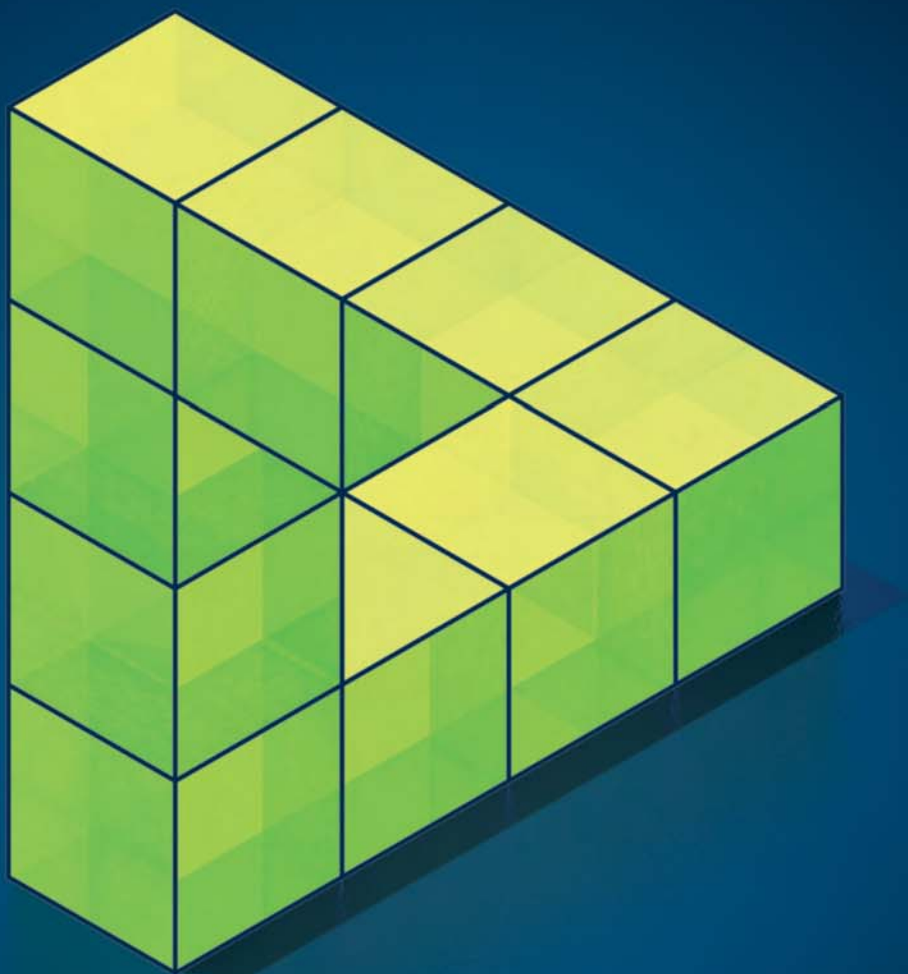
Fraunhofer

IWS Dresden

FRAUNHOFER INSTITUTE FOR MATERIAL AND BEAM TECHNOLOGY IWS

ANNUAL REPORT 2017



THE FRAUNHOFER IWS

The Fraunhofer-Institut für Werkstoff- und Strahltechnik IWS Dresden stands for innovations in laser and surface technology. As an institute of the Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e. V., IWS offers one stop solutions ranging from the development of new processes to implementation into production up to application-oriented support. The fields of systems technology and process simulation complement the core competencies. The business fields of Fraunhofer IWS include PVD and nanotechnology, chemical surface and reaction technology, thermal surface technology, generation and printing, joining, laser ablation and separation as well as microtechnology. The competence field of material characterization and testing supports the research activities.

At Westsächsische Hochschule Zwickau, IWS runs the Fraunhofer Application Center for Optical Metrology and Surface Technologies AZOM. The Fraunhofer project group at the Dortmunder OberflächenCentrum DOC® is also integrated into the Dresden Institute. The main cooperation partners in the USA include the Center for Coatings and Diamond Technologies (CCD) at Michigan State University in East Lansing and the Center for Laser Applications (CLA) in Plymouth, Michigan.


DEKRA
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Quality is the cornerstone of our success. We have made it our task to refine our own potential, as well as to establish and keep our partners' and customers' satisfaction at the highest level. For this reason, the Fraunhofer IWS Dresden introduced a quality management system in 1997, and this system has been continuously refined and regularly externally certified according to the ISO standard 9001 ever since. This audit is regarded as the basis for working sustainably by means of documented procedures on the domestic and international markets. This way we create the preconditions to achieve our organization objectives both efficiently and effectively – and always to be a reliable partner.

DRESDEN-concept: excellence in science and culture

The Fraunhofer IWS Dresden is a proactive member in the DRESDEN-concept alliance. The cooperation of the 26 partners from science and culture aims to reveal and use synergies in research, education, infrastructure, administration, and transfer. For this purpose, the members coordinate their scientific strategy and identify the fields in which Dresden is an international leader. The partners cooperate to attract leading scientists worldwide to Dresden and to keep them here.

ANNUAL REPORT 2017

FRAUNHOFER INSTITUTE FOR MATERIAL AND BEAM TECHNOLOGY IWS DRESDEN

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FOREWORD

Executive Director **Prof. Dr.-Ing. Dr. h. c. Ralf-Eckhard Beyer**

Ladies and Gentlemen,

The future is now. Keywords such as "digitization", "Internet of Things" (IoT) and "Industry 4.0" are on everyone's lips. All related developments are moving into every area of life. Technical solutions are needed to facilitate the answering of multidimensional questions. Against this background, Fraunhofer-Institut für Werkstoff- und Strahltechnik IWS Dresden sees itself as a driving force in developing laser material processing processes and surface technology. Here we offer our experience and keep on moving to support our partners and clients with sparkling ideas up to the successful launch into series production. IWS, our partners and clients, we all benefit from a stable overall situation. As the Federal Ministry of Economics and Energy (BMWi) states, Germany is experiencing a strong upturn. Accordingly, new orders and sentiment indicators are also sending positive signals to the industry. Fraunhofer IWS confirmed this trend. We are still on a stable growth course and have expanded our partner and client base. Maintaining these commitments requires all our strength and vision.

Fraunhofer IWS has managed to assert itself in a highly dynamic and highly competitive environment for more than 25 years. We are convinced that structural measures are necessary to further extend this positive development. In February 2017, for example, together with our partner TU Dresden, we inaugurated the "Center for Additive Manufacturing Dresden" (AMCD) in order to develop industrial solutions and strengthen the innovative economic power of our partners. By the end of 2016, we actively invested in the Application Center for Optical Metrology and Surface Technologies (AZOM) in Zwickau together with the Westsächsische Hochschule Zwickau (WHZ), since the subject of metrology is becoming increasingly important in connection with digitization.

Executive Director **Prof. Dr.-Ing. Christoph Leyens**

Speaking of optical metrology, the topic "hyperspectral imaging" also promises exciting fields of application. It is amazing how many different details we can derive from a surface subjected to high resolution. For instance, we can detect contaminations in technical processes, or pesticide residues on food. The subject of batteries at Fraunhofer IWS is developing just as well. Our research projects and results address an enormous demand. Our cross-divisional efforts with regard to the EU-funded ALABO project are moving in a similar direction: We are researching flexible and organic next generation solar cells intended to be produced at low cost using the roll-to-roll process. For other exciting technologies please refer to the section "About the business units".

Making the seemingly impossible possible – this motif shaped the works of the Dutch graphic artist M.C. Escher. We also were inspired by this idea, as the cover of this annual report shows. The pictured "play button" manifests itself from a seemingly impossible geometry. This way, we build a bridge to additive manufacturing where we use layer-by-layer technologies to achieve geometries, which hitherto could not be produced by means of conventional methods. M.C. Escher's idea also inspires our other business units. They constantly contribute to developing solutions for complex challenges. In that sense: "Press play!"

Enjoy reading our annual report!

Prof. Dr.-Ing. Dr. h. c. R.-E. Beyer   Prof. Dr.-Ing. C. Leyens

THE FRAUNHOFER IWS

CORE COMPETENCIES

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:

SURFACE TECHNOLOGY

A central task is to improve surface functionality. For this purpose, the IWS offers a wide range of functionalization and coating techniques. This allows us to produce coatings and layers whose thickness ranges from only a few nanometers to a number of millimeters, made of various materials and combinations. In many cases, researchers have to refine the system hardware, such as the plasma sources, for optimal component treatment or coating.

MATERIALS SCIENCE

Our core competency includes the characterization of surface and interface-treated, as well as coated, welded, cut, and micro- or nano-structured materials and parts. We consider this the foundation of process development and quality assurance tailored to the material and component. This expertise is also the basis for design that meets requirements in terms of the material properties, manufacturing, and loads and stresses.

LASER MATERIALS PROCESSING

Our main laser materials processing know-how includes the management of integrated value adding chains – from analyzing the component loads and stresses, load-adapted use of material and component-related process development up to industrial implementation of advanced techniques. Our research focusses on material- and component characteristics; from this, we derive the process- and system parameters, which, in turn, define the hardware system. Process monitoring and control complete the portfolio.

SYSTEMS ENGINEERING

Sensors for process monitoring and networking process data contribute to securing and documenting process quality. The modification of systems engineering is often inevitable. Thanks to many transfers to industry, IWS has acquired comprehensive systems engineering expertise and has brought its procedural know-how to the development, manufacture, and design of components, equipment, and systems suitable for industry and integration, as well as the necessary software.

SYSTEM AND PROCESS SIMULATION

Our simulation competency not only develops simulation modules for thermal surface technology, additive manufacturing, cutting, welding and vacuum arc coating, but also calculates optical properties of nano-layer systems. Our engineers also apply commercial simulation modules when they optimize the gas and plasma flows in coating processes and laser material processing.

BIG DATA

Big Data refers to huge, complex, or quickly changing amounts of data. Classic visual image processing, relational database systems, and statistical and visualization programs are frequently unable to process this data. Consequently, for Big Data, experts use new types of platforms, data storage devices, and machine-learning methods that function in parallel on up to hundreds or thousands of processors. The Fraunhofer IWS recognizes the tremendous research and development potential in this area.

IWS AT A GLANCE

Employees at the IWS

IWS

	Number
Scientists / engineers (TU, FH)	163
Skilled workers with technical or mercantile education	66
Trainees	13
Research assistants	157
	399

External staff

	Number
TU Dresden employees (working at the IWS)	43
Scholarship holders and external colleagues	7
	50

Total	**449**

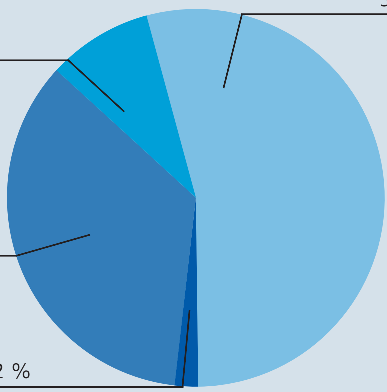
IWS PUBLICATIONS

Type of publication

	Number
Dissertations	10
Diploma theses	68
Master's theses	12
Journal papers	134
	224

PATENTS (first filing)	**28**

We provide a list of all the scientific publications of the Fraunhofer IWS from 2017 in the bibliographic database "Fraunhofer-Publica" here: **http://publica.fraunhofer.de/institute/iws/2017**



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IWS at a glance

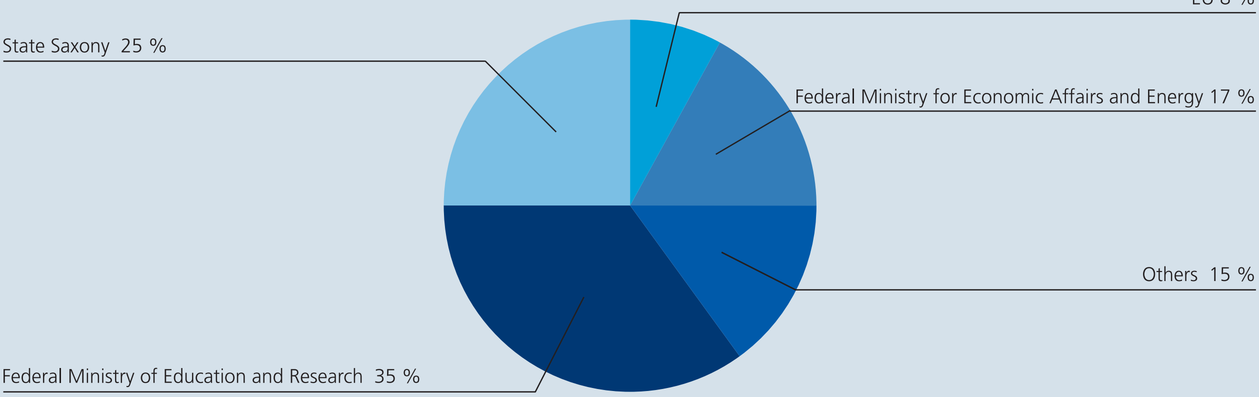
Revenues

Fraunhofer IWS and German branches 2017 (million €)

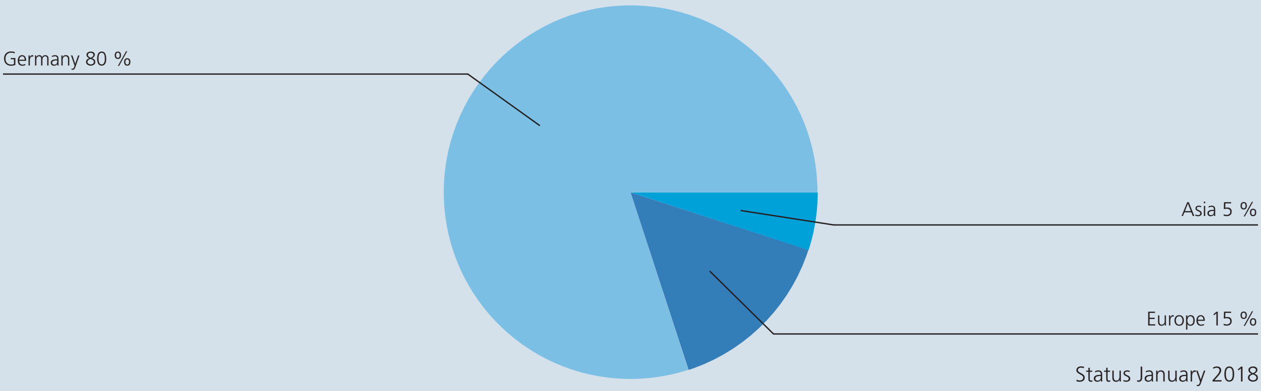
	Operation	Investments	Total
Project revenues from industry	13.2	0.2	13.4
Project revenues from federal, state and European sources	9.4	0.2	9.6
Base funding and Fraunhofer internal programs	6.3	1.5	7.8
Special investments from federal, state and European sources	0.2	0.5	0.7
	29.1	**2.4**	**31.5**

Fraunhofer industry ρ_{ind} = 45.5 %

Origin of public revenues



Geographical origin of industrial revenues



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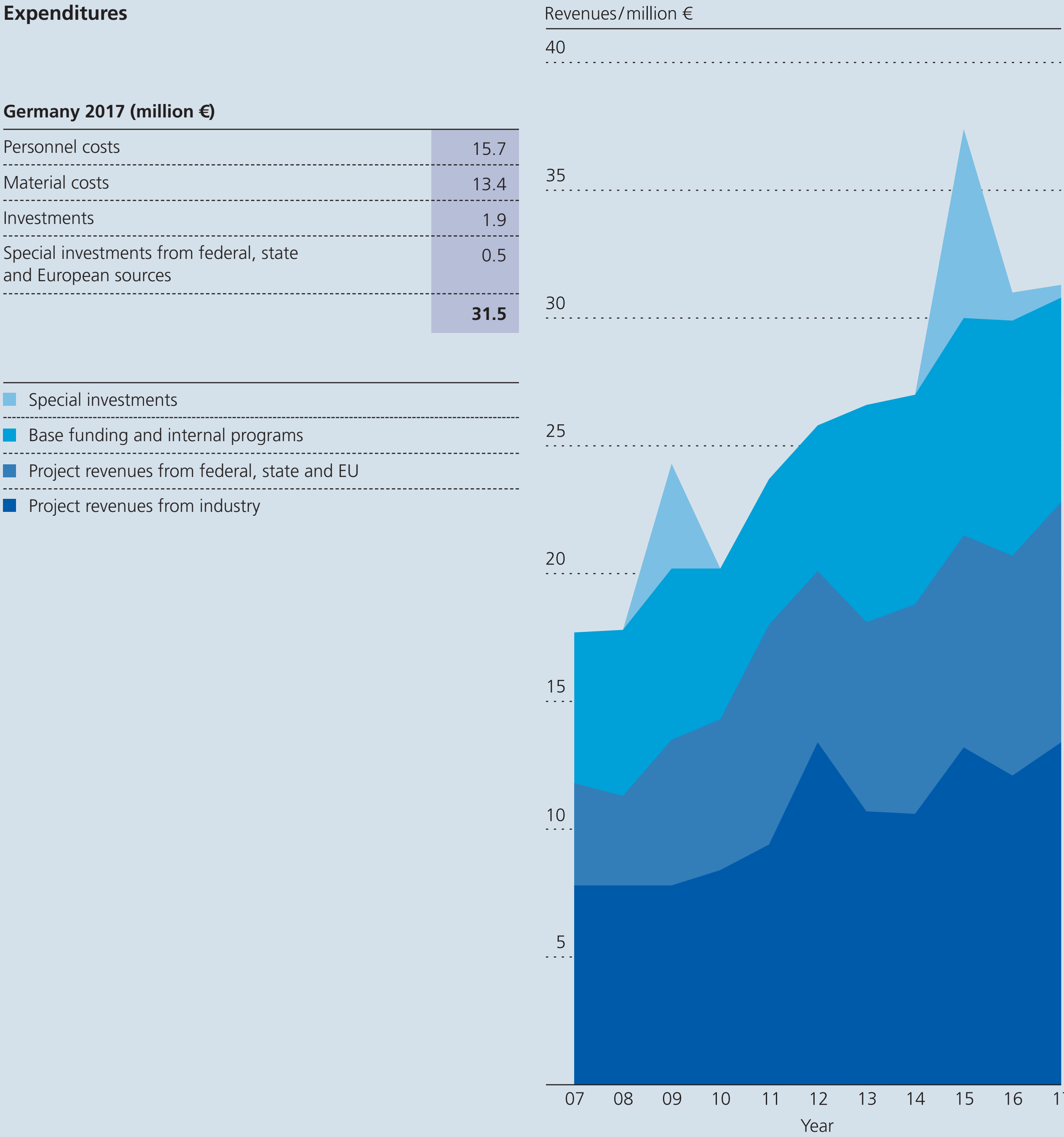
Expenditures

Germany 2017 (million €)

Personnel costs	15.7
Material costs	13.4
Investments	1.9
Special investments from federal, state and European sources	0.5
	31.5



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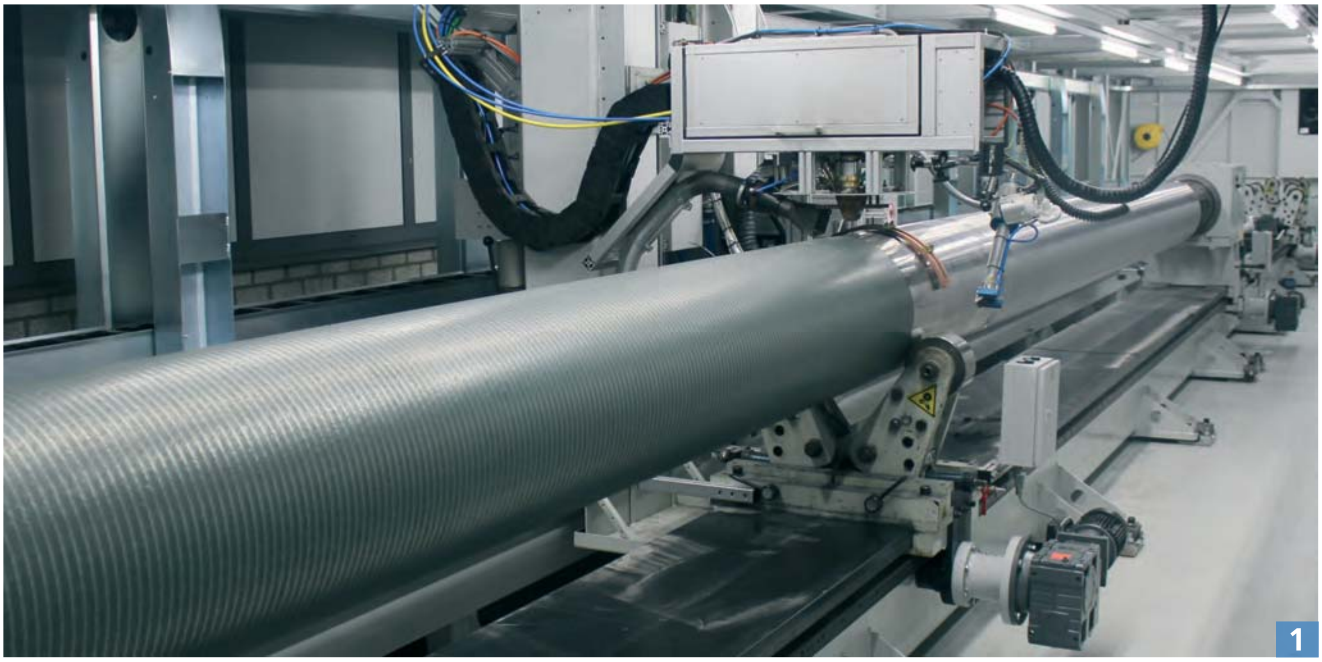
HIGHLIGHTS

As an institute of the Fraunhofer-Gesellschaft, we are committed to applied research. We are driven to design and shape the future in the fields of laser material processing and surface and coating technology. Our central task is to address emergent issues in practice with innovative development. We see "Highlights" as projects we have introduced into industrial use in the past year and present selected innovations on the following pages.



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High-power laser system for super-efficient hydraulic pistons' coating

In close cooperation with Bosch Rexroth, researchers at the Fraunhofer IWS Dresden developed an efficient high-power laser powder cladding technique. In the Dutch town Boxtel, a team of scientists retooled a system to coat large hydraulic piston rods up to 19 meters long and with a 600 millimeters diameter. The new technique can multiply the equipment's productivity and makes possible deposition rates of up to 15 kilogram per hour. The researchers optimized the system hardware for laser power values of a maximum of 20 kilowatt and readied it at the same time for applications in the field of "Industry 4.0".

In contrast to the previous configuration, the new technique allows for the coating of hydraulic piston rods by processing much higher powder quantities in substantially less time. The development's objective was to melt the weld deposit in such a way that a coating was formed to diminish wear and avoid corrosion. In the alternative thermal spraying method, the powder deposited and the basic material to be coated form a mutual metallic clamping. In contrast to the spraying method, in the new approach a metallurgical welding appears on the piston rod's surface with a simultaneously low iron dilution of low-alloy basic material in the final coating. As distinguished from plasma powder cladding, in powder laser cladding, dilution levels of less than three percent can be achieved even for a single-layer coating. In the process, the hydraulic rods to be coated are clamped in the system and rotated, while, in parallel, a laser with a homogeneous feed is guided along the rod that is being processed. This way, the researchers obtained a helical coating bead of homogeneous coating thickness. The use of the laser not only significantly accelerates the cladding procedure, but also results in a lower heat input into the basic part. Thus, the basic material remains unchanged in terms of shape and structure.

Depending on the hydraulic rod's purpose and conditions of application, engineers can apply several power types with customized properties, such as wear resistance, hardness, corrosion resistance or specific tribological characteristics.

The Fraunhofer IWS team also retooled the Bosch Rexroth system with a specifically engineered inductive heating process. This heating provided targeted process heat control, and, as a result, even crack-critical and hard-to-weld coatings can be cladded failure-free. Bosch Rexroth succeeded in expanding the coating range through customized solutions ("Enduroq" family). These solutions are effective anticorrosive and environmentally-friendly alternatives to conventional nickel-chromium coatings at a reasonable cost.

