Fraunhofer IST

Fraunhofer Institute for Surface Engineering and Thin Films IST

Annual Report 2021

Cover

Process chain digitization at the Fraunhofer IST:
Robot-assisted process engineering for investigating
collaborative process flows in electroplating.

Fraunhofer IST Annual Report

2021

Foreword of the Institute management

"In 2021, we have once again set an important course for the Fraunhofer Institute for Surface Engineering and Thin Films and have invested in the expansion of our competencies in the areas of digitalization and automation of process chains for sustainable production."

Prof. Dr.-Ing. Christoph Herrmann / Director

Dear Ladies and Gentlemen,

with the annual report 2021 we are looking back on an eventful period. The year began with a special highlight for us: On 18th February 2021, the NASA rover "Perseverance" successfully landed on Mars – and with it an optical interference filter from the Fraunhofer IST. But not only that: In 2021, we also set an important course for the further development of the institute.

Since last year, we have been a member of the Fraunhofer Group for Production, in which currently 11 institutes pool their expertise in order to provide expert knowledge for "production of the future" and to offer system solutions to German and international companies. Needless to say, we thereby draw on our competence in surface technology and continue to maintain a close exchange with the institutes in the Fraunhofer Group for Light & Surfaces.

In the fall, we conducted an audit within the framework of the Fraunhofer strategy process, thereby creating the basis for the further intensification of the thematic orientation of our work. We would like to take this opportunity to thank the auditors once again for their valuable discussions and advice.

Regional networking was and is an important success factor for us. Through our collaborations with the TU Braunschweig and the Städtisches Klinikum Braunschweig (Braunschweig Municipal Hospital) as well as the cooperation with our partners at the Wasserstoff Campus Salzgitter and the Open Hybrid LabFactory in Wolfsburg, we are constantly opening up new, important future fields such as energy storage, hydrogen technologies, mobility or sustainable production, as well as medical and pharmaceutical technology. In cooperation with the Center of Pharmaceutical Engineering (PVZ) at the TU Braunschweig, we are developing a unique translational laboratory for individualized medicine production.

The digitization of process chains all the way through to model factories is an important driver of the applied research at the Fraunhofer IST. Under the heading "Reinigung 4.0" (Cleaning 4.0), we demonstrate how cyber-physical production systems can be implemented in industrial practice. In collaboration with businesses, we will successively transfer the fundamental concept to other processes and process chains.

This past year, our work was once again impacted by the Corona pandemic, both organizationally and in terms of content. Mobile Working and New Work are topics that will continue to accompany us beyond the pandemic. During the course of our "anti-coronavirus research", we were able to successfully complete various projects: Just two examples are a mobile cleaning robot with a plasma module, and a disinfection sprayer in which ozonated water is generated by means of our diamond-coated electrodes.

Sustainability is a central guiding principle for our research. We were therefore delighted that the "SafeWaterAfrica" project was honored with the Solar Impulse Label, which is awarded for clean and cost-effective solutions. This provides us with encouragement regarding our goals of continuing to devise future-proof product and associated production systems, with sustainability as a key consideration, in 2022.

By taking a look back and also forward, we would like to take this opportunity to thank not only you, dear reader, for your interest: My special thanks go to the staff of the institute, our partners from research and development, our clients from industry, our sponsors, colleagues and friends. We thank you for the trusting cooperation and look forward to completing further exciting projects with you.

I sincerely hope that you will enjoy reading this report.

Prof. Dr.-Ing. Christoph Herrmann

Content

Content

Our Board of Trustees

The members of our Board of Trustees provide us with advice and support on matters of professional orientation and structural alterations. In 2021, the meeting of the Board of Trustees was held in digital format. Our illustrious Board of Trustees is comprised of representatives from science, industry and public life:

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Plasmawerk Hamburg GmbH

Prof. Dr. Peter Awakowicz[2]
Ruhr-Universität Bochum

Dr. med. Thomas Bartkiewicz[3]
Städtisches Klinikum Braunschweig gGmbH

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Dr. Sebastian Huster[7]
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Gast:
Dr. Kai U. Ziegler[14]
EagleBurgmann Germany GmbH & Co. KG

Excellent collaboration

An Interview with Clas Schmitz, CEO of Pfaudler interseal GmbH

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Personal details

Clas Schmitz is Managing Director of Pfaudler interseal GmbH and has been active in the field of sealing technology since 2000.

As a lateral entrant, he joined the one-man company "Interseal", founded by Rolf Schmitz in 1983, and made the further development of the technical concepts of the products his mission – all the way through to the series maturity and global market launch of the new technology, which has significantly transformed the sealing market. With the sale of interseal in 2017 to Pfaudler Holding, a significant step towards market penetration of the innovative patented sealing solutions was implemented in order to provide customers with these advanced technologies.

Today, Clas Schmitz, as Managing Director of Pfaudler interseal GmbH, based near Frankfurt, is leading the further expansion of the company within the Group as a "Competence Center for Sealing Technology", which provides sealing solutions far beyond the product-portfolio scope of the Pfaudler Group to system-relevant production companies such as BASF.

What are the current challenges for your sector and what contribution does the Fraunhofer IST provide in this context?

"The components of sealing technology must be defined as essential elements in a production process, as only flawless and trouble-free operation enables safe and high-quality production. The resulting constantly increasing demands on dynamic systems present the sector in general with the constant challenge of optimizing the systems in terms of service life.

With its comprehensive and profound knowledge in the field of tribology and sensor technology, the Fraunhofer IST provides a correspondingly fundamental contribution towards the optimization of our company's dynamic sealing systems. The technical possibilities at the Fraunhofer IST for the identification of limits in the field of tribology enable us to optimize our systems significantly and to elaborate new options for our customers.

Furthermore, in the field of sensor technology, the Fraunhofer IST is an innovative partner for the implementation of the digitalization necessary for monitoring a dynamic seal for our product – in a very demanding process environment – in order to avoid unplanned production downtimes. Particular emphasis should be placed here on the personalized, uncomplicated and product-specific support which enables us to optimize our product."

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High-tech sealing technology. © Pfaudler interseal GmbH

You have been working with the Fraunhofer IST since 2005. Which particular project do you recall which characterizes your collaboration with the IST?

"One of our first projects in the field of tribology remains an enduring memory to this day. The DLC coating of the DN350 metallic sealing system was still something unusual at that time in terms of construction size and application in the pulp-fiber industry.

During the course of further development, this led, amongst other things, to the coating of series components for our dynamic sealing systems (dry9000®), which is now used in our products for the sealing of agitators, suction filters, dryers, etc. worldwide in the field of highly corrosive processes in the chemical and pharmaceutical industries as well as in the food industry."

What plans do you have for the future – also with regard to the Fraunhofer IST?

"For our future projects and the further development and optimization of our product range, we will continue to rely on close collaboration with the Fraunhofer IST. We plan to optimize the processes of our local customers, using our products, at our now worldwide locations. The Fraunhofer IST is to be a constant companion and provider of ideas here. The area of digitalization of measured values, their evaluation and transformation into decision-making aids will thereby play a major role. The lively exchange of experience with the Fraunhofer IST will continue to be an essential element for successful collaboration in the future."

Pfaudler interseal GmbH

As a supplier of innovative products in the field of sealing technology, Pfaudler interseal GmbH specializes in the manufacture of dynamic seals and sealing components for applications in the chemical, petrochemical, pharmaceutical and food industries.

One of the main focal points thereby concerns sealing solutions which prevent contamination through otherwise common barrier media in rotating seals. The objective is an improvement in product quality. In addition, unplanned downtimes in production processes should be avoided with the aim of reducing the total cost of ownership (TCO).

Further information: www.pfaudler.com

With its dry9000® dry-running sealing technology, Pfaudler develops and manufactures a shaft-sealing solution for all types of sealing applications in the pharmaceutical and chemical industries as well as for food processing. © Pfaudler interseal GmbH

Institute profile

As an innovative and internationally recognized partner for research and development, the Fraunhofer Institute for Surface Engineering and Thin Films IST develops future-oriented products – including the associated competitive and scalable production systems.

Our research encompasses plant engineering, entire process chains of process engineering, process technology and manufacturing technology all the way through to the consideration of entire factories. Taking the requirements of sustainability as a starting point, we maintain an overview of the entire product life cycle – from the material, through the process of creating the component and product, and on to recycling.

Tailor-made and sustainable: Our sector-based solutions

In interdisciplinary teams and based on our technology and competence fields, we offer our customers from industry and research tailored and sustainable solutions for various sectors, e. g. plant and mechanical engineering, tools, vehicle construction, aerospace, energy, optics, medical and pharmaceutical process engineering, environmental technology, chemistry, and the digital economy.

Drawing on a broad spectrum of expertise, technologies, processes and coating materials, we design the optimum process chain for the respective task, right through to the digital design of the entire factory.

The core competencies of the Fraunhofer IST are:

- Energy storage systems with focus on battery cell production and hydrogen technology
- Micro and sensor technology / Industry 4.0
- Tribological systems
- Precision optical coatings
- Multifunctional surfaces for medical technology and pharmaceutical production
- Flexible production systems
- Cyber-physical systems and Computational Surface Engineering & Science

The IST has accumulated expertise in diverse technologies for the coating, treatment and structuring of surfaces. These 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
- 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 competences include the design of sustainable production and factory systems as well as life-cycle engineering (life-cycle costing, life-cycle assessment).

"Electromobility, Industry 4.0, smart tools, individualized medicine, precision optics for space applications: At the Fraunhofer IST, we offer solutions for the most diverse industries."

Prof. Dr-Ing. Christoph Herrmann / Director

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, 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 building of the application center of the Fraunhofer IST in Göttingen in cooperation with the local university provides 1500 square meters of office and laboratory area.

At the Fraunhofer Center ZESS, we are developing, in collaboration with the Fraunhofer institutes IKTS and IFAM, sustainable next-generation energy storage systems and are advancing them to market maturity. We thereby consider the entire life cycle, from raw material through to recycling, from the point of view of technical, economic and ecological aspects. A new research building is planned for the work at the Research Airport Campus in Braunschweig. During the transition phase, employees will have access to laboratory space in the Automotive Research Centre Niedersachsen NFF and offices in the Lilienthalhaus at Braunschweig Research Airport.

At the Wolfsburg location, the Fraunhofer IST, in collaboration with the Fraunhofer institutes IFAM, IWU and WKI, forms a further Fraunhofer Center. The center is part of the Open Hybrid LabFactory (OHLF), a research campus and public-private partnership for innovation. The focus here is on the topics of the circular economy, production technology, lightweight construction and materials development.

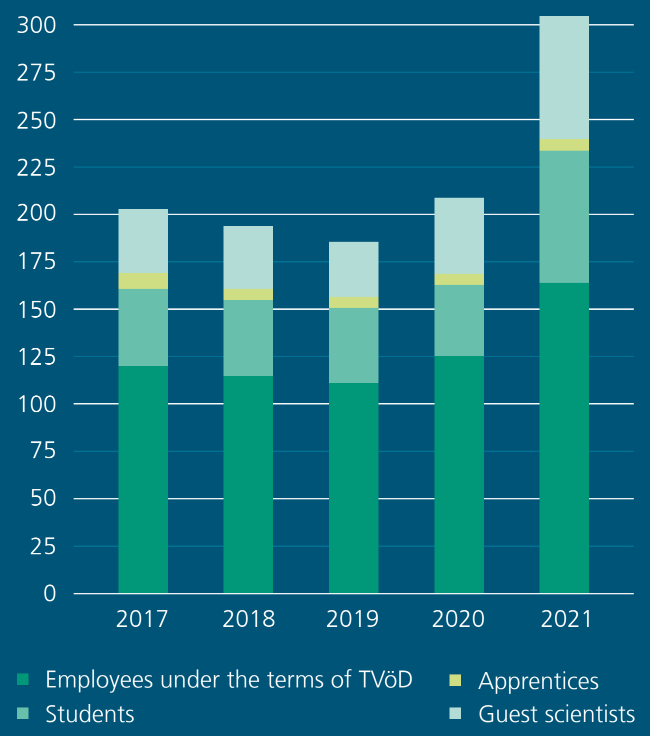
The industrial utilization of hydrogen is highly relevant with regard to both the energy revolution and a resilient energy supply. At the Salzgitter location and the Wasserstoff Campus established there, the Fraunhofer IST is working together with regional companies on technologies and concepts for the production and utilization of green hydrogen.

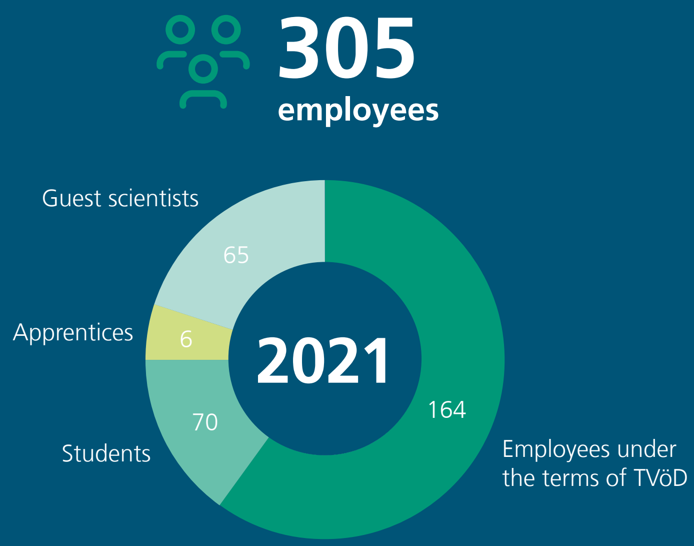
The range of services offered by the Fraunhofer IST is complemented in particular by the other member institutes and facilities of the Fraunhofer Group for Production. The Group pools the expertise of the Fraunhofer-Gesellschaft for the "production of the future" and elaborates innovative system solutions along the entire value chain for German and international companies.

Under the heading "One vision – two organizations", close collaborations also exist with institutes of the TU Braunschweig. These include the institutes directly associated with the Fraunhofer IST: Institute of Machine Tools and Production Technology (IWF), Institute for Surface Technology (IOT), and the Institute for Particle Technology (iPAT).

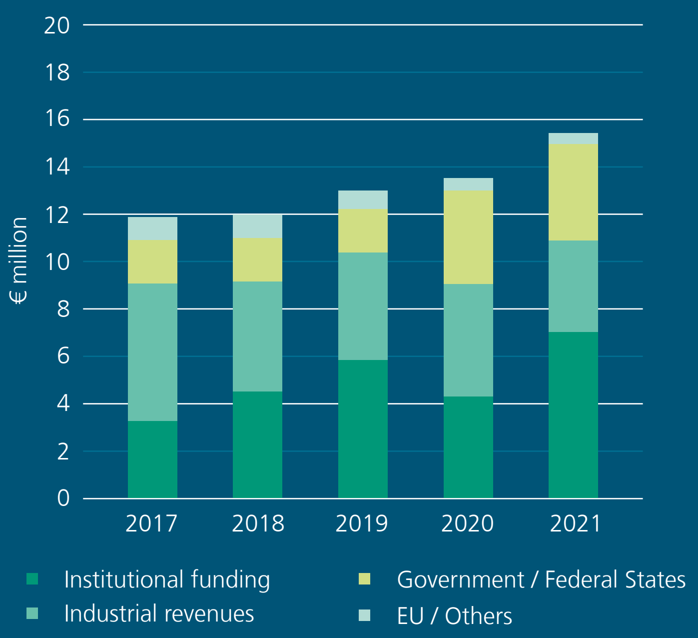
The institute in figures

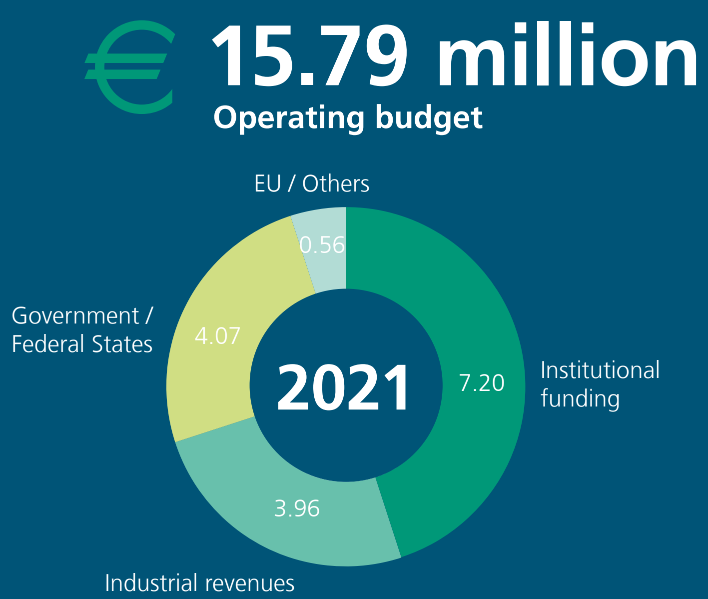
Personnel development





Operating budget





6 professorships

10 nationalities

>15 disciplines

23 conference contributions

*Employees under the terms of TVöD

46 publications and patents

5 locations

29 courses

14 master theses

2 dissertations

Professorships

The Fraunhofer IST cooperates with numerous institutes and centers of the TU Braunschweig. Thanks to the close ties with the university, we can build our project work on the latest results from university research. The Fraunhofer IST maintains connections with the Technische Universität Braunschweig in the form of five associated professorships. Since 2012, the institute has also been cooperating with the HAWK University of Applied Sciences and Arts Hildesheim / Holzminden / Göttingen within the framework of the Application Center in Göttingen.

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

Prof. Dr.-Ing. Klaus Dröder

Research foci:

- Production technologies
- Hybrid lightweight structures and integrated manufacturing
- Assembly and manufacturing automation
- Process automation

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
- Electrochemical processes
- Surface analytics

University of Applied Sciences and Arts Hildesheim / Holzminden / Göttingen HAWK

Faculty of Engineering and Health

Prof. apl. Prof. Dr. Wolfgang Viöl

Research foci:

- Laser technology
- Plasma technology
- Plasma medicine

Your contact persons

Institute management and administration

Institute management

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Fraunhofer Center Wolfsburg Open Hybrid LabFactory e.V. (OHLF)

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Highlights

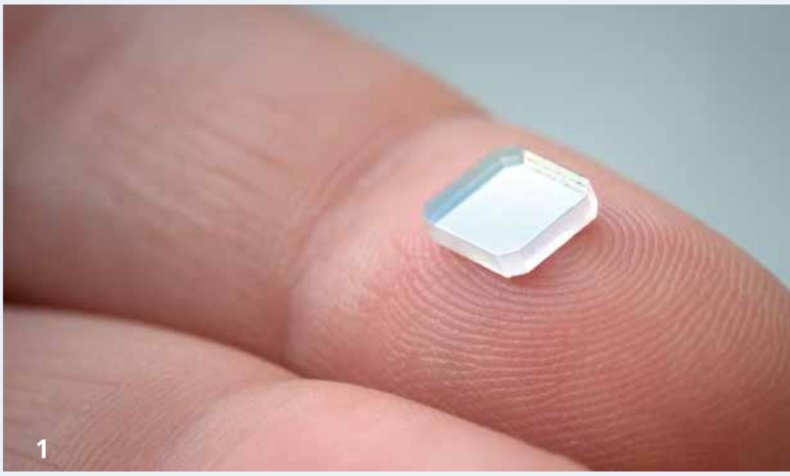
Technology from the Fraunhofer IST lands on Mars

March 04, 2021 / The 5 x 6 mm small filter assists NASA's Rover in the investigation of the dust in the planet's atmosphere – and it does so under the most extreme conditions.

After more than half a year and a journey of 472 million kilometers, the new Mars Rover "Perseverance" has successfully landed on Mars and, since its landing, has been delivering spectacular images of our neighboring planet. The goal: to obtain important information concerning possible life on Mars. For this purpose, the one-tonne Rover is equipped with extensive, highly sensitive technology – some of it from Braunschweig.

Specifically, the optical filter is located in an optical sensor for dust characterization in the "Mars Environmental Dynamics Analyzer", or MEDA for short. It performs weather measurements, including wind speed and direction, temperature and humidity, as well as radiation and the quantity and size of dust particles in Mars atmosphere. Over the course of the mission, the MEDA is intended to make a significant contribution towards preparing for human exploration of Mars.

The IST scientists manufactured the so-called bandpass filter on the EOSS® coating system by means of magnetron sputtering. In order to ensure that the extremely thin individual layers of the filter are deposited with high precision and homogeneity, the optical monitoring system MOCCA+®, also developed at the IST, is used.

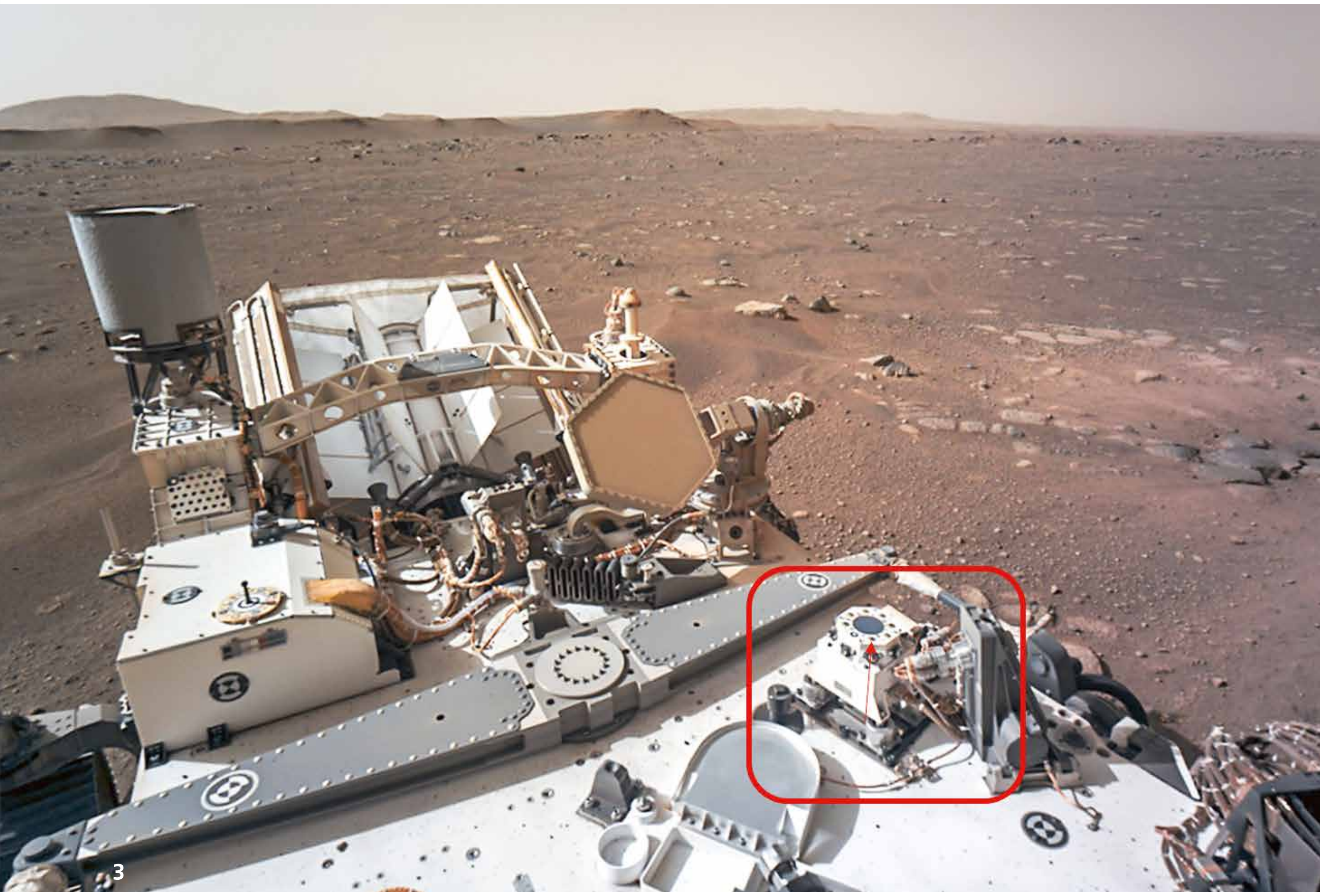


Interference filter for the Mars mission.

Top view of the turntable of the EOSS® sputter system from above.

For me it is truly special that a measuring device works at a distance of 470 million kilometers away from us on Mars because we have produced a suitable optical filter for it."

Dipl.-Phys. Stefan Bruns / Project Manager



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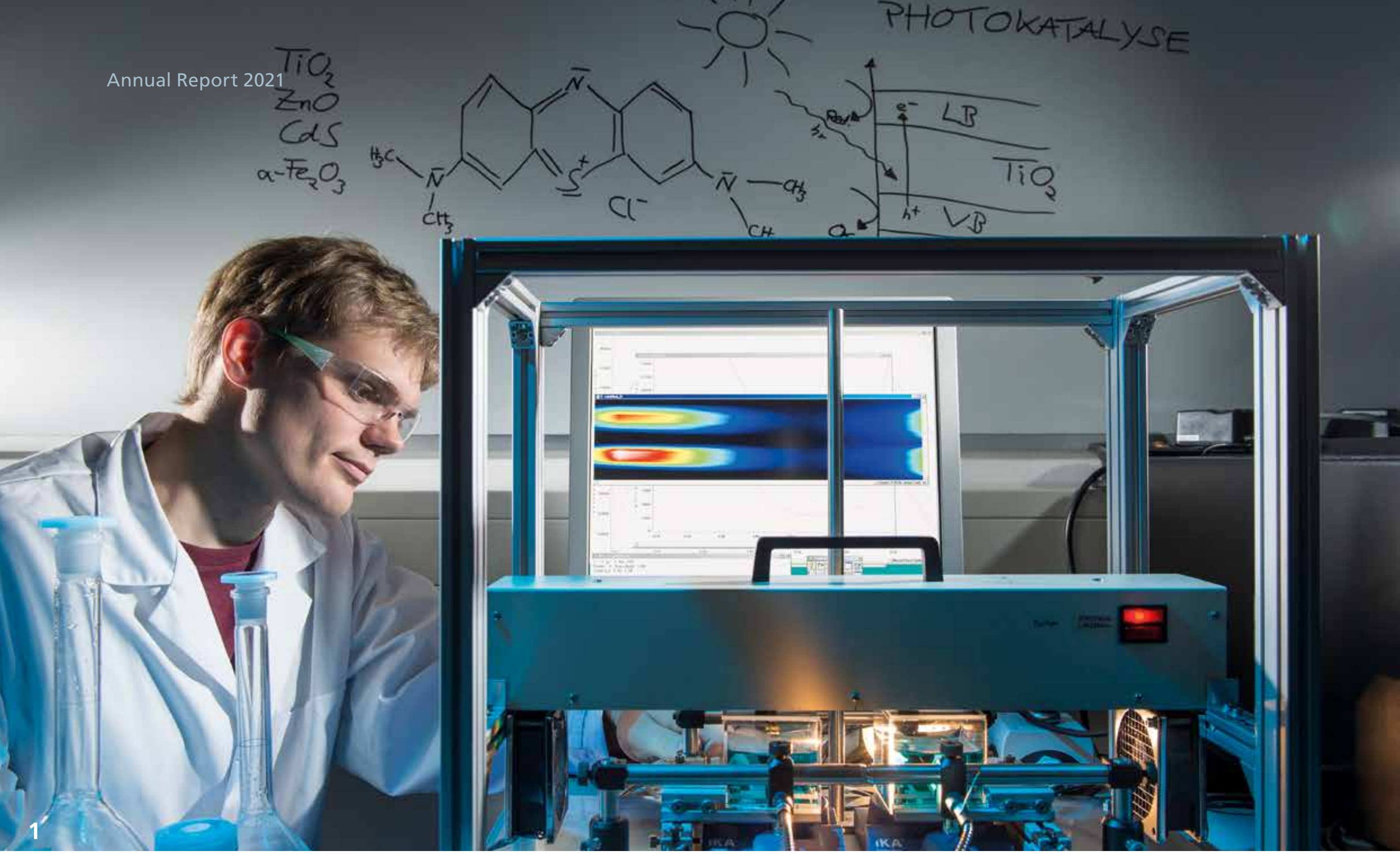
The interference filter is a component of an optical sensor for dust characterization in the "Mars Environmental Dynamics Analyzer", or MEDA for short. © Courtesy NASA / JPL-Caltech



1

Photocatalytic testing methods create added value in applications.

Robust and application-oriented – A new industrial standard for determining the photocatalytic activity of surfaces

April 01, 2021 / Everything spotless – almost without cleaning! Who would not want that? Particularly in the sanitary area, self-cleaning ceramics and tiles or glass for shower cubicles can not only make everyday tasks much easier but also prolong the service life of the products.

This self-cleaning effect is achieved, for example, through the use of photocatalytically active materials or surface coatings. 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.

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. In collaboration with partners from industry and research, the Fraunhofer IST has developed a robust and application-oriented German industrial standard for characterizing the photocatalytic activity of surfaces. In addition to a new procedure for large-format samples, new standards were hereby also developed and characterized as well as investigated with regard to their reusability. They are composed of long-term stable ceramics with defined graded photocatalytic coating

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Start of the High-Performance Center Medical and Pharmaceutical Engineering in northern Germany

2

Patient-specific implants and respiratory systems as well as individualized pharmaceutical production are at the focus of research and innovation transfer facilitated by the High-Performance Center Medical and Pharmaceutical Engineering.

April 28, 2021 / The aim of the Fraunhofer High-Performance Centers is to speed up innovation transfer. In March 2021, the High-Performance Center Medical and Pharmaceutical Engineering was launched. With a focus on personalized implants and respiratory systems as well as individualized pharmaceutical production, the goal is to create a platform for research and the transfer of innovations into patient care.

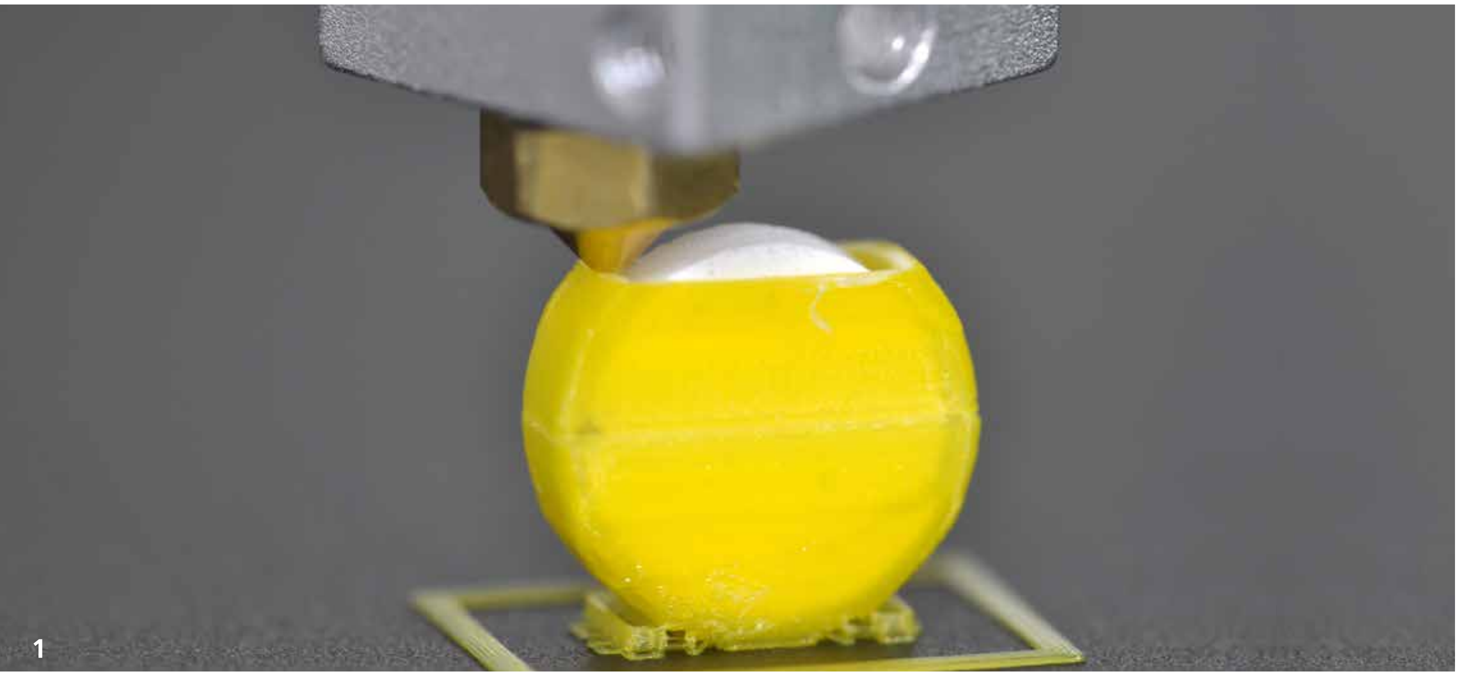
Under the leadership of the Fraunhofer Institute for Toxicology and Experimental Medicine ITEM in Hannover, the Fraunhofer IST in Braunschweig and the Fraunhofer Research Institution for Individualized and Cell-Based Medical Engineering IMTE in Lübeck have joined forces to form the High-Performance Center Medical and Pharmaceutical Engineering.

