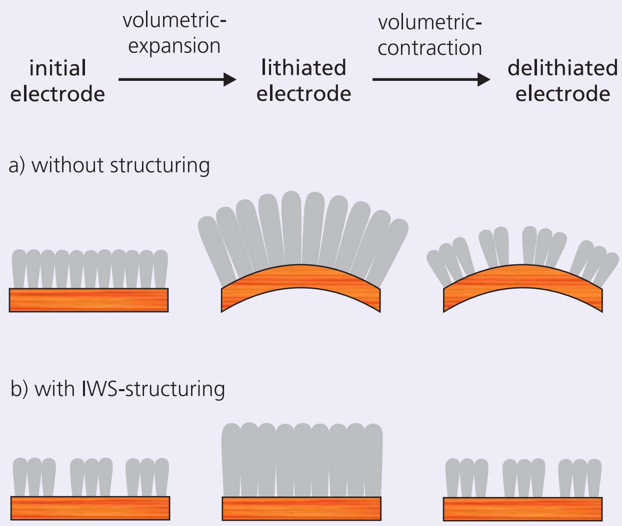
For high volumetric energy density, we have to develop pure, compact silicon electrodes that compensate for the volumetric expansion during lithiation and are suitable for use in large-sized cells.

OUR SOLUTION

Deposition of silicon on specially pre-treated substrates is a precondition for a columnar structure that adheres well to the current collector and has intrinsic porosity. Such electrodes in principle show excellent electrochemical capacity utilization. However deformation effects or cracks may be observed in the electrodes, since, due to the special silicon film growth mechanism, as well as shadowing effects, there is not enough space for the volumetric expansion.

Fraunhofer IWS has developed a post-treatment of the columnar silicon structures that avoids electrode deformations. The block-like structure of the columnar silicon film generated in the first lithiation and delithiation steps was used as a pattern (Fig. 2). The development is based on partial silicon ablation by laser micro processing (Fig. 1). The structure can be intentionally adjusted by variation of the process parameters laser power, wavelength and feed rate.

Avoiding electrode deformations during lithium insertion in columnar silicon films by laser structuring



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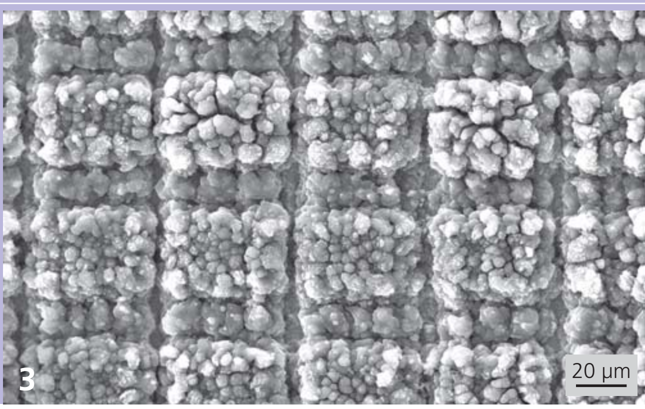

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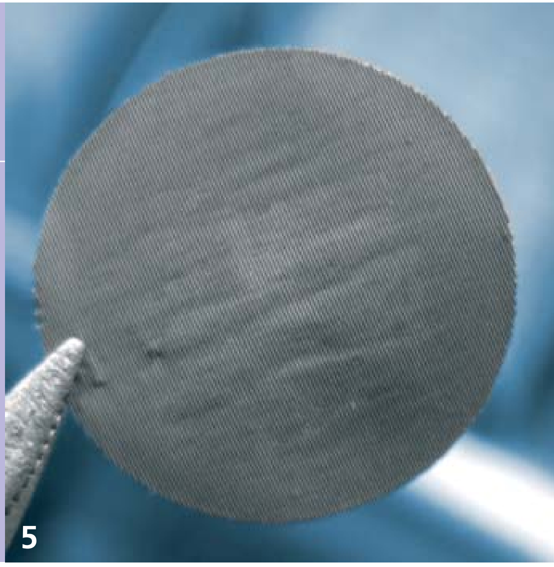

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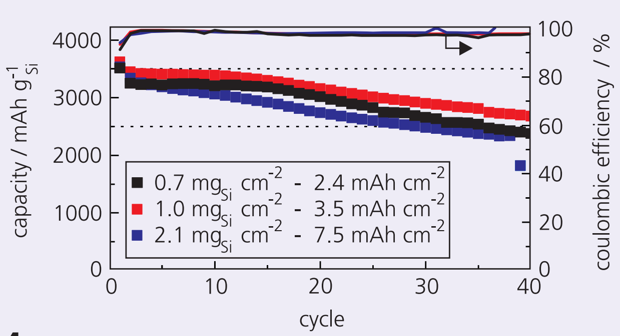
RESULTS

During the electrochemical cycle, the self-organized, block-like structure was initially adjusted by laser micro processing, thus avoiding electrode deformations (Fig. 3, 5).

The columnar silicon films were assessed with regard to their electrochemical properties in half cell tests against lithium. Increasing the silicon mass of electrodes at constant capacity retention the area capacity could be increased from about 2 mAh cm^{-2} to 7.5 mAh cm^{-2} (Fig. 4).

Influence of silicon mass of electrode on capacity retention and initial area capacity



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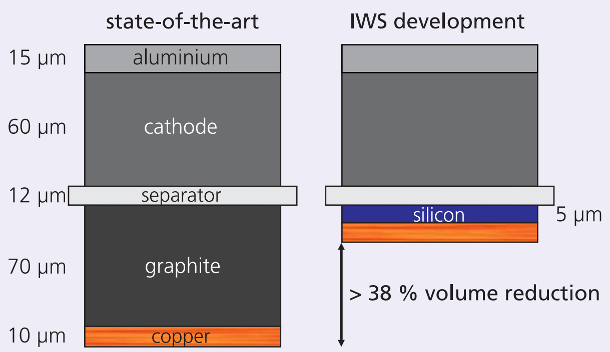
The pure and compact silicon films developed at IWS can prospectively take the place of traditional graphite anodes. The anode volume can thus be minimized at an unchanged capacity, which results in a volumetric advantage of more than 38 percent on the cell level (Fig. 6).

Secondary batteries based on this anode material have the potential to increase the volumetric energy density by 43 percent, from a current maximum of 700 to more than 1.000 Wh l^{-1}.

This means the battery pack can store a larger energy quantity at the same volume and can thus provide the technological precondition for an increase in electric car driving distances. Refinement and scaling of the Si deposition and structuring technology are key for successful industrial implementation of this approach.

Comparing the cell volume of a lithium-ion battery with graphite anode (left) and columnar silicon film anode (right) at identical area capacity



6

1 Laser micro processing of columnar silicon films

3 Eliminating macroscopic electrode deformation by structuring

5 Structured electrode after lithiation by means of expanded silicon islands

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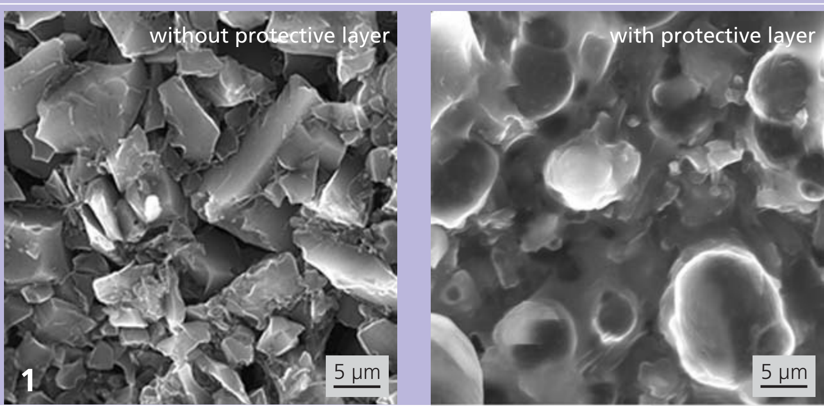


NATRIUM-SULFUR BATTERIES FOR STATIONARY ENERGY CELLS

THE TASK

Renewable energy types, such as wind and photovoltaic energies, are subject to natural variations in quantity. To compensate for these variations, high-temperature sodium-sulfur batteries are employed, for example, as stationary energy cells. Because of the kinetic mechanism of the reaction, only less than 25 percent of the theoretical capacity can be utilized. Furthermore, the high-temperature system has tremendous safety risks due to the use of liquid sodium.

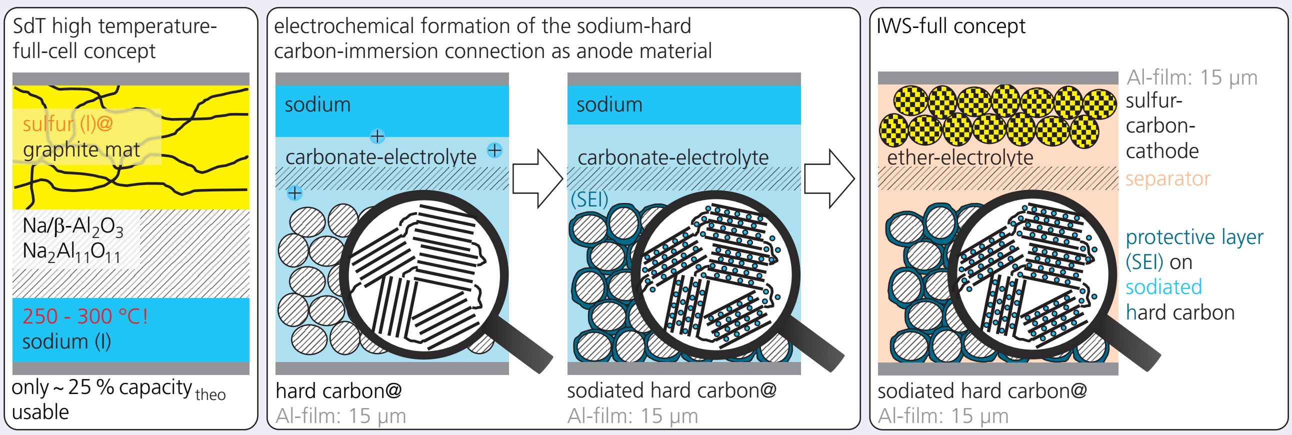
Dresden research institutes are collaborating in the funded project on novel battery components and manufacturing techniques for a room temperature Na-S battery demonstrator. In this project, Fraunhofer IWS Dresden implements the whole process chain to produce Na-S battery cells. The development tasks include material preparation, electrode production, and formation of cell stacks.

OUR SOLUTION

In the joint NaSBattSy project, registered under No. 1002 34957 by the SAB (Saxon Development Bank), the IWS sought to develop a stationary electrochemical energy cell based on sodium-sulfur cell technology. This mode of energy storage can be produced at reasonable costs and works at room temperature. The low price results from the low-cost materials that are available in almost unlimited quantities, without any toxic waste.

The latter demands an innovative, electrochemical step ahead, in which the anode material – a sodium-carbon compound Na_xC – is generated. Customized electrolyte formulation must efficiently eliminate undesirable side effects (polysulfide shuttle) and form protective layers on the anode side (Fig. 1).

Full-cell concept of the Na-S cell, developed at IWS and patented, in comparison with standard concept



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For the anode, non-graphitizable carbons are used; these carbons are presodiated with an adapted electrolyte formulation and simultaneously coated with a sulfidic protective layer (Fig. 2). For the cathode, a paste-based coating technology that has already been established for lithium-ion batteries is used, on the one hand. Alternatively, a solvent-free process is applied, in which a freestanding electrode film is produced from the carbon-sulfur composite and a binder, on the other hand. Both technologies are already common in the fabrication of lithium-ion batteries (Fig. 3) and thus do not demand new equipment.

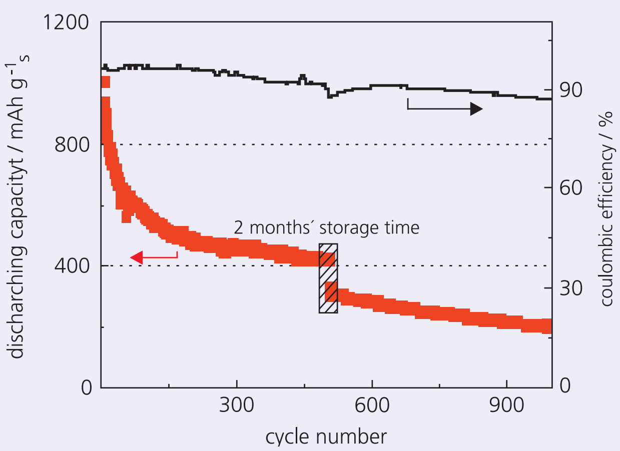
RESULTS

In the collaboration, the project partners created the electrochemical and technological basics for a new electric storage system for stationary applications. For the first time, a Na-S cell could demonstrate electrochemical stability for more than 1000 cycles at room temperature (Fig. 4). This result is an important milestone towards low-cost energy cells based on available raw materials.

Fraunhofer IWS mainly researches anode formation as an unknown process step. The electrolyte has emerged as a relevant key component in the Na-S cell. Solubility against polysulfides is defined by the composition of the solvents and the salt concentrations and significantly affects specific capacity (sulfur utilization) on the cathode side, as well as degradation and self-discharging on the anode side (due to the polysulfide shuttle effect).

