Fraunhofer IST

Fraunhofer Institute for
Surface Engineering and Thin Films IST

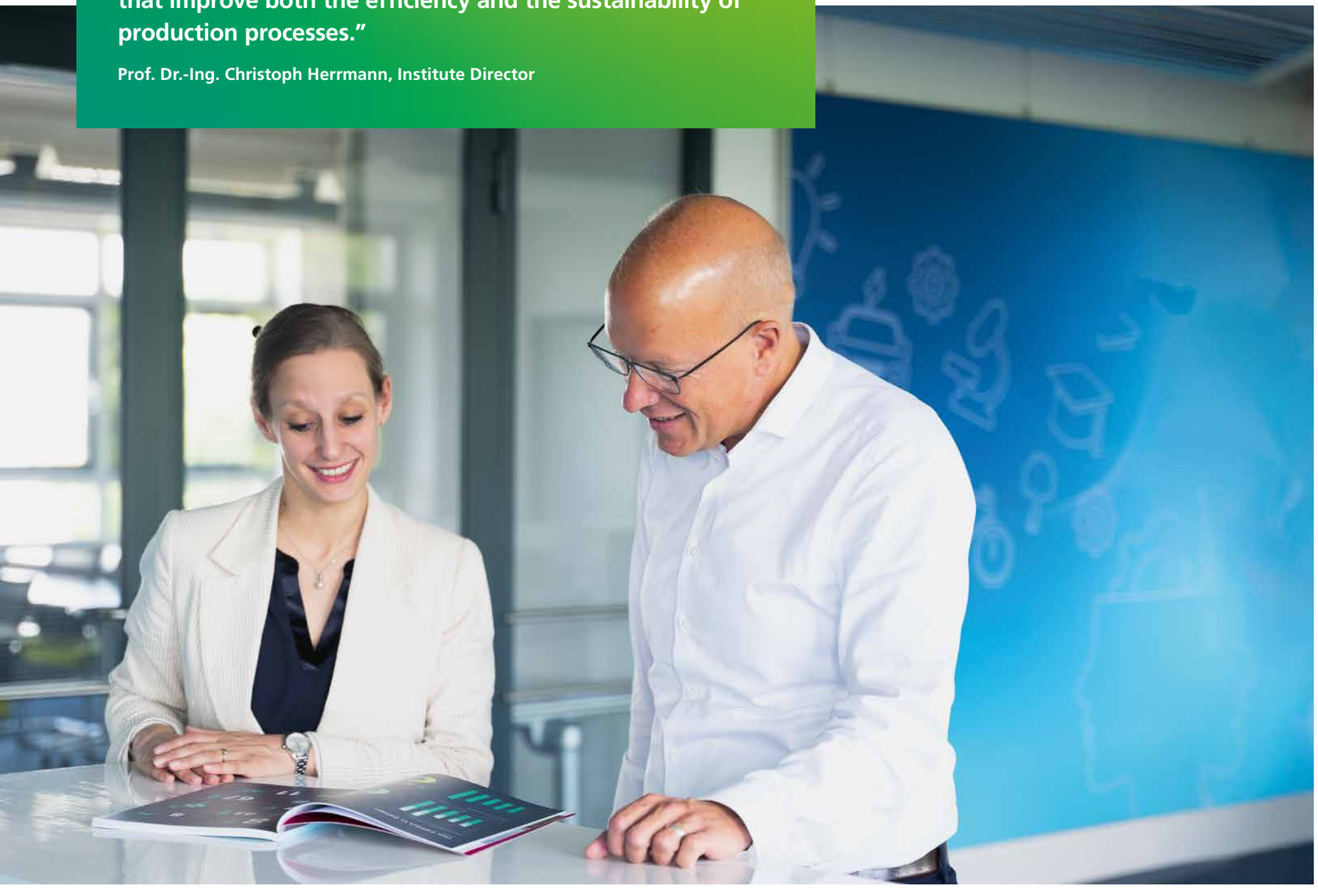
Annual Report 2024

Fraunhofer IST

Annual Report 2024

With our work, we address not only the technical but also the economic and ecological challenges of industrial production. Through close cooperation with industrial partners and interdisciplinary research, in particular intense collaboration with the TU Braunschweig, we create innovative solutions that improve both the efficiency and the sustainability of production processes."

Prof. Dr.-Ing. Christoph Herrmann, Institute Director



Prof. Dr.-Ing. Sabrina Zellmer and Prof. Dr.-Ing. Christoph Herrmann.

Foreword

Ladies and Gentlemen,

the year 2024 was characterized by groundbreaking innovations, new partnerships and a strong focus on both sustainability and technology transfer.

We are particularly proud to be able to report on two international spin-offs this year. S Mile Solutions (Pty) Ltd, based in South Africa, offers innovative, network-independent infrastructure solutions for the healthcare sector. Integrative Nanotech Ltd, based in Canada, is – in collaboration with us – driving forward the development of new systems for the detection of hydrogen leaks.

Furthermore, we were able to intensify our partnership with Feng Chia University through the foundation of the Fraunhofer Innovation Platform. Together, we are working on pioneering surface and production technologies for optical and electrical systems in order to introduce them into industrial applications.

In Lower Saxony, we have driven forward the expansion of important centers of growth and our research centers and networks: We are delighted to welcome new members, the establishment of our advisory board, and the support of the state of Lower Saxony. In Braunschweig, the new building for our Fraunhofer Center for Energy Storage and Systems ZESS is progressing rapidly. At the Open Hybrid LabFactory OHLF in Wolfsburg, we are working in close collaboration with the TU Braunschweig and Ostfalia University of Applied Sciences, and partners from industry and politics on the development of technologies for a sustainable automotive circular economy. There, we are developing a joint Campus Wolfsburg which will unite research, teaching, further education and industrial application, thereby offering an ecosystem for start-ups.

Competencies in sustainability management and Life Cycle Engineering are key success factors for the transformation of businesses. We have therefore expanded our range of further education and services in order to provide targeted support for businesses in this field. "Think green, act smart" is not just the title of the training course, but also an appeal that will continue to resonate with us in the coming year.

We would like to express our sincere thanks to all our partners and employees for their dedicated cooperation. Let us continue to work together to implement innovative ideas and shape a more sustainable future. With this in mind, we hope you enjoy reading this report and look forward to receiving your feedback and suggestions.

With very best regards,

Prof. Dr.-Ing. Christoph Herrmann
Director

Prof. Dr.-Ing. Sabrina Zellmer
Deputy Director

Content

Content

Our Board of Trustees

Interface between research and practice

Our illustrious Board of Trustees is comprised of representatives from science, business and public life. The members of our Board of Trustees provide us with advice and support on issues relating to our professional orientation and structural changes, and endow our institute with important impetus.

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Prof. Dr. Peter Awakowicz / Ruhr-Universität Bochum

Dr. med. Thomas Bartkiewicz /
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Frank Benner / B + T Technologies GmbH

Dr.-Ing. Marko Gernuks / Volkswagen AG

Uwe Heydenreich / TRUMPF Hüttinger GmbH + Co. KG

Prof. Dr. Tim Hosenfeldt /
Schaeffler Technologies AG & Co. KG

Dr. Sebastian Huster /
Niedersächsisches Ministerium für Wissenschaft und Kultur

Prof. Dr. Angela Ittel / Technische Universität Braunschweig

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Arbeitgeberverband Region Braunschweig e. V.

Wolfgang Müssel /
Bundesministerium für Bildung und Forschung

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Elektroindustrie Baden-Württemberg e. V. (Südwestmetall)

Dr. Jutta Trube

Dr. Kai U. Ziegler / EagleBurgmann
Germany GmbH & Co. KG

Excellent collaboration

An interview with Michael Gensicke, Member of the Board of Management and Technical Plant Manager at Robert Bosch Elektronik GmbH

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Personal details

Michael Gensicke has been the Technical Plant Manager at Robert Bosch Elektronik GmbH in Salzgitter since 2015. The plant employs around 1,400 people. In this role, he is responsible for coordinating production at one of the Bosch Group's largest international production facilities.

Mr Gensicke has worked for the Bosch Group at various locations in Germany and Australia since 1997. He is also a member of the board business associations Unternehmerverbände Niedersachsen e. V. and Verband der Elektro- und Digitalindustrie e. V. as well as the Wasserstoff Campus Salzgitter e. V.

What are the current challenges facing your industry, and how is Fraunhofer IST contributing?

"Fraunhofer IST is supporting us in the 'Factory Transformation' project, helping us to achieve our ambitious sustainable development goals in line with the Paris climate targets and transition to CO_2-neutral production at the site. Our goal is to use as much renewable energy as possible on site. This will be achieved by integrating innovative energy storage systems and increasing energy flexibility.

Among other things, we have installed a 4.7 MWp photovoltaic system coupled with a battery storage system, and a district heating connection, which is a special milestone. Thanks to various measures, we have significantly reduced our external energy purchases between 2019 and 2023: Natural gas by around 70 per cent, and grid electricity by around 40 per cent. Furthermore, we have also implemented the use of solid oxide fuel cells (SOFC)."

You have been working in collaboration with the Fraunhofer IST since 2019. Which project stands out as particularly distinctive in your collaboration with the IST?

"For the 'Factory Transformation' project, the Fraunhofer IST performed an energy system simulation for the site. This allowed us to evaluate various operating scenarios and the potential of hydrogen storage systems. These results will help us with our future work on designing a flexible and resilient energy system at the site.

Since 2019, we have been working with the Fraunhofer IST in the region, in collaboration with the City of Salzgitter and other industrial partners, to develop the Wasserstoff Campus Salzgitter. This was ultimately founded as an association in 2023. The Campus is a highly successful concept that demonstrates how the energy transition and hydrogen economy are being driven forward across all sectors. Alongside a number of research projects, we are increasingly focusing on specific implementation projects throughout the South-East Lower Saxony region."

What plans do you have for the future, particularly in relation to the Fraunhofer IST?

"In collaboration with the Fraunhofer IST, we intend to establish Wasserstoff Campus Salzgitter e. V. as a supra-regional contact point for industry- and research-related topics concerning the energy transition and the hydrogen economy. This encompasses national and international research projects, as well as the implementation of joint regional projects. Our aim is to establish green hydrogen value chains in the region and consequently contribute to accelerating the market ramp-up of hydrogen. Another success is the research funding for the Campus under the leadership of the Fraunhofer IST within the framework of the 'zukunft.niedersachsen' programme by the Niedersächsisches Ministerium für Wissenschaft und Kultur (Lower Saxony Ministry for Science and Culture) from 2025 until the end of 2029."

Robert Bosch Elektronik GmbH

As the lead plant for engine control units, Robert Bosch Elektronik GmbH in Salzgitter uses state-of-the-art technology to manufacture control units and coordinate their production across the Bosch Group. The site has been in existence for over 50 years. Electronic control units have been produced there for over 30 years.

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The factory premises of Robert Bosch Elektronik GmbH in Salzgitter.

