Fraunhofer IST

FRAUNHOFER INSTITUTE FOR SURFACE ENGINEERING AND THIN FILMS IST

ANNUAL REPORT 2020

20

COVER

Demonstrator of a mobile measuring gun with luminescent carrier foil.

020

FOREWORD

Dear Ladies and Gentlemen,

The year 2020 – dominated by the circumstances of the COVID-19 pandemic – was a period of particular challenges. Through the rapid expansion of digital tools for collaborative work as well as the implementation of hygiene concepts, we were able to secure our business operations and to keep our vision in sight. We worked intensively on the development of future-oriented sustainable products and the associated production systems, thereby using our technology and competence portfolio as a basis.

Several projects simultaneously targeted solutions in connection with the fight against the Corona pandemic and were in part funded by the Fraunhofer-Gesellschaft's central action program, "Fraunhofer vs. Corona".

Climate protection and the associated decarbonization of the economy are important drivers for many projects in the field of energy storage. At the same time, digitization continues to be of great importance for future production systems and was at the forefront of our developments for the production of thin-film sensors, precision optical systems and the expansion of our electroplating activities.

I am particularly pleased that we were able to further intensify our local networking in 2020. As a new member of the Center of Pharmaceutical Engineering, we are now in a position to contribute our expertise in the field of individualized medicine and pharmaceutical production.

At the Wasserstoff Campus Salzgitter (hydrogen campus), the focus is directed upon the industrial utilization of hydrogen. The Fraunhofer IST is contributing in particular its expertise in the development of materials and processes for electrolyzers, hydrogen storage and fuel cells as well as in holistic technology assessment. Further regional anchors are the Fraunhofer Project Centers for Energy Storage and Systems ZESS in Braunschweig and for Lightweight Construction and Electromobility in Wolfsburg.

After 21 years, Prof. Dr. Günter Bräuer's active period as Director of the Fraunhofer IST came to an end in September 2020. On behalf of all the institute's employees, I would like to take this opportunity to thank him once again for his valuable collaboration and his commitment to the institute and to plasma technology.

At this point, I would also like to express my special thanks to all those whose performance, commitment, trust and support contribute towards ensuring that the Fraunhofer IST continues to be optimally prepared for the future. I thank all of you: the employees of the institute, our partners in research and development, the clients from industry, our benefactors, colleagues and friends.

I hope you, dear reader, will enjoy reading this Annual Report. We look forward to further exciting projects with you!

Prof. Dr.-Ing. Christoph Herrmann

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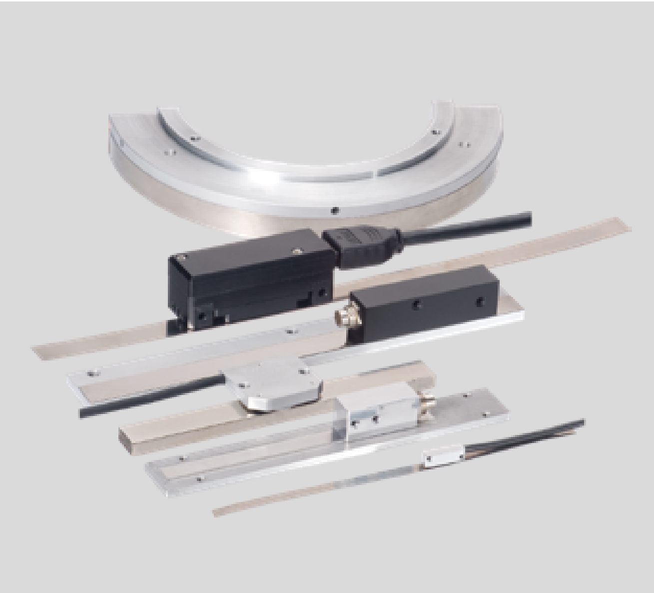
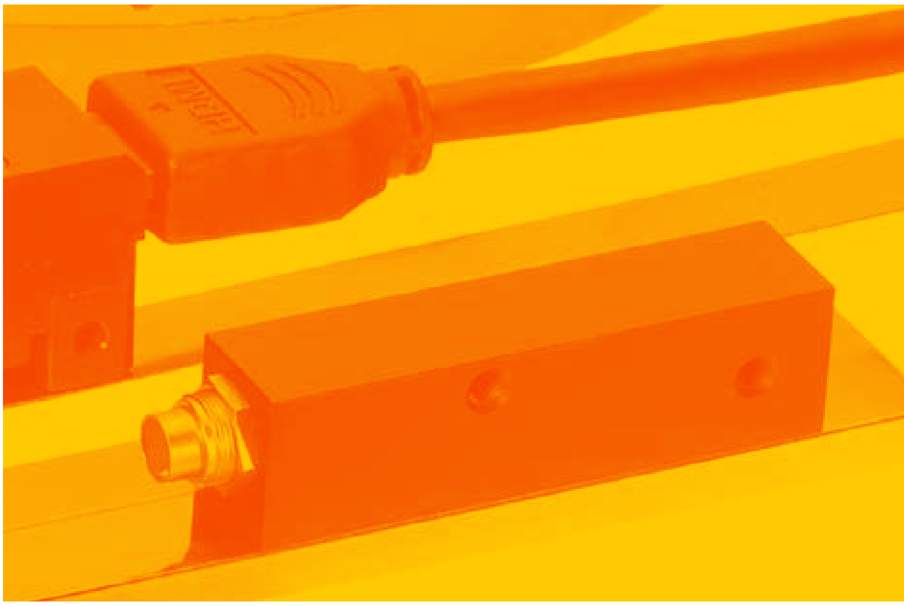
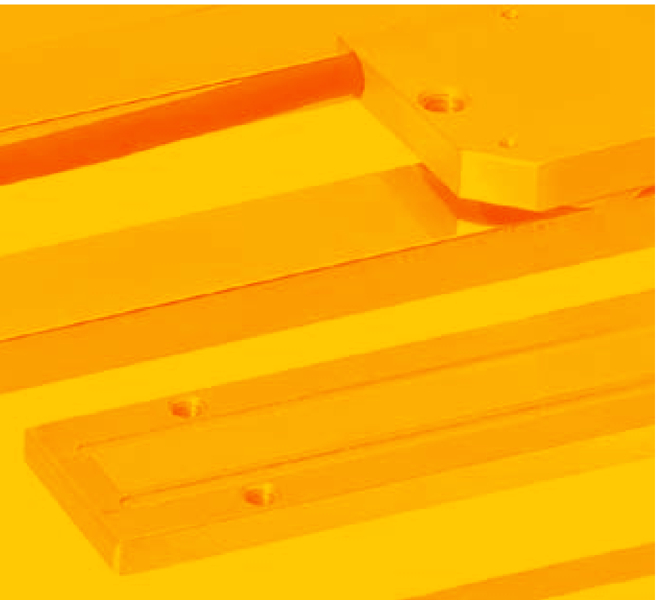
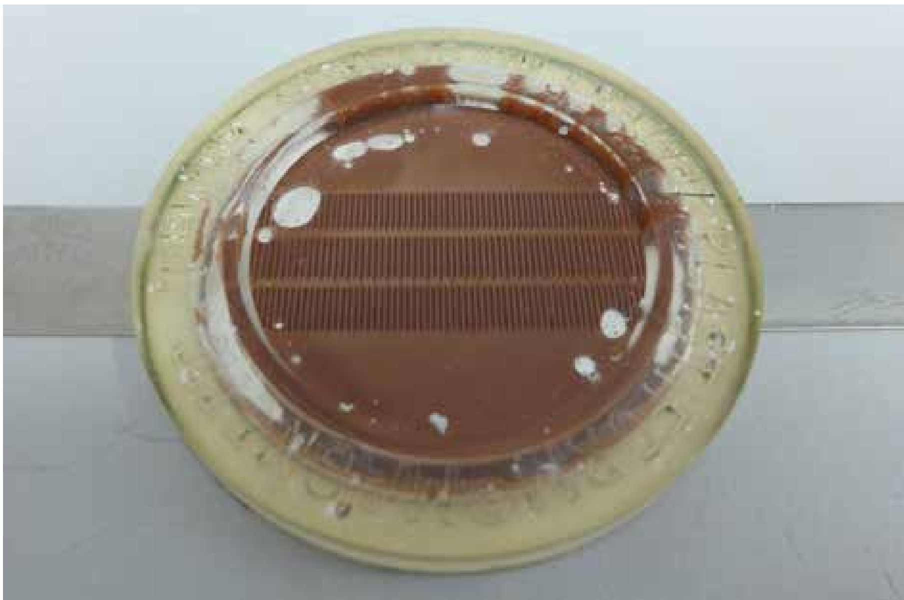
FRAUNHOFER IST

OUTSTANDING COLLABORATION







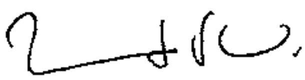


With new technology and innovative functionality, ITK Dr. Kassen GmbH sets standards in high-end microscopy. Key components such as linear motors, controllers and measuring systems are not simply bought in at ITK, but are instead manufactured in-house, enabling the problem-free realization of comprehensive adaptations and the provision of tailor-made solutions.

In order to remain at the forefront, excellent cooperation and long-term relationships based on trust are absolutely essential. The magnetic position-measurement technology made by ITK Dr. Kassen GmbH – a magneto-resistive measurement technology – is, in contrast to optical measurement systems, insensitive to impurities and has significantly fewer aging effects, even in extreme environments. In this field, ITK Dr. Kassen GmbH has been cooperating with the Fraunhofer IST since 2015.

In order to be able to meet the highest demands and to reliably offer sustainable solutions, ITK Dr. Kassen GmbH has, in collaboration with the Fraunhofer IST, developed a solution for high-precision magnetic absolute measurement systems. The core of the length- and position-measuring technology is hereby the interaction of a sophisticated coding and readout technology with robust and excellent magnetic tapes.
By means of ingenious signal processing, position resolutions in the single-digit nanometer range and repeat accuracies of ± 100 nm are made possible. During the course of joint development, a technology change was made to magnetic layers which are deposited in an environmentally friendly manner in a vacuum with high reproducibility and process reliability. The Fraunhofer IST hollow-cathode technology is hereby deployed, which, by means of unique hard-magnetic functional layers, ensures unprecedented positioning accuracy and a further increase in robustness against interference fields.

As a result of the successful cooperation between the Fraunhofer IST and ITK Dr. Kassen, a milestone in the field of precise positioning in the area of microscope tables, as well as linear scales, has been achieved which is unparalleled. On the basis of the joint developments, we at ITK Dr. Kassen GmbH, together with partners in the magnetic sensor and metrology sector, are looking into an exciting and innovative future with the Fraunhofer IST. We are convinced that this journey has only just begun and will produce many more groundbreaking insights and solutions.



Dr.-Ing. Ingolf Schäfer
ITK Dr. Kassen GmbH

INSTITUTE PROFILE

The Fraunhofer IST is an innovative partner for research and development in surface technology, with expertise in the associated product and production systems. As an internationally recognized partner in applied research, the institute taps the synergies of process engineering and production technology.

Through modification, patterning and coating of the surface, a wide range of functions and functionalities and thus sustainable products and systems can be realized. Friction reduction, abrasion and corrosion protection, optical properties through to smart sensor features are just a few examples.

Based on the mission statement of sustainability, we work together with customers from industry and research to develop customized and sustainable solutions: from prototypes, through economic production scenarios, to upscaling to industrial magnitudes – and all this whilst maintaining closed material and substance cycles.

One of the institute's particular strengths is its ability to create the optimum process chain for the respective task on the basis of a broad spectrum of processes and coating materials.

Current priorities in the sectors mechanical engineering, tools and automotive technology, aerospace, energy and electronics, optics and life science and ecology are:

- Energy storage systems with focus on battery cell production and hydrogen technology
- Micro and sensor technology / Industry 4.0
- Tribological systems and flexible production
- Precision optical coatings
- Multifunctional surfaces for medical technology and pharmaceutical production
- Diamond-based systems for clean technologies
- Cyber-physical systems / Computational surface engineering & science

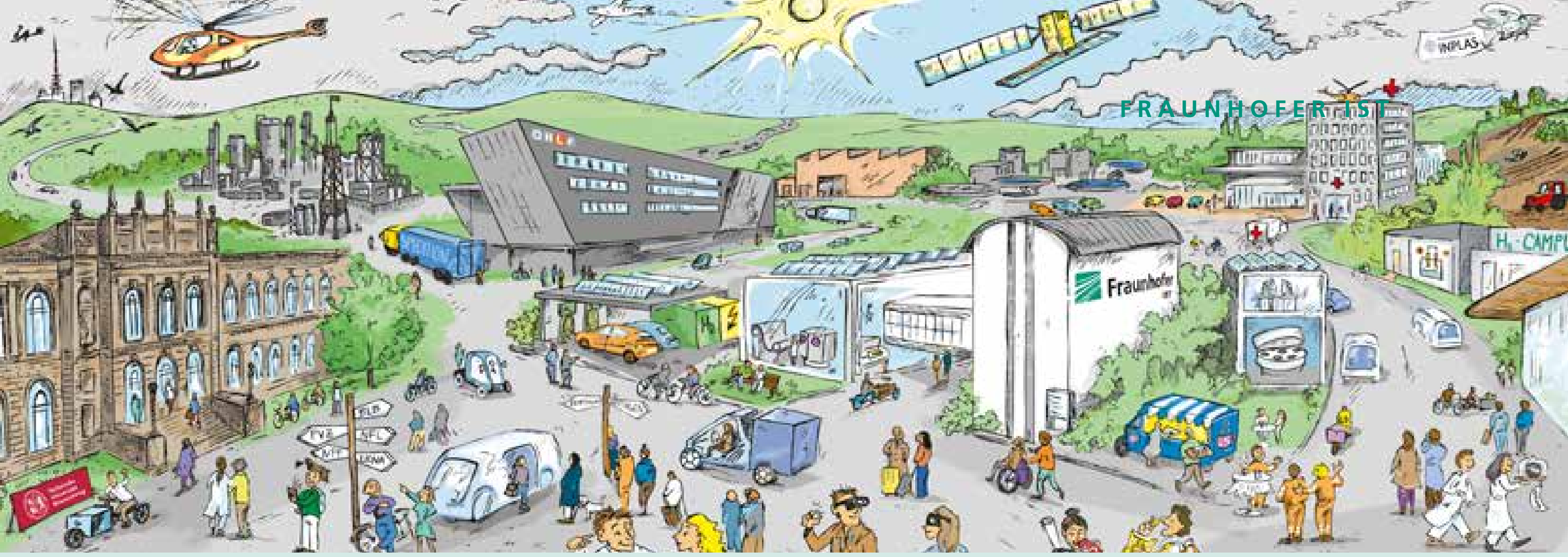
The IST has accumulated expertise in diverse technologies for the coating, treatment and structuring of surfaces. For these purposes, extensive equipment is available. The technologies include:

- Electrochemical processes, in particular electroplating
- atmospheric pressure processes
- low-pressure plasma processes with the main focus on magnetron sputtering, highly ionized plasmas and plasma-activated vapor deposition (PECVD)
- chemical vapor deposition with the main focus on hot-wire CVD as well as
- atomic layer deposition (ALD)
- chemical, mechanical and thermal surface treatment

Furthermore, the Fraunhofer IST not only has excellent capabilities in surface analysis and quality assurance using the very latest equipment but has also accumulated extensive experience in the modeling and simulation of both product properties and the associated processes and production systems. Further expertise includes the areas of sustainable factory systems and life cycle management.

In addition to application-oriented research and development, scientific principles are also researched within various collaborations with universities and research institutions. Besides direct contract research, many projects are supported through public funds from the State of Lower Saxony, the Federal Government, the European Union and other institutions.

At the site in Braunschweig the institute has an office and laboratory area of more than 4000 square meters. In addition, the new building of the Application Center for Plasma and Photonics provides 1500 square meters of office and laboratory area in Göttingen.



In collaboration with the Fraunhofer institutes IKTS and IFAM, the Fraunhofer IST is a supporting pillar in the Fraunhofer Project Center for Energy Storage and Systems ZESS. During the transition phase, the employees have access to laboratory space in the Automotive Research Centre Niedersachsen (NFF) and offices in the Lilienthalhaus at the Research Airport Braunschweig. Currently in planning is a new building, also at the Research Airport Braunschweig, into which the offices and laboratories will move.

At the Wolfsburg location the Fraunhofer IST is a partner in the Fraunhofer Project Center together with the Fraunhofer Institutes IFAM, IWU and WKI. As part of the BMBF initiative "Open Hybrid LabFactory (OHLF) Research Campus" the project center is working on various topics relating to mobility: The research fields are "resource-efficient lightweight construction", "flexible production" and "future interiors in vehicle construction". The participating Fraunhofer institutes are working together on solution approaches to develop the entire process chain for lightweight structures and to test them on an industrial scale.

Furthermore, the Fraunhofer IST is represented at the Salzgitter location in its role as scientific partner at the Wasserstoff Campus (hydrogen campus). With the signing of a cooperation agreement between Salzgitter AG, MAN Energy Solutions, Bosch, Alstom, WEVG, the Fraunhofer IST, the Projektbüro Südostniedersachsen (in which the Office for Regional Development and the Allianz für die Region GmbH act collaboratively), and the City of Salzgitter, a local political milestone was attained in September 2020 with regard to the establishment of the campus.

PROFESSORSHIPS

Fraunhofer IST maintains connections with the Technische Universität Braunschweig in the form of four associated professorships. Since 2012 the institute has also been cooperating with the HAWK University of applied sciences and art Hildesheim/Holzminden/Göttingen within the framework of the Application Center for Plasma and Photonics.

TECHNISCHE UNIVERSITÄT BRAUNSCHWEIG

Institute of Machine Tools and Production Technology IWF

Prof. Dr.-Ing. Christoph Herrmann

Research foci:
- Sustainable manufacturing
- Life Cycle Engineering
- System of Systems Engineering
- Cyber-physical production systems

Institute for Particle Technology iPAT

Prof. Dr.-Ing. Arno Kwade

Research foci:
- Mechanical process engineering
- Particle technology
- Battery process engineering
- Pharmaceutical and bioprocess engineering
- Powder and suspension processes

Institute for Surface Technology IOT

Prof. Dr. Günter Bräuer

Research foci:
- Thin film and surface technology
- Low-pressure plasmas
- Magnetron sputtering
- Plasma diffusion processes

Prof. Dr. Michael Thomas (Honorary professorship)

Research foci:
- Interfacial chemistry
- Atmospheric pressure plasma processes

HAWK UNIVERSITY OF APPLIED SCIENCES AND ART HILDESHEIM/HOLZMINDEN/GÖTTINGEN HAWK

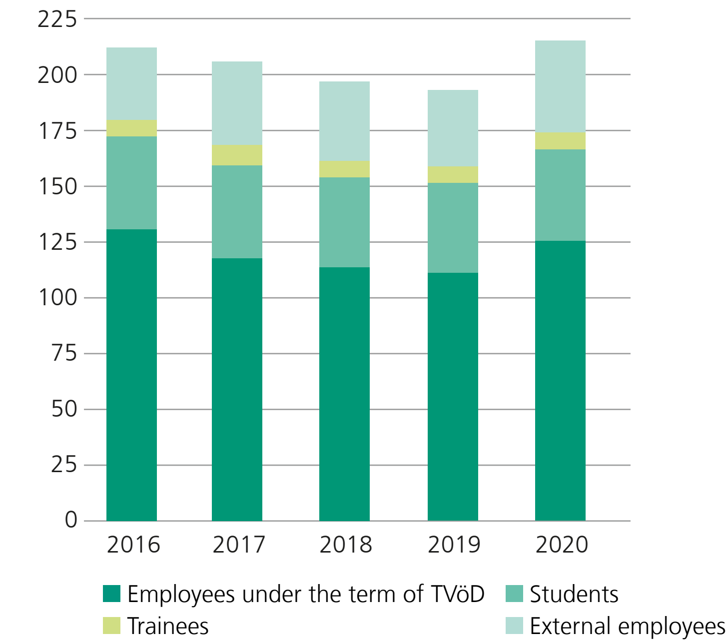
Faculty of Engineering and Health

Prof. apl. Prof. Dr. Wolfgang Viöl

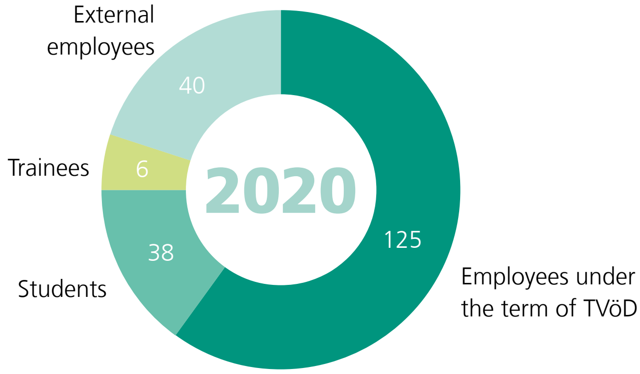
Research foci:
- Laser technology
- Plasma technology
- Plasma medicine

THE INSTITUTE IN FIGURES

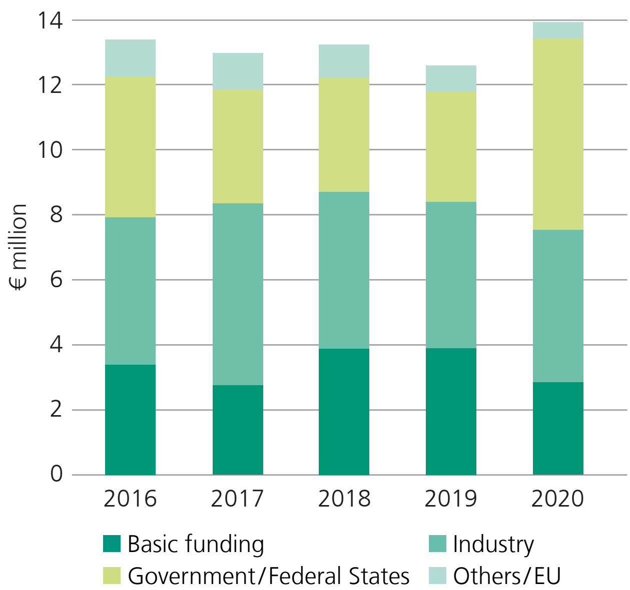
Employee development



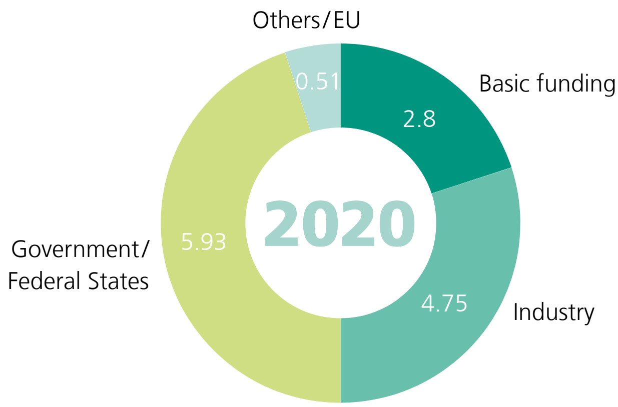
209
Employees



Operating budget



€ 13.99 million
Operating budget



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GREEN HYDROGEN TECHNOLOGY IS A JOINT PROJECT

A place in which diverse companies are working to achieve the European Union's climate-protection goals: At the Wasserstoff Campus (hydrogen campus) in Salzgitter, this place does indeed exist. With the support of the Fraunhofer IST, regional companies are working on the production and utilization of green hydrogen.

By 2050, the emission of greenhouse gases in the European Union is to be reduced by 80 to 95 percent compared to 1990. For industry and business, hydrogen could be an important module for decarbonization. In order to separate water into oxygen and hydrogen by means of electrolysis, electricity must be consumed. For some time now, renewable energies – wind and solar power – have been moving into focus for this purpose. The hydrogen produced in an environmentally friendly way (green hydrogen) can be stored easily. In cooperation with companies such as Salzgitter AG, MAN Energy Solutions, Bosch, Alstom and Salzgitter's water and energy supply company WEVG, the Fraunhofer Institute for Surface Engineering and Thin Films IST is carrying out work on the Salzgitter campus into the development of technologies for practical use.

Wasserstoff Campus Salzgitter

A joint campus for hydrogen research

In September 2020, the five companies, together with the city of Salzgitter, the Projektbüro Südostniedersachsen and the Fraunhofer IST, founded the collaborative Wasserstoff Campus. The idea for the alliance of local protagonists had already been conceived a year earlier: The search for environmentally friendly processes whilst simultaneously operating economically and preserving jobs in the region unites the protagonists. Prior to the alliance, the companies had already begun addressing the issue of hydrogen as a gaseous energy carrier within their production chains or for their products.

The results so far: Alstom's Coradia iLint attracted worldwide attention as the first passenger train to be powered by hydrogen fuel cells. Not far from the Salzgitter plant of the French train manufacturer, Salzgitter AG is working towards operating its steel mill in a CO_2-neutral manner through the utilization of regenerative energies and electrolytically generated hydrogen. On the factory premises of automotive supplier Bosch, which produces engine control units in Salzgitter, offices and facilities are being built in which procedures for the storage and usage of hydrogen are being researched and tested. Bosch is searching for possibilities for using hydrogen as an energy carrier in industrial production. The Fraunhofer IST is supporting the processes from the perspective of applied research.

Research for industrial application

Under the direction of Prof. Christoph Herrmann, the Institute for Surface Engineering and Thin Films addresses the entire value chain in the thematic area of "hydrogen technology" – from production, through storage, and on to utilization. Procedures and materials are being developed in order to enable the use of electrolyzers, hydrogen storage systems and fuel cells in factories. Hydrogen is to be incorporated into environmentally friendly and user-friendly production processes and into our mobility. The experience gained, in part through the utilization of digital tools and models, provides long-term support for the emergence of new, sustainable concepts for the use of green hydrogen. These help to establish development paths that can also be applied in subsequent research.

The Wasserstoff Campus Salzgitter receives support from the State of Lower Saxony. The city of Salzgitter is contributing around seven million euros to the Wasserstoff Campus from its funds provided by the state for the promotion of economic structures. The physical proximity to one another and to the participating companies facilitates networking for all the involved parties.