In the future, the partners will be collaborating in the joint transfer infrastructure to serve as a point of contact in northern Germany in the fields of biomedical engineering and pharmaceutical technology for external industry and research partners. To this end, the partners will set up so-called translation laboratories, where crucial steps in process and product development and in regulated product testing can be accomplished.

3

Functionalization of active ingredients and excipients by means of plasma processes for the optimized production of individualized pharmaceutical products.

Research from Braunschweig enables innovative pharmaceutical products



1

Use of additive manufacturing for the production of individualized pharmaceutical products.

April 30, 2021 / Braunschweig continues to expand its strengths in the manufacture of individualized pharmaceutical products. Therefore, the Fraunhofer IST and the Center of Pharmaceutical Engineering (PVZ) of the Technische Universität Braunschweig collaboratively establish a translational laboratory unique in Germany.

The Fraunhofer-Gesellschaft is providing 0.5 million euros to support the establishment of a translational laboratory for "Pharmaceutical and Medical Technology Production" in Braunschweig as part of the new Lower Saxony High-Performance Center for "Medical and Pharmaceutical Engineering". A mutually usable infrastructure for the individualized production of pharmaceuticals is being created with the aim of jointly bringing research results and innovations into application even more quickly as well as supporting partners as innovation pilots.

One goal of the research is to design tablets or capsules in such a way that they can be flexibly produced in small quantities, for example individually for a patient or a small group of patients. This imposes high demands on manufacturing. Process-engineering and production technology from Braunschweig is thereby set to play an important role in the future and is to be combined with the expertise from the pharmaceutical industry.

In collaboration with the PVZ, the Fraunhofer IST will also carry out research into new processes such as 3D printing in combination with innovative plasma systems and new surface coatings. These are to become part of a new modular process chain for the production of such individualized medication forms.

2

3

Through adaptation of the spatial conditions and the integration of two wet cells, infection prevention in a two-bed room can be significantly improved. This was realized in the TU Braunschweig research project KARMIN, which will be further developed as a research and study laboratory in the future in collaboration with the Fraunhofer IST and the Städtisches Klinikum Braunschweig gGmbH.

The patient room of the future comes to Braunschweig

June 15, 2021 / Architecture can prevent infections in hospitals. The walk-in model of a new type of patient room shows how this can be done.

Developed by a team from the fields of architecture, medicine and molecular biology in the KARMIN research project. After the prototype was presented to the public last year 2020 on the grounds of the Charité in Berlin, the patient room is now to become an application-oriented research and study laboratory under the leadership of the Institute of Construction Design, Industrial and Health Care Building (IKE) of the TU Braunschweig, the Fraunhofer Institute for Surface Engineering and Thin Films IST and the Braunschweig Municipal Hospital. The demonstrator will be built on an open area of the clinic.

"Functionalized surfaces and automated cleaning systems have the potential to become game changers in the hospital of the future."

Prof. Dr. Michael Thomas / Head of Department Interfacial chemistry and adaptive adhesion

Outstanding Research

Dr. Michael Thomas becomes Honorary Professor at the TU Braunschweig

Presentation of the certificate with the acting president Professor Katja Koch (left), Professor Klaus Dröder (Dean of the Faculty of Mechanical Engineering) and Professor Christoph Herrmann (right).

Dr. Michael Thomas appointed honorary professor.

April 15, 2021 / Dr. Michael Thomas, Head of Department at the Fraunhofer Institute for Surface Engineering and Thin Films IST, was appointed Honorary Professor for the Faculty of Mechanical Engineering at the Technische Universität Braunschweig on 14 April 2021.

With this appointment, the Faculty is acknowledging his commitment as a lecturer for the master's lectures "Analytik und Prüfung in der Oberflächentechnik (APO)" (Analytics and testing in surface engineering), "Oberflächentechnik mit Atmosphärendruck-Plasmaverfahren (OAP)" (Surface engineering with atmospheric pressure plasma processes) and "Ausgewählte Funktionsschichten (AFS)" (Selected functional coatings). His teaching activities strengthen the already intensive collaboration between the Fraunhofer IST and the research centers of the TU Braunschweig at the interface with applied research.

Dr.-Ing. Sabrina Zellmer awarded Manfred Hirschvogel Prize

October 06, 2021 / Customized structures made of nanoparticles could be of great importance in many areas of application in the future. However, how do we succeed in stabilizing them?

Sabrina Zellmer addressed this question as part of her doctoral thesis at the Institute for Particle Technology at the TU Braunschweig. The head of department at the Fraunhofer IST has now been awarded the Manfred Hirschvogel Prize for her research.

3

Dr.-Ing. Sabrina Zellmer (l.) and Prof. Dr.-Ing. Michael W. Gee, Frank Hirschvogel Stiftung

4

The awardee Dr. Marvin Omelan.

Dr. Marvin Omelan receives award from the Deutsche Kautschukindustrie

October 08, 2021 / Within the framework of this year's general meeting, the Arbeitgeberverband der Deutschen Kautschukindustrie (ADK – employers' association of the German rubber industry) honored Dr. Marvin Omelan as one of the best graduates of the year for his doctorate in the field of applied polymer chemistry at Leibniz University Hannover.

In his work at the Deutsches Institut für Kautschuktechnologie e. V. (DIK Society), Dr. Omelan was engaged in the development of electrically high conductive elastomer materials with low hardness which, amongst other things, are of great importance for applications in medical technology. Since April 2021, Dr. Omelan has been working at the Fraunhofer IST in the department of Interfacial Chemistry and Adaptive Adhesion in the area of atmospheric pressure plasma processes.

Prof. Arno Kwade receives Lower Saxony Science Award

November 19, 2021 / For his research achievements and his social commitment, Prof. Dr.-Ing. Arno Kwade was awarded the Lower Saxony Science Prize in the category Research.

He received the award, which is endowed with 25,000 euros, for his work in the fields of pharmaceutical process engineering and battery cell technology and production. His achievements have, amongst other things, provided a major contribution towards the development of cost-effective and safe energy storage systems and, consequently, to the implementation of the energy revolution.

5

Awarded with the Lower Saxony Science Award in the Research category 2021: Professor Arno Kwade.

SafeWaterAfrica is part of the #1000solutions to change the world.

Raw water extraction point of the demonstrator in South Africa from a polluted running waters.

SafeWaterAfrica: Sustainable, profitable and now also award-winning

June 25, 2021 / The SafeWaterAfrica project not only improves drinking-water supplies in South Africa and Mozambique and protects the environment: The technologies for water treatment are the responsibility of first and foremost African companies, which strengthen the economy and employment in these countries. For this both ecological and economic success, the project under the leadership of the Fraunhofer Institute for Surface Engineering and Thin Films IST in Braunschweig has been awarded the Solar Impulse Efficient Solution label.

20,000 liters of drinking water per day in accordance with WHO standard

The SafeWaterAfrica project made it possible: In South Africa and Mozambique, two demonstrator plants can each produce 10,000 liters of drinking water per day from river water – and in a quality that complies with the World Health Organization (WHO) standard. Near Johannesburg, solar cells and batteries have been providing an energy-autonomous water-treatment system since September 2018, which is composed of various purification and filtration stages and reduces CO2 emissions. The second plant, in Ressano Garcia, has been in operation since April 2019.

> **"We are very happy about the award for the SafeWaterAfrica project. We would like to utilize the publicity it brings in order to further advance the implementation at local level."**
>
> **Dr. Lothar Schäfer / Deputy Director of the Fraunhofer IST and coordinator of SafeWaterAfrica**

Demonstrator in South Africa: Overall view including the solar panels supplying the electrical power needed

Electrode assembly of the SafeWaterAfrica system in Ressano Garcia, Mozambique

Partners from Africa have the largest share in the project

A host of partners have collaborated on the project, which is funded by the EU's Horizon 2020 framework program for research and innovation. The majority of the partners are from Africa. Only two key technologies of the water-treatment plant originate from Europe, including the technology from the Fraunhofer IST. The two demonstrators are now so mature that they can be used in other countries in the future and can be operated there economically. The fact that SafeWaterAfrica is a gain for both the environment and the economy has prompted the Solar Impulse Foundation to award the project the Solar Impulse Efficient Solution label. The Swiss foundation, founded by environmental visionary and researcher Bertrand Piccard, rewards efficient technical solutions that sustainably combat climate change and are also economically viable.

The Solar Impulse Efficient Solution Label serves as an award for clean and profitable solutions.

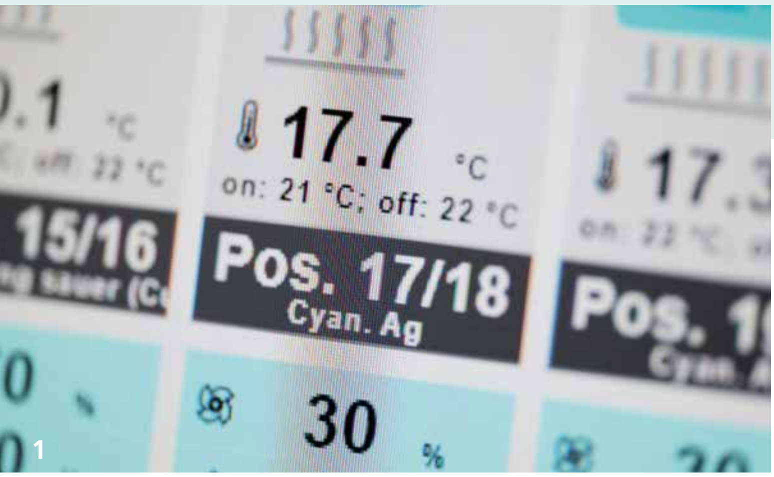
In focus: Digitalization in surface technology

In surface technology, both quality requirements and cost pressure are increasing constantly. In addition, as a study commissioned by the German Federal Ministry for Economic Affairs and Climate Action (BMWK) determined, the complexity of the products[1] is continuously increasing, as a result of which the demand for technical expertise is also becoming ever greater. One approach to providing the required extremely extensive knowledge base – at least to some extent – is a digital twin, in which relevant process and product properties are represented by simulation models. With a real-time capable digital twin, the possibility also exists to react quickly and predictably to, for example, production fluctuations or new product requirements.

Up to now, simulation has been based primarily on phenomenological, i.e. physical and/or chemical models, in which, however, the process and product properties are often incompletely reproduced or which require considerable computational effort. Data-driven models based on characteristic diagrams or methods of artificial intelligence (AI) – in particular, deep learning – can circumvent this problem.

Aside surface technology, AI-based methods are already being used successfully for web searches, recommendation systems, image recognition, speech recognition and text generation. In order to also be able to use AI in surface technology, cross-product and cross-process databases must be constructed in which process data is collected in-situ and the results of downstream sample and product analytics are integrated accordingly. The data forms the foundation for digital twins trained on the specific products and processes, consisting of a combination of simplified physics-based models with AI methods.

By means of the digital twins, production processes can be controlled and optimized on the basis of models and required maintenance can be predicted. Quality, throughput and reproducibility of coating processes in surface technology can therefore be improved, whilst the impact on the environment is simultaneously reduced.



1

The visualization of the process data plays a central role in digitalization.

[1]Bischoff, J. ; et al.: Erschließen der Potenziale der Anwendung von Industrie 4.0 im Mittelstand. Mülheim an der Ruhr: agiplan, 2015, XIV, 386 S.

2

"The digital transformation and, in particular, approaches using artificial intelligence methods are drivers for modular, flexible and scalable production systems and form the focus of current work at the Fraunhofer IST."

Prof. Dr.-Ing. Christoph Herrmann / Director

1

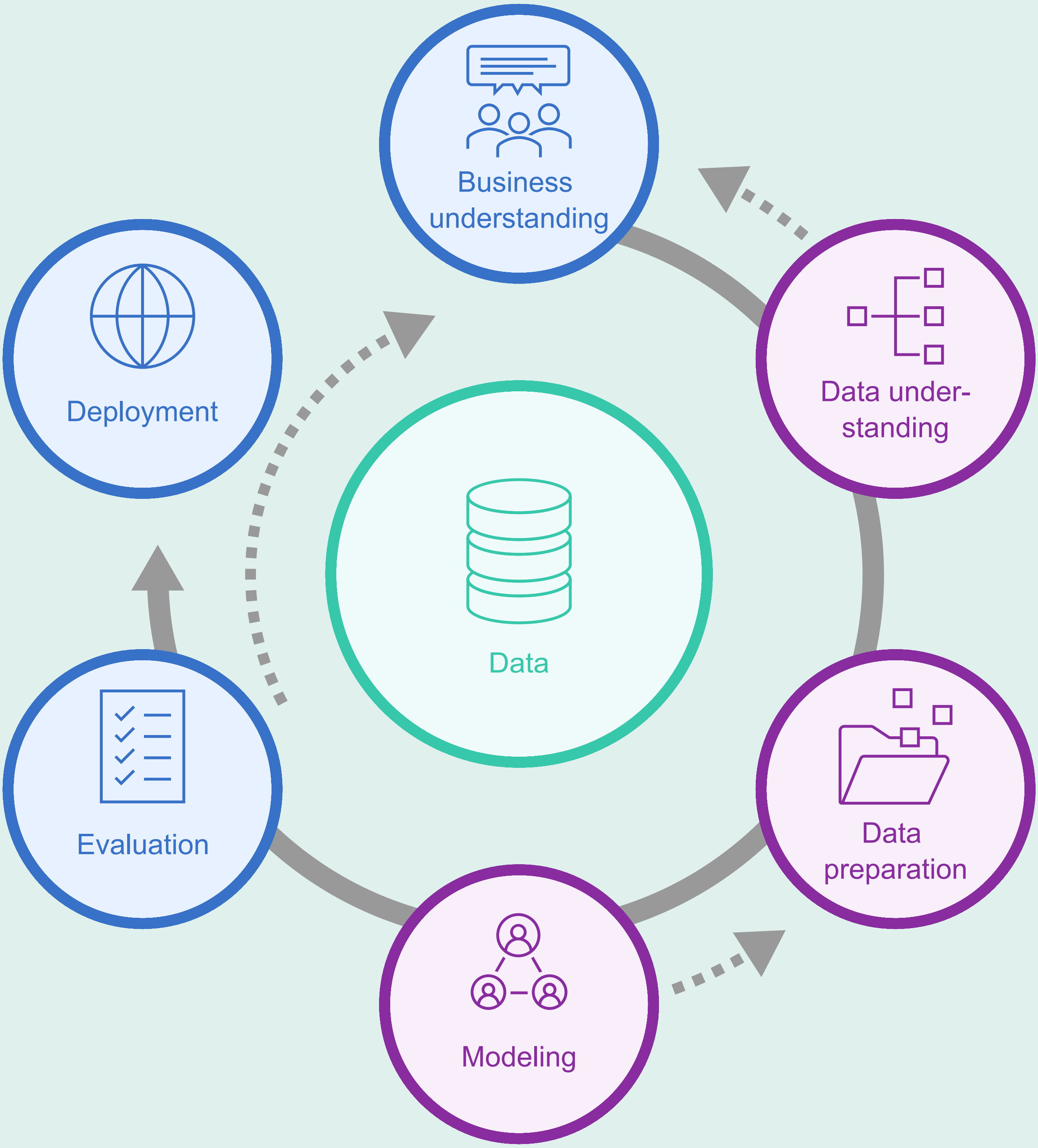
Employees of the Fraunhofer IST discuss the current process parameters.

Implementation strategy for a data-mining project

The CRISP-DM model (Cross Industry Standard Process for Data Mining) is a standard model for data mining that is widely used, cross-industry and publicly available. This model was developed around 1996 by renowned companies and offers a very good possibility for the meaningful mapping and processing of data-mining projects. The model, which we also use for orientation in our digitalization projects at the Fraunhofer IST, is divided into six phases, whereby individual process phases can also be run through repeatedly. The individual phases are described briefly below, and are illustrated using projects at the Fraunhofer IST as examples.

"Central data collection offers the opportunity to evaluate data and identify correlations. By digitalizing our processes, we are fulfilling the prerequisites for the implementation of artificial intelligence."

Dipl.-Phys. Holger Gerdes / Scientific Assistant


Business
understanding
Data under-
standing
Data
preparation
Modeling
Evaluation
Deployment
Data

2

Phase 1: Understanding of business

The first phase of CRISP-DM is a fundamental requirement for the successful completion of the project. In this phase, the objectives and requirements of the data mining are defined. The objective should hereby be **"smart"**, i.e. "**s**pecific, **m**easurable, **a**ccepted, **r**ealistic and **t**imetabled". This is essential if it is to be possible to determine, after completion of the project, whether the data mining has really been successful.

With its decades of experience and more than 200 employees, the Fraunhofer IST can look back on outstanding expertise in the field of coating and surface technology and has already implemented numerous digitalization projects. The focus has hereby been directed at a wide variety of issues. One example is the integration of commercially available environmental sensors on the basis of Message Queuing Telemetry Transport (MQTT) via Wi-Fi for the recording of room temperature, air humidity and air pressure, in order to automatically store the aforementioned parameter databases and to automatically inform employees via E-Mail when threshold values are exceeded or not achieved.

Phase 2: Understanding of data

In the second phase of the project, the project objective is compared with the existing data sets. In this phase, a decision is to be made as to whether the data sets are sufficient for achieving the project objective with a good chance of success. If all necessary data are available, the next phase can begin. If the data situation is not sufficient, either the project objective must be redefined or the data must be subsequently entered or collected.

For this purpose, the Fraunhofer IST relies, amongst other things, on Open Platform Communications Unified Architecture (OPC-UA) servers for data provision. These servers have already been implemented in new plant acquisitions, and have also been successfully retrofitted in existing plants. They enable the automated recording and backup of process parameters.

The data is saved in central databases which also contain additional information, e.g. regarding the laboratory environmental conditions, temperature, humidity and air pressure. Furthermore, web pages are made available to employees at the Fraunhofer IST as an upload front end. These upload pages accept practically any document format and also store them in databases in prepared form.

Phase 3: Preparation of data

After completion of the first two phases, it must be ensured that the data are suitable for the project objective and can now be prepared for the subsequent process. The objective of the third phase is to provide modeling with a data set containing all necessary, correctly formatted values. In order to achieve this, the often different data sources must be merged, errors in the data sets suitably corrected and, if necessary, new variables developed.

For this purpose, the Fraunhofer IST has, for example, developed software tools which make it possible to automatically divide large microscope images into smaller units, to adjust them in terms of brightness, contrast and color space and, furthermore, to provide the file name with additional information. If required, data processing can be performed within databases. For this, new tables are created, which contain the agglomerated information.

Phase 4: Modeling
In the modeling phase, a suitable method for solving the problem is sought. The possible methods encompass the utilization of simple statistics, semi-empirical models or machine-learning algorithms right through to neural networks.

At the Fraunhofer IST, machine-learning algorithms are applied in cooperation with partners for the prediction of layer properties and process parameters, and neural networks are used in image recognition.

Phase 5: Evaluation
In the modeling phase, solely the model is tested. In the evaluation phase, the aim is to test the entire processing routine and to clarify whether the process from data acquisition through processing and modeling functions reliably. These so-called pipelines should also be robustly tolerant of errors such as the omission of data.

Phase 6: Deployment
In the final phase, the project is integrated into the company processes. All digitalization projects developed at the Fraunhofer IST are prepared in Docker containers and can therefore also be ported very easily to other systems.

Glossary

Data mining
Many processes in surface technology are very complex and correlations between different process parameters are often not directly recognizable. Data mining provides support in identifying trends and interrelationships by applying statistical methods to the data sets. The term "data mining" is somewhat misleading in this context, as it does not involve generation of the data itself, but rather the acquisition of knowledge.

MQTT
Message Queuing Telemetry Transport is an open network protocol used for communication between machines.

OPC-UA
Open Platform Communications Unified Architecture is an industry standard for platform-independent data exchange.

Structured and unstructured data
Structured data, in contrast to unstructured data, have a predefined and formatted data structure. Examples of structured data are credit-card numbers, addresses, barcodes and, in particular, relational databases. Unstructured data are mainly texts such as E-Mails, presentations, reports, videos and images.

Kontakt

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Our expertise along the entire process chain

Process and production engineering for sustainable energy storage

The energy revolution is crucial for a secure, environmentally compatible and economically successful future. This can only be achieved, however, if the technologies used to generate, convert and store energy are made even more efficient, cost-effective and environmentally friendly.

Digitalization is supporting this transition by making it possible to intelligently network complex systems, such as producer networks, energy grids or industrial and private energy consumers. Furthermore, the extensive electrification and digitalization of our society, as well as climate change, are leading to an ever-greater need for energy storage systems. The cost-effective and sustainable production of energy storage systems is therefore a fundamental factor for the success of the energy revolution.

Future generations of energy storage systems, such as all-solid-state batteries (ASSBs), should be both safer and more powerful than current storage technologies. In order to develop these further and advance them to industrial maturity, extensive research is required in the field of materials and processes.

The department of “Process and Production Engineering for Sustainable Energy Storage Systems” at Fraunhofer IST focuses on research and development of materials and processes for recyclable energy storage systems and the design of factory systems for the production of energy storage systems including hydrogen technologies. The core competencies of the department include economic and environmental assessments of production systems, process optimization through multi-scale simulation, and process monitoring for energy storage technologies.

Within this department, a holistic and sustainable design of the entire life cycle of energy storage systems in terms of life-cycle management is being pursued – from material production, through the various production stages and use, and on to recycling.

In collaboration with the Fraunhofer institutes, IKTS and IFAM, the department is also participating in the Fraunhofer Center for Energy Storage and Systems ZESS. The center brings together the expertise of each institute in the area of development and production of future battery technologies. The common goal is to advance mobile and stationary energy storage systems to industrial maturity and to scale up promising production processes from laboratory scale to series application. ZESS works in close collaboration with the Battery LabFactory Braunschweig (BLB) at TU Braunschweig.

In addition, the department is active at the Wasserstoff Campus Salzgitter. Within this campus, the department collaborates with partners from industry, science and politics to establish a sustainable hydrogen economy. The department provides a range of services, including both the development of materials and processes for electrolyzers, hydrogen storage and fuel cells and the planning of the entire energy conversion chain for regional hydrogen-economy systems. Focus is also placed on modelling technical interrelationships and evaluating both economic and environmental consequences.

Electrodes for the production of battery cells.

"Innovative technologies and sustainable process chains push forward progress and enable the advancement of energy efficiency – and, consequently, resource efficiency – as one of the most important pillars of the energy revolution."

Dr.-Ing. Sabrina Zellmer / Head of Department

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Sustainable factory systems and life cycle engineering

"By actively planning and designing the product lifecycle of energy storage systems, including the associated production systems, we are able to support our customers in overcoming challenges on their individual path to a circular economy."

Nikolas Dilger M.Sc. / Group Manager

In the topic area "sustainable factory systems", the focus is on the comprehensive design of production systems for current and future energy storage systems.

The range of services covers much more than the planning and design of processes and process chains, and spans the design of the entire factory from the individual process to the factory roof. Diverse and complex interactions between products, processes, technical building equipment and buildings are considered. Our focus is particularly on methods of the "digital factory", such as simulation and the construction of "digital twins" of products and processes.

Planning from process through to factory roof

In collaboration with our partners, we develop digital models and simulations for the planning of sustainable factory systems. Our concepts support a participatory factory planning approach, with which we accompany the transformation towards a sustainable factory system – from the initial idea through to the finished factory – in cooperation with our customers.

Our models create transparency regarding discrete and continuous material, energy and substance flows and validate differing design and operating scenarios for the customer-specific factory system. Technical interrelationships are thereby modeled and economic and environmental consequences are evaluated. In this context, we place a special focus on the minimization of the environmental impact of energy storage production, and support our customers in the planning of large battery cell factories – from the initial idea, through the project phases of factory planning, and on to the implementation in industrial practice.

A further focus is the demand-oriented planning of a decentralized renewable energy supply for factory systems with the help of innovative energy storage systems on the basis of battery and hydrogen technologies. In collaboration with our customers, we identify the potential, develop appropriate design and operating scenarios, and support the decision-making process with technical, economic, and environmental analyses.

Illustration of a holistic planning of battery cell production.

2

The new building for the Fraunhofer Center for Energy Storage and Systems ZESS.

Our set of methods for life cycle management

In order to achieve continuous improvements throughout the product life cycle, sustainable solutions necessitate professional life cycle management. In this area, we offer our customers and partners support during the entire product life cycle – from material production all the way to recycling. Using methods such as "life cycle assessment" and "life cycle costing", technical, economic and environmental analyses on products and systems are carried out. We also consider security of supply and social aspects. Furthermore, "integrated computational life cycle engineering" enables a highly automated computer-aided evaluation of design options such as in the product creation process or in factory planning. Due to the holistic approach of life cycle management, new products can be evaluated in the early development phases. In this way, technological, economic, environmental and social opportunities and risks can be identified and comprehensively compared at an early stage. As a partner in applied research, we provide guidance in the active design of the product life cycle in accordance with the guiding principle of sustainability, and accompany our customers towards a circular economy.

3

Safe cell manufacturing with glove boxes at ZESS-Technical center.

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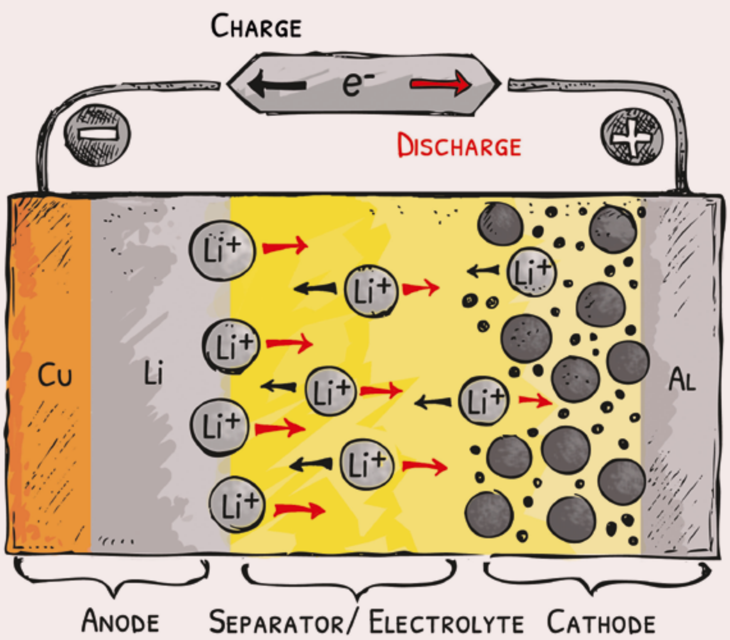
Material and process development

Prerequisites for a successful energy revolution are not only innovative materials for sustainable energy storage systems but also suitable production processes. One particular challenge in this respect is the scaling up of processes to an industrial scale.

For our customers and partners we produce, functionalize and condition novel battery materials such as solid electrolytes, active materials and lithium metal anodes. We scale up the associated production processes from laboratory to pilot scale and characterize materials and intermediate products along the process chain using a wide range of analytical methods. Furthermore, our experimental investigations are supported by simulation and modeling. We thereby focus primarily on scientific and application-oriented understanding with regard to relevant interrelationships at the particle and cell level with the aid of numerical analysis methods.

> **"For sustainable battery cell production, we develop efficient and scalable manufacturing processes for materials and components for our customers, thereby incorporating essential simulation and modeling tools."**
> **Dr.-Ing. Jutta Hesselbach / Group Manager**



Structure and functional principle of a Li-ion solid-state battery.

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Automated process chains for circular production

To increase the sustainability of energy storage devices and converters, material cycles must be closed using production-engineering approaches. Circular production must therefore start at the system level, and process chains must be designed to keep materials efficiently within the cycle.

In this context, we work together with our partners to develop automation solutions and process chains for sustainable components and systems in the field of energy storage and converters. The application spectrum ranges from storage technologies for hydrogen, components of fuel-cell systems and balance-of-plant components all the way to battery systems.

Outlook – This is what awaits you!

As the connecting link between research and industry, we strive to ensure ongoing networking between policy makers, industry and research institutions in order to achieve the necessary climate targets demanded by society. Through the expansion of our ZESS research center and the Wasserstoff Campus Salzgitter, the first milestones have been laid for the scalable circular production of sustainable energy storage systems. On this path of transformation, we are supporting industry with individually tailored seminar and qualification opportunities.

> **"By converting conventional production processes into automated process chains, resource requirements can be significantly reduced, thereby leading to an increase in sustainability."**
>
> **Dr.-Ing. Jan Beuscher / Chief Scientist**

1

Inner coating of a hydrogen tank.

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Transformation of the Salzgitter industrial site with green hydrogen technologies

At the Wasserstoff Campus Salzgitter, a broad alliance from industry – Salzgitter AG, MAN Energy Solutions, Robert Bosch Elektronik, Alstom Transport Deutschland and WEVG Salzgitter – in collaboration with local government partners, including the office for regional development and the city of Salzgitter, as well as the Allianz für die Region and the Fraunhofer Institute for Surface Engineering and Thin Films IST, is conducting application-oriented research of business models along the entire hydrogen value chain, with a focus on decarbonization of the industrial sector. In addition to working on projects, the goal of the campus is to translate research results into consulting, education and training services for higher education and vocational training. By setting up a hydrogen demonstration infrastructure, the campus also allows for the testing and demonstration of innovative technologies in practice.

The Wasserstoff Campus Salzgitter partners.