Hardened cam elements save petrol

Researchers at the Fraunhofer IWS Dresden developed a cam element laser hardening procedure for a new drive concept for a German car manufacturer. The new approach enables switching off two of four cylinders under partial load on demand. This provides a significant reduction of fuel- and CO_2 emissions. Fraunhofer IWS developments aimed at hardening the cam element at high-stress points, which, in turn, increased wear resistance and lifespan.

The complex component contours to be hardened raise particular challenges. The Fraunhofer IWS has used high-power diode lasers, which have in general been shown to be efficient laser hardening tools in terms of the price-performance ratio, beam quality and the variety of available optical systems. The decisive advantage of the laser is that the component is less distorted, and, as a result, the post-processing work is dramatically reduced. To harden the cam contours as required, the researchers used the dynamical "Lassy" beam shaping system engineered at the Fraunhofer IWS. The Lassy system sets the intensity distribution according to the process requirements and makes possible very short cycle times. Since hardening demands precise temperature control, an "E-MAqS" infrared camera was combined with a "LompocPro" temperature control system. The latter responsibly monitors the process data generated by the system and component quality. Defective components are thus automatically eliminated from the system. Unlike conventional batch processes, the cam elements are now produced in line. This way, less energy is input into the component than in conventional hardening techniques.

The Fraunhofer IWS task included both process and technology design, based on which the concept for the serial production system was drafted. The scientists also developed the system hardware, and they manufactured the assembly stages. Afterwards, they took the processes into operation, and led as well as supported them in serial production. The engineers connected the components with the equipment control and established the respective interfaces; they also developed and installed the logical procedures together with the equipment supplier. They customized all process parameters, such as temperature, feed rate and laser positions for the serial hardware. In the development, the research team also contributed to material selection and supported the automotive manufacturers in design to tailor the components and the manufacturing sequences optimally for laser hardening.

1 *The new high-power system for Bosch Rexroth coats hydraulic piston rods up to 19 meters long and 600 millimeters in diameter. The system generates deposition rates of up to 15 kilogram per hour.*

"contiLAS" cuts airbags worldwide

Fraunhofer IWS Dresden, in cooperation with the Held Systems company, transferred four "contiLAS" airbag laser cutting systems to internationally leading safety solutions producers for automotive applications in the last year. For this purpose, researchers customized the process and the software for the final users' requirements and qualified them for worldwide use. The systems primarily are tasked with reliably cutting so-called one-piece-woven airbags (OPW). Woven in a single piece, OPWs are distinguished by being flat material on one side and having recessed cavities on the other. In conjunction with a suitable coating, the technique allows the airbags to take in more air. Cutting by means of laser technology has the advantage that the edges interfuse and simultaneously prevent the so-called taking off the warp.

The challenge was to identify the positions at which the system should place cuts. The partners decided to employ remote cutting, for which Fraunhofer IWS created both the concept and the triggering software. The hardware consists of a conveyor over three meters long, on which the material is cut and removed from the manufacturing zone. The principle behind: two scanners travel across the feed to extend the working zone of the laser beams. The cut contours are segmented by means of CAM software created at Fraunhofer IWS. The CAM system enables segmenting the contour and optimizes its cutting sequence to obtain maximum output. In remote processing, the laser beam is refracted by means of moving mirror elements and guided over the component to be processed with the maximum dynamics possible. This reduces the positioning times from one processing step to the next to a minimum, and the process speed remains high even for complex geometries. The laser spot speed can achieve several meters per second, so that material processing itself, such as cutting complex airbag parts, finishes within a few seconds.


1

IWS researchers developed and customized processing optics and software solutions for industrial remote technologies. They made them available for welding, cutting, cleaning, and engraving. Compact, powerful system solutions are created through a combination of the remote technology of rapid beam movement with a continuous material feed, for instance a several meter-wide fabric panel.

First Laser-Magnetic-Domain-Refinement (LMDR) implementation in Europe

In 2017, an industrial consortium and Fraunhofer IWS were the first in Europe to succeed in implementing a Laser-Magnetic-Domain-Refinement system (LMDR) on industrial scale. This system is used in the Czech Republic by the largest steel producer in the world, the first system user outside Asia. The technology created at Fraunhofer IWS generates a refinement on grain-oriented electric or magnetic sheets used in transformers. The scientists contributed to the solution by providing the software and control components developed at

the institute based on the ESL2-100 module. In drives, sheets are used whose magnetic structure is not grain-oriented, to meet the requirements of continuously rotating components and thus changing magnetic fields, whereas transformers demand grain orientation. Sheets with a clear orientation in fields that are not moving minimize eddy current losses. The LMDR system generates a local line-oriented heat treatment in the passage of a strip before it is assembled and cut to the correct length. Sheets prepared this way are assembled in transformers worldwide. The Fraunhofer IWS solution provides maximal flexibility. The technological parameters remain constant under changing conditions, such as strip speed.

1 *"contiLAS" manufacturing systems can cut one-piece woven airbags worldwide in the future. The material to be processed is flat, but also has recessed cavities. The system exactly recognizes where it is necessary to cut.*

2 *Using the LMDR testing system at Fraunhofer IWS, researchers preliminarily demonstrated the potential of laser material processing from a final Czech customer. This was the basis for the decision to implement the technology on an industrial scale.*

FROM THE BOARD OF TRUSTEES

The Board of Trustees consults and supports the institute's management and the bodies of the Fraunhofer-Gesellschaft. The Board of Trustees held its 27th meeting at the Fraunhofer IWS in Dresden on March 24th, 2017. In the reporting period, the Board of Trustees consisted of the following members:

The digital transformation is changing our world at the most fundamental level! This change is taking place in our personal behaviors as well as in organizations, universities, and research institutes. This transformation has many faces. The extensive use of data on the internet is only one aspect. Another aspect of the digital transformation is "Industry 4.0". Even production and logistics are dramatically changing.

Current production is still strongly characterized by subtractive manufacturing, whereas, in the future, the potentialities of additive manufacturing will be exploited to a much greater extent. Additive manufacturing offers great part complexity without high cost. In principle, freedom of design is practically unlimited and only defined by physical constraints. Time-consuming and complex special tools, dies, and molds are no longer necessary. Engineers can immediately "print" the workpiece from its digital representation. In future, creativity in design will distinguish applications more than the manufacturing technique. Logistics will also be simplified, since just the digital representation, rather than the physical workpiece, will be sent around the world. Part production will be done where it is needed.

However, comprehensive research and development has yet to be done before this is reality in every industry! The manufacturing techniques of today are still very time-consuming, so that high volumes can only be generated with large machinery. Fast and precise printing is the challenge! This demand requires the expertise of the Fraunhofer-Institut für Werkstoff- und Strahltechnik IWS in order to overcome the limits that still exist today.

In 2016, the energy revolution took on ever more concrete forms. Energy from renewable sources, such as solar and wind energy, makes up an ever-increasing share of power generation. However, these types of energy sources cannot be easily controlled and distributed; consequently, the demand for energy storage is increasing.

We see a similar trend in mobility. Politicians are driving the change from the combustion engine to the electric motor. Thus energy storage in mobile systems is a higher priority in research and development, since, in batteries, we are still far away from the high energy densities of diesel and gasoline. Consequently, driving distance is still the biggest obstacle to introducing electromobility. The high price of batteries is also slowing the trend towards electric vehicles.

Battery research, as conducted by Fraunhofer IWS is becoming increasingly important. Since most of the cells for batteries are manufactured in Asia today, there is a dangerous dependency for the German economy. The know-how of the Dresden Fraunhofer institutes can provide an essential contribution to an initiative aimed at cell production in Germany.

These are only a few examples of the wide range of fascinating topics we research at Fraunhofer IWS Dresden. Creative in its research, and with a solid understanding of potential applications, the institute significantly contributes to the development of "mission critical technologies".

The Board of Trustees would like to thank our customers for their trust in our team, the staff, its management, and all partners, for their collaboration, their commitment and results achieved. We wish you a future full of success and good health!

Yours truly,

Dr. Reinhold Achatz

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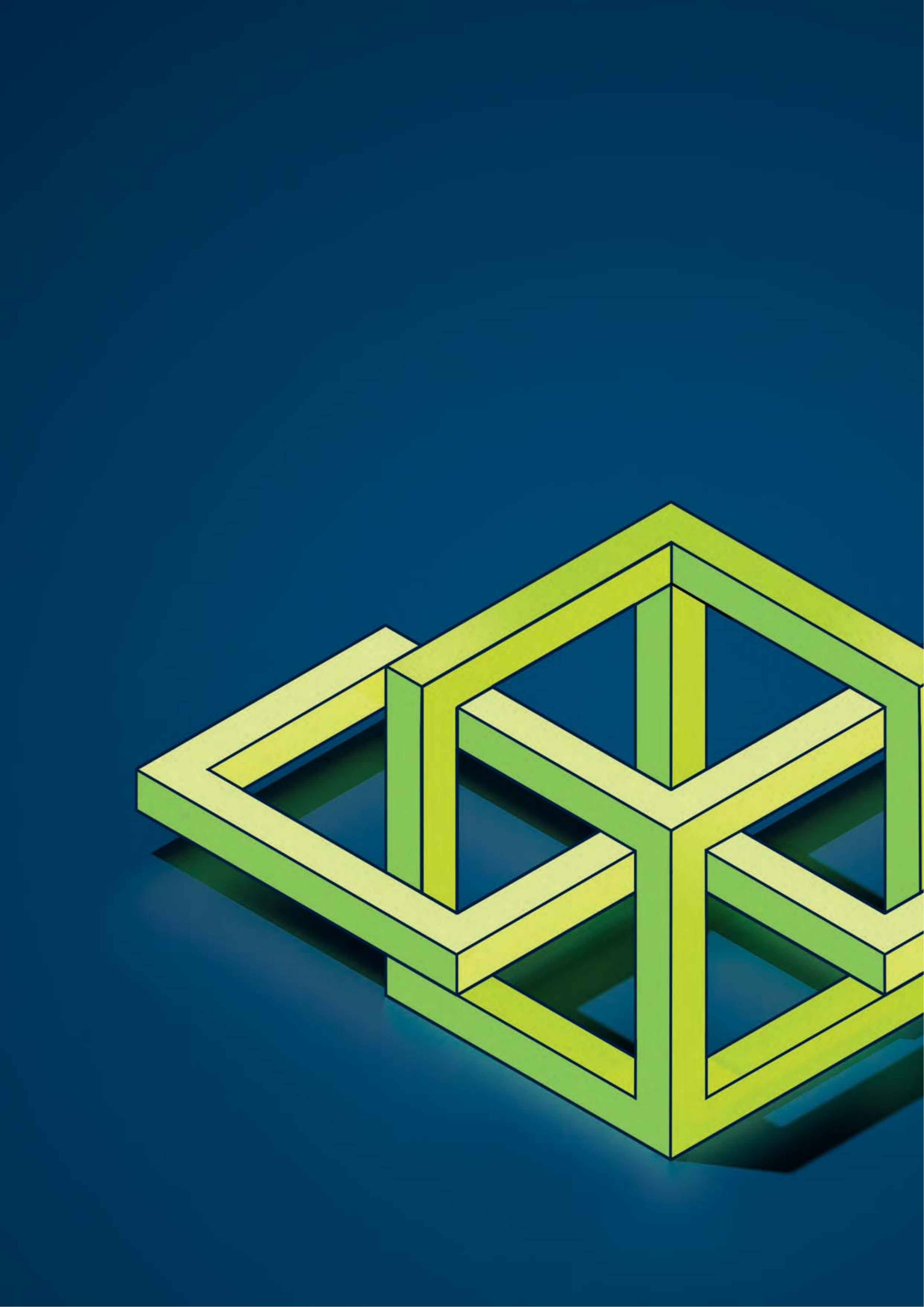

ABOUT THE BUSINESS UNITS

PVD- AND NANOTECHNOLOGY

CHEMICAL SURFACE AND REACTION TECHNOLOGY

THERMAL SURFACE TECHNOLOGY

ADDITIVE MANUFACTURING AND PRINTING

JOINING

LASER ABLATION AND CUTTING

MICROTECHNOLOGY

MATERIALS CHARACTERIZATION AND TESTING

PVD- AND NANOTECHNOLOGY

Business Unit Manager **Prof. Dr. Andreas Leson**

THE BUSINESS UNIT

Hard, with minimal friction, reflective and electrically conductive – the PVD- and Nanotechnology business unit offers unique surfaces. It focuses on research and development of techniques to generate various coatings and layer systems based on physical deposition techniques. The coating solutions provided by the business unit can be applied to a wide variety of applications. The scientists are focusing on the fabrication and application of super hard carbon coatings, which are characterized by their outstanding wear resistance and low friction. In addition to tribological considerations, functional properties are also gaining increasingly importance: Simulation techniques and customized design enable optimized coating systems tailored to particular applications. The business unit has also comprehensive expertise in the fabrication of extraordinarily precise multilayers that are deposited with atomic-level precision. Another main focus of the business unit is the research and development of hard coatings with thicknesses of up to 100 micrometer in order to increase resistance and durability of machine components or tools. The range of tasks includes not only research in coating processes but also the development of the associated plant technology.

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HERMETIC JOINING BY MEANS OF REACTIVE SYSTEMS

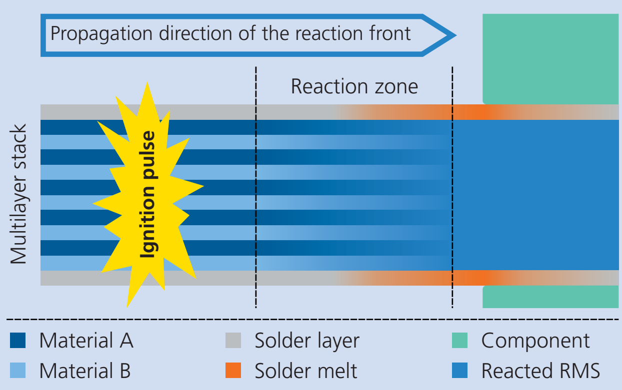
Fraunhofer IWS scientists have successfully engineered reactive multilayer systems (RMS) that are not only used as an innovative joining technology in mechanical engineering, but also for microsystems engineering. These RMS systems generate a heat source inside the joining zone and provide ultra-short process times, which enables to solder even difficult-to-join materials very quickly, without heating the surrounding area. Hermetic joining is a real challenge.

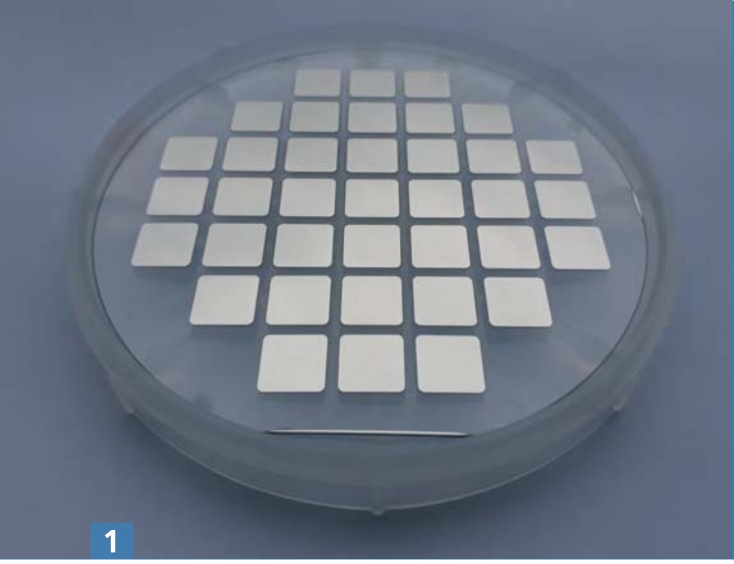
In microsystems engineering, joining processes not only have to build up a permanent bond between the components of an assembly, but also generally perform additional functions. In particular, they provide electric contacts, thermal bridges, and hermetically sealed cavities. Wafer bonding techniques, such as anodic fusion, glass frit, eutectic, or thermocompression bonding, demand high process temperatures. Using different materials with varying thermal expansion coefficients result in stress in the joining zone and high thermal load on the parts being joined. We can avoid the abovementioned disadvantages at increased process temperatures if the required temperatures are limited just to the joining position, while the parts themselves are protected. This is possible thanks to the short process times using reactive multilayer systems.

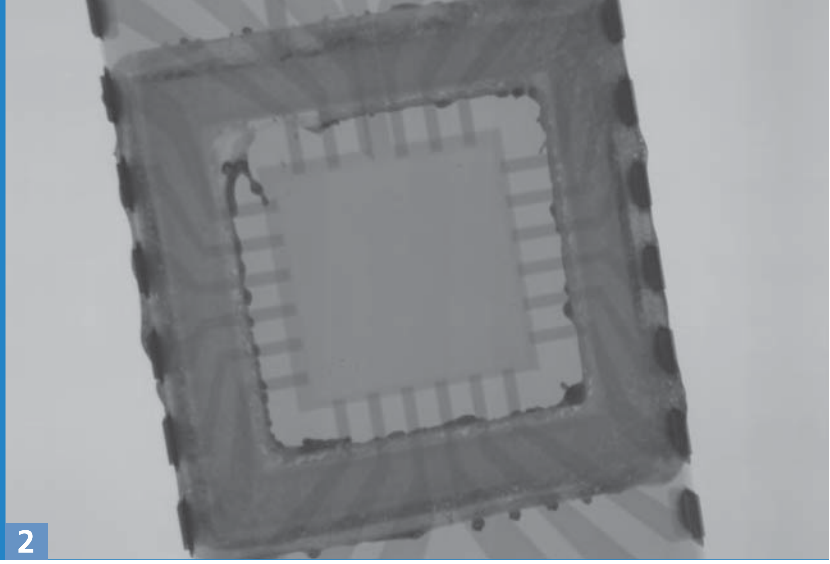
Joining strength values of maximal 30 Megapascal feasible

RMS consist of hundreds of periodically structured individual layers of two materials that can react to one another. Single layer thickness amounts to only a few nanometers. The RMS thickness ranges from 5 to 120 micrometers and can be brought into the joining zone – in the form of a freestanding film or as an integrated direct coating of the joining partners. The subsequent introduction of activation energy into the RMS results in a chemical reaction: In this process, thermal energy is set free, which can melt the parent materials or solders and thus create a joint in just fractions of seconds. The reactive joining technique makes it possible to fabricate soldered and thermoplastic joints – not only at the part, but also at the chip and wafer levels. In these joints, the researchers can achieve 30 Megapascal strength values. The joints are not only characterized by minimal stress in the joining zone, but are also highly thermally and electrically conductive, as well as extraordinarily resistant to warm, damp environments. The business unit team at Fraunhofer IWS Dresden has succeeded in demonstrating the potential of the reactive joining technology. Continuous refinement of the technology is currently opening up additional fields of application. Both projects on brazing and hermetic joining using RMS are being focussed.

RMS set-up and principle







Thermal energy storage releases energy in joining zones with time delay

During the reaction of nickel-aluminum RMS, which is most often used and is available at low cost, volume is reduced by 12.4 percent by a shrinking process. Cracks, which are a great challenge for hermetic joining, are formed subsequently in the joining zone. In conventional RMS, these cracks are not filled with solder or parent material and thus act as channels between the cavity and the environment. Current approaches to solve this problem seek to adapt the joining process technology and the RMS design in order to guarantee that the cracks are filled during the reaction. To do this, the engineers first have to bring more solder material and keep it in fusion in the joining zone as long as possible to support the flow processes. The IWS scientists achieved this by installing thermal energy storage deposits in the RMS. These deposits intermediately store the energy that is set free suddenly by the RMS reaction and release it into the joining zone more slowly. It is appropriate to use tin for thermal energy storage, because it is not part of the reaction process and functions as additional solder supplier directly in the joining zone. It has proved particularly successful to bring in 10 micrometer-thick tin deposits in a 40 micrometer-thick nickel-aluminum RMS: in this way, the maximal temperature in the joining zone is reliably reduced by up to 400 Kelvin, and the solder remains molten four times longer.

Fewer cracks and reliable filling by solder

As shown by joining tests, the tin deposits within the nickel-aluminum RMS assure hermetic joining by using tin-based solders. It is possible to reduce the number of cracks in the joining zone, on the one hand. On the other hand, we can reliably fill the cracks occurring with the solder material. Due to the energy stored, nickel-aluminum RMS with tin deposits can only use tin-based solders. Consequently, current projects deal with using high-energy zirconium-silicon RMS for hermetic joining in microsystems engineering. These systems provide several advantages; they can set free 100 percent more energy than nickel-aluminum systems and shrink substantially less than the latter. Furthermore, they can be applied for soldering and brazing. Thanks to the higher energy release, layers just a few micrometers thick are sufficient for joining to prevent crack formation and guarantee a transfer to the wafer level. Initial investigations of the use of 25 micrometer thick, freestanding zirconium-silicon RMS show good crack filling and hermetic dense joining with tin-based solders. The team achieved strength values of more than 100 Megapascal in experiments with silver-based brazings.

1 *Current projects at the Fraunhofer IWS focus on transferring the reactive joining technology into microsystems engineering. The researchers demonstrated the structured deposition of zirconium-silicon RMS on wafer level.*

2 *Hermetic joining of sensor housings applying RMS was verified at Fraunhofer IWS. The joining zones of the hermetically sealed encapsulation of the sensor housing do not show any cracks in the X-ray.*

These projects were partially funded within the scope of the IGF projects 17370B as well as 19069BG of the Research Organization of the German Association for Welding and Related Techniques (Forschungsvereinigung des Deutschen Verbandes für Schweißen und Verwandte Verfahren e. V.) (DVS) by the German Federation of Industrial Research Associations AiF in the context of the Program for Promoting Industrial Joint Research (IGF) by the Federal Ministry for Economy and Energy due at the behest of the German Bundestag.

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Federal Ministry for Economic Affairs and Energy

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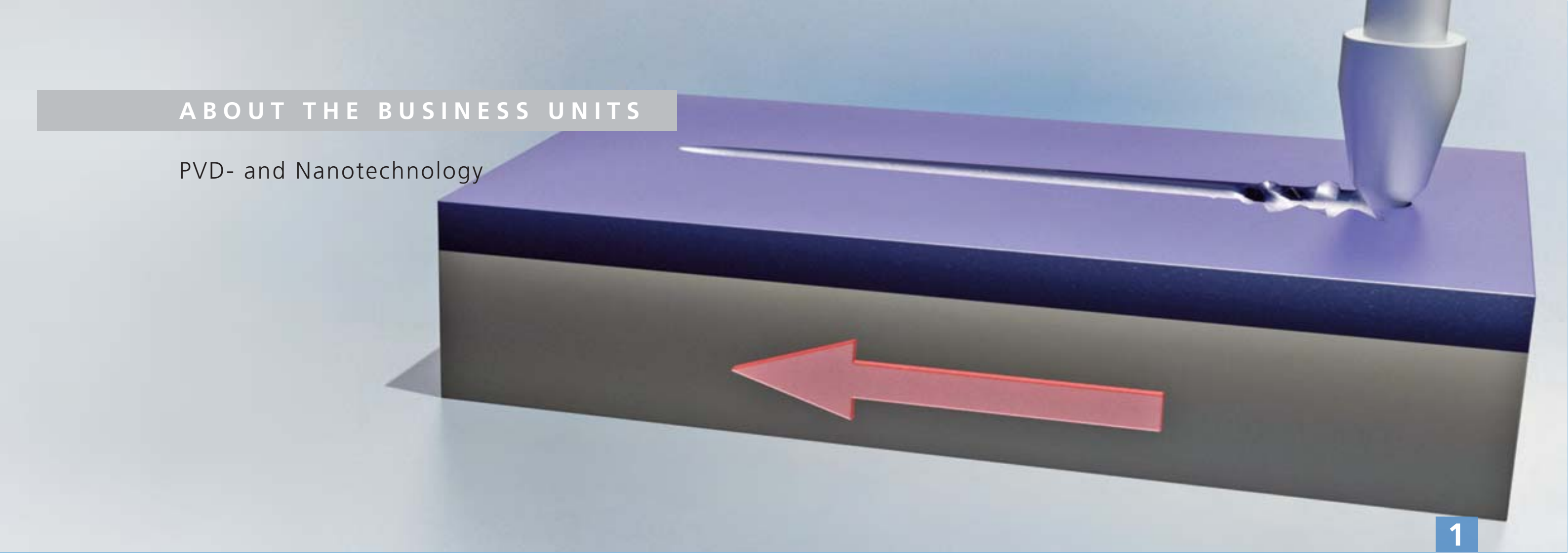

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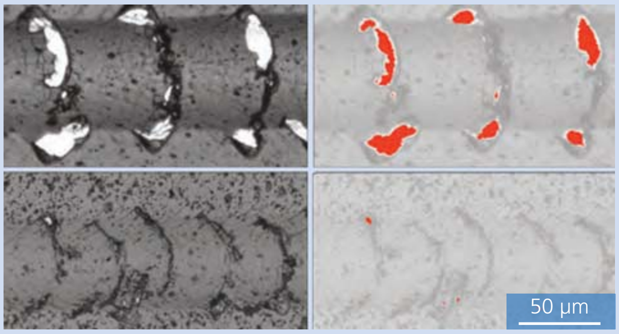
IMPROVED ADHESION TESTING THANKS TO DELAMINATION ANALYSIS

The impact of test and coating parameters limits the test of the adhesion of hard coatings by means of the scratch test. To bypass these limitations, the researchers at Fraunhofer IWS have developed a new analysis method quantifying the delamination area. This simplifies the commensurability of results and provides an independent quantification of scratch resistance.