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Fraunhofer IST will receive around €2.5 million from the Ministry for Science and Culture of Lower Saxony for research work at the Wasserstoff Campus Salzgitter. On 3 February 2025, Lower Saxony's Minister for Science and Culture, Falko Mohrs, personally handed over the funding notification at the Salzgitter location. From left to right: Christoph Imdahl (Branch Manager at Wasserstoff Campus Salzgitter); Prof. Dr.-Ing. Sabrina Zellmer (Deputy Director of Fraunhofer IST and spokesperson for the joint project); Falko Mohrs (Minister for Science and Culture, Lower Saxony); Prof. Dr.-Ing. Christoph Herrmann (Chairman of the Board of Directors at Wasserstoff Campus Salzgitter and Director of Fraunhofer IST); Michael Gensicke (Chief Financial Officer at Wasserstoff Campus Salzgitter and Managing Director at Robert Bosch Elektronik GmbH).

Institute profile

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 customized solutions that fulfill the requirements for sustainability for various sectors, e.g. plant and mechanical engineering, tools, vehicle construction, aerospace, energy, optics, medical and pharmaceutical process engineering, environmental technology, agricultural and food industry, 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.

Further 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
- Sustainability management and life cycle engineering

We apply our expertise in a diverse range of technologies for the coating, treatment and structuring of surfaces and the design of the associated production systems. 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 is very well equipped as regards surface analytics and has accrued many years of expertise in quality assurance. Added to this is extensive experience in the modeling and simulation of both product properties and the associated processes as well as production and factory systems. For the systematic consideration of sustainability requirements, the Fraunhofer IST offers extensive expertise in quantitative sustainability assessment and a circular economy using Life Cycle Engineering.

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.

Within the framework of direct contract research, the Fraunhofer IST offers its customers not only the licensing of software, patents and expertise but also consulting and innovation management, customized further-training programs, and services in the fields of process development and equipment and plant engineering.

Alongside direct contract research, we work together with partners from industry and science in publicly funded projects. In addition to application-oriented research, the staff of the Fraunhofer IST also carry out the associated fundamental scientific work in cooperation with universities and non-university research institutes.

For the Fraunhofer IST as well as for the Fraunhofer institutes as a whole, it is a matter of principle to always interact closely with the local universities. For the institute, with its headquarters in Braunschweig and regional locations in Wolfsburg and Salzgitter, the Technische Universität Braunschweig is, correspondingly, a central cooperation partner. The TU institutes directly associated with the Fraunhofer IST include: Institute of Machine Tools and Production Technology (IWF), Institute for Surface Technology (IOT), and the Institute for Particle Technology (iPAT).

Where to find us – our locations

Fraunhofer Institute for Surface Engineering and Thin Films IST

Main location

Address:
Riedenkamp 2
38108 Braunschweig
Germany

Office premises:
2,000 m²
Laboratory premises:
5,500 m²

Contact:
info@ist.fraunhofer.de
Phone +49 531 2155-0

Focus areas:
Thematic focuses at our main location encompass the areas of tribology, sensor technology, optics, diamond technology and medical technology as well as sustainability management, simulation, analytics and testing technology.

Energy storage

Fraunhofer Center for Energy Storage and Systems ZESS

Address:
Lilienthalplatz 1
38108 Braunschweig
Germany

Office premises*:
400 m²
Laboratory premises*:
250 m²

*Upon completion of the new research building, a total area of approx. 3,400 m² will be available.

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Nikolas Dilger M.Sc.
nikolas.dilger@ist.fraunhofer.de
Phone +49 531 2155-660

Focus areas:
At the Fraunhofer Center for Energy Storage and Systems ZESS, we develop sustainable energy storage systems and advance them to market maturity. Our research focuses on lithium solid-state batteries, stationary storage systems, hydrogen technologies and inspection technologies. We examine the entire life cycle of energy storage systems – from raw materials through various production steps and use to recycling, thereby taking technical, economic and ecological aspects into consideration.

Hydrogen

Wasserstoff Campus Salzgitter e. V.

Address:
on the premises of
Robert Bosch Elektronik GmbH
John-F.-Kennedy-Straße 43-53
38228 Salzgitter
Germany

Office premises:
320 m²
Laboratory premises:
1,580 m²

Contact:
Christoph Imdahl M.Sc.
christoph.imdahl@ist.fraunhofer.de
Phone +49 531 2155-669

Focus areas:
At the Wasserstoff Campus Salzgitter e. V., we conduct research into sustainable hydrogen technologies along the entire value chain. Founded by nine key players from business, science and politics, the Campus operates as a flagship project for the demonstration of a decarbonized industrial region in the hydrogen economy. Research focuses are climate-neutral sectors through the coupling of decarbonized factories and districts, closed material and product cycles, and flexible production processes. The Campus is striving towards further growth, new partnerships and research into fuel cells, electrolyzers and CO_2-neutral factories. The further training of specialists and the promotion of global partnerships are also key objectives.

Fraunhofer Center Circular Economy for Mobility CCEM

Address:
c/o Open Hybrid LabFactory e.V.
Hermann-Münch-Straße 2
38440 Wolfsburg
Germany

Office premises:
350 work places*
Laboratory premises:
2,800 m² technical center of the OHLF

*For OHLF e.V., Fraunhofer-Gesellschaft, TU Braunschweig and industry.

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

Focus areas:
In the Fraunhofer CCEM, the Fraunhofer IST, together with the Fraunhofer institutes IFAM, IWU and WKI, pools its expertise in the research topics of automated production systems, future interior concepts, Life Cycle Engineering and sustainable product design. In collaboration with research partners, the Fraunhofer IST is working towards the goal of developing and evaluating new materials, production techniques and digital methods in an economically and ecologically sustainable manner. In order to achieve this, procedures for automated dismantling, Re-X processes such as cleaning, remanufacturing and re-use as well as sustainable surface processes along a circular process chain are utilized and the large-scale testing of these technologies is driven forward.

Mobility

Circular Economy

Plasma source development

Application Center of the Fraunhofer IST

Address:
Von-Ossietzky-Straße 100
37085 Göttingen
Germany

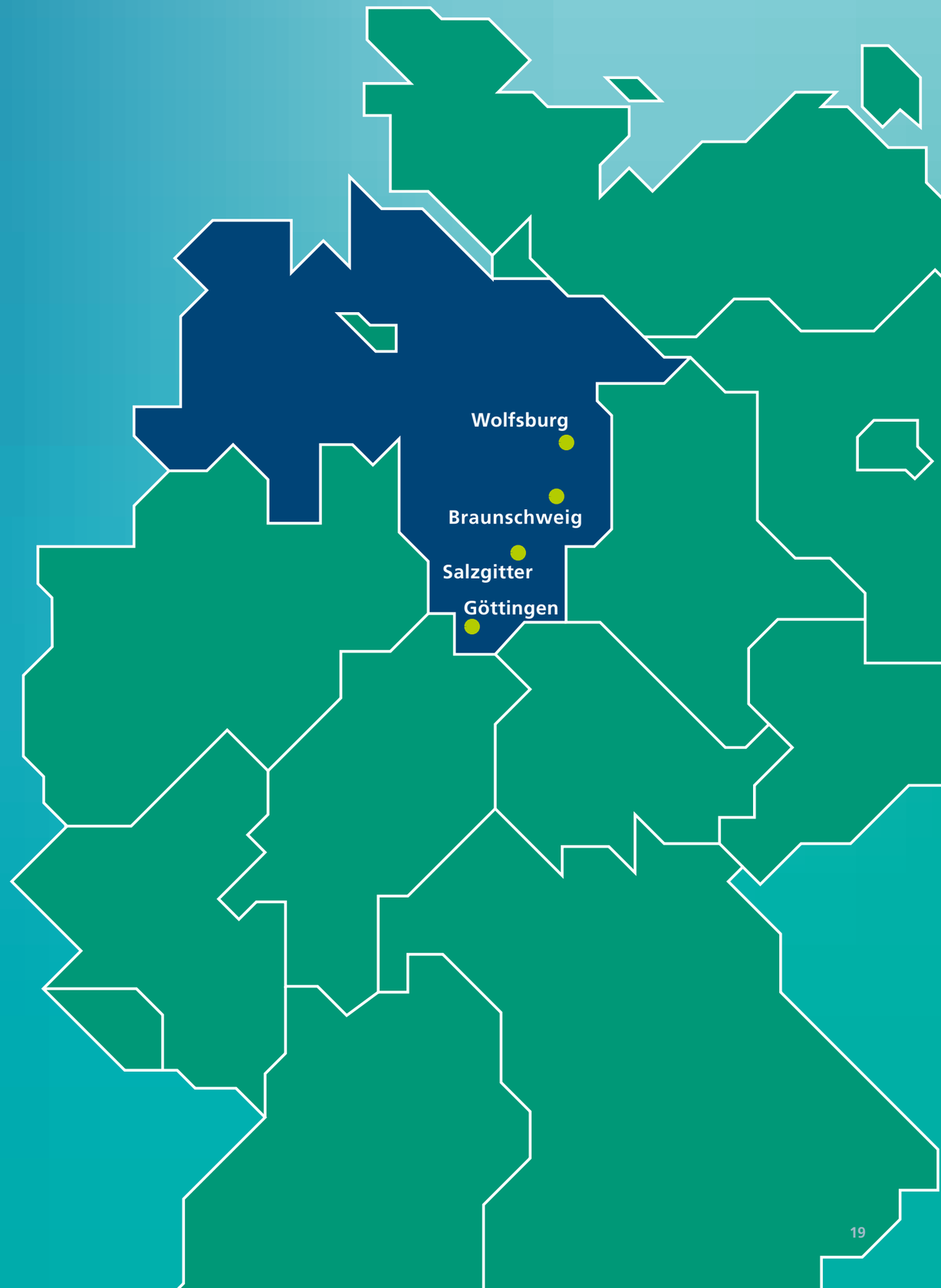
Contact:
Prof. Dr. Wolfgang Viöl
wolfgang.vioel@ist.fraunhofer.de
Phone +49 551 3705-218

Office and laboratory premises: :
1,500 m²

In cooperation with the Hochschule für angewandte Wissenschaft und Kunst HAWK.

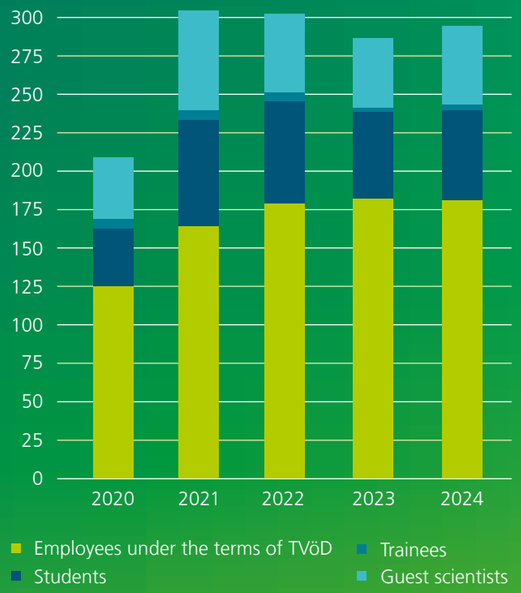
Focus areas:
At the Göttingen location, the focus lies on the development and transfer of coatings using low-energy plasma coating processes such as cold plasma spraying and the development of plasma sources for the production of resource-conserving coatings and products. These processes are aimed at recyclability and the bioeconomy and include fields of application such as fuel-cell and battery technology, tribology and sensor technology as well as powder modification form a diverse range of applications such as 3D printing.