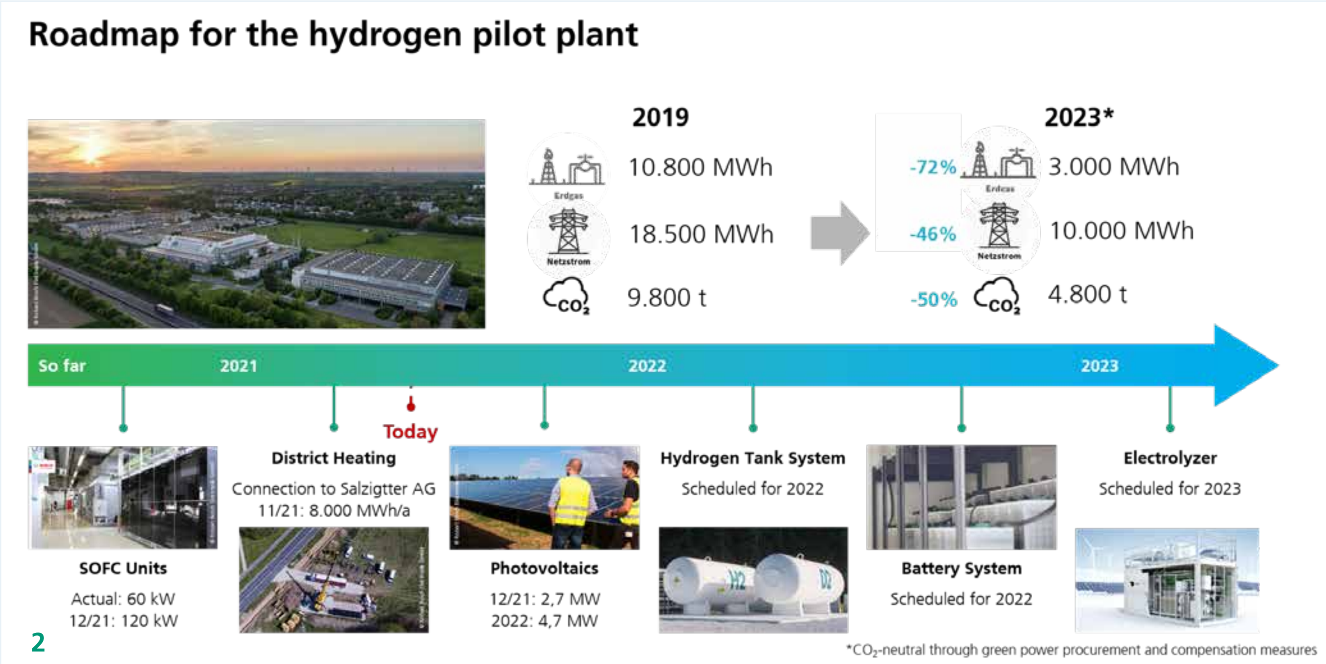
Technical work at the Wasserstoff Campus Salzgitter

At the beginning of 2021, four projects were started at the Wasserstoff Campus Salzgitter. These involve the decarbonization of factory systems, a concept for supplying the Salzgitter region with green hydrogen, the development of steel tanks for transporting and storing the energy source, and the establishment of an overarching innovation network. The State of Lower Saxony and the City of Salzgitter are supporting the projects with around five million euros from the structural assistance program.

The primary goal of the campus is to develop innovative solutions for Salzgitter as a CO_2-neutral industrial center and to consolidate the campus itself by setting up a demonstration infrastructure and developing consulting, training, and continuing education offerings.

Testing the decarbonization of the industrial sector on real hydrogen infrastructure

In the "Factory Transformation" project, a blueprint is being developed for the decarbonization of factory systems, from planning to plant operation. With the aid of a digital factory image produced by Fraunhofer IST, design and operating scenarios for hydrogen technologies are being evaluated in terms of technology, economy and the environment, thus laying the groundwork for the assessment of investment in new hydrogen infrastructure. In the course of the investigations, an additional five million euros have been invested in new infrastructure at the pilot factory of Robert Bosch Elektronik GmbH, in particular in photovoltaic systems, district heating and fuel cell systems. This has particularly increased the potential for the CO_2-neutral provision of heat and power. In the coming years, further investments will be made to integrate additional elements such as battery storage or electrolysis and refueling systems for hydrogen in order to reduce CO_2 emissions from the pilot plant by 50 percent, or 5,000 metric tons of CO_2.



The measures will enable a 50 percent reduction in CO_2 emissions from the pilot plant by 2023.

Prerequisites for the transition to low-carbon industry

Based on the factory model developed, and using the potential CO_2 savings demonstrated from the Bosch Salzgitter pilot factory, it is possible to implement the design of further factory systems in different application areas, so that significant savings effects can be generated by means of scaling across the industrial sector. Identifying sustainable business models for individual hydrogen technologies in the factory system under current boundary conditions enables the early establishment of a market, thus creating good conditions for system and component development in Germany. The project demonstrates how decarbonization of the industrial sector can succeed with the use of renewable energy and energy storage systems, in this specific case hydrogen and batteries, through generic approaches from research combined with practical expertise from industry.

Outlook

In 2022, further projects are set to be located at the Wasserstoff Campus Salzgitter, including the manufacture and recycling of fuel cells, the production of electrolyzers, energy flexibilization and the design of refueling systems. Another important cornerstone is the expansion of activities to include education, training and continuing education offerings. In this context, a basic training course on hydrogen economy and hydrogen technologies will be offered at the campus at the beginning of the second quarter in collaboration with the Fraunhofer Academy and other campus partners.

The project

The "Factory Transformation" project is funded by the State of Lower Saxony and the City of Salzgitter.

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Tribology and sensor technology

Friction, wear and corrosion cause costs amounting to billions of euros every year in Germany alone. The development of durable, high-performance and resistant tribological systems with the aid of surface refinements is a key factor in saving costs and reducing environmental pollution. Thin, highly resilient sensor layers enable the targeted monitoring of such tribosystems, thereby reducing the risk of failure and, consequently, protecting people and the environment.

Robust and high-performance – these are two requirements which are repeatedly stipulated in plant and mechanical engineering as well as in toolmaking. Often, the only option for implementing these demanding goals is the utilization of surface treatments and coatings which are adapted to the materials being used and the conditions under which they are applied.

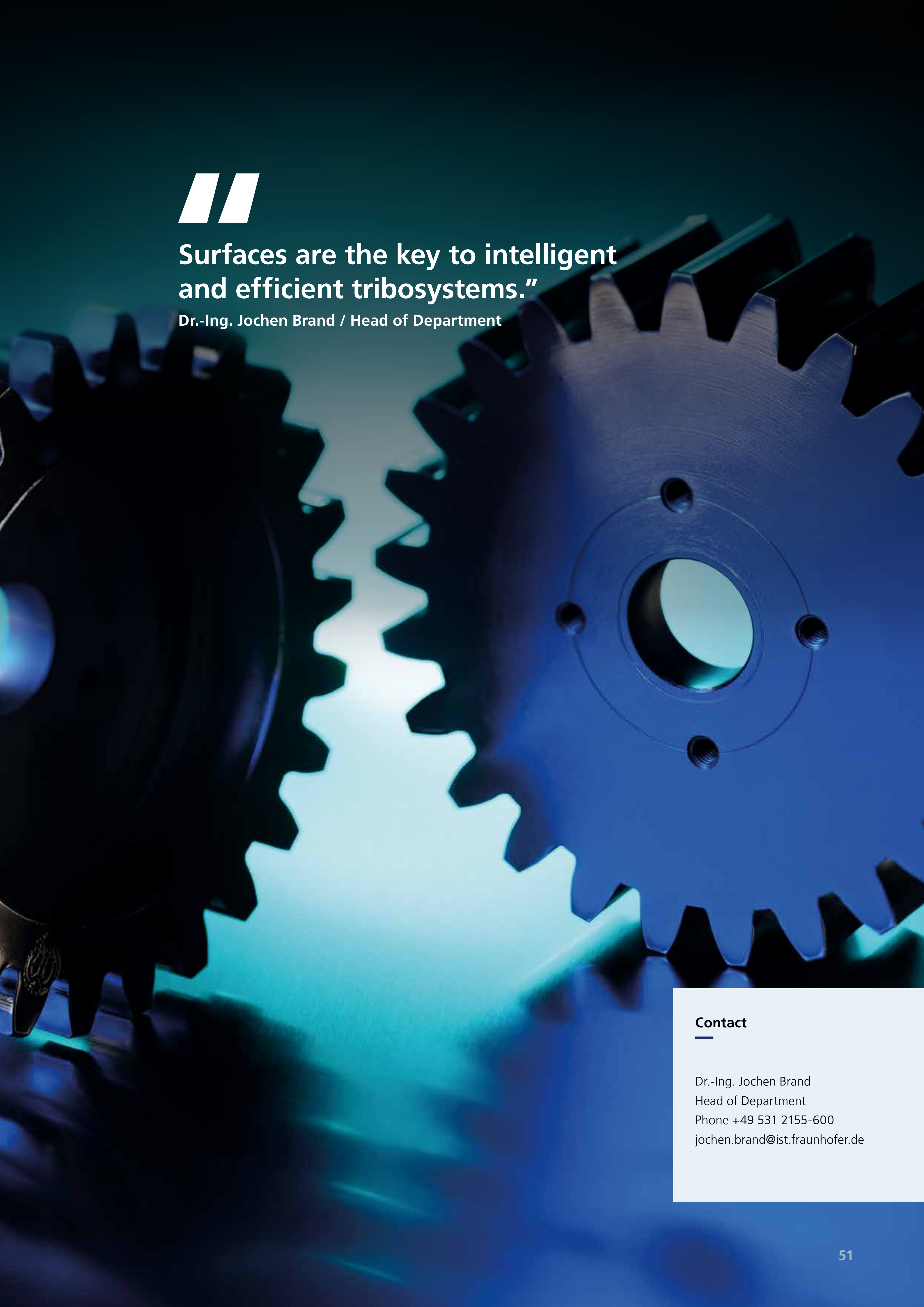
In order to comply with the increasing requirements in tribological systems, the Fraunhofer IST focuses on material composites consisting of high-tech constituents and material-specific surface finishing. Surface technology offers new approaches to the design of components, and permits the utilization of other materials or even the elimination of lubricants and release agents.

Starting from a detailed system analysis, we then develop adapted material and surface solutions for our customers. For this purpose, we employ a wide range of coating technologies and layer materials, which can be evaluated via an application-oriented approach using a wide variety of test methods. Complex requirement profiles can also be fulfilled in this way.

The monitoring of components, tools and complete manufacturing processes is a fundamental prerequisite for sustainable production and product use. In highly stressed contact points in particular, sensory functional layers can supply a wide range of information online which can be used specifically for the monitoring or control of processes.

At the Fraunhofer IST, however, we not only work on application and customer-specific solutions for the most diverse sectors but also develop economical, flexible production systems for these. As a result, our customers receive a production chain tailored to their specific requirements for the sustainable, series-production-capable implementation of the developed tribosystem and sensor solutions.

Tribological coatings on gear wheels for the automotive sector.



"Surfaces are the key to intelligent and efficient tribosystems."

Dr.-Ing. Jochen Brand / Head of Department

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Tribological systems

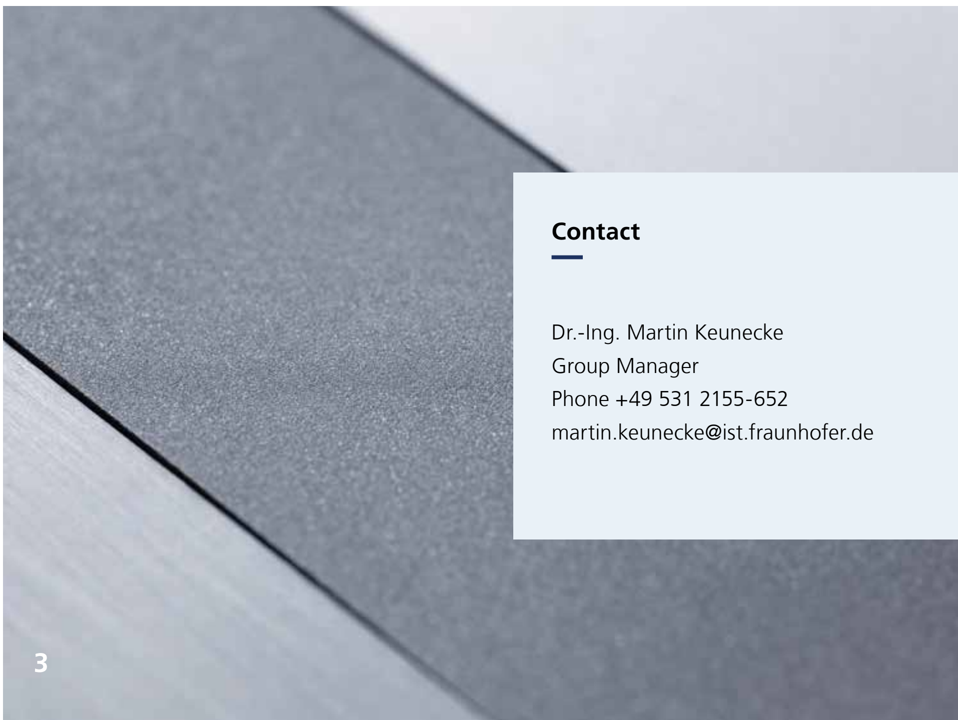
Manual blasting facility for a wide variety of blasting media.

"Application-adapted coatings and surfaces increase the performance capabilities of tools or components and improve energy efficiency in tribological systems."
Dr.-Ing. Martin Keunecke / Group Manager

The minimization or optimization of friction and wear is a fundamental challenge for many tools and components. The tribological properties have a significant influence on the service life and sustainability of products and the associated production systems.

At the Fraunhofer IST, we optimize the surface properties of tools and components with regard to their tribological effect. An increase in service life and sustainability can be achieved through consideration of the process chain and the system properties.

Important influencing variables for the function and for an application-optimized design of surface treatments and coatings include, in particular, the load spectrum in the application, as well as the material, manufacturing process, surface topography, pre-treatment and post-treatment, cleaning process. With our expertise in the areas of coating production, quality assurance and coating application as well as wear and application assessment for tools and components, a broad spectrum of coating classes, edge layer and surface modifications can be realized. Surface design can be supported by laboratory experiments and specific model tests. By taking into account the entire tribological system, the application profile and the complete process chain when designing the coating, we are able to optimize and adjust surfaces in customer-specific applications with regard to the load and performance needs.



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A variety of surface topographies and hard coatings from the process chain.

Flexible production systems

Customers increasingly expect products to be tailored precisely to their individual needs. For production, this means a greater diversity of variants with smaller batch sizes through to fully individualized products. This increasing complexity in relation to the products, in conjunction with fluctuating qualities of the raw and auxiliary materials or semi-finished products, places greater demands on the flexibility of production systems.

At Fraunhofer IST, we are building a modular production system with the aim of producing different layer systems with a high number of variants. One area of application is the production of thin-film sensors developed in the department. The objective is to make surface technology accessible for a multitude of applications in different sectors by shortening run-in times and reducing costs. Beyond the necessary adaptation of the core processes, we also consider support processes and transfer them into an overall system that can be automated. In doing so we answer, amongst others, questions concerning planning and control, logistics and ergonomics, and develop cross-technological solutions for multifunctional components.

Planning of a flexible production system for coating technologies.

4

With the establishment of a flexible production system, we are working to enable the economical manufacturing of complex layer systems in high quality, including unit-quantity variants."

Dr.-Ing. Torben Seemann / Group Manager

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Success factor surface cleaning – Cleaning 4.0

In terms of subsequent coating, surface cleaning is an essential process step that has a decisive influence on the success of the finishing process. Complete documentation of all relevant process and plant data as well as backup in a data warehouse provide new possibilities and approaches for the optimization of the existing cleaning processes and plant technology. For this reason, at the Fraunhofer IST the multi-chamber system for the aqueous cleaning and pre-treatment of components has been digitized and is now able to automatically document the cleaning process.

1

Multi-chamber system for aqueous cleaning at the Fraunhofer IST, with high reproducibility and flexibility with regard to the materials to be cleaned.

Building the infrastructure for digitization

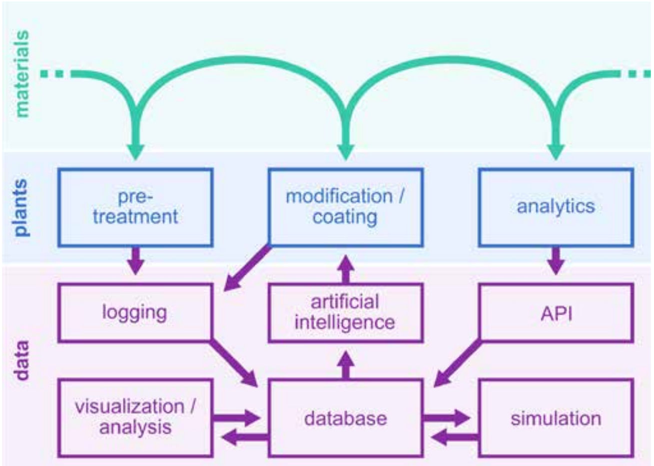
The key challenge in digitizing a wide variety of installations is to build a generalized and highly scalable infrastructure consisting of data loggers, databases, dashboards and interfaces for data analytics. In order to integrate the cleaning installation at the Fraunhofer IST, its control system was renewed and network interfaces were implemented. The result is that all plant and process parameters can now be recorded in real time and are available for data-analysis studies in the long term.

Solution approach

An infrastructure of this kind was set up and put into operation in collaboration with the Institute of Machine Tools and Production Technology (IWF) at the Technische Universität Braunschweig. In addition, five environmental sensors were installed in the cleaning laboratory in order to also record data on the room environment, such as temperature and humidity of the plant, thereby enabling the investigation of any possible influence of environmental conditions on the cleaning result.

Adaptation and transfer to customer-specific plants and systems

The aim of the project is to upgrade existing plants to cyber-physical systems. The cleaning plant serves as the first demonstrator here. The collection of all relevant system data offers the potential to optimize the plant as well as the individual process steps with regard to their resource consumption in terms of energy and material and to make the coating or cleaning processes more efficient and robust. The overall goal of digitizing the cleaning plant is to increase the robustness and precision of the processes while reducing resource consumption.



Structure of process and material data processing.

Furthermore, the developed concept can also be transferred to plants and (measuring) instruments that are also to be digitized in order to use their data for visual representation and the construction of digital twins.

Outlook

The project provides the basis for the digitization of all relevant processes that play a role within the surface-technology process chain and is thus an essential building block in the institute's digitization strategy. The integration of further processes enables the digital mapping of the entire process chain as a digital twin and permits the efficient design of processes and their linking to the point where they form complete production scenarios on the digital level.

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2

Real-time data from the digitized cleaning plant at the Fraunhofer IST.

Tool coatings for cutting fiber-composite plastics

In order to exploit the potential of new lightweight construction concepts, components made from fiber-reinforced plastics (FRP) must be processed and produced economically. There is no alternative to the high efficiency of shear cutting for high-volume production. By developing suitable tool coatings, tool geometries and process parameters, this project established basic principles for the economical processing of fiber-composite materials using shear-cutting processes. The project focused particularly on quality and long tool life.

Challenges in the shear-cutting of FRP

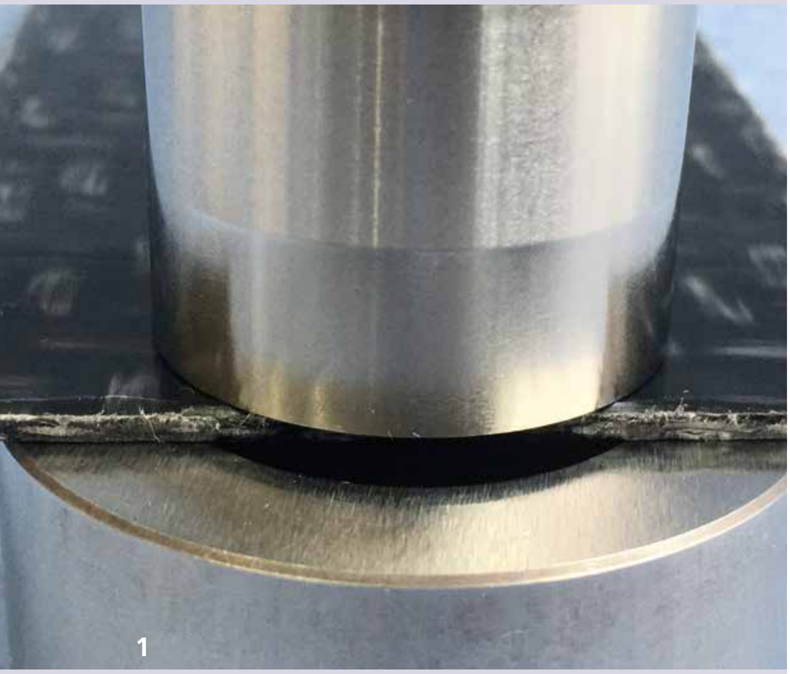
Active parts for shear-cutting processes are currently optimized for sheet-metal processing and tend to cause high tool wear and poor cut quality, e. g. in the form of fiber pullouts or delamination, when shear-cutting FRP materials. The complex combinations of different matrix plastics with, for example, solid (carbon fibers, CF) or abrasive (glass fibers, GF) fibers, different fiber contents and fiber directions present further challenges for active parts in terms of material, coating, tool geometry and cutting-process parameters of organic sheet material or tape.

Solution approach and results

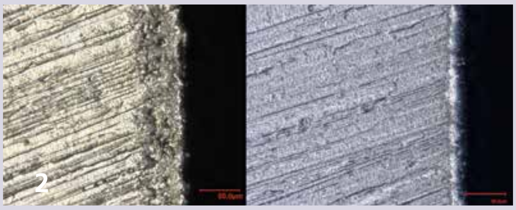
In order to be able to determine which tool coatings, nitriding, tool geometries and cutting-process parameters might be suitable, these were investigated, tested and compared with one another in various versions. Measurements taken on variously coated surfaces and the determination of tribological behavior against FRP, wear behavior, and component or release quality in cutting tests allowed property/parameter correlations and recommendations to be derived.

With active parts coated for specific applications, the project was able to achieve performance improvements such as wear reduction of around 70 percent. Furthermore, the tests showed that drawing cuts such as bevel cuts with a small wedge angle as well as a small kerf achieve good cutting results.

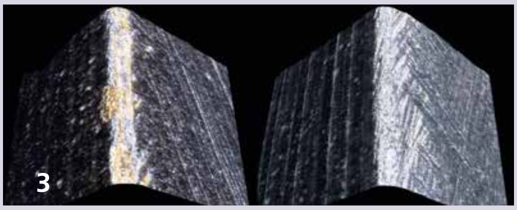
Suitable tool coatings, geometries and stamping-process parameters are essential for the economical trimming of FRP components. Through the project results and application recommendations, important preliminary work has been carried out which enables the manufacture of FRP components in an automated, reproducible and efficient manner. As a result, this high-performance material has been made more attractive for sectors such as the automotive industry. The expertise acquired supports users, toolmakers, coaters and FRP manufacturers in positioning themselves on the market and opening up further fields of application.



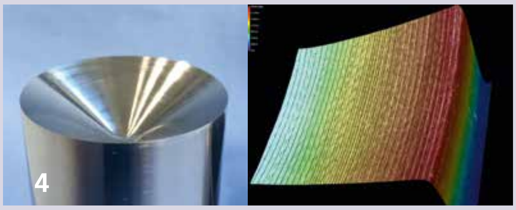
Punch, FRP material and die.



Light-microscope images (1000x) of the cutting-knife edges after 10,000 cuts; GFRP tape uncoated (left) and coated (right).



Light-microscope images (1000x) of coated punch edges after 1000 cuts; GFRP organo sheet: coating with detachment (left); suitable coating (right).



Punch (left); light-microscope 3D image (100x) of the cutting edge in color-height representation (right).

Outlook

Despite the results and correlations obtained, it was not possible to investigate in detail all the complex relationships between surface hardness, wear resistance, cutting edge, material, process parameters and cutting forces within the scope of the project. Further development work with the support of model-based data acquisition and evaluation is therefore planned in order to acquire a valid representation and detection of the correlations.

The project

The project "Entwicklung von Beschichtungen für Werkzeug-Aktivelemente zum Scherschneiden von Faserverbundwerkstoffen" (Development of coatings for active tool elements for the shear cutting of fiber composites), IGF project no. 20416 N, was performed in collaboration between the Forschungsgemeinschaft Werkzeuge und Werkstoffe (FGW, research association for tools and materials), the Institut für Werkzeugforschung und Werkstoffe (IFW, institute for tool research and materials) and the Fraunhofer Institute for Production Technology IPT. It was funded by the German Federation of Industrial Research Associations (AiF) as part of the program to promote cooperative industrial research (IGF) by the German Federal Ministry of Economic Affairs and Climate Action (BMWK) on the basis of a resolution by the German Bundestag.

9 INDUSTRY, INNOVATION AND INFRASTRUCTURE

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1 Wood veneer with integrated thin-film sensor.

Smart, modular and sustainable interior for the transportation of the future

Electrification and autonomization will have an enormous impact on the automobiles of future generations. This will increase the focus on the vehicle interior in particular. New operator concepts as well as a level of freedom during travel time gained through increasing autonomy mean that new approaches to solutions and options are required for vehicle interiors. Furthermore, increased requirements for sustainable mobility and an associated CO_2 reduction or neutrality will have a massive influence on vehicle design.

Bio-based, functionalized interior components

As a participant in a research team comprising five Fraunhofer institutes, the Fraunhofer IST is working on the modular design of the interior of future passenger cars and light commercial vehicles. This project is called "FutureFlexPro". With bundled competencies in renewable raw materials and their processing and component functionalization, solutions are being developed for rapidly interchangeable components which allow the interior to be adapted to its respective purpose, have a long service life thanks to robust surfaces, and also ensure repair and maintenance as the vehicles continue to be used in order to reduce their downtimes.

Functional mix of materials for a future interior

As part of the sub-project "Future Interior", an interior door panel is being equipped with application-specific functions as a technology demonstrator at the Fraunhofer IST. The semi-finished products and components, on the basis of natural fibers or wood veneers provided by the project partners Fraunhofer IAO, IWU and WKI, are equipped with various functions such as antibacterial and easy-to-clean surfaces, integrated temperature sensors or touch functions. In addition, the different material combinations, including in particular the functional materials, are examined in detail, for example for their adhesive strengths and interactions of the materials.

Based on the project results, solution approaches for a broad range of applications can be presented at the material, process and component levels. Examples include:

- Component-integrated sensor technology
- Use of bio-based source materials for the coating of surfaces
- Large-surface coating of components to integrate functions such as electrical conductivity or antimicrobial properties
- Unit numbers on an industrial scale
- Inline-capable, scalable and resource-efficient coating processes
- Functionalization
- Development of new operating concepts

Veneer sustainably coated by means of atmospheric-pressure plasma process.

Outlook

The results of the project will be used to expand the Fraunhofer IST's interdisciplinary cooperation with the Fraunhofer institutes for Machine Tools and Forming Technology IWU, for Manufacturing Technology and Advanced Materials IFAM, for Wood Research Wilhelm-Klauditz-Institut WKI and for Industrial Engineering IAO. The solution approaches will be transferred to the development of further bio-based interior components, with differing modes of transport being taken into consideration. More detailed investigations will thereby be carried out into the durable integration of function and the addition of further functions and operating concepts. The aim is to work with OEMs (original equipment manufacturers) and automotive suppliers to implement the technology in products or vehicles and also to adapt the results to applications in other sectors, such as medical technology or the construction industry.

Formed veneer with sensor integration.

The project

The project FutureFlexPro with the subproject Future Interior was funded by the Federal Ministry of Education and Research (BMBF) under grant number L1FHG42421.

GEFÖRDERT VOM

Bundesministerium
für Bildung
und Forschung

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Micro and sensor technology

The measurement of force, pressure, temperature, wear and other variables directly in main load zones or on tool active surfaces provides valuable data by means of thin-film sensor technology in order to optimize existing production processes or simulation models. The application of wear-resistant and tribologically adapted thin-film sensors enables measurements in areas which were previously difficult to access.

The focus of current developments lies on comprehensive digitalization for autonomous, self-controlling and, above all, sensor-supported production systems. Thin-film-based sensor technology offers ideal prerequisites for application-oriented solutions and innovations in all aspects of industrial production processes. In recent years, there has been an increasing demand from industry for sensor technology which is used directly on component surfaces in contact with the workpiece in order to be able to record local measurement data, also during the process.

At the Fraunhofer IST, we develop multifunctional thin-film systems for the local measurement of pressure and temperature distribution on surfaces, for example of tools. This involves a wear-resistant multilayer system which can record the measurement data – particularly in highly stressed areas and on complexly shaped surfaces. In collaboration with our customers, we create an individual sensor design in order for the modules to be easily integrated into existing machines and for the layer system to be applied directly to surfaces of 2D and complexly shaped 3D components. On the basis of differing physical operating principles, we introduce thin-film-based sensors and sensor systems into the most diverse applications, focusing thereby on highly stressed areas and harsh environmental conditions.

For the production of thin-film sensors, we cover the entire process chain from substrate pre-treatment, through cleaning and coating, and on to the final calibration. Our experts at the Fraunhofer IST have acquired extensive expertise in the generation of microstructures; for this, they apply a wide range of structuring processes and techniques in their dedicated clean room. For the production of high-precision structures directly onto tool and component surfaces as well as wafers or glass substrates, classical photolithographic processes with etching technology and lift-off are utilized. We successfully apply laser structuring for the further functionalization of surfaces and thin films. Our extensive experience in this field allows us to combine different processes, enabling even curved surfaces to be structured.

"Our thin-film sensors acquire data directly in high-load zone and enable, for example, the digitalization of production processes as well as optimizations in terms of product quality, resource efficiency and sustainability."

Anna Schott M.Sc. / Group Manager

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Outlook – This is what awaits you!

In the future, sensor solutions will be further developed for new fields of application in the area of energy technology and electromobility. In parallel, the necessary steps will be taken to scale up current solution approaches for successful technology transfer to industry in line with Fraunhofer's self-conception as an industry-oriented research partner. In order to achieve this, processes capable of handling large numbers of units and the associated production technologies will be developed and set up as flexible manufacturing. The focus hereby is on the digitalization of the entire process chain through to the development of cyber-physical systems. Through tribological optimization of the entire process chain, the achieved efficiency gains can provide a direct contribution towards the achievement of sustainability goals.

Measurement of preload force by means of sensory washers.

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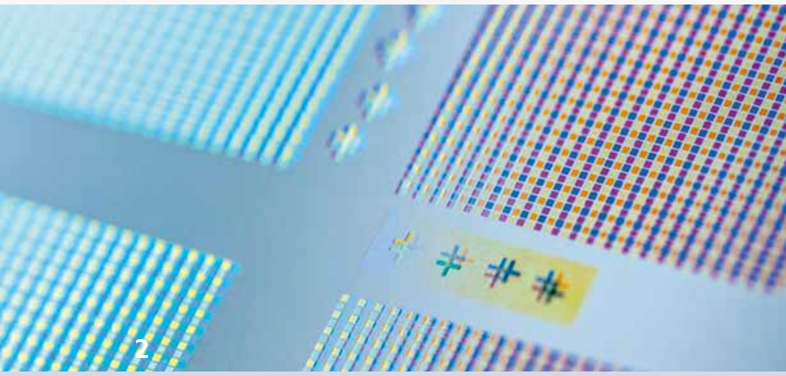

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3

Arrangement of several pixel filter areas on a glass substrate.

Photolithographic structuring of the chromium layer, which has a thickness of only 200 nm, on the kingpin for the production of the complexly routed conductive paths.

Thin-film sensor technology for the monitoring of temperature control in plastic injection molding

The resource-efficient production of plastic components by means of injection molding is dependent on a precise temperature and flow control of the injection molds. To improve the design and monitoring of mold temperature control, the real temperatures, pressures and flow rates during the injection molding process must be recorded. In order to determine these values, a multi-coupling insert with a multi-sensory and media-resistant thin-film system is being developed at the Fraunhofer IST which, in direct contact with the passing water, should enable the measurement of the variables temperature, pressure and flow rate.