1 *Vision of the Wasserstoff Campus Salzgitter.*
2 *The signatories of the cooperation agreement for the Wasserstoff Campus Salzgitter. From left: Dr. Ulrike Witt (Amt für regionale Landesentwicklung (Office for regional development), Dr. Jens Sprotte (ALSTOM Transport Deutschland GmbH), Jan Van den Houte (ALSTOM Transport Deutschland GmbH), Lord Mayor Frank Klingebiel (Stadt Salzgitter), Rainer Krause (WEVG Salzgitter), Mark Grunewald (MAN Energy Solutions SE), Prof. Dr.-Ing. Heinz Jörg Fuhrmann (Salzgitter AG), Michael Gensicke (Robert Bosch Elektronik GmbH), Prof. Dr.-Ing. Christoph Herrmann (Fraunhofer Institute for Surface Engineering and Thin Films IST), Prof. Dr.-Ing. Arno Kwade (Fraunhofer Institute for Surface Engineering and Thin Films IST), Secretary of State Matthias Wunderling-Weilbier (Lower Saxony ministry for federal and European matters and regional development) and Dr. Frank Fabian (Allianz für die Region).*

CONTACT

Dipl.-Ing. Sabrina Zellmer
Phone +49 531 2155-528
sabrina.zellmer@ist.fraunhofer.de

YOUR CONTACT PERSON

INSTITUTE MANAGEMENT AND ADMINISTRATION

Institute management

Prof. Dr.-Ing. Christoph Herrmann[1]
Phone: +49 531 2155-503
christoph.herrmann@ist.fraunhofer.de

Deputy director

Dr. Lothar Schäfer[2]
Extension: 520
lothar.schaefer@ist.fraunhofer.de

Research planning and networks
Assistant head of Institute

Dipl.-Ing. Carola Brand[3]
Extension: 574
carola.brand@ist.fraunhofer.de

Process and innovation management

Dr. Marko Eichler[4]
Extension: 636
marko.eichler@ist.fraunhofer.de

Administration

Annelie Maria Lambert[5]
Extension: 519
annelie.lambert@ist.fraunhofer.de

Marketing and communications

Dr. Simone Kondruweit[6]
Extension: 535
simone.kondruweit@ist.fraunhofer.de

IT

Andreas Schlechtweg[7]
Extension: 633
andreas.schlechtweg@ist.fraunhofer.de

Technical services

Stephan Thiele[8]
Extension: 440
stephan.thiele@ist.fraunhofer.de

HEADS OF DEPARTMENT, GROUP MANAGERS AND TEAM MANAGERS

Low pressure plasma processes

Dr. Michael Vergöhl[9]
Extension: 640
michael.vergoehl@ist.fraunhofer.de
Optical coating systems | Process engineering | Materials engineering

Magnetron sputtering

Large area electronics | Transparent and conductive coatings | Asset and process development | New semiconductor for photovoltaic and microelectronics

Highly ionized plasmas and PECVD

Dr.-Ing. Ralf Bandorf[10]
Extension: 602
ralf.bandorf@ist.fraunhofer.de
Multifunctional coatings with sensors | High Power Impulse Magnetron Sputtering (HPIMS) | Micro tribology | Electrical coatings | Hollow cathode processes (HKV, GFS) | Plasma-enhanced CVD (PECVD)

Simulation

Dr. Andreas Pflug[11]
Extension: 629
andreas.pflug@ist.fraunhofer.de
Simulation of plants, processes and coating layer properties | Model-based interpretation of coating processes

Chemical vapor deposition

Dr. Volker Sittinger[12]
Extension: 512
volker.sittinger@ist.fraunhofer.de

Dr. Markus Höfer[13]
Senior Scientist
Extension: 620
markus.hoefer@ist.fraunhofer.de

Atomic layer deposition

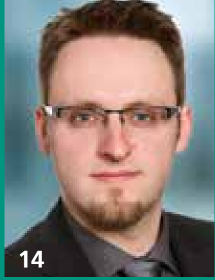
Dipl.-Chem. TG, PMP Tobias Graumann[14]
Extension: 647
tobias.graumann@ist.fraunhofer.de
Product-related system construction | Coating and process development | Highly compliant coatings of 3D structures

Hot-wire CVD

Dr.-Ing. Christian Stein[15]
Extension: 647
christian.stein@ist.fraunhofer.de
Diamond coatings and silicon-based coatings | Tool and component coatings for extreme wear resistance | Diamond coated ceramics DiaCer® | Electrical applications for semiconductors, barriers | Antireflective

Photo and electrochemical environmental engineering

Dipl.-Ing. (FH) Frank Neumann[16]
Extension: 658
frank.neumann@ist.fraunhofer.de
Test engineering | Photocatalysis | Diamond electrodes for electrochemical water treatment | Air, water and self-cleaning | Product evaluation and efficiency determination



Atmospheric pressure processes

Prof. Dr. Michael Thomas[17]
Extension: 525
michael.thomas@ist.fraunhofer.de

Atmospheric pressure plasma processes
Dr. Kristina Lachmann[18]
Extension: 683
kristina.lachmann@ist.fraunhofer.de
Surface functionalization and coating | Small volume production | Plasma printing | Microplasmas | Low temperature bonding | Electrode development and plant engineering | Adhesive layers and anti-adhesive coatings

Electrochemical processes
Rowena Duckstein, M. Sc.[19]
Extension: 619
rowena.duckstein@ist.fraunhofer.de
Process development | Metal coatings | Plastics metallization | Ionic fluids | Plastic and metal pretreatment | Electrochemical synthesis

Surface chemistry
Dr. Kristina Lachmann[18]
Extension: 683
kristina.lachmann@ist.fraunhofer.de
Biofunctional coatings | Layer-by-layer-processes | Vapor deposition and photopolymerization | Detection of reactive groups | Combination processes – Plasma / 3D print

Center for tribological coatings

Dr.-Ing. Jochen Brand[20]
Extension: 600
jochen.brand@ist.fraunhofer.de
System analysis and system optimization | Tribological coatings | Tribotesting | Device conceptions

Micro and sensor technology
Anna Schott, M. Sc.[21]
Extension: 674
anna.schott@ist.fraunhofer.de
Wear-resistant thin-film sensors for temperature, force, wear and distance measurement | Microstructuring 2D and 3D of functional coatings | Sensor modules for forming processes | Sensorized components

Tribological systems
Dr.-Ing. Martin Keunecke[22]
Extension: 652
martin.keunecke@ist.fraunhofer.de
Prototypes and small volume production | Plasma diffusion | Cleaning technology | Mechanical engineering and automotive technology | Carbon-based coatings (DLC) | Hard and superhard coatings | Wetting behavior | Tool coating (forming, cutting, chipping)

Dortmunder OberflächenCentrum DOC
Dipl.-Ing. Hanno Paschke[23]
Phone: +49 231 844 5453
hanno.paschke@ist.fraunhofer.de
Duplex treatment through plasma nitriding and PACVD technology | Boracic hard coatings | Tool coating | Coatings for hot forming | Coatings for industrial knives

Application center for plasma and photonics

Dr.-Ing. Jochen Brand[20]
Extension: 600
jochen.brand@ist.fraunhofer.de

Prof. Dr. Wolfgang Viöl[24]
Phone: +49 551 3705-218
wolfgang.vioel@ist.fraunhofer.de
Plasma particle coating and cold plasma spraying | Plasma sources conception | Plasma treatment of natural products | Laser plasma hybrid technology for micro structures and surface modification | Laser technique for material treatment and characterization

Analysis and quality assurance

Dr. Kirsten Schiffmann[25]
Extension: 577
kirsten.schiffmann@ist.fraunhofer.de
Chemical microscopy and surface analysis | Microscopy and crystal structure | Test engineering | Costumer specific test engineering | Order investigation

Fraunhofer project center for energy storage and systems ZESS

Prof. Dr.-Ing. Arno Kwade[26]
Phone: +49 531 391-9610
arno.kwade@ist.fraunhofer.de
Development of mobile and stationary energy storage devices and systems | Development and scaling of process technologies | Production of solid-state batteries

Process technology and production engineering for sustainable energy storage systems

Dipl.-Ing. Sabrina Zellmer[27]
Extension: 528
sabrina.zellmer@ist.fraunhofer.de
Product and production systems | Energy storage development and production engineering | Production Engineering | Sustainable Factory Systems | Life Cycle Management

Material and process development
Dipl.-Ing. Jutta Hesselbach[28]
Extension: 613
jutta.hesselbach@ist.fraunhofer.de
Coating and functionalization of surfaces and particles | Production of anode/cathode materials and solid-state electrolytes | Formulation strategies for solid-state batteries | Electrode production | Characterization from material to cell

Sustainable factory systems and life cycle management
Dr. Stefan Blume[29]
Extension: 532
stefan.blume@ist.fraunhofer.de
Battery cell manufacture | Data mining and data analytics | Model-based planning, simulation and operation of battery production systems | Cyber-physical production systems | Economic and ecological life cycle analyses

RESEARCH AND SERVICE OFFERS

Based on the mission statement of sustainability, we create systems from the material through the process to the component, from the process chain to the factory, to recycling.

Process development and qualification

- Pretreatment, e. g. cleaning on aqueous basis, plasma cleaning, Wet-chemical etching pretreatment, particle beam
- Surface modification and coating
- Development of customer-oriented processes, coatings and layer
- Simulation and modeling of surfaces, layer systems and coating processes
- Process technology (including process diagnostics, modeling and control))
- Development of system components
- Device and plant designn

Product and production system development

- Mobile and stationary energy storage systems
- Tribological and sensor systems
- Optical systems
- Adaptive bonding systems
- Diamond-based systems
- Combination methods, e. g. 3D print with plasma
- Adhesive-free joining process
- Ecological and economic life cycle analysis (life cycle assessment / life cycle costing)
- Sustainable factory systems: model-based planning, simulation and operation of production systems
- Universal process automation and development of cyber-physical production systems, e. g. Electroplating 4.0

Analytics and quality assurance

- Chemical micro- and surface analysis
- Microscopy and structure analysis
- Optical and electrical characterization
- Plasma diagnostics and simulation
- Production control and damage analysis
- Costumer specific test engineering
- Order investigation, 24-hour-service

Technology transfer

- Cost-of-ownership calculations, development of economical production scenarios
- Prototype development, pilot production and sample coating procedures
- Equipment concepts and integration into manufacturing lines
- Design of process chains and production systems
- Research and development during production
- Consulting and training

LABORATORY AND LARGE-SCALE EQUIPMENT

Low pressure plasma processes

- a-C:H:Me, a-C:H, hard coating production plant (up to 3 m^3 volume)
- Coating facilities incorporating magnetron and RF diode sputtering
- Sputter plant for high-precise optical coatings
- EOSS® production plant for optical interference filters
- MOCCA+® for optical in-situ layer thickness measurement and process control
- In-line coating facility for large-surface optical functional coatings (up to 60×100 cm^2)
- Industrial scale HIPIMS technology
- Plants for plasma diffusion
- Coating systems for hollow cathode processes
- Clean room environments for substrate cleaning and assembly

Chemical vapor deposition

- Coating plant for thermal and plasma atomic layer deposition (ALD), 2D and 3D
- Hot-filament-CVD units for crystalline diamond coatings (up to 50×100 cm^2) and for internal coatings
- Hot-filament-CVD unit for silicon-based coatings (batch process and run-through process up to 50x60 cm^2)
- Plasma-activated CVD (PACVD) units, combined with plasma nitriding

Atmospheric pressure plasma systems

- Atmospheric pressure plasma systems for coating and functionalization of large areas (up to 40 cm widths)
- Micro plasma plants for selective functionalization of surfaces (up to Ø = 20 cm)
- Bond aligner with an integrated plasma tool for wafer pretreatment in the clean room
- Roll-to-roll set-up for area-selective functionalization of surfaces up to 10 m/min
- Machine for internal coating of bags or bottles
- Mobile atmospheric pressure plasma sources
- S1 bio plasma laboratory with safety workbench

Laser technology and micro structuring

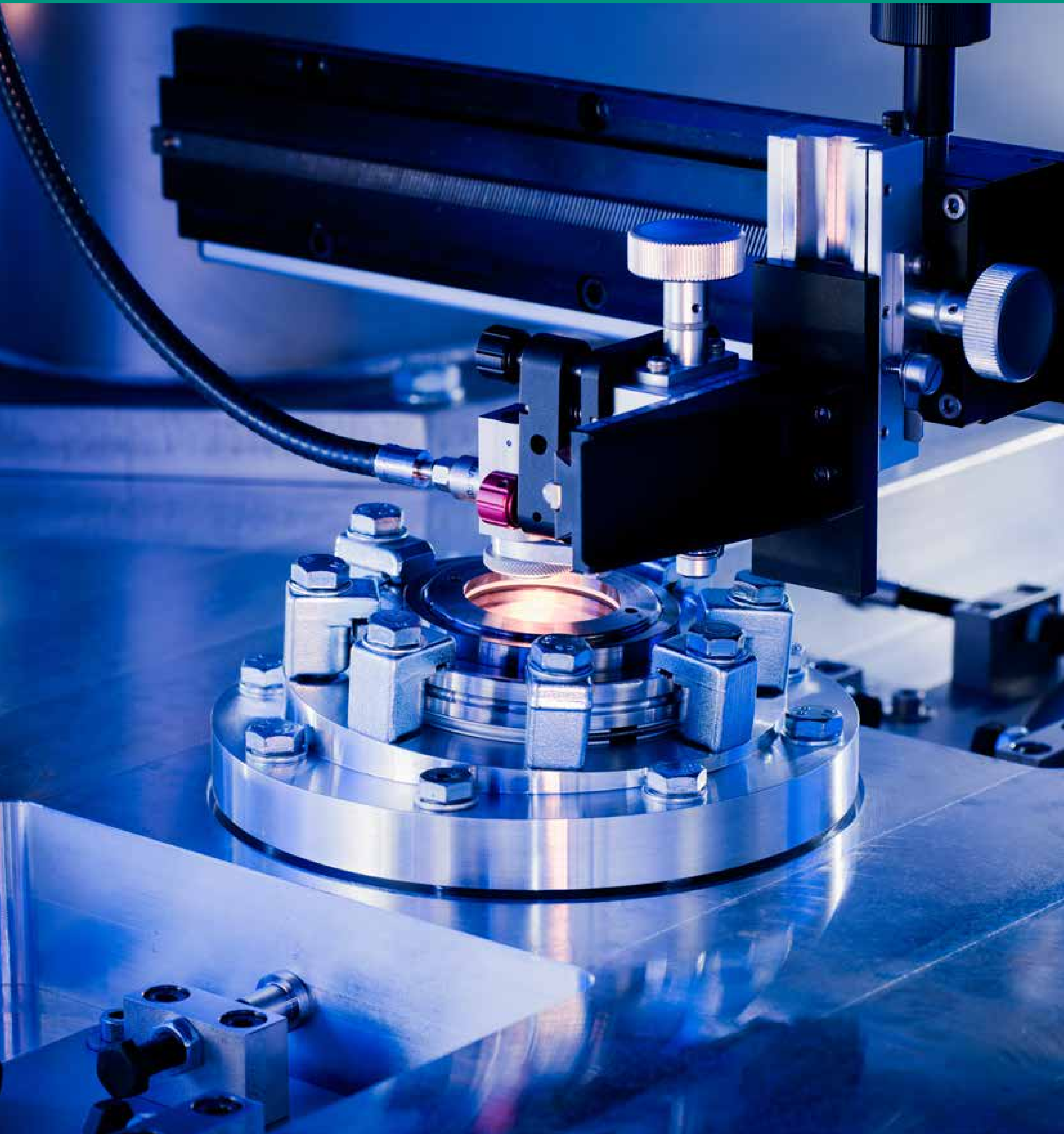
- Laser for 2D and 3D micro structuring (Nanosecond dye laser/Nd: YAG laser); CO_2 laser and excimer laser, Semiconductor laser, Picosecond laser
- Laser für 2D- und 3D-Mikrostrukturierung (Nanosekunden)
- Automated system for deposition of polyelectrolyte
- Mask aligner for photolithographic structuring
- Laboratory for micro structuring (40 m^2 clean room)
- Clean room for sensor technology (35 m^2)
- Laser structuring laboratory (17 m^2)
- EUV spectrography

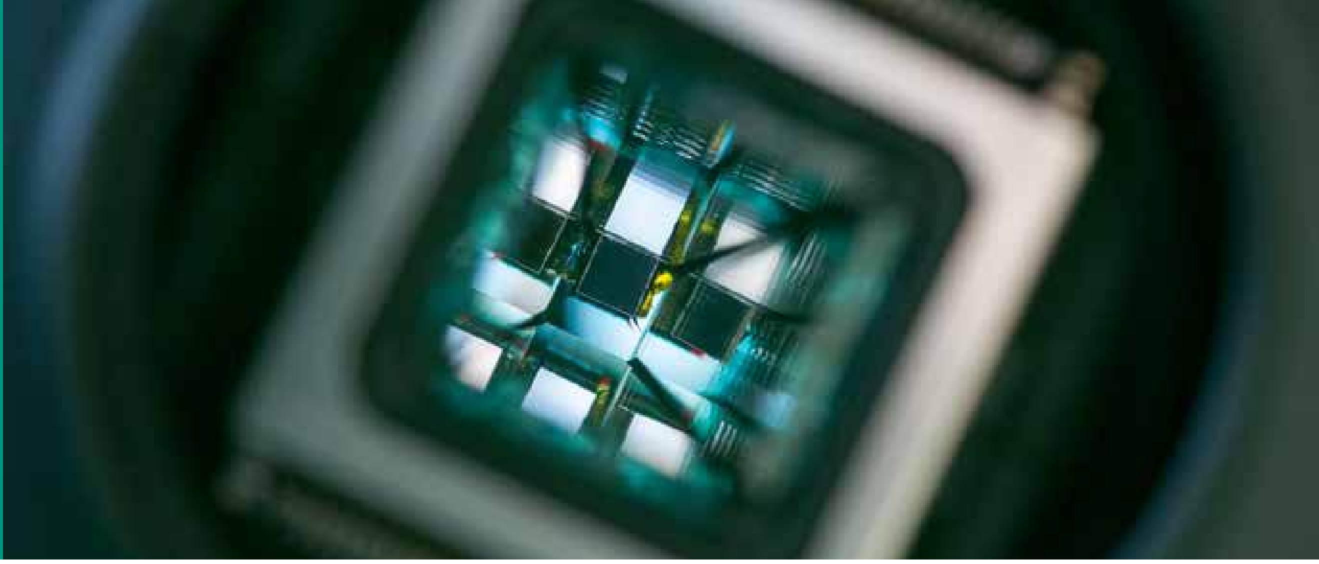
Electroplating

- Modular technical electroplating system (20 stations for active baths with a volume of each 20 l)
- Anodizing plant (11 active baths with a volume of each 140 l and 2 anodizing baths with a volume of each 350 l)

Pretreatment

- 15-stage cleaning unit for surface cleaning on aqueous basis
- Glassware cleaning plant
- Particle beam plant
- Sputter plant and plasma jets for plasma cleaning





LABORATORY EQUIPMENT AND MEASURING TECHNOLOGY

Chemical and structural analysis

- Energy-dispersive X-ray spectroscopy (EDX)
- Electron microprobe (WDX, EPMA)
- Secondary ion mass spectrometry (SIMS)
- X-ray photoelectron spectroscopy (XPS)
- Glow discharge optical emission spectroscopy (GDOES)
- X-ray fluorescence analysis (RFA / XRF)
- X-ray diffractometer (XRD, XRR)
- FTIR spectrometry (ATR, Mikroskopie, IRRAS, DRIFT)
- Raman spectrometry (532 nm, 633 nm, 785 nm, SERS, TERS)

Microscopy

- Scanning electron microscope (SEM)
- SEM with focused ion beam (FIB)
- Scanning tunnel and atomic force microscope (STM, AFM)
- Confocal laser microscope (CLM)
- Photo optical microscopes

Mechanical tests

- Micro and nano indentation (hardness, Young's modulus)
- Rockwell and scratch test (film adhesion)
- Cross-cutting test, butt-joint test (film adhesion)
- A variety of methods for the measurement of film thickness
- A number of profilometers

Measurement of optical propertiesn

- UV-VIS-IR spectrometry
- Ellipsometry
- Colorimetry
- Angular-resolved scattered light measurement (ARS)
- Integral scattered light measurement (Haze)
- Layer mapping system (0.6 x 0.6 m^2) for reflection, transmission, Haze and Raman measurement

Measurement of friction, wear and corrosion

- Pin on disk tester
- Ball-cratering test (Calo)
- Wazau high-load tribometer (in air, in oil)
- CETR high-temperature tribometer (in air, in oil)
- Plint roller tribometer (in air, in oil)
- Taber abraser test, abrasion test, sand trickling test, Bayer test
- Micro tribology (Hysitron)
- Impact and fatigue tester (Zwick Pulsator)
- Salt spray test, environmental tests, sun test

Plasma diagnostics

- Absorption spectroscopy
- Photoacoustic diagnostics
- Laser induced fluorescence LIF
- High-speed imaging
- Optical emission spectroscopy OES
- Retarding field energy analyzer RFEA
- Fiber thermometry
- Electrical performance test
- Numerical modeling

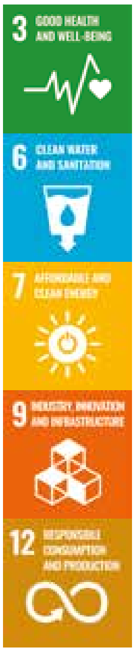
Application-specific measurement methods

Electrical measurement methods

- Measurement of sheet resistance, inductive and by means of the four-point method
- Hall, Seebeck, conductivity
- Electrochemical measurement stations (CV measurement)
- Zeta potential measuring instrument for surfaces
- Measurement of the contact resistance of coatings and materials as specified by the (U.S.) Department of Energy (DOE), applications e. g.: battery technology and bipolar plates in fuel cells
- Potentiodynamic measurements of corrosion resistance according to the specifications of the (U.S.) Department of Energy (DOE), applications e. g. battery technology and bipolar plates in fuel cells
- Characterization of solar cells

Further specialized measurement stations and methods

- Measuring stations for the characterization of piezoresistive and thermoresistive sensor behavior
- Test systems for electrochemical wastewater treatment
- Certified measuring station for photocatalytic activity
- In-situ bond energy measurement
- Contact angle measurement (surface energy)
- Biochip reader for fluorescence analysis
- Wet chemical rapid tests: colorimetrical determination of ion and molecule concentrations
- Weathering tests: cyclical simulation of UV and rain exposition
- Measuring systems for magnetic coating properties: vibration magnetometer VSM



SUSTAINABLE DEVELOPMENT AT THE FRAUNHOFER IST

Sustainability is the most important societal guiding principle of our time. Across the globe, sustainable development processes occupy first place on the agenda. In 2015, the United Nations adopted the 17 UN Sustainable Development Goals (SDGs) – an important milestone in sustainability policy. The Fraunhofer IST has anchored sustainability in its mission statement. For the work at the institute, objectives 3, 6, 7, 9 and 12 are particularly relevant; in this context, selected activities at the Fraunhofer IST are presented below. Furthermore, projects and developments are being addressed at the institute which support further or other goals.

SDG 3: Health and well-being

The improvement of health care and medical care as well as the reduction of diseases and deaths due to e. g. exposure to pollutants are fundamental goals of the UN.
The Fraunhofer IST contributes here with a focus on the following topics:

Lower pollution levels

Pollutants in the air or water are frequent causes of disease. The Fraunhofer IST is developing photocatalytic films which decompose these pollutants. Furthermore, the institute is participating in projects which address the purification or treatment of water: diamond-coated electrodes utilize electrochemical oxidation in order to kill microorganisms and decompose organic pollutants (see also SDG 6: Clean water).

Innovative medical products

In the field of health care and medical care, the development of innovative medical products and the further development of existing items is an important success factor. The Fraunhofer IST performs research in this area, for example into the production of 3D-printed biodegradable polymer framework structures – known as scaffolds – which should be applied in the treatment of missing bone fragments. They serve as a framework for newly growing bone cells and subsequently decompose over time in the body. The Fraunhofer IST is also developing coating technologies on the basis of atomic layer deposition (ALD), in order to produce thin diffusion barrier films for implants.

Disinfection of surfaces

The killing of fungal spores to protect wood, the sterilization of packaging materials, and the disinfection of food or seeds are all examples of the challenges to the improvement of health and well-being within the context of sustainability goals. At the Fraunhofer IST, atmospheric-pressure plasma processes are being developed in order to enable the disinfection of even temperature-sensitive or unstable surfaces. The utilization of physical plasmas is fast, energy-efficient and environmentally friendly and can, in many cases, replace wet-chemical processes which are, to some extent, ecologically questionable. One possibility for the chemical-free wet-cleaning of surfaces is ozonized water, which can be produced using the diamond electrodes developed at the Fraunhofer IST.

Solutions to combat the SARS-CoV-2 pandemic
From the sterilization of clothing and medical devices to the development of diagnostic and biosensor systems – surfaces play a central role in the containment of the SARS-CoV-2 pandemic. With its expertise in research and development in surface technology and competencies in the associated product and production systems the Fraunhofer IST is making an important contribution in various projects to combating the current corona pandemic and to prevention and resilience.

SDG 6: Clean water

Enabling access to clean water for all people worldwide is an important goal of the UN. Furthermore, clean water also plays a significant role in the germ-free production of, for example, food or medical products. To ensure the availability and sustainable management of water and sanitation, the Fraunhofer IST focuses on:

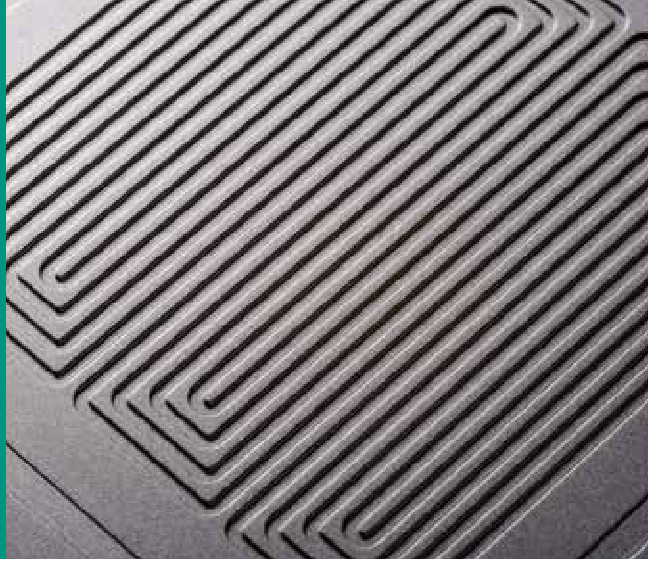
Clean (drinking) water for rural areas
In developing countries – in particular in rural areas – many people are today still without access to clean water. Numerous projects are currently addressing the development of new procedures for supplying these areas with clean water. One possibility for this is to purify and treat water from seas, lakes, rivers or wells. At the Fraunhofer IST, a system has been developed in which diamond-coated electrodes are used to disinfect the water. Electrochemical oxidation is thereby utilized to kill fungi, algae, bacteria and viruses and to decompose organic pollutants.

Aseptic (food) production
BIn the production of food and in the fields of medical technology and pharmaceuticals, ultrapure water is an indispensable starting material. The plants for the production of ultrapure water are, however, often colonized by germs after a certain period of time. The Fraunhofer IST is researching possibilities for cleaning these plants without the utilization of chemicals. One environmentally friendly and cost-efficient solution is presented by optimized cold sanitization using boron-doped diamond layers. This is based on an electrochemical process and requires neither additional chemicals nor increased temperatures. In order to prevent the formation of deposits on technical surfaces, known as fouling, the Fraunhofer IST is furthermore additionally developing special halogen-free non-stick coatings.

SDG 7: Affordable and clean energy

Against the background of climate change, energy generation utilizing wind, sun or water is playing an increasingly important role. Simultaneously, it is necessary to develop possibilities for using the available energy more efficiently. The Fraunhofer IST focuses on the following research activities to ensure access to affordable, reliable, sustainable and modern energy for everyone:

More efficient use of energy
Film systems from the Fraunhofer IST help to increase energy efficiency. One example of this is erosion-control films on aircraft engines. Very hard multilayer films comprised of ceramic and metal prevent excessive fuel consumption and decreasing efficiency. A further example is the development of electrochromic coatings for windows, which can, for example, reduce solar radiation in buildings, thereby lowering the air-conditioning costs. Energy optimization and efficiency improvements are also a topic in the sustainable factory planning offered by the Fraunhofer IST. So-called "data mining" in production – from data acquisition through to evaluation by means of machine learning methods – enables the identification of "drivers" as regards energy and resource consumption.



Energy storage for electric mobility
Energy storage technologies which are safer and more efficient are gaining constantly in importance in view of the heralded energy revolution and the anticipated boom in electric and hydrogen mobility. The institute is working intensively on, amongst other items, the development of functional films for batteries of both present and future generations, which increase the performance capabilities and service life of these systems for mobile and stationary applications. Furthermore, high-performance coatings are being developed for bipolar plates utilized in fuel cells and electrolyzers.

Clean energy from the sun
In order to promote the use of renewable energies, the technologies for energy generation must also be further developed. In this field, the Fraunhofer IST is addressing the development of solar cells with increased efficiency. Two specific examples are the production of semiconductor films for thin-film and silicon-based photovoltaics and the development of characterization methods for thin-film solar cells. In collaboration with the Fraunhofer institutes IKTS and CSP, the Fraunhofer IST is currently conducting research into modules for photocatalytic water splitting in order to produce hydrogen as an energy source.

SDG 9: Industy, innovation and infrastructure

Innovation research is an important keyword with regard to the sustainable and positive economic development of a society. With regard to the 9th sustainabe development goal of the UN, the Fraunhofer IST is working on the following topics:

Sustainable industrialization through sensor technology
In the era of Industry 4.0, the networking of production, logistics and customers is becoming increasingly important. Digitalization and automation of differing production processes play a major role in the development of sustainable industrialization.