In contrast to lithium, there are no commercially available sodium foils, which are essential for a temporally efficient formation of the sodium-hard carbon intercalation compound. Fraunhofer IWS developed a scalable concept for casting sodium foils. In the future, cyclic life can be further prolonged by adapting the electrolyte formulation.

Sulfur discharge capacity versus number of cycles of the developed full-cell concept



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1 SEM images of the hard carbon anode material, with/without protective layer

3 Roll-to-roll coating system

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1

RADIATION-SELECTIVE ABSORBER COATING FOR HIGH TEMPERATURE APPLICATIONS

THE TASK

The sun is the largest renewable energy source. However, an efficient conversion of solar energy into heat demands that specific optical parameters have to be fulfilled by the solar absorber surface. For high optical efficiency, absorption in the solar spectrum (280 nm - 2500 nm) has to be maximal, while thermal emission has to be low (Fig. 2).

Spectral distribution and emission performance of a surface depend on its temperature and the absorption characteristics. For low thermal emission, according to Kirchhoff's Law, absorption has to be low at the same wavelength. The change in the absorption characteristics, as is needed for solar applications, is achieved by so-called radiation-selective absorbers, which can only be produced in vacuum processes for high temperature applications (> 400 °C).

OUR SOLUTION

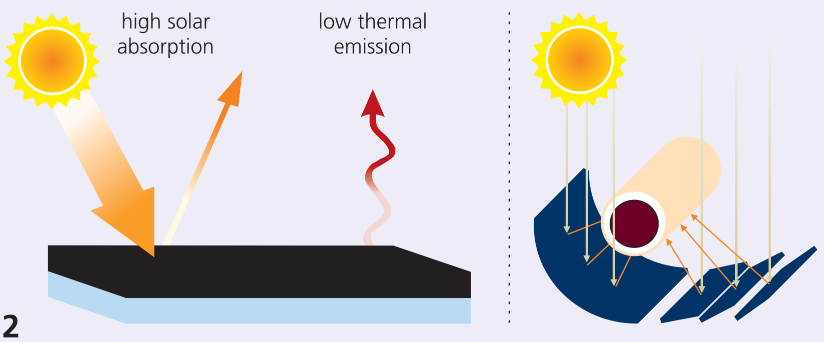
At Fraunhofer IWS Dresden, an approach based on the employment of innovative materials and low-cost processing techniques was developed. A solar absorber more effective than the current state-of-the-art was built and a patent for it was filed.

The basic structure of the newly developed film system is as follows: it consists of a highly reflecting metal film in the infrared wavelength range and a highly absorbing CNT thin film in the solar spectrum. For better adhesion of the films and improved abrasive resistance of the system, the CNT thin film is mechanically reinforced by means of an optically transparent silicon oxide film (Fig. 3).

Carbon nanotubes (CNT) have, due to their one-dimensional structure, specific optical properties, which can be intentionally used for the fabrication of radiation-selective film systems. For this purpose, it is possible to customize the optical properties of these innovative CNT-based solar absorbers for the corresponding technical range of application or the required temperature. Thanks to their excellent thermal resistance, the CNTs are also suitable for use in high temperature applications.

The coating techniques, which are required to fabricate such a solar absorber, are inexpensive, easily scalable, and may be flexibly retrofitted to suit numerous substrate materials and geometries (Fig. 3).

Principal sketch of a radiation-selective surface, as well as concentration of solar radiation with line concentrators (parabolic through collector technology and Fresnel collector)



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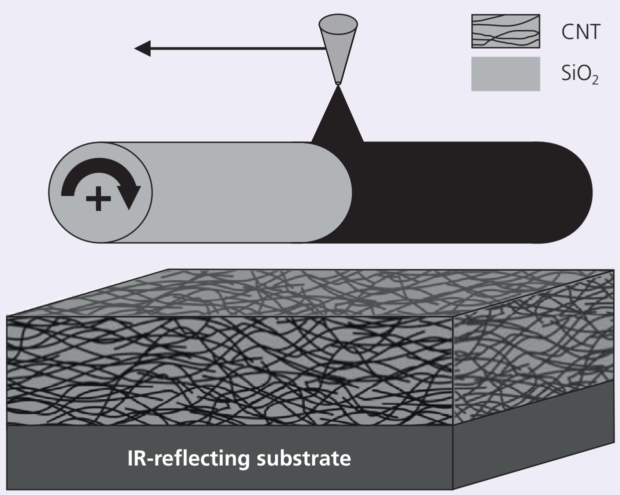
RESULTS

The absorption mechanisms occurring in CNTs are based on interactions of the electromagnetic radiation with the π plasmon and interband transitions, the so-called van Hove singularities (vHS). Radiation selectivity of the CNT film can be intentionally adjusted by the wide background absorption of the π plasmon (peak maximum in the UV range) and the specific absorption bands of the vHS, by variation of the CNT diameter and the CNT film thickness (Fig. 4).

Based on analyses of various CNT materials, several radiation-selective film systems were built and analyzed. The best results are shown in Figure 5 in comparison with commercially available products.

Thermogravimetric measurements carried out on single-walled carbon nanotubes (SWCNT) films in an oxygen-containing atmosphere demonstrated a temperature resistance of 584 °C, and in an inert nitrogen atmosphere as much as 850 °C.

Simple atomization technology to apply the radiation-selective CNT absorber films and dip-coating of the SiO_2 protective film



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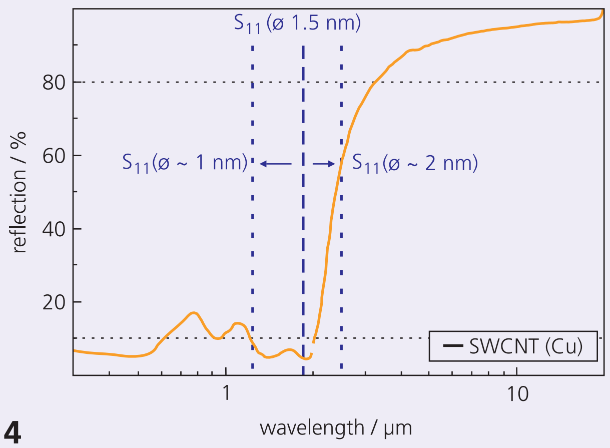
Influence of various CNT diameters on the S_{11}-vHS absorption bands in the reflecting spectrum



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Optical properties of CNT-based radiation-selective film systems in comparison with state-of-the-art

	solar absorption	thermal emission	
	α_{dir}	$\varepsilon_{100\,°C}$	$\varepsilon_{400\,°C}$
MWCNT on Cu	0.92	0.09	0.22
SWCNT on Cu	0.90	0.05	0.11
black chromium	0.96	0.19	-
Cermet	0.94	0.08	0.13

5

1 Receiver tube with CNT-based absorber tube

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imanto
imaging tools

2

CONTACTLESS EVIDENCE OF BIOCIDES IN CULTURAL PRODUCTS AND TIMBER

THE TASK

Many museums in Germany are not able to present their valuable exhibits to the public because the artifacts are contaminated with biocides. In the 1970s, good-faith efforts were made to prevent textile, wooden or prepared biological objects from being destroyed by spraying them with pesticides, such as Hylotox. Today we know that these substances carry a non-negligible health risk. Exact knowledge of the type, the volume and the location of the contamination are preconditions to determine an optimal cleaning strategy.

To find organic biocides, which altogether consist of the elements carbon, hydrogen and chlorine, a technology is necessary which is able to distinguish substances according to their molecular structure. Non-destructive near- infrared hyperspectral imaging, which makes possible quick spatially resolved and spectroscopic recording of the researched objects, can solve these problems.

HSI microscope combination for detailed investigation of minimal sample areas

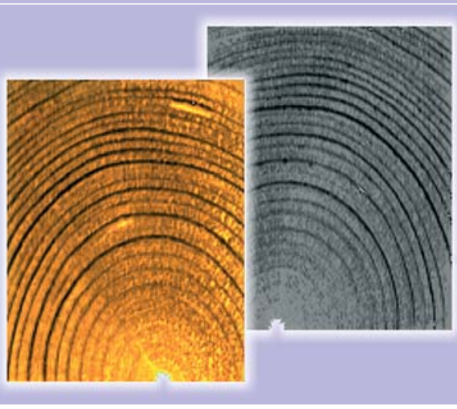
1

OUR SOLUTION

"Hyperspectral Imaging" (HSI) is a class of imaging spectrometers. Apart from laboratory applications, the compact HSI systems are also suitable for analyses on-site, without removing a sample and separately analyzing it in the laboratory. The optically contactless working principle is a major advantage in comparison with invasive inspection methods, since the cultural products investigated are not damaged by them.

Using an adaptable optical system, a wide range of working distances is feasible. A careful choice of the optical unit means that pixel resolutions of less than one micrometer to several decimeters can be implemented. Given the high level of detailed information in spectral monitoring, there is a substantially extended database for sample analysis. In addition to the chemical information recorded in the near infrared range (NIR), image data from the analysis of surface structures can also be used. It is crucial to reasonably process and interpret huge data volumes in the Gigabyte per second range.

At Fraunhofer IWS, solutions that make it possible to quickly derive information by means of multivariate data analysis algorithms, as well as image analysis methods ("soft modeling") were developed. When using the latter in particular, a quick analytical functionality can be realized that is able to analyze the data within a few seconds and to output the result. For this purpose, the software platform (imanto®pro) has been developed in-house, which can be individually tailored to the needs of each task.



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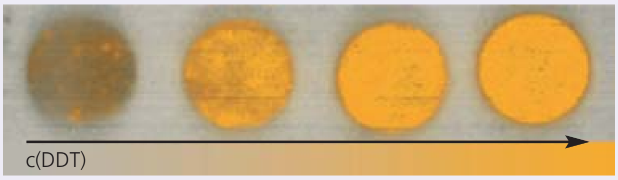
RESULTS

In preliminary studies performed on intentionally contaminated PTFE pressed parts, it was found that the biocides pentachlorphenol (PCP), g-hexachlorcyclohexane (Lindane), dichlordiphenyl trichlorethane (DDT) and parathion can be unambiguously identified with the technique.

PTFE pressed parts with increasing DDT concentration (from left to right), heterogeneous distribution at lower concentrations is clearly visible (minimal concentration < 0.5 weight percent)



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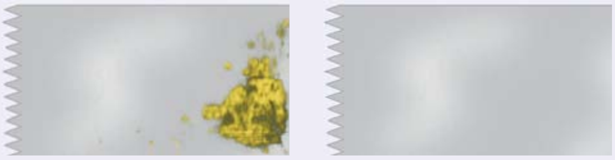
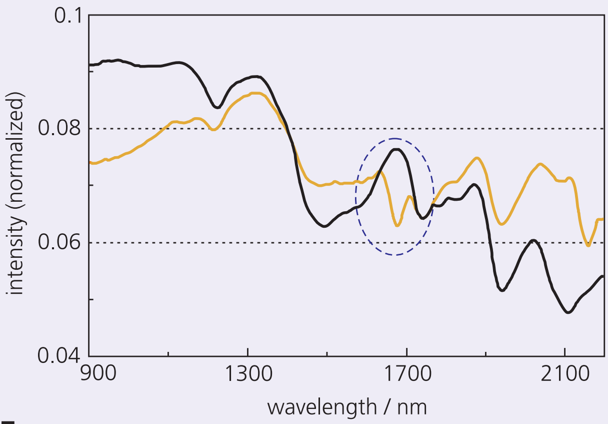
The technique was also used successfully to find biocides on impregnated timber. Biocides were found by means of spectral bands in the near infrared range that can be clearly assigned to the corresponding biocides. Based on a calibrating concentration series (for example in PTFE pressed parts), it is also possible to specify concentrations. An analysis via soft-modeling methods can be, for example, implemented by the principal component analysis (PCA).

In addition to the direct studies of the cultural products, it has also been successfully used to remove surface coatings and analyze them in laboratory afterwards. The coatings crystallized on the surfaces, can, for instance, be removed by means of adhesive tape. Figure 5 depicts samples obtained from a church roof in comparison (contaminated – not contaminated), as well as characteristic spectra.

Adhesive tape-removed sample from a church roof (left) in comparison with a reference sample (right). DDT contamination of the roof sample clearly to be seen (colored in yellow).



Spectra of reference (black) and of DDT contamination (yellow). Blue marked -DDT absorption, which is used for further analysis of the spectra.