1

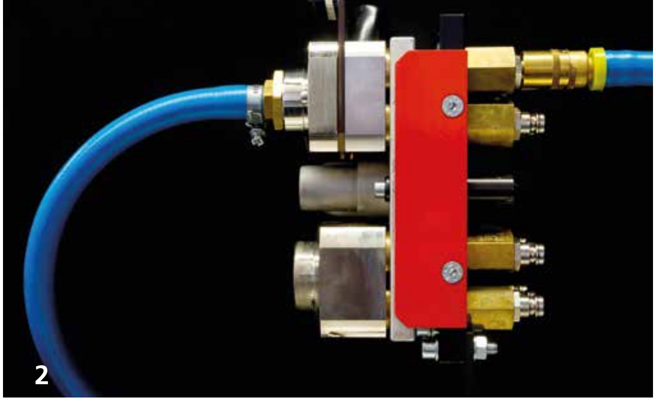
Monitoring of temperature control in plastic injection molding.

Water and chemical resistance of the sensory layer system

The aim of the "TivSee" project is to integrate the sensor insert, in direct contact with the passing water as well as various industrial cleaning agents and corrosion inhibitors, into the heating and cooling circuit of temperature control technology. It must therefore be ensured that the sensory thin-film system is resilient and highly resistant to chemical attack, water and temperature. For this purpose, a test rig was developed to investigate the suitability and behavior of the sensor structures and the protective top layer in endurance tests.

Sensory multi-coupling element

As a solution, a special sensor insert was designed for integration within a 6-circuit multi-coupling. The multi-sensory layer system was deposited with high adhesion onto this exchangeable insert into the inner areas of the bore, and conductive tracks were structured across the rounded area. This sensory and media-resistant thin-film system developed at the Fraunhofer IST is based on DLC (diamond-like carbon) coatings produced by means of PECVD (plasma-enhanced chemical vapor deposition) technologies. The integration of chrome-based sensor structures enables the spatially resolved measurement of pressure and temperature. These sensor structures are fabricated using a combination of photolithography and wet-chemical etching processes.



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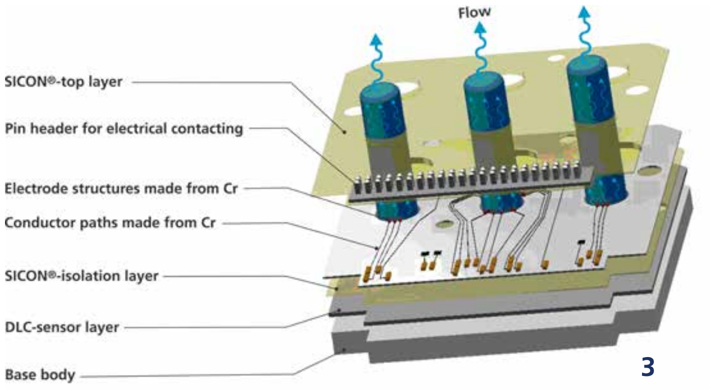
Multi coupling for temperature control in plastic injection molding.

Digitization and monitoring of production processes

This proof of the durability of the sensory thin-film system opens up further fields of application in the realization of highly resilient sensor systems for tribologically demanding systems. In addition, based on the temperature measurements carried out, important findings on measurement principles for flow measurement in thin-film technology were obtained which will be further investigated in the future. Multifunctional thin film sensors also offer far-reaching possibilities in the field of in-situ monitoring in cyber-physical production systems.



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Structure of the individual layers on the base body.

Outlook

The results of the project will be used to further develop the measurement principles for flow measurement established here. In addition, the solution developed for temperature and pressure measurement will be examined in further test phases with pilot customers. In the long term, this will result in a measuring system for the combined acquisition of temperature, pressure and flow data.

The project

The results described were achieved within the cooperation project "Temperature-control coupling with integrated networked sensor technology" (TivSee) on which the Fraunhofer IST worked in collaboration with the companies Nonnenmann GmbH and eck*cellent IT GmbH. The project was funded by the Zentrales Innovationsprogramm Mittelstand, ZIM (central innovation program for small and medium-sized enterprises, SMEs) of the German Federal Ministry for Economic Affairs and Climate Action (BMWK) based on a resolution of the German Bundestag and the German Federation of Industrial Research Associations, AiF.

9 INDUSTRY, INNOVATION AND INFRASTRUCTURE

12 RESPONSIBLE CONSUMPTION AND PRODUCTION

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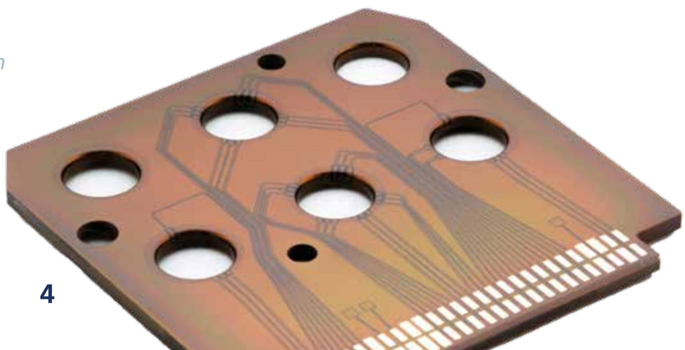
Metal base body coated with the multi-sensory layer system



4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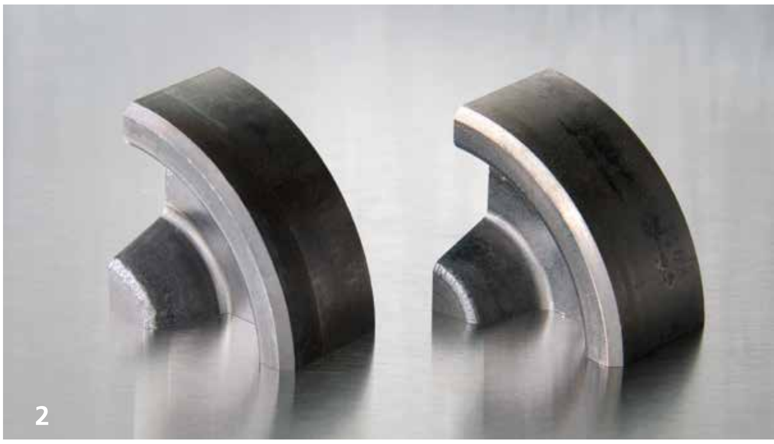
1

Dortmunder OberflächenCentrum DOC

Particularly in the field of hot forming, such as the die-forging of steel or for die-casting of light metals, high demands are placed on the surfaces and edge zones of the respective tools. These are effectively protected by hard coatings and diffusion treatments which remain resistant and chemically inert at very high application temperatures and extreme alternating thermal stresses with superimposed mechanical loading.

At the Dortmund location, the Fraunhofer IST offers coatings and diffusion treatments for the application of wear-resistant and temperature-resistant surfaces. For this purpose, we have developed special PECVD coatings, some of which are performed by means of the duplex plasma process. This combination of plasma diffusion treatment, for example plasma nitriding, with a continuous subsequent plasma coating process offers diverse technological advantages. The technology allows the production of tool surfaces, e. g. for the die-forging of steel, which can withstand the typical forming temperatures of over 1000 °C, whilst at the same time protection against wear caused by abrasion and adhesions can be offered. Further typical applications of hot forming include forms and dies for aluminum die casting or matrices for the extrusion of light metals made from hot-work steel: In addition to the required wear resistance and stability at the high application temperatures, the erosive effect of the hot or molten aluminum on the steel surface must be prevented. This is achieved very effectively by means of the boron-containing multilayer coating systems (Ti-B-N) which have been developed.



Nitrided reference tool showing wear pattern on the mandrels of the test tool after 3000 forming operations at 1150 °C (left), test tool with optimized boron-containing multilayer coating system Ti-B-N with significantly reduced wear pattern on the mandrels of the test tool after 3000 forming operations at 1150 °C (right).

"

As a highly productive process for parts made from light metal or high-strength components made from steel, hot forming benefits from our optimized wear-protection solutions."

Dipl.-Ing. Hanno Paschke / Team Manager

Plasma facility for duplex treatment by means of combined plasma diffusion and PECVD coatings at the Dortmunder OberfächenCentrum DOC.

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Diamond-based systems and CleanTech

In many sectors, materials have to fulfill extreme requirements. They must, for example, be extremely hard, durable, biocompatible or chemically inert. Diamond – the hardest material in the world – combines these properties and enables the creation of unique products and innovations.

Diamond offers enormous innovation potential for highly stressed components, tools, optical and electronic systems as well as for the chemical-free purification of water and gentle pest control.

CVD technologies (chemical vapor deposition) enable the large-area production of diamond as a coating material and, as a result, its economic and versatile utilization. Here hot-wire activated chemical vapor deposition technology is applied in the development of diamond coatings. Furthermore, the Fraunhofer IST has a broad spectrum of coating materials and adapted process controls at its disposal, extending all the way to the ultra-precise deposition of atomic layers.

Highly wear-resistant diamond coatings for durable and sustainable components and tools

The development of application-adapted coatings for highly stressed components and tools is one of our core competencies. Our extensive expertise in the design and manufacturing of CVD diamond coatings enables the implementation of diverse innovative ideas.

Transparent and highly durable

The unsurpassed extreme hardness of diamond offers great potential for use in optical applications. The utilization of diamond promises the highest possible mechanical durability, which can be achieved, amongst other things, for optical broadband anti-reflective coatings. Furthermore, the reduction of the haze caused by abrasion during use should increase the service life and the overall wear resistance of the components.

Sustainable technologies for a clean environment

Within the framework of the Water, Energy and Food-Security Nexus, the interdisciplinary teams of the Fraunhofer IST department “Diamond-based systems and CleanTech” are developing sustainable processes and systems for water treatment and disinfection. We use diamond electrodes in order to generate highly effective oxidants in water which can eliminate trace substances or prevent the formation of biofilms.

Silicon substrate with a microcrystalline diamond coating.

„

Innovative processes and products for the utilization of diamond coatings are our passion."

Dr. Volker Sittinger / Head of Department

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1

Antireflective layer system on 3D object produced by atomic layer deposition (ALD).

Atomic layer deposition

For the production of high-tech materials, components and products for which ultra-thin layers with an extremely uniform and defined layer thickness are required, including on large and structured surfaces, atomic layer deposition is often the technology of choice.

With our hybrid spatial ALD facility, atomic layer deposition processes can be combined in high rate with other coating and activation processes. This cutting-edge technology in the field of modern manufacturing processes and automation enables us to deposit thin layers homogeneously and with high conformity on the most varied components. Our services range from process development for thermal ALD coating systems to the development of customized functional coatings on particle materials and complex geometric substrates for optics, applications in medical and pharmaceutical industries as well as the energy materials development.

Economic high-throughput processes by means of spatial atomic layer deposition

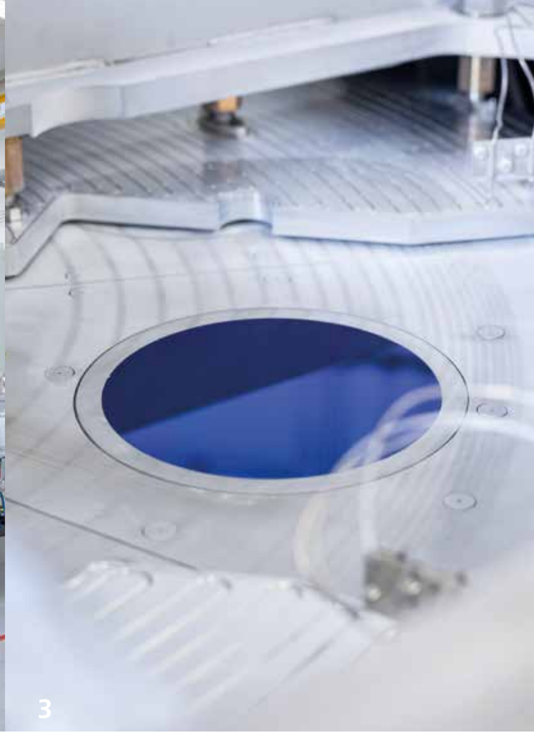
Whereas conventional ALD systems require time-consuming rinsing routines, spatial atomic layer deposition enables a high coating rate whilst maintaining the coating-technology advantages.As a result of the integration possibility of further coating and activation technologies in a hybrid area, the advantages of other technologies, e. g. PVD, CVD, can be implemented in this system in order to develop innovative coating and material systems for groundbreaking solutions for our customers.

Atomic layer deposition for medical-technology applications

Medical-technology innovations from small and medium-sized companies often fail due to the implementation of special processes which are necessary for the manufacturing of the medical product, and consequently do not achieve the transfer from basic research to the market. In contrast, expensive machines in universities are not sufficiently utilized.

The platform "Translational Manufacturing Platform Medical Innovation" optimizes the technology and knowledge transfer of special processes based on atomic layer deposition at the Fraunhofer IST. In this context, we offer, on the basis of this coating technology, the development and optimization of nanometer-thick diffusion barrier coatings for e. g. implants with deep-lying micro undercuts or vertical material interfaces.

2 *FHR Star 400x300 SALD coating system for thermal local atomic layer deposition.*



3 *View of the rotating turntable and heating block.*

4 *Local atomic layer deposition: View of the rotating turntable below the heating block in the hybrid area.*

Compliant coatings and functionalizations for applications in the energy sector

Nanomaterials are considered to be a pathway towards the implementation of renewable energy technologies – from energy generation through to energy storage. In the manufacturing of these nanomaterials and in their modification, functionalization and stabilization many challenges arise. The extensive range of ALD process variants at the Fraunhofer IST enable rapid target and customer-oriented implementation of layer and process development for a wide variety of substrate materials, geometries and dosage forms.

Outlook – This is what awaits you!

The combination possibilities of local atomic layer deposition with further activation and coating technologies are extremely diverse. The establishment and evaluation of new hybrid processes for novel innovative products – for example for sustainable tandem solar cells with highest conversion efficiency – is an essential element of current work.

> **"The technological innovations and application possibilities of atomic layer deposition are developing rapidly. Our goal is to transfer these swiftly and efficiently to our customers."**
>
> **Dr.-Ing. Tobias Graumann / Group Manager**

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Photo- and electrochemical environmental technology

Photo- and electrochemical oxidation processes are an important building block in the degradation of organic substances. Furthermore, they contribute towards the environmentally-friendly extraction of hydrogen and the conversion of carbon dioxide (CO_2) into higher-value hydrocarbons.

At the Fraunhofer IST, we develop system solutions for the sustainable and efficient purification and disinfection of water, air and soil on the basis of photo- and electrochemical oxidation processes and, at the same time, operate a test laboratory which is accredited by the German Federation for Applied Photocatalysis (FAP) for efficacy verification of photocatalytic surfaces, materials and products.

Mobile backpack sprayer for the efficient production of ozonized water for surface disinfection.

Sustainable technologies for a clean environment

The preferred methods are electrochemical oxidation using diamond electrodes (EAOP®) and photochemical oxidation and reduction with photocatalysis. Neither of the two processes uses any additional chemical substances and they are therefore among the most environmentally friendly and sustainable technologies available on the market.

The Fraunhofer IST is one of the pioneers of EAOP® technology and ranks among the leading players in the field of photocatalytic metrology and standardization. Therefore, our customers benefit from the flexible networking of our competences for the production, evaluation and adaptation of diamond electrodes and photocatalytic surfaces considering the limitations of economic efficiency and environmental sustainability.

Our technology is applied in energy-efficient diamond cells with which micro-pollutants in groundwater, drinking water and wastewater are degraded, in the coating and treatment of surfaces in order to protect against fouling and biofouling, and in disinfection systems for agricultural production and agricultural hygiene.

"Our CleanTech processes dispense with the need for additional chemicals and therefore provide a valuable contribution towards the environment and the climate-compatible assurance of an adequate supply of water, energy and food."

Dipl.-Ing. (FH) Frank Neumann / Team Manager

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Hot-wire CVD

"With the largest diamond coating plant in the world and our expertise, we have the possibility of making this unique material available for your ideas."

Dr.-Ing. Christian Stein / Group Manager

2

CVD diamond coatings for various component and tool solutions.

Complex three-dimensionally shaped surfaces, as well as large areas, can be given a high-quality coating by means of hot-wire-activated chemical vapor deposition.

At the Fraunhofer IST, we have at our disposal the world's largest hot-wire CVD coating plant for the production of diamond coatings on surfaces of up to 0.5 x 1 m^2. This enables us to apply coatings with the highest quality and value to complex components and tools and to produce silicon-based coating systems with high efficiency and unique properties. In both cases, we develop the technologies and coating modules as well as the associated processes.

The potential applications of crystalline diamond and silicon-based coating systems by means of hot-wire CVD are manifold: In addition to components and tools, they encompass optical and electronic elements, highly efficient solar cells, sensors – e. g. MEMS (micro-electro-mechanical systems) – and microsystems. CVD diamond coatings have properties comparable to natural diamond and are characterized by maximum hardness, extreme wear resistance, minimal friction coefficients and high chemical resistance. The unique material properties result in significant performance improvements and long-lasting products.

Current fields of application include high-performance tools for machining and forming technology, and highly stressed parts such as mechanical seals, bearings or guide components. We have acquired extensive expertise in the design and manufacturing of CVD diamond coatings, covering both specific treatment sequences (material selection, pretreatment, coating and process development, qualification) and the application. We provide support in the related production and process-chain considerations, in the testing and evaluation of systems, and in technology transfer all the way through to the individual design of coating systems, processes and hot-wire CVD coating technology.

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Textured tool surfaces

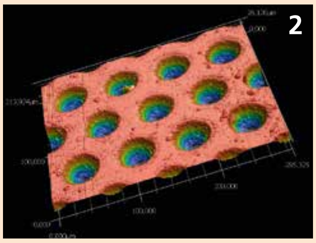
The texturing of tool surfaces and highly stressed components facilitates the targeted adjustment of tribological contact, going far beyond the possibilities of pure material and layer development. Tribologically effective structures and textures can have a decisive influence on the prevailing frictional forces. The machining of materials with a strong tendency to adhesion, for example, offers great potential. Within the framework of the Fraunhofer-internal project TexSpan, suitable methods for the production of laser-textured carbide indexable inserts coated with diamond or AlTiN were developed.

Challenges in tool texturing

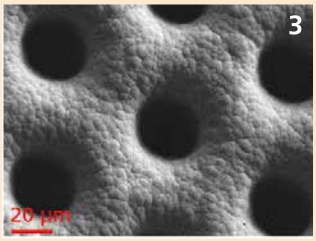
The economic and sustainable machining of aluminum and steel materials is of major relevance for automotive and mechanical engineering as well as for aerospace. The high adhesion tendency of many materials, however, poses a considerable challenge. Material adherence on the tool surface increases tool wear, reduces component quality and hampers productivity. Tribological structures for the reduction of material adherence have been identified in fundamental studies.

For the technological verification and subsequent economic utilization, however, a systematic investigation of the influence of different texture geometries on the reduction of material adherence is still required. Furthermore, knowledge is lacking regarding an effective and economical manufacturing process for these textures. The conventional methods for shaping carbide tools, such as green machining or machining of sintered carbide via eroding or mechanical processes, are limited in the design freedom of possible structures and dimensions and are, in many cases, uneconomical.

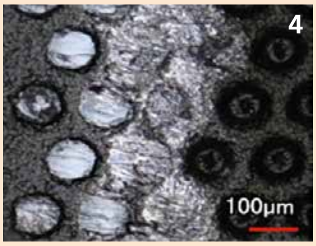
CVD-Diamond coated cutting inserts.



Cell structures with AlTiN layer.



Textured chip surface with diamond layer.



Textured chip surface with diamond and run-in layer following turning of AlSi17.

Our solution approach

In the TexSpan project, procedures for the texturing of chip surfaces by means of laser ablation were developed, and both the parameters for the processing of carbide tools and the processing of AlTiN and diamond coatings were researched. Subsequently, treatment sequences for the coating of laser-structured carbide were developed, including the investigation of micro-sandblasting as an optional pretreatment. The cleaning and chemical etching treatment, PVD deposition of AlTiN and hot-wire CVD deposition of diamond were also examined. As an additional optimization approach, run-in layers of amorphous carbon were tested. For the evaluation of the machining of stainless steel (V4A) and a hypereutectic aluminum-silicon alloy (AlSi17), structured tools were produced and subsequently coated. For this purpose, cell and groove structures were parameterized in a design of experiment (DoE) whereby the largest possible ranges of different structure sizes and machined-area fractions were investigated, which, from the point of view of the application, were judged to be of interest and practicable to implement.

Results and application

Laser machining of carbide indexable inserts (WC-Co) with an ultrashort-pulse disk laser allows reliable, flexible and fast generation of cell, groove and other structures in the selected structure-size range from 25 µm to 100 µm with structure depths from 15 µm to 30 µm. With adapted pretreatment and coating processes, textured chip surfaces can be combined with both AlTiN and diamond of good quality and coating adhesion (see Figures 2 and 3). The diamond-coated tools showed no visible wear when turning AlSi17.

Whilst the experiments indicate a slightly reduced degree of material adherence on certain tools, no systematic correlation to the form of the various structures was apparent.

Diamond coatings with an additional run-in layer showed a significantly reduced tendency to form adherences in the turning tests with AlSi17. The best results were obtained in particular in combination with a high laser-machined area fraction (40 %) and large cell spacing (140 µm).

Outlook

The treatment sequences developed for the production of structured and coated material surfaces can be transferred to other tool systems in machining and forming technology as well as to highly stressed components. The combination with adaptable multifunctional and run-in coatings enables adaptation to differing tribosystems, operating conditions and applications, which are to be developed in subsequent projects.

9 INDUSTRY, INNOVATION AND INFRASTRUCTURE

12 RESPONSIBLE CONSUMPTION AND PRODUCTION

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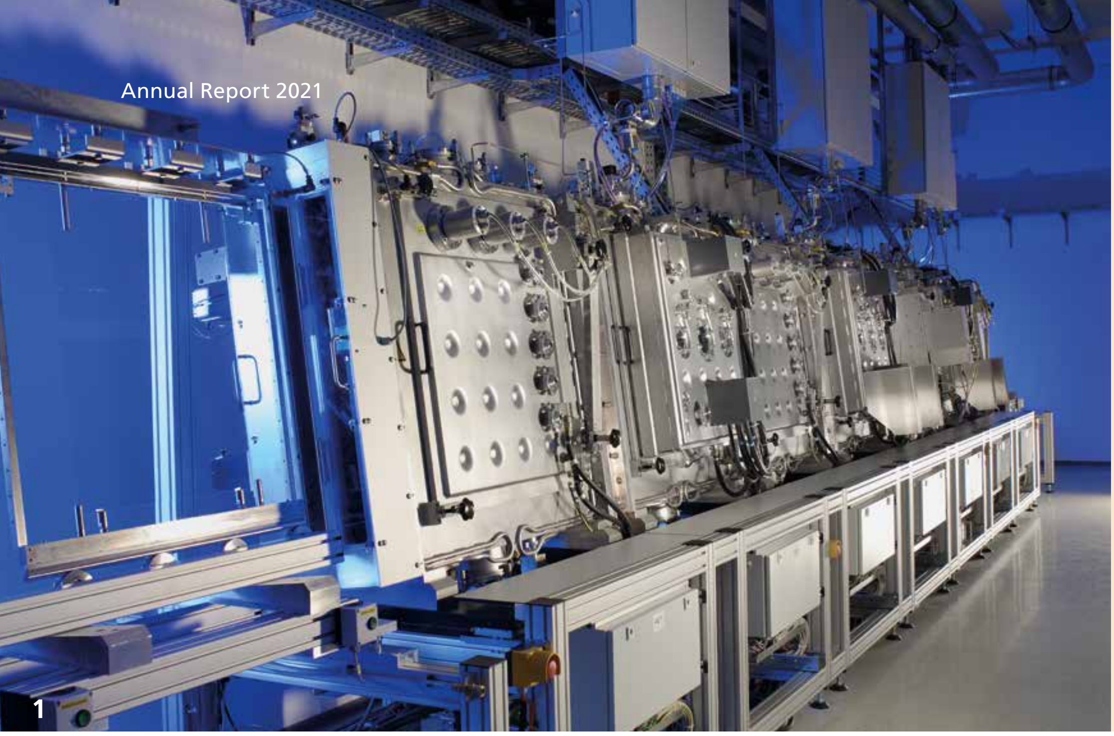

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7-chamber inline system for the deposition of silicon and silicon nitride layers using the hot-wire CVD process. Maximum substrate dimensions: 500 mm x 600 mm.

Vertical integration of MEMS sensors on application-specific integrated circuits (ASICs)

Nowadays, it is impossible to imagine our everyday life without consumer electronics products such as smartphones, tablets and smartwatches. Essential components of these products are the micro-electro-mechanical systems (MEMS) based sensors. While the dimensions of components, assemblies and devices are constantly being reduced; the size requirements of the wiring and encapsulation of the MEMS-ASIC components becomes a limiting factor for this size reduction.

In a joint project with the Fraunhofer institutes ILT and ISIT, the Fraunhofer IST has developed a deposition process for silicon which enables the direct deposition of silicon onto an application-specific integrated circuit (ASIC). As a result, the necessity of wiring between the MEMS and the ASIC component is completely eliminated, allowing for a significant reduction in overall component size.

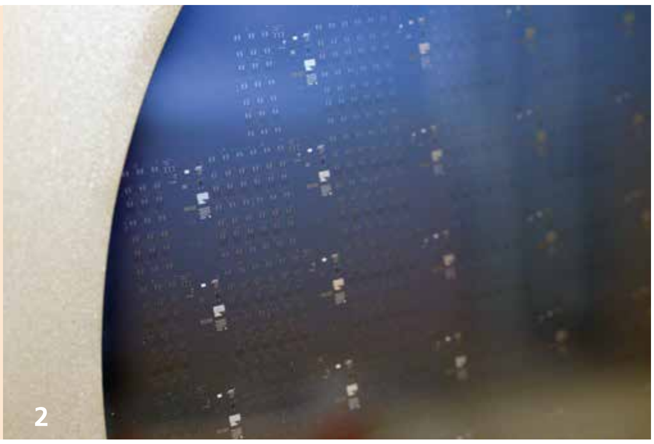
Limitations of current solutions

More than 80 percent of all MEMS inertial sensors are fabricated in an epitaxial process by means of chemical vapor deposition (CVD), whereby deposition temperatures can exceed 1000 °C. Although there are possibilities for reducing the substrate temperature, significant limitations exist. A non-epitaxial thermal CVD process enables substrate temperatures to be reduced to ~650 °C; however, this leads to low deposition rates and amorphous, low-conductive, films. Advances in plasma-enhanced CVD (PECVD) have also achieved significant reductions in substrate temperatures, but result in a significant introduction of stresses into the resulting films, which in turn leads to deformation of fine MEMS structures.

The hot-wire solution

This is where hot-wire CVD (HWCVD) distinguishes itself. By depositing silicon at low substrate temperatures, a low-stress silicon film with large-area uniformity can be achieved whilst simultaneously achieving high deposition rates. In addition, high film conductivities can be achieved by adjusting the process parameters in such a way that the crystallinity of the films is increased. The 7-chamber inline system at the Fraunhofer IST enables the deposition of silicon, silicon oxide and silicon nitride layers with industry-scale coating areas of more than 600 mm x 500 mm.

With the objective of direct MEMS-ASIC integration, the Fraunhofer IST has developed a novel silicon deposition process by means of HWCVD. This process enables the deposition of thick (> 10 µm), highly conductive (~0.1 Ωcm), nanocrystalline silicon films with the significant advantage of near-zero (< 10 MPa) film stresses. This is achieved whilst maintaining a low substrate temperature (< 420 °C), high deposition rates (> 1.8 nm/s) and very good scalability. The silicon layers were deposited on silicon wafers with NMOS (N-type metal-oxide-semiconductor) test structures, following which, MEMS structures were fabricated from these layers at the Fraunhofer IST.



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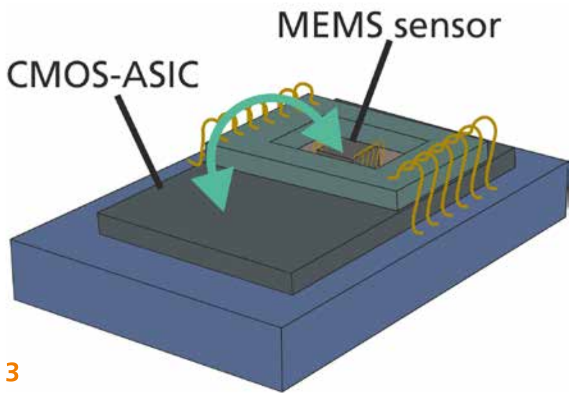
Successful deposition of nanocrystalline silicon on 8" silicon wafer with etched contact points.

The fundamental advantages of HWCVD silicon deposition are the resulting very low film stresses as well as the controllability of the film crystallinity. The performed work highlights an industrially relevant application of HWCVD technology in the further development of MEMS/ASIC sensor combinations. Vertical integration can provide a contribution towards further reducing the dimensions of electronic devices.

Outlook

This work describes an important advance in the application of HWCVD technology. A knowledge base for low-temperature processes has been established which, in addition to vertical MEMS-ASIC integration, opens up new possibilities for the deposition of MEMS-grade silicon on temperature-sensitive substrate materials.



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Objective of the MAVO-MUSIC project: The reduction of the overall device size through the direct vertical integration of MEMS on ASIC components.

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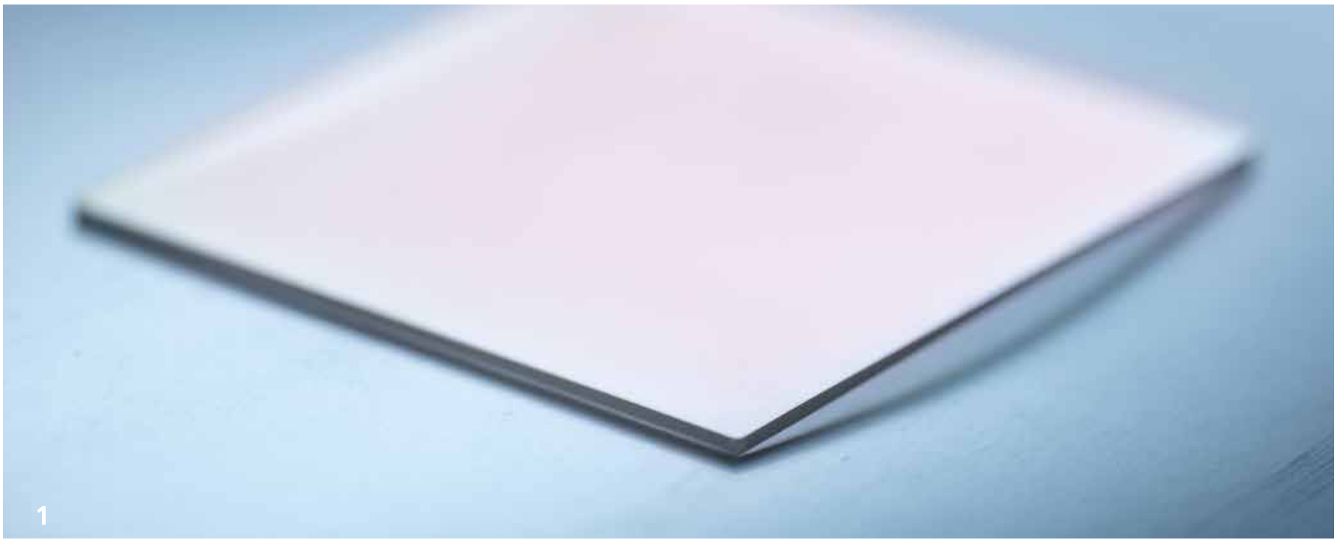
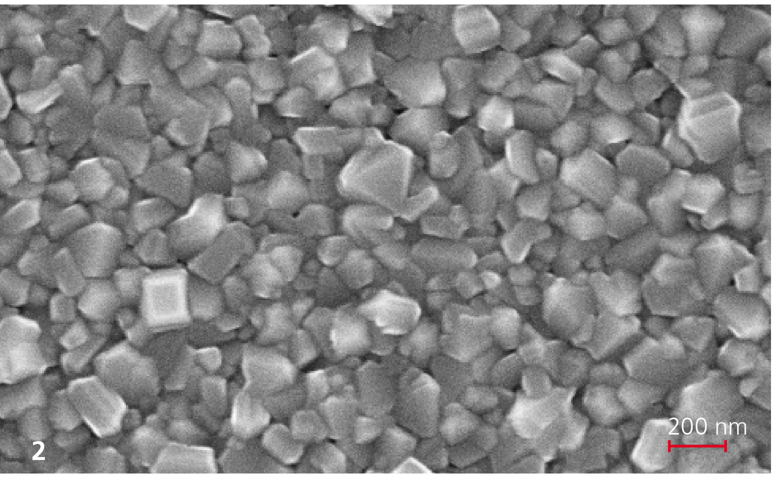
Ultra-hard optical diamond coatings



Diamond-coated quartz glass with very homogeneous coating pattern.