Scratch tracks on two different specimens of similar coating thickness



Coating material: tetrahedrally amorphous carbon. Left: images from optical microscope. Right: detection of adhesive damages (shown in red).

Sound adhesion to the substrate is essential for the use of hard coatings on tools or components. Consequently, one main task in the use of coating techniques is to adequately test the coating's bond. For this purpose, the scratch test is commonly used: a diamond tip is drawn across the surface with increasing force. The researchers evaluate the bond in a comparative approach by means of the load at which the coating peels off. However, these critical loads strongly depend on the properties of the substrate, coating, and diamond tip. As a result, in many cases, it is not possible to obtain quantitative values for bonding.

With a focus on interface property

Fraunhofer IWS has developed a method by which the analysis of scratch resistance can be substantially improved. Researchers evaluated the area of the delamination surface in the case of coating failure in this method. It turned out that this parameter depends much less on the test conditions. The new method is particularly sensitive to the truly crucial properties – those of the interface. Despite different bonds, the coatings investigated have similar critical loads. The bond can be unambiguously distinguished by quantifying the delamination area. The diamond tip size is also adapted to the coating thickness. As a result, the stress applied during scratching is intentionally placed at the interface between the layer and substrate material. To quantify the critical load alone was insufficient even in this case. Since the magnitude of delamination correlates with the stress at the interface, this parameter is suitable to evaluate "customized" scratch tests.

1 *Scratch test: A diamond tip is moved across the surface with increasing pressure. One can evaluate the coatings's quality depending on the amount of coating removed.*

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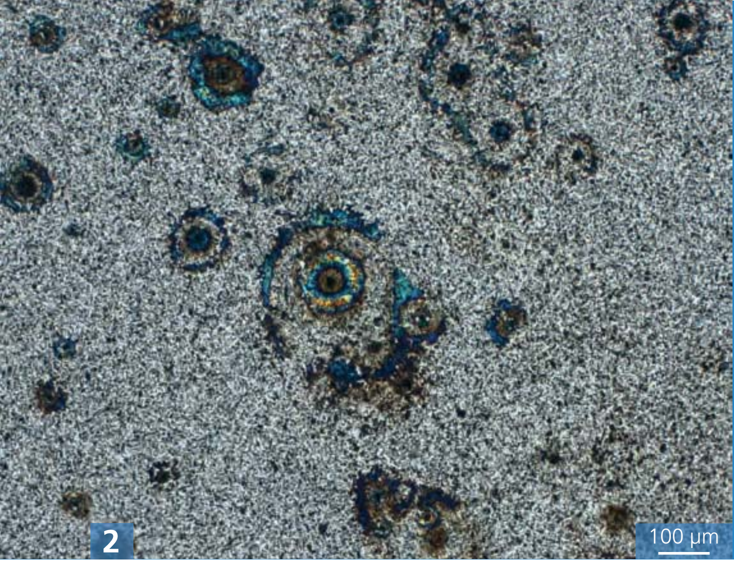
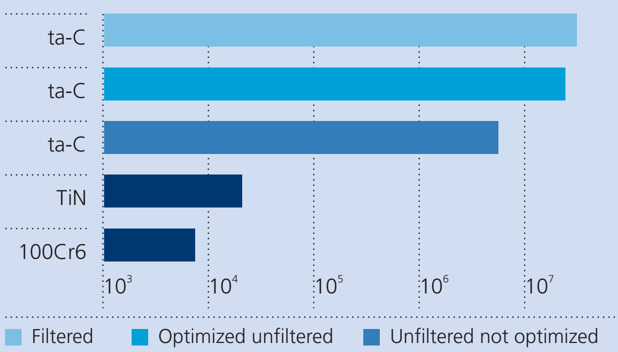


CORROSION-RESISTANT CARBON COATINGS

Superhard carbon coatings are optimally suitable for lubricated tribological applications. Fraunhofer IWS has refined the corrosion resistance of systems of tetrahedral hydrogen-free amorphous carbon coatings (ta-C) and evidenced it by means of electrochemical impedance spectroscopy.

In the future, applications exposed to corrosion and partially unlubricated tribological applications should also benefit from the superhard ta-C coatings. With electrochemical impedance spectroscopy (EIS), Fraunhofer IWS scientists qualified a measurement method in order to verify the suitability of coating systems like these for corrosion protection in a quantitative manner. Researchers were able to execute optimizations: they imprinted the test system – consisting of a coated substrate and an electrolyte – with an alternating voltage signal at different frequencies and recorded the resulting alternating current signal. They derived an equivalent circuit diagram describing the structure of the coating, from the curve. Reactions, coating porosity and homogeneity were represented this way. In the end, intentional optimizations at final coatings and intermediate layers were possible, since alterations of the corrosion resistance are frequently due to individual coating areas. As the researchers observed, a high charge transfer resistance R_{ct} correlates with high corrosion resistance. IWS researchers significantly improved the charge transfer resistance by systematically varying the composition, the deposition parameters of the intermediate layer and the final coating. In comparison with titanium nitride (TiN), ta-C achieved an R_{ct} value two magnitudes higher, which could be further increased by optimizing the interface. Another increase resulted from the use of a plasma filter, thus obtaining more homogeneous ta-C coatings. The improved homogeneous coatings enable further increases in efficiency, for instance in the automotive industry, if the task is to switch over to lubricants that are both water-based and of less viscosity.

Charge transfer resistance (R_{ct} in Ω) of different coatings



The team measured an area of 0.2 square centimeters with 0.6 mole of the sodium chloride electrolyte (35 gram per liter).

2 A non-optimized surface may be damaged by corrosion from natural stress.

3 The surface appears more homogeneous after optimization. IWS researchers could verify the strongly reduced tendency to corrode by electrochemical impedance spectroscopy EIS.

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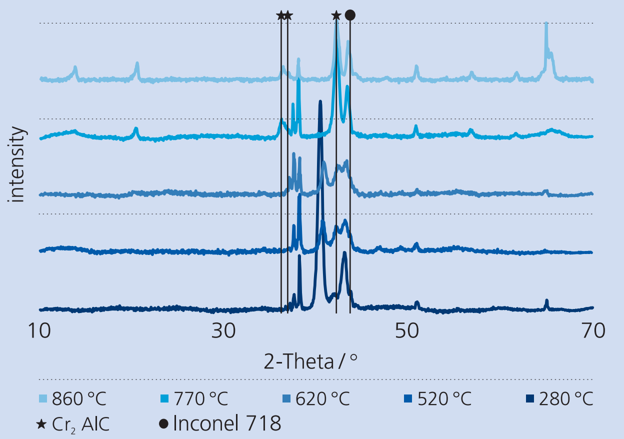
ANTI-ABRASION LAYERS OF THE FUTURE

They are regarded as the material of the future in turbine construction and aviation industry: MAX phase materials. Chemical compounds are hidden in a laminar structure that combines ceramic and metallic properties. Fraunhofer IWS investigated their fabrication as a thin-film system using industrial "arc-PVD technology".

MAX phase materials combine the characteristics of ceramic and metallic materials. This makes the combination of properties, such as hardness and ductility, promising for a variety of applications, even as thin-film systems. The abbreviation "MAX" stands for transition metal (M), main group element (A) and for carbon or nitrogen (X). The Fraunhofer IWS team investigated whether it is possible to fabricate these coatings by means of the dc-Arc technology, a standard procedure for coating of tools and components. Researchers selected chromium-aluminum-carbon-MAX phases as the specific material system, since these phases have the potential for various applications. The coatings are – due to the fabrication procedures – a blend of phases and have additional carbide and intermetallic phases. The composition mainly depends on temperature during coating fabrication.

Phase formation as a function of deposition temperature



The engineers were able to achieve the highest MAX-phase contents at temperatures from 800 to 900 degrees centigrate.

Promising alternative to hard and ductile surfaces

The coatings showed encouraging results in the erosion test. They provided a good protective effect even in the case of very different angles of incidence of the jet material – a clear indicator for both metallic and ceramic properties, in particular those of high hardness and low brittleness. The researchers of the Fraunhofer IWS evidenced that it is possible to fabricate MAX coatings on an industrial scale so that they can withstand erosion. Thus, they are a potential alternative for applications that demand hard surfaces that are also ductile. These requirements are, among other fields, typical for machine components subjected to strong load. The next step is to transfer the new layer system to industrial applications.

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MULTILAYER LAUE LENSES FOR NANO-ANALYTICS

X-ray microscopy provides various opportunities for non-destructive testing of material properties. The achievable spatial resolution of the X-ray optics is limited by the numerical aperture and the demanding fabrication. A researcher team at Fraunhofer IWS has developed X-ray lenses enabling high-resolution in-situ investigations.

The IWS team fabricates multilayer Laue lenses (MLL) to focus X-rays in nanometer beam sizes. MLLs are optics that particularly suit hard X-rays with photon energy of more than five kiloelectron volt. MLLs consist of a depth graded multilayer system with many thousands of individual layers. The thinnest layers are only a few nanometers thick while the total thickness is currently up to 100 micrometers. A special challenge is process reliability during the layer deposition process, since this takes several days. Subsequently, the researchers structured the MLL coating by means of laser ablation process and Focused Ion Beam (FIB) milling. For two-dimensional focusing or full field imaging, it is necessary to configure two MLL lamellae in a crossed in-line set-up. With such a lens combination, the IWS researchers achieved a focus diameter of less than 25 nanometers with a working distance of several millimeters. This allowed performing in-situ experiments with this resolution for the first time.

Increased efficiency

Particularly for MLLs, the IWS team developed a method allowing the deposition of more individual layers. For the reduction of residual stress, they use carbon as transition layer in addition to molybdenum and silicon. In comparison with other systems, this combination allows for very high focusing efficiencies. Therefore, the multilayer Laue lenses concentrate a high percentage of the primary incidence X-rays into the focal point. By achieving further optimization of the MLL geometry and the deposition process, the researchers expect still substantially smaller focal points and higher efficiencies for relevant X-ray energies in the future.

1 *Finished MLL lamella after structuring. The central thin area is the aperture of the lens and was treated by means of the FIB milling.*

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CHEMICAL SURFACE AND REACTION TECHNOLOGY

Business Unit Manager **Prof. Dr. Stefan Kaskel**

THE BUSINESS UNIT

The business unit Chemical Surface and Reaction Technology focusses on next generation batteries. Central research topics include electromobility and stationary energy storage. The scientists design methods for fast, efficient, and reliable battery manufacturing; they focus not only on lithium-sulfur technology, but also on other innovative approaches, such as solid state batteries. They rely on an in-depth understanding of the chemical processes inside the battery. This is the basis for IWS scientists to develop adapted system technology, monitoring and characterization methods to quickly analyze processes and coatings of varying dimensions by means of imaging techniques. For surface analysis, the team combines detailed technical expertise in system design with sophisticated materials knowledge. No matter whether coatings or functional materials are developed, the team has profound knowledge of the physical properties and application characteristics. The business unit also offers customized methods for surface evaluation, such as optical inspection by means of hyperspectral imaging.

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LITHIUM-SULFUR BATTERIES: LIGHT AND SAFE?

Lithium-sulfur technology (Li-S) promises an increase in energy density; however, many essential cell properties demand further investigation. In the "SepaLiS" project, Fraunhofer IWS worked with partners to develop and evaluate Li-S prototype cells. In initial safety tests, another advantage of lithium-sulfur cell chemistry emerged.

The expectations to be met by future energy storage for electric cars are ambitious and complex. The researchers have to focus on the crucial criteria, such as range, quick chargeability, lifetime, costs, and – most of all – safety. The scientists can evaluate new cell chemistry in terms of these demands only if it is possible to fabricate suitable prototype cells in a reproducible manner. As a rule, tests of button cells or other laboratory cells do not provide any insight into the properties in the case of real application. As a result, there is a clear gap between academic research results and the need for industry-relevant data on future battery systems.

Fraunhofer IWS brings the cell chemistry of the next generation into prototype manufacturing

This is where Fraunhofer IWS comes in with its Center for Battery Research. Its labs, the institute has established the equipment and techniques required to implement the overall process chain – from material engineering to the fabrication of the battery cells. Coating techniques for electrode fabrication, tailoring by means of laser cutting, automated assembling of cell stacks, and bonding by laser welding are essential elements of this chain. Within the scope of the "SepaLiS" project funded by the Federal Ministry for Education and Research BMBF, a consortium consisting of four industrial enterprises and two Fraunhofer Institutes has now developed a cell design that will be implemented through the IWS process line for providing test series of prototype cells. IWS researchers make use of coated separators, engineer new cathodes, and fabricate these components using the roll-to-roll technology. Another key component is the patented electrolyte system by means of which the characteristics of Li-S cells can be redefined. Using solvents based on sulfones and fluorinated ethers, the IWS electrolyte enhances Li-S cells in terms of lifetime, energy density, and safety. Prototype cells with this electrolyte composition have already achieved more than 100 charging and discharging cycles with only minor losses in capacitance (< 10 percent). Ion transport in this electrolyte system also functions in strongly compacted cathodes so that it is possible to build compact cells with high volumetric energy density that achieve more than 400 watt-hours per liter.

How safe are lithium-sulfur cells?

Only a few facts are known about the safety of Li-S cells. While some well-known battery experts warn about the risks of using Li-metal anodes, developers of Li-S technology advertise safe cell chemistry. Fraunhofer IWS has now fabricated Li-S prototype cells of 3.5 ampere-hours capacity and allowed them to be evaluated by its industrial project partner for safety. The partner subjected the cells to standard tests that are necessary for approval in the automotive industry. The temperature characteristics are monitored, and visual modifications are recorded by a camera. The tests include:

- Overcharging (the cell is charged to 200 percent of the voltage limit not to be exceeded during charging)
- External short circuit (the cell is grounded at low impedance)

– Simulated internal short circuit (the cell is penetrated by means of a ceramic nail)
– Artificial overheating (the cell is heated to 150 degrees centigrade by means of a defined ramp)

The results were better than expected. The Li-S cells achieved a "hazard level" (HL) less than or equal to three. That means that the cell opens, and electrolytes evaporate under specific conditions, but in no case did the tests result in thermal runaway or even in explosion. Cells of similar design based on lithium ions may explode just by overcharging or in case of a short circuit. A temperature of more than 180 degrees centigrate is critical in itself for Li-S cells: at this temperature metallic lithium melts, which can result in a vigorous combustion of the cell. Fortunately, the team did not reach this temperature under the standardized test conditions, so that it can certify the Li-S cells are altogether very safe.

Summary and Outlook

The results showed increased safety as an essential feature of Li-S technology. The new electrolyte made by the IWS also contributes to achieving high energy density values up to 400 watt-hours per liter. This result clearly outstrips any previously measured results for Li-S cells. With these intermediate results, the Fraunhofer IWS team and its "SepaLiS" project partners embarked upon the next phase, aimed at the automated fabrication of large-sized pouch cells that will then undergo additional tests. They aim to refine the electrolyte and the new membrane technology to enhance the cells' cycle stability.

1 Equipment for automated separation of electrode films by means of laser cutting.

2 New electrolyte system and lithium-sulfur cell prototype.

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1

CLEAN AIR THROUGH INNOVATIVE FILTERING MEDIA

Clean air is essential to health. Whether in the city or on a workplace in closed rooms – good air quality offers a high standard of living and personal safety everywhere. Improvement of air quality and a guarantee of air without contamination require reliable control and monitoring of gas and particle emissions.

Air pollution impedes our everyday life; more efficient purification in almost every part of life is needed. Industrial production processes causing hazardous gas or particle emissions require emission monitoring; such situations profit from adapted encapsulation or advanced filter systems to guarantee occupational safety and health for employees and expert users. Airborne particles as well as noxious gases, such as carbon dioxide, nitrogen oxides (NO_x), and a number of volatile organic compounds (VOCs), such as formaldehyde or toluene are focus topics for environmental protection and occupational health. For the development of customized gas and particle abatement an expert knowledge of composition and characteristics concerning the emerging hazards is crucial. Which hazardous substances are present, and in which state – as gas, particles or both – do they occur in the exhaust stream or the ambient air? What are the concentration levels, and what are the maximal allowable concentration levels? In which respect do temperature, pressure, and air humidity matter? Answering these questions results in the design of individual gas and particle filtration modules. Fraunhofer IWS not only offers analysis of airborne particle size distributions for process exhausts and workplaces, but also gas phase analysis using infrared spectroscopy. The researchers record the relevant metrological variables with a measuring setup tailored to the gas stream to be analyzed. Based on these data, they recommend suitable functional materials (adsorbents, catalysts, membranes) for the abatement system. The development of new measuring equipment and test methods to characterize the gas phase and functional filter materials is another key task. Based on studies, recommendations for individual gas and particle filtration modules for system implementation are developed.

1 Innovative filtering media can filter out hazardous gases for cabin air.

Highly sensitive measuring devices for particle and gas analysis enable the detection of minute constituents in process exhaust gas streams.

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RECYCLING IN LIGHTWEIGHT CONSTRUCTION – HIGH RECOVERY QUALITY OF CARBON FIBERS

Carbon fiber-reinforced plastics (CFRP) enjoy considerable popularity in lightweight construction. However, when their period of use ends, the question remains of how to recover the carbon fibers from the composite. The recycling method determines the quality of the recovered fibers and their potential for reuse as reinforcement material.

Recycling of used CFRP parts is a great challenge for industry. Due to the low quality of recycled carbon fibers, researchers seek new alternative methods. Up to now, only pyrolysis has been used on an industrial scale in special furnaces; in this procedure, a polymer matrix is thermally decomposed under the exclusion of oxygen. Mechanical crushing of the CFRP parts has to be done before, which clearly reduces the fiber length. Long-term thermal treatment in pyrolysis results in decreased mechanical strength of the carbon fibers. Recovery and reprocessing of pre-cuts, so-called patches, offers clear advantages in comparison with disordered short fibers; consequently, emphasis is put on this topic. Researchers at the Fraunhofer IWS have developed an innovative technique for recycling CFRP patches, removing the polymer matrix very gently and efficiently.

Direct heating of fibers decomposes the surrounding polymer

The technique utilizes of the embedded fiber filaments for direct heating of the composite part "from inside out". The researchers apply a voltage to the carbon fibers, so that current is conducted through the fibers to heat them. The surrounding polymer decomposes under these conditions into its gaseous components, and the revealed carbon fibers remain. An intentional control of the fiber temperature prevents overheating of the material. The carbon fiber patch alone remains as it was. Keeping fiber length and orientation within a patch makes it possible to generate a new CFRP composite part from several carbon fiber patches and a polymer. This composite part has higher strength characteristics than a part made from short fibers. Due to the direct fiber heating, the technique is extremely quick and energy-efficient. The matrix material is also removed among the individual filaments with no residue. Post-processing with oxidative gases in the same or a downstream process step removes final residues on the fibers and simultaneously activates the fiber surface for the follow-up embedding in the polymer matrix.

2 *CFRP sandwich with epoxy matrix – carbon fibers to be recycled.*

3 *Recycled and easy-to-separate carbon fibers made of the CFRP shown in Figure 2. The textile structure is retained during the process.*

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SURFACE INSPECTION SIMPLIFIED

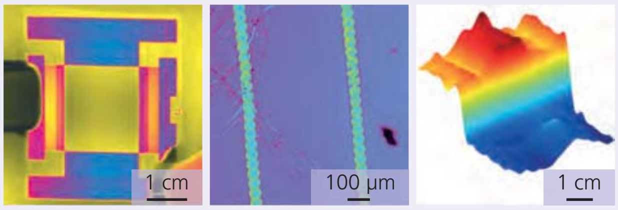
Hyperspectral imaging (HSI) generates comprehensive data records. Powerful software is needed to record, process, and visualize "hyper-cubes" of several gigabytes. With "imanto®*pro*" the researchers at the Fraunhofer IWS reveal unexpected options to solve inspection tasks in industry.

Hyperspectral imaging is a rapidly growing domain in the optical inspection technology, particularly in continuous 100 percent inspection. This technique finds detailed information about the chemistry and the structure of an exploration object by simultaneously measuring the reflected radiation in a spectral and lateral resolution. With this as the basis, it is possible to derive quality parameters of the specimens using automated analysis afterwards, and it becomes easy to localize defective zones. With imanto®*pro* , the Fraunhofer IWS has developed the appropriate software solution for application-specific recording, processing, and analysis of the hyperspectral data records. Users can follow all inspections steps, beginning with the evaluation of the measuring task, the adaption of individual hardware, and measurement parameters, up to the specification of the measurement report.

HSI-assisted process control

The software imanto®*pro* provides both opportunities for data exploration in the case of new measurement tasks, and a connection to production processes for further processing of results. Even for the latter, model-based algorithms are available that enable a rapid evaluation within the cycle times of "inline processes". Optical contactless measurement is suitable for a wide range of inspection tasks for parts, surfaces, powder, or unit loads. They may include tasks like the assessment of cleanliness, defect inspection, the identification of foreign substances, or even application-specific quality criteria.

HSI-assisted inspection of thin-layer systems



Visualization of material distribution in an OLED part at 1310 nanometers (left), assessment of laser ablation homogeneity in the fabrication of organic solar cells (middle), and visualization of a change in surface resistance of an ITO coating by using flashlights (right).

Users can also intentionally determine characteristic values with local resolution, such as layer thickness or the surface resistance of thin layers.

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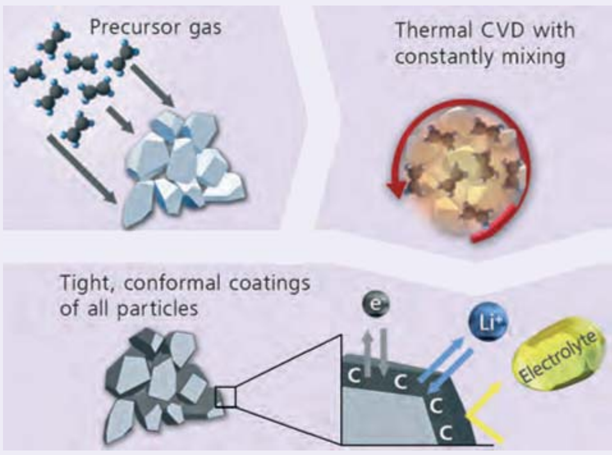
CARBON COATINGS FOR THE NEXT GENERATION OF BATTERY MATERIALS

The next generation of battery materials features higher energy densities and thus opens up a tremendous market. A prerequisite for this is customized surfaces that reduce decomposition reactions during electrolyte contact or allow to control these reactions. Only in this way the required lifetime for high-energy cathodes can be achieved.