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2 *Detailed view of illumination in laboratory setup*

3 *Spectral images of pine cross sections at 1430 nm, with/ without biocide impact*

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1

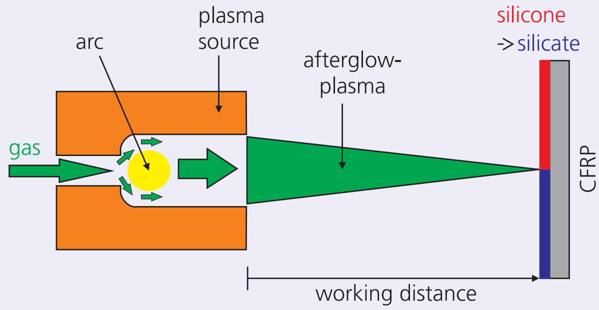
PLASMA CLEANING TO REMOVE RELEASE AGENT FROM CFRP SURFACES

THE TASK

Carbon fiber-reinforced plastics (CFRP) are being used more and more in the aircraft and automotive industries thanks to their extraordinary material properties. To utilize their lightweight potential to the full extent, established joining technologies, such as riveting or screwing, have to be replaced by new adhesive bonding technologies tailored to the CFRP materials. Adhesive bonding technology is characterized by its simple feasibility and reduction of stress concentrations inside the component. Surface pre-treatment is the basis for successful adhesive bonding of the components. Pre-treatment of CFRP materials does not only address fine-cleaning but also the complete removal of release agent residuals due to fabrication.

To reduce manufacturing costs, the currently established removal of release agent residuals by manual grinding is to be replaced in the future by a plasma pre-treatment. The plasma technology must have a wide technological range in terms of the manufacturing distance, because large, complex and slightly shaped surfaces have to be treated.

Working principle of the LARGE plasma source for CFRP treatment



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OUR SOLUTION

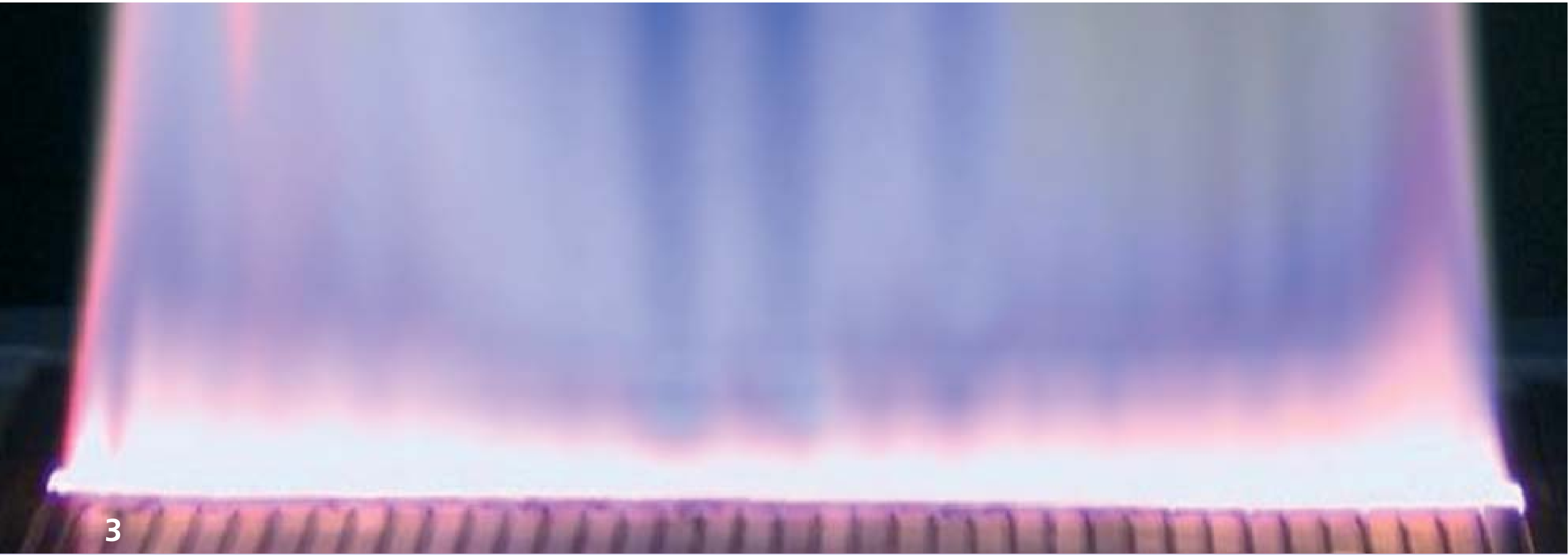
For the removal of the release agent from CFRP surfaces, a specific linear arc plasma source (LARGE) with adaptable working width has been developed at Fraunhofer IWS Dresden. With the LARGE plasma source, Fraunhofer IWS provides a plasma technology for large surface applications at atmospheric pressure (Fig. 2). The plasma source generates a homogenous linear afterglow plasma sheet of maximal 350 mm length. The source works at atmospheric pressure making it very easy to integrate the system into existing process chains.

A special feature of the LARGE plasma source is that a variety of usable plasma gases and their mixtures, such as compressed air, Ar + O_2, N_2, CO_2, H_2, NH_3 etc., can be employed. This makes it possible to modify the plasma treatment intentionally for the CFRP surface to be treated.

Another advantage of the LARGE plasma source is its long torch length of up to 20 cm. Thus, even shaped components can be treated without great positioning efforts.

RESULTS

For the removal of release agents, representative CFRP samples were treated with the LARGE plasma technology. The working distance to the plasma source, the plasma gas composition, and the speed were optimized to achieve the maximal adhesive bond in the adhesive joint to be created subsequently. Both liquid release agents (Marbocote) and release films (Super Release Blue) based on silicone were examined and tested.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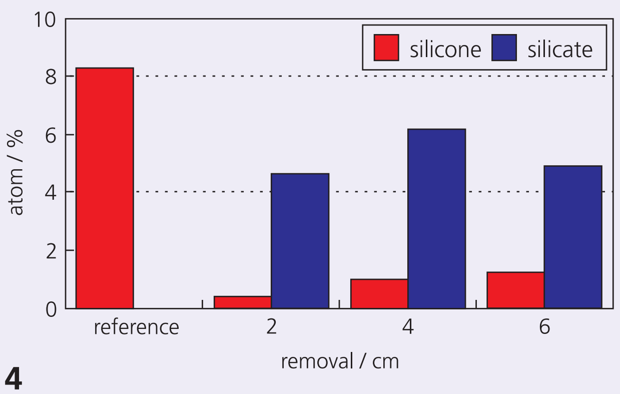
The chemical composition of the CFRP surface was determined both before and after the plasma treatment by X-ray photo-electron spectroscopy (XPS). The bond strength of the adhesive joints was found by the pull off test according to DIN EN ISO 4624, as well as the G1C test (industrial aircraft standard). The reference samples were ground and cleaned with acetone afterwards. The XPS results show that the silicone content in the CFRP surface clearly decreases after the plasma treatment (Fig. 4). Due to the high plasma activity of the source, silicone-based release agent residuals are converted to silicates. These layers, which are similar to fused quartz, act as an additional bonding agent in the subsequent adhesive bonding process, thus enhancing the bond strength.

XPS surface analysis of one CFRP sample, cleaned



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Pull-off- and G1C adhesive tests performed at cleaned and adhesively bonded CFRP samples

5

The pull-off tests to quantify the bond strength were performed on a Lumifrag centrifuge. The best bond strength was achieved at treatment distances of 40 mm and 60 mm. Even if the treatment distances are 80 mm, the bond strengths achieved were clearly higher than those of the reference samples (see Fig. 5).

The results of the G1C adhesion tests confirmed the findings of the pull off tests. In comparison with the reference sample, here clearly higher G1C energies for processing distances from 4 cm to 8 cm were obtained (Fig. 5).

In addition to the adhesive energies, the fracture surfaces of the adhesive joints according to DIN EN ISO 4624 were examined. In all the samples, either a cohesive failure in the adhesive or inside the matrix material was found.

1 150 mm LARGE plasma source mounted on a robot lever for CFRP treatment

3 LARGE plasma torch

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PRECISE BORON DOPING OF SINGLE-CRYSTALLINE DIAMONDS

THE TASK

Diamond is one of the most promising materials for applications in high-temperature, high-power and high-frequency electronics. The unique combination of extraordinary physical properties (Fig. 1) makes it possible to design electronic components that clearly exceed the performance of other semi-conductor elements (Si, SiC and GaN). A new generation of power electronic equipment that can be run with voltages of several 10 kV and a power from 100 kW to 5 MW is conceivable. Diamond-based power electronics are suitable for use at higher temperatures, without necessary external cooling and extensive protective circuits, saving both weight and costs.

To utilize the full potential of diamond electronics, the electrical properties of diamond, such as electrical breakdown field strength and charge carrier conductibility, have to be maximized, and precisely defined doping profiles have to be achieved for p- and n-doping. Fabrication of doping profiles with exact lateral and vertical sizes and defined acceptor and donor concentrations are the key to achieving semi-conductor transitions in diodes and transistors with controlled electrical fields and breakdown field strengths.

Physical properties of several semi-conductors

properties	Si	GaAs	6H-SiC	GaN	diamond
band gap, E_0 (eV)	1.12	1.43	3.03	3.45	5.45
breakdown field strength, E_C (kV cm^{-1})	300	400	2500	2000	10000
thermal conductivity, λ (W cm^{-1} K)	1.5	0.46	4.9	1.3	22

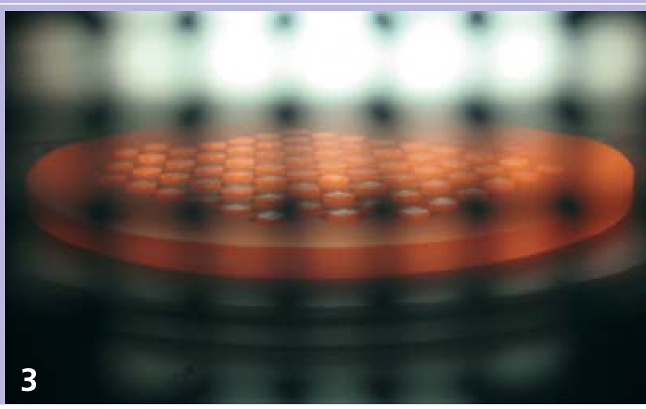
1

OUR SOLUTION

Doping of diamond typically occurs with boron as the p-dopant and phosphorous as the n-dopant. Normally doping is performed in-situ during the homoepitaxial diamond synthesis by adding doping sources (for example in the form of a process gas) during the CVD process. However, direct doping during growth has a major disadvantage: it is impossible to vary the lateral doping profile. This is in stark contrast to other semi-conductor materials, in which doping is typically performed by ion implantation of the doping atoms and subsequent thermal curing.

For diamond, this method can only be implemented in a complicated manner, since diamond represents only a meta-stable carbon variant at atmospheric pressure. This mainly affects annealing, in which diamond may convert to graphite. Doping atoms do not diffuse well in diamond because the high atom density results in very low diffusion rates, unless the diamond is subjected to very high temperatures, at which, in turn, a conversion to graphite can occur.

The Fraunhofer USA Center for Coatings and Diamond Technologies CCD, in conjunction with Michigan State University MSU, received a grant for a 4-year research project from the US National Science Foundation (NSF) to examine new doping methods for diamond to implement power electronics. The research focuses on further optimization of the doping process, even through alternative methods, such as diffusion of a solid doping source and ion implantation with doping atoms.



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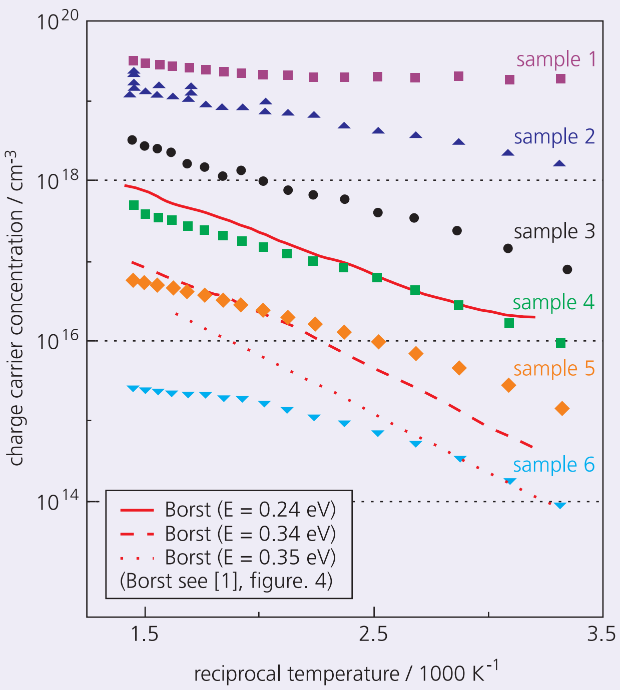
RESULTS

At Fraunhofer CCD, the synthesis of doped diamond is performed as in-situ doping in a standard process. During the CVD diamond synthesis (Fig. 3), the doping gases diborane (as n-dopant), and phosphine (as p-dopant) are added. Doping concentrations from 1015 cm^{-3} to 1020 cm^{-3} were achieved both with the p- and the n-dopant. Figure 2 depicts the defect concentration of Boron-doped diamond films at various doping concentrations, measured by the Hall effect. The study on in-situ doping is focused on the optimization of the growth process to reduce the defect density in the epitaxially grown layer. It is also important to vary the individual process parameters successively, so that defined doping concentrations can be deposited.

Charge carrier concentration in doped diamonds in a temperature range from 300 K (room temperature) to 700 K. The various samples were created with different doping gas concentrations.