Transparent glasses with high scratch protection is needed in many industries today: From viewing panels for smartphones and watches to optical instruments and sensor systems to applications in medical technology. In a collaborative project with the Institute for Materials Research (IMO) of the Belgian University of Hasselt, the Fraunhofer IST is developing and researching ultra-hard optical diamond coatings. The aim of the project is to enable transparent and durable diamond coatings and coating systems for optical applications with high mechanical resistance and improved utility value.



SEM image of a CVD diamond layer on glass.

Challenge and project goal

Transparent coatings with scratch protection often determine the usability and service life of optical components. If the dial of a wristwatch or the lens of an optical measuring system is scratched or clouded by abrasion, further use is often no longer possible. Transparent scratch protection or a combination of scratch protection and anti-reflective coating (AR coating) is already used in many industries, but existing coating solutions are reaching physical limitations. The demand for improved scratch protection and thus longer product lifetimes is constantly increasing.

3

CVDiamond XXL hotfilament chemical vapor deposition installation.

Diamond offers excellent protection against abrasive influences due to its high hardness and mechanical resistance. Ultra-hard nanocrystalline and transparent diamond coatings show the potential to complement and extend existing coating solutions as scratch protection of optical applications. In addition, optical diamond coatings could be used in a complementary layer structure as an AR coating and thus increase the resistance of the coating system.

Solution

The novelty of the proposed solution to be investigated here is the deposition of very thin and smooth diamond layers with low absorption. High transmission is crucial for optical applications, as is the avoidance of stray light and reflections. For the development of ultra-hard anti-reflective coating systems, diamond coatings with precisely defined thicknesses are embedded in multilayer systems of low- or medium-refractive conventional coatings and tested therein.

The Fraunhofer IST uses hot filament chemical vapor deposition (HFCVD) for this purpose. The fully automated coating systems developed in-house allow coating areas of up to 1000 mm x 500 mm.

The coating processes for optical diamond coatings are being developed in the project in such a way that the economic production of very uniform coatings is possible. The selection and optimization of the base material, the substrate pre-treatment and the process design are essential focal points of the project.

The base bodies to be coated include various types of glass such as quartz glass, borosilicate glass, float glass and sapphire. In the research project, HFCVD diamond coating processes with reduced coating temperatures are being developed and researched in adaptation to these basic bodies, some of which are temperature-sensitive. The focus here is on optical properties such as absorption and scattering as well as mechanical resistance to abrasive loads.

Outlook

Transparent ultra-hard diamond coatings in AR coating systems should lead to abrasion-resistant surfaces. At the end of the project, findings on the wear resistance of the optical diamond coatings and diamond coating systems on various substrates will be available. The customer benefits resulting from the unsurpassed hardness and durability of diamond will thus be demonstrated for optical applications.

The project

The project is funded by the German Federal Ministry for Economic Affairs and Climate Action based on a resolution of the German Bundestag. Funding of the individual research project by the Industrielle Gemeinschaftsforschung (IGF project no.: 263 EN) from the German federal budget within the framework of a transnational CORNET overall project.

Gefördert durch:

Bundesministerium für Wirtschaft und Klimaschutz

aufgrund eines Beschlusses des Deutschen Bundestages

9 INDUSTRY, INNOVATION AND INFRASTRUCTURE

12 RESPONSIBLE CONSUMPTION AND PRODUCTION

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Optical systems and applications for surface technology

Optical technologies rank among the most important growth and future industries of the German economy. In addition to the external appearance, the focus is also on the functionalization of optical components. For the widest variety of applications, thin-film technologies provide an important contribution towards the development of innovative solutions.

Across all sectors, optical components are just as necessary for automated production processes as for the application itself. There are optical systems in fitness trackers as well as on a Mars Rover. This requires layers – ranging from one single layer to several hundred – which are stable against environmental influences and which must be deposited with an accuracy of only a few atomic layers.

At the Fraunhofer IST, we develop such precision optical systems and the associated production processes. Important components are in many cases interference filters to reduce reflection, limit transmission or select polarization. The use of different light sources from LED to laser and the combination with suitable sensor technology lead to multiple requirements across wide spectral ranges.

Understanding the process enables flexibility with the highest precision

Based on a simulation-supported understanding of the process, we are able to adapt our coating processes to produce the best coating and substrate properties.

With the coating platform EOSS® (Enhanced Optical Sputtering System), a production-ready system for high-precision interference filters is available and, in combination with the process monitoring and control software MOCCA+®, complex filters with many hundreds of layers can also be achieved, which we design based on the requirements of our customers.

Model-based product and process improvement, improved process knowledge

Product and process simulation – provided valid models are available – enables us to perform feasibility and optimization studies, together with the evaluation and efficient utilization of the results with initially minimal experimental effort. We therefore create customized simulations and virtual coating runs for the optimization of processes and facilities. We link these with optical measurement technology for process control and quality assurance.

Black coating with dielectric beamsplitter film for use in outer-space applications, e.g. in spectrometers.

"With increasing digitalization, optical applications are becoming more and more important. We offer our customers application-oriented solutions for optical systems in the field of coating and surface technology."

Dr. Michael Vergöhl / Head of Department

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1

Optical broadband monitoring system MOCCA+®.

2

With the EOSS® system, state of the art high-precision coatings can be produced.

Precision optical coatings

In many industrial applications such as photovoltaics, display technology, architectural and automotive glazing, fine optics, traffic, information and electrical engineering as well as aerospace, the coating of optical assemblies with the highest precision is the key to realizing required product properties such as reflection, transmission, polarization, scattering or color.

For the production of optical coatings, the Fraunhofer IST relies on the magnetron sputtering technology. In consideration of the process chain and system properties of tools and components, we develop load-optimized surfaces for customer-specific applications. The EOSS® technology licensed to equipment manufacturers enables the production of new and extremely sophisticated optical coatings on an industrial scale with high process reliability.

The productivity of the coating facilities of our customers can be enhanced through our MOCCA+® software, which not only allows optical in-situ monitoring, but can also adaptively control the coating process. Beginning with a simulation-based understanding of the process, we have the ability to optimally adapt our coating processes to all required coating properties and substrate geometries. Furthermore, we have a wide range of options for combining these with special properties such as scratch protection, contact angle or even structuring. We are able to achieve the required optical properties even on unusual substrates such as sapphire or plastics in a wide variety of sizes, flat or curved. These competences are supplemented by the development of optical measurement technology, tailored to the specific wishes and requirements of our customers.

"With the EOSS®, we are able to realize many things that seemed impossible 10 years ago. Today, we are working on the further development of this innovative technology, where digitalization is playing an increasingly important role."

Dipl.-Phys. Stefan Bruns / Project Manager

Kontakt

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Optical and electrical systems

"Our thin-film systems with tailored optical and electrical properties are key components for the energy transition."
Dr.-Ing. Ralf Bandorf / Group Manager

Optical reflection or transparency as well as electrical insulation or a defined layer resistance represent the key requirements for a multitude of products. Solar cells, sensors, heating elements, or local hydrogen generation: in many products, the targeted adjustment of optical and electrical properties is essential.

Based on the current issue, we at the Fraunhofer IST can model desired optical properties and offer suitable coating solutions. This is possible in combination with the realization of specific electrical conductivity requirements. On various substrates such as metal, plastic or ceramics, the desired optical or electrical functions can be implemented in a vast range of sizes from flat to complex three-dimensional surfaces. Prototyping up to to small series evaluation is performed using industrial coating equipment. This is accompanied by the optical and electrical characterization of the developed coatings or coating systems.

3

Glass tube of the BASF group with transparent ITO heat conducting coating for heating of distillation columns in chemical process engineering.

Kontakt

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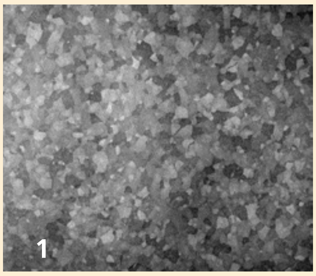
Sustainable hydrogen from sunlight

In the search for energy sources of the future that avoid CO_2 emissions and still provide a stable energy supply, hydrogen has a key role to play. For this reason, a tandem module is being developed within the framework of the Fraunhofer joint project "Neo-PEC", which in future will generate green hydrogen directly by means of sunlight in a cost-effective and clean manner and thus enable a decentralized hydrogen supply.



Laser scanning microscope image of a half-cell (glass/ In_2O_3:Sn/TiO_2:Nb) of the n-type (photo anode). The lateral structure sizes of the uppermost TiO_2:Nb layer reach up to approx. 3 µm.

Solar water splitting

The underlying principle has been known for more than 40 years and is similar to natural photosynthesis: **P**hoto **E**lectro-**C**atalytic **PEC** (water splitting) is a light-driven water electrolysis in which electrons and holes are first generated by sunlight in a suitable semiconducting absorber material. In the simplest case, this can be achieved with titanium oxide particles in an electrolyte, for example (see Figure 2). The electrons and holes energetically raised by light then reach the interface of the particle to the aqueous electrolyte by diffusion and/or band bending and drive a chemical reaction there for hydrogen and oxygen formation respectively.

Figure 3 shows photocatalytic water splitting using an illuminated n-type semiconductor layer for oxygen production and a platinum counter electrode for hydrogen production. The advantage over the variant with particles is that the water and oxygen production already take place spatially separated. This setup, which is also referred to as a half cell, usually also requires a small external auxiliary voltage to further increase the energy of the electrons and holes.

Project approach

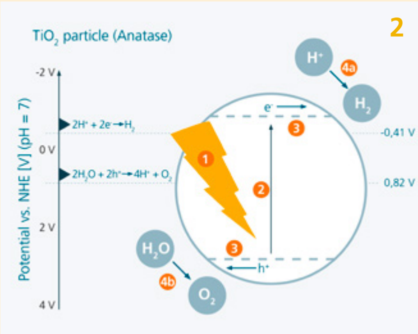
The approach chosen in the joint project "Neo-PEC" envisages the realization of a tandem cell consisting of two half-cells (see Figure 4), which allows the gases produced in the process to be discharged separately. With this type of cell, a maximum efficiency of photocatalytic water splitting of more than 25 percent is theoretically possible[1], since the semiconductors each use a different part of the solar spectrum. There is an analogy here with natural photosynthesis, which also uses two areas of sunlight, the blue and red color components. In practice, however, only about one percent efficiency is currently achieved for such simple tandem cells. The reasons for this are manifold:

- Insufficient quality of the semiconductors
- Highly absorbent contact structures
- apid degradation in the electrolyte and losses due to mismatched half cells

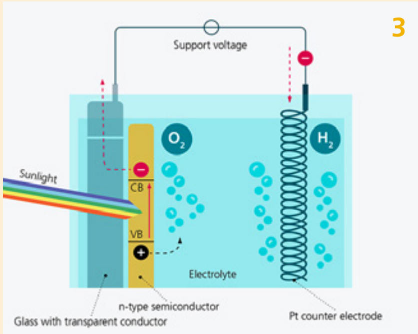
On the other hand, 19 percent efficiency has already been demonstrated with a complex structure, technically complex deposition processes and expensive materials[2].

This is where the project comes in. The aim is to close the gap between the 19 percent already achieved and the one per cent, while maintaining a structure as simple as possible. To achieve this, the entire system is being optimized: The many years of know-how of the Fraunhofer IST will be used for the transparent contacts and adapted to the requirements of the tandem cell. High-quality semiconductors with intrinsic durability are to be realized at the Fraunhofer IST using novel and modified PVD processes which permit large-area, low-defect and low-cost deposition.

Literature:
[1] Montoya et al., Materials for solar fuels and chemicals, Nature Materials 16 (2017), 70–81.
[2] Cheng et al., Monolithic Photoelectrochemical Device for Direct Water Splitting with 19% Effciency, ACS Energy Lett. 3 (2018), 1795–1800.



Schematic representation of the processes occurring during water splitting on a semiconducting particle (1 - 4).



PEC half-cell assembly with an n-type photoanode conductively connected to a platinum counter-electrode.

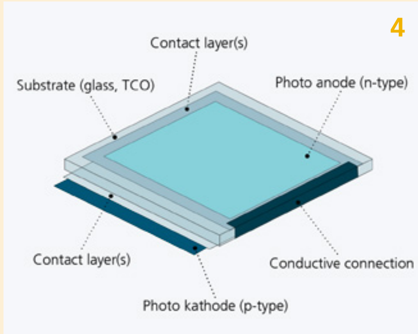


Illustration of a tandem cell consisting of one n- and one p-semiconductor, connected by transparent contacts for the generation of oxygen (anode) and hydrogen (cathode).

The project is being implemented in close cooperation with the Fraunhofer Institute for Ceramic Technologies and Systems IKTS and the Fraunhofer Center for Silicon Photovoltaics CSP, which contribute expertise in the areas of sputtering target production, thermal treatment, photoelectric characterization and large-scale demonstrator construction.

Results

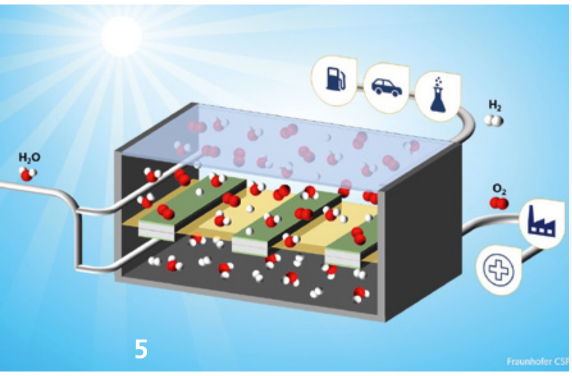
In the first phase of the project, n-type half cells based on titanium oxide were realized at the Fraunhofer IST by means of sputter deposition and subsequent "explosive growth" as a model system for test purposes (see Figure 1). The measurement of the photocurrents in the aqueous electrolyte was carried out at the Fraunhofer CSP (see Figure 6). The current difference between light and dark conditions proves the desired effectiveness as a photoanode and the associated photoelectric oxygen generation.

In addition, for voltages above about 1.5 volts, the conventional voltage-driven electrolysis can be recognized by the strongly increasing current. Overall, however, the photogenerated currents of 10 to 20 μA/cm² are still low compared to the targeted values in the milliampere range.

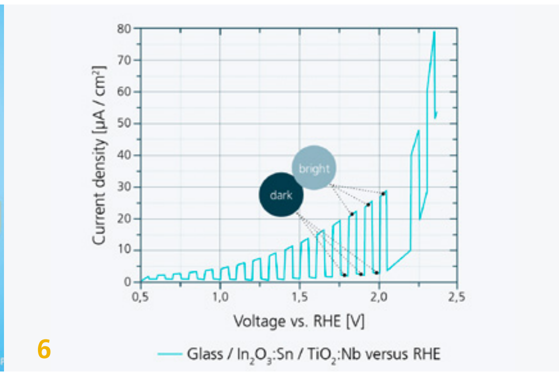
Outlook

In the further course of the project, there will be a transition to tungsten oxide as an n-type material, which allows higher photocurrents than titanium oxide, and the establishment of copper chromium oxide ($CuCrO_2$) as a p-type cathode for hydrogen production. Together with the project partners, weak points are identified and the photocurrent and efficiency are increased on this basis. The goal is a demonstrator module with an area of 1 m² (see Figure 5).

7 AFFORDABLE AND CLEAN ENERGY



Tandem module for solar water splitting. ©Fraunhofer CSP



Bias voltage and illumination dependent photocurrent of a glass/In_2O_3:Sn/TiO_2:Nb half cell versus Ag/AgCl reference electrode, pH: 6-7.

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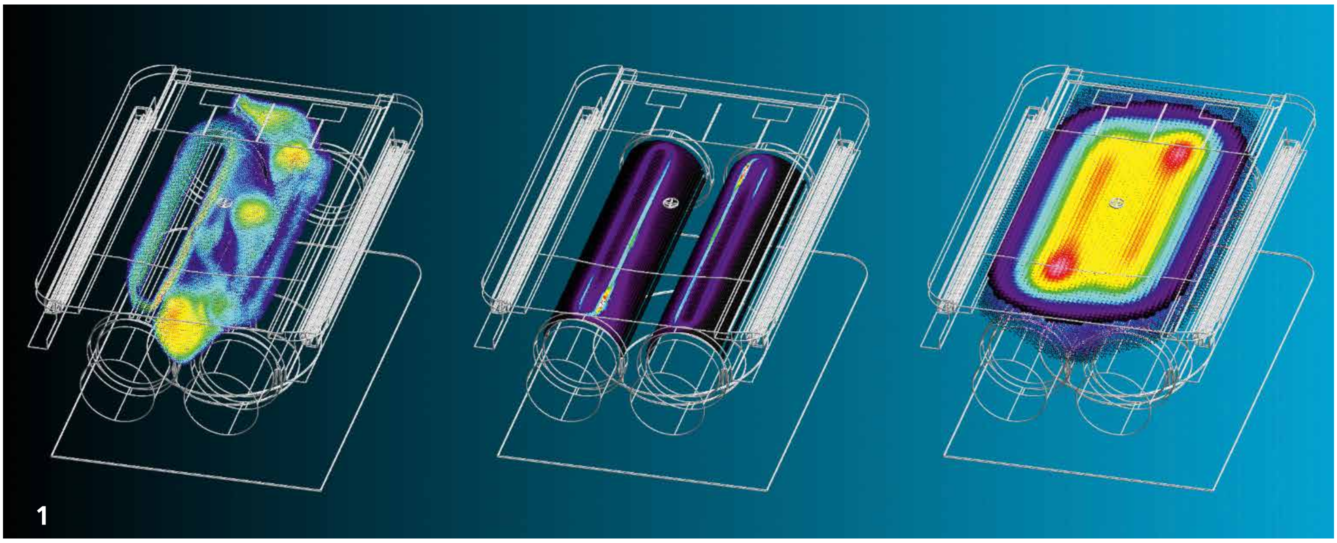
Simulation & Digital Services



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Plasma simulation of a sputtering process with double tube targets (left), extraction of the erosion profiles on the targets (middle) and simulation of the coating current density on the substrate (right).

In combination with improved sensor-data acquisition, process simulation enables the exploitation of increasingly efficient and precise coating processes. As a result, the progressively increasing cost and quality requirements in thin-film technology can be fulfilled and additional information on the productivity and sustainability of process chains can be obtained.

At the Fraunhofer IST, we develop simulation software and codes in order to gain insights into the process dynamics and parameter-property relationships of coatings.

Test series in process and plant development can thereby be partially substituted, enabling our customers to save time and costs. When carrying out simulation studies, we benefit from our expertise in thin-film coating technology. In addition, our extensive plant equipment enables the validation of our models. Furthermore, we are also offering know-how transfer via courses, hands-on training workshops and licensing of our simulation software.

Moreover, our service includes:

- Optimization of low-pressure deposition processes
- Plasma and gas-flow simulation
- Modelling of dust and aerosol transport
- Thermodynamic simulation
- Software for metrological solutions
- Data acquisition and data science

"Simulation enables the testing and evaluation of new processes prior to construction. Data collection and in-situ modeling form the foundation for knowledge-based process control for higher product quality and reduced waste."

Dr. Andreas Pflug / Group Manager

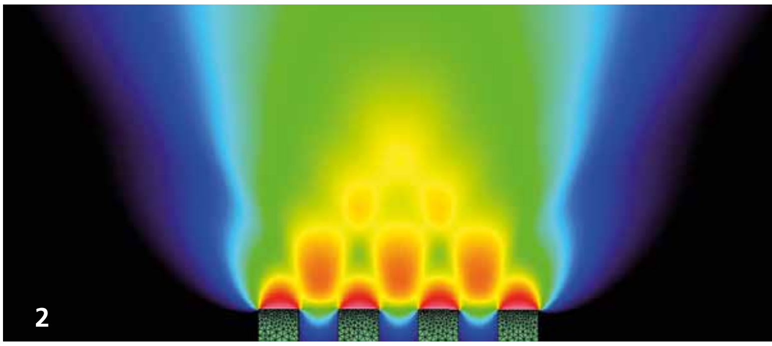
We offer software licenses (Direct Simulation Monte Carlo (DSMC)- und Particle-in-Cell-Monte Carlo (PIC-MC), support for HPC- and cloud computing, do simulation case studies and perform courses and training workshops.

Data acquisition and model-based process optimization

At Fraunhofer IST numerous plants for coating and surface treatment are acquiring real time process data and store them in centralized databases. This also includes metadata. Based on this, various concepts for process data visualization and their model- or data driven evaluation are developed and implemented. This activity is an important building block in our strategy towards a systematic digitalization of all processes and process chains.

Data driven models enable product and process optimization by various AI or model based approaches. Examples are deep learning based on neural networks, grey-box models or simplified physical models which are real-time capable. We support our customers in their infrastructure implementation towards digitalization via data acquisition and development of tailored product and process models.

DC dual-magnetron discharge simulated with PIC-MC.



Outlook – This is what awaits you!!

Our physics-based simulation codes enable a multiscale overview from the process through to the coating and product properties. With the transfer of these codes into semi-empirical models and data-driven AI approaches, we are currently working on the development of real-time-capable digital twins of coating processes. In the future, this will allow the optimization and model-based monitoring of coating processes – with minimal time expenditure. Process drifts are tracked online by the model and the prediction of required maintenance avoids unnecessary rejects and increases the overall productivity of process chains.

Dashboard view of in-situ process data from the cleaning line at Fraunhofer IST.

Kontakt

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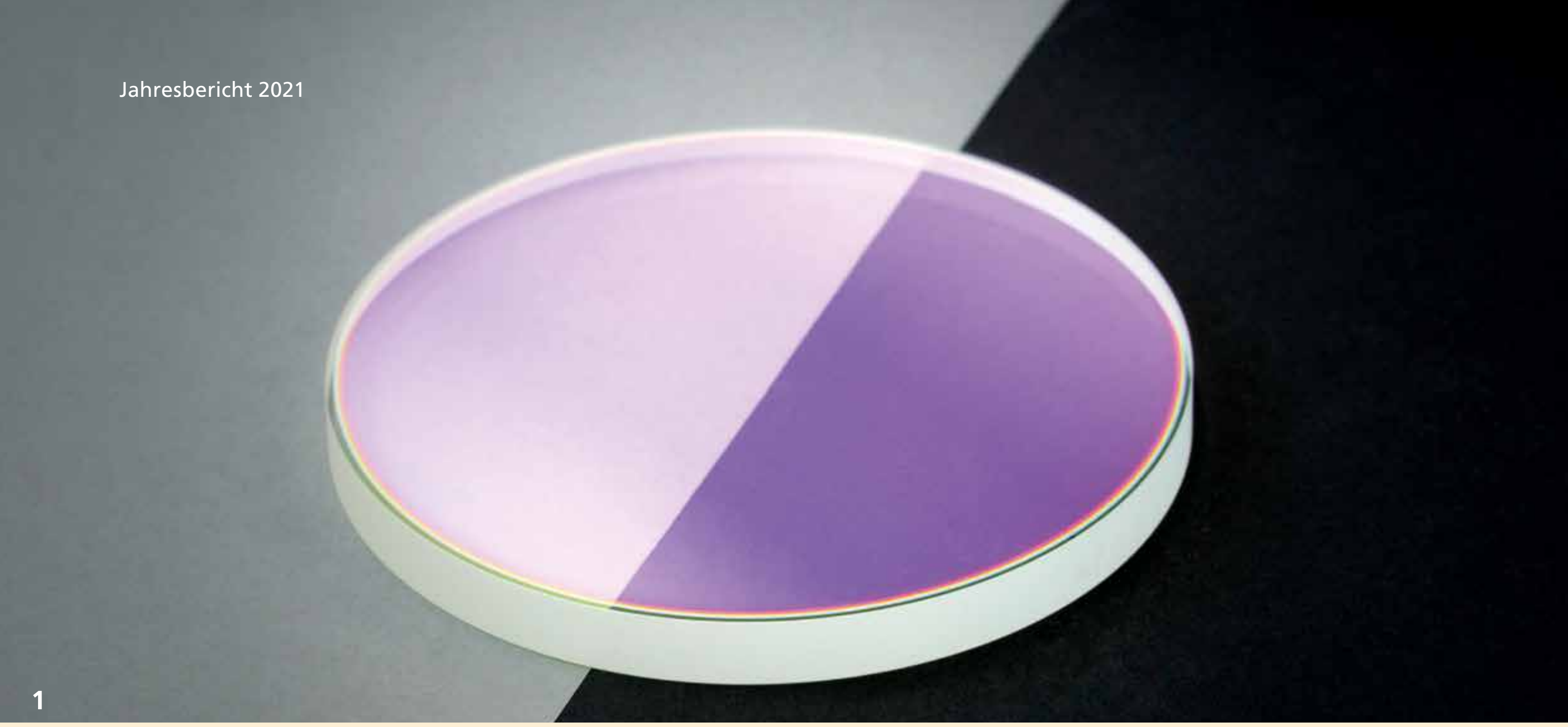


1

Dielectric beam splitter produced with MOCCA+®.

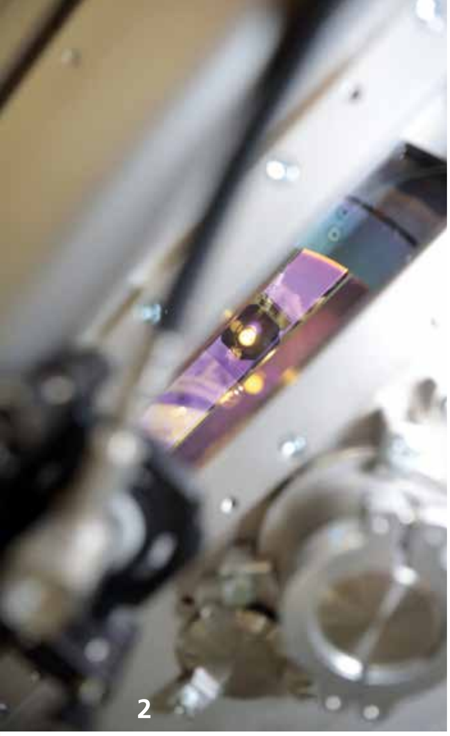
Process automation with MOCCA+®

The complexity and product diversity of industry-relevant optical systems is increasing continuously. With advancing digitization, flexible product changes are becoming a necessity. Users, including those in the thin-film industry, expect an ever higher degree of automation of the systems. With the EOSS® technology (Enhanced Optical Sputtering System), the Fraunhofer IST offers the possibility of flexible production of optical thin-film systems of the highest quality. The MOCCA+® software (Modular Optical Coating Control Application) developed at the Fraunhofer IST is capable not only of optical broadband-monitoring of the individual layers of a filter but also of controlling the EOSS® facility. Between the individual coating tasks, intervention by the user is no longer necessary, as the exchange of the substrates is performed automatically.

Production planning

Producers of optical components and their coatings are increasingly demanding the possibility of planning many coating batches in succession, for example in order to be able to continue production throughout the weekend. The production planning integrated in the MOCCA+® software is capable of taking over this task. For this purpose, the system operator defines the substrate types to be coated for each individual process in a visual interface – simply and conveniently by drag-and-drop. Before the process starts, the system determines whether the defined substrate types are available in the required quantities in the process chamber and the magazine chamber. If this is the case, the coated substrates are automatically discharged and new uncoated substrates are transferred to the process chamber.

The actual coating process takes place under high vacuum. Through the use of a separate magazine chamber, ventilation is, however, also possible during an ongoing process. As a result, coated substrates can be removed from the magazine chamber at any time, and uncoated substrates can be inserted for the next planned processes. Once the substrates have been successfully exchanged, the magazine is then pumped out again. In order to ensure the uninterrupted completion of several processes in succession, the operator therefore only needs to ensure that the magazine is ready again at the end of the current coating process. Depending on the product, several hours are available in order to ensure this. For thinner layer stacks, MOCCA+® also supports multiple magazine chambers.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3

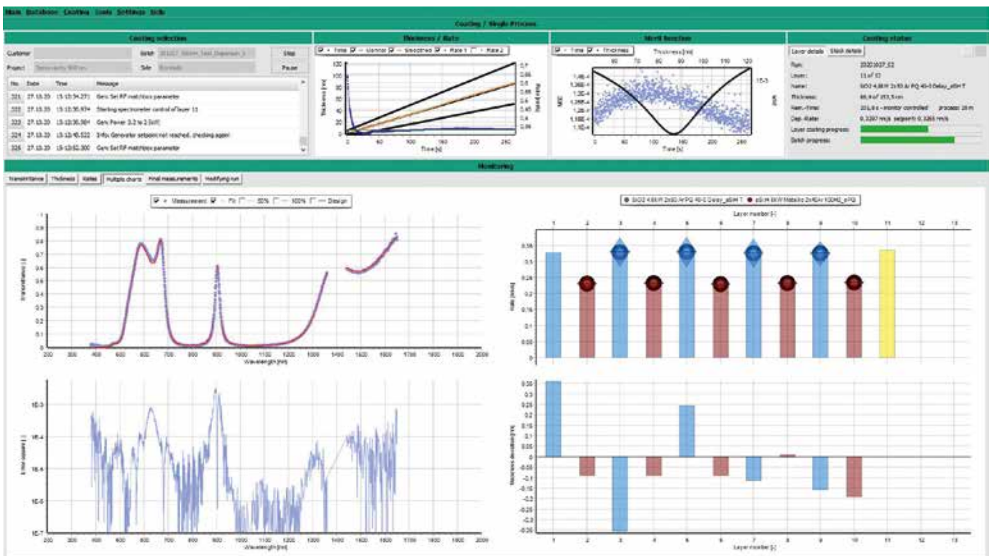
Beam path through the system (left) and window with variable measuring position above the substrate (right). Source: VON ARDENNE Corporate Archive.

Process reliability

MOCCA+® is directly linked to the programmable logic controller PLC, the main component for the control of the coating facility. This enables a very fast reaction in the event of, for example, error messages and therefore significantly increases process reliability. By avoiding the failure of entire coating batches, both time and material can be saved. MOCCA+® is able to stop the coating process if a critical deviation from the expected coating process is detected. Furthermore, the PLC pauses the process as soon as one of the system components deviates from its specified parameter range or communication malfunctions occur.

As a result of these quick interruptions, undesirable coating conditions can be avoided. Once the operator has resolved the cause of the problem, coating can continue. In the event of a power failure, this is also communicated to MOCCA+® and the process and the PC can be shut down in an orderly manner while the UPS (uninterruptible power supply) is still active. This prevents data loss and, in many cases, even enables subsequent successful coating. As a result of the modular structure of the MOCCA+® software, it is also possible to perform adaptations on other types of coating facilities. Contact us and we can discuss the possibilities together.

4



Program surface during a coating operation.

Kontakt

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Interfacial chemistry and adaptive adhesion

For the defined wetting of surfaces and the targeted control of adhesion, e.g. of coatings, adhesives and biomolecules, or in the case of delamination in recycling processes, the optimum design of the interface is a critical success factor and a key to innovations.