Scientists at the Fraunhofer IWS have developed a process for chemical vapor deposition (CVD) of carbon. CVD technologies make it possible to coat powder-like battery active materials. Continuous mixing of the powder in the reactor means that all particles are homogeneously coated with carbon. A gentle processing enables the coating of heat-sensitive materials without destroying the lattice structure. The carbon coatings created this way act as protective layer against electrolyte and humidity for materials such as lithium-manganese-nickel oxide (LMNO), lithium titanate (LTO), or lithium-nickel-cobalt oxide (NCM). They also improve electrical conductivity of the oxidic particles. By modifying the process parameters, the researchers can adjust properties such as tightness of coating, homogeneity of deposition, and thickness of the layer (from 1 to 100 nanometers). They are also capable of modifying carbon from its amorphous to graphitic state and can thus tune electrical as well as lithium-ion conductivity.

Principle procedure of carbon coating via chemical vapor deposition (CVD)



1 *Uncoated (white) and coated (black) active material.*

Development of battery cells with higher stability

The intentional modification of the surface characteristics of the active powder materials is a part of the process chain to develop next generation battery cells at the IWS. Other major topics are processes to produce customized electrodes at a reasonable cost, and the assembling and evaluation of prototype cells. This allows material innovations to be evaluated quickly and with a focus on application.

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THERMAL SURFACE TECHNOLOGY

Business Unit Manager **Dr. Denise Beitelschmidt**

THE BUSINESS UNIT

From a single source to a highly automated process: the team in the Thermal Surface Technology business unit focusses on the entire value-added chain of systems and process engineering with respect to coating structure and heat treatment. Energy and resource efficient design considerations meet issues in terms of process economy and ecology. If the task comes to efficiently designing highly complex procedures, implementing them into innovative processes, and bringing them in line with the target product, the business unit can score with its experience in research and practice. Services include process and system engineering for laser-supported coating and layer techniques, thermal spraying, and heat treatment with a special focus on highly precise surface layer hardening. With the catchphrase "Industry 4.0", the researchers at the Fraunhofer IWS constantly strive for ever higher levels of automation. The major goal is to guarantee the process reliability of a valid, reliable technology to prevent costly idle times and enable competitive and high-quality final products.

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MATERIAL-EFFICIENT LASER STRIP CLADDING

Another cladding process adds diverse spraying and welding technologies for coating of large-sized cylinder-shaped parts. For rollers, pistons or rods, these technologies have up to now mainly been based on filler materials in wire or powder form. The researchers at the Fraunhofer IWS have engineered a new laser processing head that can process metallic strips with increased material efficiency and high deposition rates – up to ten kilowatts laser power.

The process of coating large surfaces to protect and functionalize tribologically stressed metallic surfaces needs to be productive and reliable over the long term. The techniques of hard chromium plating, thermal spraying and laser arc cladding have long been used industrially. In addition to this, laser cladding with powders as filler materials is in use everywhere in industry where there are special requirements in terms of corrosion and wear resistance. In contrast to the arc welding techniques, wires and strips for large-area laser welding are still unexplored. The advantage of these endless materials is that they can be utilized 100 percent during the process. Also, no powder particles are present in the manufacturing environment during the process, so that hazards to both the operator and the equipment are minimal. Another advantage arising from the newly designed laser process is that, in contrast to submerged arc welding and electroslag welding, no additional powder is needed to cover the molten bath. In the new process, the users can employ the same standard shielding gases as in arc welding with shielding gas, giving rise to other technological and environmentally relevant advantages in comparison with the conventional welding technology. For large-scale processes, strip materials are commercially available 0.5 millimeters-thick and 30 to120 millimeters wide. The IWS scientists have used the 30-millimeters variant. For this size, they designed a suitable optical system that can be run with a fiber-linked high-power diode laser as the beam source. The strip processing head is a functional system module, on which laser optics, the strip drive, media supply for cooling and shielding gas, and a cross-jet as splash-protection are installed. The angle between the laser beam and the strip supply can be adjusted from 20 to 70 degrees. The total weight is 24 kilogram.

New flexible process guidance with strips as filler material

Systematic welding tests with various design patterns demonstrated that a drive arranged as close to the process as possible, and a zero-backlash, as well as low-friction guidance, provide optimal dynamics for the strip feed. The engineers integrated a deflection mechanism to avoid damage to the strip processing head due to potential process failures or collisions. The beam shaping unit mainly consists of the two-inch optical components collimation, homogenizer and focusing. The laser fiber is adapted to a numerical aperture of 0.2 via user-friendly interface type LLK-D and thus provides a link to current high-power lasers. The homogenizer shapes the round beam into a line spot in the focal position. In this configuration, a rectangular laser spot of 36 x 4 square millimeters forms on the part. This dimension has been shown to be very suitable for qualification welding with the strip materials investigated. The researchers used strips made from the corrosive-resistant nickel alloy Inconel 625 and flat substrates made of unalloyed mild steel, and solid shafts made of

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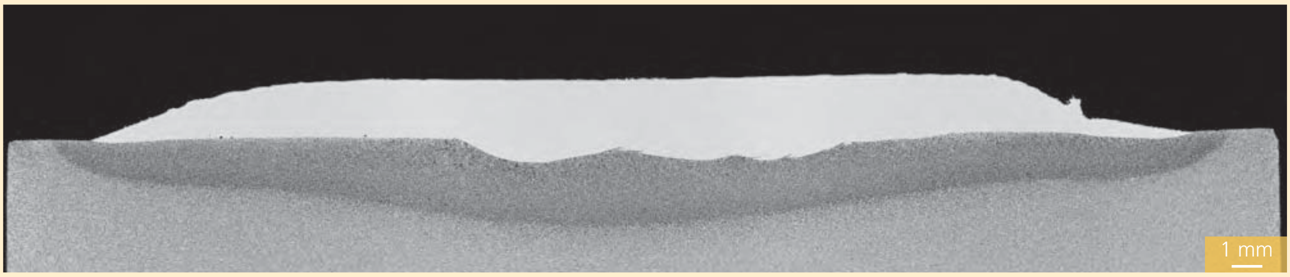
Cross section of a single track – made of nickel alloy Inconel 625 on mild steel



A typical weld with the newly developed laser strip processing head has an evenly pronounced surface shape with homogeneously flat sloping welding bead flanks and no inner pores or cracks. These characteristics are suitable for large-surface wear protection coatings more than one millimeter thick.

heat-treated steel. The research team determined on a strip feed rate of 0.8 meters per minute at a welding speed of 0.25 meters per minute for a reliable process at 9 kilowatt laser power. The laser strip cladding process has achieved a deposition rate of 6.1 kilogram per hour at a coating rate of 0.44 square meters per hour. For single tracks, the width is 34 and layer thickness 1.8 millimeter. For surface coatings, in this case, it is suitable to overlap the tracks by 5.0 millimeters to keep layer waviness minimal. At the time of the development status, the parameters of penetration depth and heat-affected zone, as well as micro pores emerging in the bonding zone, can also be further optimized. Moreover, the qualification of system hardware, such as driving unit, shielding gas protection, and beam shaping are always central topics of practical feasibility of both equipment and process.

1 *Solid shaft and flat substrate (from left) with overlap welds; investigated material combination Inconel 625 on mild steel.*

2 *The newly developed laser strip processing head can be fixed on industrial robots enabling flexible and clean process guidance to process strip filler materials.*

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SUSPENSION SPRAYING: "INDUSTRY 4.0 READY"

Lower surface roughness and greater homogeneity of the microstructure – these properties distinguish suspension-sprayed coatings from layers classically sprayed with powder. The Fraunhofer IWS offers the entire process chain, from industry-proven hardware up to customized coating solutions for the component.

Suspension spraying delivers high-quality, thermally sprayed coatings. Submicro- or nanopowders that are finely dispersed in water or in organic solvents are used as spray feedstock. The suspensions can be used both for atmospheric plasma spraying (APS) and in high velocity flame spraying (HVOF). For continuous industrial use, high process stability and reliability are necessary. These criteria can only be fulfilled if qualified user-specific hardware components are applied.

Suspension feeders as a basis for environmentally friendly digitization of coating processes

The Fraunhofer IWS researchers developed a stand-alone suspension feeder suitable for industry. For this task, they created the so-called "three pressure vessel approach", which makes it possible not only to spray conventional coating compositions in continuous use, but also to fabricate multilayer and composite coatings. The team integrated industrial sensors and actuators, as well as smart cascade controllers and data log functions, for automated process control and analysis. Simple recognition of error sources and the minimization of disturbing influences enabled the scientists to develop innovative spraying strategies; they also guarantee increased process reliability and reproducibility. This way, Fraunhofer IWS has created the preconditions for process digitization with the objective of self-controlling procedures. This also offers environmental benefits: the IWS researchers produced corrosion and wear protection coatings and coating solutions for electric and thermal isolation from aqueous and alcoholic suspensions on industrial scale. The accompanying tests were successful.

Suspension feeder based on the "Three pressure vessel approach"

1 *High velocity flame spraying using suspensions.*

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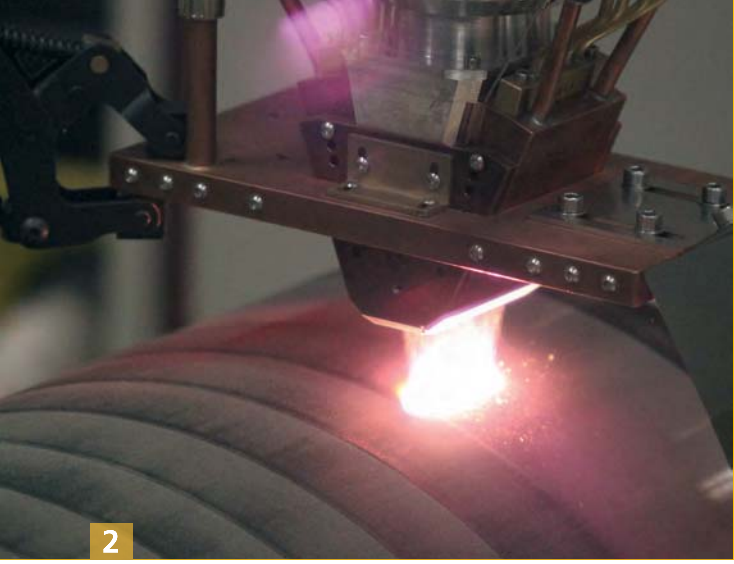

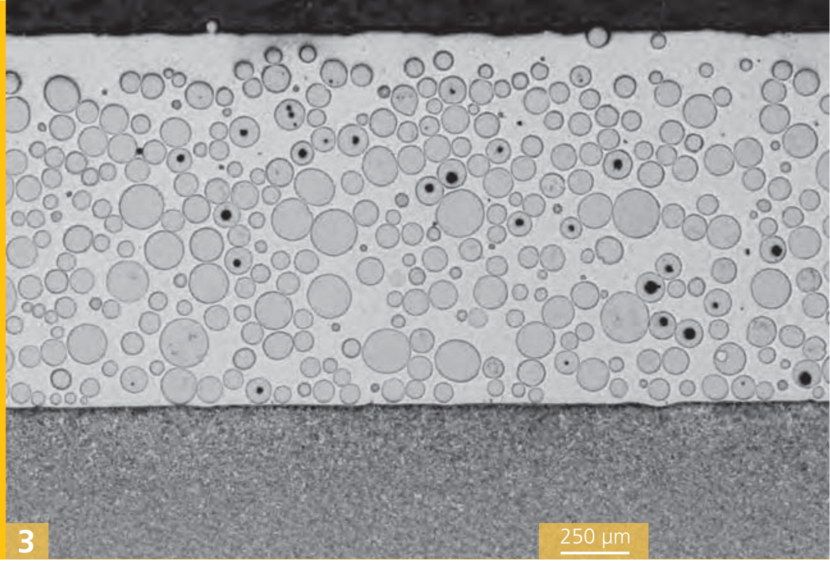

RECORD-BREAKING: HIGH-POWER LASER CLADDING AGAINST WEAR

To utilize the full power of new high-power laser beam sources also for laser powder cladding, the researchers of the Fraunhofer IWS have enhanced the coating procedure with wide beam powder nozzles qualified for hard-material-containing wear protection coatings.

Laser powder cladding is a coating technique for corrosion and wear protection and has already been established on an industrial scale. In industry, laser power values of maximum 8 kilowatts are generally used, although lasers of 20 kilowatts and higher are available. Among other factors, the power density in the laser spot or the intensity limits the power to be used for laser powder cladding processes. In cases of too high intensity, undesirable effects appear, such as molten bath overheat, evaporations, and pore formation. These effects are particularly critical in the carbide composite layer system "WSC-NiCrBSi", in which molten tungsten carbides (WSC) are embedded in a nickel, chromium, boron and silicon alloy (NiCrBSi). At too high intensity, the carbides dissolve, and, as a result, wear resistance is reduced, and the otherwise ductile Ni-Matrix alloy becomes brittle.

Highest laser power values at low intensity

The researchers at the Fraunhofer IWS have now designed a new wide beam coating head of the COAX11V6 type, intended for rectangular laser spots up to 45 millimeters wide. The large laser spot surface provides – even at maximal laser power values – a low intensity of, for instance, 7.5 kilowatts per square centimeter at 20 kilowatts. This, in turn, also makes it possible to weld critical material systems, such as WSC-NiCrBSi, at a significantly higher deposition rate and extremely high productivity, while maintaining high quality. Thus, IWS scientist succeeded in producing a 45 millimeters-wide WSC-NiCrBSi welding bead at a deposition rate of 22 kilograms per hour. The carbides in the wear protection coating are homogeneously distributed and do not evidence any dissolution characteristics. The newly developed wide beam processing head is also suitable for cladding corrosion protection coatings based on nickel or cobalt and is therefore a highly productive, economical and environmentally-friendly alternative to hard chrome coatings, for example, to coat huge hydraulic cylinders. The option to use 20 kilowatts laser power provides the opportunity for extremely high deposition rates and coating powers. In the future, researchers will seek new applications and to extend the material portfolio, such as for coating with copper-based sliding bearing materials.

2 *Laser powder cladding of tube with a 45 millimeters wide track and 20 kilowatts laser power.*

3 *Detailed image of a transverse microsection: The carbides embedded homogeneously do not have indicators for thermal decomposition.*

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ADDITIVE MANUFACTURING AND PRINTING

Business Unit Manager **Prof. Dr. Frank Brückner**

THE BUSINESS UNIT

Researchers in the Additive Manufacturing and Printing business unit apply materials layer by layer, in a wide range of applications. They fabricate entire components from basic materials, such as powder, wires, pastes and strips. They primarily work with metallic and plastic materials. The technologies used may be classified as remelting, additive manufacturing, and printing. Our outstanding procedural and material expertise are particular noteworthy; both competencies are necessary to create complex innovative parts – both produced cost-effectively and reliable in use – by means of additive manufacturing. The team employs various techniques, such as laser buildup welding using powder, laser, and electron beam welding, as well as hybrid processes linking material removal with additive manufacturing methods. In these efforts, IWS scientists not only focus on individual processes, but also research and develop solutions along the entire process chain. Working with industrial clients, IWS scientists follow the part's entire journey from the initial idea to creating the feasibility study and developing the system hardware all the way to complete marketability.

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ATHENA AIMS FOR THE STARS WITH ADDITIVE MANUFACTURING

The task of the Advanced Telescope for High-Energy Astrophysics (Athena) is to research temperature and energy flow in the universe. The European Space Agency (ESA) selected the underlying concept for the mission in 2013 as one of the most urgent scientific topics for a major future space mission. Fraunhofer IWS provides an optical bench that is one of the three main components.

How did the large-scale structures of the universe originate? How did black holes grow and how did they shape the universe? Athena's task is to help answering these questions by combining locally resolved X-ray spectroscopy with in-depth, large-surface and energy-dispersive radiograms. The intent is that the performance of the telescope will greatly extend that of existing X-ray observatories. A specific optical bench is one of the three main components of the telescope. In addition to a platform with instruments and a mirror module, the optical bench has a telescopic design and is equipped with 1062 silicon optics.

Optical bench in hybrid manufacturing

The Fraunhofer-Institut für Werkstoff- und Strahltechnik IWS produced the optical bench by means of a hybrid manufacturing strategy combining laser powder buildup welding and precision cutting. This approach is one of the main research topics of the Hybrid Manufacturing working team employed at the "Additive Manufacturing Center Dresden" (AMCD). This group particularly deals with the combined application of innovative manufacturing strategies. Dr. Johannes Gumpinger, the head development engineer of the European Space Agency ESA, explains the significance of this project: "For the development of future satellites and carrier rockets, we are constantly searching for manufacturing processes that offer more degrees of freedom in design, increased efficiency, and reduced costs and delivery times. The fulfillment of these requirements has just been established by the 'Advanced Manufacturing Program'

Additive manufacturing of the optical bench

Robots shape the optical bench layer by layer up to a maximum height of 300 millimeters. Only the robot's radius of action makes it possible to manufacture this large-sized part.

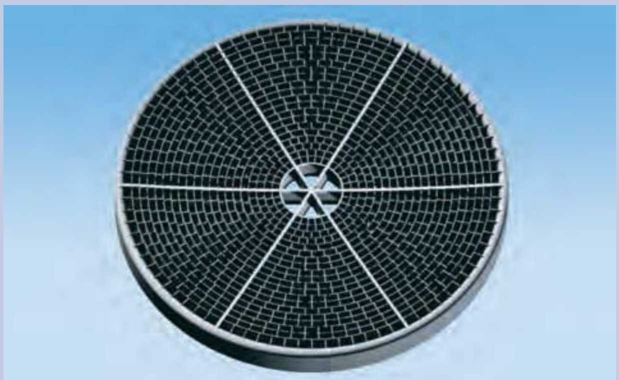

Illustration of a telescoping optical bench (diameter: 3 meter; height: 30 centimeter). The engineers installed silicon pore optics into each of the 1077 pockets (SPO).

at ESA. Additive Manufacturing complies with the criteria mentioned above and thus is regarded as an extraordinarily promising fabrication method." The technology has the potential to revolutionize not only the design of single components, but also, in the near term, even entire space shuttles. The ESA studies additive manufacturing techniques not only for small to medium-sized parts, but also for those up to several meters in size. The optical bench, which is essential for the ATHENA mission, is 30 centimeters high and has a 3-meter diameter. As a result, the choice of the fabrication technology is clearly limited. Gumpinger adds: "The robot-based laser buildup powder welding developed at Fraunhofer IWS, in combination with precision milling, belongs to the group of additive manufacturing techniques, and we see it as extremely promising to realize the project."

The goal in sight

Hybrid additive manufacturing of a complex large-sized part is extremely challenging in terms of production engineering. In intensive analysis, the team first evaluated the high-performance material used, the required geometric precision, and the necessary productivity in combination and derived a customized manufacturing cell. This cell unites the latest systems engineering from additive laser buildup welding, high-performance cutting, tactile and optical metrology, as well as smart process monitoring and control. A handling system linking two high-precision multi-axis robots with an NC rotary table with a diameter of 3.4 meters functions as the interface. During the implementation of the hybrid manufacturing system, the researchers combined the additive laser powder buildup technique with cryogenic high-performance cutting in one system for the first time. This enabled the intermediate milling of the component – which is essential for the process flow – without contaminating the surface. This approach makes use of maximal variety in design and the opportunities for functional integration in an entirely new way. Thanks to this development, the IWS researchers contributed to making this ambitious project reality. The next step is to execute a series of comprehensive tests to determine the material properties.

1 *Illustration showing the ESA Athena mission.*

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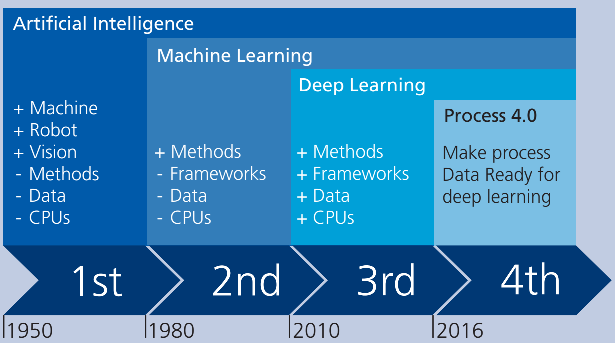
"LASER PROCESSES 4.0": SOFTWARE AND CONTROL

Scientists at the Fraunhofer IWS and the TU Dresden work together to study the connections among control systems, software, and machine learning in the "Data Management" competence center. The objective of these efforts is to engineer smart laser processes suitable for applications in the field of "Industry 4.0".

The "Data Management" competence center is a cooperative effort between the TU Dresden and the University Hospital Dresden. Together the partners develop interactive database systems and methods to process huge data volumes. The focus is on research, sensor, patient, and digital image data, as well as process parameters. Research and development includes sensors, statistics, automated pattern recognition, and image acquisition; image processing, modeling and visualization; and operator interfaces and application design. Data management and responsible handling of data are as important as they are for laser processes. Digital twins connect processes, products, production equipment, and employees – all of them communicate via the internet. The term "Big Data" indicates the management of data structures whose volume, diversity, and complexity demand new data processing and analysis techniques to disclose hidden knowledge. This knowledge, in turn, is transmitted into processes so that machine or in-depth learning becomes possible.

New methodology for Process 4.0 at Fraunhofer IWS



The scientist at the Fraunhofer IWS Dresden test such solutions for the "Process 4.0" under laboratory conditions. The range of competencies available at the Image Processing and Data Management group of the Fraunhofer IWS includes the following solutions and results:

- Process database for tracking and monitoring of laser-based processes
- Development of image databases and technologies for process data management
- Image processing and interactive visualization of process data: hardening, cutting and welding for real-time process monitoring
- "Human Machine Interfaces" (HMI) and software systems to control and monitor the IWS hardware systems
- Big Data solutions for programmable controllers as a key to higher productivity and efficiency in production
- "Process Data Analyzer": analysis and visualization of all programmable controller and sensor values
- Professional software engineering and consultation for efficient integration of hardware
- Research into Industry 4.0 technologies for process data

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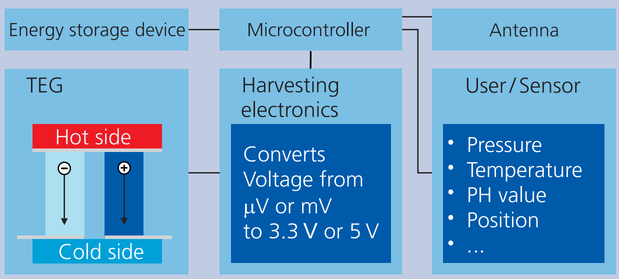
UTILIZING WASTE HEAT WITH ADDITIVELY MANUFACTURED TEGS

The engineers at the Fraunhofer IWS build thermoelectric generators (TEG) and Peltier elements using additive manufacturing techniques. In parallel they have developed the materials required for this, and also the measurement and communication system connected at the end.

The Thermoelectric Energy Harvesting principle is impressive in its simplicity: thanks to the Seebeck effect, it is sufficient to place a Peltier element on a heating unit to generate a current that flows between the two electrodes. With this principle, the researchers can also exploit unused waste heat potentials. According to several studies, unused waste heat is responsible for 18 to 36 percent of companies' energy consumption. When applying voltage to the same device, engineers can also use them for cooling. Why then are there only a few application examples for thermoelectric generators that use waste heat? There are several reasons:

- The material properties are insufficient
- The generator has a rigid design, whereas flexible or at least tube-like contours are needed
- Lack of supplies caused by problems in manufacturing
- No systematic consideration of reasonable use of the technology or estimation of the expected energy outcome

Schematic of an autarkic sensor with power supply by a TEG



Maximal freedom of thermoelectric generator design

To provide the adaptability of thermoelectric generators to individual applications, IWS researchers have developed additive manufacturing processes and materials. Ultimately, they succeeded in increasing the power factor of printed bismuth telluride by 100 percent. The power factor represents the product of the electric conductivity and the squared Seebeck-coefficient; it is a sound indicator of material quality. The scientists also implemented energy conditioning, energy storage and consumption for the operation of sensors by means of adapted electronic devices. A temperature difference of four Kelvin is sufficient to send measured air pressure and temperature values 150 times per hour to a receiving station eight meters away. A system like this provides the option to recover small amounts of energy, such as for autonomous sensor networks. Comprehensive materials, systems and process engineering knowledge is essential for the design of thermoelectric systems. The Fraunhofer IWS offers this service in single-source responsibility.