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During diffusion, carbon films that include boron or phosphorous are deposited on the doping surface. Subsequently the compound is heated in a furnace in a nitrogen atmosphere at temperatures from 1000 °C to 1600 °C. The main goal of the study is to quantify the diffusion coefficients of boron and phosphorous in the diamonds as a function of temperature. The analysis is mainly based on SIMS and capacity-voltage (CV) measurements, and the determination of the material constants by using the Hall effect.

The process of ion implantation, hitherto only applied to separate diamond wafers without losses, is modified so that doping atoms are implanted near the surface. Heating to high temperatures leads to a homogeneous allocation of the doping atoms in the conductive layer. Doping of the conductive layer at very high doses (1019 cm^{-3}) and the integration of the foreign atoms in the diamond lattice are the greatest challenges in this study, since ion irradiation at too high doses disturbs the crystal lattice and converts these regions into graphite.

[1] Borst, T. H.; Weis, O.: Electrical characterization of homoepitaxial diamond films doped with B, P, Lo and Na during crystal growth, Diamond and Related Materials 4 (1995) 948-953

3 Homoepitaxial synthesis of 70 diamond crystals of 3.5 x 3.5 mm^2 size

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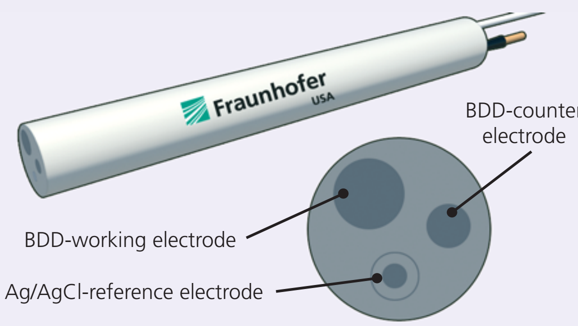
PORTABLE BORON-DOPED DIAMOND SENSOR FOR ANALYSIS OF TOXIC HEAVY METALS

THE TASK

Boron-doped diamond (BDD) has the largest electrochemical potential range of all electrode materials and, as a result, is considered an excellent sensor and electrode material. BDD has a wide range of application – from water treatment techniques to chemical syntheses and electrochemical analyses. Its extreme mechanical and chemical stability, the low background current and the low double layer capacitance make the BDD material particularly useful to detect traces of toxic heavy metals in water.

The increasing occurrence of toxic heavy metals in potable water is a growing problem. Continuous exposure to heavy metals, such as lead, cadmium and mercury is carcinogenic and results in physical damages including renal failure, massive nerve damage and lower IQ. Children's bodies absorb these poisons more quickly, so that these hazardous effects can be observed in children to an increased extent. The World Health Organization (WHO) reports in Europe indicate that the IQ of children drops even at blood lead values of less than 10 µg dl^{-1} or 1 ppm.

Portable BDD sensor, configuration with three electrodes



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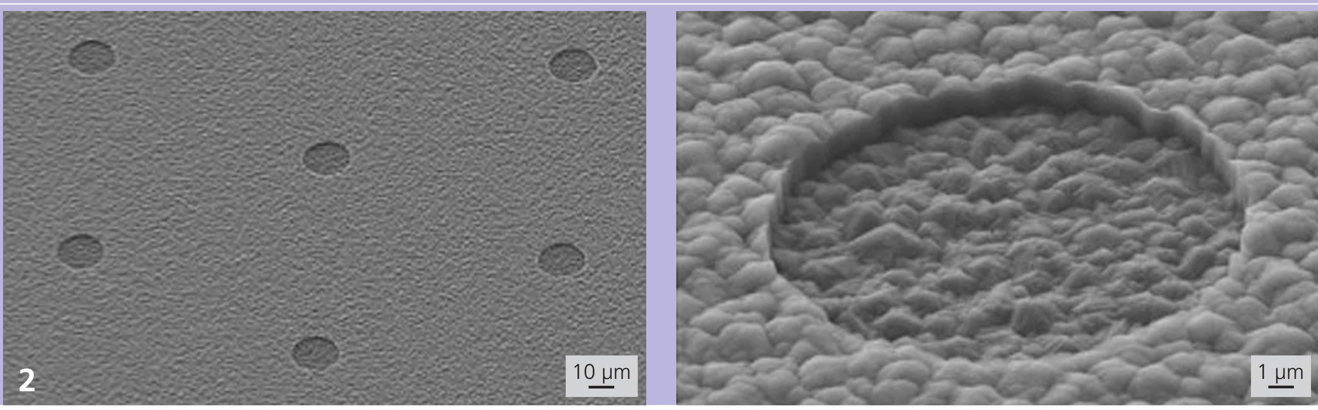
It is necessary to detect these metallic poisons before they enter the human body to avoid potential lifelong suffering. For this reason, it is very important to develop a simple and user-friendly sensor.

OUR SOLUTION

Researchers at the Fraunhofer Center for Coatings and Diamond Technologies CCD in Michigan, USA, engineered a portable electrochemical sensor for universal use, based on the boron-doped diamond technology. The sensor makes it possible to reliably measure even minimal heavy metal concentrations in potable water, for instance in the municipal water treatment station or at home. The sensor (Fig. 1) consists of a BDD working electrode, an Ag/AgCl reference electrode and a BDD counter electrode.

The development of a suitable BDD working electrode calls for investigations of microelectrode arrays (MEA) and macroelectrodes. Several geometry variants (diameter and center point-to-center point distances) of the MEAs were analyzed in detail to optimize sensitivity and detection limit. Figure 2 shows images of an individual microelectrode and the hexagonal configuration of the BDD-MEA.

The CCD researchers developed a miniaturized low-cost potentiostat to set up a complete measuring system. The potentiostat can control and measure the voltage curves required and resultant currents for a wide variety of electrochemical measuring techniques. Square-wave-stripping voltammetry (SWSV), in which the measured current is proportional to the concentration of the analyte in the solution, is a sensitive measuring technique that may also be used.



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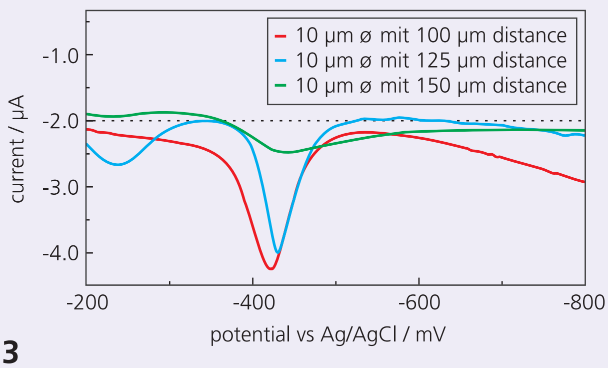
RESULTS

With SWSV, trace elements can be detected in heavy metal ions by eliminating the capacitive background currents. Thus the measured current only consists of faradaic current or current, which is caused by the analyte. Figure 3 lists the SWS voltammograms of lead, which were measured by various MEA geometries. Each electrode shows a clearly quantifiable reaction at a trace concentration of only 5 ppb (25 nM) lead in the solution. A 10 µm individual electrode diameter and a center point-to-center point distance of 100 µm proved to be the best option.

Square-wave-stripping voltammograms of a lead concentration of 5 ppb (25 nM) in PBS solution (pH 4.0), recorded by means of BDD-MEA electrodes of different geometries.



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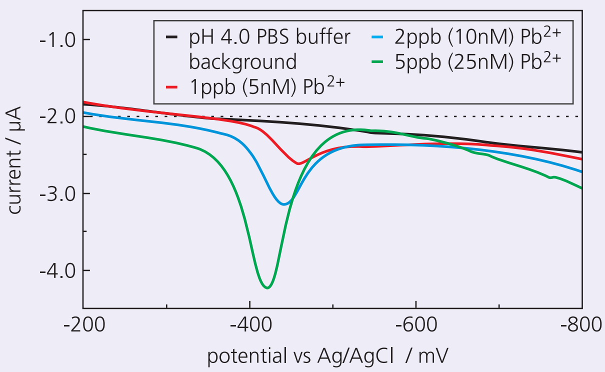
Square-wave-stripping voltammograms of several Pb^{2+} concentrations at a BDD-MEA with 10 µm diameter and 100 µm distance in PBS solution.



4

Further examinations using the 10 µm x 100 µm BDD-MEA are summarized in Figure 4. In this case, a series of different lead concentrations from 1 to 5 ppb (5 to 25 nM) was analyzed. These concentrations were chosen to determine whether the BDD sensor was able to reliably measure concentrations below the maximum permissible values for potable water. For lead, for instance, these values are 10 ppb (50 nM) according to the German Federal environmental agency (German abbrev.: UAB) in Germany and 15 ppb (75 nM) according to the Environmental Protection Agency (EPA) in the USA.

As can be seen in the Figures 3 and 4, it is possible to obtain clearly quantifiable current measurements even for 1 ppb of lead. A linear correlation between the growing lead concentration and the current deflection obtained demonstrates that the BDD-MEA sensor created by Fraunhofer reaches a detection limit of 0.2 ppb (1 nM), which is 50 times or 75 times less than the permissible value for potable water according to the German UAB and the US EPA, respectively.

The CCD researchers also engineered optically transparent BDD electrodes for spectral-electrochemical measurements (such as to investigate polycyclic aromatic hydrocarbons), as well as BDD arrays for ozone generation, and flexible diamond electrodes – packed in polymer – to analyze neurotransmitters.

2 *Scanning electron microscopic image of a boron-doped microelectrode array (BDD-MEA)*

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RELIABLE MEASUREMENT OF THE WATER VAPOR TRANSMISSION RATE OF WEBS BY MEANS OF LASER

KURT PIETSCH
Managing Director
Sempa Systems GmbH

DR. WULF GRÄHLERT
Group manager process monitoring
Fraunhofer IWS Dresden

Editor: Mr. Pietsch, your company, the Sempa Systems, is known for its expertise in the field of highest purity gas installation. How did you find out about the IWS and its research on permeation measurement?

Mr. Pietsch: Our collaboration in this area began with the IWS' idea of measuring the water vapor transmission rate of barrier webs by means of the laser diode spectroscopy. In terms of sensitivity, the goal was to represent the former state-of-the-art, at least. In 2007, the transnational "PermaBar" project was initiated, incorporating not only Sempa Systems, but also laser manufacturers from Norway and a manufacturer of permeation measuring systems from Germany. Shortly after the project began, the equipment manufacturer left the consortium. The original application channel was no longer available, and there was a risk that the project would be cancelled. In the given group of partners, it was hardly possible to substitute partners equivalently. Since, at that time, the IWS and Sempa Systems had already collaborated in R&D for a long time, we worked together to figure out how to continue the project in the new situation. Based on the competency of Sempa Systems GmbH in highest purity gas installation, and, since development activities were planned anyway in the "PermaBar" project, Sempa Systems should establish itself as the future provider of permeation measuring systems.

Editor: What was the target market?

Mr. Pietsch: Without question: the future market "Organic electronics". Long-term stable functioning of components in organic electronics (OLEDs) significantly depends on the absence of humidity. This condition has to be achieved by ultra-barriers that let through a maximum of a millionth of a gram of water vapor per day per square meter. At the start of our collaboration,

this "water vapor transmission rate" parameter could not be measured at this level. First steps towards a measuring device suitable for industry were typical work packages of an R&D project: "proof of concept" and "development of a prototype". The results achieved in the project were of such quality that they could be implemented in a commercial product by Sempa Systems immediately after the initial project was concluded. A name was found quickly: "High Barrier Sensor", abbreviated "HiBarSens".

Editor: What requirements does your device fulfill? How does it distinguish itself?

Dr. Grählert: The excellent detection sensitivity of laser diode spectroscopy for trace humidity measurement was given. To use for similarly excellent sensitivity to the quantification of the water vapor transmission rate, some basic questions had to be solved first:

- How can one measure only the permeated water vapor, rather than the water vapor that has migrated from the ambient atmosphere into the measuring cell?
- How can the detection limit of the measuring system be reduced below the detection limit that represents the current state-of-the-art?
- What is the "correct value" for water vapor permeation altogether? What physical effects determine the "correctness of the measurement" and how should this be considered in terms of concept design and hardware?

Having answered all three questions successfully paved the way for the HiBarSens system to be ready for the market. The detection limit of this device is by more than two orders of magnitude better than the original target. Ultra high barrier materials for OLED fabrication, ranging around 10^{-6} g m^{-2} d^{-1}, are currently easily and reliably detectable. As a result, the system now defines the state-of-the-art itself.

Editor: How did you succeed in penetrating the permeation measurement market as a newcomer?

Mr. Pietsch: Of crucial importance was and is the development and protection of the measuring modes by patent law, which made a detection limit of water vapor transmission rate measurement of < 10^{-6} g m^{-2} d^{-1} possible. Profound understanding of the physical-chemical processes in the measuring cell and its consideration in the measurement setup played an important role. And commercialization was strongly supported from the first prototype onward: by international papers presented by Fraunhofer IWS and the worldwide presentation of this technology at tradeshows and to potential customers.