In the production of widely differing goods, quality requirements and specifications are high and, as in e.g. medical and pharmaceutical technology, lead to intense pressure as regards innovation and cost-effectiveness. The nature of the interfaces often determines the functionality, durability, recyclability and, ultimately, the quality of a product.

At the Fraunhofer IST, we are working on solutions for product and production systems which have one thing in common: an optimum interface. We deploy our extensive expertise in the pretreatment and coating of complex surfaces as well as industry-oriented and sustainable electrochemical processes and atmospheric-pressure plasmas in order to develop an optimal process chain for our customers.

On the basis of our modular process concept with a focus on sustainable and resource-saving technologies, process-associated analytics, and with the aid of simulation methods, we develop the appropriate system solution for individual problems.

For the validation of the results, we have an extensive portfolio of surface-analysis methods at our disposal. As a result, sustainable products are created along the entire value chain, from the development stage through to recycling.

Selectively functionalized surface for the formation of "hanging drops" for 3D cell models.

> **"The adhesion of many material combinations can be significantly increased through an optimal interface. For many products, the range of applications can thereby be expanded, and the functionality and long-term stability can be improved."**

Prof. Dr. Michael Thomas / Head of Department

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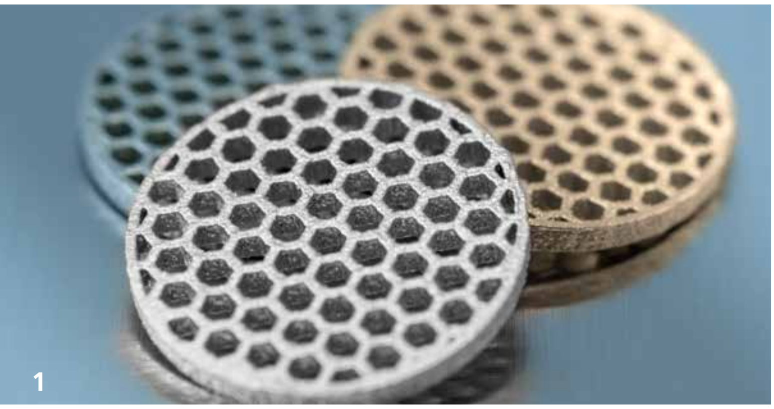
Electroplating and wet-chemical processes



1

Additive manufacturing: electroplating on filigree structures.

If a coating is intended to improve the properties of a base material, add new properties or protect the surface, electroplating continues to play a key role in many sectors as an effective and cost-efficient process.

As a result of increasing customer requirements in terms of process transparency, high personnel and energy costs, and steadily growing demands regarding occupational and chemical safety, driven in particular by the European Chemicals Regulation REACH, the pressure to innovate is high.

In order to address these challenges, we are working intensively on the digitalization of our coating processes and on fully automated, environmentally compatible and resource-efficient process technology.

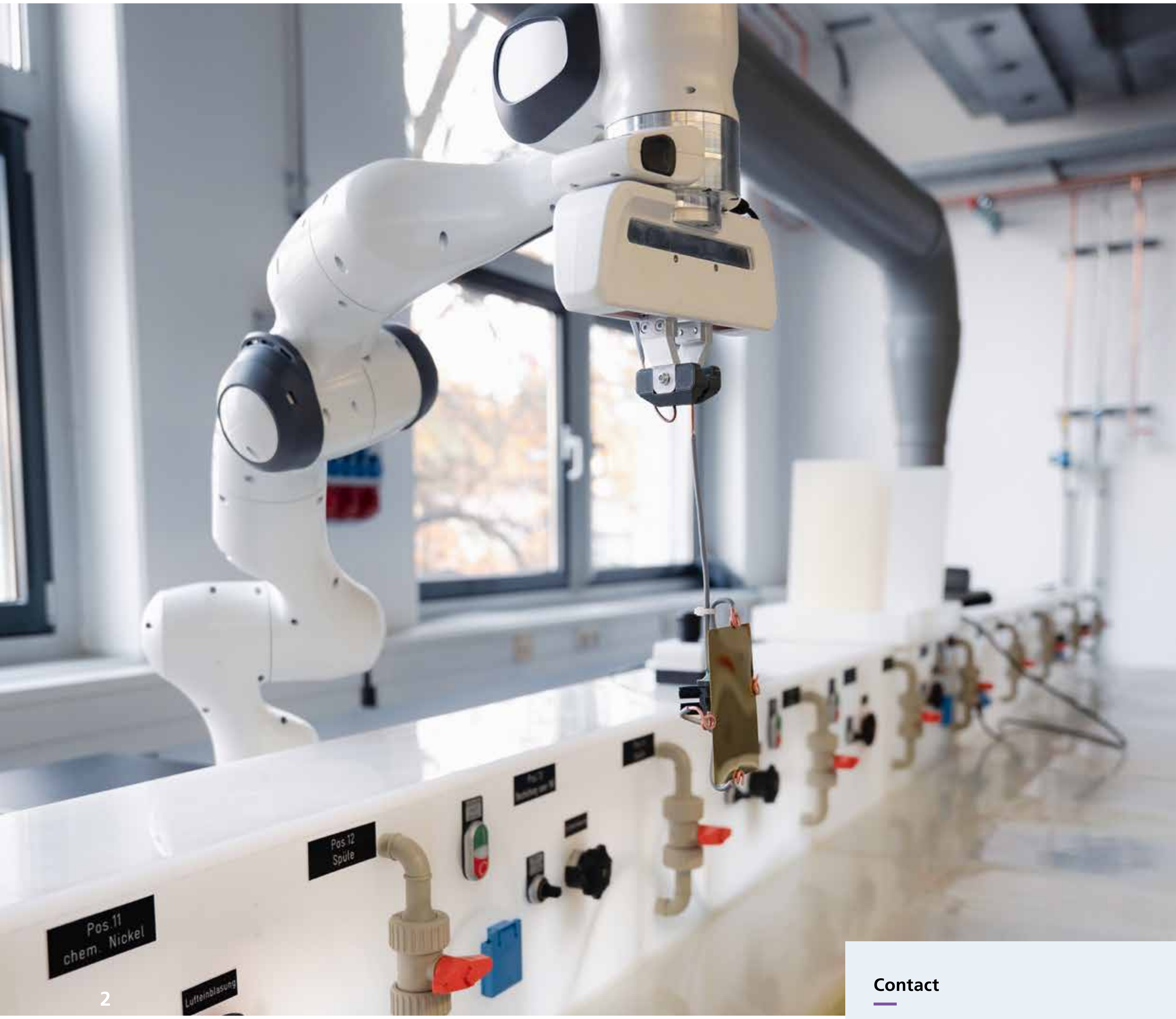
In collaboration with our customers and partners, we develop solutions for a wide range of issues, including the topics of Cr(VI) substitution, REACH-compliant pretreatment and coating of plastics, pretreatment for hybrid injection molding, coating development for multi-material systems, and electrochemical processes for the recycling of rare earths.

Outlook – This is what awaits you!

At the Fraunhofer IST, it will be possible in future to demonstrate product and process development for electroplating technology – from laboratory to pilot-plant scale – with the aid of the latest plant and analysis technology. In interaction with upstream and downstream process steps, the elaboration of a comprehensive understanding of data for agile and flexible production and the products thereby generated as well as the conception and development of new methods and tools for the digitalization of the production system are important goals.

"Through the utilization of digital methods, we see the possibility of making electroplating processes more agile, flexible and sustainable in the future."

Rowena Duckstein M.Sc. / Group Manager



2

Robot-assisted process engineering for investigating collaborative process flows in electroplating.

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1

Modular, process-controlled electroplating plant on a 20-liter scale with integrated bath analysis and automated post-dosing.

Digitization in electroplating technology

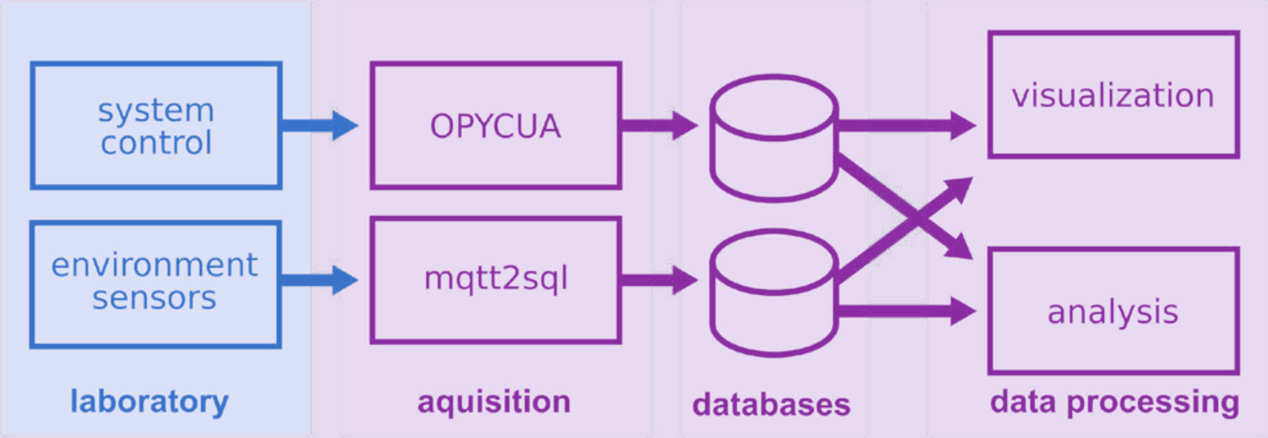
Electroplating is one of the most effective and cost-effective surface engineering processes and has the world's largest market share in this field. However, production technology is characterized by a high degree of complexity and depends on a large number of factors, both internal and external to the process. As a result, there is very high pressure to innovate in order to digitize processes and develop fully automated, environmentally compatible and energy- and resource-efficient process technology. This pressure is further intensified by increasing customer requirements and environmental legislation.

Challenges of digitization in electroplating technology

Implementing digitization requires the recording of all relevant process parameters to map the entire coating process chain in a digital twin. The availability of the relevant data as well as software for data acquisition and evaluation is an essential prerequisite for this. In industrial surface technology, however, there is as yet no suitable and sufficiently cost-effective measurement technology; even critical process parameters can often only be monitored offline. Product quality can therefore only be determined at the end product.

Automated data acquisition and processing

At the Fraunhofer IST, all research and pilot-plant-scale electroplating plants are currently being equipped with state-of-the-art plant control and in-situ analysis of the process baths and linked to automated data acquisition and processing. To this end, software is being developed which, for example, uses the OPC UA standard to access process data, compute it and store it in central databases. Central data storage makes it possible, among other things, to calculate the deposited layer thickness in real time during the coating process and make this information available to the operator.



Software tools for capturing, storing and preparing process-related data.

Innovative solutions in the field of sustainable process development and management as well as in quality management

The modular design of the system allows flexible processing of individual customer requests for setting a wide variety of layer functions on a wide variety of substrates. Continuous process-data acquisition provides transparent process and layer development with a range of evaluation and visual representation options. In addition, digital interfaces enable collaboration of manufacturer-independent measurement and production systems and thus automated electrolyte control. This means that the processes can be run with long-term stability and in a resource-conserving manner.

Outlook

The work described forms the basis for the development of a digital image of electroplating process chains. This means that within a cyber-physical system, i.e. the linking of the physical production process with the data from the digital image, innovative approaches to finding solutions can be provided, for example for real-time control, for predictive maintenance or for supporting decisions in sustainable process development, as well as for the training of employees.

2

Rowena Duckstein and Holger Gerdes discuss the real-time data on the dashboard which enables continuous quality control of the processes.

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Optimizing electroplating processes by understanding the potential for hydrogen hazard

The basis for the safe application of high-performance steels is reliable corrosion protection that is stable over the long term. This can be ensured by means of galvanic zinc-based coatings. However, during the coating process, hydrogen enters the material, increasing the risk of fractures due to hydrogen-induced stress corrosion cracking (HI-SSC) as the strength of the steel increases. In the IGF (cooperative industrial research) project "HAEgaS", systematic investigations were carried out to determine the critical conditions of the operating materials and coating parameters.

Current handling of production-related hydrogen hazard potential

By means of post-production heat treatment, the introduced hydrogen can be stimulated to effuse so that it does not cause any damage to the material. However, treatment parameters are set on a purely phenomenological basis due to lack of knowledge. The effectiveness of process control and heat treatment could alternatively be verified by the stress tests described in DIN 50969-2. However, continuous in-process inspection is time-consuming and costly, because fractures due to HI-SCC can still occur even after a stressing time of 200 hours.

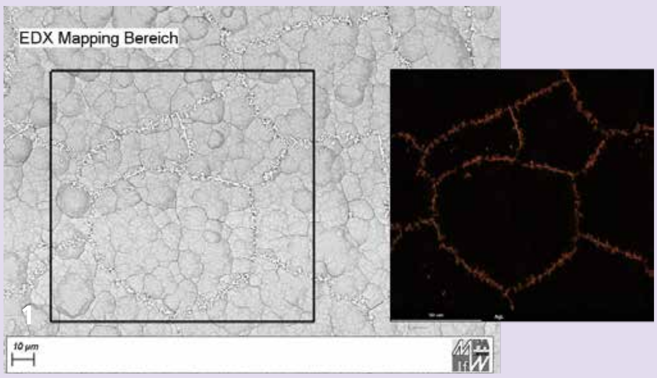
Systematic analysis of process-related influences on hydrogen uptake

Within the "HAEgaS" project, the galvanic zinc-nickel coating of steel was investigated at the Fraunhofer IST using statistical design of experiments methods. With this methodology, hydrogen absorption and effusion behavior of the coated steels as well as composition, coating rate, chemical consumption and other important parameters of coating and process could be described and optimized as a function of a total of eight factors. In addition to temperature, current density and barrel rotation speed, the bath composition was investigated in detail, i. e. the concentrations of Ni, Zn, OH, complexing and brightener additives.

Determining critical conditions for operating materials and coating parameters

The statistical evaluation of the results with regard to the significance and weighting of the influencing factors makes it possible to quantify the individual variables influencing the process. In addition, the type of operating materials used allows conclusions to be drawn concerning the resulting coating properties in general and the hydrogen absorption and effusion behavior in particular. This in turn permits the development of feasible intervention limits for the processes to counteract increased production-related hydrogen absorption.

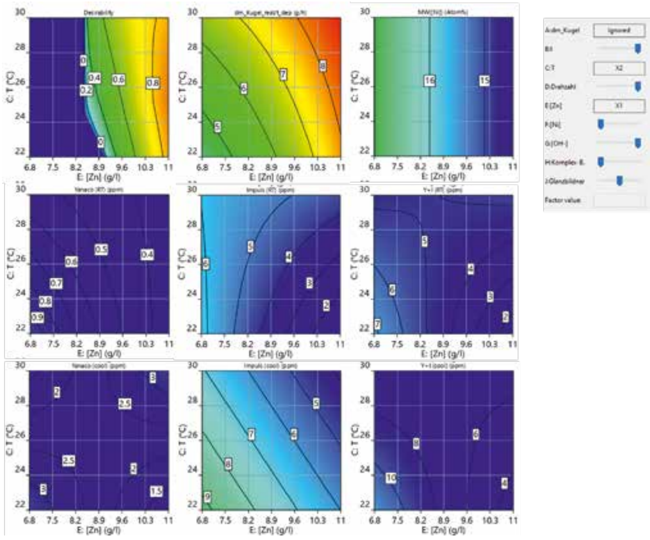
Visual representation of hydrogen effusion pathways



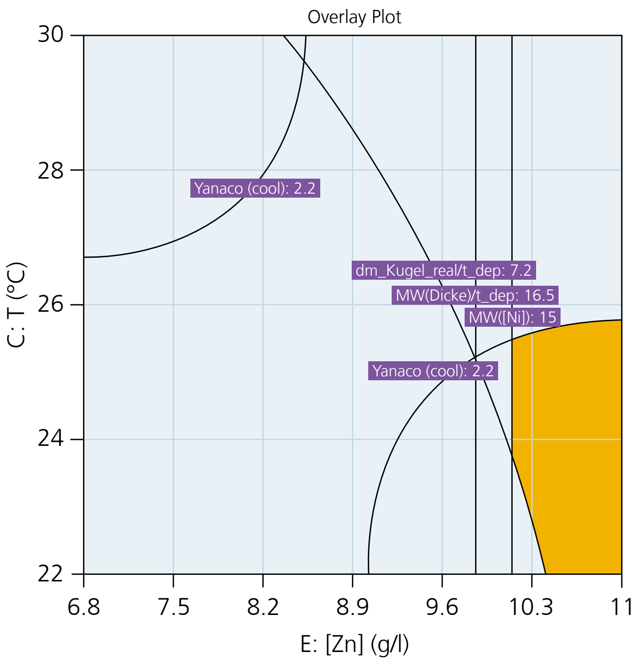
REM image of an alkaline zinc-nickel coating (left), EDX mapping of the region marked in the REM image showing the effusion pathway of hydrogen (right). © MPA/IfW Darmstadt

Outlook

Taking the data generated in this project and the resultant findings as a basis, further projects are planned to develop the continuous representation of the process chain by means of a digital twin. This will include a combination of simulation models and data-based maps for the electroplating mechanisms acting on different time and length scales. This will consequently enable a targeted post-treatment to be derived to minimize H-SpRK and will also further optimize costs and energy expenditure.



Color coding of the value range for selected response variables according to the parameter specifications of the overlay plot.



Overlay plot of all model descriptions of the influencing factors studied. The area marked in yellow corresponds to the optimal parameter space to achieve the target values.

The project

The IGF project "HAEgaS" (19759 N) of the Forschungsvereinigung Forschungsgesellschaft Stahlverformung e.V. was funded by the German Federal Ministry for Economic Affairs and Climate Action (BMWK) via the German Federation of Industrial Research Associations (AiF) as part of the program to promote cooperative industrial research (IGF) on the basis of a resolution by the German Bundestag. The research institution involved in addition to the Fraunhofer IST was the Technical University of Darmstadt, State Materials Testing Institute Darmstadt. The project monitoring committee comprised 18 members.

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1

Functionalization of active ingredients and excipients by means of plasma processes for the optimized production of individualized pharmaceutical products.

Medical and pharmaceutical systems

Optimal patient-centered and individualized care is an important goal in medical and pharmaceutical technology. In addition, digitalization poses further challenges for the industry.

In interdisciplinary teams, the Fraunhofer IST develops solutions for product and production systems in medical and pharmaceutical process engineering. Our focus in the range of individualized medicine production is on additive-manufacturing technologies and the modification of active constituents and excipients for improved processing and functionality as well as the interactions between medicines and production systems.

We thereby consider the specific regulatory, plant-specific and operational conditions. Our customers and partners are offered new integrable process systems and adapted surfaces: from adhesion control, through functionalization and encapsulation of medicinal substances, through to new packaging concepts.

Furthermore, as a member of the High-Performance Center Medical and Pharmaceutical Engineering we, together with the Fraunhofer research institutes ITEM and IMTE, are pursuing the goal to create a platform for research and the transfer of innovations into patient care. The focus here is on personalized implants and respiratory systems as well as individualized pharmaceutical production.

2

Through adaptation of the spatial conditions and the integration of two wet cells, infection prevention in a two-bed room can be significantly improved.

Outlook – This is what awaits you!

On the premises of the Städtisches Klinikum Braunschweig, we are building a new application-oriented research and study laboratory in the form of a patient room of the future. This is being carried out in collaboration with the TU Braunschweig and the Städtisches Klinikum.

The initial focus lies thereby on a patient room for standard care. Together with industry partners, we want to drive forward current issues of infection prevention and digitalization in innovative projects. Further training courses for care staff and doctors are also planned in the future.

> **"Infection prevention remains a topical issue, even beyond the coronavirus. One focus of our work is therefore the automated cleaning of surfaces with functional properties."**
>
> **Dr. Kristina Lachmann / Group Manager**

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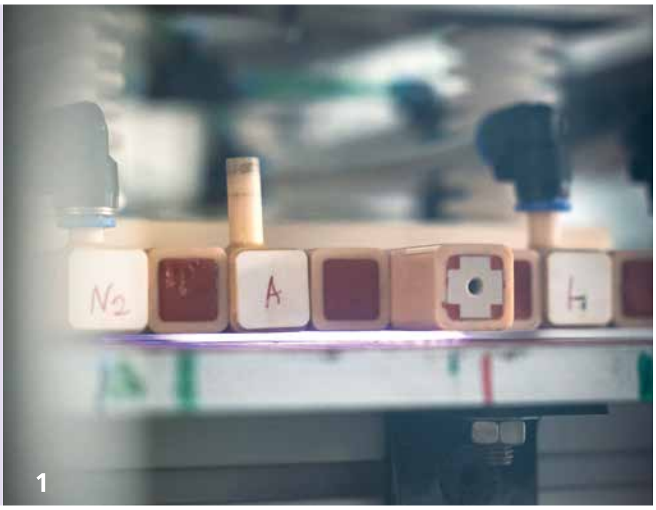
Improving inhalation therapy by means of anti-adhesive surfaces

Particularly in the case of chronic lung diseases such as asthma, many people use inhalers in order to ensure that their airways remain unobstructed. However, a proportion of the particles to be inhaled often remains adhered to the inhaler itself. By means of an optimized ultrathin coating of the plastic surfaces in inhalers, the Fraunhofer IST has been able to demonstrate that the surface properties of these medical devices can be specifically adjusted. With the aid of the coating, it was possible to significantly reduce surface adhesion for very fine drug particles. As a result, the application safety of inhalers and the effective utilization of drug doses can be substantially increased.



As a result of plasma coating, functional anti-adhesion layers are applied within a short time via a dry process control.

Small particles – large interactions: Loss of active pharmaceutical substances during application

For the administration of API into the lungs, they must be applied as mists or particle aerosols with a particle size of less than 5 µm in order to reach their target site deep in the respiratory tract. Due to their small size, however, the API particles have a strong tendency to adhere, especially to the surfaces of the inhalers used for their application. This can lead to reduced or fluctuating dose delivery of the API to the patients and, consequently, a jeopardization of therapy safety.

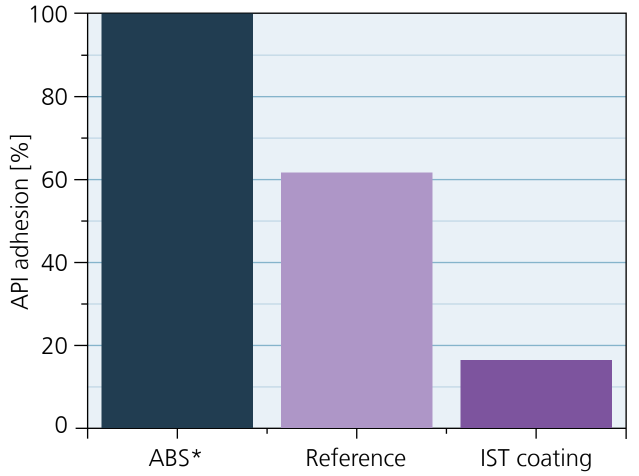
Customized ultrathin coatings significantly inhibit the adhesion of API

Through the functional coating of the inner plastic surfaces of inhalers, their physicochemical properties can be controlled in such a way that the interaction potentials can be aligned to the properties of the API particles, thereby enabling the knowledge-based reduction of the adhesion tendency. The chemical precursors employed for the coating as well as the parameters of the coating process thereby serve the control of the coating properties.

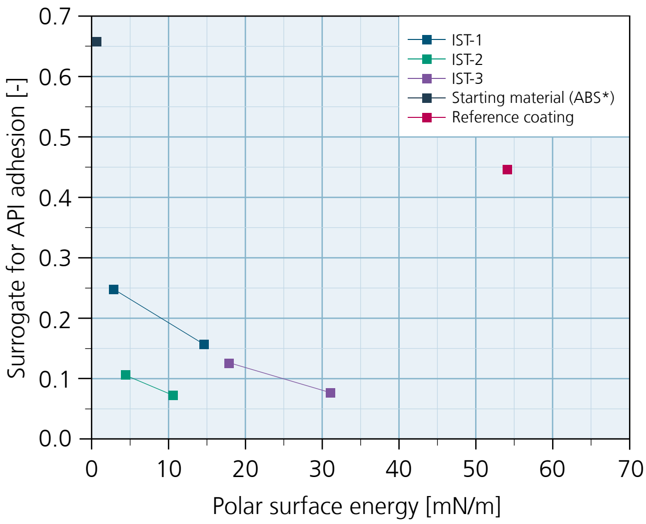
Reduce losses – Improve therapy – Protect the environment

By specifically reducing the deposition of API particles, the dosage of the medication delivered to the patient becomes significantly more precise and reproducible, thereby increasing therapy safety. Furthermore, quantities of API that would otherwise remain in the inhaler can be saved. The cleaning effort for the inhaler is reduced, as is the environmental impact caused by the unused quantities of API removed from the inhaler.

Inhalers are medical devices that disperse powdered drugs during application in such a way that the fine API particles (< 5 µm) can penetrate the lungs. The danger: Such small particles have a strong tendency to adhere to surfaces, in this case in particular to the plastic parts of the inhalers.



The coating developed at the Fraunhofer IST reduces the relative adhesion of the API by approx. 85% compared with the starting material.



Through the analysis of the coatings, a preferred property range for the prevention of adhesion of the API can be derived.

**acrylonitrile-butadiene-styrene copolymers*

Part of a whole – Pharma-related research at the Fraunhofer IST

Research into the adaptation of the interaction between medication forms and surfaces is part of the still-young field of application for medical and pharmaceutical technology at the Fraunhofer IST. It is located in the High-Performance Center Medical and Pharmaceutical Engineering, in which the IST is active in collaboration with the Fraunhofer Institute for Toxicology and Experimental Medicine ITEM and the Fraunhofer Research Institution for Individualized and Cell-Based Medical Engineering IMTE. Further fields of application of the Fraunhofer IST are here the coating and functionalization of pharmaceutical particle systems, the development of adhesion- and wear-resistant coatings for process equipment and tools, functional coatings of primary packaging materials, and the further development of vaccines.

Outlook

The solution approach for adhesion control in inhalers can be transferred almost generically not only to other fields of application within the pharmaceutical industry but also outside of it, in order to control the deposition of ultra-fine particles, customized to their properties. In combination with the functional coating of API particles, it is possible not only to improve application safety but also, for example, to prolong the release profile of medications and, consequently, their realease profile over time, or to "program" a release in response to specific stimuli.

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Atmospheric pressure plasma processes

"Our expertise in plasma-source development, in combination with adapted coating technologies and flexible production processes – with a focus on sustainably functional surfaces – provides an important building block for the circular economy."

Dr. Kristina Lachmann / Group Manager

In order to effectively modify, functionalize or purify surfaces, atmospheric-pressure plasma processes are successfully applied in many sectors of industry. In addition to medical technology, examples include microsystems technology, the packaging and capital goods industries, the electronics industry, the automotive sector and the aerospace industry.

At the Fraunhofer IST, we develop application-specific plasma sources and coating systems which cover a wide range of coating functions and which can therefore not only be deployed in a targeted manner for the cleaning, functionalization or coating of a wide variety of materials and geometries but can also be integrated into existing process chains. In addition to conventional organosilicon layer formers, bio-based systems are also increasingly being used for this purpose.

Industrially suitable, implementable processes

Coating procedures that dispense with wet-chemical processes or downstream drying processes possess great potential for industrial applications. In order to replace established processes, alternative processes must have attained a sufficient degree of maturity, offer added value and, ideally, conserve resources. Atmospheric-pressure plasma processes offer numerous advantages here.

1

Plasma discharge in a roll-to-roll system for surface functionalization.

2

Implementation of near-industrial processes through roll-to-roll coating processes: Aldyne™ system for continuous functionalization, crosslinking and coating.

3

By means of atmospheric-pressure plasma processes, a wide range of different materials can be coated.

Sustainable bio-based coating systems

The functionality of surfaces depends significantly on the chemical composition of the surface. This is indeed the case in established atmospheric-pressure plasma processes. If layer formers, so-called precursors, are then added to the plasma, thin layers can be deposited by means of APPP. Increasingly, bio-based systems are hereby being used which, due to their chemical properties, have a specific functionality, e.g. hydrophobic, dirt-repellent or antimicrobial properties. In many applications, examples from nature serve as models.

Adapted plasma processes for specific requirements

In contrast to highly volatile, conventional organosilicon layer formers, it is necessary to adapt the coating systems to such higher-molecular-weight starting materials. This is where our expertise really comes into play. Not only large-volume roll-to-roll processes requiring linear coating systems are taken into consideration, but also the robot-guided deployment of plasma jets or spatially-resolved coating by means of plasma printing. Adapted plasma processes and coating systems then provide the basis for the deposition of sustainable coating systems.

Outlook – This is what awaits you!

Through the expansion of plasma polymerization to high-molecular, complex layer formers, it will prospectively also be possible to address applications that currently still require a combination of plasma and wet-chemical processes.

There exists therefore considerable potential for making the coating process even more sustainable – in particular if precursors from waste streams are utilized. Furthermore, we are also addressing triggerable adhesive systems in order to further optimize material cycles and to be able to reuse or recycle materials despite their being coated.

4

Wood veneer with anti-soiling coating.

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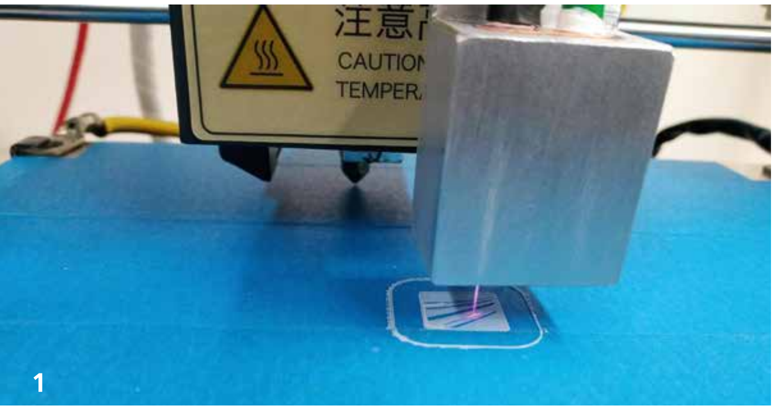
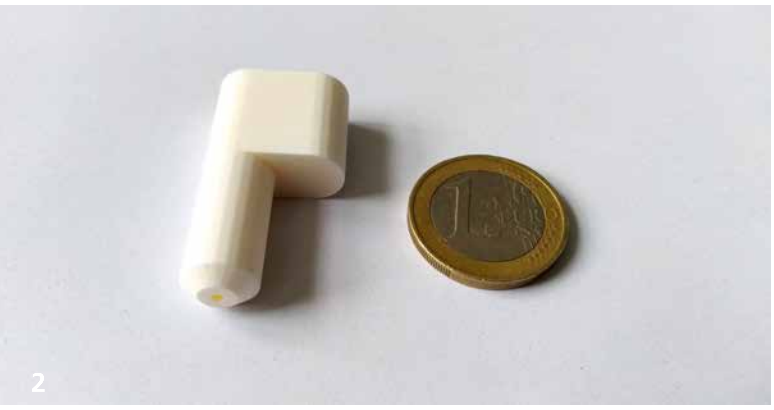
Atmospheric pressure plasma sources for additive manufacturing

Adhesion plays a essential role in additive-manufacturing processes such as fused deposition modeling (FDM). It influences the stability of the printed components, the print quality and the adhesive forces between different surfaces. Through the integration of atmospheric-pressure plasma technology into additive manufacturing, it is possible to influence the interfacial chemistry and, consequently, the adhesion on the treated surfaces. As a result, subsequent processes, such as painting or bonding, can be optimized and different materials, e.g. composites and metals, can be better combined with one another. Furthermore, it also opens up new areas of application that require specific surface chemistry, for example in the field of medical implants. Applications range from the automotive industry, through the aerospace sector, and on to medical technology.