The Fraunhofer IST is therefore performing research into the development of various thin-film sensors which enable force, pressure, strain or temperature measurements. So-called “smart tools”, intelligent tools with extended functions, enable highly accurate measurements of loads in a multitude of industrial application fields, increase production efficiency, and contribute towards fulfilling heightened safety requirements. As an example, modules with thin-film sensor systems are integrated into thermoforming devices and propulsion machinery in order to ensure a more efficient forming and processing of components.

Sustainable factory planning
A prerequisite of sustainable industrialization is an analysis of different life cycles. The Fraunhofer IST is therefore working on target-oriented and systemic factory planning in the field of battery cell production. Model-based planning, simulation and the operation of battery production systems are important factors thereby. The activities of the institute encompass the complete life cycle of battery systems – from raw materials through to battery recycling – and focus equally on technical, economic and ecological issues.

Innovation through simulation
The simulation and modelling of coating processes forms an important foundation for innovation. Based on data from a process simulation carried out at the Fraunhofer IST, it was possible to construct, for example, a “digital twin”, which enabled the development of highly complex precision optical filter systems.

SDG 12: Sustainable consumption and production patterns

The increasing scarcity of raw materials makes the development of sustainable consumption and production patterns an important goal for the UN. The Fraunhofer IST’s contribution to ensuring sustainable consumption and production patterns focuses on:

More efficient use of resources

At the Fraunhofer IST, innovative processes and materials are developed which reduce the use of raw materials during production. As an example, combination processes of atmospheric-pressure plasma procedures and electrochemical methods enable a more precise application of materials. Moreover, optimized hard-material and nanostructured film systems for forming, cutting or machining tools extend the service life of diverse facilities, which leads to a more economical and therefore resource-saving production. Furthermore, the development of new materials also plays an important role. By combining existing films and basic bodies, materials with new properties are realized at the institute.

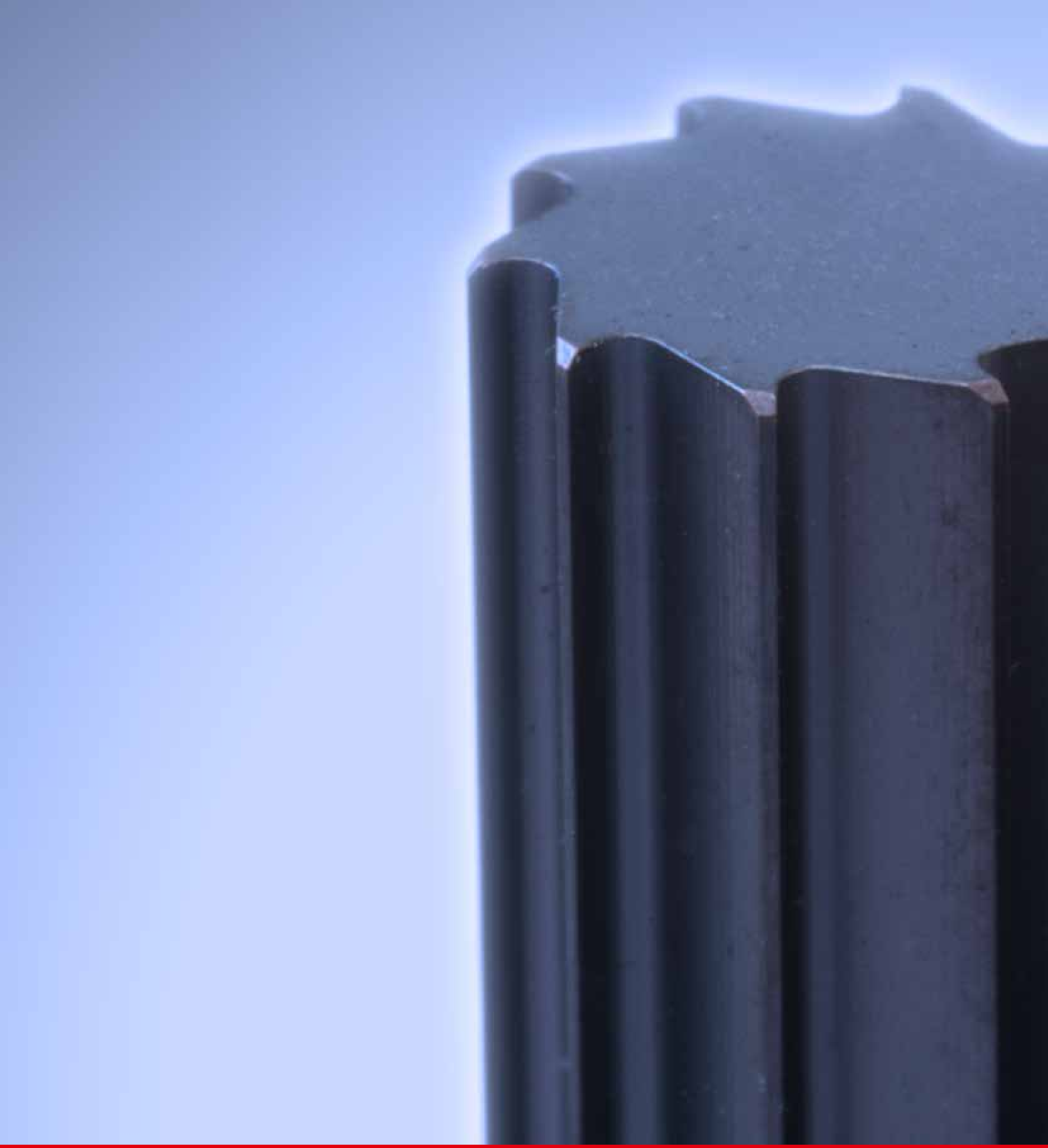
Simulation-supported production

A further thematic focus at the Fraunhofer IST is presented by the field of simulation and modeling. Simulations enable ever-shorter development times; highly efficient production chains, for example, can be realized through the model-based design and implementation of coating processes. Furthermore, by coupling specific simulation models, interactions between products and production systems become evaluable, thereby enabling savings potentials to be made visible. The development of cyber-physical production systems enables a more sustainable production design. Through the use of so-called "digital twins", design alternatives can be analyzed in real time.

Less waste

Recycling is an important keyword for the work at the Fraunhofer IST. In order to reduce the amount of waste and simultaneously promote the more environmentally friendly handling of chemicals, the institute is carrying out work in the fields of material development and substitution. Examples include the development of alternative materials and production processes, with the aim of replacing diverse environmentally harmful substances such as indium tin oxide (ITO) or chromium (VI).

SUSTAINABLE DEVELOPMENT GOALS



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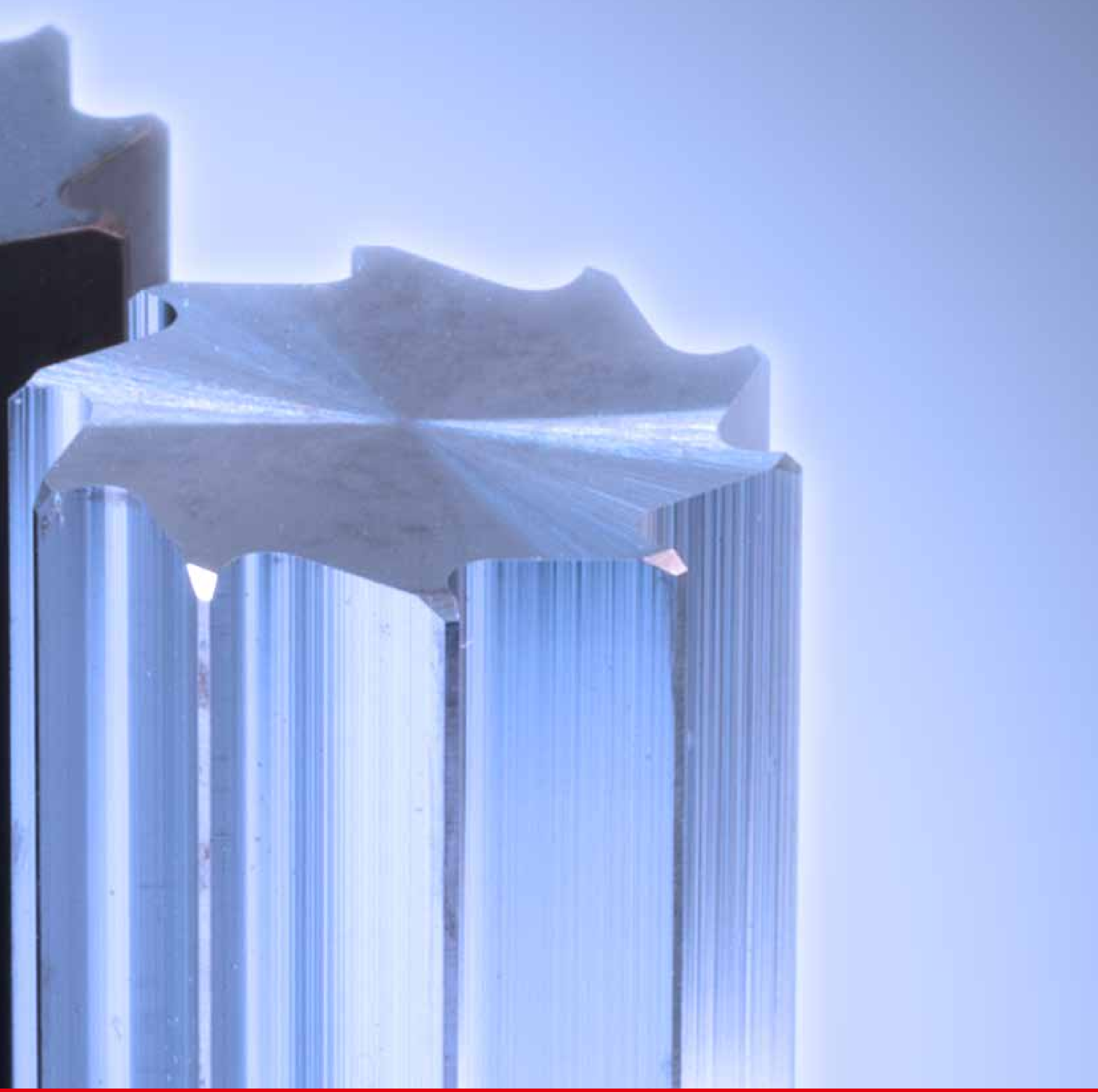

MECHANICAL ENGINEERING, TOOLS AND AUTOMOTIVE TECHNOLOGY

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SMART SCREW CONNECTION – THIN-FILM SENSOR REPORTS LOOSE SCREWS

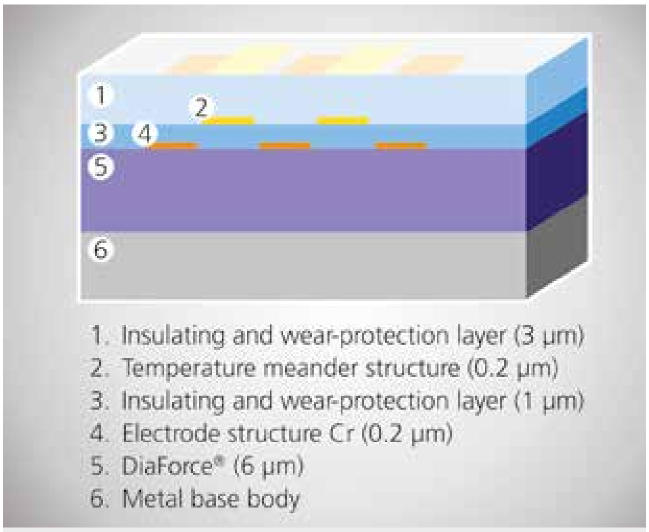
Screws in important joints such as in bridges, wind-power plants or machines on production lines which become loose over time pose a considerable safety risk. The research center IoT-COMMs – part of the Fraunhofer Cluster of Excellence Cognitive Internet Technologies CCIT – has therefore developed an intelligent screw connection which enables wireless and energy-independent monitoring. A thin-film sensor, developed at the Fraunhofer IST, thereby measures both the forces acting on the screw connection and changes in the ambient temperature at the installation site. The aim is the realization of an energy-independent monitoring of structures such as bridges, scaffolding or wind-power plants through permanent long-term surveillance.

Thin-film sensor technology

The integration of the sensor technology into the screw connection is performed at the Fraunhofer IST through the application of a thin-film system to the surface of washers. For this purpose, the piezoresistive DiaForce® film developed at the Fraunhofer IST is first homogeneously deposited on the washer by means of a PACVD process (plasma-assisted chemical vapor deposition). After this, individual electrode structures made from chromium are fabricated which form the sensor surfaces for the load measurement as well as a structure for temperature compensation (see Figure 3). On a subsequent electrically insulating SiCON® intermediate layer (a hydrocarbon film modified with silicon and oxygen which is also deposited using the PACVD process), both conductor paths to the contact points and a temperature-measuring meander structure made from chromium are composed. These structures are protected against abrasion by a second SiCON® sealing layer (adjacent Figure). On test rigs at the Fraunhofer IST, the temperature-dependent and load-dependent linear characteristics of each individual sensor structure can be measured.

Properties of the “Smart Screw Connection”

The smart screw connection is a fully integrated IoT device which enables wireless and energy-independent monitoring of screwed joints. For this purpose, the sensory washer system is connected to a screw body in which the power supply and data transmission are integrated (see Figure 1). With the aid of the wireless transmission technology mioty®, the sensor system regularly transmits measured values to a cloud-linked control body. Prior to assembly, the screws are configured in the manipulation-proof programming unit ”FunkeyBox” and receive their own security key. As a result, the sensor data is tamper-proof during transmission to the base station or backend. Thanks to energy harvesting technology the screw connection does not require an external power supply. Inside the screw is a thermogenerator which, when exposed to even the smallest temperature gradients, generates electrical energy via the screw thread. Alternatively, the sensor and transmitter can be powered by a solar cell or battery (see Figure 2).



Schematic representation of the thin-film system.

Outlook

Following a market study and user workshops, the achieved project results will be utilized to optimize and realize screws for three selected target applications and to make them available to potential users in the form of evaluation kits.

The project

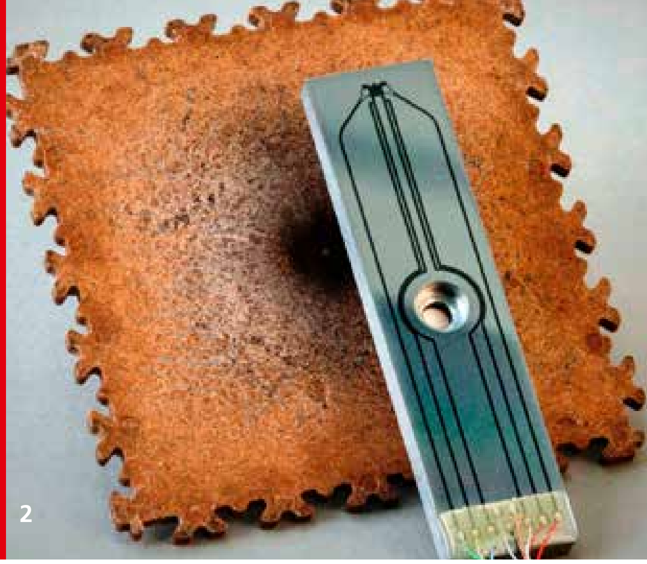
This solution is being developed within the framework of the Fraunhofer Research Center IoT-COMMs in collaboration with the Fraunhofer institutes IIS, IST and AISEC. The FIoT-COMMs is part of the Cluster Initiative CCIT (Cluster of Excellence Cognitive Internet Technologies) of the Fraunhofer-Gesellschaft.

1 *Deployment of the smart screw connection.*
2 *Wireless and energy-independent monitoring.*
3 *Sensory washer.*

CONTACT

Marcel Plogmeyer, M.Sc.
Phone +49 531 2155 661
marcel.plogmeyer@ist.fraunhofer.de

Anna Schott, M.Sc.
Phone +49 531 2155 674
anna.schott@ist.fraunhofer.de



SMART SURFACES FOR FUTURE-ORIENTED AUTOMOTIVE DESIGN – FRAUNHOFER IST@OHLF

Current megatrends such as the electrification of mobility and autonomous driving have an enormous influence on the design of the car of future generations. New business models such as "shared mobility" and (autonomous) taxi systems are playing an increasingly important role and changing the way we look at the vehicle, its functions and requirements. The focus is on longer running times and shorter stationary times, an individualized interior and different usage scenarios based on autonomous driving: the mobile office during the daily commute to work or to a meeting, a big shopping trip or group excursion, goods transport instead of unproductive waiting times, which today account for about 95 percent of the vehicle life. In addition, the automotive industry's requirements for sustainability and CO_2 efficiency are increasing, thus exerting a massive influence on future vehicle design. Several Fraunhofer Institutes are working together to develop solutions for the technological challenges of resource-saving and cost-effective lightweight construction as well as for increasing efficiency, reducing traffic-related emissions and recycling vehicle components. The Fraunhofer IST focuses on the further development of smart surfaces such as surface-integrated thin-film sensors.

Four Institutes pool their expertise in the Fraunhofer Project Center in Wolfsburg

The Fraunhofer Society is a partner in the Open Hybrid LabFactory (OHLF) research campus, which was established at the Wolfsburg site as a public-private partnership for the research field of mobility. In 2014, as part of OHLF's activities and with the support of the state of Lower Saxony, Fraunhofer founded a project center in which the Fraunhofer Institutes for Manufacturing Technology and Advanced Materials IFAM, for Surface Engineering and Thin Films IST, for Machine Tools and Forming Technology IWU and for Wood Research WKI are represented. Within their joint infrastructure, the Institutes are pooling their expertise in materials science, component and process development, and production technology to develop integrated system solutions for future mobility. One focus lies on the combination of light metals and fiber-plastic composites in hybrid lightweight construction with a focus on vehicle structure. Other research fields address the interior, flexible production and, in cooperation with the Fraunhofer Project Center for Energy Storage and Systems ZESS, the integration of energy storage systems for alternative propulsion systems into the overall vehicle.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Future production of surface-integrated thin-film sensors with a matrix-based production system

The Fraunhofer IST extends the expertise of the Project Center Wolfsburg through its extensive experience in the field of coating technologies, especially micro- and sensor technologies with the development of smart surfaces. In close partnership with the Institute of Machine Tools and Production Technology IWF at the TU Braunschweig, a matrix-based production system is currently being developed which will allow the flexible and efficient production of functional layers and surface-integrated thin-film sensors in the starting constellation. The planned integration into the Open Hybrid LabFactory system technology will allow an extension of the processes for functionalization and individualization of components from conventional production methods. Possible approaches can be found in the interior, for example in the area of smart surfaces, the condition monitoring of passengers and the autonomous vehicle, or in production engineering via tool-integrated sensors for intelligent process control.

Background information

The public-private partnership Open Hybrid LabFactory eV (OHLF) was initiated in 2012 under the leadership of the Automotive Research Centre Niedersachsen at TU Braunschweig and is funded within the framework of the BMBF initiative "Research Campus – Public-Private Partnership for Innovations". The aim is to develop material, manufacturing and production technologies suitable for large-scale production for the economically and ecologically sustainable manufacture of hybrid lightweight components made of metals, plastics and textile structures.

1 *A view of the technical center at the Wolfsburg OHLF project center.*
2 *Sensory inserts for the efficient production of natural fiber reinforced plastics.*
3 *The Fraunhofer Project Center Wolfsburg at the OHLF.*

To this end, OHLF is mapping the entire value-added chain for hybrid components: from conceptual design, semi-finished textile products and organic sheet production as well as production processes for hybrid components to the life cycle design and engineering including recycling. Partners in the Open Hybrid LabFactory are, in addition to the research institutes TU Braunschweig and the Fraunhofer Gesellschaft, industrial partners such as Volkswagen AG, Magna Cosma, Magna Exteriors & Interiors, thyssenkrupp, IAV, Engel, Zwick/Roell and the city of Wolfsburg. In addition, over 20 project-related research and industrial partners are members of OHLF.

The establishment of the Fraunhofer Project Center Wolfsburg is supported by state funds of the "Niedersächsisches Vorab" (funding number: VWZN2990).

CONTACT

Dr.-Ing. Torben Seemann
Phone +49 531 2155 605
torben.seemann@ist.fraunhofer.de


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MEASUREMENT METHODS FOR THE EVALUATION OF MATERIALS FOR HYDROGEN TECHNOLOGIES

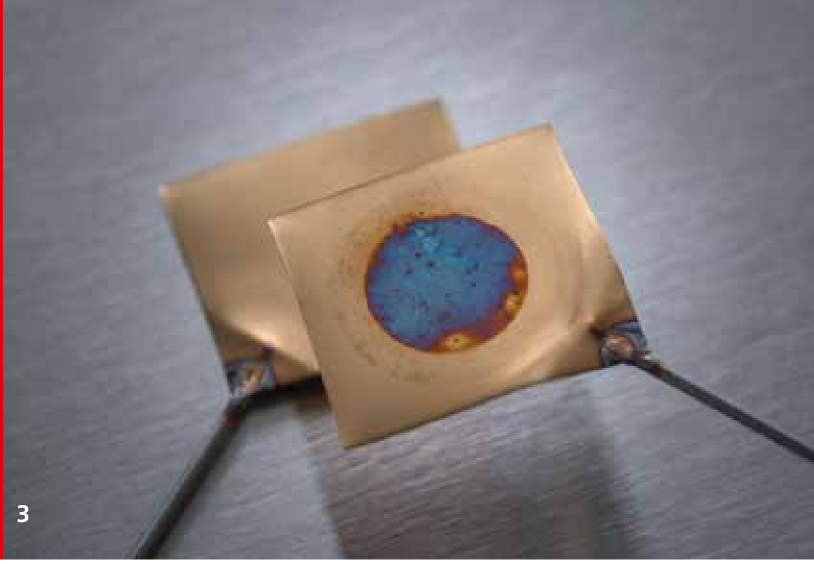
The energy revolution is crucial for a secure, environmentally compatible and economically successful future. With the aim of realizing a sustainable energy supply, the development of climate-friendly hydrogen technologies is increasingly being focused upon in Germany. In addition to the infrastructure and storage of hydrogen, special material properties are decisive. One example of energy generation from hydrogen is the fuel cell. During application, the components of a fuel cell have to fulfill partially contradictory requirements. The bipolar plate, for instance, is required to have high corrosion resistance and, at the same time, high electrical conductivity. In order to enable the qualitative measurement of these properties and the consequent improvement of the surface coatings and modifications with regard to these requirements, the Fraunhofer IST, in collaboration with the Institute for Surface Technology (IOT) at the TU Braunschweig, has developed suitable measurement procedures for the assessment of differing materials and surface treatments.

Challenges in fuel-cell development

The fuel cell harbors great potential for a sustainable energy supply. A fuel cell consists of several stacks. A core element within a stack is the bipolar plate (BPP), which simultaneously fulfills various tasks. In addition to the electrical connection of the cells, it is responsible for cooling and transporting the reaction gases respectively reaction products via a channel structure. This results in various requirements for the properties of the bipolar plate, such as high electrical and thermal conductivity, high corrosion resistance, low material and manufacturing costs, and high gas tightness. The utilization of low-cost metallic bipolar plates suitable for series production is currently limited by the required corrosion resistance in combination with sufficient electrical conductivity.

Corrosion measurement device

The basis for the electrochemical corrosion measurement of materials is a potentiostat. In the measuring cell, the material to be tested is brought into contact with an electrolyte and connected as a working electrode. Through the application of a cell voltage, an electric current flows between the substrate and the counter electrode, whereby the electrode potential between the substrate and the reference electrode, e. g. Ag/AgCl, is measured. The measurement setup at the Fraunhofer IST was thereby modified to such an extent that a test can be carried out in accordance with the stipulated requirement of the Department of Energy (DOE).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The following test variations are possible:

- Measurement with constant voltage (static) or over a defined range (dynamic)
- Variation of the electrolyte (e. g. H_2SO_4 and NaCl), the gassing (O_2 and N_2) and the reference electrodes
- Variation in temperature control and purging with various gases.

1 *Contact-resistance measurement device.*
2 *Corrosion measurement device.*
3 *Corrosion on a coated sample.*

Device for contact-resistance measurement

A converted material-testing machine from the Zwick company can be used to analyze surfaces. This includes contact resistance, which describes the electrical resistance of a contact surface and is therefore a measure of the conductivity of a surface. In conductivity tests of this kind, it is customary to vary the normal force within certain limits. In order to be able to perform the measurement in accordance with the DOE, a modified measurement method was developed and validated at the Fraunhofer IST. The table below summarizes the possible measurement methods.

Benefits of the measurement methods for the application

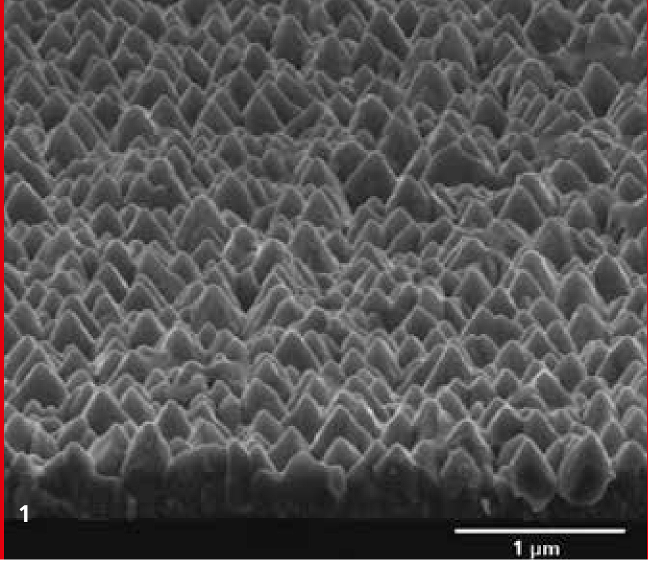
With the developed measuring procedures, it is now possible to compare and evaluate materials and layer systems for application in hydrogen technology and to develop them further through a deeper understanding of the interrelationships. Other possible applications in which these measurement processes and methods can support material characterization include tanks, pipes or valves for the storage and transport of hydrogen.

	Davis Method	Wang Method	Measurement method modified at the Fraunhofer IST
Suitability	Comparison purposes (before/after)	Contact resistances	Contact resistances
Special feature	Rapid assessment of surface modification	Fulfills requirement of DOE	Fulfills requirement of DOE (correlated with Wang method)
Preparation outlay	Low, as only comparative	High, as only valid for samples with same surface properties on both sides (roughness, coating thickness, etc.)	Low, as valid for samples treated on one side

Advantages and disadvantages of different methods of measuring contact resistance.

CONTACT

Phillip Marvin Reinders, M. Sc.
Phone +49 531 2155 835
phillip.reinders@ist.fraunhofer.de



ANTI-ADHESIVE SYSTEMS FOR PLASTICS MOLDING

The reliable production of high-quality and optical plastic products with very smooth surfaces is often massively impeded or even prevented by the adhesion of polymers to the polished mold surface. Within the framework of the IGF project "GLANZFORM", the Fraunhofer Institute for Surface Engineering and Thin Films IST was successful in further developing anti-adhesive coating systems for tools. These enable a significant reduction in demolding forces without impairment of the quality of the component surface.