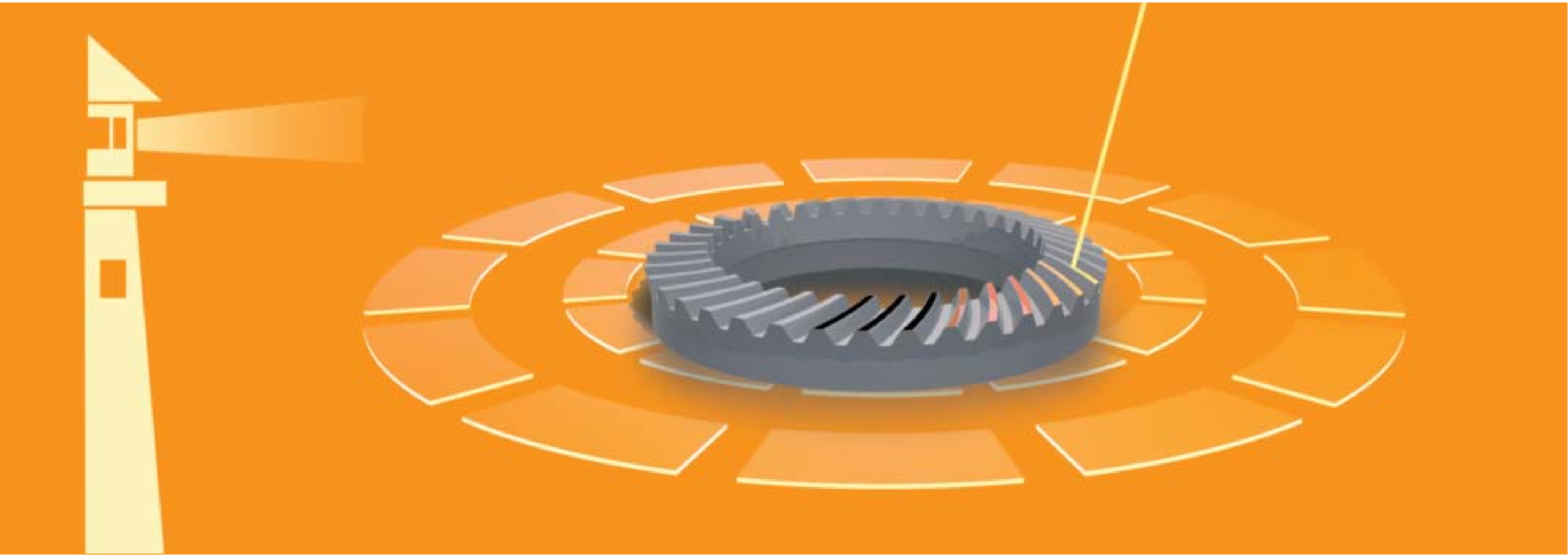
Editor: Where do you stand now? What are the next goals for development?

Mr. Pietsch: After the "revolutionary steps" at the beginning, which were marked by the use of the laser diode spectroscopy in high-performance measurement modes, we are now getting into a moderate, more evolutionary mode. Currently we are designing the HiBarSens system for high temperatures and preparing the simultaneous quantification of further gases, such as oxygen.

Editor: What, from your point of view, made the collaboration with an industrial partner particularly good?

Dr. Grählert: I considered the strategic decision of our partner to enter a totally new business unit to be very courageous. The great commitment, as well as strength and patience to push the development in the direction of making it ready for the market, and to enter this market as a "newcomer" was finally fruitful. We are particularly proud of the exceptionally short development period, which results not least from our strong partnership.

CENTERS



THERMAL SURFACE TECHNOLOGY – UNIQUELY MULTIFUNCTIONAL

The IWS has been honing its expertise in thermal surface technology for many years. Any kind of surface – metal, plastic or ceramic – can be coated and refined in a procedure which is unique in Europe. The most important techniques established at the IWS Center for Thermal Surface Technology are:

- laser buildup welding
- alloying by laser
- laser hybrid technologies
- plasma spraying
- HVOF-/cold gas spraying
- suspension spraying
- wire/vapor spraying
- thermochemical coating
- laser hardening
- laser induction hardening

Its pronounced materials knowledge qualifies the IWS to offer complete solutions for complex tasks from various industries, alone or in collaboration with its industrial and scientific partners. Materials and process engineering expertise are enhanced by well-proven systems engineering expertise. In addition to laboratory solutions, our customers also benefit from the IWS ability to implement technological developments incl. application-specific hardware and software components in industrial production. Research findings can be implemented in practice rapidly – this means an important competitive advantage for our customers.

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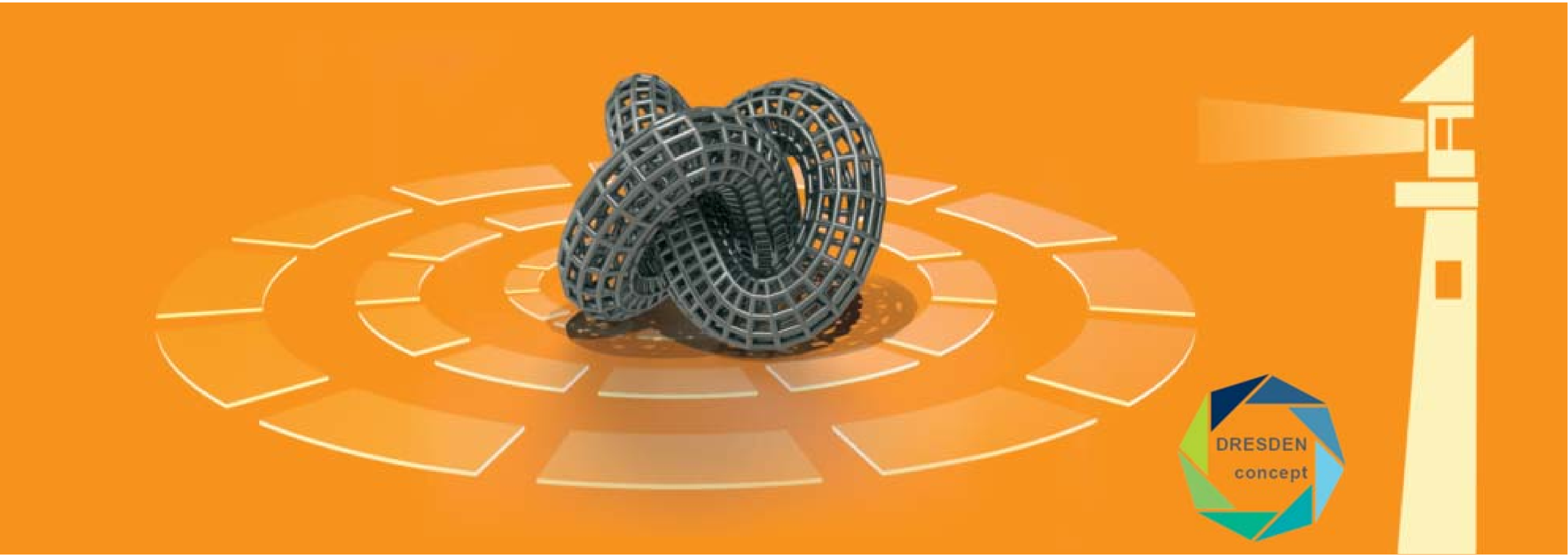
The IWS's many different customers employ thermal surface technologies in the automotive, energy, oil, gas and medical device industries, as well as in aeronautics, tool and die-making, and mechanical engineering. The parts range in size from a few millimeters to several meters. The production of coated or refined parts ranges from single-part production for use in space travel to series with millions of parts per year in the automotive industry.

Product solutions created at the IWS are regularly checked and analyzed in-house in our material laboratory in the development stage. The results, in turn, are incorporated into the process design. The customer receives a proven solution with respect to process and material.



ADDITIVE MANUFACTURING – COMPETENCE IN MATERIALS AND MANUFACTURING ENGINEERING

The additive manufacturing of components leads to a paradigm shift in manufacturing technologies. When building a part layer-by-layer materials are only used where they are needed. Furthermore, additive manufacturing concepts allow new degrees of freedom, which surpass the limitations of conventional manufacturing with respect to optimizing parts for their function, realizing new design geometries and in terms of production flexibility. Accordingly, industry is very much interested in the qualification of additive manufacturing processes for the manufacturing of products with industrial quality.

While additive manufacturing offers great potential there are also numerous unsolved questions. These can only be answered through close collaboration between industry and science. One of such initiatives is the project "Additive generative manufacturing" (in short Agent-3D), which was initiated by Fraunhofer IWS. A consortium of more than 80 partners drives forward the development of additive manufacturing methods and builds a network between industry and research organizations.

The Fraunhofer IWS together with the TU Dresden established an internationally recognized competence Center for Additive Manufacturing within the framework of "DRESDEN-concept". The center uses a wide range of process technologies to work on manufacturing processes and materials solutions to fabricate challenging products. Current foci are in the aerospace, automotive, energy, tool ,die and medical industries. The center offers the ideal networking platform for industry with basic research at universities and applied research in a rapidly developing high technology field.

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The available range of processes includes among others:
- laser buildup welding with powder and wire,
- selective laser and electron beam melting,
- 3D printing

for metallic and nonmetallic materials, plastics, functional materials as well as multi material systems. In addition to process development current efforts address the development of systems technology, sensorics and process diagnostics. The research at the Center for Additive Manufacturing focuses on typical process chains for products in different industries. This starts with component design and includes the actual manufacturing process as well as post-processing steps, repair and recycling. Another competence of the center is the evaluation and testing of the generated materials and components.

ENERGY EFFICIENCY – WE ARE NOT FINISHED YET!

The economical consumption of energy and the refinement of resource-conserving technologies is a central concern of the Fraunhofer IWS. Since its establishment, the institute has developed and deployed numerous technologies, which have provided substantial energy savings to industry and society. One example was the development of an innovative, locally applied heat treatment process, which increased the energetic efficiency of steam turbines. Similarly, a laser treatment process was developed to increase the efficiency of transformers and electric motors.

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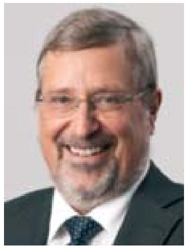

www.iws.fraunhofer.de/energy

The IWS also introduced a technology for the laser welding of lower fuselage structures of several Airbus models, which allowes for a significant weight reduction in the structure. Laser welding of primary structures reduces weight by about 10 percent.

Reduction of friction is important for higher energy efficiency. It also reduces wear and improves material efficiency. Friction and wear were significantly diminished by the diamond-like coatings developed at the IWS. In automobile manufacturing, the energy consumption of the motor and the power train was reduced. Meanwhile the IWS technology was implemented in mass production for several applications. This pioneering development was distinguished with several awards.

The "Dresden Innovation Center Energy Efficiency DIZE^{EFF}" was established in 2009 to drive forward and accelerate future innovations in energy efficiency for industry in the Dresden region beyond institutional boundaries and is coordinated by the IWS. In the DIZE^{EFF}, researchers of the TU Dresden and the Dresden Fraunhofer institutes collaborate on numerous projects in the fields of high-performance solar cells, fuel cells, high-temperature energy technology, lightweight construction, energy efficient manufacturing and energy saving displays.

Current research and development at the IWS are focused on the recovery of thermal energy by means of thermoelectric generators and the reduction of magnetic losses in electric motors. The latest findings in energy efficiency are presented to industry at the Hannover Industry Trade Fair every year.

BATTERY RESEARCH AT IWS – TECHNOLOGIES FOR NEW ENERGY STORAGE SYSTEMS

Developing low-cost energy storage devices with higher energy density is a challenge for growing markets in electric mobility, stationary storage solutions and, in future, aeronautics. Specific battery energy can only be significantly increased by introducing new cell technologies.

The lithium-sulfur technology has been refined at the IWS since 2010. This material system makes it possible to store 40 percent more energy per weight than the best Li-ion cells on the market do. The lithium-sulfur technology is still in its initial development stage, and the potential for its improvement of performance is high. New material concepts promising another increase in energy density and cycle stability of batteries were engineered in the research projects SepaLiS (registered under 03XP0031A) and StickLiS (registered under 03XP0030B) funded by the Federal Ministry of Education and Research (BMBF).

The electrolyte system is a key component for the improvement of Li-S technology. A nonflammable electrolyte was developed at the Fraunhofer IWS Dresden, by means of which the sulfur on the carbon cathode surface is converted and reduces corrosion at the lithium anode, which makes the cycles much more reliable.

The development of low-cost and scalable production techniques is crucial for launching a new battery system generation on the market and reducing the cost of existing cell production technologies. In the IWS Battery Center, a process chain for battery system manufacturing was established, which incorporates all of the steps from electrode manufacturing to packaging and assembling of electrode stacks up to the packed pouch cell.

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The activities are centered on the classical wet coating of battery electrodes and the solvent-free processing of the initial materials into freestanding electrode films. The electrodes are laser cut for packaging and can be adapted to several cell formats. These techniques were applied to implement a new electrode concept in the EC project ECLIPSE (GA 687306): a laser perforates the metal films used for current supply, thereby reducing the weight of the component by up to 73 percent.

Numerous techniques and concepts are being refined with our industrial partners and prepared for the introduction in prototype manufacturing lines for future battery cells.