1 Building thermoelectric generators by dispensing.

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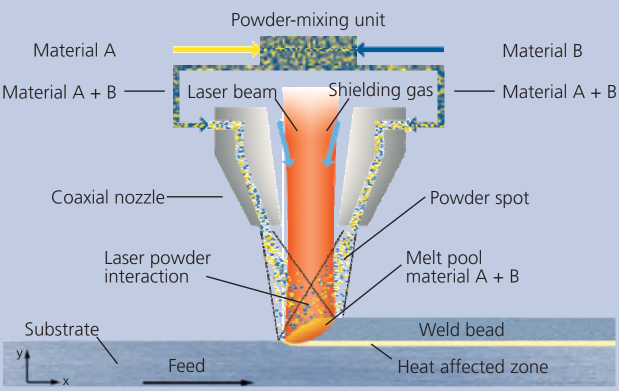
CUSTOMIZED: LASER POWDER BUILDUP WELDING OF 3D MULTI-MATERIAL

Additive manufacturing processes are now established in industry. This provides numerous opportunities to refine existing design in terms of lightweight construction, functional optimization, and cost reduction. In this context, the processing of various powder materials by laser buildup welding especially makes it possible to generate highly efficient parts tailored to the customer.

Greater part and property requirements arise from the increasing complexity of industrial applications. One material alone is often not capable to meet these requirements and makes the combination of a wide materials variety, the so-called "Multi-material approach", unavoidable. The researchers at the Fraunhofer IWS have identified laser buildup welding of powder, an additive manufacturing technique itself, as the process of choice for this application. Hardware developed in-house makes it possible to process up to four different materials simultaneously. The IWS researchers feed the various powder materials into the process zone according to the intentional material composition by means of a powder-mixing unit. In this unit, the laser generates a metallurgically fused compound, and in this way, it is possible to adapt the material properties to the part requirements locally.

Process head and procedural principle for laser buildup welding of powders (multi-material approach)



The powder-mixing unit supplies several materials to the process zone, where they are preheated by means of a laser and subsequently absorbed by the molten pool. This treatment makes it possible to generate three-dimensional material transitions and graded materials, or even to fabricate metal-ceramic composites.

Successful 3D transition of steel to nickel-based super alloy

The engineers at the Fraunhofer IWS have already succeeded in applying this procedural approach to a wide range of materials and applications. Beginning with a stainless steel alloy, they generated, for example, a gradual, three-dimensional transition to a high-temperature nickel-based super alloy. An application of this alloy in the energy sector is promising. The gradual material transition enables the elimination of mechanical and thermo-physical discontinuities and reduces occurring stresses inside the joining zone. Other ranges of application are the combined processing of high-strength steel and copper alloys of good conductivity, as well as the infiltration of a metallic matrix with ceramic hard materials.

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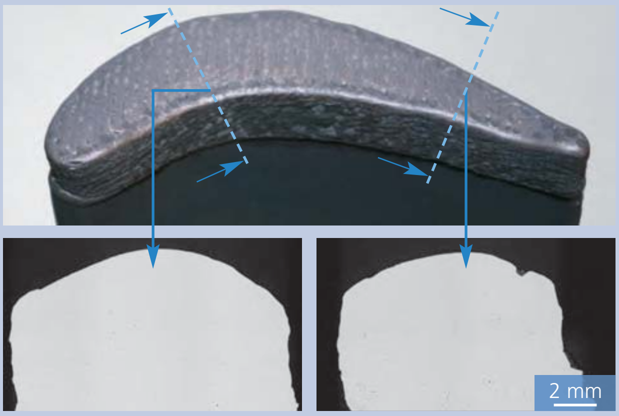
SMALL PROCESS WINDOW, GREAT PERFORMANCE

Super alloys are high-performance materials providing application temperatures of more than 1000 degrees centegrate even in oxidizing atmospheres. Even in these ranges, they are characterized by high strength and minimal deformations, which is, in turn, possible thanks to the precipitation of a hardening phase whose volume can be up to 75 percent.

Super alloys are regarded as impossible to weld by conventional means due to their complex alloy compositions. To form the precipitation phase, the basic element, for example nickel, has additional elements added to it, such as aluminum, titanium, tantalum, molybdenum and/or tungsten. In practice, often the weldability is limited by this addition. As a result, a pronounced crack formation tendency is observed, which increases as a function of the amount of the existing precipitation phase. In terms of the type of crack formation, it is preferable to distinguish between hot and cold cracks. In many cases, the exact retrieval of the crack characteristics demands a holistic and mutual consideration of the materials used, the joining technique, and the principle of process guidance. The Hybrid Processes working group at the Fraunhofer IWS studies this correlation in detail.

Demonstrating of a super alloy without defects



Fabrication free of defect and close to the contour

In this context, the researchers aim in part to identify the smallest range of constraints that makes it possible to process these crack-sensitive materials. On this basis, the scientists have developed customized solutions. A representative application is the reworking of worn turbine parts. Because these parts are very expensive, this reworking makes sense and is of tremendous economic importance for enterprises. One example is the repair of turbine blades. The IWS team has already verified the weldability of the nickel-based super alloy CM 247 LC in a case of application; this alloy – regarded as unweldable – could be welded without defects and near net shape by means of the hybrid laser powder buildup welding. In the next step, the researchers will transfer the results obtained to complex three-dimensional structures. This provides great potential for the manufacturing and repair of highly stressed and complex parts and offers time-saving and resource-efficient production at the same time.

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JOINING

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THE BUSINESS UNIT

The Joining business unit provides solutions in single-source responsibility. Equipped with profound technical materials knowledge, the researchers cover the complex process chain from analysis of material characteristics, via process development, up to implementation in equipment. The business unit develops adapted joining technologies and is even available for support in industrial application. Laser welding makes it possible to generate defect-free welds from materials that are highly prone to cracking. For bonded joining of advanced functional materials and metallic composites, the IWS team refines techniques, such as friction stir welding and electromagnetic pulsed joining. Advanced labs and efficient hardware are available for the development of adhesive bonding and fiber composite technologies. In component design, the Joining business unit runs structure-mechanic Finite-Element simulations, as well as thermally-mechanically linked calculations, and verifies them in experiments. Other services are the development of customized systems hardware.

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BONDING WITHOUT ADHESIVE – DIRECT JOINING OF METALS AND THERMOPLASTICS

The thermal direct joining technique enables quick adhesive joining of thermoplastic components with metal. After laser structuring, the metal is pressed with the plastic and locally heated. The thermoplastic melts due to heat conduction, penetrates into the structures, and adheres to the surface. In this way, bonding can be done in a few seconds.

Advanced lightweight design frequently demands the combination of metal and plastics, both with and without fiber reinforcement. For this purpose, the scientists need efficient process chains, using optimized pre-treatment and joining technologies tailored to specific stresses, as well as adapted tools for process simulation and characterization of properties. Fraunhofer IWS researchers, therefore, focus their work on developing productive solutions for direct and form-fit joining. They combine many years of experience in general bonding technology with modern system engineering developments in the field of remote laser technology.

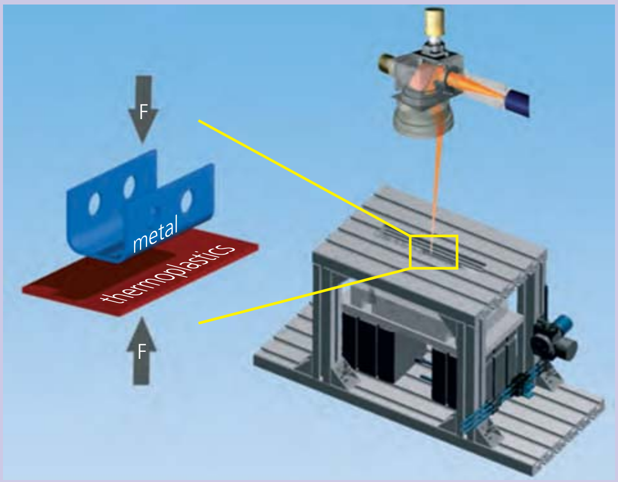
Pre-treatment makes the difference

Since thermoplastics and metals have very different physical properties (such as the melting temperature or thermal expansion coefficient), the optimization of the adhesion between these joining partners is very important. For this reason, the researchers developed a laser ablation process being able to generate structure depths of 100 micrometers and more. Continuously radiating high-power lasers are focused on the metal via a remote or scanner optics and quickly deflected. This process removes contaminations adhering to or inside the boundary layer from the surface. At the same time, the resulting topology ensures that plastic which penetrates later can be anchored in undercuts by a positive fit. In addition to the option of a local laser pre-treatment, another advantage is that chemical cleaning by solvents or pickling baths is unneeded.

Quick heat by laser or induction

The intrinsic joining procedure is very simple: the pre-structured metallic joining partner is pressed with the thermoplastic. At the same time, the metal is heated in the joining zone, so that the thermoplastic's melting temperature is achieved at the interface. The higher the temperature gradient in the metal, the lower the losses due to thermal conduction during the process. A special challenge is the homogeneous heating of the metallic joining partner. The use of two-dimensional laser beam oscillation makes it possible to shape the beam dynamically and easy to control. If it is not possible to directly heat the metal

Principle of laser induced direct joining



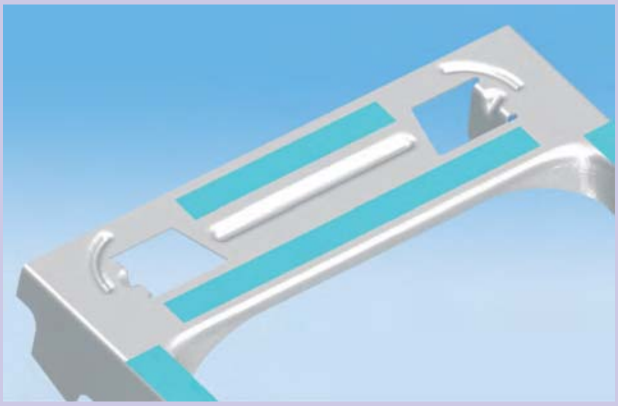
by the laser beam, an applied magnetic field generates eddy currents in the metal, whose losses result in a quicker temperature change. Here, it is a particularly demanding task to dimension the inductor to suit the joining contour.

Simulation tool optimizes heating process

To transfer the basic technological principle to real part designs in a time-efficient manner, the team developed a heating simulation, as well as process and path planning tools. They optimized the heating process of the metallic joining partner using the simulation tool "COMSOL". This tool enables them to design the inductors in a way adapted to contour. The laser structuring process also offers advantages when using a "CAD/CAM" system. The researchers can select material-specific parameter records from a database and apply them to the surfaces being structured. Then the CAD/CAM programming tool generates the NC programs – both for the remote optics and the machine axis system. Together with industrial and research partners, the Fraunhofer IWS Dresden evaluated the technique developed by applying a complex technology demonstrator. In this process, the scientists replaced a pure welding assembly made of mild steel with a multi-material design made of an organosheet and metallic cover plate to demonstrate the lightweight potential. In addition to thermal direct joining, the researchers also created direct joints using the web-slot design between metal and organosheet. In basic experiments, the transfer strength values were specified under different load states as input data for part dimensioning and design, and the material characteristics were summarized on a material data card. After part design and definition of the joint design, planning of the laser structuring paths was completed. The researchers also used simulation software tools for modeling to optimize the heating process. They generated many test demonstrators that successfully passed the mechanical tests. This thermal direct joining process is characterized by short process times, robust process guidance, and ease of automation. The laser surface pre-treatment is also highly suitable for environmental protection, since it works without etching baths or leaching agents. Above all, the process is suitable for applications in which complex fiber composite parts are joined with metallic constructions.

1 Formed organosheet shell (right), support structure for passenger car center arm rest and cover plate.

Path planning for local laser structuring



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MUVAX FOR HIGHER EFFICIENCY IN AIRPLANE PART MANUFACTURING

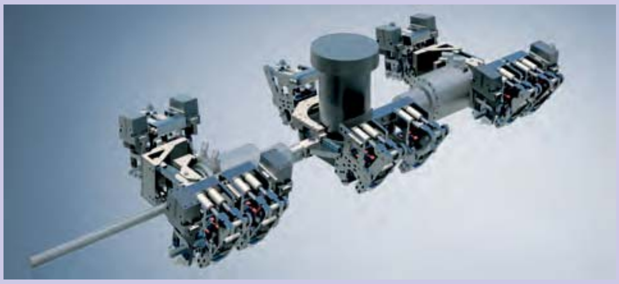
Thanks to its advantages in comparison with riveting technology, friction stir welding is regarded as an alternative technique for the assembly of airplane fuselage shells. The challenge is to develop hardware systems and processes allowing huge part sizes and the welding process forces. The Fraunhofer IWS Dresden has developed the system "Multi Use Vacuum Assisted Exoskeleton" (MUVAX) for this purpose.

Metallic fuselage shells have been so far joined by means of the proven riveting technology, which requires many expensive process steps and results in long manufacturing times. It also demands a lap joint that results in higher material consumption in the joining zone. The current high request for new passenger planes requires more efficient production methods. Friction stir welding has the potential to substantially increase manufacturing efficiency and reduce airplane structure weight at the same time.

Welding in combination with milling

This technique does not require a lap joint, and fewer process steps are necessary. However, we need customized equipment for reliable welding of the up to 12 meters long large parts. To meet these requirements, the researchers at the Fraunhofer IWS have developed the MUVAX system: MUVAX consists of a combined welding and milling robot, and a vacuum-based clamping system. Based on an initial laboratory demonstrator, the new MUVAX system makes it possible to friction stir weld demonstrator parts on the scale of real airplane structural parts. The manufacturing concept provides secure part fixing and milling of edges in the weld line area to the nominal size defined for the welding process. In this setup, the part is subsequently friction stir welded. A single welding and milling robot executes all process steps. The development of the MUVAX system represents an important step towards the introduction of friction stir welding into aircraft construction.

Unique welding and milling robot



1 The MUVAX system enables friction stir welding of demonstrator parts.

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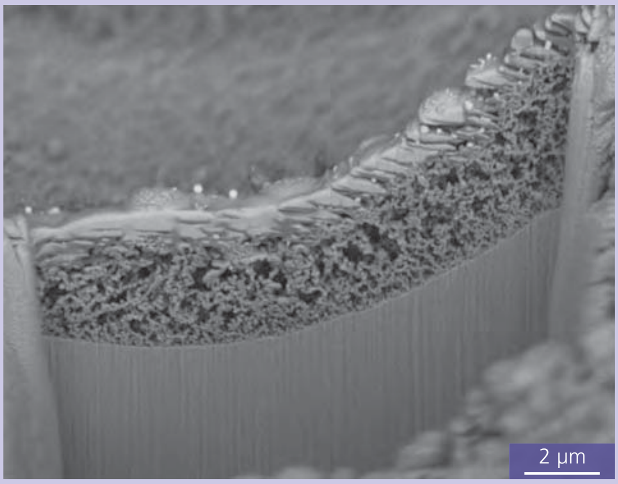
LASER STRUCTURES FOR A CLEAN ENVIRONMENT

The Fraunhofer IWS has developed a laser structuring technique for adhesive bonding of metal surfaces with fiber-reinforced plastics, which is able to replace the chemical pre-treatment bath. The laser beam cleans and structures aluminum sheets and generates a thicker artificial oxide layer. The test results show good adhesive strength and corrosion resistance.

Composite laminates made of metal and fiber-reinforced plastics are lightweight materials with great future potential. In comparison with pure metals, these materials do not only save weight, but also enhance burn-through and impact characteristics, and – due to the delayed crack propagation – improve fatigue parameters. The production has so far been very time-intensive and critical in terms of ecology; the aluminum sheets pass through chemical baths for cleaning and pre-treatment. The Fraunhofer IWS approach aims at economical manufacturing and intends to pre-treat the surfaces to be adhesively bondable by means of a laser beam. For material ablation, pulsed laser systems have been used up to now. However, in this process, the challenge was to structure surfaces of several square meters.

Focused Ion Beam (FIB) – section of the aluminum oxide layer



For this purpose, the IWS team employed a powerful continuous wave solid state laser and remote technology. Focusing the laser beams precisely and providing quick spot movements at the same time enables reproducible material removal. To achieve high productivity, the laser spot moves line-wise at maximally 300 meter per second over the surface. Thus, the Fraunhofer IWS engineers achieved current surface rates of one square meter per minute. The approximately 10 micrometer structure depth achieved on the aluminum surfaces provides optimal adhesion to the adhesive film. The research team verified that the native porous oxide layer was removed and a homogeneous boundary layer with clearly enhanced corrosion protection properties was formed. Consequently, the team could work without chemical sheet pre-treatment.

2 *Principle of high-speed beam deflection by means of scanner technology.*

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SOLUTIONS ENGINEERED FOR THE POWERTRAIN

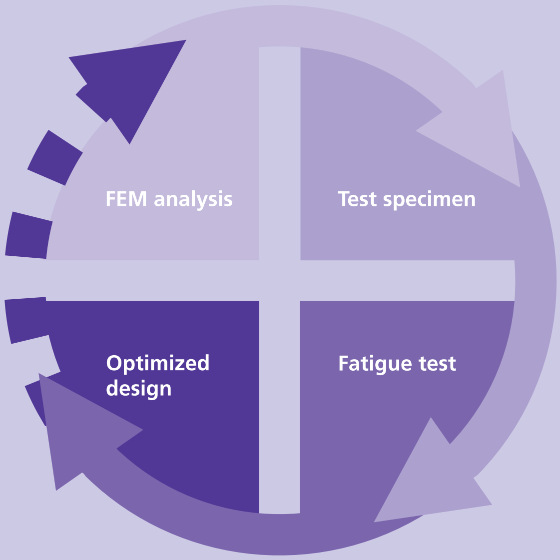
Component design respecting load situation and manufacturing aspects for component load and manufacturing is an absolute must for the development of advanced driving systems. Engineers at the Fraunhofer IWS have developed a method for component dimensioning and design for laser welded powertrain components based on experiments.

The key terms of downsizing and stability under load characterize the current development of vehicle drive components, such as transmission shafts or differential gears. Laser welding has been established as an economical and low-damage manufacturing technique to join such parts. Frequently, however, engineers cannot achieve optimal utilization of the weld seam, because no characteristic values for fatigue weld strength under loads typical for transmissions are available. As a rule, practical verification of the component's load capacity demands time-intensive tests of the transmission or even the vehicle as a whole.

Model-supported component design to determine weld strength under near-real conditions

The Fraunhofer IWS has developed a method enabling early and efficient load-oriented design of laser welded powertrain components. Right from the design stage, local stresses, as well as the weld strength, can be analyzed for simplified specimens under near-real conditions. A FEM-simulation of the real part under service load delivers critical weld seam stresses, which will be transferred into the test specimen design. Experimental cyclic tests with combined torsion-axial load enable the determination of the actual fatigue weld strength under transmission-load cases. In this way, an optimized weld design tailored to specific loads can be obtained, including cost-effective proof of the component's load capacity.

FE-based component design for laser welded powertrain components



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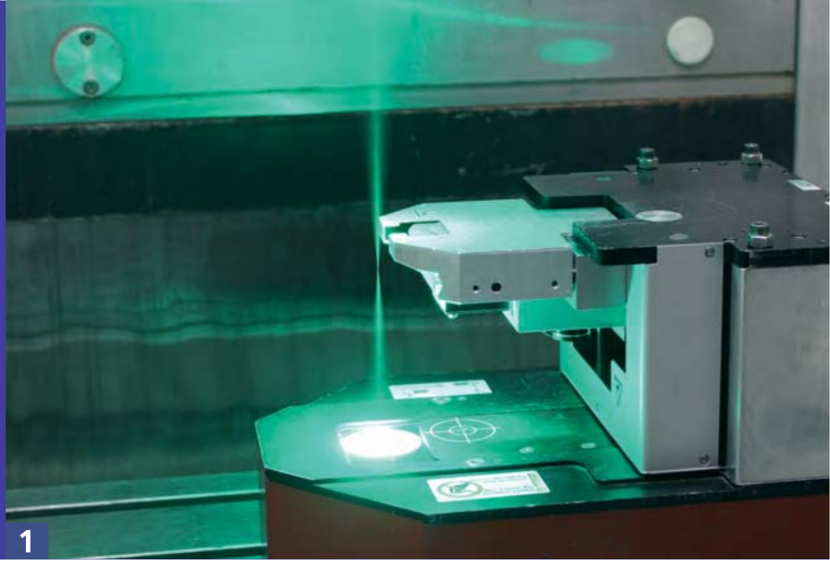
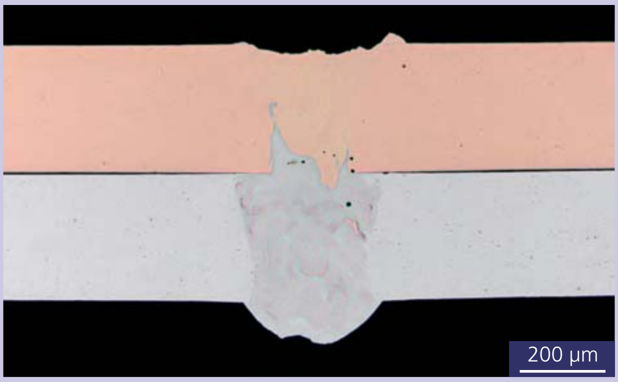


WELDING OF HIGHLY REFLECTIVE METALS

Metals with outstanding electric conductivity are very useful for applications in electric mobility and power electronics. However, they strongly reflect laser beam radiation in the infrared wavelength range, which is a great challenge to be tackled in laser materials processing. Beam sources with only 515 nanometers wavelength open up new fields of laser welding application.

The development of innovative electric mobility concepts is rapidly moving forward. Advanced joining technologies, such as for battery cells bonding or in power electronics, have to guarantee that the applications addressed can cope with the requirements in terms of process stability, electric conductivity, and long-term durability. Laser-based solutions are particularly suitable for these attributes. The researchers at the Fraunhofer IWS have developed a method for laser processing of outstandingly electrically conductive metals, such as copper. They employed in these processes advanced lasers of 515 nanometers wavelength to provide reliable, high-quality welding processes. The beam quality is 2.5 millimeter multiplied with millimeter-mrad. It is possible to efficiently produce specific overlap welds joining copper or hybrid materials with aluminum sheet for sheets about 1 millimeter thick with one kilowatt laser power.

Weld made of copper and aluminum; homogeneous weld seam form.



Controlled thermal conduction welding enabled

The researchers have engineered powerful welding processes for diverters, bus bars, and contacts like those needed, for example, in batteries for future products made by well-known customers. They could also count on 2D beam oscillation options to optimize, among other parameters, the mechanical properties of the welds, such as by using wider seams. The researchers could additionally use this option to intentionally influence the energy input into the component. In contrast to the infrared laser beam of 1070 nanometers wavelength, the beam source with 515 nanometers wavelength provides controlled thermal conduction welding. Thin walled bonding occurs without noteworthy material damage next to the weld.

1 Beam measurement of the 515-nanometer laser source – characteristic beam formation.

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LASER ABLATION AND CUTTING

Business Unit Manager **Dr. Andreas Wetzig**

THE BUSINESS UNIT

Highly specialized and innovative – the business unit Laser Ablation and Cutting plays its part whenever needs arise for which the market does not offer commercial solutions. The IWS researchers study and develop techniques and hardware systems for laser applications. Process design and analysis complete the portfolio of services and guarantee efficient use of these solutions. The Fraunhofer IWS business unit provides a wide variety of commercially available laser sources of different wavelengths, laser power, and beam quality. The researchers focus both on metallic and non-metallic materials. Moreover, they have comprehensive expertise in laser processing of soft magnetic materials. In procedural research, the focus is on cutting speed, edge quality, contouring accuracy, and optimization of cycle time. The team employs methods, such as laser beam melting, flame cutting, and remote laser beam cutting, as well as drilling, ablation, and high-speed processing with high laser power.