Challenges in the molding of high-quality plastic components

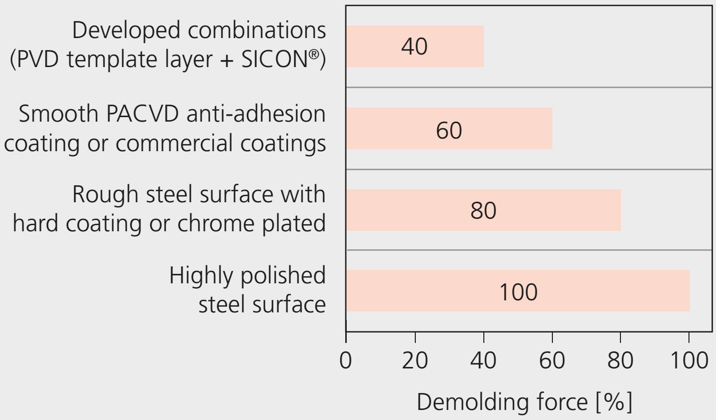
In injection molding or hot-stamping processes for the production of high-quality plastic products, new innovations are constantly required as a result of rising customer demands together with ecological and economic parameters such as increased requirements for sustainability and efficiency. Products such as optical, medical and microsystem-technology components, as well as credit and ID cards and decorative and interior elements with high-quality or optical surfaces are subject to the demand for the highest surface quality. This, in turn, is primarily determined by the surface of the molding tool and its reliable molding process. With increasing surface quality of the mold, however, the molding forces increase disproportionately, which can severely impair component quality and prevent efficient production.

One means of reducing molding forces during plastic molding is to coat the tool with an anti-adhesive layer with the lowest possible surface energy and low polar content, such as silicone-containing coatings, or the use of release agents, which are utilized in many production processes.

For many plastic-molding processes, however, satisfactory and flexibly applicable adhesion-reducing coating solutions which fulfill the high demands on surface quality have not existed up to now. Many established coatings lead to a roughening of the polished mold surface and are not sufficiently adhesion-reducing or wear-resistant.

Our solution approach

The task of the Fraunhofer IST within the described project was the development of tool coatings which reduce adhesion or molding forces. This was achieved through chemical means by minimizing the intermolecular interaction between the tool surface and the polymer and simultaneously through mechanical means by setting a defined roughness in the sub-micrometer range. For this purpose, PVD/PECVD (physical vapor deposition/plasma enhanced chemical vapor deposition) combination coating systems consisting of Cr/CrN and a-C:H:Si:O layers (SICON®) were developed. It was possible to adjust the topography of the Cr/CrN layers by means of parameter variation during PVD magnetron sputtering in such a way that they could serve as a target-oriented template layer for the anti-adhesive SICON® layer..



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Results and application

Through the developed PVD/PECVD combination coating systems, the associated modification of the surface chemistry and supplementary reduction of the adhesion forces via controlling of the contact surface by means of targeted adjustment of the roughness, it was possible to achieve an adhesion-force reduction of approx. 60 percent compared to highly polished steel surfaces in the hot-stamping of polyethylene terephthalate (PET). With this coating system, it was possible to demonstrate improved demolding in the hot-stamping of optical components without any significant deterioration in the surface quality of high-gloss surfaces in an industrial environment.

This was also achieved for the first time in the specific area of very smooth surfaces (Sa ≤ 20 nm), which are typical for high-gloss plastic surfaces. As a result, new and innovative approaches to the design of tool surfaces are possible in the application, which could make the use of release agents or molding-compound additives for easier demolding superfluous in the future. These advantages can also be exploited by coating companies, whose production results can be optimized not only by adjusting the surface chemistry but also through the adjustment of the surface topography as a further correcting variable.

Outlook

The developed approach, consisting of topography adjustment and adapted coating, is to be further developed for other coating systems, in particular for tools in polymer molding. In collaboration with the project partners, the Fraunhofer Institute for Structural Durability and System Reliability LBF in the area of polymer molding and the Fraunhofer Institute for Mechanics of Materials IWM in the area of modeling, an expandable and openly usable database for process, material and tool-surface designs for more efficient, demolding force-optimized and sustainable plastic-molding processes is to be developed.

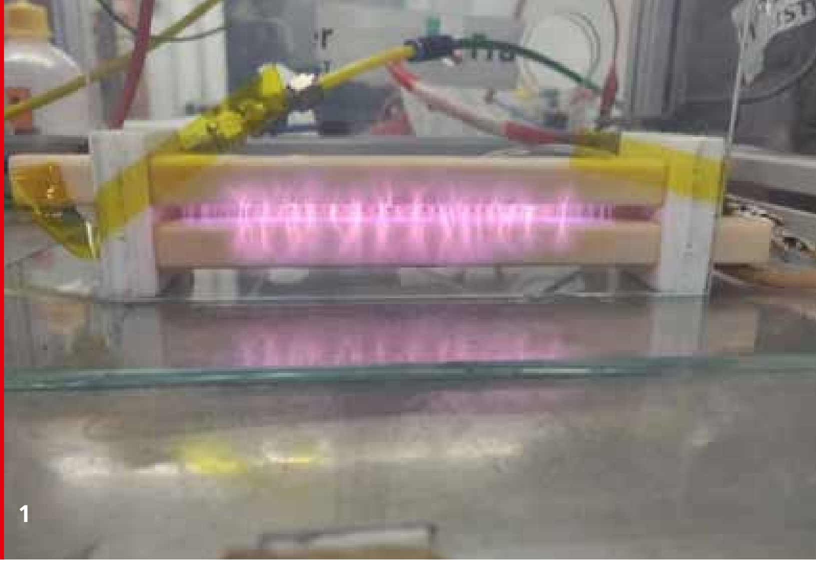
1 *SEM image. Topography of a Cr template coating.*
2 *Adhesion forces during hot-stamping of PET.*
3 *Coated hot-stamping tool surface with water droplets.*

The project

The IGF project "Glanzform" (19545 N) of the Forschungsvereinigung Forschungsgesellschaft Kunststoffe e. V. (FGK), Haardtring 100, 64295 Darmstadt, Germany was funded by the German Federal Ministry for Economic Affairs and Energy via the AiF within the framework of the program for the promotion of joint industrial research and development (IGF) on the basis of a resolution of the German Bundestag.

CONTACT

Dr.-Ing. Martin Keunecke
Phone +49 531 2155 652
martin.keunecke@ist.fraunhofer.de



INVESTIGATION OF VUV RADIATION IN DIELECTRIC BARRIER DISCHARGE PROCESSES

Vacuum ultraviolet (VUV) radiation, which covers the spectral range from 100 to 200 nm, is extremely energy-rich and can break organic bonds. This property can be used, amongst other things, to crosslink polymer surfaces and thereby create migration barriers for harmful phthalate-containing plasticizers in PVC. A special VUV spectrometer is used at the Fraunhofer IST in order to characterize and optimize such processes.

Investigation of VUV radiation in atmospheric-pressure plasma processes

Through dielectric barrier discharges (DBD) at atmospheric pressure, VUV radiation can be effectively generated (see Figure 1). DBD treatment is therefore suitable for the production of migration barriers on polymer surfaces. In order to optimize this process, VUV radiation was measured at the Fraunhofer IST within the framework of the project "Vernetzung von weichmacherhaltigen PVC-Oberflächen durch plasmaerzeugte UV-Strahlung und Gasphasen-fluorierung" (Crosslinking of plasticizer-containing PVC surfaces by means of plasma-generated UV radiation and gas-phase fluorination) using a special VUV spectrometer which enables the analysis of short-wave UV radiation in the range from 100 to 300 nm in atmospheric-pressure plasma processes. In this way, the influence of various DBD process parameters (such as gas composition, power, and purge duration) on VUV emissions – and, consequently, on the creation of migration barriers – can be investigated.

A major challenge in the measurement of VUV radiation is the strong absorption by most media such as air, water, glass and polymers. For this reason, both the spectrometer itself and the entire experimental setup used to generate the radiation must be purged with a suitable gas – in this case, argon. VUV radiation was generated in a simple DBD configuration and the influence of the composition of the gas atmosphere on the emission was investigated. Minimal admixtures in the range of 0.1% oxygen, nitrogen or water to the argon process gas lead to an almost complete absorption of shortwave UV radiation below 200 nm (see adjacent Figure on the left). Through the addition of helium to the argon, the VUV intensity is increased by 50 percent (see adjacent Figure on the right). The composition of the gas atmosphere therefore strongly influences the short-wave UV emission. Through the higher VUV intensity, process speeds of UV-based treatments can be increased and energetic efficiencies can be improved.

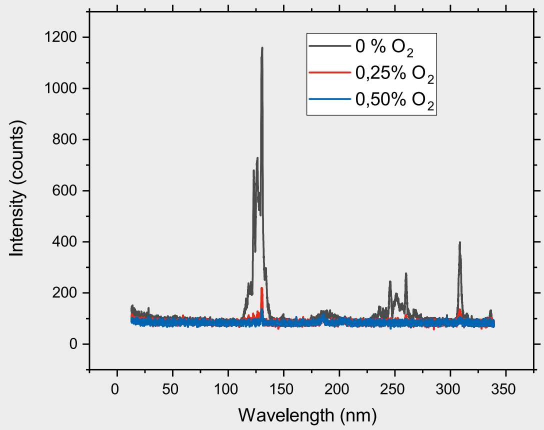
1 *Dielectric barrier discharge for the generation of plasticizer migration barriers in PVC.*

Outlook

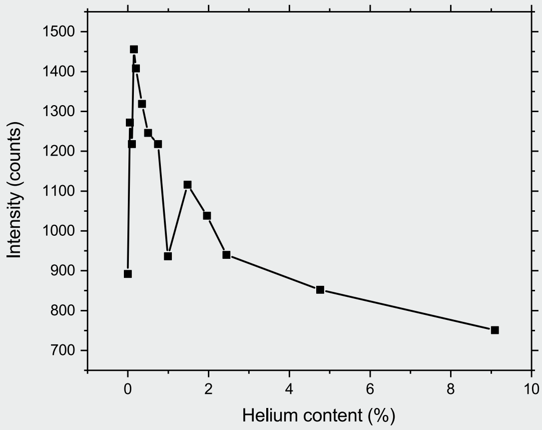
The possibilities at the Fraunhofer IST for the spectroscopic analysis of short-wave UV radiation in the range from 100 nm to 300 nm in atmospheric-pressure plasma processes offer an important prerequisite for an improved understanding of plasma-based processes and their optimization. The aim is to utilize this to accelerate the process speeds of, in particular, the UV-radiation-based effects of surface treatment – such as crosslinking, polymerization or disinfection – in order to enable their industrial application.

The project

The project was funded under grant number 20542 BG within the framework of the program for the promotion of joint industrial research (IGF) by the German Federal Ministry for Economic Affairs and Energy on the basis of a resolution of the German Bundestag.



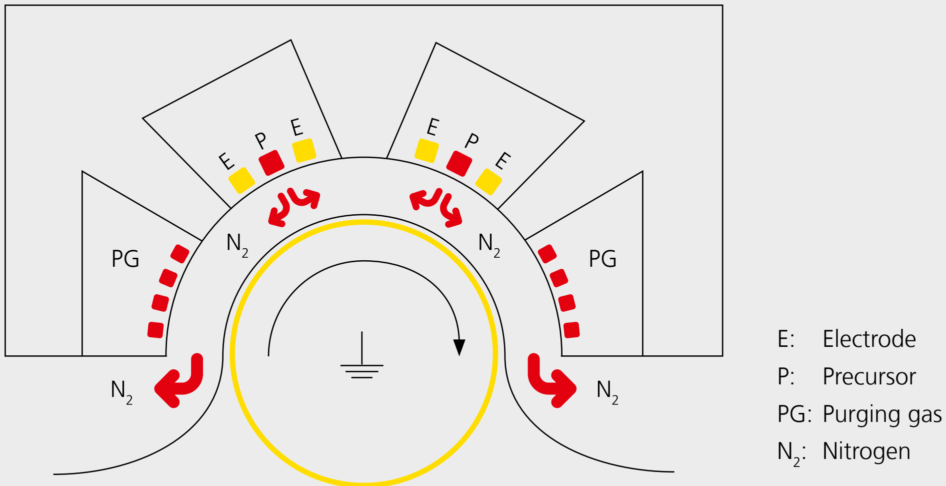
VUV emission spectra for argon with various oxygen impurities.



VUV plasma intensity for argon with various helium impurities.

CONTACT

Dr. Thomas Neubert
Phone +49 531 2155 667
thomas.neubert@ist.fraunhofer.de



1

ADHESIVE-FREE JOINING OF PLASTIC-METAL FILMS

Innovative materials form the basis for modern industrial products in all areas of life. The market for products such as special films for food packaging, flexible printed circuit boards or decorative and protective films is expanding continuously. The challenge: These materials have to fulfill a multitude of requirements. They must, for example, be optically transparent, temperature-stable, easy to process, or permeable to oxygen and water vapor. When such complex functions are relevant, composite films are particularly suitable, as they are comprised of differing layers and therefore combine differing material properties. These composite materials often consist of plastics and metals and are bonded using differing adhesives, which results in undesirable side effects such as the consumption of large quantities of adhesive, a lack of long-term stability, a tendency to creep, and migration. The Fraunhofer IST is therefore working on a new adhesive-free low-temperature joining process as an alternative for the joining of plastic and metal foils made from aluminum and polyethylene.

Alternative for joining plastic and metal films

In the new adhesive-free, low-temperature joining process, thin layers are applied to the polymer and metal surfaces by means of atmospheric PECVD (plasma-enhanced chemical vapor deposition) in the form of a nanometer-thick "adhesive layer" which covalently bonds to the activated films. In a subsequent step, the materials are bonded using a thermocompression bonder at moderate pressure (1.85 N/mm^2) and low temperature (< 100 °C). The best results were obtained when bonding polyethylene to aluminum with adhesive forces of more than 13 N/cm. Through optimal adjustment of parameters such as treatment time/rolling speed, precursor concentration, plasma power and film thickness, composites with high long-term stability can be produced.

Results

Using the approach described, it was possible to successfully deposit chemically reactive ultra-thin films which, after subsequent joining, can be utilized in the production of composite materials, e.g. from aluminum and polyethylene films. The following observations were made (see Figure 1):

- The composites exhibit high bonding strength and very good long-term stability.
- A strong influence of the layer thickness of the AP-PECVD coating on the bonding strength exists. The coating thickness can be achieved through treatment speed, doubling of the electrode system and by increasing the precursor concentration.
- Activation by means of air plasma prior to coating (A+B) leads to increased bonding forces up to cohesive failure (*) of the film and significantly increases the reproducibility.

2

3

1 *Schematic representation of Aldyne® plasma system for layer deposition.*

2 *Ignited plasma in Aldyne® system.*

3 *Examination of bonding strength between composite materials via peel tests.*

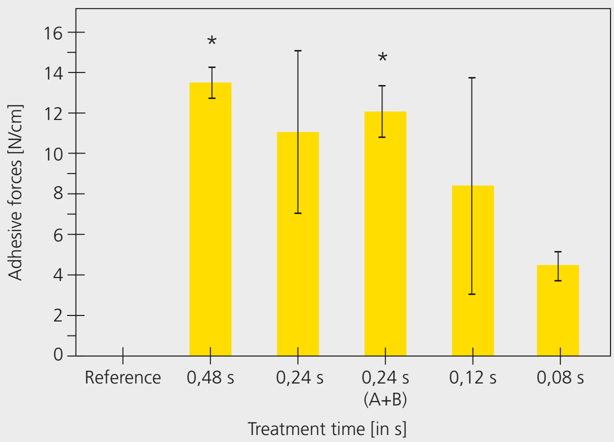
– In the pre-treatment process, a higher dosage of corona discharge leads to a further increase in bonding strength and reproducibility through cleaning, activation and etching processes.
– An oxygen-free atmosphere between pre-activation and coating supports adhesion.
– There exists a strong influence of the storage time of freshly treated films before joining between coating and bonding.

Outlook

In the future, the results are to be transferred to a combined roll-to-roll process, in which both coating and joining take place, and to other material combinations, in particular to future-oriented bio-based materials such as polylactides (PLA), bio-polyethylene and cellulose-based polymers.

The project

The project "Entwicklung eines kontinuierlichen Rolle-zu-Rolle-Verfahrens für das klebstofffreie Niedertemperaturfügen von Kunststoffen mit verschiedenen Materialien" (Development of a continuous roll-to-roll process for the adhesive-free low-temperature joining of plastics with various materials) NTF4R2R with a duration of 01.06.2017 to 30.11.2019 was funded under the grant number 19571 BG within the framework of the program for the promotion of joint industrial research (IGF) by the German Federal Ministry for Economic Affairs and Energy based on a resolution of the German Bundestag.



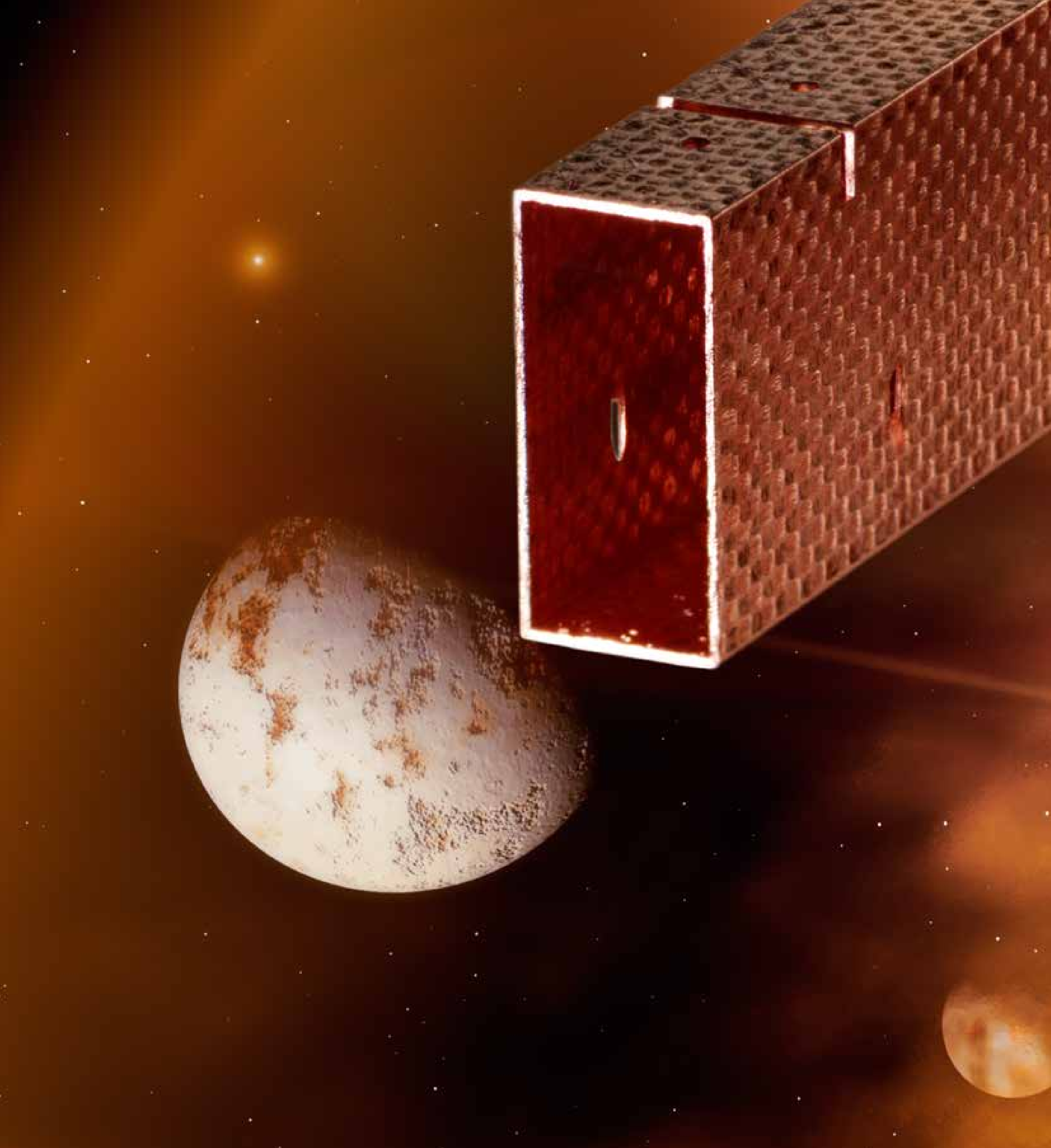
A = Activation, B = Coating, * = Film torn

Bonding strength between composite materials in relation to parameters of treatment.

CONTACT

Annika Mann, M.Sc.
Phone +49 531 2155 639
annika.mann@ist.fraunhofer.de

Dr. Kristina Lachmann
Phone +49 531 2155 683
kristina.lachmann@ist.fraunhofer.de



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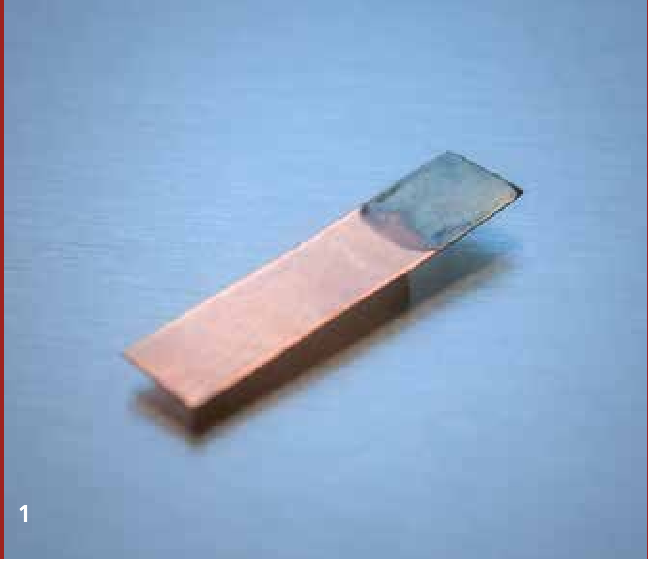
AEROSPACE

2020



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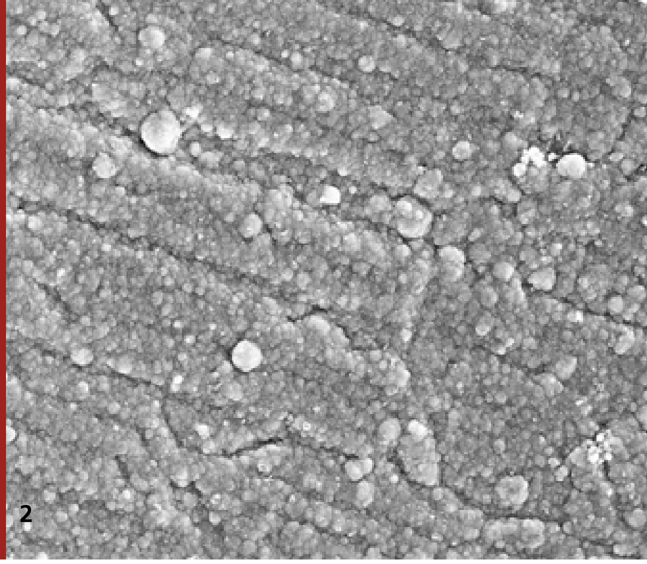


2

CLOSED-LOOP ELECTROCHEMICAL PROCESSES FOR THE EXTRACTION OF PURE ELEMENTS FROM LUNAR REGOLITH

An important prerequisite for a long-term and sustainable human presence on the moon is the availability of resources such as pure metals and oxygen in order to construct, for example, building accommodation, a research station and the necessary infrastructure for astronauts. The so-called lunar regolith, loose rock found on the surface of the moon, consists of metal oxides such as iron, titanium, aluminum and magnesium. In these oxides, oxygen is present in a bound form, thereby accounting for around 50 percent of the total mass. In order to make both the oxygen and the metals in their pure forms available to humans, a process under space conditions without consumable materials is necessary. In collaboration with the Institute of Space Systems (IRAS) at the TU Braunschweig, the Fraunhofer IST is working on a procedure for extracting pure elements from lunar regolith, considering the conditions prevailing on the moon.

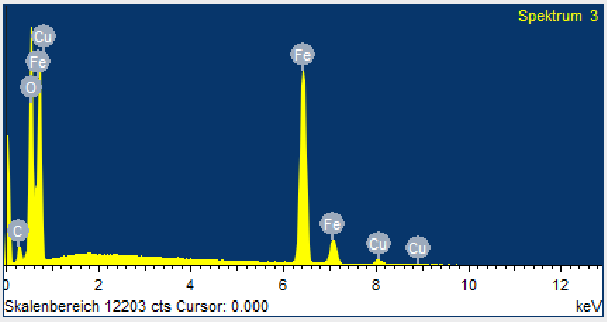
Electrochemical deposition of pure metals from regolith

As a result of the lack of genuine lunar regolith (the Apollo and Luna missions only brought around 360 kg of the material back to Earth), so-called regolith simulants – such as the European Astronaut Centre lunar regolith simulant 1 (EAC-1A) or the Johnson Space Center-developed lunar simulants JSC-1A and JSC-2A – must be utilized for the development of processing technologies.

The goal is to extract metals and oxygen from regolith (or rather the simulants). Ionic liquids are the solvent of choice. They can be used not only to dissolve oxides but also to produce electrochemically oxygen and even metals such as aluminum, titanium and magnesium as well as silicon, that are not accessible in aqueous media.

Advantages of ionic liquids as solvents

Ionic liquids are organic salts which are liquids at temperatures below 100 °C. They have negligible vapor pressure and do not evaporate in a vacuum. Consequently, no risk of material loss or environmental contamination exists – even on the moon. As ionic liquids are often sensitive to moisture, special safety precautions must be taken when processing them on Earth, for example the application of dry inert gases such as nitrogen or argon. This is not necessary on the moon, as a vacuum is present there. As a result, moisture is not a problem, and the process control is therefore simplified enormously.



3

1 *Dissolution of iron oxide in ionic liquid and subsequent galvanic deposition as iron without consumable materials.*

2 + 3 *SEM image of iron deposits on the copper substrate and corresponding EDX profile.*

The project

The aim of the "ELMORE" project is the dissolution of regolith by means of modern electrochemical procedures within a closed-loop system and the deposition of the desired pure metals as well as the capture of the oxygen generated thereby. In a first process step, the regolith simulants produced by IRAS are chemically dissolved in ionic liquids and the metal ions are subsequently converted into the corresponding pure metals. The electrochemical deposition of the metals thereby takes place at the cathode. Simultaneously, oxygen is generated at the anode.