The 5th workshop on lithium-sulfur batteries was organized and carried out by the IWS in Dresden in November 2016 and was attended by scientists and industry customers from Germany and abroad. The 6th workshop on lithium-sulfur batteries is planned to be held November 6-7, 2017 and is mainly intended for potential industrial customers.

TAILORED JOINING – JOINING TECHNOLOGY COMPETENCES IN DRESDEN

Joining is a key challenge in production and is frequently very costly. Current developments in joining technology are often able to provide significant improvements and ideas. The Fraunhofer IWS, together with the TU Dresden and other partners, has established the Tailored Joining center. Its goal is to give an overview of opportunities and limitations in several joining technologies, provide unbiased comparisons of technologies, map new developments succinctly and demonstrate industry-oriented solutions. The center is thematically based on the globally extraordinarily wide range of joining technologies that are explored and refined in Dresden.

The application- and industry-oriented developments at the Fraunhofer IWS are related to:

- laser beam welding,
- laser hybrid welding (plasma, arc, induction),
- brazing with laser and reactive multilayers,
- magnetic pulse welding (forming and welding),
- friction stir welding,
- form fitting laser beam joining (web-slot joints),
- diffusion welding (laser roll bonding),
- adhesive bonding and direct thermal joining of metal-plastic mixed joints.

Our TU Dresden partner at the chair of Joining Technology and Assembly focuses on techniques and tools for thermal joining (arc-based techniques, brazing), hybrid and mechanical joining, joining by forming (screwing, pressing), holistic planning of assembly, and handling and joining processes as well.

Since 2014, Dresden University of Applied Sciences (HTW) has supported the collaboration with its electron beam welding expertise. All partners use an independent comparison of various solutions to support the user in decision making.

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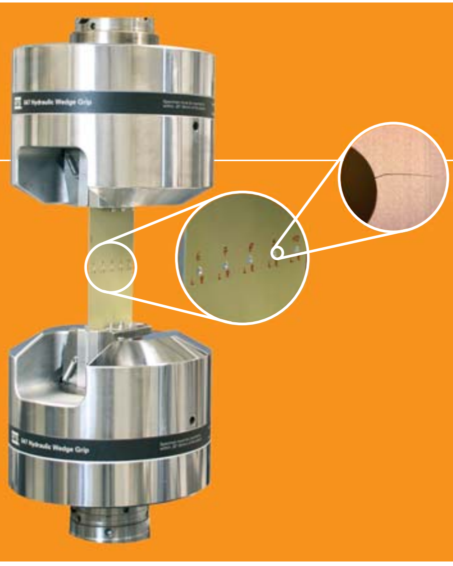
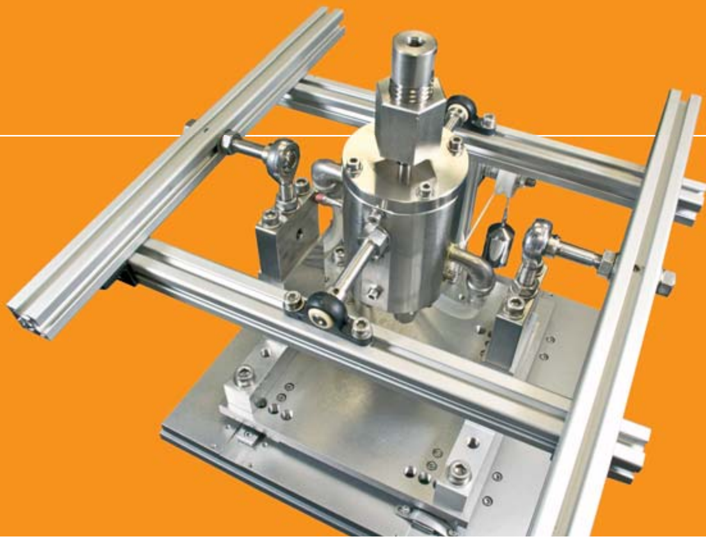
The international symposium "Tailored Joining", held together with the International Laser Symposium from February 23-24, 2016, was an excellent platform for the exchange of experience. The symposium presented a wide range of advanced joining techniques and current developments. Introductory courses on specific techniques, combined with practice demonstrations in the partners research labs were organized. This allowed new-comers to learn about a technology quickly and evaluate its opportunities and limitations.

The next "International Laser and Joining Symposium" will take place at the International Congress Center Dresden February 27-28, 2018. More information is provided here: www.fuegesymposium.de/en





COMPETENCE FIELD MATERIALS CHARACTERIZATION AND TESTING

The development of reliable and innovative products is based on and driven by new high performance materials. Existing processing technologies must be adapted to existing technologies, and the component characteristics achieved must be evaluated. Feedback from the findings of the materials characterization and the development of new process technologies customized for each application ensures maximal quality standards. The close interconnection of materials characterization and testing is the cornerstone of the impact of IWS scientists seeing themselves as partners for industry customers and as in-house service and consulting providers for all business units.

A current goal of IWS research is to improve the fatigue properties and the resistance to the propagation of fatigue cracks of a new fiber-metal laminate (FML) from the aircraft industry. Before using the new material for airplanes over short and medium distances, the mechanical properties need to be explored and a micro state must be found that will enable the fatigue cracks to grow in a controlled manner.

At the IWS, a new testing concept was also developed for the investigation of interacting wear and corrosion properties of a plain bearing-piston couple under near-practice conditions. Actuator systems for the automotive industry frequently consist of moveable control members and are subjected to complex mechanical and tribological loads as well as corrosion during operation. An actuator testing concept using, e. g. AdBlue, as an intermediate medium was created and commissioned, whereby the regions critical for faults and wear mechanisms were unambiguously identified in long-term tests.

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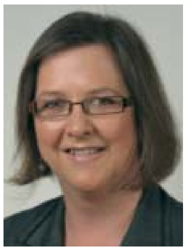

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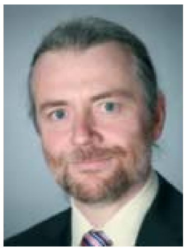

www.iws.fraunhofer.de/characterization

Research foci in structural materials characterization and damage analysis are:

- high resolution analysis of friction-reducing protective coatings, such as ta-C coatings and hard coatings,
- TEM (transmission electron microscopy) analysis of carbon and silicon nanoparticles for future energy storage devices,
- analysis of the formation of intermetallic phases in mixed metal joints (see pages 78/79) and
- investigations of material structures and coatings with focused ion beam (FIB, see pages 94/95).

FRAUNHOFER PROJECT CENTER AND WROCLAW CENTER OF EXCELLENCE FOR MANUFACTURING

The expertise of the Fraunhofer Project Center Laser Integrated Manufacturing in Wrocław (IWS PCW), which was founded in 2008, refers to the following key issues researched at the Fraunhofer IWS Dresden:

- ablation, cutting and joining,
- thermal coating, surface and microtechnology,
- 3D printing for medical applications,
- big data platform for production and medical objects.

The major departments of the Center for Advanced Manufacturing Technologies (CAMT) at the Wrocław University of Technology contribute additional expertise in:

- process monitoring and data processing,
- production management and quality inspection system,
- production automation and control.

Collaboration primarily aims at contract research and development for industrial customers in Poland and the expansion of the successful Fraunhofer business model to the markets of Poland and Eastern Europe. The qualification offer of the center and its transnational scientific exchange are promoted.

New methods and technologies for optical measurements and surface inspections of complex parts are on the agenda of the Fraunhofer Project Center in Wrocław. Reverse engineering activities focus on digitizing physical objects and creating 3D computer models. Work in laser materials processing, rapid prototyping and rapid tooling is closely related to the activities in materials testing.

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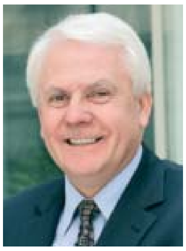

PROJECT CENTER LASER INTEGRATED MANUFACTURING

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In 2016 several research projects were performed in laser materials processing, additive manufacturing, biotechnologies, industrial image processing and acquisition of contour data. Entrepreneurs from Poland have already placed 350,000 Euro research orders with the IWS.

SURFACE TECHNOLOGY CENTER DORTMUND – DORTMUNDER OBERFLÄCHENCENTRUM (DOC®)

Customized surface technologies to be applied for steel coils in continuous processes are being developed at the Surface Technology Center Dortmund – Dortmunder OberflächenCentrum DOC®. First of all, resistance to corrosion and scratch, electrical conductivity, and cleaning properties are to be enhanced. The Fraunhofer IWS runs as a cooperation partner a project group at the DOC®. This group mainly works on surface coating by PVD, thermal surface techniques and laser surface processing.

Current foci in surface technology (thin film coatings) are:

- conductive, formable carbon layer systems (graphite-like carbon – GLC) and plasma nitrocarburized surfaces for electric mobility are used for Al and Cu electrodes for batteries, super capacitors and steel bipolar plates for fuel cells with a conductivity comparable to gold without degradation in fuel cells stack test, see pages 110/111,

IWS Open House for Industry at the Dortmunder Oberflächen-Centrum DOC®

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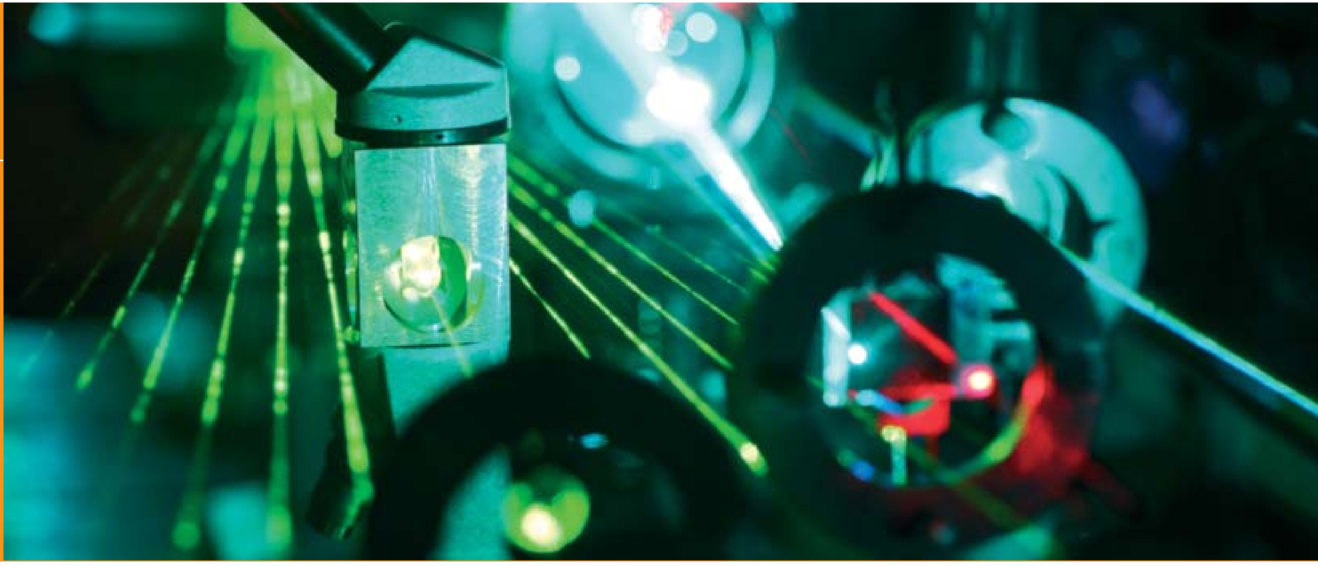
- Diamor® coating systems (ta-C: tetrahedral amorphous carbon) as wear protection, based on short-pulsed arc (spArc®)-processes (such as coating for self-sharpening kitchen knives),
- the latest PVD high-performance processes at pressures above 30 mbar for finishing steel coils and the development of systems for anti-corrosive protection coated by zinc alloys, to be used in highly corrosion resistant metallic ZnMg and ZnFe coatings for thermal forming,
- vacuum arc spray technology in spray booths or vacuum chambers, also with a laser,
- laser remelting of large areas with high-power lasers for finishing steel strips with and without oxygen (such as melting down of zinc or chromium coatings on high-strength steels for corrosion protection).



APPLICATION CENTER FOR OPTICAL METROLOGY AND SURFACE TECHNOLOGIES

The new Fraunhofer IWS Application Center for Optical Metrology and Surface Technologies (AZOM) launched its operations in August 2015. It is established on the campus of the West Saxon University of Applied Sciences (WHZ) and connects the Fraunhofer IWS in Dresden with the companies in West Saxony. The Free State of Saxony funds the project of the application center with the amount of 3 million Euros.

The new application center extends even further the joint activities of the Fraunhofer-Institut für Werkstoff- und Strahltechnik and the University of Applied Sciences (WHZ), while the IWS range of applications is extended in the field of surface analysis. Students and graduates of the University of Applied Sciences in Zwickau are given the chance to work in industrial projects. In 2016, the Fraunhofer Application Center, which is unique in the new federal states, moved to new laboratory space in the Keplerstraße in Zwickau. The new labs are equipped with optical tables, system components and numerous measuring devices and analytic systems for surfaces, such as a gloss meter and electron microscope.