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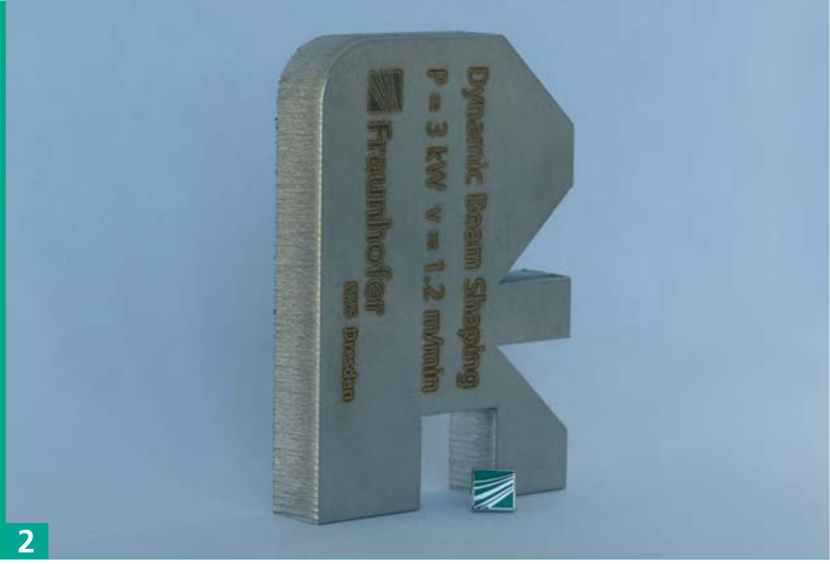
TRIGGERING SCANNERS FOR HIGHLY DYNAMIC BEAM SHAPING IN REAL TIME MODE

Highly dynamic beam shaping is advantageous in the process of laser beam cutting. Having created a new control paradigm, Fraunhofer IWS Dresden makes it possible to transfer these strengths to complex contours.

Laser processing of materials is becoming more complex, with ever-greater requirements in terms of quality and productivity. As a result, the team at the Fraunhofer IWS brings together all the components involved in the manufacturing process. The developments within the context of digitization described in "Industry 4.0" are regarded as drivers. The galvanometer scanner, employed for highly dynamic beam shaping, is particularly important. The basic idea in laser beam cutting is to benefit from the advantages of high-brilliance laser beam sources even as sheet thickness increases. Spatial time-controlled redistribution of the efficient laser energy provides optimal absorption conditions. For the local distribution of the beam intensity, the researchers at the Fraunhofer IWS combine galvanometer scanners with a cutting head. In comprehensive laser cutting experiments, they have demonstrated with a straight separating cut that it is possible to increase the cutting quality and the process speed for sheet metals from six millimeters upward.

Oscillating laser beam – even for complex contours

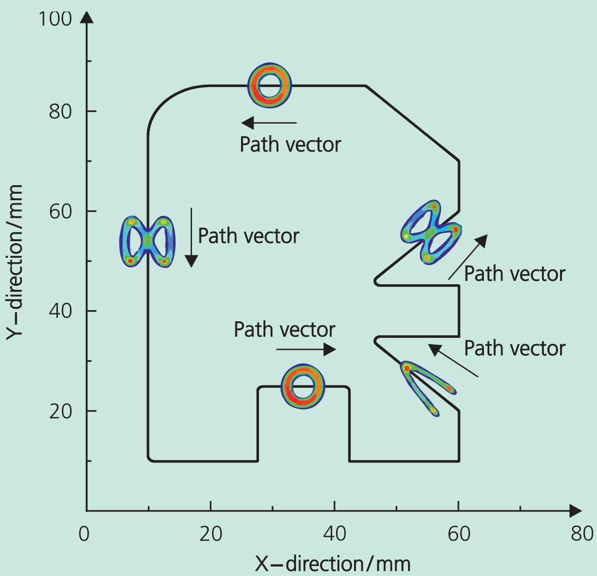
The latest step in refining highly dynamic beam shaping aims at using it in contour cutting. The researchers place special emphasis on versatile and flexible coupling to the machine control. For this reason, they have chosen a control that provides the movement of a galvanometer scanner via a programmable controller and a field bus system in real time. The precondition for this approach is the ESL2-100 module developed at the Fraunhofer IWS, which functions as a gateway between the industrial field bus system EtherCAT and the scanner protocol (SL2-100 or XY2-100). The module can be easily integrated into an available control system and is able to trigger an X-Y scanning system. To allow the transfer of the highly dynamic beam oscillation to a complex part geometry, it is necessary to track the motion pattern of the laser beam along with the machine movement. The tracking must be calculated cyclically at intervals of 100 microseconds based on the currently valid position data. In the same cycle, the ESL2-100 module makes it possible to modify the oscillation parameters such as amplitude, frequency, and phase. The user decides whether the machine operator is authorized to make this decision or whether process sensor signals should be used. When process sensors are used, they can be easily and flexibly integrated via the available field bus system. The sensors also make it possible to affect the trajectory of the galvanometer scanner. The user can freely implement the type of linking, the number of sensors, and their combination as a function of the manipulated variables of the manufacturing process. For highly dynamic beam shaping, this means that, in addition to tracking, the user can modify even the oscillation pattern itself – as a function of the rate of path speed. The user can freely select the type of oscillation and the threshold for switching over. The process know-how acquired in comprehensive experiments and mapped by means of the new control concept based on the ESL2-100 module forms the basis.



Highly dynamic beam shaping during contour cutting

To achieve efficient contour cutting, the researchers at the Fraunhofer IWS extend conventional cutting heads with highly dynamic beam oscillation using the galvanometer scanner. The ESL2-100 module, developed in-house, provides the galvanometer triggering from a programmable control's environment and the integration into the machine control via field bus system. The engineers modify the oscillation pattern depending on the contour in real time, based on position data. When analyzing the process sensor results, it might be necessary to further modify the laser beam trajectory, and these modifications can be implemented. The engineers successfully demonstrated the interaction of the galvanometer scanner with the ESL2-100 module and the machine control in fusion cutting of 12 millimeter thick stainless steel. They combined a scan system with a conventional head for cutting complex contours. The ESL-200 module controls the galvanometer scanner. The industrial field bus system is the interface to the machine control, so that one can calculate the correction of the oscillation pattern according to the current positions. The team machines the contour in a fusion cut, exemplarily for stainless and mild steel, at twelve millimeters thick in each case. The researchers used specific oscillation patterns, linked with the machine control through the ESL2-100 module, for both materials. In this way, a three-kilowatt fiber laser achieved cutting speeds of 1.2 meters per minute. A change in the process parameters was able to impact the cutting quality. The results demonstrate that the new control strategy is able to successfully transfer the very promising results obtained for the separation cut to contour cutting.

Schematic sketch of laser beam cutting with highly dynamic beam shaping.



The oscillation pattern is tracked as a function of the contour according to the current positioning data from the master machine; it can then be, for example, reversed, depending on the process. The user can implement the link to the process at will.

1 *The Fraunhofer IWS team developed the ESL2-100 module to the trigger the galvanometer scanner. It makes it possible to cut complex geometries.*

2 *Highly dynamic beam shaping offers advantages in gas-assisted laser fusion cutting. Users can employ the ESL2-100 module to transfer the technology of highly dynamic beam shaping into contour cutting (example: 12 millimeter-thick stainless steel).*

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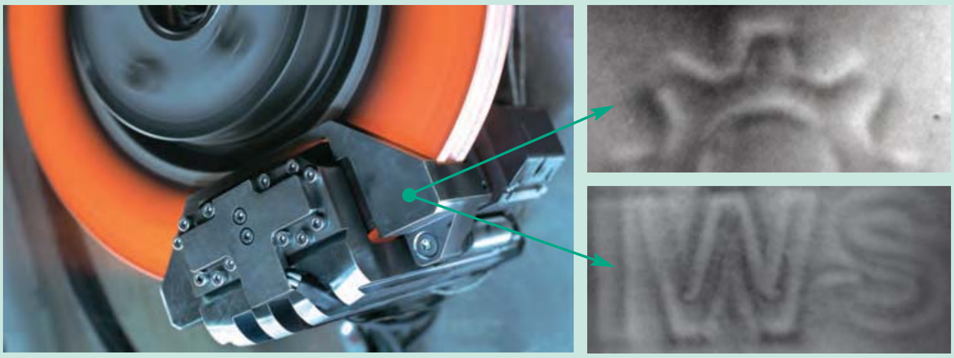
INNOVATIONS FOR PRODUCT PROTECTION

This new progressive Fraunhofer IWS innovation is a forward-looking technology for safe and unambiguous identification, as well as "track and trace" functionalities of components. This method is based on invisible properties that can be detected with a specially developed measurement setup and mapped.

Braking device with invisible features for unambiguous identification.



The development of innovative products offers medium-sized companies a way to open up new markets. Traceability, design, and unambiguous identification are important aspects of this process. Currently hologram stickers and QR codes serve these functions. However, they sometimes negatively impact product esthetics. Additionally, they do not guarantee total security or authenticity across the entire product life cycle because they can be easily altered. For this reason, there is a great demand for an invisible, but easy-to-read marking technology that cannot be tampered with. A recent Fraunhofer IWS development provides just these opportunities. The technology is a new cornerstone in product tracking and the fight against gray-market trade and product piracy.

More product safety and unambiguous product identification

For this purpose, Fraunhofer IWS Dresden developed and tested a method to generate and detect innovative safety features. A laser applies the feature, which is invisible from the outside, to the products to be marked. Depending on the user's requirements, the coding technology allows for simple or more detailed structures to be put on the products, and these structures protect the products against tampering and destruction. Upon identification of the safety feature, the measurement apparatus quickly and reliably reads out the feature. The user or manufacturer can determine the product's authenticity with absolute certainty based on the image that emerges. In this way, the measurement method combines reliable validity inspection with part identification of the product.

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NEW WAYS OF SEALING EDGES ON CFRP MATERIALS

The use of multi-material design is an important pillar of advanced lightweight design. When the right materials are used in the right place, their property profiles can be used in an optimal manner. Safe application of the possible material combinations, however, is limited by the joining methods available, and thus demands the refinement of previous joining techniques.

Corrosion is one limiting factor when applying multi-material design that is relevant for lightweight construction. Above all, carbon fibers are characterized, in comparison with metals, by a great electrochemical difference in potential. Cutting of fiber-reinforced plastics for shaping and trimming uncovers the fiber ends from the surrounding matrix material at the cutting edges – for any technique. In bolt and rivet joints with parts made of carbon fiber-reinforced plastics (CFRP), the different material components have direct contact. Using these joints in areas with electrolytic ambient media causes an electrochemical corrosive reaction. To avoid this circumstance, engineers in the aircraft industry employ expensive titanium fasteners.

Sealing of edges and insulation of corrosive partners

Fraunhofer IWS has developed an innovative method for sealing edges that addresses this issue and which, in particular, reworks CFRP edges cut by remote laser beam. The technology can also be applied to other cutting methods. Its purpose is to seal bore edges by using an epoxy layer and thus to prevent the destructive corrosive reaction. The resin injection method introduced here is similar to Resin Transfer Molding Technology (RTM). The research team injects an epoxy resin of low viscosity through an applied vacuum into a prototype mold and distributes it in a cavity around the bore edge. With this prototype, the Fraunhofer IWS has shown that it is possible to implement reprocessing of bore edges assisted by a mold in a process. The team at the IWS has provided the fundamentals for a process to be automated and have proven that the sealing layer functions as cathodic corrosion protection. The corrosion reaction was clearly decelerated or prevented altogether when aluminum pins and zinc-coated steel pins were subjected to a salt spray test over four weeks. In further research aimed at the transfer of the technology into series production, the researchers have mainly to reduce the cycle times and improve manageability. Having solved these problems, with the sealing method, the scientists will be able to offer another process expanding the portfolio of usable material combinations and offering the potential for lightweight design at lower cost.

1 Prototype mold (tool) for sealing of CFRP edges.

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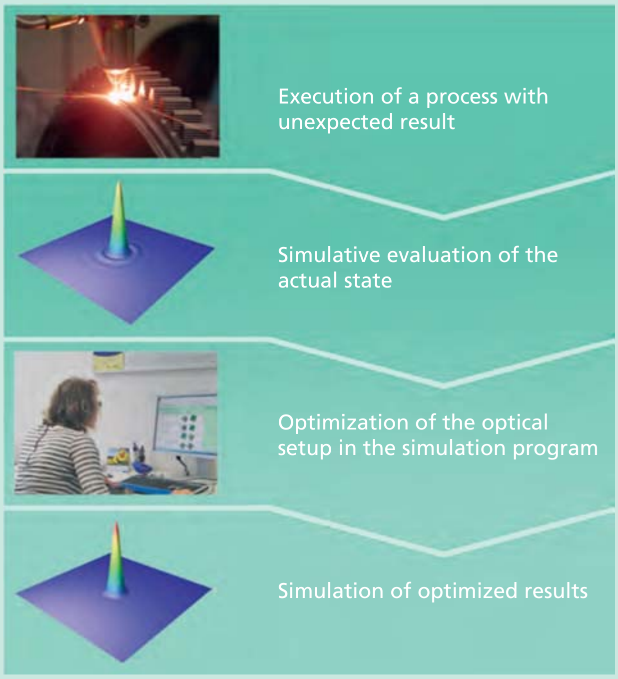
TROUBLESHOOTING: OPTIMIZATION OF OPTICAL SYSTEMS

Unexpected effects and a lack of reproducibility in manufacturing results may arise from faults in the optical setup. Simulation tools are frequently able to show these deficits clearly. Analysis and optimization, in turn, eliminate them efficiently. Thus, tedious trouble tracking in the setup can be avoided.

Laser-assisted plasma arc welding is a hybrid joining technology with application potential to thin metal sheets. Fraunhofer IWS scientists use a plasma torch developed in-house for this technique. The engineers observed process instabilities after a regular exchange of the protective window and the hollow cathode in use. Subsequent beam diagnostics show pronounced beam aberrations and a by 10 millimeter shifted focal plane. This resulted in a 20 percent larger diameter on the component, which was the basis for the instabilities observed. To assess these deviations, the scientists analyzed the optical system with two identified bottlenecks in the plasma-laser setup in a simulation run. The simulation results obtained for the real state suggested that the beam was constricted at one position. Using the simulation, the researchers were able to exclude the protective window as the cause of the beam aberrations and identified the inlet bore of the new hollow cathode as the defect cause instead. Following calculations, an extension of this bore by 0.2 millimeters was sufficient to guarantee unhindered beam propagation through the hollow cathode. Repeated measurement of the beam verified these results. Consequently, the simulation can be used as an efficient tool to identify and eliminate errors in the optical system. The calculations proved to be less time-consuming than experimental trouble tracking according to the trial-and-error principle.

Process chain for optimization of optical systems



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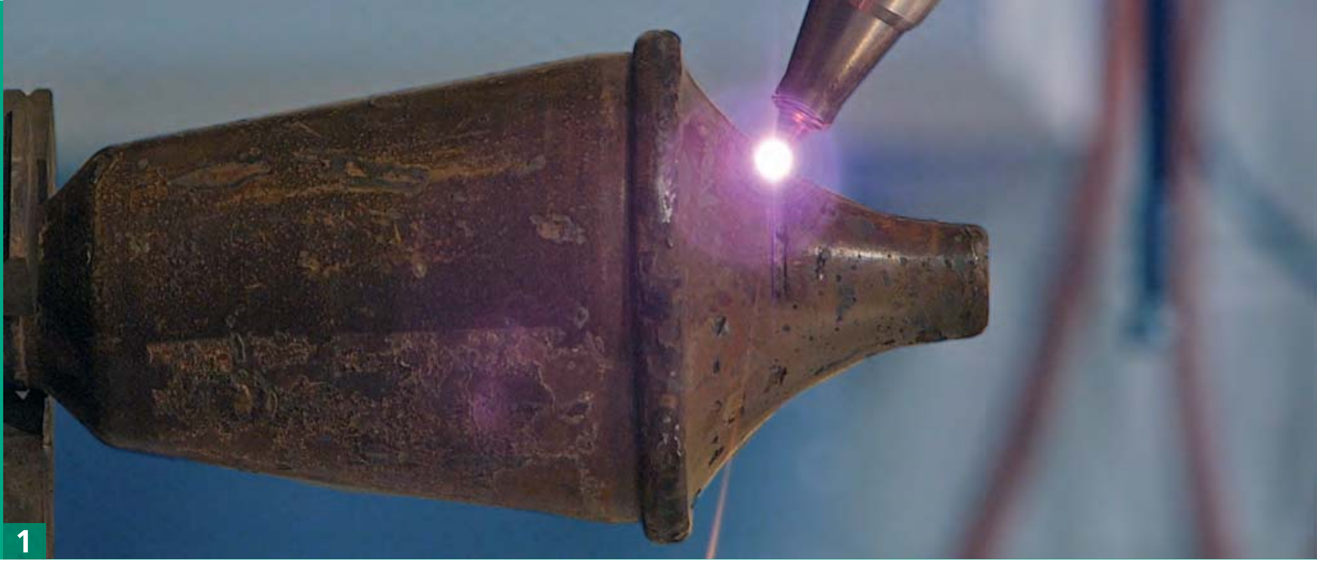

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LASER TECHNOLOGY FOR SAFE WEAPONS REMOVAL

In times of increasing political conflicts, Fraunhofer IWS points the way to the future of easing tensions. Scientists at the Dresden Institute have developed several techniques for safe disposal of ammunition. Automation and flexible strategies reduce the dismounting and setup time for ever-changing requirements. The development efforts focus on the operator's protection and the environment.

All over Germany safety personnel deactivates and salvages 5,500 unexploded bombs per year. It is estimated that there are still more than 100,000 explosive bodies undiscovered in Germany. After removal of the fuse, commercial disposal companies start their work by separating the metal from the explosive and disposing it separately. 70 years of environmental impacts and deformations caused by being thrown make the deactivation of a single one of these objects a uniquely dangerous challenge to be met by manual work. Based on 25 years of experience in the development of special solutions for laser beam cutting and welding, the Fraunhofer IWS has engineered concepts for the automated safe opening and isolation of such weapons. Industrial robots that can be used flexibly and are equipped with advanced sensors make it possible to specifically plan how to cut a path to open up the individual metal casing and then to cut it by means of the laser beam. An extension using rotary and tilting tables encompasses virtually every type of design, including even hollow chamber bullets.

Contactless inactivation at a safe distance

To liquefy the explosive only at the boundary surface, induction equipment proven in industry is used. The sliding layer formed provides the means to separate the explosive – as solid matter – from the casing. The inductors applied can be used for multiple purposes and to compensate for existing variations in diameter and deformations through modified path planning. With the temperature control LompocPro developed for laser hardening, the researchers at the Fraunhofer IWS have available proven hardware enabling exact control according to the melting temperature of each explosive at the boundary surface. The engineers can make mobile use of and remotely control the equipment. They can thus execute all processes at a safe distance in the bomb shelter. It is also possible to process ammunition in protective atmospheres for air-reactive weaponry. As a contactless tool, the laser is not subject to any kind of wear and does not generate any toxic waste products, as contaminated cooling water would do. The task is not only to salvage other ammunition found, but also to empty the bulging warehouses of the disposal companies and to dispose safely of incoming old ammunition from the army today and in the future. The technology has the potential for worldwide application.

1 Several laser-assisted methods developed at the Fraunhofer IWS provide safe deactivation and disposal of explosives at a safe distance.

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MICROTECHNOLOGY

Business Unit Manager **Dr. Udo Klotzbach**

THE BUSINESS UNIT

The Microtechnology business unit specializes in laser technology under microscope. IWS scientists research and develop surfaces with functionalities mimicing lotus leaves or shark skin. Progressive miniaturization in electronics, semi-conductor fabrication, and the medical and biotechnological industries demand ever smaller and more precise structures for a wide variety of substrates. Fraunhofer IWS makes this possible – as the scientists work with laser micro processing using comprehensive modern equipment and profound technical knowledge. IWS services offer aim at product-oriented users who need in-depth system knowledge of the material and laser parameters to answer very specific questions. The researchers of the business unit developed, for instance, the technique of laser interference patterning and readied it for industrial use for the first time. The Microtechnology business unit plays a pioneering role in the field of "Embedded Systems": collecting, analyzing, and optimizing visual data in terms of the process speed – this is what future users will benefit from.

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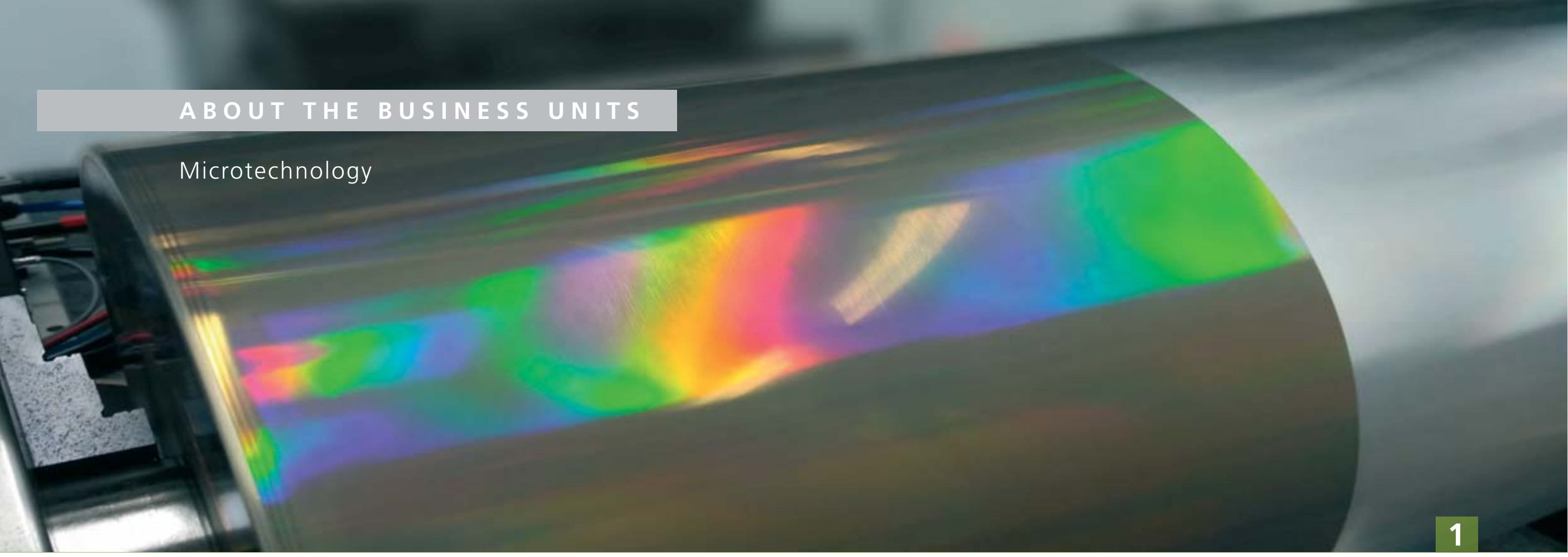

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LASER STRUCTURING OF SEAMLESS EMBOSSING ROLLS

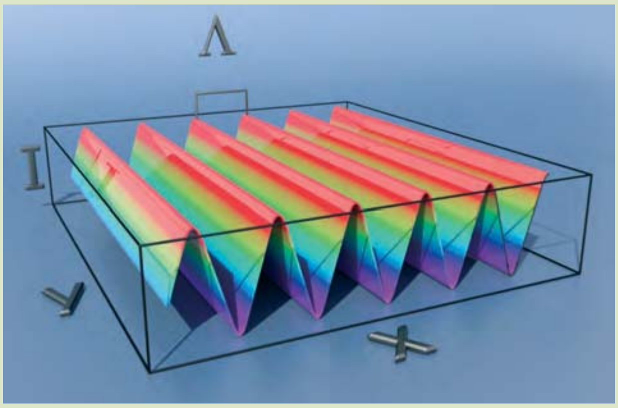
Direct laser interference patterning (DLIP) generates defined nano- and microstructures on embossing rolls. These DLIP structures can be used for customized surface functionalities by means of the roll-to-roll technique. The technique is becoming more and more important for industrial applications mostly due to rapid technical progress in the development of laser sources.