1

Punctiform atmospheric-pressure plasma source integrated into FDM 3D printer.



2

Plasma nozzle made from Al_2O_3 ceramic with size comparison.

Integration of plasma sources in 3D printing

In order to be able to use atmospheric-pressure plasma sources in extrusion-based 3D printing, the sources must have a high local resolution and be relatively small and light to enable direct integration into the extruder. In addition, the control system must be adapted accordingly to ensure that simultaneous optimal and safe operation of the extruder and plasma is possible. For this, fast switching times and good electrical shielding are necessary in order to prevent interference with the printer's electronics and to ensure long-term stable and reliable operation.

Miniaturization and integration of a plasma source

At the Fraunhofer IST, two approaches are being pursued for the application of atmospheric-pressure plasma sources in additive manufacturing in order to develop customer-specific process-engineering solutions. The first approach uses miniaturized conventional plasma nozzles. A punctiform nozzle of this kind allows the structured sequential treatment of printed polymer layers in high resolution. In the second approach, annular plasma sources are being investigated, which are mounted around the extrusion nozzle and thereby allow direct treatment of the surfaces in parallel with the printing process.

Annular plasma source.

Alteration of the wetting behavior of a PE surface as a result of treatment with the plasma nozzle.

Optimum adhesion through integrated plasma sources

Through the developed patented prototypes, it is possible to extend extrusion-based 3D printing processes by a parallel or sequential plasma treatment. With the aid of plasma treatment, various functions can be achieved at the interface. The possibilities range from etching and cleaning, through chemical modifications and functional coatings, and on to crosslinking of surfaces or polymers. As a result, the application areas of additive-manufacturing processes can be significantly expanded – including for sustainable materials – enabling existing products to be improved and new products to be developed.

Outlook

Future work will address the investigation of different application scenarios of plasma sources in 3D printing. The focus will hereby be on improved mechanical properties of filament-based 3D printing and multi-material composites. The utilization as a tool for "smart repair" applications will also be researched. Furthermore, the plasma sources can be applied in many other forms of robot-guided treatment of material surfaces.

The project

The development and investigation of the plasma sources was financially supported by the Fraunhofer-Gesellschaft in the InnoPush project "Marktflexibilität und Resilienzsteigerung durch Anlagenplattformen robotergeführter Drucktechnologien" (Market flexibility and resilience enhancement through system platforms of robot-guided printing technologies) (MaraPrint).

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Application Center at the HAWK Göttingen

"Cold" plasma technology has enormous potential when it comes to the resource-conserving creation of recyclable and future-oriented materials or products.

At the Application Center, we conduct and develop an extensive range of "cold" plasma processes on the basis of diversified technologies with regard to plasma generation, the handling of the material to be treated, and the desired objective.

With certain plasma discharges, it is possible, for example, to modify raw materials whilst simultaneously maintaining their recyclability, and to make natural materials usable in the sense of a bioeconomic orientation. One current example is the plasma coating of paper with biodegradable protective films. Paper products can thereby be impregnated and strengthened against damage by water, light, chemicals or heat. They can then be used instead of petrochemical products as packaging materials or in furniture and exterior construction.

A further, genuine plasma process at the Application Center is the so-called gas-phase deposition for the coating of particle surfaces. In this process, doping or coating of microparticles takes place during the continuous circulation and separation of a powder. The objective is to apply this technique in order to produce novel battery materials or lightweight construction powders for 3D printing.

Furthermore, we have been working for several years on the expansion of the plant technology for "cold-plasma spraying". The main feature of this technology is a low-temperature plasma jet, generated from air or nitrogen, into which ultra-fine metal particles are injected. This type of coating material is melted very efficiently in the plasma jet. In this way, the plasma power to be injected and/or the energy consumption can be minimized, as can the thermal loading of objects.

The process makes it possible to produce both narrow conductor-path structures and coatings which cover the entire surface. Thanks to a special powder-conveying technique, not only metals classically used in electrical engineering but also aluminum, constantan, stainless steel, titanium and metal combinations can be created in the form of homogeneous or graded layer systems.

Coating deposition by cold plasma spraying at the Fraunhofer IST.

On the basis of a profound understanding of processes in combination with creativity and excellent networking with material suppliers, mechanical-engineering specialists and research partners from diverse disciplines, at the Application Center we are able to offer R&D services and technology transfer in the fields of plant engineering, production and quality assurance.

Currently, we are working on cold-plasma coating solutions for products with integrated current conduction and sensors, for example thin-film thermocouples as used in safety technology or for the temperature-resistance testing of laser optics. Furthermore, we also produce electrodes for energy storage on sensitive films, and corrosion-protection coatings for three-dimensional assemblies.

"Our goal is the transfer of eco-efficient plasma coating processes. These are ingenious, as they can be used to make traditional natural materials robust and re-utilizable as well as to equip high-tech assemblies on-demand electrically and with sensors."

Nils Mainusch M.Sc. / Scientific Assistant

Kontakt

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Cleaning of room air through plasma – PlasmaAirCleaner

Viruses spread particularly well in closed rooms via aerosols in the air. This means that the risk of infection increases when people are together in the same room. Rapid transmission of infectious diseases through aerosols in indoor air is a major problem, and the development of new and viable solutions for indoor-air purification is an important task, especially in the context of the current SARS-CoV-2 pandemic. The ”PlasmaAirCleaner”, or PAC for short, developed at the Fraunhofer IST in collaboration with HAWK, combines various approaches to cleaning indoor air in a low-maintenance, efficient and reliable manner. In this process, plasma, UV-C radiation and photocatalysis interact in the air-purification process to produce an optimum result.

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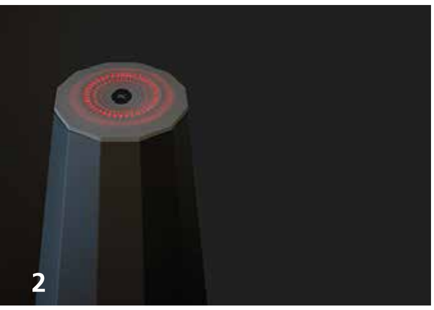
The plasma air purifier in activated carbon mode in a waiting room.



2

Red light signals the ozone mode has been activated.

Challenge

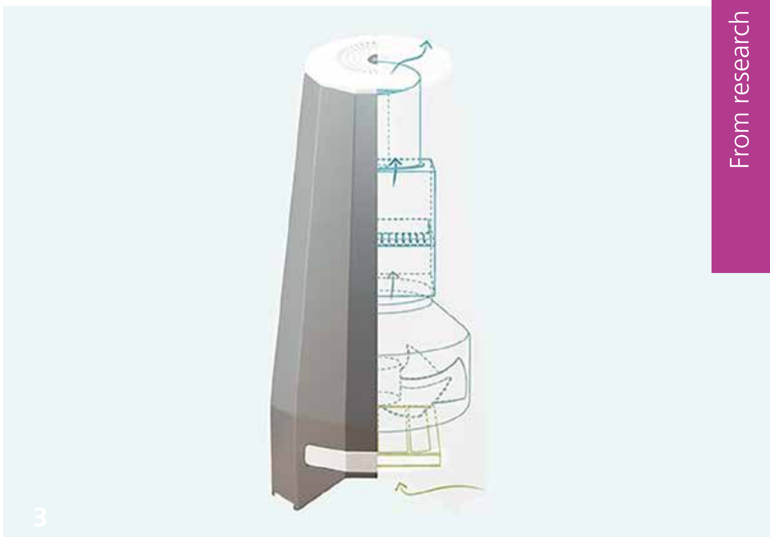
The aim of the ”PERFEKT” project was to develop a plasma air purifier that fulfills the function of air purification and, at the same time, enables surface disinfection, for example in hospital rooms. A special ”bypass function” is intended to allow the room air flowing through the system to be directed either through the activated carbon or to bypass it. In ”activated carbon mode”, all guideline values for gas concentrations in the room must be observed. In ”bypass ozone mode”, on the other hand, the surfaces in the room are disinfected by outflowing ozone. The functionality is validated by measurements and flow simulations.

Operating principles of the plasma air purifier

After the air flows into the unit in a pre-filter stage, it passes through the axial fan and a cascaded, full-surface volume-plasma source consisting of 28 paired Al_2O_3 ceramic electrodes. These electrodes have been equipped with a photocatalytically active titanium dioxide coating, which ensures that the electrodes remain clean and sterile for optimal plasma discharge. The radiation required is generated by a UV cold cathode lamp with 254 nm wavelength and emitted by the plasma discharge itself.

Combined mechanisms of action: Air purification and surface disinfection in one device

Ozone-depleting UV-C radiation enables the amount of activated carbon in the unit to be reduced so that volume flow increases due to reduced flow resistance. The plasma air purifier thus enables extremely efficient air purification in operation (from 50 watts). In addition, the plasma air purifier can run very quietly. As soon as the bypass is opened, ozone flows out of the unit and enables disinfection of germ contamination on the surfaces in the room. Changing modes is easily performed via the app.



Technical components in the plasma air purifier.

Outlook

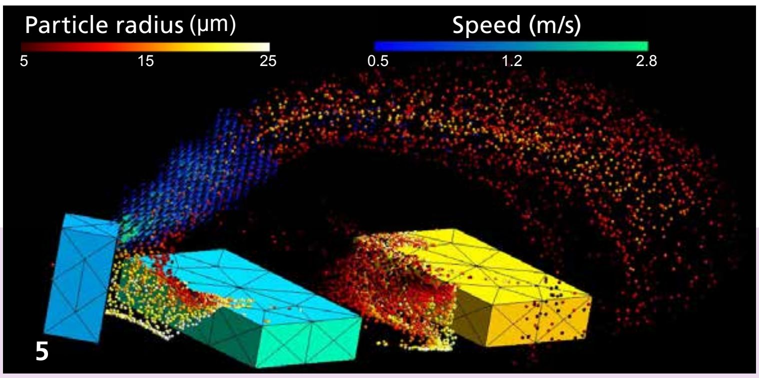
The effectiveness and safety of the device have been investigated in extensive tests at the Fraunhofer Institute for Wood Research, Wilhelm-Klauditz-Institut WKI. Attention was paid both to compliance with all limit values in activated carbon mode and to reliable surface disinfection in ozone mode. The device must operate efficiently and also comply with the limit value for noise pollution. The clean air delivery rate – CADR for short – is determined as a meaningful value for competition purposes. Simulations determine the arrangement required for optimal disinfection effect in a given room geometry.

The plasma air purifier in a waiting room.

The project

This project was funded under grant number "Anti-Corona 840255" within the framework of the Fraunhofer Internal Programs.

Simulation of particle flow in a hospital room with two beds and a PlasmaAirCleaner.



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Film and surface analysis for industry and research

The availability of analysis and testing methods is a decisive factor for success in the development of new materials and manufacturing processes, in quality assurance, in production, and in the clarification of damage.

The Fraunhofer IST is a department offering services across many sectors. We offer our customers from industry and research a wide range of methodologies in the fields of coating and surface analysis and testing technology. We also carry out complex material analyses.

With more than 4,000 investigation contracts over twenty years for more than 400 customers, the Fraunhofer IST has built up an extensive range of experience in dealing with issues of relevance to industry.

We offer our customers and partners:

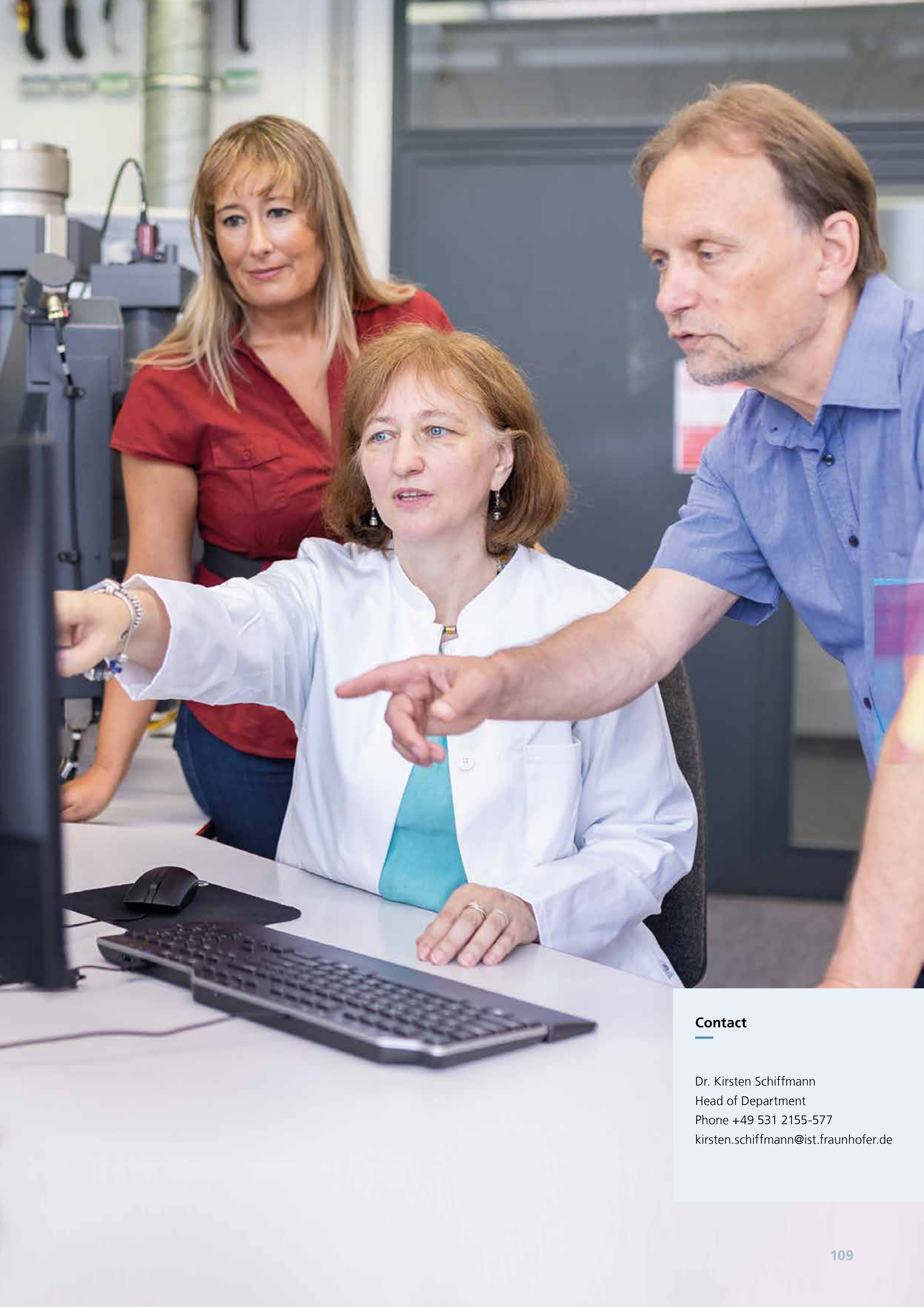
- Support in material and process development
- Quality assurance in production
- Defect analysis
- Development of customer-specific test engineering
- Analysis of surfaces, films and solid materials
- Advice on optimal analysis methods
- A combination of a wide range of state-of-the-art methods

A team of experienced employees processes your orders, possibly within 24 hours if required. This is achieved using a pool of large-scale analytical instruments for chemical, structural and morphological analysis and more than 40 other test instruments for characterizing the application properties of materials such as roughness, friction, wear, hardness, adhesion and coating thickness as well as electrical, optical, magnetic and photocatalytic properties, corrosion and surface energy.

"For me, our customers are at the heart of what we do. Our team provides advice and reliably delivers meaningful material analyses. With 30 years of professional experience, we know plenty of tricks of the trade to get the most out of our equipment and methods for our customers."

Dr. Kirsten Ingolf Schiffmann / Head of Department

Analytical laboratory at the Fraunhofer IST.



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1

Energy dispersive and wavelength dispersive X-ray spectroscopy for chemical element analysis with high resolution and sensitivity.

Chemical and structural analysis

The chemical composition and structure of a coating or surface provides valuable information with regard to its properties and thus for the targeted development and optimization of products with the associated process chains. These analytical methods also play an important role in detecting the causes of damage and as part of the quality assurance process.

The Fraunhofer IST offers the possibility of determining the chemical elemental composition of films and surfaces with high lateral and high vertical resolution, high detection limit and high surface sensitivity.

With the aid of X-ray diffraction, the crystal structure, grain sizes, textures and residual stresses can be characterized. With our position-sensitive semiconductor detector, standard measurements can be accelerated by a factor of 10 to 50.

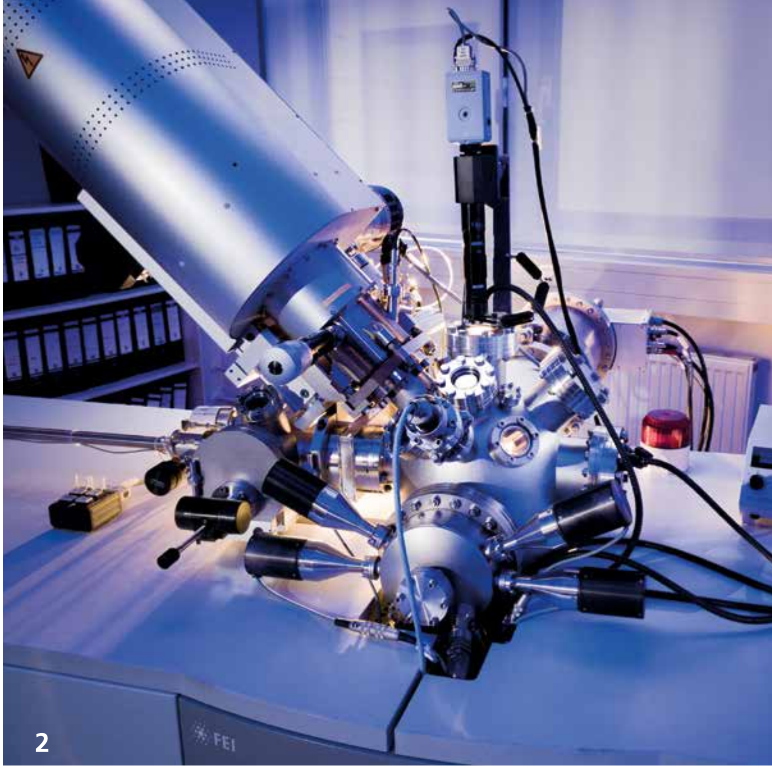
For energy dispersive and wavelength dispersive X-ray spectroscopy (EDX/WDX) the Fraunhofer IST has two scanning electron microscopes with EDX detectors, as well as an electron beam microprobe (EPMA) with 5 WDX detectors. This enables high-resolution imaging of surfaces (< 1 µm) and chemical point analysis with micrometer resolution.

> **"I'm always happy when we can support technical developments with our measurement and testing technology."**
> **Dipl.-Ing. Reinhold Bethke / Test Engineer**

X-ray photoelectron spectroscopy at the Fraunhofer IST for chemical element analysis of surfaces and bonding states.

4

Chemical depth profile analysis using secondary ion mass spectroscopy at the Fraunhofer IST: Cameca Quadrupole SIMS.

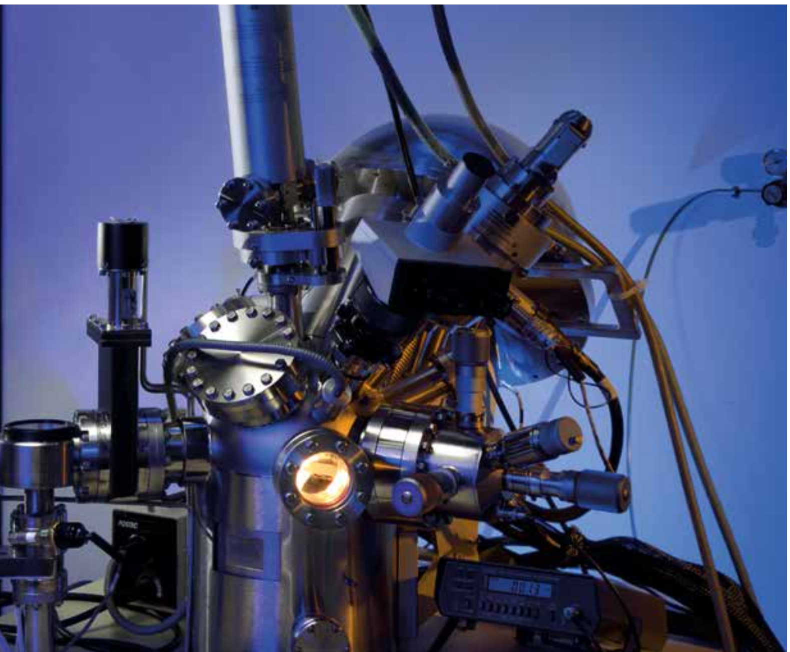


XPS analysis (X-ray photoelectron spectroscopy) provides information on chemical composition and bonding states near the surface and, thanks to the integrated ion gun, also allows depth profiles. It is used, for example, in the analysis of surface impurities, inspection of cleaning processes, chemical analysis of ultrathin layers and analysis of surface treatments.

In secondary ion mass spectrometry (SIMS), the sample surface is ablated layer by layer with an ion beam. A mass spectrometer allows the chemical characterization of the ablated material with high vertical resolutions (~1 nm), resulting in a depth profile of the chemical composition.

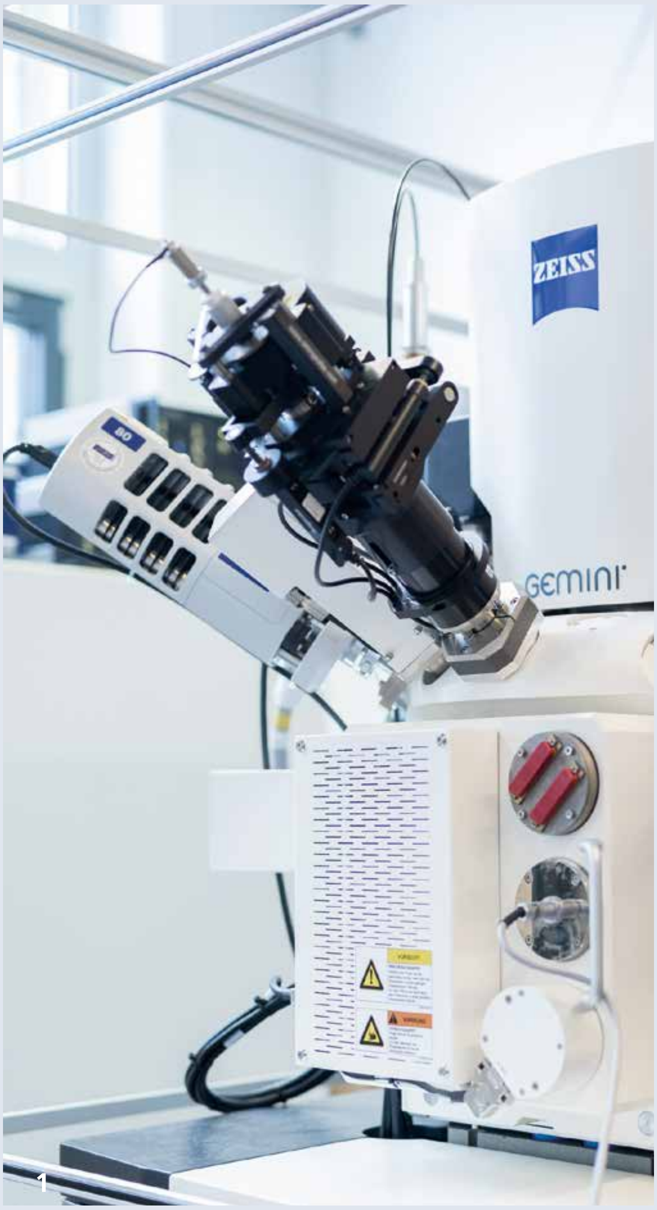
Further procedures for chemical and structural analysis which we offer at Fraunhofer IST are glow discharge spectroscopy (glow discharge optical emission spectroscopy, GDOES) for determining chemical composition as a function of depth for film thicknesses to a few hundred micrometers and X-ray reflectometry (XRR) to determine thickness, density and interfacial roughness of ultra-thin layer systems.

X-Ray diffractometer X'Pert MRD Pro from Panalytical for crystal structure analysis and for studying grain sizes, textures and residual stresses with primary X-Rax mirror Eulerian cradle, proportional- and position sensitive detector.



X-ray diffractometer X'Pert MRD Pro from Panalytical for XRR measurement on ultra-thin film systems to determine thickness, density and roughness.

Microscopy and surface measurement



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The Cross-Beam 340 (FIB) for the production of local precision cross-sections allows a view below the surface.

Microscopic examinations are often indispensable for quality assurance, damage analysis and product optimization.

At the Fraunhofer IST, a multitude of microscopy methods are available. Depending on requirements we can use the simple stereo magnifier but also diverse optical microscopes with high-quality digital image acquisition and confocal laser microscopy which allows optical 3D imaging and measurement. The lateral resolution of our laser microscopes is around 1 µm, the vertical resolution is a few nanometers. Within a few minutes, the method provides quantitative information on surface topography, roughness, step heights, pitch angles or particle sizes, among other things.

Also available is the tactile profilometry method for 2D and 3D imaging of surfaces, scanning electron microscopy with up to 100,000x magnification and, finally, atomic force microscopy (AFM), with which the highest lateral and vertical resolutions (< 1 nm) can be achieved. AFM is particularly suitable for characterizing extremely smooth surfaces.

The combination of scanning electron microscope (SEM) and focused ion beam (FIB) makes it possible to specifically cut into material on the smallest scale (nanometer range) and directly image the material structure below the surface. This allows, for example, the precise localization and chemical analysis (EDX) of local faults. This works for almost any material in a solid state, whether soft or extra hard.

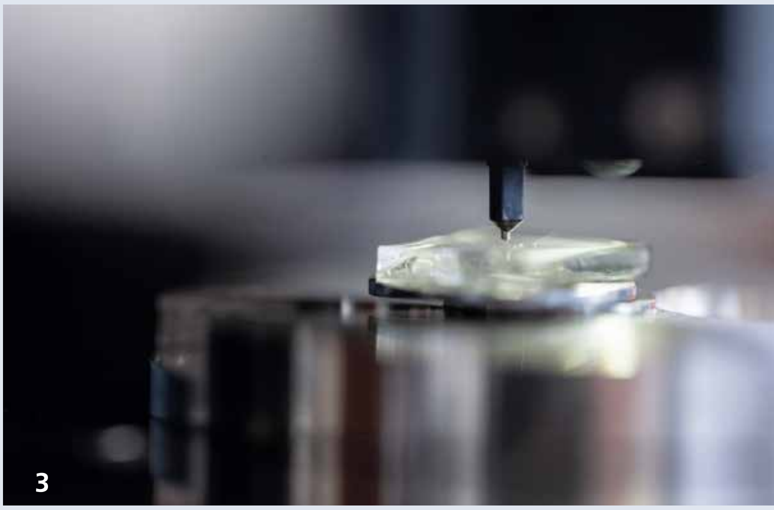
2

Confocal laser microscope: analysis of battery particles.

Mechanical characterization

Mechanical properties – in combination with the thickness of a coating – influence in many cases the functionality, quality and service life of the product, making them important parameters for developers and producers.

We offer a range of measurement and testing methods with which the mechanical properties of films and surfaces can be determined. These include micro- and nanoindentation, which can be used to determine the hardness and modulus of elasticity of coatings in the micrometer and sub-micrometer range. Mechanical residual stresses can be determined for crystalline materials by means of X-ray diffraction. A further important mechanical parameter of films is also the strength of the adhesion of the films to the substrate. This can be determined for hard materials by means of scratch or Rockwell tests. Tensile and bending tests can simulate specific strain loads on coated components. Another important parameter is layer thickness, which we determine using methods appropriate to the material, thickness, substrate and geometry.



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Micro- and nanoindentation for determination of hardness and modulus of elasticity of thin films.

Friction and wear measurement

The reliable measurement of friction and wear is an important element in the optimization of products and production processes.

At the Fraunhofer IST, a range of friction and abrasion test rigs are available with which various mechanical contact situations can be simulated: dry running, running with lubricants, running at high temperatures or high loads, abrasive conditions, fatigue wear or testing on the microscale. Many of these tests can be performed in accordance with ISO, DIN or ASTM standards.

4

Ball-cratering device with three balls to determine precisely the wear resistance of coatings and surfaces.

5

Determination of fatigue strength of coatings and materials under continuous load: Impact test during inspection of a coating on a piston ring.

Optical characterization and measurement technology

Characterizing components and products in terms of their optical properties is not the only use for optical metrology: Non-contact technologies are also being used increasingly in manufacturing and for process optimization.

Layers and surfaces can be characterized at the Fraunhofer IST with the aid of various optical methods. For substrates or individual layers as well as layer stacks, spectral properties such as transmission, reflection and absorption are determined, as are the refractive indices and layer thicknesses. In addition to measurements in accordance with standards or adapted to customer requirements, we also offer evaluation and interpretation of the measurement data.

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Ellipsometry for determination of thicknesses and dispersions of layers using Sentech SE 850 (SENresearch).

In addition, we use optical metrology to optimize our processes and equipment. To this end, we link tailor-made simulations and virtual coating runs with our process control and quality assurance optical measurement technology, e. g. in-situ control with the MOCCA+® monitoring system, an ex-situ mapping system for ellipsometry, photometry and Raman spectroscopy, or particle and defect analysis using FIB-REM and confocal microscopy.

Contact

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Determination of the self-cleaning effect of photocatalytically active materials and surfaces by means of the Dirt Test.

Photocatalytic measurement technology

Photocatalytically active materials and surfaces promise self-cleaning, air-purifying and antimicrobial properties. The measure of photocatalytic activity is the determination of effectiveness, i. e. how effectively and efficiently harmful or disturbing substances are broken down.

The Fraunhofer IST is a recognized testing laboratory of the German Federation for applied Photocatalysis (FAP) and a member of the DIN standard committee on photocatalysis. This function permits us to offer our customers a large number of specific and standard-compliant test methods for their product and technology development, covering different areas of application in compliance with the current DIN, CEN and ISO standards and to certify them according to FAP guidelines. One example is the assessment of the air-purification effect of photocatalytically active materials and surfaces for the decomposition of nitrogen oxide according to ISO 22197-1. This test standard describes a method in which the test specimen is permanently in contact with a model pollutant of polluted air under irradiation with UV light. The test specimen is placed in a flow-through photoreactor and activated by UV radiation, and the air purification capacity is determined based on the net amount of nitrogen oxides removed using a chemiluminescence detector.

Furthermore, a special demand of our customers exists in the determination of photocatalytic activity by degradation of methylene blue in accordance with DIN 52980/ISO 10678. This standard describes a test method for coatings on glass that use sun, rain, or a combination of sun and rain to improve the cleanliness of the glass.

Determination of the air-purification effect of photocatalytically active materials and surfaces - degradation of nitrogen oxide.

Contact

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How deeply does hydrogen penetrate surfaces?

Hydrogen (H_2) will increasingly be used as an energy source in the future. To enable this development, it must be manufactured, transported and stored. It is known that H_2 penetrates into the materials of pipes and tanks, which can lead to hydrogen embrittlement and even fracture in steels, for example. Possible solutions include the coating of surfaces or the selection of special steel grades that reduce or prevent the diffusion of hydrogen into the material. To verify this, the Fraunhofer IST has developed a method which can measure the penetration depth and penetration intensity of the hydrogen.