Cold pasma spraying

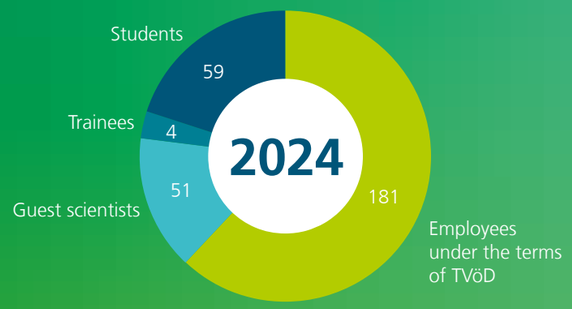


The institute in figures

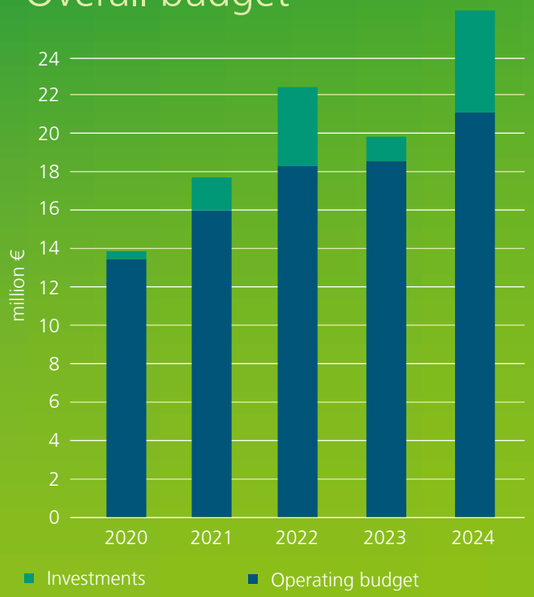
Personnel development



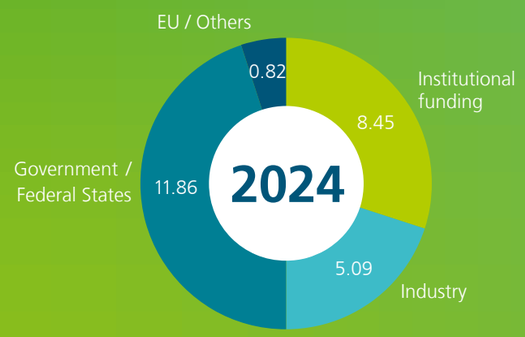
295
employees



Overall budget



€ 26.22 million
overall budget



91 conference contributions

59 student assistants

8 professorships

15 nationalities

employees under the terms of TVöD

3,2% disabled-employee quota

45 publications and patents

6 locations

6 women in leadership positions

5 vocational professions

3060 followers

>15 disciplines

Last updated: December 31, 2024

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 seven 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:

- Assembly / disassembly
- Process automation
- Battery and fuel cell production
- Production technologies

Prof. Dr. Stephan Krinke (Honorary professorship)
Research foci:

- Sustainability management in industry
- Life Cycle Engineering
- Decarbonization
- Circular Economy

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

Prof. Dr.-Ing. Sabrina Zellmer
Research foci:

- Sustainable energy storage
- Material and process development for novel batteries
- Hydrogen economy and hydrogen technologies
- Sustainable factory systems and Life Cycle Assessment

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
- Surface technologies for circular processes

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

Faculty of Engineering and Health

Prof. apl. Prof. Dr. Wolfgang Viöl
Research foci:

- Laser technology
- Plasma technology
- Plasma medicine

Your contact persons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Institute management, administration and central services

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Product development and design / Production and conditioning of energy storage materials / Production of battery components and further processing into coin and pouch cells / Reconditioning and recycling / Particle, material and process simulation

Sustainable process chains for battery systems
Nikolas Dilger M.Sc. 9
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Life cycle engineering for energy storage technologies / Planning, modelling, simulation of process chains / Digitization of production / Sensor technology for energy storage systems

Sustainable hydrogen systems and technologies
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Digital methods for energy conversion chains and simulation of sustainable factory systems / Manufacture and recycling of fuel-cell components, modules and systems / Automated assembly and testing of fuel-cell stacks

Sustainability management and Life Cycle Engineering
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Sustainability management
Advice on corporate sustainability strategy of companies / Decarbonization target derivation and implementation / Sustainable Development Goals (SDGs) / Materiality analysis / Resource efficiency and circular economy / Learning concepts on sustainability management and life cycle assessment

Life Cycle Engineering
Technical measures for environmental impact reduction / Life cycle-based tools and methods for holistic product and process optimization / Life cycle engineering and life cycle costing / Hotspot analyses / Certified carbon and water footprints / Roadmaps for decarbonization and circular economy

Analytics and quality assurance
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Chemical micro-range analysis / Microscopy and surface measurement / Mechanical characterization / Friction and wear measurement / Testing technology / Customer-specific testing methods / Commissioned investigations

Interfacial chemistry and adaptive adhesion
Prof. Dr. Michael Thomas 13
michael.thomas@ist.fraunhofer.de | Phone+49 531 2155-525

Circular products and processes
Plasma-based recycling processes for complex components / Automated systems for cleaning, remanufacturing and functionalization / Sustainable materials and surfaces for interior and exterior components / Plasma polymerization (process and source development) / Circular economy

Medical technology and pharmaceutical systems
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Surface technology for pharmaceutical production and primary packaging / Adhesion control on medical devices / Cleaning and sanitation / Atmospheric pressure plasmas (process and source development) / Chemical functionalization

Optical systems and applications
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Precision optical coatings
Dr. Philipp Farr 16
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Production technology for optical interference filters / Measurement technology for process control and quality assurance / Development and demonstration of filters in accordance with customer specifications

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Optical, electrical and magnetic functional layers / Large-area coating / Gas-flow sputtering technology / High power impulse magnetron sputtering (HIPIMS) / Sensor technology

Simulation
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Simulation of plasma and gaseous fluxes (PICMC) / Digital analysis and optimization of coating processes / Prediction of particle and aerosole movement (PALADIN) / CFD simulation (computational fluid dynamics) / Software development / Cyber-physical systems (digital twin)

Diamond-based systems and CleanTech
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Atomic layer deposition
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Coating processes for medical products / Coating of 3D substrates for micro-optics and membranes / Particle coating / Catalyst deposition for energy conversion and systems

Hot-wire CVD
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Application-specific diamond coatings and processes / Solutions for diamond tools and machine elements / Development of HCVD components and production systems / Development of highly efficient solar cells

Photo- and electrochemical environmental technologies
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Flexible production systems for surface technology / Bio-inspired processes and products / Bio-based coolants and lubricants

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Electroplating / Electrochemical processes / Wet-chemical processes / Corrosion testing / Digitization

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Cold plasma spraying / Particle coating / Development of production-compatible plasma sources / Particle sorption and modification / Plasma characterization

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Development of mobile and stationary energy storage systems / Development and scaling of process technologies / Battery production / Process engineering / Design of the production system for energy storage systems / Life Cycle Management

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Automated cleaning and treatment processes / Functional and smart surfaces / Application of bio-based and secondary materials / Future interior concepts / Life Cycle Engineering and sustainable product design

Wasserstoff Campus Salzgitter e.V. (engl. Hydrogen Campus Salzgitter)
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Hydrogen technologies / Hydrogen economy / Circular economy / Network building / Sector coupling / Sustainable factory systems / Decarbonization of industry / Continuing education

Prof. Dr. Heinz Dimigen
** 20.02.1936*
† 03.10.2024

We bid farewell

The Fraunhofer IST mourns the loss of its founding father and long-standing Institute Director, Prof. Dr. Heinz Dimigen, who passed away on the 3rd of October 2024 at the age of 88. His tireless commitment to research and development in the field of surface technology has significantly shaped not only our institute, but also the entire sector.

In 1988, at the behest of the Fraunhofer-Gesellschaft, Prof. Dimigen conceptualized the institute in order to address the issues of coating and surface technology. He headed the Fraunhofer IST from its foundation in 1989 until his retirement in 1999. Prof. Dimigen's passion for surface technology had already become apparent during his time as Head of "Thin-Film Technology" at the Philips Research Laboratory in Hamburg, where the PhD physicist recognized the importance of thin-film technology, in particular amorphous or diamond-like carbon coatings. These coatings were later further developed at the Fraunhofer IST in collaboration with industrial partners and are used in numerous applications today.

In 2002, Prof. Dimigen was awarded the first "Manfred von Ardenne Prize for Applied Physics" in recognition of his work, particularly with regard to the field of amorphous carbon and its application.

Heinz Dimigen was a loyal, knowledgeable and decisive manager and an outstanding scientist who always had a sympathetic ear for everybody and who possessed the necessary intuition and ingenuity. He lived by values such as integrity and respect, was known for his readiness to help, and was deeply appreciated by his employees and partners.

We mourn the loss of a dear, highly esteemed person whose memory will always be cherished at our institute. Our sincere condolences go out to his family.

Highlights

Commitment to sustainability, environmental management and circular economy

March 13, 2024 and November 04, 2024 /
Prof. Dr. Stephan Krinke was appointed to the Advisory Board of the Association for European Sustainability and Eco-Management Professionals, VNU e. V. in December 2023. In the fall of 2024, he was appointed to the ninth government commission "Circular Economy" of the state government of Lower Saxony.

The Association for European Sustainability and Eco-Management Professionals, VNU e. V., is an independent collective that brings together industry, science and certification bodies and supports the practical implementation of sustainability and environmental management in companies. Furthermore, the VNU networks the stakeholders through conferences and regional meetings and helps to enable the implementation of the latest developments from science and standardization into practice.

Prof. Dr. Stephan Krinke, Head of Department Sustainability Management and Life Cycle Engineering at the Fraunhofer IST.

The focus of the new commission is directed at the further development of the classic recycling economy towards a circular economy in order to confront the challenges of climate protection and resource conservation. Prof. Stephan Krinke has been appointed as a member of this commission, in which he will represent the Fraunhofer Institute and the TU Braunschweig.

The thematic priorities of the 20-strong commission are the development of reusable products, recycling, durability and reparability. A central focus will be formed by the work at the Center for Circular Economy in Mobility at the Open Hybrid LabFactory (OHLF) in Wolfsburg. Here, the Fraunhofer IST is collaborating with other Fraunhofer institutes together with research partners from the automotive and supplier industry in order to develop innovative technical concepts for a sustainable circular economy.

The pupils were able to paint the glasses according to their own wishes.

WOn Future Day 2024, scientists from the Fraunhofer IST answered questions from the girls and boys in the laboratories.

Future Day at the Fraunhofer IST

"When I grow up, I'm going to Fraunhofer."