Functionalization of technical surfaces is even now regarded as an innovation tool of the 21st century. It is no longer just the applied material or its chemical surface characteristics that influence the performance and capacity of many technical products. Artificially induced, defined microstructures give the previously simple boundary surfaces additional new functional elements. As a result, the precise and efficient creation of artificial surface topographies is becoming more and more a focus in industrial applications. Even today, surface structures adapted largely from nature offer significant innovation potential in ranges of application, such as tribology for automotive applications, biocompatibility of implants, and modified wettability for self-cleaning surfaces, as well as in product and trademark protection. The manufacturing methods required range from laser direct writing and electron beam lithography via micro-milling, eroding and sand-blasting, up to plasma etching processes. Making use of these techniques, it is possible to fabricate stochastic or periodic surface structures on a nano- or micrometer scale. The fabrication of these structures for a variety of uses is nowadays one of the greatest technical challenges in the discovery of new, customized surface functionalities. Consequently, there is a growing motivation to open up new technologies or technological directions and to make them available for industrial applications.

Highly profitable process in the roll-to-roll technique

The researchers succeeded for the first time in transferring interference patterning developed at the Fraunhofer IWS into an economical replication process in the roll-to-roll technique to functionalize polymer films. The deciding factor in this success was close cooperation with the Chair of Large Area Laser Based Surface Structuring at the TU Dresden. The key innovation is the high-speed patterning of the master sleeves by means of Direct Laser Interference Patterning (DLIP). In the DLIP process,

DLIP intensity distribution for two-beam-set-up



The overlapping of coherent laser beams modulates the laser intensity distribution periodically and thus enables the targeted generation of surface structures.

a coherent, pulsed laser beam with pulse lengths on the pico- to the nanosecond scale is split into two or more partial beams and overlaid again on the material surface in a controlled manner. The researchers intentionally used the interference pattern formed in the laser profile as a kind of laser stamping in a process step to fabricate functional surface topographies on metals, polymers, ceramics and coatings. The DLIP technique is highly suitable for industrial use, because it does not need special conditions like a vacuum or clean room.

Highly economical functionalization of polymer films for technical use

The DLIP technique demonstrates its disruptive properties to create defined micro- and nanostructures with the help of already achievable sleeve tooling speed values. The researchers were able to functionalize master-sleeves of 600 millimeters wide rolls and 300 millimeters roll diameter in less than 60 minutes by means of structures in the micro- and sub-micrometer range. This corresponds to an effective patterning speed of 57 square millimeters per minute. Comparable technologies required many times over. The DLIP technique itself benefits both from progress in commercially available high-power laser sources and the refinement of innovative beam guidance concepts, so that the achievable tooling speeds can be further increased in the future. With the DLIP method, it is also possible to implement weldless roll bodies – a clear advantage over competing patterning technologies. The roll bodies patterned by means of DLIP are suitable for roll-to-roll techniques, such as hot or UV embossing. Both embossing methods mentioned have already been used in many industrial ranges of application. Thanks to the DLIP processing, they benefit from significantly reduced tooling costs with cost savings up to 90 percent.

The roll-to-roll-DLIP approach enables effective speeds for patterning of polymer films of 15 square meters per minute with 300 millimeters wide rolls. Potentially, it will be possible to industrially scale the fabrication speeds for functionalized polymer substrates more than 300 millimeters wide by means of the DLIP procedure used to pattern the embossing roll barrels. Thus, the technique’s flexibility to generate individual, functional surface structures significantly contributes to the development of new, competitive products. All ranges of application can prospectively benefit from individualized mass fabrication: organic electronics, light management, product protection, packaging solutions and decorative applications.

1 Full-area patterned roll sleeve, seamless.

2 Roll patterning system with DLIP modules of the Fraunhofer IWS.

TECHNISCHE UNIVERSITÄT DRESDEN

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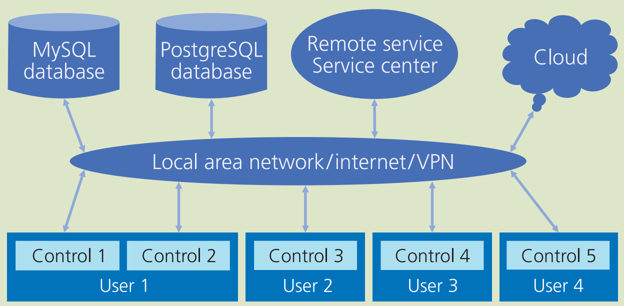
UNIVERSAL CROSS-LINKABLE CONTROL

Advanced devices and systems are needed to assist users in their work, which is becoming more and more complex. This assumes a new control generation that makes available functionalities such as self-optimization, self-diagnosis, machine learning, and communication. Fraunhofer IWS has successfully developed a universally linkable control for the quick implementation of customized solutions.

Modern industrial processes demand more and more complex controls to assist the users in their evermore demanding work. In parallel to established control and closed-loop control tasks, the researchers had to integrate additional functions, such as machine learning, communication, self-optimization, and self-diagnosis. The phrase on everyone's lips is "Industry 4.0".

Schematic set-up of the complete system



For this higher level of complexity, Fraunhofer IWS researchers developed a universal, cross-linkable control. As in mobile phones and tablets, a compact single-board computer (build as a system-on-a-chip) functions as the central processing unit. These systems-on-a-chip are inexpensive and combine very different resources, from multi-core-processors via interfaces to programmable logics. They are also able to implement different requirements on one platform. The new control offers the following functionalities:

– Capturing, preprocessing, analysis and recording of process data
– Measurement, control and closed-loop control via user-specific input and output interfaces (real-time capability thanks to programmable logics)
– Data exchange with PostgreSQL and MySQL databases
– Interaction with cloud systems
– Web-based administration

The control is already in use

The universal, cross-linkable control has already been successfully employed in basic medical research, substance testing, and personalized medicine, to run complex lab-on-a-chip systems. In parallel to control and closed-loop control, the control takes on the job of preprocessing, analysis, and recording of process data, as well as communication with database systems. Prospectively, it is planned to use the control also in laser micro materials processing and additive manufacturing.

1 *Photo of a universal, cross-linkable control.*

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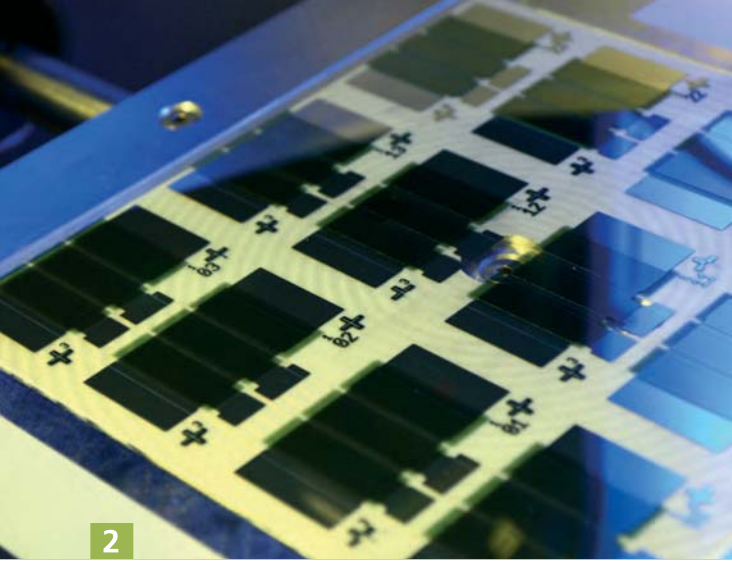
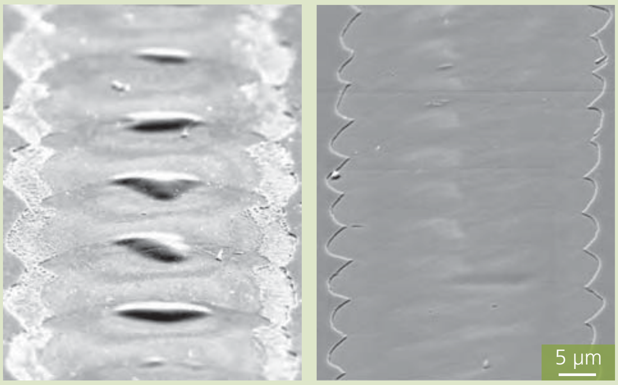


FUNCTIONALIZE ORGANIC THIN FILM ELECTRONICS WITH SHORT-PULSED LASERS

The market success of advanced electronic items, such as monitors and mobile phones, is based on technical properties, such as color brilliance and luminance, as well as additional convenience functionalities like touch operation or even flexibility. These products are only conceivable due to the use of stacked, ultra-thin transparent layers made of different high-performance materials.

The development of electronic items is never-ending. As the technology becomes more sophisticated, the opportunities multiply. One example is organic photovoltaic (OPV): these are solar modules whose organic functional layers are deposited on films. It is possible to generate energy on free-formed surfaces in a mobile mode by means of efficient, lightweight, flexible and partially translucent modules. First, the properties have to be customized. The Fraunhofer IWS, as both the partner and coordinator of the European funded joint project "Alabo", has developed a solution that isolates and interconnects layers with no damage and invisibly in the later product – compareable to batteries configured in series. In this organic photovoltaic variant, three of five 60 to 250 nanometer thick layers have to be scribed separately, without affecting the subjacent functional layers.

Non-homogeneous scribe with barrier damage (l.) and scribe free of damage (r.)



Low-damage functionalization

The application of picosecond lasers, whose individual pulses ablate microscale material volumes, is without alternative. Researchers processed the partially translucent organic and highly reflective metallic coatings extremely gently and thus achieved strong photoelectric module performance. The work results show that it is possible to functionalize stacked surface electronics with integrated barrier layers against environmental impacts almost without damage. Cost saving effects of approximately a third of the total production costs can be achieved by this new approach. In cooperation with the developments of the partners, Fraunhofer IWS created a technologically seminal total package with a high level of digitization.

2 *Laser-patterned functional sample of organic solar cell modules.*

3 *Roll-to-roll processed organic solar cell.*

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MATERIALS CHARACTERIZATION AND TESTING

Division Manager **Prof. Dr. Martina Zimmermann**

THE DIVISION

Researchers destroy in a controlled process what others have built up: the materials and component testing researchers look into the interior of the material and get to the bottom of even the smallest detail. In this way, they evaluate the materials and component quality and offer solutions to optimize the manufacturing processes. Comprehensive materials knowledge, many years of methodical experience, and a wide range of available equipment and devices form the bases for research and development work. The service portfolio includes the metallographic characterization, the electron-microscopic materials analysis and their compounds – from the macro- down to the nano-scale. The scientists determine characteristic properties and derive strategies for part design tailored to material requirements and expected stresses. They assess suitability, select materials, and optimize the component for the development and refinement of manufacturing technologies. In addition, they develop, evaluate, or modify test methods. Failure and damage analyses complete the portfolio.

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QUICK DIAGNOSTICS OF FATIGUE BEHAVIOR

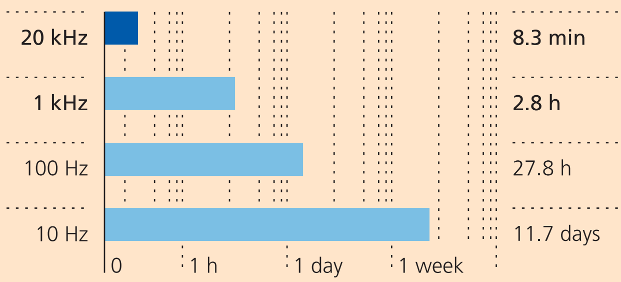
Analyzing a part's fatigue behavior is frequently costly and time-consuming. Fraunhofer IWS provides innovative test technologies as well as wide-ranging experience in determining fatigue properties quickly, such as for in-depth parameter studies on the fatigue behavior of structures made by additive manufacturing.

In the qualification of manufacturing processes, when applying lightweight design and resource-efficient material use, researchers have often to investigate both reliability and the fatigue properties of parts. This problem becomes particularly obvious in topology-optimized structures made by additive manufacturing. Very promising results obtained in quasi-static tests often face significant losses in terms of the cyclic strength values. The fatigue behavior of additively manufactured structures is generally significantly less than that of rolled or forged materials. In addition, the degree of variation in the results increases dramatically. To develop a reliable process chain and identify failure-critical irregularities despite many influencing parameters in additive manufacturing techniques, such as deposition direction and powder batch, it is absolutely necessary to test an extensive test matrix. Classic test labs (for instance, with servo-hydraulic test stands) often need several months for such a task. In the digital era, the time required conflicts with immediate quality assurance of new production chains throughout the process.

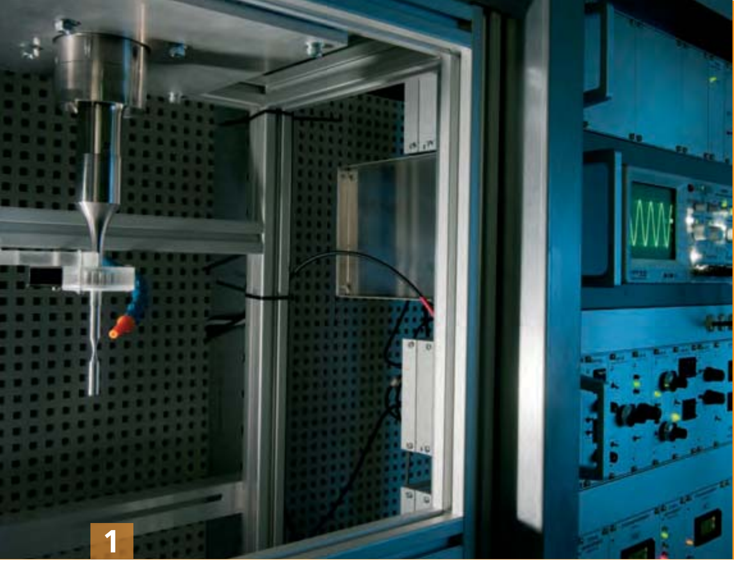
Time saving through highly efficient testing equipment

Fraunhofer IWS has a lab equipped with a wide range of high-frequency fatigue testing systems that can reduce the time needed to determine fatigue behavior data from several months to a few days. The researchers can make use of the ultrasonic fatigue testing systems enabling tests at approximately 20 kilohertz frequencies. This testing equipment enables testing the actual component life up to 10^7 load cycles and more in the lab within a few minutes. This statement is also valid in cases in which the effective test frequency is less for some materials to avoid unintentional temperature effects. It takes the researchers at the IWS only approximately two days to find the fatigue strength statistically proven for a minimum of 15 samples.

Required test period for 10^7 load cycles as a function of the test frequency



IWS researchers can also employ resonance pulsators with one kilohertz test frequency. These systems are optimal for tests of high-cycle loaded structures under near-real conditions. If this equipment is used to determine a statistically proven fatigue endurance limit curve (10^4 to 10^6 cycles), it can be found out in just a few days. Several systems are available for each testing technology. Thus, it is also possible to further reduce the test time or to test the influence of various test conditions in parallel. The Fraunhofer IWS has not only efficient testing machines, but also extensive options to characterize structures and surfaces.



The methods range from macroscopic analyses to high resolution scanning electron microscopy (SEM). Above all, the fractographic analysis of fracture surfaces by means of SEM ideally extends the experiments on fatigue behavior. Fraunhofer IWS' expertise lies in the bundling of these competencies, especially when it comes to short-term and competent statements on fatigue properties. The Dresden Institute performs extensive test series, both in process design and for parameter studies to optimize a serial process, on short notice. Thanks to years of comprehensive experience in design for materials, the IWS researchers reliably identify and optimize critical technological factors.

Typical application: Additively manufactured 17-4PH steel structures

In a feasibility study, the Material Characterization and Testing team checked the practicability of the above-described quick diagnostics for additively manufactured materials. The IWS researchers chose the age-hardenable and stainless 17-4PH steel as an example. To represent a batch comparison, they checked the states "as-built", "heat-treated" and, as reference, the "rolled state". The quasi-static experiments delivered only slight differences in the tensile strength among the three states. However, the results of cyclic testing at high frequencies illustrated the necessity of individual determination of characteristic values for the additively manufactured material. The stress amplitude of the heat-treated batch was approximately 40 percent lower than that of the rolled material. In the "as-built" state, the stress dropped down by as much as 75 percent. The results also scattered. Consequently, to qualify additive processes, it is absolutely necessary to perform experiments on the fatigue behavior as a function of the respective process strategy. In addition to the mechanical testing, the IWS researchers characterized the structure properties from the macro- down to the microlevel. The analysis of fracture surfaces identified the failure-critical imperfections. These findings served as input for modifications in the manufacturing process to optimize the fatigue behavior. The fatigue behavior of additively manufactured materials, captured in the example shown, fit in well with the so far published results. The study proves the efficiency of the high-frequency testing equipment used and simultaneously underscores the quality of the results obtained.

1 *Test setup of an ultrasonic-fatigue testing system working at about 20 kilohertz test frequency.*

2 *Test setup of a resonance pulsator, with one kilohertz test frequency.*

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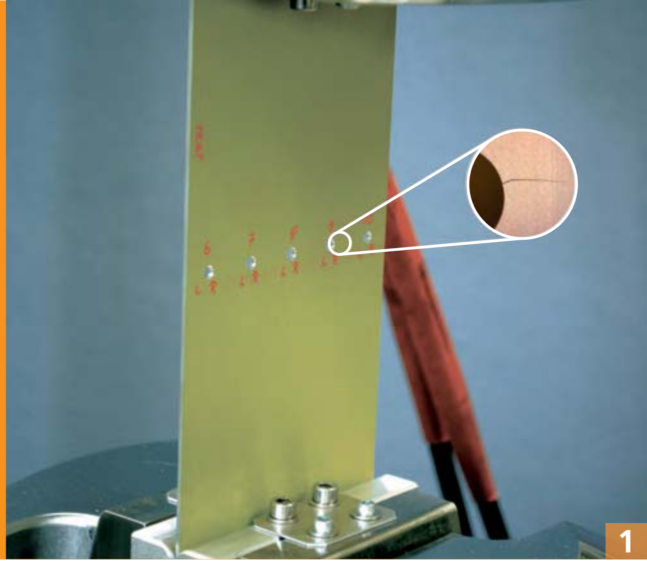


RELIABILITY OF INNOVATIVE COMPOSITE LAMINATES

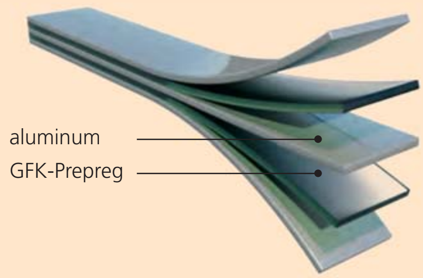
Fiber-metal laminates (FML) are hybrid lightweight structures consisting of a layered composite of metal and fiber-reinforced plastics. Glass fiber-reinforced aluminum is primarily used in aircraft fuselages; the material is currently based on an Al-Mg-Cu alloy in combination with impregnated glass fiber fabrics (prepregs). This composite is also called "GLARE" (glass reinforced aluminum).

The objective of the "AutoGlare" research project is to expand the fields of laminate application and to reduce the laminate fabrication cost at the same time. In this context, the use of innovative Al-Mg-Sc alloys (such as AA5028) can provide a solution. These alloys have similar mechanical properties with reduced density and improved corrosion resistance. To obtain a release for use in the aeronautical industry, it is necessary to certify these very promising mechanical properties of the base material in the layered composite.

Realistic test conditions

Due to the intentional range of application, the researchers at the Fraunhofer IWS characterized the laminate mainly in terms of fatigue life and damage tolerance. The use of specially developed specimen shapes (5-hole specimen) allows for complex experimental scenarios under realistic test conditions. In comparison with the known "Glare", the fiber-metal laminate (FML) with the AA5028 alloy showed increased resistance to crack initiation and propagation. The cracks grew stably from about 1 millimeter long cracks on; as a result, the researchers could reliably predict the residual life of a cracked structure. The level of the quasi-static residual strength of the FML is approximately 10 percent higher than that of the laminate currently in industrial use. The combination of the density reduced by approximately 3.5 percent with the significantly enhanced strength creates new application opportunities for the innovative laminate in the fuselage structure of aircrafts and in other branches of industry.

Layer structure of the fiber-metal laminate investigated



1 FML fatigue test to determine the fatigue properties.

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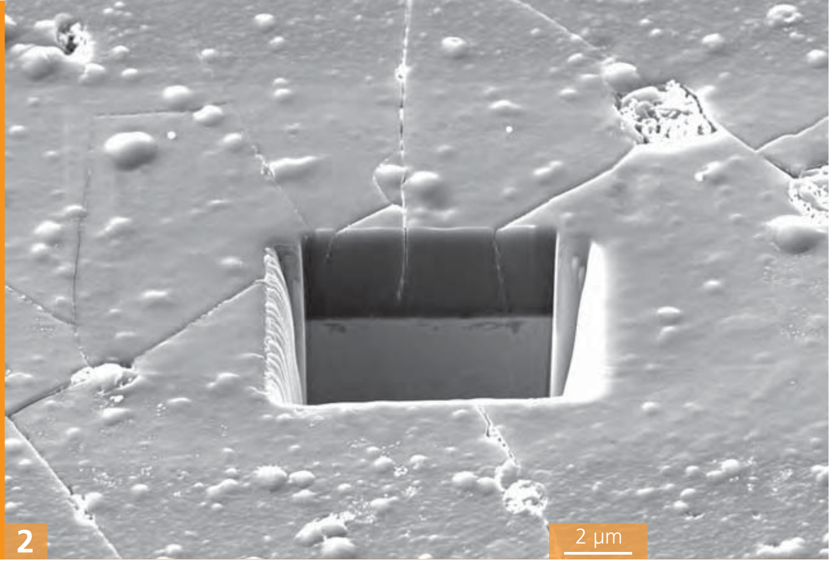
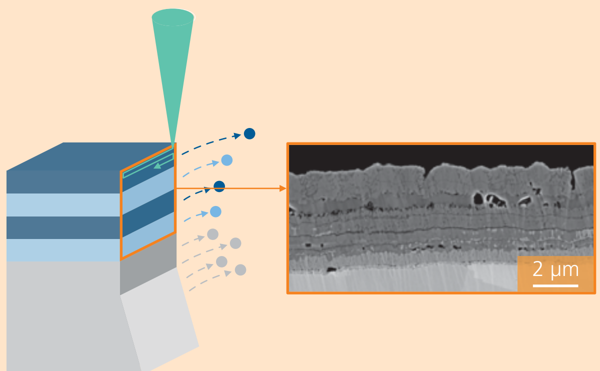


LAYER AND DAMAGE ANALYSIS BY MEANS OF FOCUSED ION BEAM TECHNOLOGY

The reliability of innovative material and layer systems directly depends on their manufacturing history and the modification of the related micro structure. The researchers can only implement customized properties, such as wear resistance or long fatigue life, if they know the effects caused by the process chain, for the material or the layer system.

For laser welding and PVD coating, as well as in additive manufacturing, the process technologies developed at the Fraunhofer IWS usually create a thermally affected zone in the material, which can have a significant influence on the component's properties. If the interaction among the process, structure and properties is not understood, a component may fail early. The thermal input, just as in laser-based processes, is limited to a micrometer to submicrometer scale. If the scientists have to explore the bonding mechanisms of a layer system on a substrate, a target preparation on nanometer scale is required. The range of analysis services provided by the IWS was enhanced by the focused ion beam (FIB) technique. This allows the IWS researchers to explore the open issues mentioned before. In this way, the FIB technique directly affects process development.

Focused-Ion-Beam through a multilayer structure



Focused Ion Beam (FIB)
Investigated area
Substrate
Multilayer structure

One can compare the control of a focused ion beam with that of a scanning electron microscope (SEM). In contrast, however, the beam scanning across the specimen consists of gallium ions rather than of electrons. As a result, a focused ion beam enables targeted local material removal. In combination with the SEM and other analysis tools, such as "energy dispersive X-ray spectroscopy" or "electron backscatter diffraction", it is possible to represent a three-dimensional material structure. Thus, FIB technology is able to visualize the material structure under the position of a crack origin and thus to show if, for instance, a local structure heterogeneity in a layer system or an additively manufactured structure is the cause of a macroscopic failure.