Results

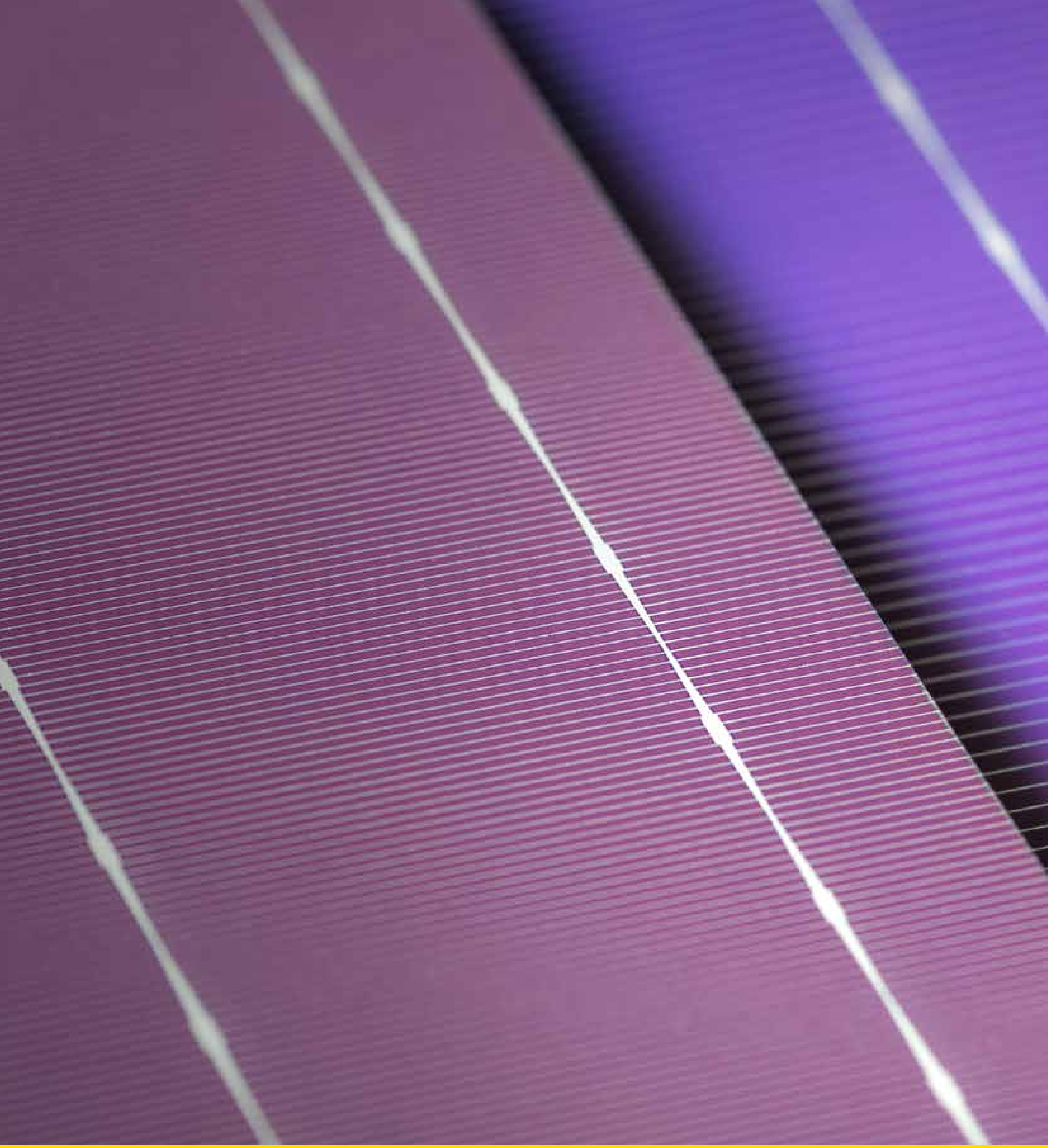
For a proof of concept, iron oxide as a component of regolith was chemically dissolved in ionic liquids and subsequently electrochemically deposited on a copper substrate at 100 °C (see Figure 1). Figure 2 shows the SEM image of the iron deposition on the copper substrate. Figure 3 shows the EDX profile of the iron layer deposited on the copper. This iron layer did not contain any impurities except oxygen as a result of rapid oxidation of iron in air and formation of iron oxide.

Outlook

The available results represent solely the simple metal-oxide dissolution and its electrochemical extraction. In a next step, the proof of concept is to be transferred to simulants of lunar regoliths. At the Fraunhofer IST, investigations are being carried out into how metal oxides dissolve at various temperatures in differing ionic liquids. Subsequently, regolith is to be dissolved in ionic liquids. Further experiments are planned in which metals such as aluminum and iron will be deposited potentiostatically or galvanostatically at the cathode, whilst oxygen is released at the anode. The advantage of this procedure is the transfer to processes that are environmentally friendly; the terrestrial production of e. g. iron or aluminum is a process which emits large quantities of CO_2. The energy demand for the lunar process of aluminum extraction is around 7 kWh/kg aluminum. In comparison, terrestrial procedures require 15 kWh/kg aluminum as a result of the upstream smelting process.

CONTACT

Dr. Essam Moustafa
Phone +49 531 2155 673
essam.moustafa@ist.fraunhofer.de



ANNUAL REPORT 2020

2020

ENERGY AND ELECTRONICS

1


2

ENERGY STORAGE SYSTEMS OF THE NEXT GENERATION

Fewer emissions, more climate protection. In order to reduce CO_2 emissions and preserve the environment, electrification requires advances in the development and production of stationary and mobile energy storage systems. The Fraunhofer Institute for Surface Engineering and Thin Films IST is addressing these challenges. At the Fraunhofer Project Center for Energy Storage and Systems ZESS in Braunschweig, next-generation energy storage devices are being developed, such as lithium solid-state batteries which, in contrast to established Li-ion batteries, use a solid as opposed to a liquid electrolyte. The advantages are more power and increased safety. In addition to the manufacture of energy storage systems, the focus of the Fraunhofer IST at ZESS is the engineering of their entire product life cycle, including raw material extraction, production, use, and end of life.

New research building in Braunschweig for battery development

At the Research Airport Braunschweig, which covers more than 5,000 m², modern working environments and laboratories for research on stationary and mobile energy storage systems are being built. The heart of the building is formed by a drying room with almost 400 m² of production space, and whose ambient air enables the safe processing of battery materials. In this environment, energy storage systems are to be developed and manufactured in accordance with industry-oriented standards. Through comprehensive networking of the building and plant technology, interactions between material properties, process parameters and product performance can be examined and the production environment optimized.

The design of the drying room, laboratories and working environments has already achieved a high level of detail. The new Fraunhofer ZESS building is scheduled for completion in 2023.

Research start in the transitional technical center

The production of energy storage systems places high demands on the flexibility of the facilities and the conditioning of the production environment. In order to conduct practical research activities prior to the completion of the new building, a transitional technical center has been established at the Automotive Research Centre Niedersachsen (NFF) of TU Braunschweig. At this center the entire process chain is mapped from material synthesis through to formation. Here, the Fraunhofer institutes IST, IKTS and IFAM, which are participating in the Project Center ZESS, apply their expertise in battery research to further develop and evaluate the production processes on a laboratory scale. The technical equipment for processing, analysis and measurements were put into operation at the end of 2020. This includes three gloveboxes that enabled the processing of sensitive materials in an inert gas atmosphere (see Figure 3). The production processes can subsequently be implemented on a resized scale in the research infrastructure of the new building.

1 *Illustration of a holistic approach to battery cell production.*

2 *Planned new ZESS building.*

3 *Gloveboxes in the new technical center.*

Outlook:
Sustainable energy supply and mobility

The goal of the Fraunhofer Project Center for Energy Storage and Systems ZESS is to develop efficient, climate-friendly energy storage systems up to industrial maturity.

Our application-oriented research benefits not only the environment but also economic sectors which develop solutions for sustainable energy supply and mobility. An essential component of project success is collaboration with strong partners. At the Fraunhofer ZESS, the Fraunhofer institutes for Manufacturing Technology and Advanced Materials IFAM, for Ceramic Technologies and Systems IKTS, and for Surface Engineering and Thin Films IST are working together with TU Braunschweig to develop system solutions for batteries and fuel cells in the field of electromobility, and stationary storage systems.

CONTACT

Dipl.-Ing. Sabrina Zellmer
Phone +49 531 2155 528
sabrina.zellmer@ist.fraunhofer.de

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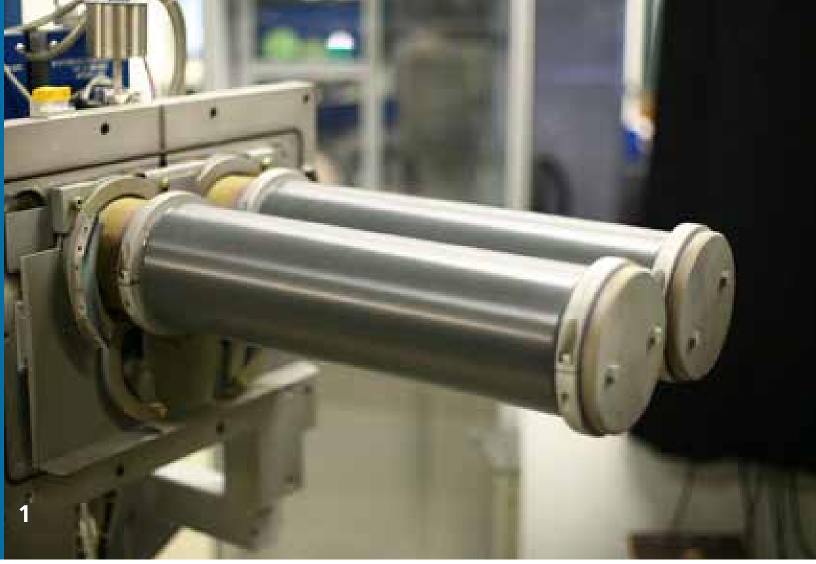


UV BANDPASS FILTER FOR SUN OBSERVATION

In June 2022, the balloon-borne solar observatory "Sunrise III" is scheduled to begin its journey. The aim of the mission is to investigate the magnetic fields and convective plasma flows of the lower solar atmosphere. On board are bandpass filters developed and manufactured at the Fraunhofer Institute for Surface Engineering and Thin Films IST; their task is to restrict the wavelength range on the detectors to the wavelengths which are to be investigated and to block higher orders.

Bandpass filters block light from the UV to NIR spectral range

Within the framework of the "Sunrise III" mission, the sun will be studied using a telescope from a flight altitude of around 37 kilometers. The central component is the UV spectropolarimeter (SUSI) built by the Max Planck Institute for Solar System Research. This will be used to study the 300 to 430 nm range, which is not possible from Earth due to disturbance caused by the atmosphere. In addition to high sensitivity in the ultraviolet spectral range, low noise levels are also required.

This is ensured by the bandpass filters developed at the Fraunhofer IST. The scientists at the Institute have calculated a layer design for a total of four bandpass filters with central wavelengths between 399 nm and 316 nm and a minimum transmission of 80 percent.

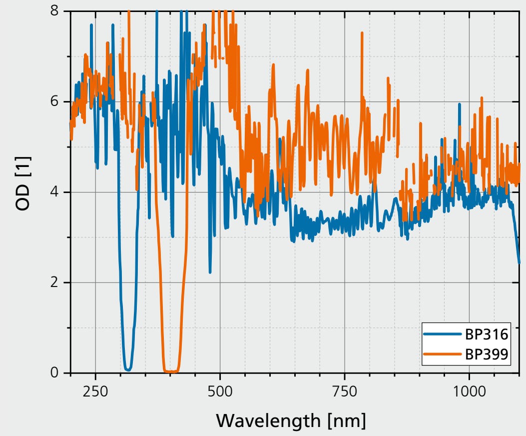
Together with the required blocking of up to OD5 in the range from 200 to 1100 nm, more than 200 layers with a total thickness of 21 to 23 µm were required in each respective case. A special feature is that bandpass and blocker were applied on one side in order to avoid multiple reflections. On the reverse side, one silicon oxide layer was applied for stress compensation, together with an anti-reflective system consisting of four layers. As a result, the back reflection in the transmission wavelength range could be held below 0.2 percent.

Production of the bandpass filters

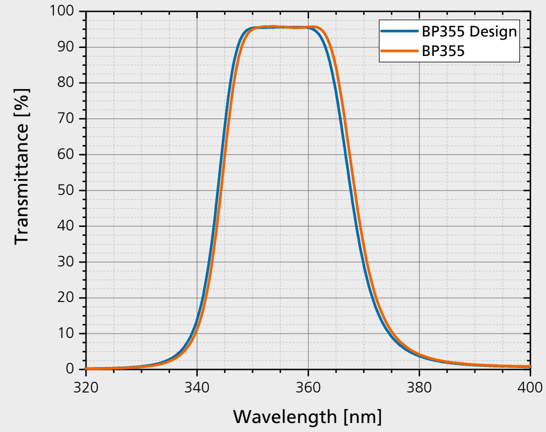
The filters were deposited on the EOSS® coating system (Enhanced Optical Sputtering System) developed at the Fraunhofer IST. Coatings for filters in the ultraviolet spectral range must fulfill special requirements, as below 400 nm the absorption and scattering increase significantly. During the production of the filters for the "Sunrise III" mission, the

Central wavelength (CWL)	Full width at half maximum (FWHM)	Layers	Total thickness
316 nm	18 nm	252	21,6 µm
327 nm	20 nm	230	21,3 µm
355 nm	24 nm	216	21,3 µm
399 nm	32 nm	227	23,4 µm

Properties of the bandpass filters and the associated layer design.



Blocking of the bandpasses with central wavelength at 316 and 399 nm.



Very accurate coverage between measurement of the deposited filter and design of the bandpass at 355 nm.

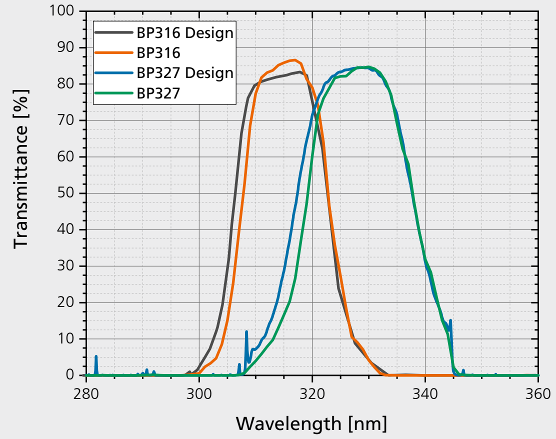
Fraunhofer IST relied on new material. Whilst the established tantalum oxide (Ta_2O_5) could still be used for the 355 nm and 399 nm filters, novel tube targets made from zirconium oxide (ZrO_2) were utilized for the other two. The oxygen present in the target and its particularly high purity therefore enable high transmission and low absorption in conjunction with oxidation through an RF plasma source. Zirconium is significantly less expensive than the often-used hafnium. Zirconium coatings were realized through co-sputtering of silicon. In order to avoid crystallization and resulting stray light, the ZrO_2 coatings contain a few percent SiO_2.

1 Tube target for the EOSS®, made from sub-stoichiometric zirconium oxide.

2 Coated filter substrate placed on the corners in 3D printed box.

Broadband monitoring – MOCCA+® for process monitoring

The coating process was monitored and controlled in each case using the monitoring system MOCCA+® (Modular Optical Coating Control Application), which was also developed at the Fraunhofer IST, including several test-glass changes. The transmission measurements for the calculation of the respective current coating thickness were carried out in the range from 380 to 1650 nm. The fitting range of three filters was therefore outside the measurement range. Nevertheless, the position and shape of the filters could be realized in very good conformity with the design.



Comparison between design and measurement of zirconium oxide deposited filters. Solely the filter at 316 nm was annealed after deposition.

Summary and outlook

Through the process development with zirconium oxide tube targets, the possible spectral range for optical coatings was extended in the direction of UV, and precise control of coatings was also realized outside the spectral range measured during coating. This presents new opportunities for the design and deposition of interference filters.

The project

The work was funded by the German Federal Ministry of Education and Research (BMBF) within the framework of the "EPIC-Lens" project (FKZ 13N14583), and by the Max Planck Institute for Solar System Research within the framework of the "Sunrise III" project.

CONTACT

Dipl.-Phys. Stefan Bruns
Phone +49 531 2155 628
stefan.bruns@ist.fraunhofer.de

ANNUAL REPORT 2020

LIFE SCIENCE AND ECOLOGY

2020

1

MODEL CALCULATIONS FOR THE DEGRADATION OF NITROGEN OXIDES BY MEANS OF PHOTOCATALYSIS

Over the course of the corona pandemic, a considerable reduction in road traffic has occurred and, as a result, nitrogen dioxide (NO_2) emissions have fallen sharply. Since the end of the lockdown in mid-April 2020, significant increases have, however, already been recorded. Looking back to the year 2019, the annual average limit value for NO_2 of 40 µg/m³ air was exceeded at around 20 percent of the measuring stations in Germany, which are located close to traffic – despite the fact that diesel driving bans were already in force and environmental zones had been established. In comparison, in 2018 this figure was still 42 percent of the stations.

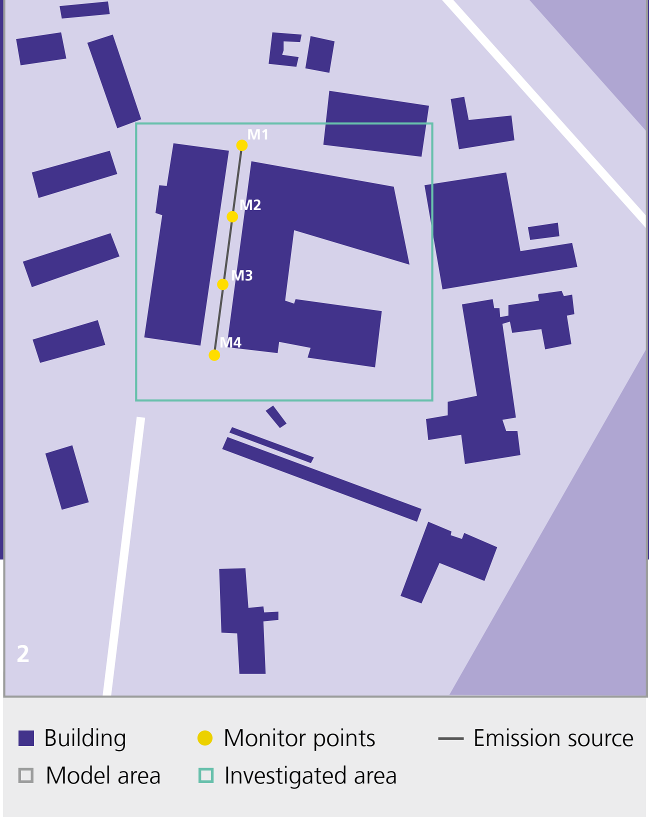
For many years, the Fraunhofer IST has been working on the development of surfaces which, when equipped with photocatalytic activity, can contribute to the reduction of air pollutants. Particularly in urban environments, large built-up areas are available for this purpose. In collaboration with the Ostfalia University of Applied Sciences in Wolfenbüttel, a study was therefore initiated within the framework of a master's thesis with the aim of applying numerical simulation to determine the degradation potential of photocatalytically equipped surfaces for nitrogen oxide reduction. For this purpose, the model of a real street canyon on the premises of the Fraunhofer IST was selected, as, firstly, the pollutants are poorly removed here under certain wind conditions and, secondly, sufficient surfaces are available which can potentially be equipped with photocatalytic properties.

The method

As an evaluation parameter for the photocatalytic activity, the photocatalytic deposition velocity of nitrogen monoxide (NO) was determined in the laboratory in accordance with prEN 16980-1:2020 for a number of commercially available building products such as glass, concrete paving stones and roughcast. These values were then used to calculate the photocatalytic resistance, which in turn is an essential parameter for atmospheric dispersion calculations. Taking into account meteorological data on wind flow and solar radiation, the values of the photocatalytic resistance served as input variables in the investigation in which the programs LASAT (Lagrange Simulation of Aerosol Transport for the simulation of the dispersion of pollutants in the atmosphere) and WinMISKAM (prognostic microscale flow and dispersion model for Windows) were utilized in order to simulate the reduction of NO_x concentrations on basis of the year 2018 using the example of the street canyon on the premises of the Fraunhofer IST (see Figure 1 and 2).

Improving air quality through photocatalysis

The results showed that, assuming a complete photocatalytic equipping of road, façade and roof, the annual average NO_x concentrations can be reduced by 1 to 2 percent, even at low deposition rates of 0.14 cm/s. By using high-performance photocatalytic building materials with average deposition rates of up to 1.50 cm/s, such as those developed in the BMBF joint project "PureBau", the NO_x emissions can be reduced by an



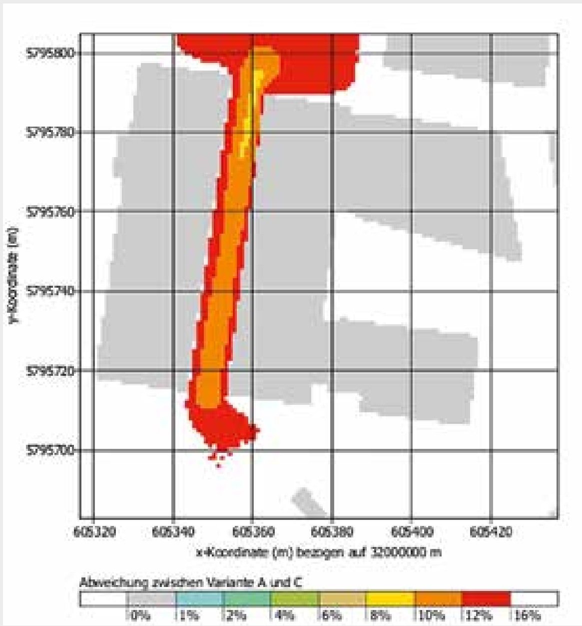
1 *Model canyon on the premises of the Fraunhofer IST in Braunschweig.*
2 *ArcMap model sketch.*
3 *Percentage reduction of NO_x emissions in the photocatalytically active model canyon.*

average of 10 to 12 percent (see Figure 2). The degradation rates thereby fluctuate between 2 and 4 percent in winter and between 16 and 18.5 percent on typical summer days.

Photocatalysis can therefore verifiably provide a decisive contribution towards the improvement of air quality in our city centers, even in areas of the republic, which experience less sunshine.

Outlook

Within the scope of an expansion of the laboratory capacities, the measurement technology available at the Fraunhofer IST is being expanded to include the possibility of determining the photocatalytic deposition rates of nitrogen dioxide (NO_2) and ozone (O_3) in order to be able to determine the atmospheric input variables even more precisely. Parallel to this, the IST, as a member of the DIN standards committee Photocatalysis, supports the development of future test standards in this field and will therefore be able to offer its customers a comprehensive range of services in the future for the evaluation of their photocatalytically active products – from the material through to the application.



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CONTACT

Dipl.-Ing. (FH) Frank Neumann
Phone +49 531 2155 658
frank.neumann@ist.fraunhofer.de

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#WEKNOWHOW – THE FRAUNHOFER IST VS. CORONA

The corona pandemic has changed the world and confronts us with major challenges in many areas. The Fraunhofer-Gesellschaft has launched the "Fraunhofer vs. Corona" action program in order to pool the diverse proficiencies of the institutes Fraunhofer-wide and, in so doing, to contribute towards mastering the direct and indirect consequences resulting from the SARS-CoV-2 virus. With its expertise in process-engineering and manufacturing technology, in particular for process and application-oriented surface technology, the Fraunhofer IST is addressing the corresponding solution approaches in the fields of protective textiles, medicine, and hygiene and disinfection.

Surface technology for medical solutions

Reliable tests for the rapid determination of a SARS-CoV-2 infection are an important building block in the fight against the corona pandemic. In cooperation with the Städtisches Klinikum Braunschweig (Braunschweig Municipal Hospital), the Fraunhofer IST is participating in the further development of ultra-fast PCR tests. For such "disposables", which are needed in quantities of millions, the manufacturing costs are a decisive factor. The IST researchers are thereby optimizing the films utilized in the test by means of a spatially selective functionalization of the surface by means of plasma technology. In this way, the films can be made locally wettable in such a way that the sensitivity of the fluorescence-based diagnosis is increased, as a result of which the accuracy and reliability of the test systems are enhanced.

Surface technology can also play a significant role in medical care. Patients with a severe case of COVID-19 illness, which, in most cases, is accompanied by pneumonia, often require artificial respiration. In order to determine at what point artificial respiration becomes necessary and how long non-invasive respiration will suffice, reliable respiratory monitoring is necessary. Furthermore, affected patients and also medical staff should be protected against viral infection to the greatest extent possible. In cooperation with two Fraunhofer institutes and industrial partners, the Fraunhofer IST is therefore working on a smart virus filter – an innovative combination of fast sensor elements for measuring respiratory flow, pressure and respiratory gas together with a filter. The Fraunhofer IST is hereby concentrating on the development of a manufacturing technique for thin-film sensors for pressure measurement which are inexpensive to produce and which can be easily integrated.

2

1 *Fraunhofer experts are at the front line in working towards bringing the pandemic under control. They help both society and the economic sector to cope with immediate and upcoming consequences of the pandemic.*

2 *Structuring of the surface combined with locally selective functionalization enables the films used in PCR tests to become completely and permanently wettable.*

Protective textiles – sustainable and antiviral

At the beginning of the corona pandemic, there was a lack of suitable protective clothing as well as face masks with FFP2 and FFP3 classification for medical personnel and nursing staff. The need for high-quality protective masks remains particularly acute. Optimal disinfection of masks represents a sustainable and resource-saving option in order to enable multiple reuse of protective masks. In collaboration with the Städtisches Klinikum Braunschweig, the Fraunhofer IST therefore investigated suitable test methods which, in addition to sterilization effects, can also be used to test particle permeability and the impermeability of the material following sterilization.

Functional protective clothing which, in addition to its protective function, also kills viruses and other germs offers both medical and nursing staff improved protection against infection. In collaboration with eight other Fraunhofer institutes, the focus is being directed on the development and testing of novel carbon-based coatings for antiviral protective textiles. For this purpose, innovative materials and process-engineering approaches of gas-phase-based coating processes are being investigated at the Fraunhofer IST. The coatings produced in this way are validated regarding their anti-microbial functionality and mechanical stability. The aim is to establish a sustainable, scalable and reliable manufacturing process for the antiviral finishing of textile materials.

Disinfection and cleaning

In times of crisis and disaster, such as the corona pandemic, mobile, decentralized systems for cleaning and for the provision of disinfectants in the medical care of the population can be a crucial supplement to the health infrastructure.

With this in mind, a team from six Fraunhofer institutes is developing an integrated system of mobile, decentralized medical care. Drawing on its experience in decentralized and autonomous water treatment, the Fraunhofer IST is working on a system for surface disinfection which can make disinfectants directly available via a spray system by means of diamond electrodes or plasma processes. This system is intended to be used autonomously for surface sterilization and can be deployed, for example, in a mobile test platform which can also be utilized in emerging and developing countries.

Furthermore, the Fraunhofer IST is also conducting research within a Fraunhofer team on technologies for mobile disinfection robots which disinfect potentially contaminated surfaces in public buildings or on public transport in a targeted, efficient and gentle manner. The focus of the IST's work lies thereby on the development of miniaturized plasma systems and their integration into the disinfection robots as well as on the investigation and evaluation of material damage caused by the various cleaning tools such as plasma, UV-C or aqueous cleaning.

In the field of mobile disinfection, a further objective of the Fraunhofer IST is the development of a mobile room-air cleaning system. This device is intended to effectively destroy viruses, bacteria and fungi in the room air in order to reduce the risk of infection. The Fraunhofer IST is therefore working on the calculation and simulation of the flow dynamics of bioaerosols in indoor areas. On the basis of these results, the development of a regulated plasma air purifier should be made possible.

Outlook

The process-engineering and manufacturing solutions based on plasma and surface technology addressed within the anti-corona projects lay the foundation for future work on combating infectious diseases. As a result, in the future it will be possible in the medical sector to utilize functional coatings with antimicrobial efficacy and cleaning technologies for the automated and active combatting of infectious agents in order to prevent the spread of or immediately disinfect microbial contaminations. Through the optimization of medical technology solutions in diagnostic testing and monitoring systems, improved patient care will be established in the long term. Sustainability and resource-saving processes hereby play a decisive role. Here at the Fraunhofer IST, the appropriate demonstrators are being created, which, in the next step, will be optimized in collaboration with industrial partners and subsequently transferred to the application.