April 25, 2024 / Future Day comes around every year – and the Fraunhofer IST, in collaboration with the neighboring Fraunhofer WKI, participated once again, opening its doors to 24 children and providing them with an exciting insight into the work of the two research institutes.

How thin are thin layers? How clean are clean glasses? How does a coating system work? How do you check the quality of a coating? These and many other questions relating to glass coating kept the 16 girls and 8 boys busy during their visit to the Fraunhofer IST. As is usual in the coating process, the tour started with the cleaning of surfaces within an almost 14-meter-long modular cleaning facility.

In the next step, the 11-to-15-year-olds prepared glasses for subsequent coating. While painting and labeling, they were able to freely express their creativity. With the prepared glasses in their bags, they moved on to the magnetron sputtering system, in which a wafer-thin layer was deposited. The young researchers then built a practical holder in order to be able to transport and present their work safely. The last stop on the institute tour led to the analytics department of the Fraunhofer IST, where the children were able to examine various samples using a scanning electron microscope, thereby identifying even the finest structures.

At the end, everyone was satisfied - not only the pupils, but also the employees: "It was such a pleasure to see how enthusiastic the children were about the project. We hope that this effect will have a lasting impact and that we will meet some of them again at a later date, for example as trainees or students at the Fraunhofer IST." The Fraunhofer IST offers apprenticeships in technology, IT and administration. Students have the possibility of completing theses or internships and, as student assistants, are able to gain an insight into the practical work.

Science Minister visits the Fraunhofer campus in Braunschweig

July 08, 2024 / Within the framework of his summer tour, Lower Saxony's Minister for Science and Culture, Falko Mohrs, visited the Fraunhofer institutes for Wood Research, Wilhelm-Klauditz-Institut WKI and for Surface Engineering and Thin Films IST in Braunschweig on the 8th of July 2024.

At the Fraunhofer IST, Minister Mohrs was provided with information on the latest developments in coating and surface technology and sustainable technologies for production. "With our work, we address not only the technical but also the economic and ecological challenges of industrial production," explained Institute Director Professor Dr. Christoph Herrmann. "Through close cooperation with industrial partners and interdisciplinary research, in particular intense collaboration with the TU Braunschweig, we create innovative solutions that improve both the efficiency and the sustainability of production processes. The focus is thereby also on measures for decarbonization and the promotion of a circular economy."

In the laboratory, Minister Mohrs was presented with an example of a technological innovation for the development and manufacture of precision optical parts and components, which are required for automated production processes across all industries. With the newly developed OptaX facility, double-sided optical coating of the highest precision can be realized for the first time.

Together for innovation made in Braunschweig: Science Minister Falko Mohrs with the institute directors Prof. Dr.-Ing. Bohumil Kasal (Fraunhofer WKI) and Prof. Dr.-Ing. Christoph Herrmann (Fraunhofer IST) as well as the deputy institute director of the Fraunhofer IST Prof. Dr.-Ing. Sabrina Zellmer (From left to right: Prof. Dr.-Ing. C. Herrmann, Prof. Dr.-Ing. B. Kasal, F. Mohrs, Prof. Dr.-Ing. S. Zellmer).

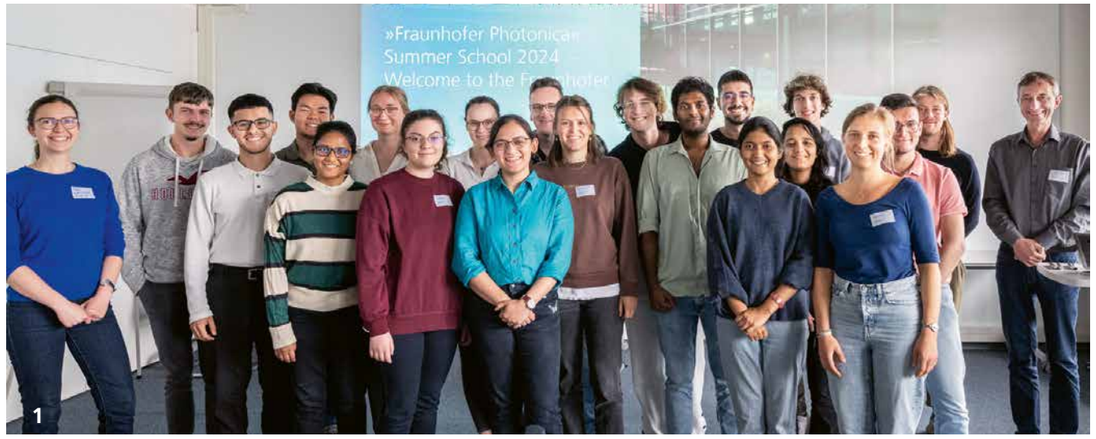
At the Fraunhofer IST, Minister Falko Mohrs gains an insight into thin-film sensor technology for measuring the load and temperature distribution in the main load zones of components for mobility applications such as the kingpin in order to compensate for the tensile and shear forces occurring in the trailer coupling.

"These two Fraunhofer Institutes in Brunswick are impressive proof of the innovative strength and scientific expertise in the region. Renewable commodities and resource-saving production processes have huge potential to significantly advance our industries on their path to sustainability – and are therefore decisive factors for a successful future. It is exciting to get to know these developments at first hand."

Falko Mohrs, Lower Saxony's Minister for Science and Culture

The importance of thin-film sensor technology for mobility applications was demonstrated by IST employees by means of a kingpin. This component connects the cab unit and the trailer of a truck. Thin sensor layers were applied to the main load zones, with which the force can be measured directly; these results are then applied in order to compensate for the tensile or shear force in the trailer coupling. This is particularly decisive for electrically powered vehicles in order to optimize the interaction of the individual components such as the drive module and traction battery. As a result of the reduced load on the towing vehicle, energy consumption and CO_2 emissions can be minimized.

The reduction of CO_2 is also a key topic in the development of "Low Carbon Energy Technologies" at the Fraunhofer IST. The Deputy Director of the institute, Professor Dr. Sabrina Zellmer, presented the Minister with the latest developments at the Fraunhofer IST in the field of batteries and fuel cells. Furthermore, she described the current status of the construction of the Fraunhofer Center for Energy Storage and Systems ZESS: "The three Fraunhofer institutes for Manufacturing Technology and Advanced Materials IFAM, for Surface Engineering and Thin Films IST, and for Ceramic Technologies and Systems IKTS are pooling their expertise at the Fraunhofer ZESS.



The participants of this year's Fraunhofer Photonica at Fraunhofer IST.

The scientific program at the institute covered the topics of batteries and hydrogen technologies as well as precision optics.

In three laboratories, the young researchers were able to try their hand at important steps in the precision optics production chain.

Journey through the world of photonics

Start of the Fraunhofer Photonica Summer School 2024 at Fraunhofer IST

September 23, 2024 / Already for the second time, the Photonica Summer School inspired twenty young international scientists. They spent a week gaining an insight into five Fraunhofer Institutes and their research in the field of photonics, traveling from Braunschweig to Berlin via Jena and Dresden. Fraunhofer Photonica was organized by the Fraunhofer Group for Light & Surfaces under the direction of Fraunhofer IPM.

Lasers, photonics and surfaces – these are three of the topics that link the Fraunhofer institutes of the Fraunhofer Group for Light & Surfaces to one another. At this year's Summer School Photonica, five member institutes gave participants an insight into application-oriented research in this field: from September 15 to 21, they visited Fraunhofer IST (Braunschweig), Fraunhofer IOF (Jena), Fraunhofer IWS and Fraunhofer FEP (both in Dresden) as well as Fraunhofer HHI (Berlin).

A varied program gave participants the chance to get to know the research areas and find out about career opportunities at Fraunhofer. They learned about different fields of application, gained insights into laboratories, were able to conduct their own experiments and had the opportunity to talk to the employees and institute directors. The participants were impressed by the variety of the program and recommend the summer school to all photonics enthusiasts.

About Fraunhofer Photonica:

The Summer School Fraunhofer Photonica is organized by the Fraunhofer Group for Light & Surfaces. Its aim is to spark the young talented scientists' interest in the subject area of the Fraunhofer Group and to show them career opportunities offered by the Fraunhofer-Gesellschaft in general and the Group in particular.

Knowledge transfer, particularly in the field of photonics and surfaces, is focused on – in theory and practice. Fraunhofer Photonica is aimed at students who are interested in photonics and potentially see their future in this subject area. The event language is English. Information about, e. g. the application process, can be found here:

www.photonica.fraunhofer.de

Research results from the Fraunhofer IST in the field of precision optics were closely examined by the students.

Participants in the Fraunhofer Photonica Summer School got to know the science city of Braunschweig on a guided tour.

Award

Two SVC Distinguished Presenter Awards

May 08, 2024 / Within the framework of this year's conference of the Society of Vacuum Coaters (SVC TechCon 2024), the two long-standing employees of the Fraunhofer IST, Dr. Ralf Bandorf and Dr. Volker Sittinger, were honored with the "Distinguished Presenter Award", which was conferred for the very first time. The award honors individuals who have enriched the SVC technical program through sustainable contributions towards the advancement of vacuum coating, surface engineering and related technologies.

The prerequisites for being honored with the Distinguished Presenter Award are stringent: ten SVC conferences with a poster contribution or presentation, participation in five consecutive SVC conferences, and a minimum of five years' membership of the Society of Vacuum Coaters (SVC) prior to nomination. In the almost 70-year history of the SVC, only the seven award winners have been able to fulfill the criteria for the newly introduced award – including no fewer than two representatives of the Fraunhofer IST.

The two scientists are delighted with the award. For the future, both scientists hope that they can maintain and further expand their existing contacts. Furthermore, they want to continue to play an active role in shaping the SVC and to encourage young colleagues in particular to become actively involved.

The award winners Dr. Volker Sittinger (left) and Dr. Ralf Bandorf.

> **"The SVC TechCon not only offers me a platform for scientific exchange, but has also made a very practical contribution towards the development of project partnerships."**
>
> **Dr. Volker Sittinger,**
> **Head of Department at the Fraunhofer IST**

Fraunhofer IST recertified as Zukunftgeber

June 17, 2024 / Zukunftgeber is an accolade awarded by Braunschweig's regional Employers' Association (Arbeitgeberverband, AGV) to outstandingly attractive employers in the Braunschweig-Wolfsburg region. Our institute has been bearing the seal for two years and has now been recertified.

In the pragmatic audit process, the working conditions were assessed in up to ten areas according to their attractiveness for employees – the Fraunhofer IST scored well in nine out of ten categories. We are very proud of this achievement and will constantly work to maintain this high standard for our employees.

Dominique Moré-Jones, Head of HR at AGV (left), and Carolin Buttler, HR manager at Fraunhofer IST, during the presentation of the certificate.

Research transfer: Fraunhofer IST goes international

Think. Act. New business.

The Fraunhofer-Gesellschaft is one of the leading research organizations in Europe and places great emphasis on the transfer of scientific knowledge to industry. One of the goals that it pursues is the promotion of a start-up culture in Germany and beyond.