The AZOM center enriches the range of competences in industry-focused research in West Saxony and offers the regional SMEs additional chances to join the market. The AZOM offers the companies services in the development and testing of optical measurement methods suitable for industry in various technologies. Sensors for different process parameters and variables, complex measuring stations and measurement devices connected to the customers EDP (electronic data processing) are available.

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FRAUNHOFER APPLICATION CENTER FOR OPTICAL METROLOGY AND SURFACE TECHNOLOGIES AZOM

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The Fraunhofer AZOM has already executed cooperation projects with industry at a volume of approximately 250,000 Euro, which will clearly increase with the new laboratory. At present, the AZOM has 10 employees, among whom several are currently working on PhD, Bachelor's and Master's theses.

Grand opening of the AZOM on November 15th, 2016

CENTER FOR COATINGS AND DIAMOND TECHNOLOGIES (CCD)

The Fraunhofer Center for Coatings and Diamond Technologies CCD is situated in East Lansing, Michigan, on the Michigan State University (MSU) campus. The MSU and the IWS subsidiary CCD have been collaborating in thin film and diamond technology research for 13 years. The Fraunhofer CCD supplies customized technologies by combining process, materials and systems engineering know-how with scientific excellence, quality and project management.

The CCD has 15 employees and 15 research assistants and had a turnover from external projects of approximately 2.4 million US $ in 2016, which was almost twice as high as in 2015. Approximately 0.8 million US $ were immediately earned in industrial and about 1.6 million US $ in publicly funded projects. The total center budget comprises approximately 3.8 million US $. The 2015 plan to expand with the MSU is making progress. New labs were commissioned and the equipment was continuously modernized and extended.

In the ARPA-E project, researchers of the Fraunhofer CCD and the MSU are developing a diamond-based diode operating at a breakdown voltage of 1200 V and a forward current of 100 A. The project has entered a new proof-of-concept stage. With highly moveable charge carriers and a high electrical breakdown strength, diamond is thermally conductive, and is thus excellently suited for electronic applications. The partners are highly experienced in the specific processes and are equipped with patented systems for diamond synthesis and processing of high quality monocrystalline diamond materials (see pages 132/133).

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Researchers at the Fraunhofer CCD, the Mackinac Technology Company, and the University of Michigan have developed an anti-reflective coating for bus windshields in an SBIR (small business innovation research) project, which was partially funded by the American Ministry for Transportation. Enhanced transportation safety is aimed at reduction of reflections due to the interior illumination for the passengers (see pages 112/113). The team demonstrated that innovative amorphous diamond-like carbon (DLC) coatings can clearly reduce reflection and significantly enhance the driver's vision. Project stage II is aimed at speeding up the commercialization for windows of a line bus.

CENTER FOR LASER APPLICATIONS (CLA)

All of the laser activities of the Fraunhofer USA are brought together in the Fraunhofer Center for Laser Applications CLA. They are focused on making available laser technologies and systems for industrial applications. The CLA is located in Plymouth, Michigan, near Detroit. The 1200 m^2 area laser application lab is equipped with the latest laser systems and systems technology.

The Fraunhofer CLA offers several processes using lasers – welding, cutting, drilling, coating, heat treatment, surface structuring, and additive manufacturing. Another special field is the development of monitoring and control systems, as well as processing heads for buildup welding and additive manufacturing.

The CLA, with 10 employees and 7 scientific assistants, raised external funds of 4 million US $ in 2016. About 3.7 million US $ came from direct industrial orders. The total center budget is approximately 4.8 million US $.

The successful implementation of processes and systems for additive manufacturing of large components at GKN Aerospace, USA, was the highlight of 2016. The Fraunhofer CLA designed a reliable and reproducible process to manufacture titanium alloy components in a shielding gas atmosphere. A robot was used in conjunction with the wire buildup welding head COAXwire and the E-MAqS process monitoring system; the latter were made at the IWS. The customers can significantly save manufacturing time and material costs with this technology.

The CLA effectively upgraded monitoring systems for welding processes (see pages 80/81) and optimized numerous welding processes for industry customers.

KOORDINATION

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FRAUNHOFER USA

CENTER FOR LASER APPLICATIONS CLA

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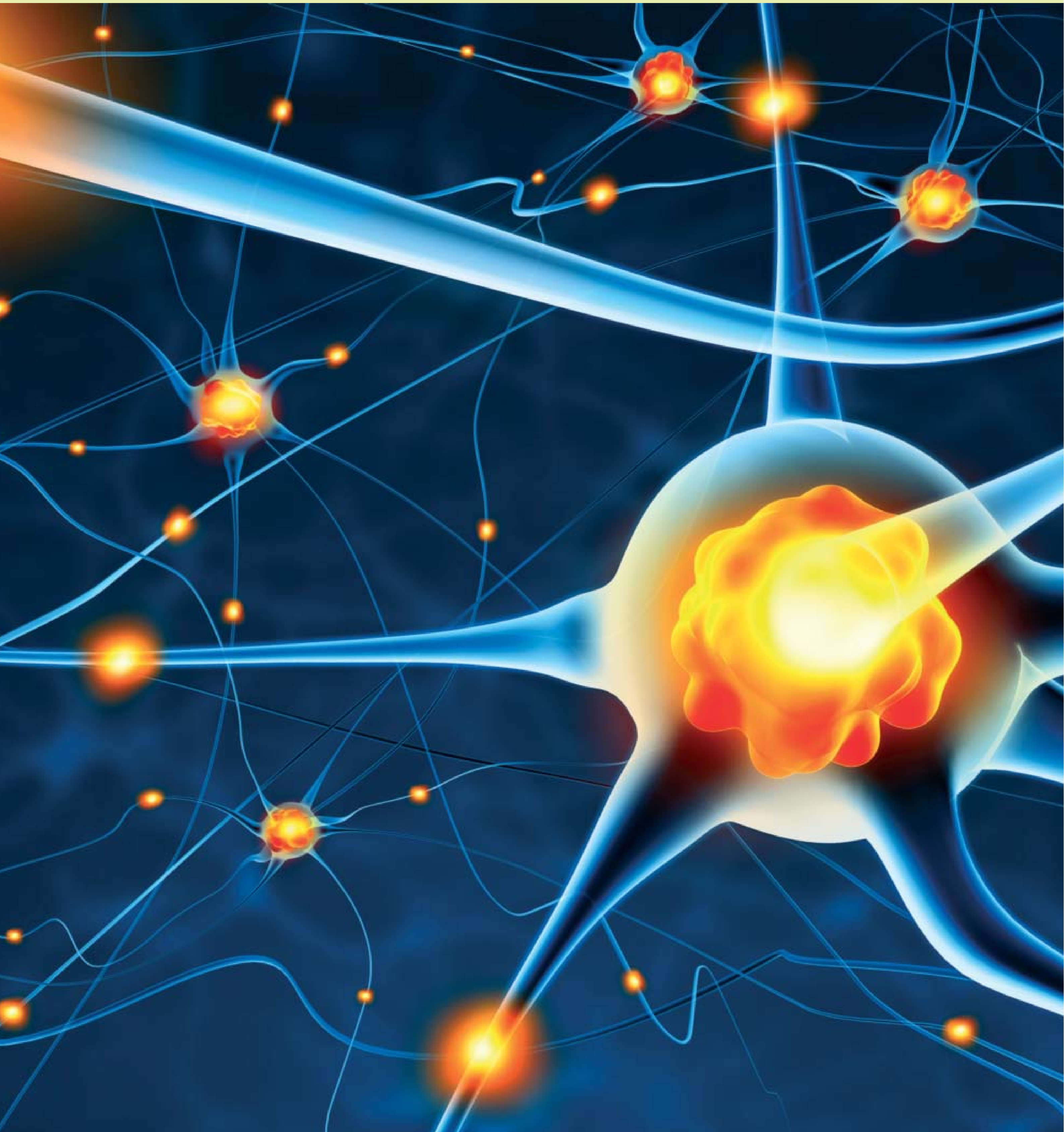
www.cla.fraunhofer.org

The Fraunhofer CLA scored also in the acquisition of projects with public funding. The center collaborated with the Mackinac Technology Company and the Fraunhofer CCD for energy efficient window glazing in public institutions. The task was to develop low-cost films, with thermal insulation coating, installed in a frame and easy to use in retrofitting buildings.

The center's participation in trade shows and conferences is crucial to customer acquisition. During the ALAW 2017, the Fraunhofer CLA will invite the conference participants to visit their labs and to exchange experience with the Fraunhofer researchers on 7 June. In 2016, 150 participants attended the open house.

NETWORKS



Joseph von Fraunhofer

THE FRAUNHOFER-GESELLSCHAFT

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

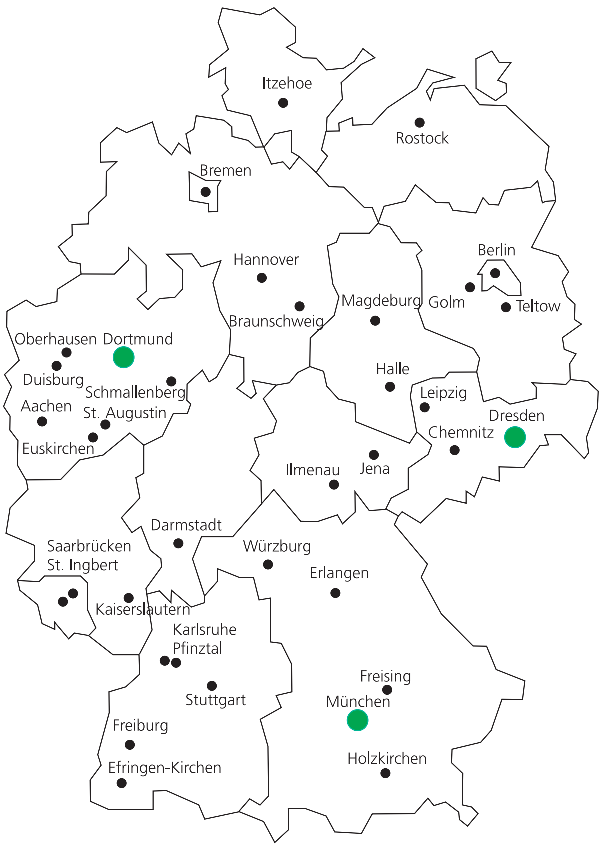
At present, the Fraunhofer-Gesellschaft maintains 69 institutes and research units. The majority of the 24,500 staff are qualified scientists and engineers, who work with an annual research budget of 2.1 billion euros. Of this sum, 1.9 billion euros is generated through contract research. More than 70 percent of the Fraunhofer-Gesellschaft's contract research revenue is derived from contracts with industry and from publicly financed research projects. Almost 30 percent is contributed by the German federal and state 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.

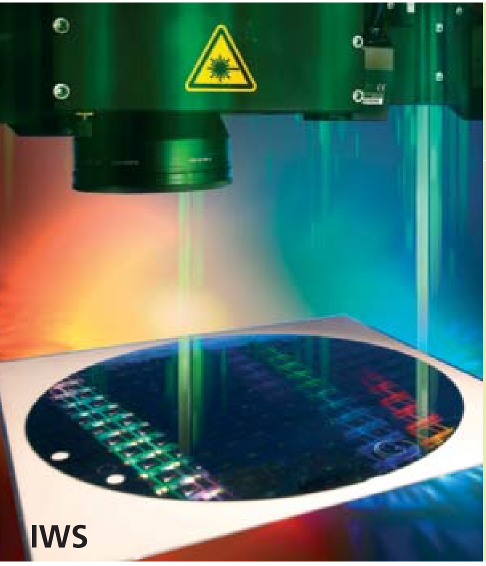
International collaborations with excellent research partners and innovative companies around the world ensure direct access to regions of the greatest importance to present and future scientific progress and economic development.