3 *Illustration of a plasma air cleaner.*

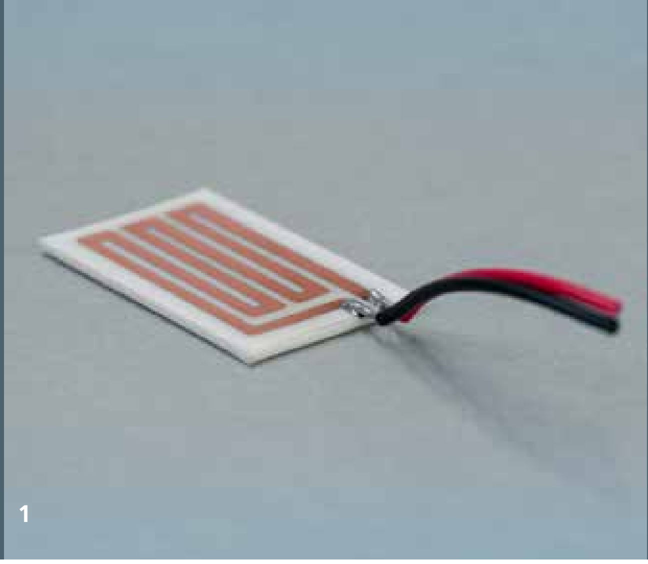
4 *The Fraunhofer IST is working on test methods that can be used to determine sterilization effects, particle permeability and a material's impermeability after sterilization.*

CONTACT

Prof. Dr. Michael Thomas
Phone +49 531 2155 525
michael.thomas@ist.fraunhofer.de

Dr. Kristina Lachmann
Phone +49 531 2155 683
kristina.lachmann@ist.fraunhofer.de

SERVICES AND COMPETENCIES



FIELDS OF TECHNOLOGY

Physical Vapor Deposition (PVD)
- Magnetron sputtering
- Highly ionized pulsed plasma processes like HIPIMS, MPP
- Hollow cathode processes

Chemical Vapor Deposition (CVD)
- Hot-wire CVD
- Atomic layer deposition (ALD)
- Plasma-enhanced CVD (PECVD)

Plasma diffusion
- Nitriding / Carbonitriding
- Oxidizing
- Boriding

Atmospheric pressure plasma
- Plasma polymerization
- Dielectric barrier discharge
- Microplasma and plasma printing
- Integration of plasma in additive production processes
- Plasma particle coating
- Cold plasma spraying

Electrochemistry
- Galvanical metallization
- Chemical metallization
- Metal deposition from ionic liquids
- Dispersion deposition

Laser technology
- Laser-plasma hybrid processes
- Laser-induced fluorescence
- Laser structuring

Surface chemistry
- Dip coating
- Spin coating
- Photopolymerization
- Chemical derivatization

3

ENERGY STORAGE AND SYSTEMS

Energy storage development and production engineering

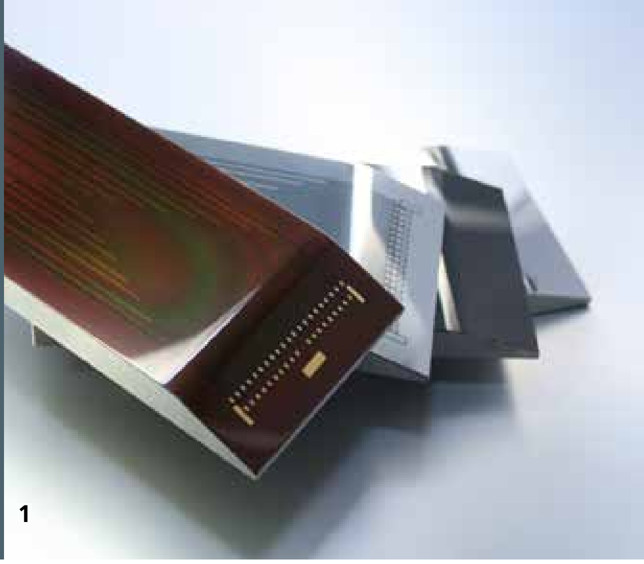
- Development of mobile and stationary energy storage devices and systems through to industrial maturity
- Formulation and production strategies for solid-state batteries*
- Scalable manufacture and fabrication of materials for energy storage systems*
- Particle and surface coating
- Surface functionalization
- Characterization of particles, powders and suspensions*
- Electrode manufacture*
- Cell characterization and safety*

Sustainable factory systems and life cycle management

- Battery cell production*
- Model-based planning and operation of battery production systems
- Simulation from product to factory scale
- Networking of virtual models with real battery production in cyber-physical production systems (CPPS)
- Data mining and data analytics along the battery process chain
- Ecological-economic life cycle analyses

*in cooperation with the Battery LabFactory Braunschweig (BLB).

1 *Solder pattern – copper traces on PET with soldered cable.*
2 *In-line vacuum coating system (FHR Anlagenbau SV470) with spectroscopic plasma plasma monitoring (PLASUS EMICON).*
3 *Electrodes for the production of battery cells.*



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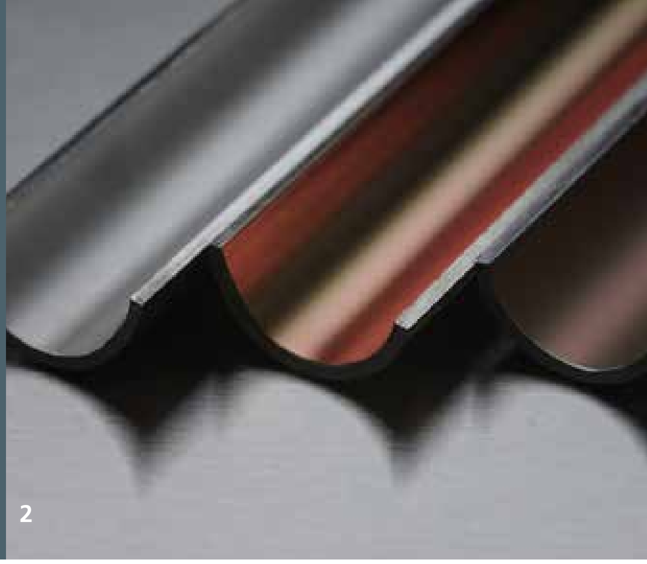


2

FIELDS OF EXPERTISE

Friction reduction and wear protection
- Amorphous carbon coatings (DLC)
- Diamond coatings
- Hard coatings
- Nitride/Cubic boron nitride (cBN)
- Metal coatings
- Plasma diffusion/DUPLEX processes
- Dry lubricants
- Erosion protection
- Corrosion protection
- Anti-adhesion and antifouling coatings
- Diffusion barriers

Electrical and optical coatings
- Precision optics
- Transparent conductive coatings
- Electrochromic coatings
- Low-E and sun control coatings
- Diamond electrodes
- Silicon-based coatings for photovoltaics and microelectronics
- Semiconductors (oxide, silicon-based, diamond)
- Insulation coatings
- Piezoelectric coatings
- Magnetic coatings
- Plastics metallization

Micro- and nanotechnology
- Thin-film sensor technology
- Microtechnology
- Nanocomposites
- Control of coating adhesion
- Structured surface coating and activation

Biofunctionalization
- Antibacterial coatings
- Adhesion and anti-adhesion coatings
- Chemical reactive surfaces

Photocatalysis
- Air and water purification systems
- Photocatalytically active coatings with antimicrobial effectiveness

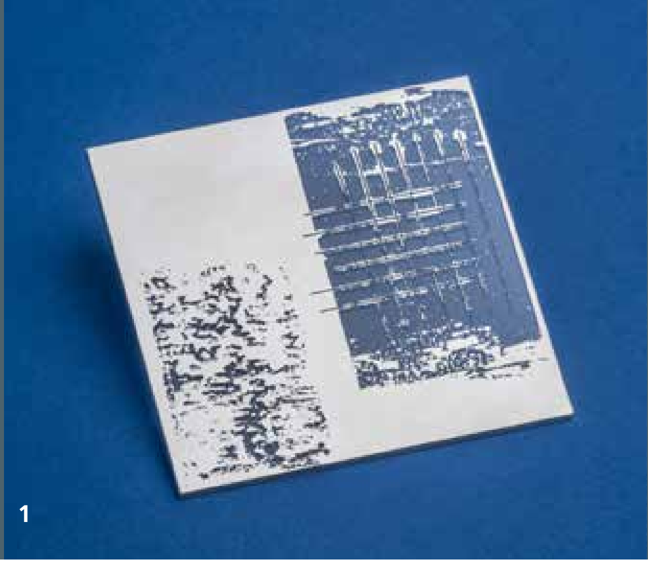
1 *Sensor module for monitoring of the draw-in movement of sheet metal during deep-drawing processes.*
2 *Milling tool with SIC diamond coating.*
3 *Impact tester.*

Pretreatment and functionalization
- Wetchemical cleaning
- Functionalization and coating of interfacial layers
- Surface structuring
- Plasma activation and cleaning
- Oxidation and reduction of metals
- Plasma surface modification
- Optimization of adhesive bonds

Product and production systems
- Life cycle management
- Sustainable factory planning
- Design of process chains and production systems

Simulation
- Simulation of plants, processes and coating layer properties
- Model-based interpretation of coating processes

Analytics and quality assurance
- Chemical analysis
- Crystal structure analysis
- Microscopy
- Analysis of chemical reactive surfaces
- Optical and electrical characterization
- Plasma diagnostics
- Tribological tests
- Mechanical tests
- Standardized photocatalytic measurement technology including test systems and devices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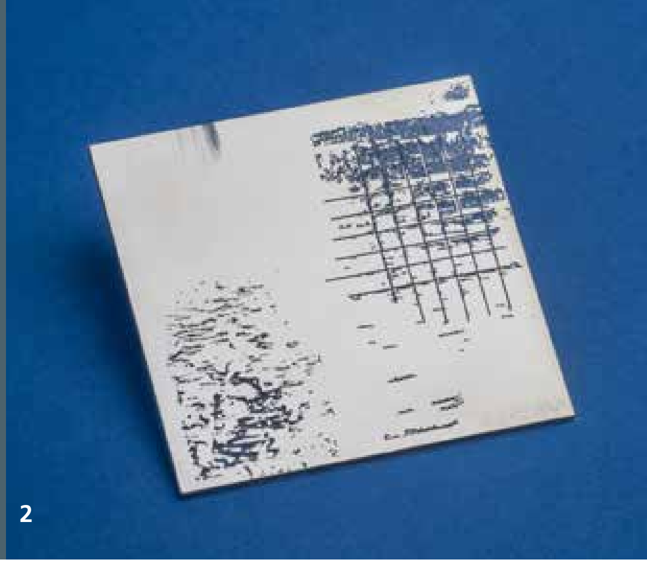
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DIRECT METALLIZATION OF PLASTICS BY MEANS OF HIPIMS

Although metallized plastics have been industrially produced and utilized for several decades now, the direct metallization of plastics still remains a highly topical issue. Due to the vast number of different plastics and the necessary individual development of intermediate layers and/or targeted pretreatment, there is still a high demand for processes which enable a strongly adherent metallization of plastics. High power impulse magnetron sputtering (HIPIMS) is a process which offers considerable application potential in this respect. At the Fraunhofer IST, studies into direct metallization with aluminum and with chromium have been carried out; these studies have produced promising results with regard to the adhesive strength on plastics.

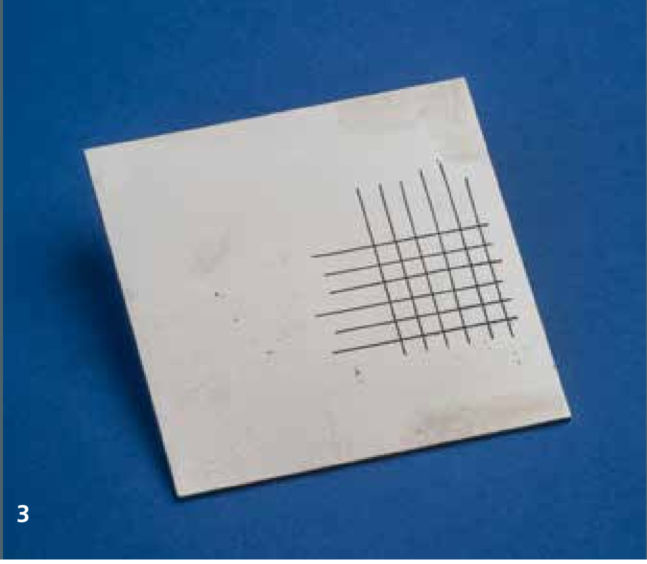
Direct metallization with aluminum

Within the framework of the investigation, various plastics were coated with aluminum. Thereby, no form of pretreatment outside the coating chamber was performed and no form of plasma pretreatment was used. After being enclosed, the plastics were coated directly with aluminum. Particularly for the polyamides PA6 and PA6.6 and for the polymethylmethacrylates (PMMA), an excellent adhesion (HK 0) could be achieved. As regards PMMA in particular, a direct plasma coating with reliable adhesion has not been known until now. Usually, a lacquer is applied or an intermediate layer is vapor-deposited without plasma prior to the actual metallization. In the present case, it was determined that the fraction of ions plays a major role in the HIPIMS process. The higher the ion fraction, the better the adhesion. In the case of plastics, differing behavior during the coating process can indeed occur if the substrates are obtained from different manufacturers. For PMMA, repeated tests have also shown that it is generally possible to achieve excellent adhesion.

Direct metallization with chromium

Particularly with regard to the EU REACH regulation and the prohibition of hexavalent chromium (Cr VI), both the widespread pretreatment with chromium pickling and the galvanic coating, if Cr VI is involved, must be replaced. Furthermore, the color impression of chromium layers which are produced using trivalent chromium differs from the familiar impression of Cr VI layers.

Here, HIPIMS technology offers the option of overcoming both of these challenges. Firstly, the HIPIMS coatings are characterized by very good adhesion to the substrates. It was even possible to produce an adhesive layer on polytetrafluorethylene (PTFE), whereby further development is required in order to achieve good to very good adhesion. Secondly, the HIPIMS chromium layers exhibit a bluish hue, as is familiar from many established coatings. In this case, very good adhesion values of HK 0 to 1 could again be realized for polycarbonate (PC) and polyamide (PA 6, PA 6.6).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Direct Al metallization of PMMA:

1 *DC reference.*

2 *Medium ionization.*

3 *High ionization.*

Characterization of adhesion

The characterization of the adhesion was performed by means of a combination of a cross-cut test in accordance with DIN EN ISO 2409 and a subsequent tape test. In the cross-cut test, a pattern is initially scored into the coated surface and the breakouts at the cut edges are then evaluated. To exacerbate the situation, an adhesive tape with a defined adhesive force is applied to the scored surface and pulled off abruptly.

Outlook

The Fraunhofer IST has various vacuum systems (batch and in-line coaters) at its disposal with a variety of cathode sizes for the customer-specific development of HIPIMS processes. With its superb industrial equipment, the Fraunhofer IST is able to utilize HIPIMS in order to implement an adhesive metallization, either as a seed layer for further reinforcement or as a thin functional layer, without any additional processes, for various applications.

CONTACT

Dr.-Ing. Ralf Bandorf
Phone +49 531 2155 602
ralf.bandorf@ist.fraunhofer.de

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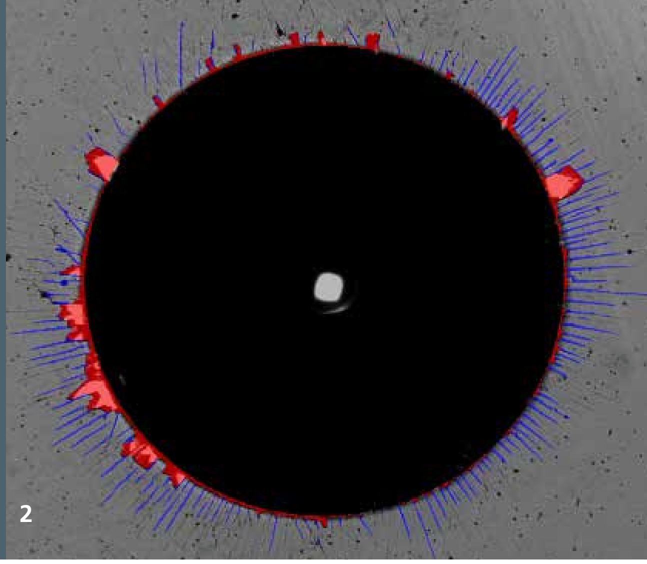

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AUTOMATION OF THE ROCKWELL ADHESION TEST FOR RELIABLE QUALITY CONTROL

The coating adhesion of hard coatings is a major quality criterion for the functional reliability of a coated component. In cooperation with industrial partners, a new evaluation procedure based on machine learning has been developed at the Fraunhofer institutes IST and ITWM which enables the automation of the evaluation of the coating adhesion by the Rockwell indentation test. Not only the determination of the adhesion classes but also the Rockwell indentation and the microscope image acquisition are performed in an automated process. In just a few minutes and without manual intervention, a component can be reliably tested for coating adhesion at several test points.

Rockwell indentation test for evaluation of coating adhesion

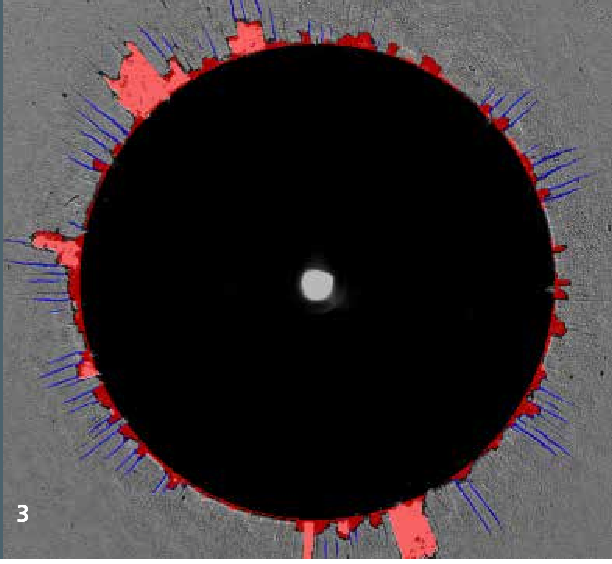
The Rockwell indentation test is a testing procedure for the evaluation of coating adhesion and has been established in industry and research for many years. As with a Rockwell hardness test, an indent is generated on the coated component by means of a diamond indenter. Any damage to the coating at the edge of the indent is evaluated qualitatively and classified through visual impression into adhesion classes (HF, German: Haftklassen) in accordance with the DIN 4856 and ISO 26443 standards.

Motivation

Despite the specified standards for the procedure, the result of the adhesion test incorporates a subjective grade depending on the experience of the test person. A random sample of more than 500 images, which were evaluated by four experts, revealed frequent differences: Good (HF 1) and poor coating adhesion (HF 5 and 6) are generally evaluated uniformly by different testers. In the case of medium coating adhesion (HF 2 to 4), however, evaluation differences frequently occur. Figures 2 and 3 show typical Rockwell indents for the evaluation of coating adhesion, for which differences can occur during visual evaluation. Depending on the test person, an adhesion class of 2 or 3 was assigned in Figure 2, and HF 3 or HF 4 in Figure 3. For industrial applications, this indicates the necessity for an objective evaluation and finer subdivision of the adhesion classes with one decimal, in order to enable repeatable quality assurance and controllability of the coating processes.

A new, automated evaluation procedure

In cooperation with the companies BAQ and Schaeffler, a new test bench for the evaluation of coating adhesion has been developed which achieves the aforementioned objectives (see Figure 1). The generation of the Rockwell indent as well as the microscope image are thereby performed fully automatically. The automatic analysis of the damage is carried out by means of electronic image processing on the basis of machine learning. This was developed at the Fraunhofer Institute for Industrial Mathematics ITWM and is based on a characteristics



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1 *Test bench developed by BAQ within the project for automated Rockwell coating adhesion tests.*
2 *Rockwell indentation, evaluated by assessors as HF 2 or 3.*
3 *Rockwell indentation, evaluated by assessors as HF 3 or 4.*

analysis, i.e. the schematic sketches of each adhesion class present in the standards form the basis for the evaluation. The adhesion classes HF 2, HF 3 and HF 4 are specified with one decimal. The automated evaluation of the sample images results in a reproducible and objective coating adhesion of HF 2.9 (Figure 2) or HF 3.4 (Figure 3). The automated Rockwell coating adhesion test was validated at the Fraunhofer IST on various amorphous carbon coatings (diamond-like carbon, DLC) using real industrial components, in order to optimize the optical recording technique and the characteristic criteria.

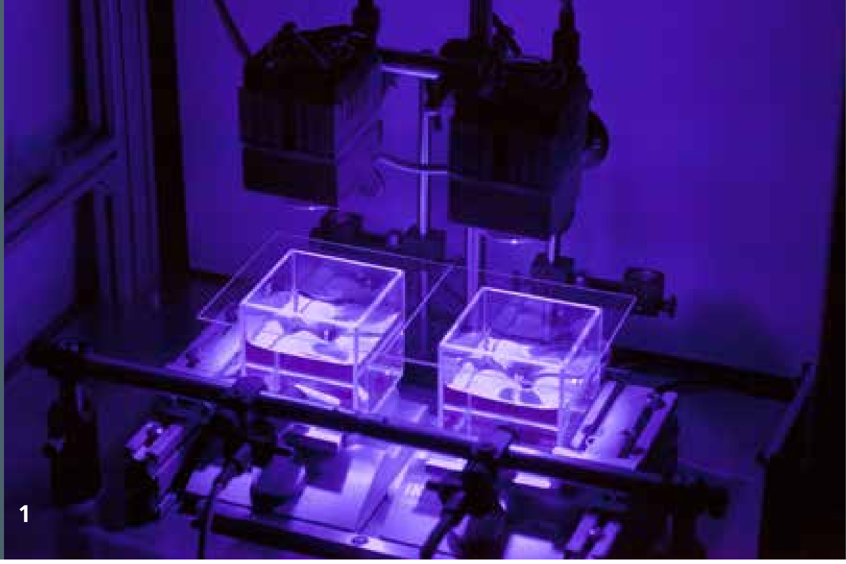
The project

The project "Automatisierte Rockwell-Schichthaftungsprü-fung – AUROS" (automated Rockwell coating adhesion test) is being conducted within the framework of the "WIPANO" funding program. The project is Supported by Federal Ministry for Economic Affairs and Energy on the basis of a decision of the German Bundestag.

Bundesministerium
für Wirtschaft
und Energie

CONTACT

Dr.-Ing. Jan Gäbler
Phone +49 531 2155 625
jan.gaebler@ist.fraunhofer.de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DEVELOPMENT OF AN INDUSTRIAL STANDARD FOR DETERMINING THE PHOTOCATALYTIC ACTIVITY OF SURFACES

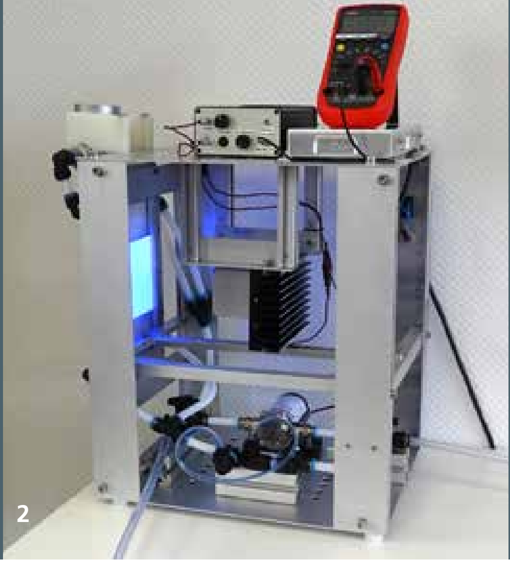
Self-cleaning surfaces on products such as glass and ceramics for sanitary applications or self-cleaning wall paints or roof tiles can make everyday tasks considerably easier and prolong the product life. This self-cleaning effect is achieved, for example, through the use of photocatalytically active materials or surface coatings. When light of the appropriate wavelength falls on the photocatalytically active surface, organic contaminants are decomposed. There is also an additional secondary effect: The light causes a so-called "hydrophilization" of the surface, making it "water-loving", i.e. water forms a film that can infiltrate the dirt particles, enabling them to be rinsed off more easily.

Depiction of sample occurrences that are as real as possible

Parallel to the market development of such products, the demand for standardized test procedures is increasing in order to verify their effectiveness, to increase their market acceptance and, ultimately, to ensure active consumer protection and fair competition by discriminating against ineffective or harmful products. In addition, since the original elaboration of the first test standards, significant progress has been made in the photocatalyst and product-development sector, in particular as regards increasing the efficiency of the materials. These advances also need to be taken into account. In order to be able to compare the photocatalytic activity of different products, the German industrial standard DIN 52980:2008 is applied, whereby the verification is carried out via the degradation of methylene blue. The range of application is, however, limited to very few and, moreover, small-format products. Furthermore, in the past, strong fluctuations of the measurement results occurred repeatedly in practice, and a number of weak points in the current method have also been pinpointed in the scientific literature. For the Fraunhofer Institute for Surface Engineering and Thin Films IST, this was an incentive to work in collaboration with partners from industry and research in order to develop a robust and application-oriented German industrial standard for characterizing the photocatalytic activity of surfaces, thereby depicting sample occurrences which are as real as possible.

Application-oriented test method

In the "DePhakto" project, which was made possible by the BMWi-funded program "WIPANO – Wissens- und Technologietransfer durch Patente und Normen" (Knowledge and technology transfer via patents and standards), the Fraunhofer IST and its project partners collaborated on the examination of the specifications of the existing measurement methodology and drew up proposals for adaptations and amendments in a draft revision of the standard. In addition to a new procedure for large-format samples, new ceramic calibration standards were hereby developed and characterized as well as investigated with regard to their defined graded photocatalytic efficiency and reusability. A round-robin test coordinated by the Fraunhofer IST shows that the measurement results when utilizing the new application-oriented calibration standard and the new test methodology are significantly more precise and reliable than



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1 *Methylene blue measuring facility in accordance with DIN 52980.*
2 *Methylene blue measuring facility for large-format samples.*

with the original procedure: The coefficient of variation of the reproducibility is now only 4.95 percent as opposed to the original 30.6 percent. It has also been possible to increase the surface area to be tested to up to 100x100 mm^2, thereby enabling the assessment of large-format specimens such as entire floor tiles or roofing tiles.

The Fraunhofer IST is actively involved in the Photocatalysis Working Committee of the German Institute for Standardization DIN. During the project, there was already a consistent close exchange taking place with the institutions and industrial companies represented there in order to ensure the practical suitability of the obtained results. The new test method was published in November 2020 as draft DIN 52980:2020-11 by the Beuth-Verlag publishing house.

The project

The realization of the research project "Entwicklung eines robusten und anwendungsnahen deutschen Industriestandards zur Bestimmung der photokatalytischen Aktivität von Oberflächen – DePhakto" (Development of a robust and application-oriented German industrial standard for the determination of the photocatalytic activity of surfaces – DePhakto) was made possible through funding from the German Federal Ministry for Economic Affairs and Energy – BMWi as part of the "WIPANO – Wissens- und Technologietransfer durch Patente und Normen" (WIPANO – Knowledge and technology transfer via patents and standards) program with the funding code FKZ 03TNG016C.

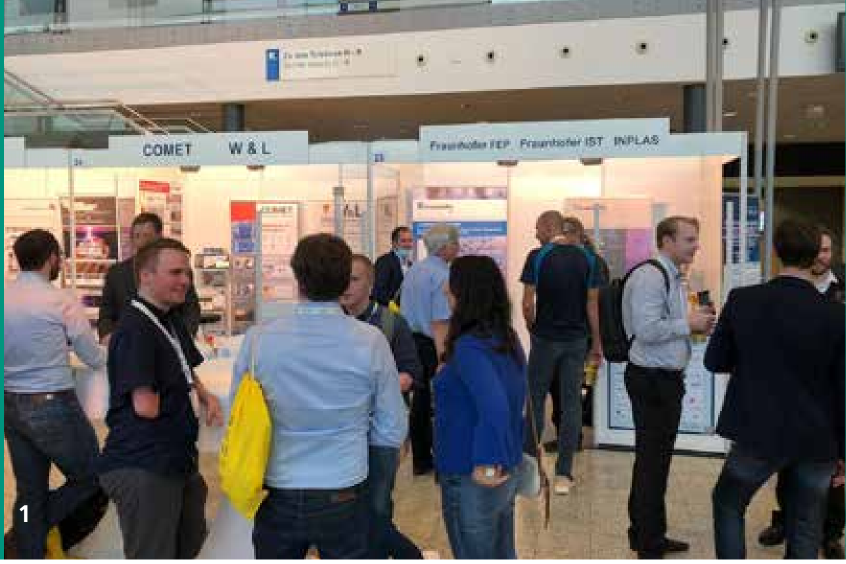
CONTACT

Dipl.-Ing. (FH) Frank Neumann
Phone +49 531 2155 658
frank.neumann@ist.fraunhofer.de

ANNUAL REPORT 2020

2020

NAMES, DATES, EVENTS



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TRADE FAIRS, EXHIBITIONS, CONFERENCES

DVG Member Contact Day

Karlsruhe, 10th – 11th February 2020. Under the motto "Wissenschaft trifft Industrie + Industrie trifft Wissenschaft" (Science meets industry + industry meets science), the Member Contact Day of the Deutsche Vakuum-Gesellschaft DVG e. V. (German vacuum society) was held on the 10th and 11th of February 2020 in order to enhance the bridge between industry and science for vacuum-based technologies and applications for the mutual benefit of both parties. The main topic of the event was "Modern PVD/CVD coating technology – vacuum technology for research and industry in the interest of the environment". Two contributions were provided by the Fraunhofer IST.