In the 2024 reporting year, the Fraunhofer IST was able to write not only one, but two success stories involving spin-offs. S Mile Solutions, a South African spin-off of the Fraunhofer IST and the Fraunhofer ISE, provides off-grid infrastructure solutions that enable access to clean water, electricity and primary healthcare in remote regions of sub-Saharan Africa. The Canadian start-up Integrative Nanotech utilizes nanotechnologies developed at the Fraunhofer IST in order to make hydrogen technology safer and more efficient. Both examples impressively demonstrate how the Fraunhofer IST, through visionary research and targeted knowledge transfer, is able to create sustainable solutions to global challenges.

Spin-offs are just one way in which we transfer the results of our scientific work into application – but a particularly visible one. Every successful start-up reflects the innovative nature of our research and is simultaneously an important step towards a sustainable and future-oriented society.”

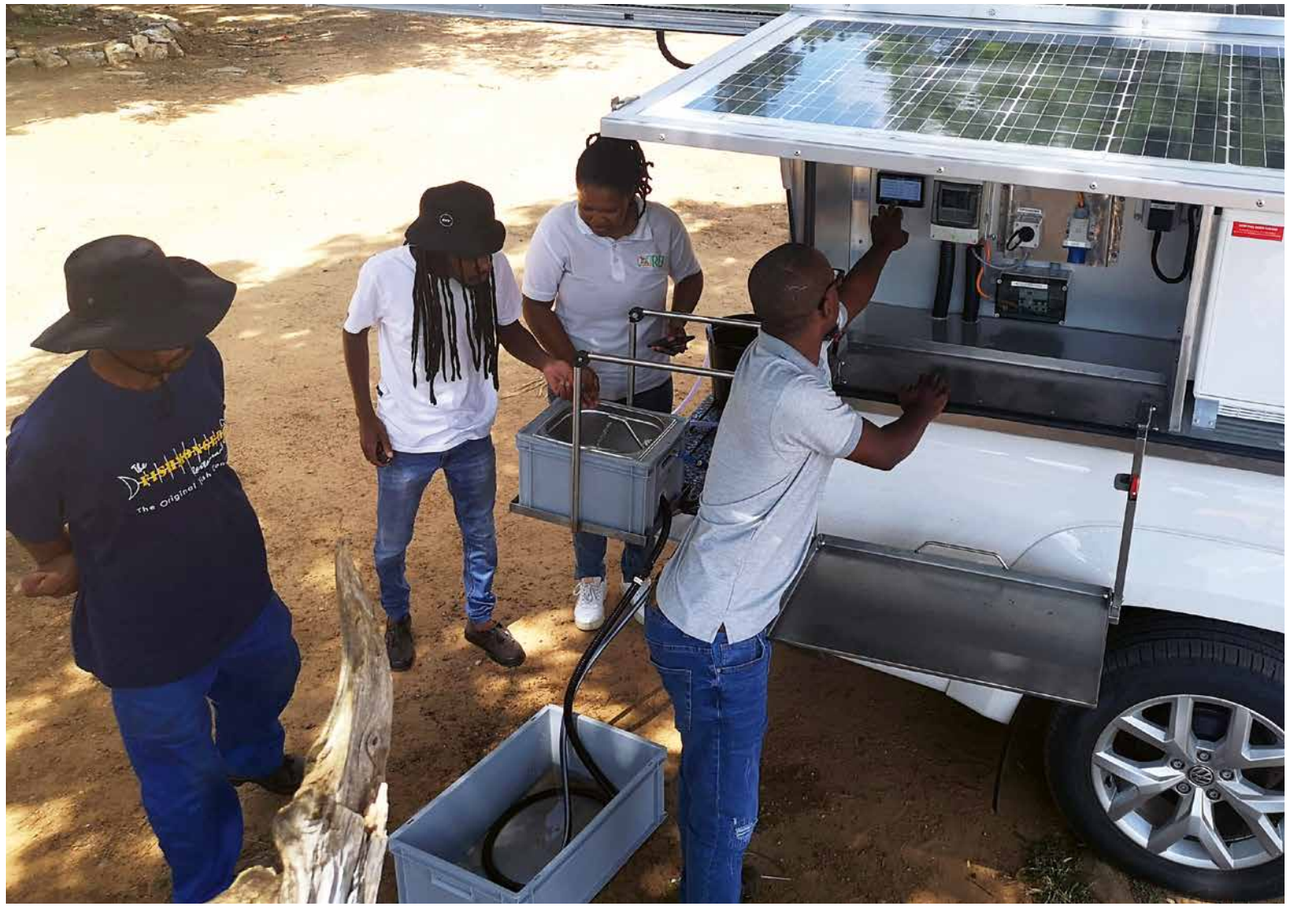
Prof. Dr.-Ing. Christoph Herrmann, Institute Director

Help for the last mile in the sub-Saharan region

March 12, 2024 / No clean water, no functioning electricity grid, no primary healthcare – a scenario that is not uncommon in remote areas of the sub-Saharan region. The founding of "S Mile Solutions (Pty) Ltd", a spin-off of the Fraunhofer Institute for Surface Engineering and Thin Films IST and the Fraunhofer Institute for Solar Energy Systems ISE, is seeking to change this. The start-up, based in Stellenbosch, Western Cape, South Africa, provides smart, small-scale and off-grid infrastructure solutions that are mounted on commercially available pick-up trucks, thereby enabling companies and institutions to access rural and remote communities with their services and products.

The objective of "Smart Last Mile Solutions", or S Mile for short, is to allow infrastructure-based services along the last mile and, as a result, improve the living conditions and prospects of the most vulnerable communities in rural sub-Saharan Africa. Examples include the supply of clean water and electricity, as well as their storage, the inclusion of hygiene measures and the provision of telecommunications for the establishment of primary healthcare with telemedicine and data-management opportunities in the field.

The basis for the business idea behind S Mile was created in joint projects between the two Fraunhofer institutes IST and ISE and the Fraunhofer Innovation Platform for the Water-Energy-Food Nexus at Stellenbosch University (FIP-WEF@SU), in which the first prototype of a self-sufficient platform for mobile medical care was developed. During the foundation phase, the group of four entrepreneurs received support from the Fraunhofer Venture Group and the Fraunhofer Future Foundation.



The prototype of a mobile supply platform in field tests.

About S Mile Solutions (Pty) Ltd

Company headquarters:
Stellenbosch, Western Cape, South Africa

Founding date:
October 20, 2023

Founding members:
Dr. Martin Hamann, Fraunhofer Innovation Platform for the Water-Energy-Food Nexus at Stellenbosch University (FIP-WEF@SU)
Dr. Lothar Schäfer, ehem. Fraunhofer IST
Frank Neumann, Fraunhofer IST
Dr. Joachim Koschikowski, Fraunhofer ISE

Fraunhofer projects in the context of this business start-up:
"MATSE" – Mobile autarke Testplattformen zum Einsatz in Schwellen- und Entwicklungsländern (Mobile self-sufficient test platforms for utilization in emerging and developing countries)
"PreCare" – Health Care for Everyone and Everywhere
(This project was funded by the Fraunhofer Future Foundation)

PreCare

Leakage Technology: Fraunhofer spin-off revolutionizes hydrogen leak detection

Max 15, 2024 / Making hydrogen safer and more efficient to use is Dr. Hunter King's vision. His spin-off, Integrative Nanotech, based in Canada, and its parent institute, the Fraunhofer IST, has joined forces with its parent institution to revolutionize hydrogen leak detection.

This strategic partnership will significantly accelerate the development of next-generation hydrogen leak detection systems and prove their production methods on industrial-scale production systems. The collaboration aims to propel the hydrogen-powered transportation sector into a safer and more efficient future.

How did this come about? As is so often the case, it was pure chance that led Hunter King, who was conducting research on materials for micro-electromechanical systems (MEMS) at Fraunhofer IST, to discover a novel method of producing nanostructured silicon materials on a large scale. It was only after completing his doctorate that he recognized the potential of his innovative nanomaterial, which achieves higher performance in gas and liquid sensor applications due to its extremely large sensor area.

Dr. Volker Sittinger (left, Fraunhofer IST) and Dr. Hunter King (right, Integrative Nanotech) finalizing agreements to develop high performance hydrogen sensors for leak detection applications.

The heart of this collaboration lies in the exclusive licensing agreement recently finalized between Integrative Nanotech and Fraunhofer IST. By leveraging Fraunhofer's extensive facilities and expertise, Integrative Nanotech gains unprecedented access to advanced technologies, and expertise in thin-film processes, production systems, and process upscaling.

"We're thrilled to be working with Fraunhofer on this cutting-edge technology. This collaboration is a prime example of the strength that international partnerships bring to tackling global challenges like climate change. At Integrative Nanotech, we're especially proud that our office and operations are based right here in Atlantic Canada. This project shows that world-leading solutions to fight climate change can be developed right here in our region."

Dr. Hunter King, CEO of Integrative Nanotech

F.l.t.r.: FIP-SPE@FCU Director Prof. He (FCU), FIP-SPE@FCU Deputy Director Dr. Bandorf (Fraunhofer IST), President Prof. Wang (FCU), Dr. Johann Eckl (Fraunhofer-Gesellschaft), Vice president Prof. Tang (FCU).

Opening of the first Fraunhofer Innovation Platform FIP in Taiwan

Fraunhofer IST and Feng Chia University (FCU) develop surface and production technology for optical and electrical systems

About Fraunhofer Innovation Platform FIP

A Fraunhofer Innovation Platform is a temporary Fraunhofer-esque research unit operated by a university or a non-commercial research institution in a foreign country in close cooperation with one or more Fraunhofer institutes in Germany and initially established for a period of five years. In order to exploit, transfer and commercialize scientific research results, the collaborating partners develop a common strategy and a unique business offering in which they synergistically combine their complementary expertise.

October 29, 2024 / As versatile as possible, consistently precise and reproducible but, at the same time, increasingly complex: The requirements for future coating and production systems are constantly increasing. The Fraunhofer Institute for Surface Engineering and Thin Films IST and Feng Chia University (FCU) are collaborating on the "Fraunhofer Innovation Platform for Surface and Production Engineering for Optical and Electrical Systems at Feng Chia University FIP-SPE@FCU" to fulfill this demand.

The aim of the Fraunhofer Innovation Platform is the development of solution approaches for sustainable production systems for high-precision coatings.

By consolidating the collaboration within the Fraunhofer Innovation Platform, we are creating an institutional framework to intensify and further strengthen the partnership between Feng Chia University and the Fraunhofer IST. The close alliance with Feng Chia University creates an important interface for expanding mutual exchange between our two innovation ecosystems and markets to our mutual benefit."

Prof. Holger Hanselka, President of the Fraunhofer-Gesellschaft

Simulation and modeling, as well as the monitoring, control and automation of processes – taking into account human-computer interaction – thereby play an important role. The range of services for industry is supplemented by a comprehensive program of further training in the field of surface technology and production.

The official opening of FIP-SPE@FCU took place on 28th October 2024 in Taiwan. With the signing of the cooperation agreement, the collaboration between the Fraunhofer IST and Feng Chia University – which has already been in existence since 2015 – has attained a new quality.