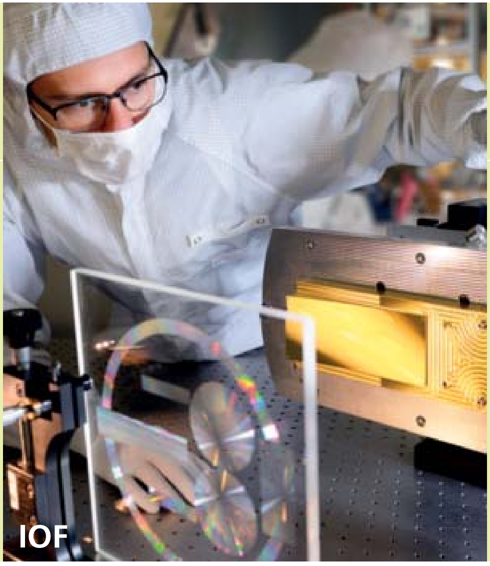
With its clearly defined mission of application-oriented research and its focus on key technologies of relevance to the future, the Fraunhofer-Gesellschaft plays a prominent role in the German and European innovation process. Applied research has a knock-on effect that extends beyond the direct benefits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

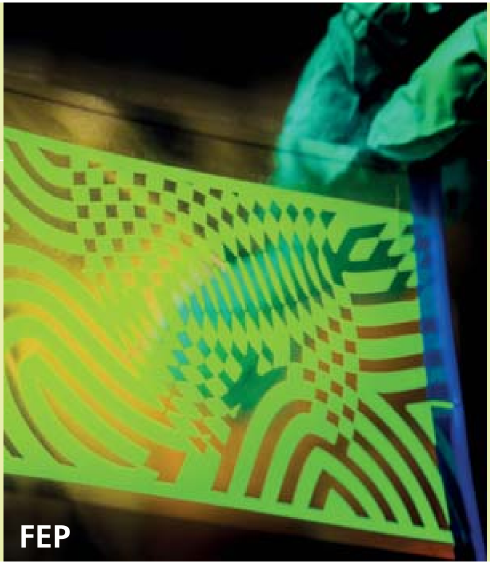
As an employer, the Fraunhofer-Gesellschaft offers its staff the opportunity to develop the professional and personal skills that will allow them to take up positions of responsibility within their institute, at universities, in industry and in society. Students who choose to work on projects at the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

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









FRAUNHOFER GROUP FOR LIGHT & SURFACES

COMPETENCE BY NETWORKING

Six Fraunhofer institutes cooperate in the Fraunhofer Group for Light & Surfaces. Coordinated 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 ORGANIC ELECTRONIC, 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 has developed 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 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 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 MATERIAL AND BEAM TECHNOLOGY IWS, DRESDEN

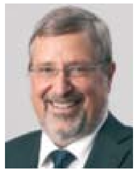
The Fraunhofer Institute for Material and Beam Technology is known for its innovations in the business units joining and cutting as well as in the surface and coating technology. Across all business units our interdisciplinary topics include energy storage systems, energy efficiency, additive manufacturing, lightweight construction and big data. 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 solutions with regard to laser material processing and coating technology have been developed and have found their way into industrial applications.

www.iws.fraunhofer.de

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

FACULTY OF MECHANICAL SCIENCE AND ENGINEERING
INSTITUTE OF MANUFACTURING TECHNOLOGY

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



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

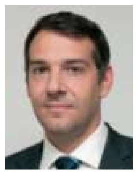
FACULTY OF MECHANICAL SCIENCE AND ENGINEERING
INSTITUTE OF MANUFACTURING TECHNOLOGY

CHAIR OF NANO- AND COATING TECHNOLOGY
PROF. DR. RER. NAT. ANDREAS LESON

Topics:
- nanotechnology
- thin film technology

FACULTY OF MECHANICAL SCIENCE AND ENGINEERING
INSTITUTE OF MANUFACTURING TECHNOLOGY

CHAIR FOR LARGE AREA BASED SURFACE MICRO/NANO-STRUCTURING
PROF. DR.-ING. ANDRÉS-FABIÁN LASAGNI



Topics:
- fabrication of large area 2D and 3D micro and nanostructures
- surface functionalization
- laser structuring
- two photon polymerization
- simulation of structuring processes
- process development

"Learning is like an ocean without beaches."
Konfuzius

**FACULTY OF MECHANICAL SCIENCE AND ENGINEERING
INSTITUTE OF MATERIALS SCIENCE**

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

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

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

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

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

**FACULTY OF MECHANICAL SCIENCE AND ENGINEERING
INSTITUTE OF MATERIALS SCIENCE**

**CHAIR OF MECHANICS OF MATERIALS
AND FAILURE ANALYSIS
PROF. DR.-ING.
MARTINA ZIMMERMANN**

Topics:
- mechanical properties and microstructure
- fatigue (high frequency test engineering)
- failure analysis and prevention
- structure and component reliability

**FACULTY OF MEDICINE
CLINIC FOR NEUROLOGY**

**CHAIR OF DATA MANAGEMENT
AND EVALUATION
PROF. DR.-ING.
KAROL KOZAK**

Topics:
- imaging
- machine learning
- big data

AWARDS AND HONORS

Prof. Dr. **Stefan Kaskel**, professor of inorganic chemistry at the Technische Universität Dresden and head of the Chemical Surface and Reaction Technology business unit at the Fraunhofer-Institut für Werkstoff- und Strahltechnik (IWS) Dresden, received the Award of the Japan Society for the Promotion of Science (JSPS). This award is in recognition of his scientific activities in the field of energy storage materials. The award includes a dedicated stay for research at the National Institute of Advanced Industrial Science and Technology (AIST) in Osaka, Japan.

Prof. Dr. Frank Mücklich, Prof. Dr. **Andrés Lasagni** and ten of their employees at the Universität des Saarlandes (Saarland University), the Steinbeis Material Engineering Research Center Saarland, the Technische Universität Dresden, and the Fraunhofer IWS took second place in the 2016 Berthold Leibinger Innovation Competition. They performed basic research and engineered systems suitable for industrial use, which can be applied in many industries to micro and nanostructuring of large areas by means of laser interference.

Mr. Rank, Mr. **Lang**, Dr. **Kunze** and Prof. **Lasagni** were awarded the prize for best poster presentation on "Direct Laser Interference Patterning of Nickel Molds/Sleeves used for thermal Plate-to-Plate and Roll-to-Roll Nanoimprint Lithography" at the 15^{th} International Conference on Nanoimprint & Nanoprint Technology.

The **Fraunhofer IWS** Dresden won second prize at the EARTO Innovation Award 2016 in the category for the impact of the development of super hard diamond-like carbon coatings for higher energy efficiency on October 12, 2016. These coatings are applied to piston rings and other power train parts and reduce fuel consumption by 1.5 percent on average, and the CO_2 emissions by 3 g km^{-1}. The EARTO Innovation Awards have acknowledged and conveyed appreciation of essential contributions to innovations by research and technology organizations since 2009. Prof. Leson, Dr. Scheibe, Dr. Weihnacht and Mr. Englberger (f. l. t. r.) received the prize in Brussels.

The Recognition Award of the Dresden Lord Mayor, Dirk Hilbert, went to the **Fraunhofer IWS** Dresden for an "Extraordinary Program for Integration" and was presented during the Intercultural Days on December 20, 2016. The project recruits scientists and engineers for three-month internships at a Dresden Fraunhofer institute, where they are mentored by volunteers and prepared for further education or employment.

Prof. Dr. **Stefan Kaskel**, professor of inorganic chemistry at the Technische Universität Dresden and head of the Chemical Surface and Reaction Technology business unit at the Fraunhofer IWS Dresden, was one of the most frequently cited researchers in 2016, according to an HCR list published by Clarivate Analytics in 2016.

The IWS prize winners of 2016 were nominated on 16 December.

Jörg Bellmann received an award for the best scientific thesis as a next-generation scientist for his "Approaches to determine and expand the process limits in electromagnetic pulse welding". Electromagnetic pulse welding is a joining technique with a great application potential for clean and energy-efficient industrial volume manufacturing; pulsed magnetic fields provide acceleration, intentional contact and welding of the sheet metal or tubular parts. Mr. Bellmann has significantly advanced the design, production and commercialization of a compact optical-device-based measurement and analysis device and the analysis of acoustic signals by means of optical microphones.

The award for the best innovative product idea for the establishment of a new business unit went to Prof. Dr. **Andrés Lasagni**, **Matthias Bieda**, **Valentin Lang** and Dr. **Tim Kunze**. The idea was to implement their in-house developed laser interference patterning system with adequate processing modules in industry. Customized surfaces for industrial use can be manufactured by the direct laser interference technology (see pages 90/91).

The team of **Adam Kubec**, Dr. **Jörg Bretschneider**, **Volker Franke** and **Jürgen Schmidt** won the award for the best scientific-technical achievement of a next-generation scientist. They researched the manufacturing and structuring of multilayer Laue lenses for X-ray microscopy with high resolution. They deposited 12,000 individual layers for a total coating thickness above 50 µm, by means of the PVD technique. The coating was removed from the substrate subsequently and prefabricated by means of laser structuring. The blank produced this way is then finished by the focused ion beam to finally obtain the lens. Two lenses were vertically aligned one with each other with a specific mechanical outfit and a fixture to get the point foci. During the tests, beam profiles of less than 25 nm median width in both directions were achieved in the X-ray. For these applications, this is a top result Europe-wide.

Ms. **Elisa Starruß** received an award for her outstanding studies in printing of polymer-based piezosensors by means of aerosol printing technology. She engineered and improved the reliability of the printing process for ultrasound atomization and incrementally optimized the operation parameters for a wide range of materials.

Nikolai Schröder received an award for his distinguished student research findings. His studies are impressive insofar as they developed a new method for fabrication of machine-readable safety features with the related magneto-optical detection device. The development contributes to technical product protection.

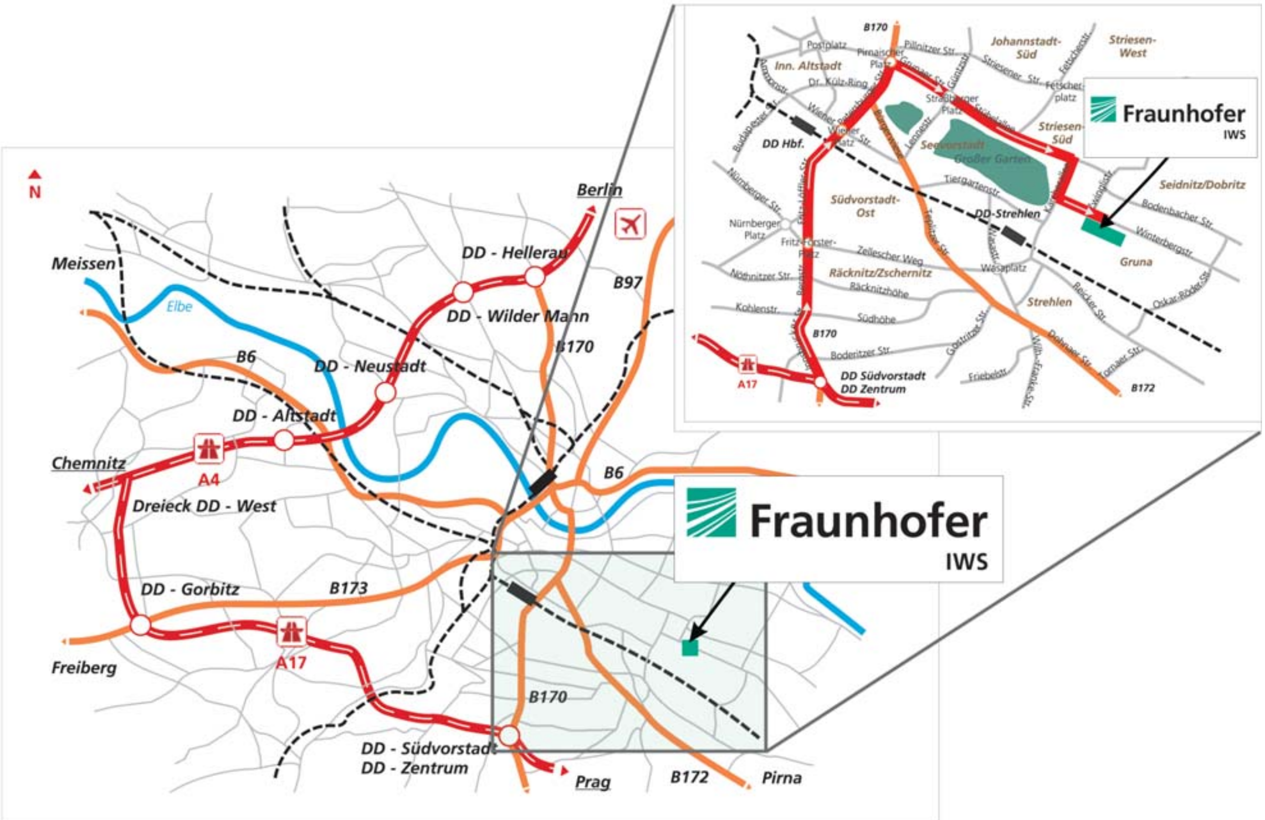
The Special Award of the institute went to Ms. **Jana Obermann** for her great commitment to the IWS employees health and organization of the "Health Day".

PUBLICATIONS

Please download a list of the scientific publications issued by the Fraunhofer IWS in 2016 at:

http://publica.fraunhofer.de/institute/iws/2016

HOW TO REACH US



by car (from Autobahn / highway):

- take Autobahn A4 or A13 to intersection Dresden-West, follow new Autobahn A17 to exit Südvorstadt / Zentrum,
- follow road B170 in direction Stadtzentrum (city center) to Pirnaischer Platz (about 6 km),
- at Pirnaischer Platz turn right towards "Gruna / VW-Manufaktur",
- continue straight until the end of the "Großer Garten" (Great Garden) and then turn right onto Karcherallee,
- at the next traffic light turn left onto Winterbergstraße and continue straight until IWS.

by railway and tram:

- from Dresden main railway station take line #10 to Straßburger Platz,
- change to line #1 (Prohlis) or #2 (Kleinzschachwitz) heading out from the city; exit at Zwinglistraße stop,
- 10 minutes to walk from there (in the direction of Grunaer Weg).

by air plane:

- from Airport Dresden-Klotzsche with a taxi to Winterbergstraße 28 (about 10 km),
- or with public transportation (shuttle train) to the main railway station (Hauptbahnhof), and continue with the tram.

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	p. 156 (Fig. 4)	Andreas Tampe
	all other pictures	Fraunhofer IWS