2 *FIB technology enables the visualization of crack formation in a ta-C layer after repeated indentation under the specimen surface.*

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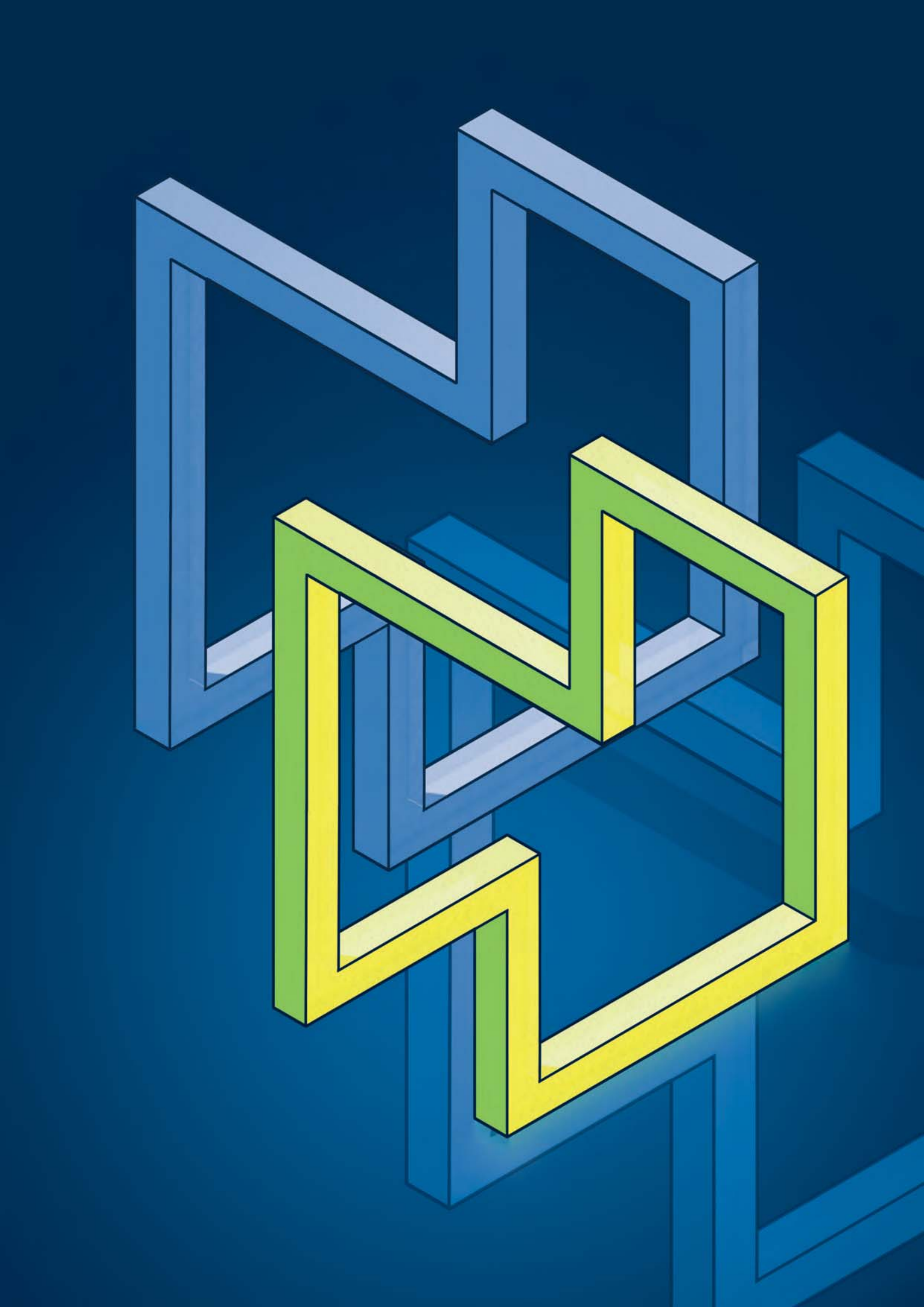

CENTERS AND NETWORKS

COOPERATION PARTNER

CENTER FOR COATINGS AND DIAMOND TECHNOLOGIES (CCD)

Staying competitive in today's economic situation calls for innovative products and manufacturing solutions. In particular, the Fraunhofer CCD's projects address coating and technology solutions that combine expertise in processes, materials, and systems engineering with scientific excellence, quality and project management. The services involve material coating and testing for customer applications, research and development projects for product development, consultation and engineering services, and material characterizations, as well as system development, integration, installation and support. The Fraunhofer Center for Coatings and Diamond Technologies (CCD) is located in East Lansing, Michigan, on the campus of the Michigan State University (MSU). For thirteen years IWS scientists have been cooperating with the Fraunhofer CCD and MSU in the fields of thin layer and diamond technology.

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CENTER FOR LASER APPLICATIONS (CLA)

The Fraunhofer Center for Laser Applications (CLA) is the result of bundling all the laser research activities of the Fraunhofer USA in a joint center. Since 1994, this center has been developing new laser applications in the United States for a wide variety of industrial users. With its expertise in laser processing of materials and its state-of-the-art laser systems, Fraunhofer CLA provides support in the process solutions development for customized use. Its activities focus on providing laser technologies and systems. The center provides a wide range of laser processes, including welding, cutting, drilling, coating, heat treatment, surface marking, and patterning, as well as additive manufacturing. Another special field is systems development for process monitoring and control. The researchers at the Fraunhofer CLA also develop processing heads for build-up welding and additive manufacturing. The CLA is located in Plymouth, Michigan, next to Detroit.

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FRAUNHOFER PROJECT CENTER – WROCŁAW CENTER OF EXCELLENCE FOR MANUFACTURING

Founded in partnership with the Wrocław University of Technology, the "Fraunhofer Project Center for Laser Integrated Manufacturing" expands the Fraunhofer IWS' cooperation network to Eastern Europe and plays a pioneering role in Germany-Poland cooperation. The objectives in the cooperation prioritize contract research, as well as development and engineering services for Polish industrial customers. Furthermore, the cooperation partners also expand the center's training programs and contribute to transnational scientific exchange. The researchers at the Fraunhofer Project Center in Wrocław are working on new methods and technologies for optical measurements and surface inspections of components that are difficult to refine. Reverse Engineering activities are closely linked with physical objects digitization and 3D computer model creation. In addition, Wrocław's scientists research laser materials processing, rapid-prototyping and tooling as well, exchanging approaches and findings with the researchers in the Material Testing field at the Fraunhofer IWS.

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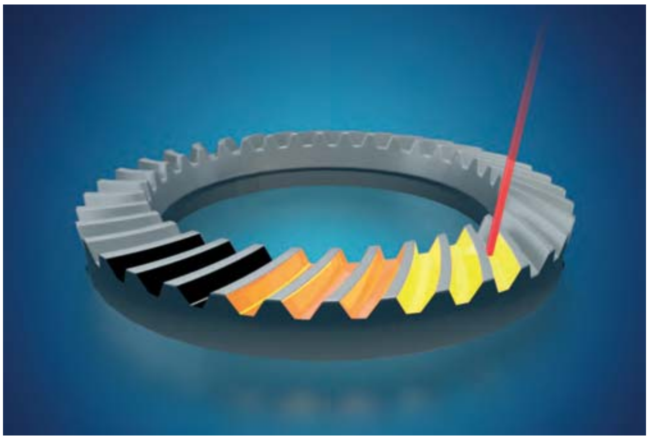
CENTERS



CENTER FOR THERMAL SURFACE TECHNOLOGY

Fraunhofer IWS has established a variety of surface coating and refinement techniques that is unique in Europe. The Center for Thermal Surface Technology deploys this profound material knowledge to develop complete solutions for complex tasks from a wide range of industries and rapidly transfers the results into practice. The Center does not offer laboratory solutions. Users benefit in particular from Fraunhofer IWS' experience in transferring the technological developments, including application-specific hardware and software components, to industrial production. Users of the thermal surface techniques portfolio come from the automotive industry and electrical power engineering, the aeronautics and space industries, medical engineering, gas and oil industries, mechanical engineering, as well as tool and die-making. The parts sizes range from a few millimeters to several meters.

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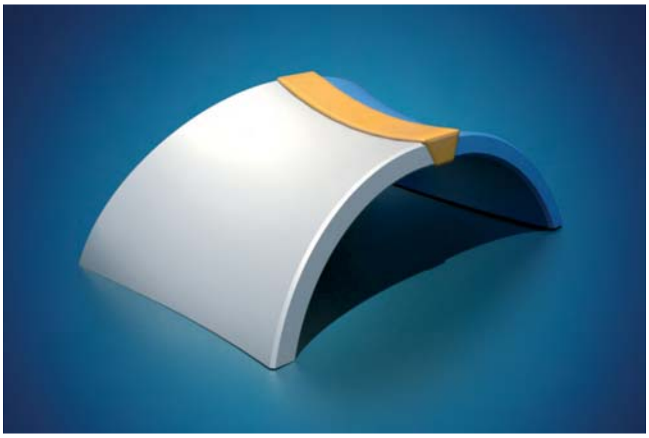

CENTER FOR TAILORED JOINING

Joining represents a key challenge in production and frequently significant costs. The "Tailored Joining" Center was established in cooperation with the TU Dresden and other partners to achieve further improvements and inspire new ideas. The aim is to give users an overview of the possibilities and limitations of various joining processes, to enable a direct comparison, to present new developments in a compact way and to show industry-related solutions. The partners in the Center are the TU Dresden and the University of Applied Sciences – Hochschule für Technik und Wirtschaft (HTW). The TU Dresden, with the Chair of Joining Technology and Assembly, focuses on techniques and tools for thermal, mechanical and hybrid joining, as well as joining by forming; the chair also deals with integrated planning of assembly, handling, and joining processes. The University of Applied Sciences HTW Dresden with its electron beam welding know-how has actively contributed to the Dresden research alliance since 2014. All partners pay special attention to comparing the various solutions without assessment, so that users receive direct decision support for their particular tasks.

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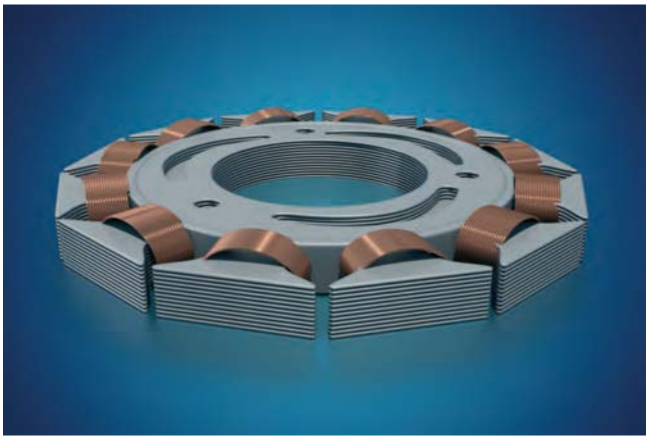
CENTER FOR ENERGY EFFICIENCY



Research and development activities at the Center for Energy Efficiency primarily focus on using energy economically and refining resource-saving technologies. The Center for Energy Efficiency concentrates researchers' strengths to establish and expand energy efficiency as an integral part of research and development projects. To sensitize the public outside the institute to energy efficiency and to accelerate new developments, Fraunhofer IWS, for example, founded the "Dresden Innovation Center for Energy Efficiency DIZE^{EFF}" in 2009. In the DIZE^{EFF}, scientists at the TU Dresden and the Dresden Fraunhofer Institutes collaborate in numerous projects and research in the areas of high-performance solar and fuel cells, high-temperature power engineering, lightweight design, and highly efficient electric motors, manufacturing and energy-saving displays.

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CENTER FOR ADDITIVE MANUFACTURING

Paradigm shift in manufacturing technology: part fabrication layer by layer can overcome the conventional manufacturing limits and enable completely new geometries. This great opportunity faces many unsolved questions. In its close connection between science and industry, the Center for Additive Manufacturing elaborates cross-procedural material and manufacturing solutions for challenging products. Fraunhofer IWS and TU Dresden have established the "Additive Manufacturing Center Dresden" (AMCD) as an institution with a strong international reputation, developing cross-procedural material and manufacturing solutions for demanding products. The Center is an ideal industry networking platform to cross-link basic research at the university and user-oriented studies in a fast-paced high-tech field.

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CENTERS

CENTER FOR BATTERY RESEARCH

The scientists at the Center for Battery Research focus on technologies for new energy storage devices. The challenge: finding solutions with higher energy density at a reasonable cost for many growth markets. Developing cost-efficient production techniques scalable for industrial use is not only crucial to bringing a new cell generation to the market, but also to reducing existing cell technologies costs. Consequently, the Fraunhofer IWS has established a process chain for battery cell production – from electrode fabrication via configuring, assembling electrode stacks, up to packed pouch cells. In addition to the classical battery electrodes' wet coating, the researchers are developing a completely solvent-free approach to process initial materials to free-standing electrode films. Configuration and assembly of the electrodes are laser cut and can thus be adapted to various cell formats.

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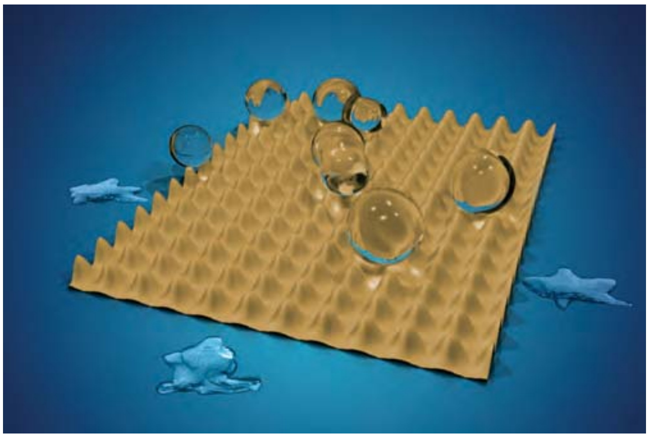

CENTER FOR ADVANCED MICRO-PHOTONICS (CAMP)

CAMP explores laser-based surface modification and patterning methods. Driven by current trends in laser-based micro processing, the Center targets opportunities and challenges in the development of new system, process and measurement solutions. To transfer technologies into industrial processes, the researchers implemented every operation of the entire process chain. CAMP demonstrates cross-operational approaches from simulation via laser process and optical measurements to machine learning. In these endeavors, scientists at the Fraunhofer IWS, in cooperation with the TU Dresden, focus on various applications of laser micro processing and measuring operations. The Center deploys a wide range of current technologies, with numerous applications, such as micro drilling, micro cutting and patterning, as well as laser marking and laser interference patterning.

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BRANCHES

PROJECT GROUP OF THE FRAUNHOFER IWS AT THE DORTMUND SURFACE CENTER (DOC®)

The DOC® typically provides customized coatings to be used in continuous techniques on steel strips. The development projects primarily target improving functions such as corrosion and scratch resistance, electric conductivity, or cleaning properties. The group's activities concentrate on PVD surface coatings and thermal coating techniques, as well as laser surface processing. Among other objectives, the DOC® emphazises on engineering electrically conductive, formable carbon layer systems and surfaces for electric mobility for fuel cells, Diamor® coating systems for wear protection, based on the "short pulsed Arc" (spArc®) technique, the latest PVD high-performance methods, arc wire spraying under vacuum and large-area remelting with high-power lasers for strip refinement.

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APPLICATION CENTER FOR OPTICAL METROLOGY AND SURFACE TECHNOLOGIES (AZOM)

Situated in the Westsächsische Hochschule Zwickau's (WHZ, University of Applied Sciences) neighborhood, the AZOM bridges the gap between the Fraunhofer IWS in Dresden and regional industry. The researchers develop and proof test optical measuring techniques for industry companies. The portfolio of services comprises sensors for different process parameters and variables, as well as complex measuring stations and devices, connected with the customers' data processing equipment. AZOM expands Fraunhofer IWS' range of application in surface analytics. At the same time, students and graduated WHZ engineers get the chance to collaborate in industrial projects. The Fraunhofer Application Center, which is unique in this sense in the new Federal States in Germany, features laboratory rooms equipped with optical tables, system modules and numerous measuring devices, as well as systems for surface analysis.

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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.

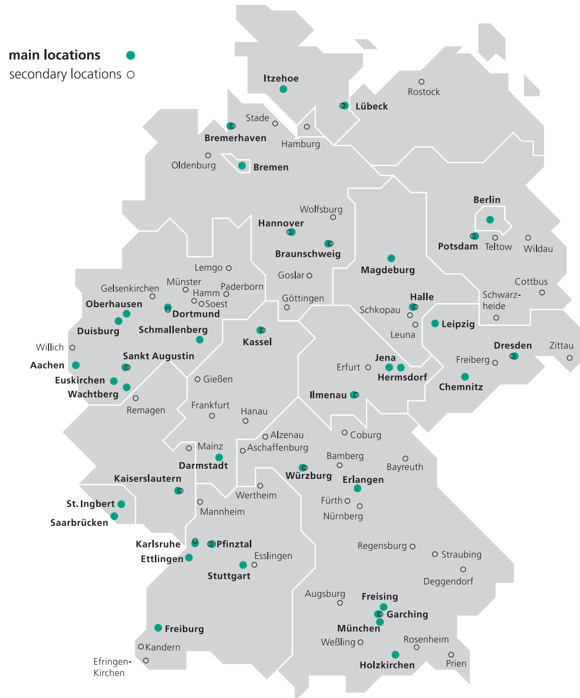
At present, the Fraunhofer-Gesellschaft maintains 72 institutes and research units. The majority of the more than 25 000 staff are qualified scientists and engineers, who work with an annual research budget of 2.3 billion euros. Of this sum, almost 2 billion euros is generated through contract research. Around 70 percent of the Fraunhofer-Gesellschaft's contract research revenue is derived from contracts with industry and from publicly financed research projects. Around 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.



TECHNISCHE UNIVERSITÄT DRESDEN

Excellent cooperation: Since its founding in 1997, the Fraunhofer IWS has continuously expanded its collaboration with various chairs at the TU Dresden. This enables the scientists to combine the university's comprehensive fundamental knowledge with the application-oriented development at the IWS. Professors and scientists at the TU Dresden are closely involved in the institute's research projects and participate in its technical equipment and infrastructure. The IWS managers and employees assist the university in qualifying students and doctoral candidates, thus recruiting the next generation of scientists.

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Faculty of Mechanical Science and Engineering
Institute of Manufacturing Technology

Chair of Laser and Surface Technology

PROF. DR. CHRISTOPH LEYENS
Faculty of Mechanical Science and Engineering
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Chair of Materials Science

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Chair of Mechanics of Materials and Failure Analysis

PROF. DR. STEFAN KASKEL
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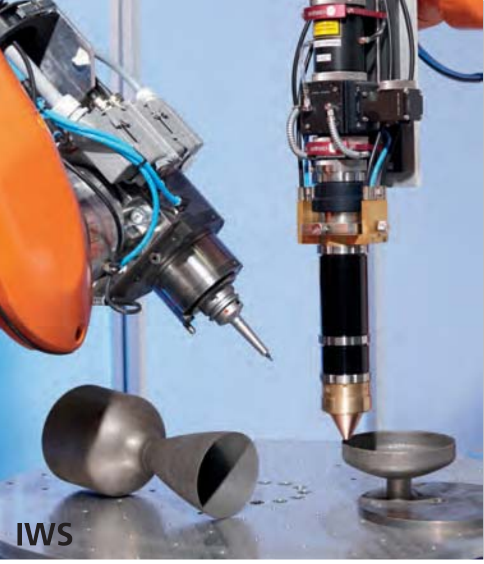
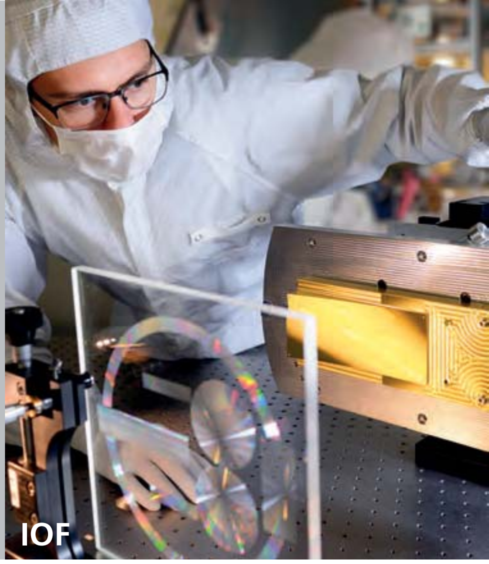
PROF. DR. KAROL KOZAK
Faculty of Medicine
Clinic for Neurology

Chair of Data Management and Evaluation

TECHNISCHE UNIVERSITÄT DRESDEN





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 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 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 MATERIAL AND BEAM TECHNOLOGY IWS

Light and layer: Fraunhofer IWS works wherever lasers and surface technology meet. The Dresden institute comes into play if the task is to deposit different materials layer by layer, to join, cut, functionalize or analyze. Services range from developing new techniques via integration into manufacturing, up to user-oriented support – in single-source responsibility. The Fraunhofer IWS is meeting the challenges of digitization with a focus on researching and developing solutions for "Industry 4.0".

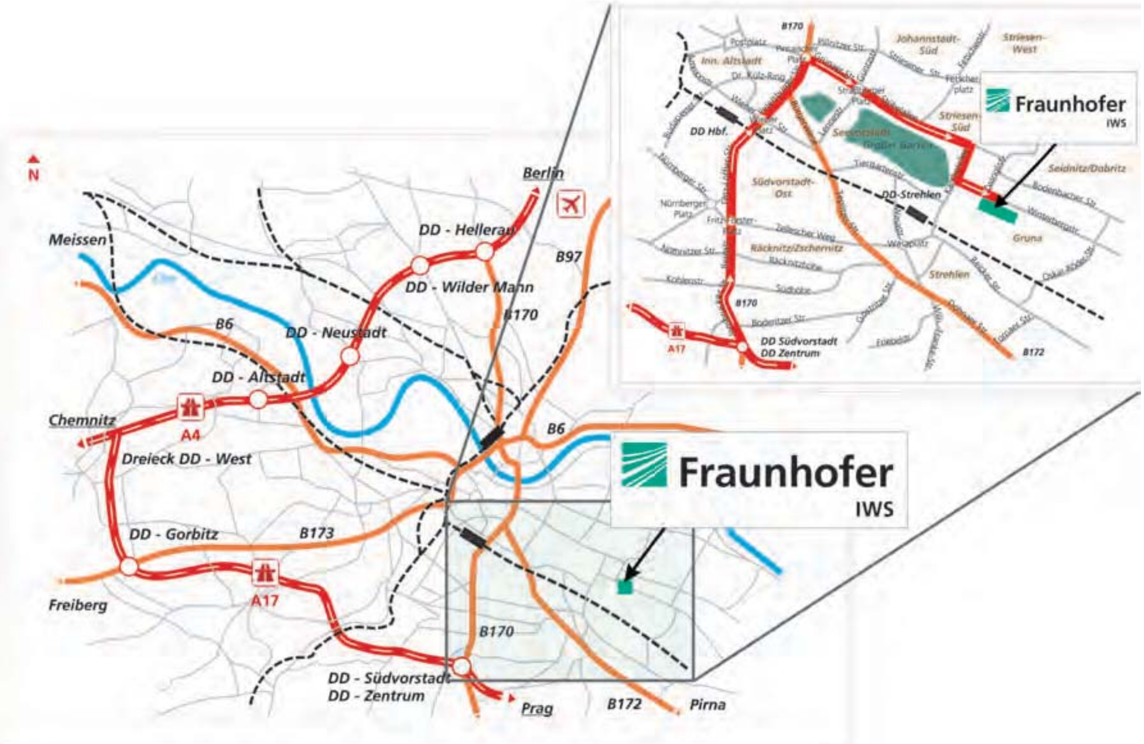
www.iws.fraunhofer.de

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

HOW TO REACH US



By car (from Autobahn):

- Take Autobahn A4 or A13 to intersection Dresden-West, follow Autobahn A17 to exit Südvorstadt/Zentrum,
- Follow road B170 in direction Stadtzentrum (city center) to Pirnaischer Platz (about six kilometre),
- 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,
- Ten 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 kilometer),
- Or with public transportation (shuttle train) to the main railway station (Hauptbahnhof), and continue with the tram.

Address:

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