Underway to trade fairs and exhibitions

1

At HANNOVER MESSE, the Fraunhofer IST trade-fair team presented wear-resistant thin-film sensors that enable precise process monitoring by measuring temperature and pressure directly at the tool surface.

2

Lower Saxony's Minister for Economic Affairs, Olaf Lies, and Minister for Science, Falko Mohrs at HANNOVER MESSE, shown here with the team from the Wasserstoff Campus Salzgitter. (From left to right: Olaf Lies, Dr.-Ing. Stefan Mecke, Falko Mohrs, Thomas Ahlswede-Brech, Prof. Sabrina Zellmer).

3

In the 2024 reporting year, the Fraunhofer IST was once again underway to present the institute's latest research results to audiences of experts at trade fairs, conferences and exhibitions. More than ever before, the Fraunhofer IST recruiting team was present at job and career fairs, establishing contact with young people and showcasing the attractiveness of the institute as an employer.

The Fraunhofer IST was present at HANNOVER MESSE from the 22nd to the 26th of April 2024 with the topic of "Thin-film sensor technology & AI". The focus of its participation within the scope of the adaptronics business area was on the prediction of product quality by means of temperature and pressure measurement directly at the tool surface. With the help of a joint exhibit in the form of an additively manufactured turtle, researchers from the Fraunhofer Group for Production illustrated the different post-processing methods that can be applied to additively manufactured components.Each part of the turtle thereby represented one of a total of nine post-processing methods for plastic, metal or hybrid components.

Furthermore, the institute was present as a partner of the Wasserstoff Campus Salzgitter e.V. at the joint stand of the State of Lower Saxony. One highlight was the visit by Lower Saxony's Ministers Olaf Lies and Falko Mohrs. With participation from Professor Sabrina Zellmer, the discussion focused on the importance of hydrogen for climate protection and the objectives of the Wasserstoff Campus, as well as current activities and project results.

A place where people from our town can engage in conversation with researchers from the region

"How does the Fraunhofer IST fit in with the Helmstedt lignite mining region?" Dr. Guido Hora provided answers to this question at the Salon der Wissenschaft (science salon) on 15th May 2024. As coordinator of the Helmstedt Innovation Center, he is working on the establishment of new projects on technologies and services for the energy transition, the circular economy and sustainable digital agriculture in order to promote value creation in the region. The format is organized by ForschungRegion Braunschweig e.V. and the City of Braunschweig and focuses on interpersonal dialogue rather than traditional presentations. In a series of concurrent rounds, participants were able to engage in personal discussions with scientists from the Braunschweig region on topics such as sustainability, climate protection, digitalization, healthcare, mobility and education.

Change starts with us.

Under the motto of the Fraunhofer-Gesellschaft's new employer-branding campaign "Change starts with us", the Fraunhofer IST recruiting team was present at a number of job fairs in the year under review in order to provide pupils and students with inspiration regarding the numerous career opportunities at the Fraunhofer IST.

4

At the company contact fair "bonding", the institute's job-fair team provided interested pupils and students with information regarding the possibilities of apprenticeships and student jobs at the Fraunhofer IST.

Online format "TransferTalk"

The Fraunhofer IST's online event format "TransferTalk – Industry meets Science", which was launched in June 2023, was continued in the reporting year. In three concise presentations centered around the topic of "Sustainability as the Success Factor in Industries" with subsequent discussion, the participants were provided with information on, amongst other things, how small and medium-sized companies can develop and implement a sustainability strategy and what opportunities and challenges are associated with this.

Continuing education at the Fraunhofer IST

In the 2024 reporting year, the Fraunhofer IST conducted three courses with a total of 26 participants. Alongside the established courses for the changeover to hydrogen, two new programs “think GREEN, act SMART” and “EPR for batteries” were launched. For 2025, an expansion of the “think GREEN, act SMART” training program is planned. In addition to the introductory course on sustainability for companies, two new courses on Life Cycle Assessment will be launched. Our programs at a glance:

Net Zero Scenario – how to achieve it with hydrogen

Since 2022, the Fraunhofer IST, in cooperation with the Fraunhofer Academy, has been offering continuing-education programs for qualification in the hydrogen economy. The training program “Net Zero Scenario – how to achieve it with hydrogen” was developed for management representatives, engineers, employees of municipal utilities, planners, master craftsmen, supervisors and experts who proactively want to understand the opportunities presented by the utilization of hydrogen. Within the framework of e-learning courses, live online meetings and face-to-face events, participants become familiar with the entire value chain of the hydrogen economy. They learn why hydrogen is a key element for a climate-neutral economy and which factors are important for their company when changing over to hydrogen.

The “Net Zero Scenario” program is offered both as a basic course and as a certificate course. While the basic course is aimed at persons who want to acquire a solid basic knowledge of hydrogen and who prefer self-determined learning, the certificate course is particularly suitable for persons who proactively want to understand the opportunities presented by the utilization of hydrogen. The course offers the possibility of obtaining the TÜV personal certificate and, following successful completion of the examination, the title “Hydrogen expert with TÜV Rheinland-certified qualification”.

A total of twelve participants completed this training program in 2024. An English-language version entitled “Net Zero Scenario - how to achieve it with hydrogen” was offered in parallel.

think GREEN, act SMART: Introduction to sustainability for companies

In April 2024, the new continuing-education program “think GREEN, act SMART” – was launched with the course “Introduction to sustainability for companies”. It is aimed at (prospective) sustainability officers and managers as well as employees from purchasing and sales departments who are involved in the development and implementation of sustainability strategies. The emphasis is on topics such as sustainable procurement, transparency in the supply chain, and strategies for the avoidance of greenwashing. In the reporting year, six people participated in this course.

EPR for batteries: Rethinking the cycle

A further offer is the continuing-education program “EPR for batteries: Rethinking the cycle”, which addresses extended manufacturer responsibility for batteries. It teaches the theoretical fundamentals regarding the life cycle of batteries and presents current recycling strategies and legal frameworks. Furthermore, in cooperation with GRS Service GmbH, practical aspects such as the safe collection and storage of used batteries are also covered.

In addition to e-learning and live online sessions, a face-to-face workshop was also conducted at the end of the course. Eight participants successfully completed this course.

The continuing-education programs were met with great interest. The practical relevance, the interactive exchange with experts and the possibility of gaining directly applicable knowledge were particularly appreciated. The Fraunhofer IST now plans to further expand its range of programs in order to be able to meet the increasing demand for specialist knowledge in the fields of hydrogen technologies, sustainability and the circular economy in the future as well.

Information on the current range of continuing-education programs can be found on our website:

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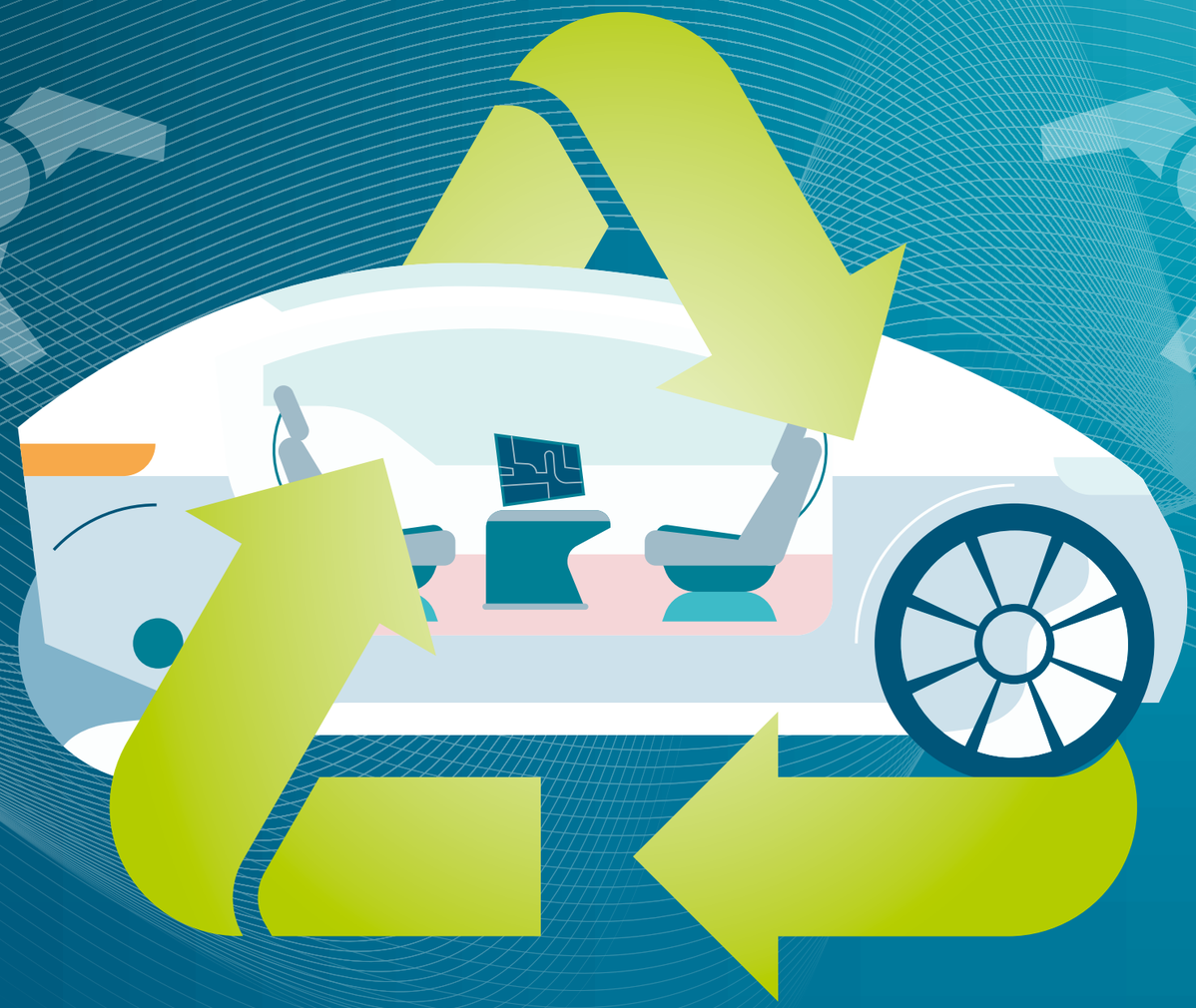
jutta.janssen@ist.fraunhofer.de

The mobility transition

Innovative surface technology as the key to the circular economy



In focus

The mobility sector is facing a radical transformation process towards a sustainable circular economy. Future legal requirements stipulate the increased utilization of recycled materials and the recovery of strategic raw materials in order to reduce geopolitical dependencies. Innovative surface technologies can play a decisive role in the development of durable, resource-conserving and recyclable solutions for mobility.

The transformation of the mobility industry presents an enormous global challenge and necessitates not only innovative strategies for the sustainable utilization of materials but also resource-conserving production processes. Traditional linear production methods result in high resource consumption and considerable environmental pollution, in particular through greenhouse gases that are harmful to the climate. In view of the enormous pressure of costs in the mobility sector, the Fraunhofer IST is developing sustainable solutions for surface technologies that enable an efficient circular economy. The responsible approach towards materials and the reduction of CO_2 emissions are thereby continuously gaining in importance as it is necessary to fulfill the requirements of future legislation within the framework of the Green Deal.