Specialist conference "Schlüsseltechnologien für die Oberflächenmodifikation" (Key technologies for surface modification)

Lüdenscheid, 3rd – 4th June 2020. The conference "Key technologies for surface modification" provided an overview of the marketable processes in the field of tool surfaces, the current stage of technology and new developments, and presented a diverse range of possible applications. The Fraunhofer IST was represented by Dr.-Ing. Jochen Brand with a presentation on the topic of "Diamond-like carbon coatings for tools".

Fraunhofer Direct Digital Manufacturing Conference DDMC

Online, 23rd June 2020. Due to the Corona pandemic, the first virtual Fraunhofer Direct Digital Manufacturing Conference DDMC took place this year. This was presented by and broadcast live from the Fraunhofer Forum in Berlin. Almost 20 speakers from all over the world logged in to exchange views with the participants on topics related to the context of additive manufacturing. The Fraunhofer IST supplemented the program with a contribution on the subject of "post-processing".

Fraunhofer Competence Forum China

Online, 14th July 2020. The Fraunhofer Competence Forum China took place online due to the pandemic. Experts from the Fraunhofer institutes ISC, IST, IZFP and ITWM highlighted their expertise in the field of "surface technologies". The Fraunhofer IST presented results from the field of thin-film sensor technology as well as precision optics.

2

1 *Industrial evening at this year´s Special PSE in Erfurt.*

2 *The virtual Fraunhofer event in fall 2020 – the Fraunhofer Solution Days.*

International Conference on Plasma Surface Engineering / Special PSE 2020

Erfurt, 7th – 10th September 2020. At the International Plasma Surface Engineering PSE, which took place for the 17th time, everything revolved this year around the role of plasma technology for new energy concepts. The Fraunhofer IST took part in the Special PSE on the joint stand of the INPLAS competence network and participated via a number of contributions to the scientific conference program.

37th European Photovoltaic Solar Energy Conference and Exhibition PVSEC

Online, 7th – 11th September 2020. EU PVSEC is the largest international specialist conference for photovoltaics in the fields of research, technologies and applications, and has an accompanying industry exhibition in which representatives of the photovoltaic industry present their technologies, innovations and new concepts. This year, the EU PVSEC took place exclusively online. The Fraunhofer IST participated with a poster presentation.

Fraunhofer Solution Days 2020

Online, 26th – 29th October 2020. In the fall of this year, the Fraunhofer Solution Days, a digital Fraunhofer event, took place. The focus was thereby directed on four topics with high relevance for the innovative power of Germany and Europe: Health. Digital economy. Plant and mechanical engineering. Mobility. The Fraunhofer IST participated in the event in collaboration with the team from the "KryoRet" project and its contribution towards the development of a smart screw connection at the IoT-COMMs research center.


1

EVENTS

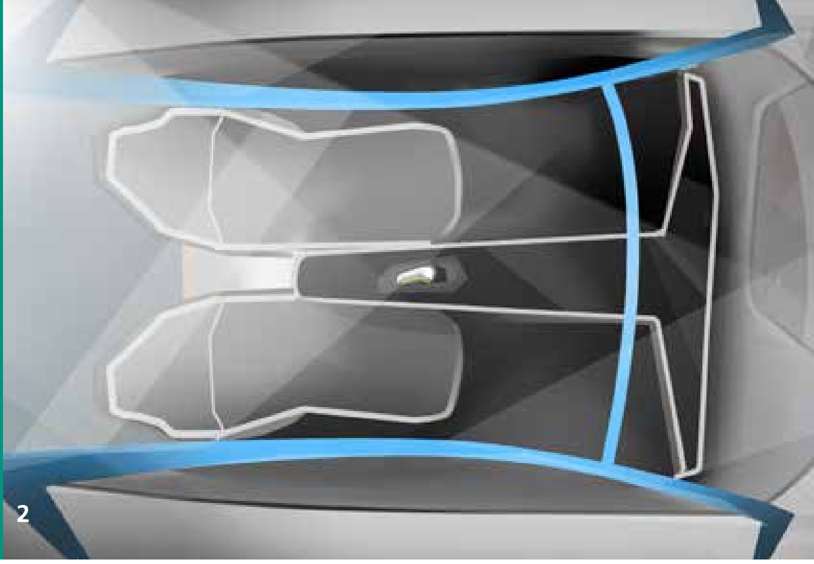
Science Day at Fraunhofer IST

Braunschweig, January 28, 2020. Fourth time in a row, the "Science Day" took place at the Fraunhofer IST. PhD students of the Fraunhofer IST and the Institute of Surface Technology IOT as well as the Institute of Machine Tools and Production Technology IWF of the TU Braunschweig had the opportunity to present their doctorate's current status to employees of the involved institutes. For the employees of the participating institutes it is an opportunity to exchange ideas and information about current research exchange information and ideas on current research topics.

Flexible and individual: Fraunhofer team develops groundbreaking vehicle concept

How can individualized luxury mobility be designed for the world of the year 2040? A world that will be driven by the idea of a circular economy and products with significantly longer lives. A world that will also be characterized by the desire for individual and quickly evolving lifestyles. How can the maximum level of driving comfort be achieved between these two polar opposites? To answer these questions, an interdisciplinary research team made up of experts from the Fraunhofer Institutes for Chemical Technology ICT, for Surface Engineering and Thin Films IST, for Industrial Engineering IAO, for Manufacturing Technology and Advanced Materials IFAM, for Machine Tools and Forming Technology IWU, and for Wood Research, Wilhelm-Klauditz-Institut, WKI, has developed "Vision PI", a modular futuristic mobility concept.

The concept calls for a modular passenger cell, following the logic of a shell principle, that can be flexibly adapted to the individual needs of the travelers: during the day, it serves as a communicative lounge; at night, it becomes a peaceful capsule for rest and recovery on long-haul trips. The interior can be adjusted flexibly and adapted in terms of settings. The materials used are made from renewable sources or are designed to optimize their ability to be reused or recycled. The entire module can be coupled with various mobility bases – with a vehicle platform, an air taxi, or a Hyperloop solution, depending on the need. It can also be transformed into an interactive virtual-reality lounge that enables limitless virtual travel around the whole world, thus contributing to an innovative component of new mobility and building designs.



The innovative mobility concept was one of five recommendations taken by Fraunhofer to the #NEXTGen Moving Tomorrow Pitch, an idea competition organized by car manufacturer BMW. The competition is aimed at finding a "visionary, sustainable, and holistic complete concept for mobility in 2040." Around the world, BMW had called on researchers from a total of ten renowned research institutes to submit recommendations that would improve the lives of future generations, are designed for the users, make cities smarter, or are meant to enable entirely new technologies. Fraunhofer was the only nonuniversity research institute that took part in the idea competition. Along with two teams from the elite Chinese Tsinghua University, the Vision PI team from Fraunhofer made it into the top three with its idea of an individual passenger cell.

1 *PhD students of the Fraunhofer IST and the Institute of Surface Technology IOT as well as the Institute of Machine Tools and Production Technology IWF of the TU Braunschweig at the "Science Day".*

2 *Sketch of the interior of "Vision PI".*

EVENTS

THE FRAUNHOFER IST BIDS FAREWELL TO LONG-STANDING INSTITUTE DIRECTOR

On 30th September 2020, Prof. Dr. Günter Bräuer's active term as Director of the Fraunhofer Institute for Surface Engineering and Thin Films IST came to an end. As the planned official event had to be postponed due to the corona situation, the farewell ceremony took place on a small scale within the campus in a hybrid format. Günter Bräuer did not, however, have to forego a serenade: absolutely corona-compliant, this was compiled using individual photos of the employees. Professor Herrmann and long-time companion and former curator Eckhard Dietrich paid tribute to Prof. Dr. Bräuer's achievements in the field of plasma technology and his 21 years of service to the Institute. Dr. Andreas Dietz, one of the very first employees of the Fraunhofer IST, shared a few inside stories.

In 1999, Günter Bräuer assumed management of the Fraunhofer IST in Braunschweig and, until 2008, also of the Fraunhofer Institute for Organic Electronics, Electron Beam and Plasma Technology FEP in Dresden. At that time, he was motivated by the fun of working together with students and the desire to share with Fraunhofer the benefit of the industrial experience which he had gained during his time at Leybold. In the same year, Prof. Dr. Bräuer was called to the Technische Universität Braunschweig.

From 2003 onwards, Prof. Dr. Bräuer also led, in addition to the IST, the Institute for Surface Technology at the TU Braunschweig and over the years has supervised around 250 student projects. In 2013, he was appointed "Visiting Professor" at Sheffield Hallam University in Great Britain.

Günter Bräuer has received numerous honors and awards for his scientific work and his commitment in the field of vacuum coating and plasma technology. Furthermore, in 2012 he was also awarded the Fraunhofer Medal for his exceptional services to the Fraunhofer-Gesellschaft. He already has many plans for his retirement. The fact that he has nevertheless declared his willingness to continue to support the IST henceforth in an advisory capacity is deeply appreciated by not only the Institute Director Professor Christoph Herrmann and the Deputy Institute Director Dr. Lothar Schäfer but also by the entire team.

1 Co-founder and director of the Fraunhofer IST until 1999, Prof. Dr. Heinz Dimigen (right) and Prof. Dr. Günter Bräuer (left).

2 2012, Professor Bräuer receives the Fraunhofer Medal.

3 The institute management from 2018 to 2020, Prof. Dr. Günter Bräuer (left) and Prof. Dr.-Ing. Christoph Herrmann (right).

4 The farewell to Professor Bräuer took place as a hybrid format. Most of the employees attended the event online.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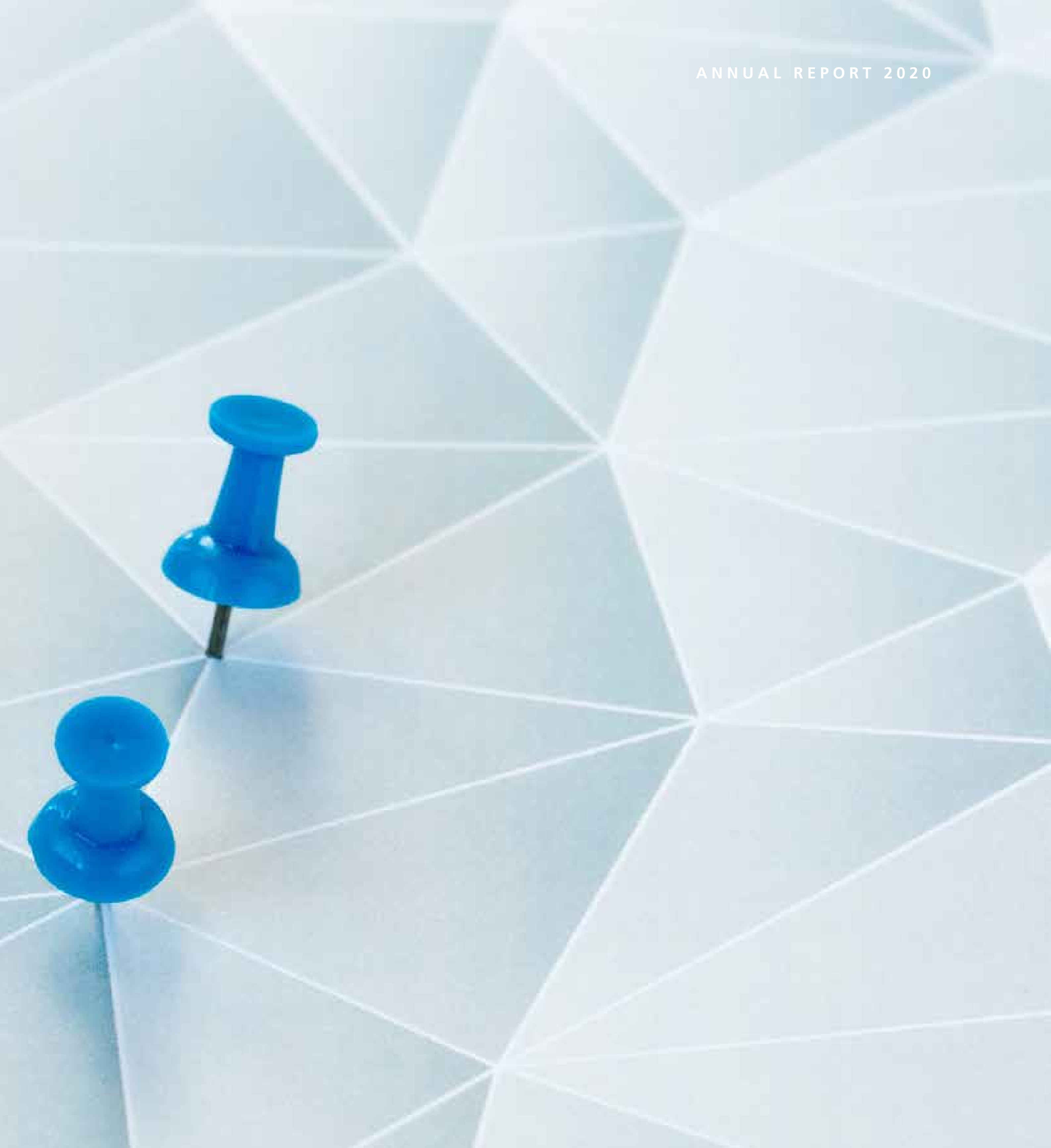
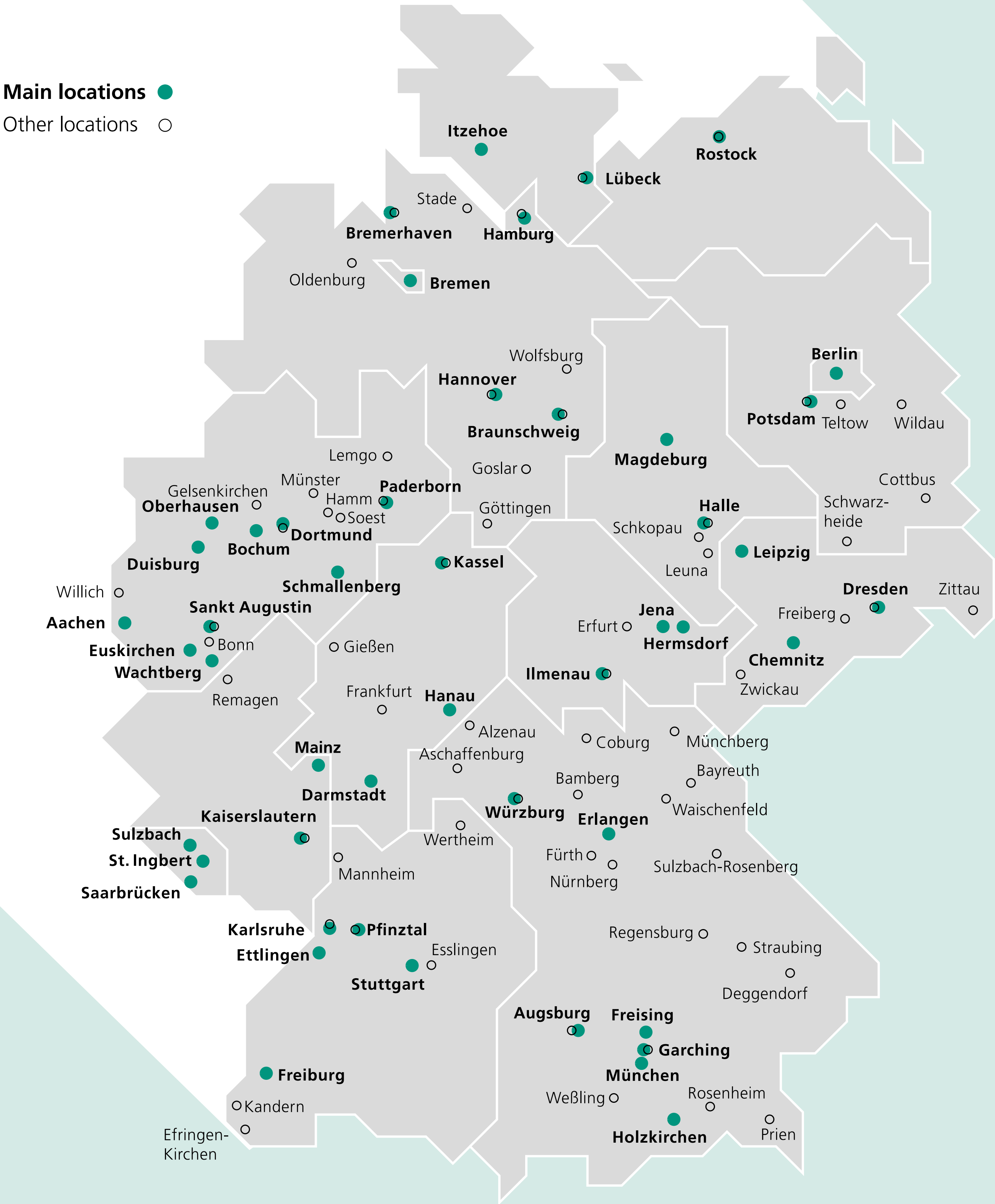
ANNUAL REPORT 2020



THE FRAUNHOFER IST IN NETWORKS


Main locations
Other locations
Itzehoe
Rostock
Lübeck
Stade
Bremerhaven
Hamburg
Oldenburg
Bremen
Wolfsburg
Hannover
Berlin
Potsdam
Teltow
Wildau
Braunschweig
Magdeburg
Lemgo
Goslar
Cottbus
Münster
Gelsenkirchen
Paderborn
Hamm
Halle
Schwarz-
heide
Oberhausen
Soest
Göttingen
Schkopau
Dortmund
Bochum
Leipzig
Duisburg
Kassel
Leuna
Schmallenberg
Willich
Sankt Augustin
Dresden
Zittau
Aachen
Jena
Freiberg
Erfurt
Bonn
Gießen
Hermsdorf
Euskirchen
Chemnitz
Wachtberg
Ilmenau
Zwickau
Remagen
Frankfurt
Hanau
Alzenau
Coburg
Münchberg
Mainz
Aschaffenburg
Bayreuth
Bamberg
Darmstadt
Waischenfeld
Kaiserslautern
Würzburg
Erlangen
Sulzbach
Wertheim
St. Ingbert
Fürth
Sulzbach-Rosenberg
Mannheim
Nürnberg
Saarbrücken
Karlsruhe
Pfinztal
Regensburg
Straubing
Esslingen
Ettlingen
Stuttgart
Deggendorf
Augsburg
Freising
Garching
München
Freiburg
Weßling
Rosenheim
Kandern
Efringen-
Kirchen
Holzkirchen
Prien

THE FRAUNHOFER-GESELLSCHAFT AT A GLANCE

The Fraunhofer-Gesellschaft is the world's leading applied research organization. With its focus on developing key technologies that are vital for the future and enabling the commercial exploitation of this work by business and industry, Fraunhofer plays a central role in the innovation process. Based in Germany, Fraunhofer is an innovator and catalyst for groundbreaking developments and a model of scientific excellence. By generating inspirational ideas and spearheading sustainable scientific and technological solutions, Fraunhofer provides science and industry with a vital base and helps shape society now and in the future.

At the Fraunhofer-Gesellschaft, interdisciplinary research teams work together with partners from industry and government in order to transform novel ideas into innovative technologies, to coordinate and realize key research projects with a systematic relevance, and to strengthen the German and the European economy with a commitment to creating value that is based on human values. International collaboration with out-standing research partners and companies from around the world brings Fraunhofer into direct contact with the key regions that drive scientific progress and economic development.

Founded in 1949, the Fraunhofer-Gesellschaft currently operates 75 institutes and research institutions. The majority of our 29,000 staff are qualified scientists and engineers who work with an annual research budget of 2.8 billion euros. Of this sum, 2.4 billion euros are generated through contract research. Around two thirds of Fraunhofer's contract research revenue is derived from contracts with industry and publicly funded research projects. The remaining third comes from the German federal and state governments in the form of base funding. This enables the institutes to work on solutions to problems that are likely to become crucial for industry and society within the not-too-distant future.

Applied research also has a knock-on effect that is felt way beyond the direct benefits experienced by the customer: Our institutes boost industry's performance and efficiency, promote the acceptance of new technologies within society and help train the future generation of scientists and engineers that the economy so urgently requires.

Our highly motivated staff, working at the cutting edge of research, are the key factor in our success as a scientific organization. Fraunhofer offers researchers the opportunity for independent, creative and, at the same time, targeted work. We therefore provide our employees with the chance to develop the professional and personal skills that will enable them to take up positions of responsibility at Fraunhofer, at universities, in industry and within society. Students who work on projects at Fraunhofer Institutes have excellent career prospects in industry by virtue of the practical training they enjoy and the early experience they acquire of dealing with contract partners.

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.

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THE FRAUNHOFER GROUP FOR LIGHT & SURFACES

The Fraunhofer Group for Light & Surfaces brings together the Fraunhofer-Gesellschaft's scientific and technical expertise in the areas of laser, optical, measurement and surface technology. Members are the following Fraunhofer Institutes:

- Fraunhofer Institute for Organic Electronics, Electron Beam and Plasma FEP
  www.fep.fraunhofer.de[3]
- Fraunhofer Institute for Laser Technology ILT
  www.ilt.fraunhofer.de[2]
- Fraunhofer Institute for Applied Optics and Precision Engineering IOF
  www.iof.fraunhofer.de[5]
- Fraunhofer Institute for Physical Measurement Techniques IPM
  www.ipm.fraunhofer.de[4]
- Fraunhofer Institute for Surface Engineering and Thin Films IST
  www.ist.fraunhofer.de[1]
- Fraunhofer Institute for Material and Beam Technology IWS
  www.iws.fraunhofer.de[6]
- Fraunhofer Institute for Telecommunications Heinrich Hertz Institute HHI
  www.hhi.fraunhofer.de (associated)
- Fraunhofer Institute of Optronics, System Technologies and Image Exploitation IOSB
  www.iosb.fraunhofer.de (associated)

With a total of approximately 1900 employees, the Fraunhofer Institutes in the Group work together to solve complex, application-oriented customer inquiries at the cutting edge of science and technology.

But the Fraunhofer Institutes are not only partners in innovation. They also work to produce new generations of scientific and technical experts. In cooperation with the local universities, the young scientists at the Fraunhofer Institutes bring together academic research and industry.

CONTACT

CHAIR OF THE GROUP
Prof. Dr. Karsten Buse
karsten.buse@ipm.fraunhofer.de

HEAD OF CENTRAL OFFICE OF THE GROUP
Dr. Heinrich Stülpnagel
Telefon +49 761 8857-269
heinrich.stuelpnagel@ipm.fraunhofer.de

www.light-and-surfaces.fraunhofer.de/en

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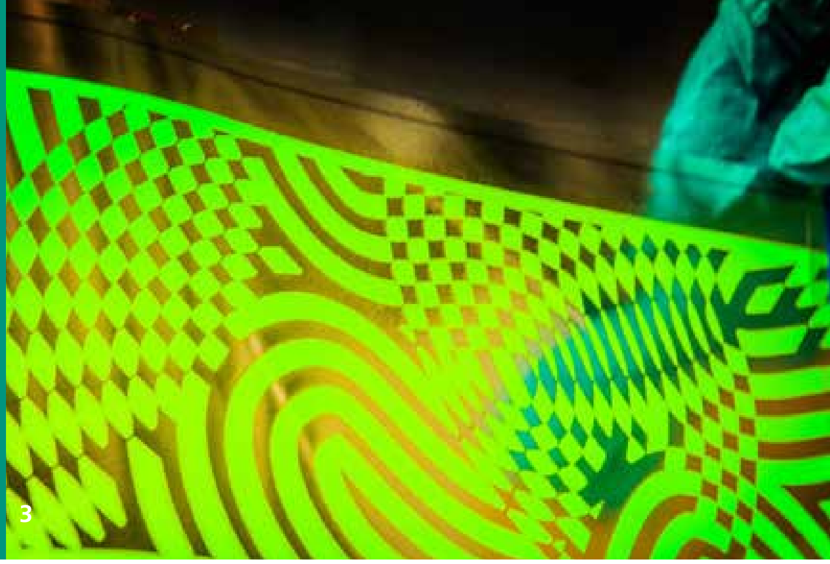

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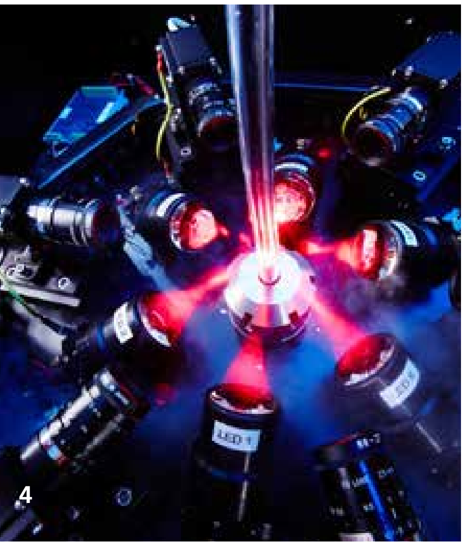

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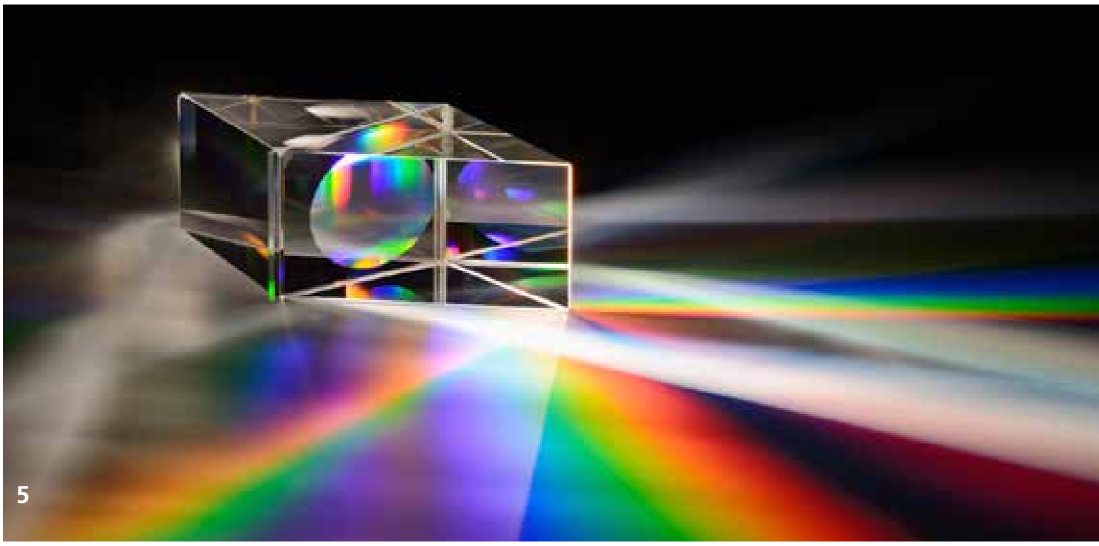

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NETWORK WITHIN THE FRAUNHOFER-GESELLSCHAFT

The Fraunhofer IST is a member of the Fraunhofer-Gesellschaft alliances, research and business areas, research and competence fields as well as networks. In addition, the Fraunhofer IST is part of the strategic cooperation "Fraunhofer Innovation Platform for the Water-Energy-Food Nexus at Stellenbosch University" (FIP-WEF@SU). The FIP-WEF@SU is a joint project between Stellenbosch University and the Fraunhofer Institutes IGB, ISE, IOSB and IST as well as the Fraunhofer Alliance SysWater as an associated partner. The aim of the innovation platform is to bring together know-how and technologies in the field of water treatment and use and to develop solutions for South Africa and the sub-Saharan states through joint research and development.