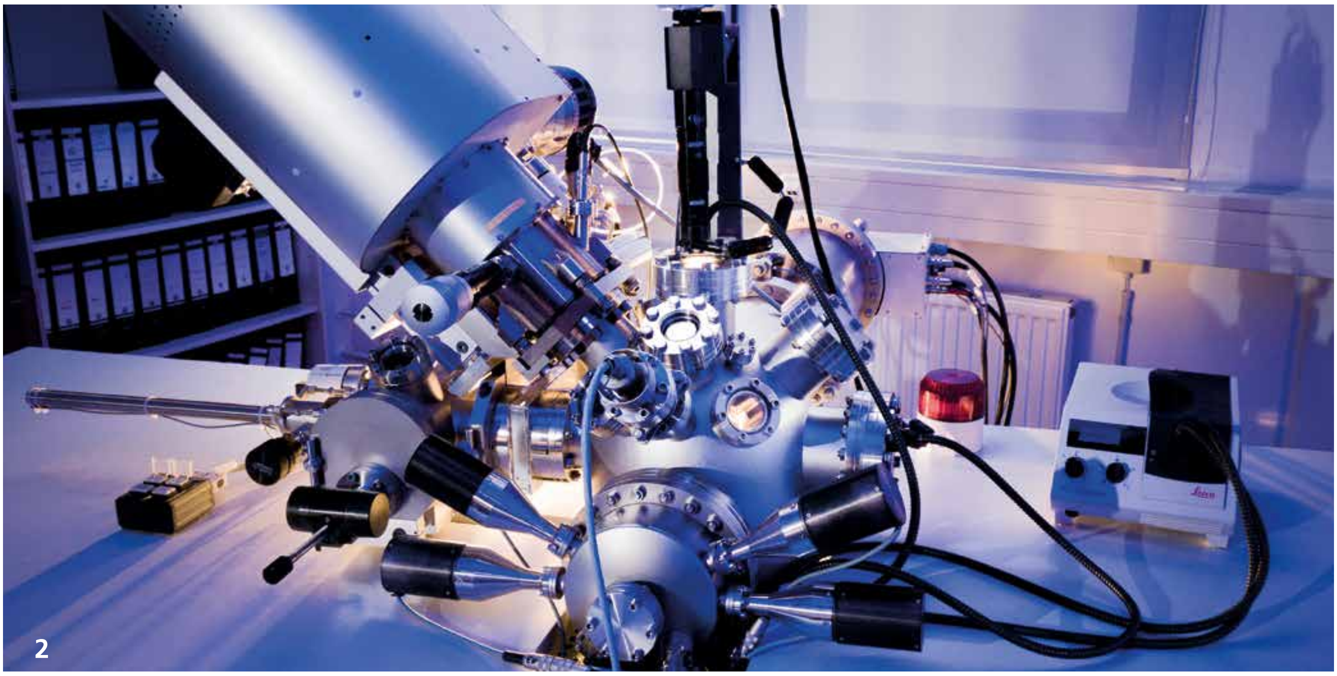
Deuterium reactor for controlled loading of samples with hydrogen or deuterium gas with pressures up to 200 bar and temperatures up to 300 °C.

SIMS depth profile analysis of the diffusion of hydrogen

Secondary ion mass spectroscopy (SIMS) is used to measure hydrogen in the surface of materials. The material is removed in a vacuum, layer by layer, with the aid of an ion beam and the number of escaping hydrogen ions is detected with high sensitivity by means of a mass spectrometer. In this way, a depth profile of the hydrogen distribution within the surface can be made. The problem here is that hydrogen is present on practically all surfaces, e. g. in the form of water or organic impurities.

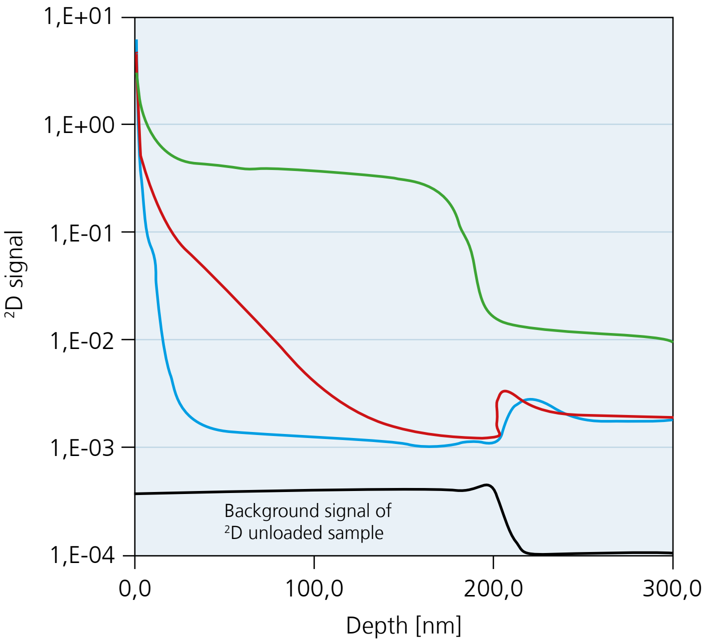
Deuterium instead of hydrogen: Sample loading in the high-pressure reactor

In order to charge surfaces with hydrogen in a controlled manner, a high-pressure reactor has now been set up at the Fraunhofer IST in which samples can be exposed to a hydrogen atmosphere at pressures of up to 200 bar and temperatures of up to 300 °C. The high pressure simulates the conditions in tanks or pipes, while the high temperatures accelerate the diffusion processes, reducing testing times from weeks to hours. However, in order to distinguish this hydrogen from the water that is ubiquitous in the world, and similar substances, heavy hydrogen, i. e. deuterium gas, is used instead of normal hydrogen. This is chemically identical to regular hydrogen, but can be clearly detected in the mass spectrometer thanks to its higher mass.



UHV system for secondary ion mass spectroscopy of hydrogen or deuterium in surfaces.

Relative deuterium distribution



Depth distribution of deuterium in three different hydrogen barrier layers.

Advantages of the method

In contrast to other methods in which the absorbed hydrogen is often only recorded as an integral value by means of expulsion, this method permits the measurement of depth distribution and thus the barrier effect of, for example, different surface treatments can be directly compared. The new reactor means that samples can be treated with hydrogen and analysis can be offered from a single source. Furthermore, the loaded samples can be used for microstructural analysis or mechanical testing in addition to examination by SIMS.

The new process will be utilized for projects within the Hydrogen Campus Salzgitter and will also be offered as a service to other companies or institutes.

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The Fraunhofer IST in networks

Headquarters of the Fraunhofer-Gesellschaft.

The Fraunhofer-Gesellschaft at a glance

The Fraunhofer-Gesellschaft based in Germany is the world's leading applied research organization. Prioritizing key future-relevant technologies and commercializing its findings in business and industry, it plays a major role in the innovation process. It is a trailblazer and trendsetter in innovative developments and research excellence. The Fraunhofer-Gesellschaft supports research and industry with inspiring ideas and sustainable scientific and technological solutions and is helping shape our society and our future.

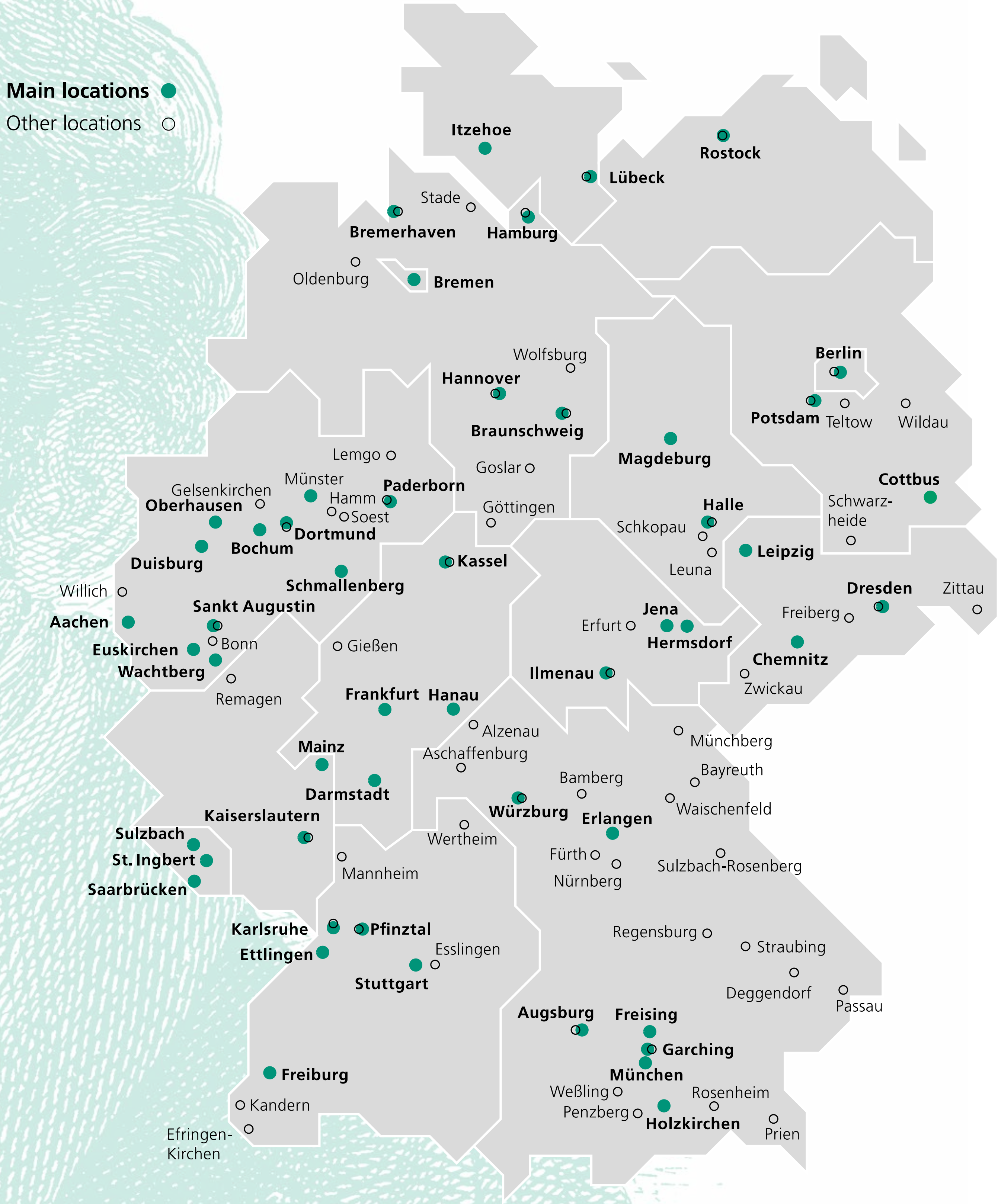
The Fraunhofer-Gesellschaft's interdisciplinary research teams turn original ideas into innovations together with contracting industry and public sector partners, coordinate and complete essential key research policy projects and strengthen the German and European economy with ethical value creation. International collaborative partnerships with outstanding research partners and businesses all over the world provide for direct dialogue with the most prominent scientific communities and most dominant economic regions.

Founded in 1949, the Fraunhofer-Gesellschaft currently operates 76 institutes and research units throughout Germany. Over 30,000 employees, predominantly scientists and engineers, work with an annual research budget of €2.9 billion. Fraunhofer generates €2.5 billion of this from contract research. Industry contracts and publicly funded research projects account for around two thirds of that. The federal and state governments contribute around another third as base funding, enabling institutes to develop solutions now to problems that will become crucial to industry and society in the near future.

The impact of applied research goes far beyond its direct benefits to clients: Fraunhofer institutes enhance businesses' performance, improve social acceptance of advanced technology and educate and train the urgently needed next generation of research scientists and engineers.

Highly motivated employees up on cutting-edge research constitute the most important success factor for us as a research organization. Fraunhofer consequently provides opportunities for independent, creative and goal-driven work and thus for professional and personal development, qualifying individuals for challenging positions at our institutes, at higher education institutions, in industry and in society. Practical training and early contacts with clients open outstanding opportunities for students to find jobs and experience growth in business and industry.

The prestigious nonprofit Fraunhofer-Gesellschaft's namesake is Munich scholar Joseph von Fraunhofer (1787–1826). He enjoyed equal success as a researcher, inventor and entrepreneur.


Main locations
Other locations
Itzehoe
Rostock
Lübeck
Stade
Bremerhaven
Hamburg
Oldenburg
Bremen
Wolfsburg
Hannover
Berlin
Braunschweig
Potsdam
Teltow
Wildau
Magdeburg
Lemgo
Goslar
Cottbus
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Gelsenkirchen
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Hamm
Oberhausen
Soest
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Synergies through networking – Networks within the Fraunhofer-Gesellschaft

Through its research and development activities, the Fraunhofer Institute for Surface Engineering and Thin Films IST is an integral element of various internal and external networks which are active with diverse focal points in the field of tension between industry, science and politics.

Within the Fraunhofer-Gesellschaft, the Institute has been contributing its expertise since this year (2021) as a new member of the Fraunhofer Group for Production, which consolidates the specialist knowledge of the Fraunhofer-Gesellschaft for the "production of the future". Furthermore, the Fraunhofer IST continues to participate as a guest member in the Fraunhofer Group for Light & Surfaces, as well as in various alliances, business sectors, research and competence fields, and networks. The objective is to offer customers and partners optimum solutions for their tasks, including cross-technological options. In addition, the Fraunhofer IST is actively involved in the Fraunhofer Centers for Energy Storage and Systems ZESS and for resource-efficient lightweight construction, flexible production and future interior in vehicle manufacturing in Wolfsburg. In the High-Performance Center Medical and Pharmaceutical Engineering, which was launched in March 2021, the institute is involved in the development of a platform for research and innovation transfer in patient care.

Fraunhofer Group
Production

Fraunhofer Group
Light & Surfaces

Research Field
Lightweight Design

Business Area
Adaptronics

Business Area
Cleaning

Fraunhofer Alliance
SysWasser

Fraunhofer Cluster of Excellence
Cognitive Internet Technologies

Performance Center

Medical and Pharmaceutical

Fraunhofer Alliance

Battery

Fraunhofer

POLO®

Fraunhofer Network

Sustainability

Fraunhofer Network

Hydrogen

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autoMOBILproduction

Fraunhofer Network

Simulation

Fraunhofer Competence Field

Additive Manufacturing

Fraunhofer Center

Wolfsburg

Fraunhofer Alliance

Space

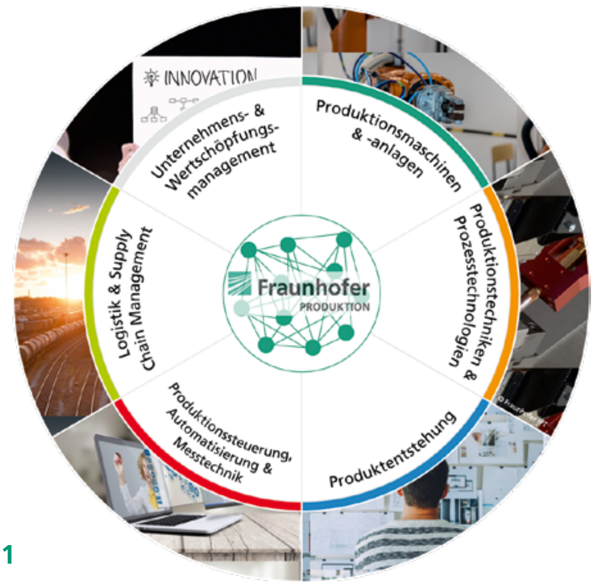
Fraunhofer Center for

Energy Storage and Systems

Fraunhofer Group for Production

The Fraunhofer IST is a member of the Fraunhofer Group for Production, an alliance of eleven Fraunhofer institutes as well as the Fraunhofer Austria Research GmbH. The objective is to jointly conduct production-related research and development. Based on the latest findings from production and engineering sciences as well as computer science, the Fraunhofer Group for Production offers a wide range of services for research and consulting.

The Group jointly creates innovative technology and system solutions in production engineering as well as logistics and, in close alliance with industry, combines current needs and challenges with the expertise of the cooperating community of values. The Fraunhofer Group has a substantial influence on the future in the field of production research and application-oriented development for a sustainable industrial society in Germany and Europe.



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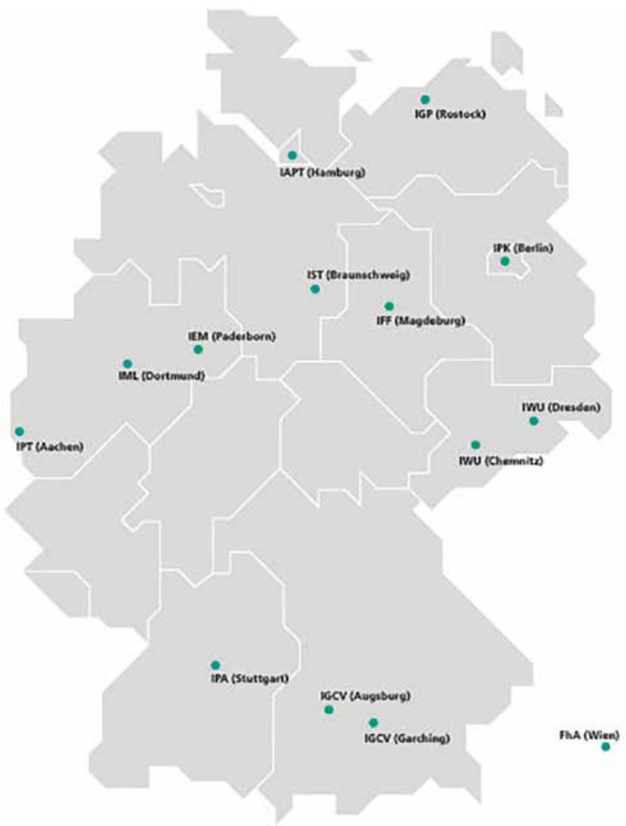
Member institutes



The institutes of the Fraunhofer Group for Production represent the leading network of application-oriented research in Germany.

Competency Portfolio

The Competency Portfolio of the Fraunhofer Group for Production covers all areas along the supply chain:

- **Production Machinery and Facilities**
  This includes factory planning as well as competences in the field of machine tools and robot systems through to maintenance.
- **Manufacturing Technologies and Process Technologies**
  All competencies in the area of manufacturing technology, in particular in classical and additive manufacturing, are consolidated. Process and surface technologies also form focal points in the Group for Production.
- **Product Development**
  The Group offers integrative solutions in the areas of systems-, software- and virtual-based engineering.
- **Production Control, Automation and Measurement Technology**
  Through smart sensor and plant networking, processes can be automated, whilst the utilization of AI and digital assistance systems enables them to be designed efficiently.

- **Business and Value-Added Management**
  The Group for Production provides support in the development of corporate strategies and business models. Extensive competencies in innovation and technology management assist organizations in their digital transformation.
- **Logistics and Supply Chain Management**
  The design of intelligent logistics and material-flow systems as well as a modern ICT software architecture combine to form the holistic approach of the Group for Production.

2

Smart Maintenance
Production plants are becoming increasingly complex and networked and require comprehensive IT know-how for operation and maintenance. Digitization is the criterion that distinguishes successful companies from less successful ones. The sustainable safeguarding of value creation through production and investment in new production sites with modern facilities in Europe will depend on how we succeed in setting up our production digitally.

The Smart Maintenance Community which was founded by the Fraunhofer Group for Production pursues the goal of providing comprehensive support to companies in securing and expanding their production sites by closely networking application-oriented research and rapid, industrial deployment. Smart Maintenance is the enabler that drives and ensures the necessary digital transformation processes.

Central research questions of the Group 2021

Resilient Value Creation Systems
Influenced in particular by the pandemic situation, the Group for Production has joined forces in an interdisciplinary project consortium in order to address the requirements of Germany as a business location with regard to resilient and dynamic value-creation systems with consistently high productivity and individualization, and to implement them in future-oriented research topics. Resilience to disruptive events of all types is becoming a decisive competitiveness factor.

The main objective of the joint innovation program "RESYST" is the development of business models that can adaptively adjust to the crisis situation, as well as the development of value-creation networks that are capable of early detection, protection and countermeasures with regard to unexpected events. Specific design and action recommendations for both the planning process and the operational phase of resilient production systems, including manufacturing and process-engineering measures, are being developed. The guiding principle of maintenance-free production and logistics systems characterizes the vision for adaptable and resilient production systems.

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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.

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 Center Wolfsburg

The lightweight campus "Open Hybrid LabFactory e.V. (OHLF)" is considered one of the leading addresses in Germany for the research and development of hybrid components of the future. Here the Fraunhofer 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 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.

Fraunhofer Center for Energy Storage and Systems ZESS

As a joint research and transfer platform, the Center is working on the development of system solutions for batteries and fuel cells in the field of electromobility as well as for stationary storage systems as components of the energy revolution. With the objective of developing mobile and stationary storage technologies to market maturity, the Fraunhofer IST, together with the Fraunhofer Institutes IKTS and IFAM as well as the Battery LabFactory Braunschweig of the TU Braunschweig, is pooling its technical expertise and researching the further development of the technologies into prototype-capable solutions and systems.

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 regional companies to develop CO_2-neutral solutions for industrial use with regional hydrogen expertise.

Cooperations with the TU Braunschweig

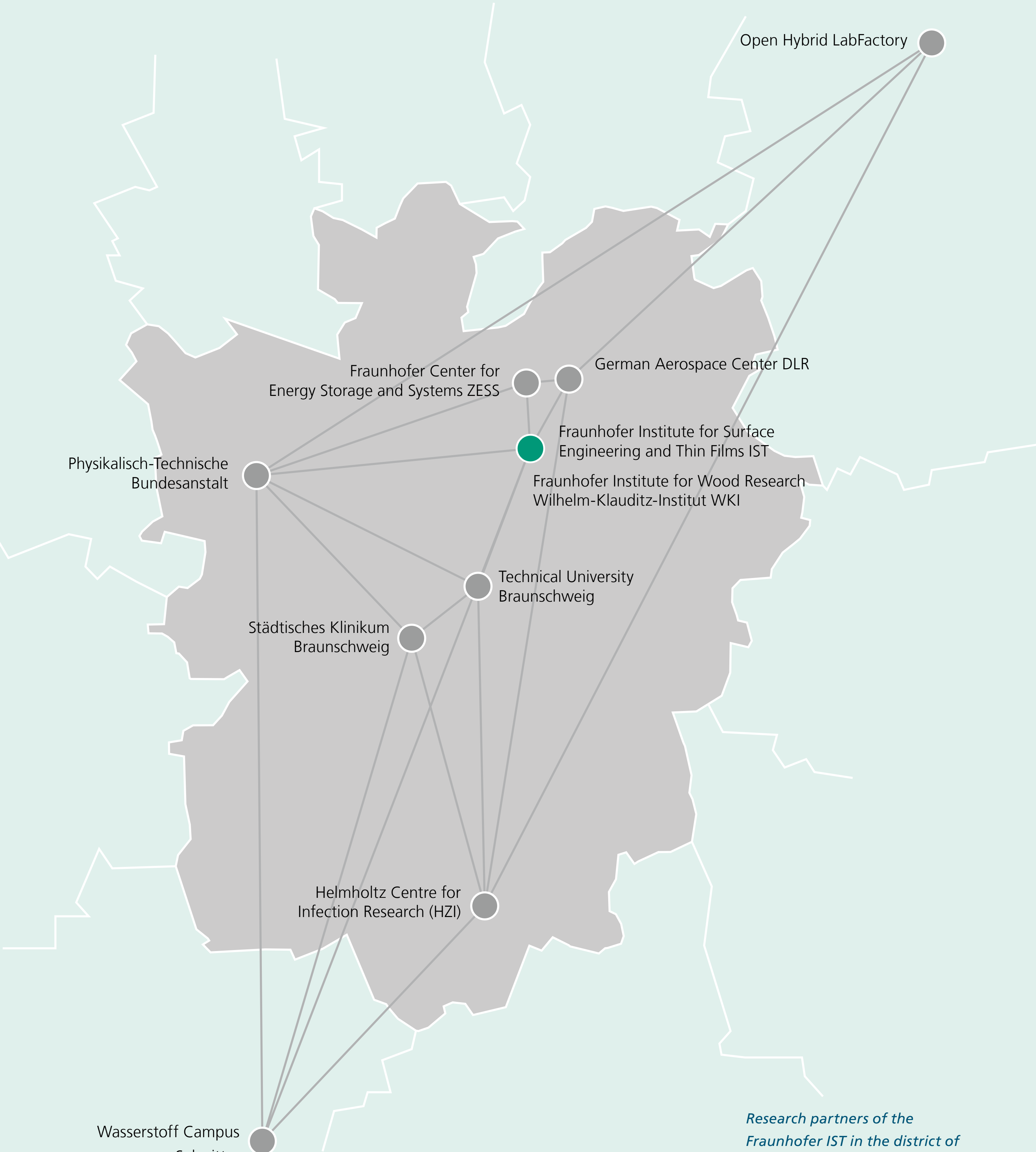
- Battery LabFactory Braunschweig BLB
- Automotive Research Centre Niedersachsen NFF
- Aeronautics Research Centre Niedersachsen NFL
- Center of Pharmaceutical Engineering PVZ
- Open Hybrid LabFactory e.V.

Sites Göttingen and Dortmund

The department Application Center 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 the Dortmunder OberflächenCentrum DOC, ThyssenKrupp Steel Europe, together with its on-site partners Fraunhofer IST and Fraunhofer IWS, develops industry-ready solutions in the field of surface engineering for flat steel products. The 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.

The Competence Network Industrial Plasma Surface Technology e. V. – INPLAS

The competence network INPLAS e. V. pursues the objective of raising awareness of the potential of plasma technology and supporting, promoting and mediating developments in the numerous fields of application in their respective complexity. The network is accredited by the German Federal Ministry for Economic Affairs and Climate Action (BMWK) in the "go-cluster" program and has been awarded the Silver Label Cluster Management Excellence. INPLAS currently has 55 members from industry and science with approximately 200 active individuals. Seventy-five percent of INPLAS members are from industry.

Despite the current pandemic-related restrictions, INPLAS has once again organized diverse activities related to plasma technology, predominantly within the framework of digital formats. We thank all the members for their commitment and active support at this time. A number of highlights of the 2021 activities, projects and events are presented in the following:

11th HIPIMS Conference

In June 2021, INPLAS co-organized and participated in the 11th International Conference on Fundamentals and Industrial Applications of HIPIMS, which was primarily organized by the University of Sheffield in collaboration with further partners. This time, the conference was held in digital format. The focus was on developments in the field of tribological coatings for applications in machining and aerospace as well as digitalization in surface technology. Furthermore, presentations covered such topics as carbon-based coatings for tribological, antimicrobial and sensory applications, industrial and reactive HIPIMS processes, modeling and simulation, and plasma characterization.

44th and 45th Meetings of the Industry Working Committee "Tool Coatings and Cutting Materials" (German: Industrie-Arbeitskreis, IAK)

Tool manufacturers and users, predominantly from industry, convened in virtual form in early May and November 2021 for the respective 44th and 45th IAK editions in order to exchange information on the latest developments and trends in the field of cutting tools and their coatings. Topics addressed in presentations from industry and the scientific community included ultra-hard cutting materials and coatings, HIPIMS, CVD for machining applications, diamond tools, novel

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Highlight in 2021: Foundation of the INPLAS focus group "Digitalization and AI".

multi-element PACVD coating systems, diamond hardness and graphite lubrication, combining DLC coatings, CFRP-GFRP machining challenges, the process chain for PVD coatings, carbide as a high-performance material on the way to "nano", hard machining, and the machining of lightweight materials. Furthermore, a milling machine with robotic kinematics was presented. The IAK, organized by the partners the Institut für Werkzeugmaschinen und Fabrikbetrieb IWF of the TU Berlin, the Fraunhofer Institute for Production Systems and Design Technology IPK, the Fraunhofer IST and INPLAS e.V., is held twice a year, usually in spring in Berlin and in fall in Braunschweig.

INPLAS working groups

In April and May, the participants of the first two meetings of the "Digitalization and AI" focus group, which was newly established in spring 2021, discussed the status and development needs in the field of Industry 4.0 applications relating to industrial plasma and coating technology. Within the group, a number of ideas for funded and contract research

INPLAS member overview (Status: January 2022). **2**

projects have already been generated. In July, on the occasion of the "QPTDat Workshop Plasma Surface Technology" event organized by the Leibniz Institute for Plasma Research and Technology (INP), the INPLAS administrative office utilized the opportunity to provide the focus group with a presentation focusing on the topic of research management in plasma technology and to attract further collaborators from science and industry.

During virtual meetings in May and November, the WG "Novel Plasma Sources and Processes", with the leadership team of Dr. Anke Hellmich, Applied Materials GmbH & Co. KG, Matthias Nestler, scia systems GmbH, and Dr. Ulf Seyfert, Von Ardenne GmbH, addressed the topics of temperature measurement in vacuum and particle avoidance in low-pressure plasma processes. At the November meeting, a keynote address on the subject of "Opportunities and limits of energy storage technology" was given by Dr.-Ing. Sabrina Zellmer of the Fraunhofer IST, which was extremely well received.

The "Tool Coatings" WG under the leadership of Hanno Paschke, Fraunhofer IST, also met twice in virtual form. At the two meetings in May and December 2021 the participants discussed the possibilities, tasks and opportunities of standardization work in the tool field as well as surface technology in the additive process chain. The objective is to initiate project outlines.

In the October 2021 meeting of the community committee "Combined Surface Technology", chaired by Prof. Dr. Petra Uhlmann, Leibniz Institute of Polymer Research, the topics addressed by the participants online included the wet-chemical surface modification of plastic parts as well as the topic complex of tribology and coatings.

16th INPLAS General Meeting

The 16th INPLAS General Meeting was once again held in digital form in 2021. The main agenda items were the introduction of new members, the election of the Board and the auditor as well as information on the future contents of the INPLAS working groups and planned events. Further developments were presented on thematic focal points such as the INPLAS joint-project offers in the fields of anti-adhesion coatings, digitalization/AI under the heading "Plasma 4.0", and CO_2 footprint.

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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

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

DGO Deutsche 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

European Lithium Institute eLi
www.lithium-institute.eu

Fachverband Angewandte Photokatalyse (FAP)
www.vdmi.de/de/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 Adaptronics Alliance
www.adaptronik.fraunhofer.de/en.html

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www.automobil.fraunhofer.de/en.html

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www.batterien.fraunhofer.de/en.html

Fraunhofer Cluster of Excellence Cognitive Internet Technologies
www.cit.fraunhofer.de/en.html

Fraunhofer Competence Field Additive Manufacturing
www.additiv.fraunhofer.de/en.html

Fraunhofer Group for Light & Surfaces
www.light-and-surfaces.fraunhofer.de/en.html

Fraunhofer Group for Production
www.produktion.fraunhofer.de/en.html

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www.fraunhofer.de/en/research/current-research/hydrogen.html

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www.simulation.fraunhofer.de

Fraunhofer POLO® – Polymer Surfaces
(POLymere Oberflächen)
www.polo.fraunhofer.de/en.html

Fraunhofer Research Field Lightweight Construction
www.leichtbau.fraunhofer.de/en.html

Fraunhofer Space Alliance
www.space.fraunhofer.de/en.html

Fraunhofer Sustainability Network
www.fraunhofer.de/en/about-fraunhofer/corporate-responsibility/governance/sustainability/fraunhofer-sustainability-network.html

Fraunhofer Water Systems Alliance (SysWasser)
www.syswasser.de/en.html

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

Leistungszentrum Medizin- und Pharmatechnologie
www.lz-mpt.fraunhofer.de/

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

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

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

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

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

Optence e. V.
www.optence.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

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

Zentrum für Pharmaverfahrenstechnik PVZ
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Imprint

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