FRAUNHOFER ALLIANCE AUTOMOBILE PRODUCTION

FRAUNHOFER ALLIANCE BATTERY

FRAUNHOFER ALLIANCE SPACE

RESEARCH AREA TECHNICAL TEXTILES

FRAUNHOFER WATER SYSTEMS ALLIANCE SYSWASSER

FRAUNHOFER NETWORK
HYDROGEN

RESEARCH FIELD
LIGHTWEIGHT DESIGN

BUSINESS AREA
ADAPTRONICS

BUSINESS AREA
CLEANING

FRAUNHOFER COMPETENCE FIELD
ADDITIVE MANUFACTURING

FRAUNHOFER NETWORK
SUSTAINABILITY

FRAUNHOFER NETWORK
SIMULATION

REGIONAL AND NATIONWIDE NETWORKING

A stronger networking and interlinking of both research topics and research protagonists is at the forefront of the activities of the Fraunhofer IST, not only in Braunschweig but also throughout Germany. As a result, research efficiency can be increased. The aim is to offer customers and partners optimal, trans-technological solutions for their assignments.

ForschungRegion Braunschweig

In order to network knowledge, to sustainably promote innovation and to strengthen the leadership position of the science region Braunschweig, in 2004, a total of 27 universities, colleges, federal research institutes, Helmholtz institutes, Fraunhofer institutes, research facilities of the Leibniz Association, museums, libraries, the Klinikum Braunschweig and further institutions with internationally highly regarded research joined forces to form the ForschungRegion Braunschweig e. V. – and the Fraunhofer IST is a participant.

Fraunhofer Project Center Wolfsburg

The lightweight campus "Open Hybrid LabFactory e. V. (OHLF)" is considered as one of the leading addresses in Germany for the research and development of hybrid components of the future. Here the Fraunhofer Project Center Wolfsburg and the TU Braunschweig are working together on the goal of producing hybrid lightweight components made of metals, plastics and textile structures for industrial use in an economically and ecologically sustainable manner. At the Fraunhofer Project Center Wolfsburg the Fraunhofer IST is conducting research together with the Fraunhofer Institutes IFAM, IWU and WKI to find solutions for developing the entire process chain for lightweight structures in the automotive sector and testing them on a large scale.

Wasserstoff Campus Salzgitter (Hydrogen campus)

At the Wasserstoff Campus Salzgitter (Hydrogen campus) the Fraunhofer IST is working in cooperation with the City of Salzgitter, Salzgitter AG, MAN Energy Solutions, Bosch, Alstom, WEVG and the Projektbüro Südostniedersachsen to develop CO_2-neutral solutions for industrial use with regional hydrogen expertise.

Cooperations with the TU Braunschweig

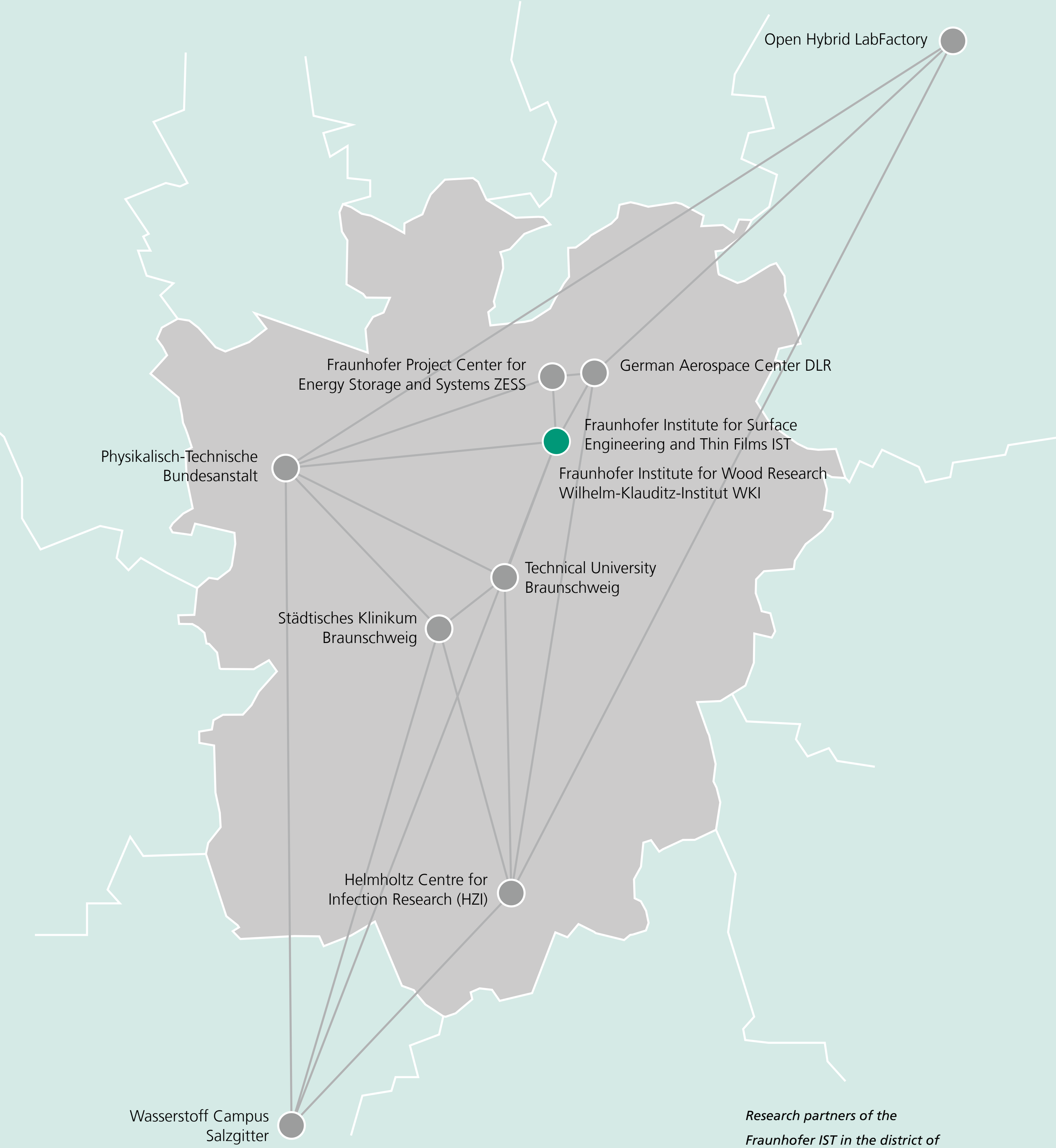
- Battery LabFactory Braunschweig BLB
- Automotive Research Centre Niedersachsen NFF
- Aeronautics Research Centre Niedersachsen NFL
- Center of Pharmaceutical Engineering PVZ
- Open Hybrid LabFactory e.V

Sites Göttingen and Dortmund

The department Application Center for Plasma and Photonics of the Fraunhofer IST in Göttingen focusses on the research on new, application-oriented fields in the area of plasma technologies under atmospheric pressure, photonics and the development of tailor-made plasma in cooperation with the HAWK University of applied Sciences and Art. At Dortmunder OberflächenCentrum DOC ThyssenKrupp Steel Europe with its on-site partners Fraunhofer IST and Fraunhofer IWS develops industry-ready solutions in the field of surface engineering for flat steel products. Fraunhofer IST primarily offers coatings for the application of wear and temperature-resistant surfaces at the Dortmund location.

Strategic partnership with the Kompetenzzentrum Tribologie in Mannheim

In cooperation with the Hochschule Mannheim – University of Applied Sciences the Fraunhofer IST is working on the expansion of their joint research activities in the field of tribology and surfaces.



Research partners of the Fraunhofer IST in the district of Braunschweig and the region.

PROMOTION OF YOUNG TALENT AND TRAINING AT THE FRAUNHOFER IST

Promoting young talent – for the Fraunhofer Institute for Surface Engineering and Thin Films IST, this means not only being active as a trainer and in the university context but also introducing adolescents to scientific topics, helping them to overcome their fears and anxieties, and filling young people with enthusiasm for industry-related research. Due to the Corona pandemic and the accompanying measures regarding the restriction of personal contact, both the Future Day for Boys and Girls and student internships could not take place in 2020.

Training professions

Together with the Fraunhofer WKI we train the following seven professions:

- Physics laboratory technician
- Surface coating technician (Electroplater)
- Office management assistant
- Media and information services assistant – Libraries
- IT Specialist – System integration
- Wood technician
- Industrial mechanic

This year, two trainees were able to begin their training as physics laboratory technicians.

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THE COMPETENCE NETWORK INDUSTRIAL PLASMA SURFACE TECHNOLOGY E. V. – INPLAS

The Competence Network INPLAS e. V., which is accredited as a network by the German Federal Ministry for Economic Affairs and Energy (BMWi) in the "go-cluster" program and which was recertified in 2020 for a further three years with the Silver Label of the European Cluster Excellence Initiative (ECEI), has its offices on the premises of the Fraunhofer IST in Braunschweig. INPLAS currently has 54 members from industry and science with around 200 active persons. 75 percent of the members come from industry.

The goal of the network is to make plasma technology more widely known and to support, promote and present the development within the numerous fields of application in their respective complexity. As a result of the pandemic, the INPLAS network was also presented with diverse challenges in 2020. The majority of attendance events were cancelled or converted to digital formats. We would like to thank all our members who continued to support and drive forward the activities within the network during this time. A number of highlights of the 2020 activities, projects and events are presented below:

17th International Conference on Plasma Surface Engineering – Special PSE 2020 in Erfurt

As a result of the constraints imposed by the COVID-19 pandemic restrictions, this year's Special PSE 2020 in Erfurt replaced the PSE traditionally held in Garmisch-Partenkirchen. A total of around 200 visitors came to Erfurt. The accompanying industrial exhibition registered 40 exhibitors. INPLAS was once again represented with a joint booth shared by Comet AG, Fraunhofer FEP and IST, HAWK University of Applied Sciences and Arts, SINGULUS TECHNOLOGIES AG, W&L Coating Systems GmbH and the INPLAS administrative office.

43rd meeting of the Industrie-Arbeitskreis Werkzeugbeschichtungen und Schneidstoffe (industrial working group tool coatings and cutting materials, IAK)

Tool manufacturers and users, predominantly from industry, met at the beginning of November 2020 for the 43rd edition of the Industrie-Arbeitskreis Werkzeugbeschichtungen und Schneidstoffe (industrial working group tool coatings and cutting materials, IAK), which was this time held in virtual form, in order to exchange views on the latest developments and trends in the field of cutting tools and their coatings. The topics presented in talks from industry and science included, for example, PVD multi-layer coatings for carbide cutting tools, lateral ARC and central sputtering (LACS) technology, CVD-coated cutting tools through laser-sharpening, bonded PcBN milling tools and CVD-diamond micro-milling bits. Hosted by the partners IWF from the TU Berlin, the Fraunhofer IPK, the Fraunhofer IST and INPLAS e. V., the IAK takes place twice a year, usually in spring in Berlin and in fall in Braunschweig.

INPLAS working groups

During a virtual meeting in November, the WG "Novel Plasma Sources and Processes", with a management team comprised of Dr. Ulf Seyfert, Von Ardenne GmbH, Matthias

Nestler, scia systems GmbH and Dr. Anke Hellmich, Applied Materials GmbH & Co. KG, focused on solid-state microwave technology and particle avoidance in low-pressure plasma processes.

The WG "Tool Coatings", headed by Hanno Paschke, Fraunhofer IST, met twice in 2020 in virtual form. At the two meetings in June and November 2020, the participants discussed the possibilities of utilizing artificial intelligence to evaluate analysis data from the digitalized plasma production Plasma 4.0 and new project ideas, for example on standardization tools for machining.

Within the framework of the activities of the WG "Plasma4Life", a business meeting was held at the premises of our partner BioEconomy Cluster in September 2020. The main topic of the meeting was cellulose and its role in the development and implementation of the circular bio-economy. INPLAS member Fraunhofer IST contributed with a presentation on plasma functionalization of paper. In the bio-economy, however, plasma technology is not only of interest for individual improvements of the properties of bio-based products but also for safe food production and the realization of non-chemical crop protection in agriculture.

In the two meetings of the Joint Expert Panel "Combined Surface Technologies", which is headed by Dr. Petra Uhlmann, Leibniz Institute of Polymer Research, held in February 2020 at Schaeffler Technologies AG & Co. KG and online in September 2020, the participants addressed the metallization of plastics with a focus on chromium(VI)-free processes. Further topics included the surface modification of galvanized plastic parts and the optimization of complex galvanic processes by means of cyber-physical systems.

1 *INPLAS joint stand at the Special PSE 2020 industrial exhibition in Erfurt, Germany.*

2 *INPLAS member overview (Status: December 2020).*

15th INPLAS General Meeting

Unfortunately, the 15th INPLAS General Meeting also had to take place digitally, meaning that for this important members' meeting as well, personal contact could not be used as intensively as usual. The main agenda items were the introduction of new members, amendments to the articles of association – amongst other things to make it easier for start-ups to obtain membership of INPLAS – and thematic focal points such as the INPLAS jointproject opportunities in the fields of anti-adhesive coatings, Plasma 4.0, CO_2 footprint and developments in the area of hygiene-pharmaceutical medical technology.

CONTACT

Dipl.-Ing. Carola Brand
Managing Director
Phone +49 531 2155 574
carola.brand@inplas.de

Dr. Jochen Borris
Project Manager
Phone +49 531 2155 666
jochen.borris@inplas.de

www.inplas.de

Memberships

Arbeitsgemeinschaft Wärmebehandlung und Werkstofftechnik e. V.
www.awt-online.org

A.SPIRE
www.spire2030.eu

DECHEMA – Gesellschaft für Chemische Technik und Biotechnologie e. V.
www.dechema.de

Deutsche Gesellschaft für Elektronenmikroskopie e. V.
www.dge-homepage.de

DGO Gesellschaft für Galvano- und Oberflächentechnik e. V.
www.dgo-online.de

Deutsche Vakuum-Gesellschaft DVG e. V.
www.physik.uni-kl.de/dvg/index.php/die-dvg

Europäische Forschungsgesellschaft für Blechverarbeitung e. V. (EFB)
www.efb.de

Europäische Forschungsgesellschaft Dünne Schichten e. V. (EFDS)
www.efds.org

European Factories of the Future Research Association (EFFRA)
www.effra.eu

European Joint Committee on Plasma and Ion Surface Engineering (EJC/PISE)
www.ejc-pise.org

Fachverband Angewandte Photokatalyse (FAP)
www.vdmi.de/deutsch/produkte/angewandte-photokatalyse.html

FGW Forschungsgemeinschaft Werkzeuge und Werkstoffe e. V.
www.fgw.de

F.O.M. Forschungsvereinigung Feinmechanik, Optik und Medizintechnik e. V.
www.forschung-fom.de

ForschungRegion Braunschweig e. V.
www.forschungregion-braunschweig.de

Forschungsvereinigung Räumliche Elektronische Baugruppen 3-D MID e. V.
www.3d-mid.de

Fraunhofer-Allianz autoMOBILproduktion
www.automobil.fraunhofer.de

Fraunhofer-Allianz Batterien
www.batterien.fraunhofer.de

Fraunhofer-Allianz Space
www.space.fraunhofer.de

Fraunhofer-Allianz SysWasser
www.syswasser.de

Fraunhofer Forschungsbereich Textil
www.textil.fraunhofer.de

Fraunhofer Forschungsfeld Leichtbau
www.leichtbau.fraunhofer.de

Fraunhofer Geschäftsbereich Adaptronik
www.adaptronik.fraunhofer.de

Geschäftsbereich Reinigung
www.allianz-reinigungstechnik.de

Fraunhofer Kompetenzfeld Additive Fertigung
www.additiv.fraunhofer.de

Fraunhofer-Netzwerk Nachhaltigkeit
www.fraunhofer.de/de/ueber-fraunhofer/corporate-responsibility/governance/nachhaltigkeit/fraunhofer-netzwerk-nachhaltigkeit.html

Fraunhofer-Netzwerk Simulation
www.simulation.fraunhofer.de

Fraunhofer-Netzwerk Wasserstoff
www.fraunhofer.de/de/forschung/aktuelles-aus-der-forschung/wasserstoff.html

Fraunhofer-Verbund Light & Surfaces
www.light-and-surfaces.fraunhofer.de

Deutsches Flachdisplay-Forum e. V.
www.displayforum.de

German Water Partnership
www.germanwaterpartnership.de

Göttinger Research Council
www.uni-goettingen.de

Haus der Wissenschaft Braunschweig GmbH
www.hausderwissenschaft.org

Innovationsnetzwerk Niedersachsen
www.innovationsnetzwerk-niedersachsen.de

International Council for Coatings on Glass e. V.
www.iccg.eu

Kompetenznetz Industrielle Plasma-Oberflächentechnik e. V. (INPLAS)
www.inplas.de

Measurement Valley e. V.
www.measurement-valley.de

Nanotechnologie Kompetenzzentrum Ultrapräzise Oberflächenbearbeitung CC UPOB e. V.
www.upob.de

NANOfutures European Technology Integration and Innovation Platform (ETIP) in Nanotechnology
www.nanofutures.info

Optence e. V.
www.optence.de

Open Hybrid LabFactory e. V.
www.open-hybrid-labfactory.de

PhotonicNet GmbH – Kompetenznetz Optische Technologien
www.photonicnet.de

Plasma Germany
www.plasmagermany.org

Spectaris – Deutscher Industrieverband für Optik, Photonik, Analysen- und Medizintechnik e. V.
www.spectaris.de

netzwerk-surface.net – Kompetenznetzwerk für Oberflächentechnik e. V.
www.netzwerk-surface.net

Wissens- und Innovations-Netzwerk Polymertechnik (WIP)
www.wip-kunststoffe.de

Board memberships

Abraham, T.: Fachausschuss FA 10 "Funktionelle Schichten" der Arbeitsgemeinschaft Wärmebehandlung und Werkstofftechnik e. V. AWT, Member.

Bandorf, R.: Europäische Forschungsgesellschaft Dünne Schichten e. V. (EFDS), Advisory board.

Bandorf, R.: Forschungsvereinigung Räumliche Elektronische Baugruppen 3-D MID e. V., Member.

Bandorf, R.: International Conference on HIPIMS, Conference Chairman.

Bandorf, R.: Society of Vacuum Coaters, Lecturer.

Bandorf, R.: Society of Vacuum Coaters, Member board of directors.

Bandorf, R.: Society of Vacuum Coaters, Program Chairman.

Bandorf, R.: Society of Vacuum Coaters, Session Chairman.

Bandorf, R.: Society of Vacuum Coaters, Volunteer mentor.

Baron, S.: VDI-Richtlinien-Fachausschuss "CVD-Diamant-Werkzeuge", Member.

Brand, C.: Arbeitgeberverband Region Braunschweig, Member.

Brand, C.: Europäische Forschungsgesellschaft Dünne Schichten e. V. (EFDS), Member.

Brand, C.: Kompetenznetz Industrielle Plasma-Oberflächentechnik INPLAS e. V., Managing director.

Brand, C.: Plasma Germany, Member of the coordination committee.

Brand, J.: Gesellschaft für Tribologie (GfT), Member.

Brand, J.: International Colloquium Tribology, Tribology and Lubrication Engineering, Member in the programme planning committee.

Bräuer, G.: European Joint Committee on Plasma and Ion Surface Engineering (EJC / PISE), Chairman.

Bräuer, G.: International Conference on Coatings on Glass and Plastics (ICCG), Chairman of the organizing committee.

Bräuer, G.: International Council for Coatings on Glass (ICCG) e. V., Board member.

Bräuer, G.: Institut für Solarenergieforschung, Member of the advisory board.

Bräuer, G.: Kompetenznetz Industrielle Plasma-Oberflächentechnik INPLAS e. V., Chairman of the board.

Bräuer, G.: Zeitschrift "Vakuum in Forschung und Praxis", Member of the board of trustees.

Bräuer, G.: Zentrum für Mikroproduktionstechnik e. V., Member of the board.

Dietz, A.: Arbeitsgemeinschaft Elektrochemischer Forschung (AGEF), Member.

Dietz, A.: Deutsche Gesellschaft für Galvano- und Oberflächentechnik e. V. (DGO), Member of the board.

Dietz, A.: EARTO - European Association of Research and Technology Organisations, Working Group Space Research.

Dietz, A.: Fachausschuss "Forschung" der DGO, Member.

Dietz, A.: Fachausschuss "Kombinationsschichten" der DGO, Member.

Gäbler, J.: DIN Deutsches Institut für Normung e. V., Normenausschuss 062 Materialprüfung, Arbeitsausschuss "01-60 Überzüge und Korrosion", Member.

Gäbler, J.: DIN Deutsches Institut für Normung e. V., Normenausschuss NA 062 Materialprüfung, Arbeitsausschuss "01-64 Kohlenstoffschichten und keramische Hartstoff-schichten", Vice-Chairman.

Gäbler, J.: European Technology Platform for Advanced Materials and Technologies EuMaT, Member.

Gäbler, J.: European Technology Platform NANOfutures, Member.

Gäbler, J.: ISO Technical Committee TC 107 "Metallic and other inorganic coatings", Member.

Gäbler, J.: VDI-Richtlinien-Fachausschuss "CVD-Diamant-Werkzeuge", Member.

Gerdes, H.: Society of Vacuum Coaters, Lecturer.

Gerdes, H.: Society of Vacuum Coaters, Session Chairman.

Gerdes, H.: VDI/VDE-GMA Fachausschuss 2.11 "Elektrische Messverfahren; DMS-Messtechnik", Member.

Keunecke, M.: EFDS-Fachausschuss "Tribologische Schichten", Member.

Keunecke, M.: SAE International, Member.

Keunecke, M.: Society of Vacuum Coaters, Lecturer.

Keunecke, M.: Society of Vacuum Coaters, Session Chairman.

Lachmann, K.: COST Action MP1101 "Biomedical Applications of Atmospheric Pressure Plasma Technology", Management Committee, Substitute.

Neumann, F.: DIN Deutsches Institut für Normung e. V., Normenausschuss 062 Materialprüfung, Arbeitsausschuss NA 062-02-93 AA "Photokatalyse", Vice-Chairman.

Neumann, F.: DIN Deutsches Institut für Normung e. V., Normenausschuss 062 Materialprüfung, Arbeitsausschuss NA 062-02-93 AA "Photokatalyse", Head of the working group "Photokatalytische Selbstreinigung".

Neumann, F.: Europäisches Komitee für Normung, CEN/TC 386 "Photocatalysis", Delegate of the technical committee.

Neumann, F.: Europäisches Komitee für Normung, CEN/TC 386 "Photocatalysis", Member.

Neumann, F.: Fachverband Angewandte Photokatalyse (FAP), Forschungsausschuss, Member.

Neumann, F.: Ostfalia Hochschule für angewandte Wissenschaften, Fakultät Versorgungstechnik, Studiengang "Bio- und Umwelttechnik", Member of the advisory board.

Neumann, F.: ISO Normenausschuss TC 206/WG 9 "Photocatalysis", Member.

Paschke, H.: Fachausschuss FA10 "Funktionelle Schichten" der Arbeitsgemeinschaft Wärmebehandlung und Werkstofftechnik e. V. AWT, Member.

Paschke, H.: Industrie-Arbeitskreis "Werkzeugbeschichtungen und Schneidstoffe", Management.

Paschke, H.: Kompetenznetzwerk für Oberflächentechnik "netzwerk-surface.net", Scientific advisory board (speaker).

Paschke, H.: Kompetenznetz Industrielle Plasma-Oberflächentechnik INPLAS e. V., Head oft he working group Werkzeugbeschichtungen.

Schäfer, L.: Beirat der CONDIAS GmbH, Member.

Schäfer, L.: Industriearbeitskreis "Werkzeugbeschichtungen und Schneidstoffe", Member.

Schäfer, L.: Nanotechnologie-Kompetenzzentrum Ultrapräzise Oberflächenbearbeitung CC UPOB e. V., Member.

Schäfer, L.: VDI-Richtlinien-Fachausschuss "CVD-Diamant-Werkzeuge", Member.

Schäfer, L.: Kompetenznetz Optence e. V., "Networking in Photonics", Member.

Sittinger, V.: European Photovoltaic Solar Energy Conference and Exhibition, Scientific Committee Member, Paper Review Expert.

Sittinger, V.: Society of Vacuum Coaters, Program Chairman, Session Chairman.

Stein, C.: Society of Vacuum Coaters, Lecturer.

Stein, C.: Society of Vacuum Coaters, Session Chairman.

Stein, C.: VDI-Arbeitskreis "Schneidstoffanwendungen", Member.

Thomas, M.: Anwenderkreis Atmosphärendruckplasma (AK-ADP), Member.

Thomas, M.: Arbeitsgruppe "Plasma4Life" INPLAS e. V., Member.

Thomas, M.: DECHEMA – Gesellschaft für Chemische Technik und Biotechnologie e. V., Member.

Thomas, M.: Kompetenznetz Industrielle Plasma-Oberflächentechnik INPLAS e. V., Board member.

Thomas, M.: Plasma Germany, Koordinierungsausschuss, Member.

Thomas, M.: International Conference on Plasma Surface Engineering, International Program Committee IPC, Member.

Thomas, M.: European Joint Committee on Plasma and Ion Surface Engineering (EJC/PISE), Chairman.

Vergöhl, M.: Europäische Forschungsvereinigung für dünne Schichten e. V. (EFDS), Board member.

Vergöhl, M.: Europäische Forschungsvereinigung für dünne Schichten e. V. (EFDS), stellvertretende Leitung des Fachausschusses "Beschichtungstechnologien für optische und elektronische Funktionalisierung", Deputy head.

Vergöhl, M.: Lenkungskreis "Photonik" des VDMA, Member.

Vergöhl, M.: Optical Society (OSA), Lecturer.

Viöl. W.: Amt für regionale Landesentwicklung Braunschweig, Member of the advisory board Südniedersachsen.

Viöl, W.: Bundesministerium für Bildung und Forschung BMBF, Member of the program advisory board.

Viöl, W.: Deutsche Gesellschaft für Plasmatechnologie e. V. DGPT, Board member.

Viöl, W.: DFG Fachkollegien, Member.

Viöl, W.: Gesellschaft Deutscher Naturforscher und Ärzte e. V. GDNÄ, Board member.

Viöl, W.: HAWK Hochschule für angewandte Wissenschaft und Kunst Hildesheim/Holzminden/Göttingen, Vice president for research and transfer.

Viöl, W.: Hochschulrektorenkonferenz Forschungskommission Fachhochschulen.

Viöl, W.: Kompetenznetz für Nachhaltige Holznutzung (NHN) e. V., Board member.

Viöl, W.: Kompetenznetz Industrielle Plasma-Oberflächentechnik INPLAS e. V., Treasurer.

Viöl. W.: Nationales Zentrum für Plasmamedizin, Board member.

Viöl, W.: Spectaris – Deutscher Industrieverband für Optik, Photonik, Analysen- und Medizintechnik e. V., Fachverband Photonik, Member of the steering committee.

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Herrmann, C. (2020): Ringvorlesung "Kernbegriffe für die Stadt der Zukunft": Stadtfabrik, 08.09.2020, Online – Lecture.

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Herrmann, C. (2020): Life Cycle Engineering von Leichtbaustrukturen. DLR Wissenschaftstage 2020 "Kreislaufwirtschaft im Faserverbundleichtbau". 29.10.2020, Online – Lecture.

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Vergöhl, M.: Deposition of demanding optical coatings by magnetron sputtering. Fraunhofer Competence Forum China. 14.07.2020 – Lecture.

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Fraunhofer Institute for Surface Engineering
and Thin Films IST

Director of the Institute
Prof. Dr.-Ing. Christoph Herrmann

Deputy Director of the Institute
Dr. Lothar Schäfer

Bienroder Weg 54 E
38108 Braunschweig
Phone +49 531 2155-0
Fax +49 531 2155-900
info@ist.fraunhofer.de
www.ist.fraunhofer.de

Editorial and coordination
Dr. Simone Kondruweit
Sandra Yoshizawa

Layout
nils hildebrandt designer
www.nilshildebrandt-designer.de

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