Legal framework conditions and recycling quotas for sustainable vehicle production

The EU has already defined ambitious recycling quotas in order to drive forward the circular economy within the mobility sector. For example, the new ELV Directive (End-of-Life Vehicles Directive, 2000/53/EC) stipulates that from 2031, a minimum of 25 % of the plastic used in new vehicles must come from post-consumer recycling and end-of-life vehicles. In combination with further measures, the aim is to achieve an annual reduction in CO_2 emissions of 12.3 million tons by 2035, improved recycling of 5.4 million tons of materials, and increased recovery of important raw materials. In order to achieve these decarbonization targets throughout the entire life cycle of a vehicle, it is becoming increasingly important for production methods to become more sustainable, product-usage phases to be extended, and recycling processes to be implemented.

“The transformation of the mobility industry is one of the greatest global challenges of our time. At the Fraunhofer CCEM, we implement innovative solutions that drive forward the sustainable utilization of materials as well as resource-saving production and dismantling processes. We see ourselves as pioneers for circular processes within the automotive industry, with the goal of leading it into an environmentally-friendly future.”

Prof. Dr. Michael Thomas, Head of the Fraunhofer CCEM

Pioneering work for circular processes within the automotive industry

In order to achieve these goals, innovative technologies are required that close material cycles and reduce emissions. This is where the Fraunhofer Center Circular Economy for Mobility CCEM in Wolfsburg comes into its own. At the Fraunhofer CCEM, the Fraunhofer IST is working in collaboration with the Fraunhofer institutes IFAM, IWU and WKI on the development of solutions that encompass the entire automotive-industry value chain - from material production, through the manufacturing process, and on to the automated reconditioning and dismantling of battery cells, recycling and the development of holistic approaches for Life Cycle Assessment. One particular focus thereby lies on surface technologies for circular processes that enable the efficient application of secondary materials and renewable raw resources, extend the service life of components, and support environmentally-friendly end-of-life strategies for products.

Vehicle interiors of the future: flexible, sustainable, recyclable. Autonomous driving and new mobility concepts are fundamentally changing interior design. Innovative materials can thereby significantly improve durability and recyclability.

Spotlight on sustainability and flexibility

Future Interior

Autonomous driving and new mobility concepts such as “shared mobility” are shifting the focus to the requirements of future vehicle interiors. While today the driving experience constitutes the primary concern, in future versatile usage scenarios will determine the design - from the mobile workplace through to the relaxation area. Furthermore, customer demand is increasing as regards sustainable, durable and recyclable materials that enable both comfort and flexibility in the vehicle interior. In addition, the mobility industry needs economically viable solutions for recycling requirements.

Coating and surface technologies as the key to sustainability

In order to overcome these challenges, the Fraunhofer IST is conducting research into sustainable coatings in which functions can be integrated. One example is bio-based coatings that make sensitive natural materials more resistant, thereby enabling their long-term utilization in interiors without impairing their recyclability. In addition, possibilities for adhesion control and debonding-on-demand technologies are being developed in order to ensure the recyclability of material composites.

Extended service life through innovative methods of cleaning and repair

Particularly in the field of “shared mobility”, the service life of interior components is significantly influenced by the extent to which they can be cleaned and repaired. Conventional methods are often non-sustainable or economically inefficient. The Fraunhofer IST is therefore working on automated, material-friendly cleaning and repair methods that contribute towards an extension of the service life, thereby driving forward the sustainable transformation of the mobility industry.

“In order to meet the needs of users, the environment and industry, we focus on developing processes and materials that combine comfort, sustainability and technology in a seamless and regenerative manner.”

Lara Natalie Bohe, Research Associate at the Fraunhofer CCEM

Recyclable composite materials with functional surfaces.

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The establishment of a circular economy in the automotive industry requires innovative approaches that not only protect the environment and secure the access to raw materials, but can also be economically implemented through automated processes.”

Tom Heise M.Sc., Research Associate at the Fraunhofer IST

2

Key technology for sustainable mobility

Automated dismantling processes for a closed-loop automotive industry

In view of the global ecological challenges and scarcity of resources, the establishment of a circular economy in the automotive industry is increasingly gaining in importance. In particular, the multitude of vehicle variants and the often unknown condition of end-of-life vehicles make dismantling and recycling more difficult. As a result, manual dismantling is inefficient and is generally only carried out for selected components. In order to achieve an efficient circular economy with type-sorted material recovery, the Fraunhofer IST is concentrating on the automation of dismantling processes.

Increased efficiency through automated dismantling of complete vehicles

A central focus concerns the development of automated dismantling of the entire vehicle, which begins by separating component groups from the vehicle. To achieve this, dismantling strategies are being developed that take into account the economic, ecological and technical complexity of the dismantling process – depending on the vehicle type, equipment and condition. The aim is the development of an automated dismantling cell that can react flexibly to these strategies. For this purpose, a robot cell has been constructed with which the releasing of joints and the recognition of components and their condition can be tested.

Innovative robot technology for the safe disassembly of high-voltage batteries

A further focus is the automated disassembly of high-voltage batteries from electric vehicles. This presents challenges that go beyond the classic disassembly problems, particularly in the case of components that are not suitable for disassembly, such as connectors with an engaging mechanism. The Fraunhofer IST has developed a robot cell for the safe and efficient disassembly of such connectors. This is equipped not only with an end effector with a gripper that is adapted to the connector geometry, but also with component recognition by means of computer vision.

Component recognition by means of computer vision. (Above) Robot cell for the automated disassembly of connectors. (Below)

New pathways to sustainable mobility

Efficient recycling through surface technologies

The vehicle of today will become the raw material of tomorrow.

Recycling loop for painted polymer components in the automotive industry.

Recycling in automotive manufacturing is increasingly gaining in importance due to the fact that resource scarcity, strict environmental regulations and the necessity to reduce CO_2 emissions are presenting the industry with new challenges. Modern vehicles are made from materials that are becoming more and more complex – in particular composite materials, which reduce weight, increase efficiency and enable new combinations of properties. It is, however, precisely this diversity of materials that makes recycling difficult, as different materials are often firmly and durably bonded to one another.

Separation processes for efficient recycling

This is where innovative surface technologies come into play: With the aid of special separation processes, composite materials can be selectively broken down, thereby enabling valuable raw materials to be recovered efficiently. Laser and plasma technologies can specifically remove coatings, for example to prepare plastic components for processing, repair or recycling of the raw materials. In addition, chemical and mechanical processes make it possible to remove coatings without damaging the base material.

A further approach is so-called “debonding on demand”, in which targeted surface modifications enable material composites to be designed in such a way that they can be specifically detached as required – a technology that will make future Re-X processes considerably easier.

These and other solutions from the Fraunhofer IST provide a decisive contribution towards a circular economy in automotive construction, reduce material losses, and enable enhanced sustainability in production processes.

The future of mobility requires innovative solutions for the recycling of complex material composites. Through the application of state-of-the-art surface technologies and separation processes, we are able to efficiently recover valuable resources.”

Dr. Thomas Neubert,
Research Associate at the Fraunhofer CCEM

Taking the end of life into account right from the start

Holistic Life Cycle Engineering

Vehicle production is one of the most resource-intensive industries in the world and, according to Statista, generated sales of more than 564 billion euros in Germany in 2023. The Paris Climate Treaty and the global scarcity of resources necessitate a radical paradigm shift in the industry. In this context, the EU is currently revising the End-of-Life Vehicles Directive, thereby proposing a future-proof system of rules that improves end-of-life recycling, promotes reutilization and ensures the most efficient utilization of valuable resources.

Future-oriented vehicle production: Life cycle- and AI-based strategies for the circular economy

Amongst other things, these requirements are forcing car manufacturers to increase the proportion of secondary materials and to take into account – from the product-development stage onwards – the extent to which components can be dismantled and separated. At the Fraunhofer CCEM, the Fraunhofer IST, in collaboration with the TU Braunschweig and the Ostfalia University of Applied Sciences, is researching an AI-supported evaluation methodology that enables Re-X strategies to be effectively integrated into the development process of vehicles and their components.

With its comprehensive expertise in multi-criteria evaluation and Life Cycle Engineering, the Fraunhofer IST provides automotive manufacturers with support in the identification of potential for improvement in product development and in the profitable implementation of Re-X strategies. This not only promotes the circular economy, but also contributes towards the sustainable development of the automotive industry in Germany and Europe.

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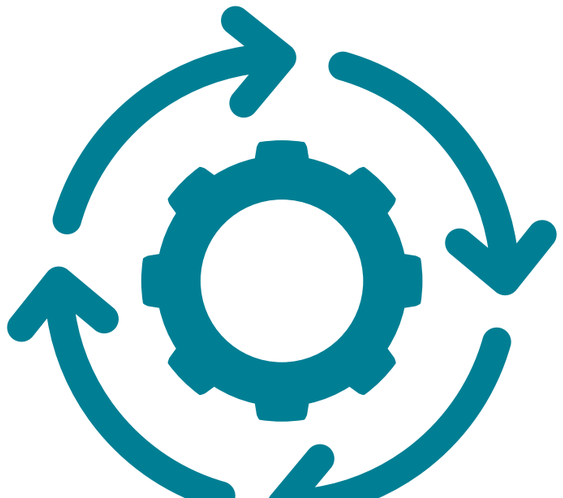

> **Life Cycle Engineering provides concrete technical measures which enable the achievement of an environmental goal set in vehicle development."**
>
> **Prof. Dr. Stephan Krinke, Head of Department at the Fraunhofer IST**

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Tailor-made and sustainable

Our industry solutions for your applications

Sustainable energy storage systems and converters:
Sustainable solutions for green hydrogen and energy storage systems

The future of solar-cell production

From research:

- Project "ScaleH2":
  Innovative electrolyzers for the import of hydrogen into Germany
- Analytics for battery technology
- Sustainable recycling of silicon photovoltaic modules
- Functional layers for highly efficient perovskite-silicon tandem solar cells

Functional sustainable solutions for future vehicle concepts

Innovative solutions for aerospace:
Focus on precision, sustainability, and progress

Highly stressable thin-film sensors for in-situ measurement results

From Research:

- Thin-film sensors and PVD coating systems:
  Innovative face contacts for extremely high-power energy transmission
- Investigation into tribocorrosive stresses:
  Interactions of wear and corrosion
- Substitution of the chemical pretreatment by inter-layer systems:
  CVD diamond coatings for cutting tools

Optical technologies for the future:
Precision and innovation

From Research:

- Compact hyperspectral filters:
  The key to smart agriculture

Coating and surface technology for medical technology and pharmaceutical systems

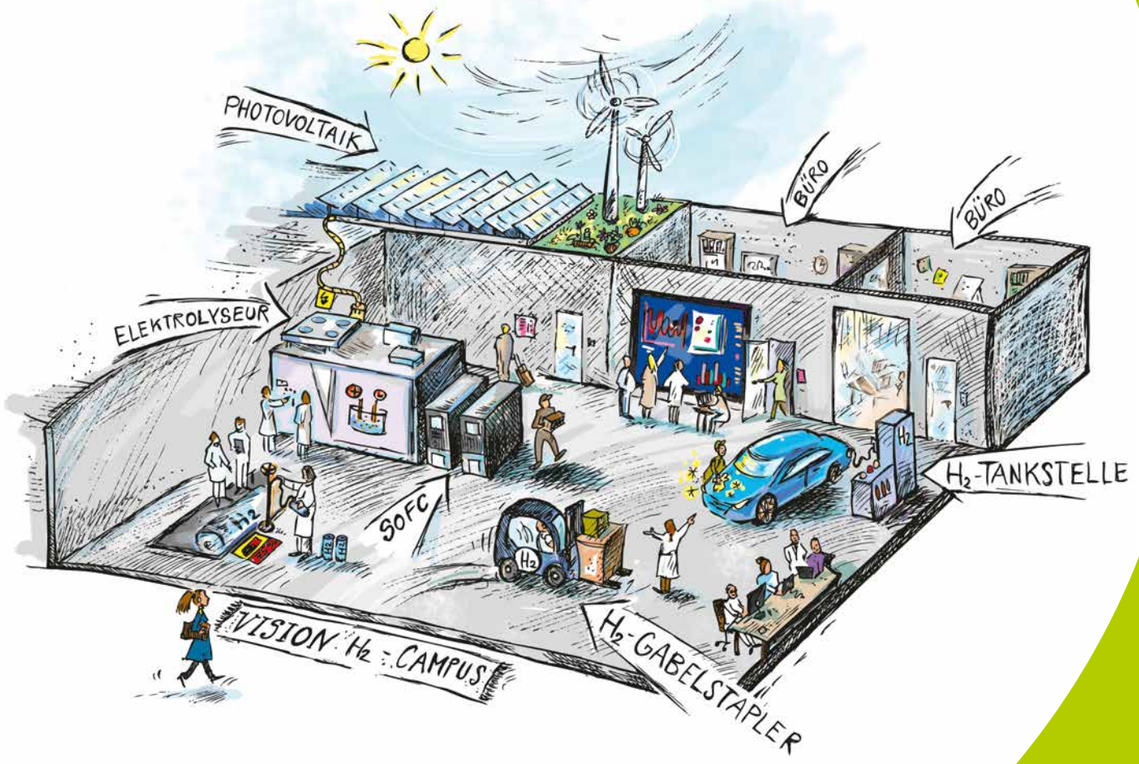
From Research:

- Project "KaPlaTech":
  Low-energy plasma spraying for plasma-mediated drug delivery

Sustainability management und Life Cycle Engineering:
Enhancing the sustainability of German industry through application-oriented solutions

From Research:

- Project "TranSensusLCA":
  Holistic analysis of the environmental profile of vehicles throughout their life cycle



What once began as a vision is now a reality: a networked research and innovation platform that drives hydrogen technologies sustainably forwards along the entire value chain – from their creation, through their utilization, and on to their storage.

By working in cooperation with us, you can benefit from:

- Customized further-training programs
- Development of material, production and recycling processes
- Analysis of existing processes and development of customized LCM strategies

Sustainable energy storage systems and converters

Sustainable solutions for green hydrogen and energy storage systems

What are the biggest challenges in the field of energy technologies?

"In the transition from fossil fuels to renewable energies, a holistic view of the entire product life cycle of components for hydrogen and battery applications is crucial; this will enable the effective and resource-conserving storage of energy from renewable sources and the promotion of a green energy economy. In addition, high production costs and the lack of infrastructure are major hurdles standing in the way of widespread market acceptance. At the Fraunhofer IST, we pursue the goal of realizing technologies economically and ecologically. In order to achieve this, we are developing innovative approaches for the production, utilization and recycling of energy storage systems and converters."

What does the Fraunhofer IST offer companies that are working on energy storage systems and converters?

"At the Fraunhofer IST, we develop holistic concepts for the creation and utilization of green hydrogen as well as for the production of sustainable components for energy storage systems and converters. One particular focus is on the sustainable design of the entire product life cycle, from which our customers benefit through targeted methodological support. Furthermore, we offer training programs in which participants from industry and research acquire fundamental knowledge and have access to the latest research results. In this way, practical specialist knowledge is promoted in order to drive forward innovative and sustainable solutions within companies."

Looking back and looking forward – what was your personal highlight in the reporting year and what can the industry expect from the Fraunhofer IST in the future?

"Within the framework of the Wasserstoff Campus Salzgitter, numerous projects have been successfully completed, including in the field of factory transformation. In collaboration with the Innovationsverbund (innovation network) and further projects, the Campus was able to firmly establish itself and was ultimately founded as the Wasserstoff Campus Salzgitter e. V. The association, which was initiated by key players from business, science and politics, pursues the goal of driving forward hydrogen technologies along the entire value chain – from creation through to utilization – whilst taking into account the economic and ecological aspects. Furthermore, it serves both regionally and nationally as a training and further-education platform for specialists and managers."

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From research

Project "ScaleH2"

Innovative electrolyzers for the import of hydrogen to Germany

In order to achieve Germany's climate targets, 50 to 70 percent of future hydrogen demand will have to be covered by imports from abroad by 2030. The establishment of international energy partnerships is therefore a core element of the German hydrogen strategy and, at the same time, opens up considerable potential for the export of German hydrogen technologies for the expansion of global production capacities with cost-effective systems for electrolysis.

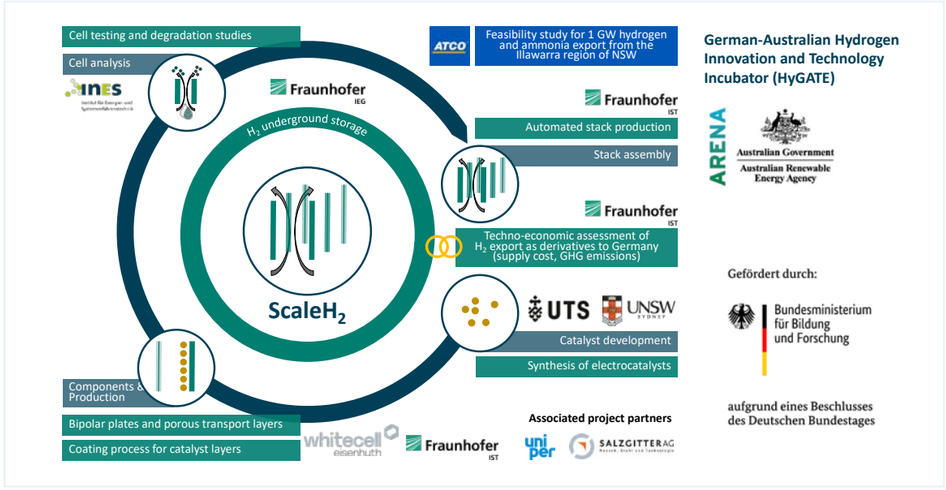
The successful launch of the hydrogen economy can only be achieved through the economic creation of green hydrogen by means of highly efficient and sustainable electrolysis technologies. In the "ScaleH2" project organized by the German-Australian funding initiative HyGATE, the Fraunhofer IST is working in collaboration with German and Australian partners on, amongst other things, the further development of proton-exchange membrane (PEM) electrolysis. The focus thereby lies on the development and processing of innovative catalyst materials as well as the optimization of the automated production of electrolysis stacks. One key element in reducing investment costs and scaling up the production capacities of commercially available PEM electrolyzers is the reduction of the quantity of platinum and iridium used in the catalysts – without thereby compromising the performance capabilities of the electrolyzers.

Efficient production of electrolysis stacks: innovative coating processes and automation

A fundamental aspect of the project is the process development for the production of the membrane-electrode unit coated with the catalyst material – the main component of the electrolysis cells. Cold plasma spraying, an innovative coating procedure, is hereby utilized in order to process the catalyst produced at the University of New South Wales. Simultaneously, the automation of scalable production procedures in the stacking process for the electrolysis stacks is being further developed in order to enable efficient and economical series production. The implementation and optimization of the automated production of the stacks is performed using the Fraunhofer IST stacking machine at the Hydrogen Campus Salzgitter.

Cost analysis and environmental assessment of hydrogen exports from Australia to Germany

The project builds upon the feasibility study conducted by the company ATCO, which investigates the development of an electrolysis capacity of 1 GW in the state of New South Wales as well as the export of green ammonia for the European market. The Fraunhofer IST is thereby modeling the economic feasibilty and potential for cost reduction – from hydrogen production to potential offtakers in Germany. In addition, the greenhouse-gas emissions along the entire supply chain are being evaluated based on the requirements of the Renewable Energies Directive III for the utilization of hydrogen and hydrogen-based products. In line with the project work carried out by the Fraunhofer IEG, the potential of underground hydrogen-storage facilities in Germany and Australia is also being taken into account.



Project overview with respective areas of focus.

Outlook

The next important step in the project is the production of the electrode layer using the catalyst material supplied from Australia. Subsequently, the electrochemical characterization and the evaluation of the performance capabilities of the electrolysis cells will be carried out. The fabricated components of the membrane-electrode units and bipolar plates will be used to manufacture the stacks.

The project

Funding body: German Federal Ministry of Education and Research

Duration: 01.05.2023 - 30.04.2027

Funding reference: 03SF0711A

Project partners:

- ATCO
- Fraunhofer Research Institution for Energy Infrastructures and Geotechnologies IEG
- TU Braunschweig, Institute of Energy and Process Systems Engineering
- University of New South Wales
- University of Technology Sydney
- Whitecell Eisenhuth GmbH & Co. KG

Automated stacking machine for the production of PEM electrolysis stacks at the Wasserstoff Campus Salzgitter.

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From research

Analytics for battery technology

Battery storage systems play a decisive role in the transformation towards the utilization of renewable energies. Next-generation battery systems must achieve a higher storage capacity, a longer service life, a lower environmental impact and a high level of safety. In addition to the development of battery materials and battery cells, the Fraunhofer IST offers comprehensive possibilities for the characterization of these materials and cells, thereby enabling an in-depth understanding of the materials and properties of batteries.

Precision cut through an NMC particle comprised of $Li(NiMnCo)O_2$ battery material by means of a focused ion beam in order to illustrate the internal pore structure.

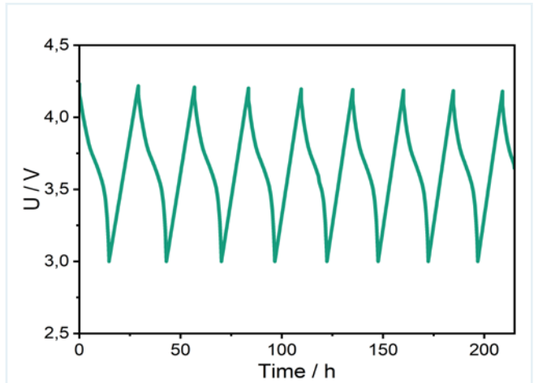
Preparation of electrochemical measurements of new materials in button cells.

Sample preparation under exclusion of air

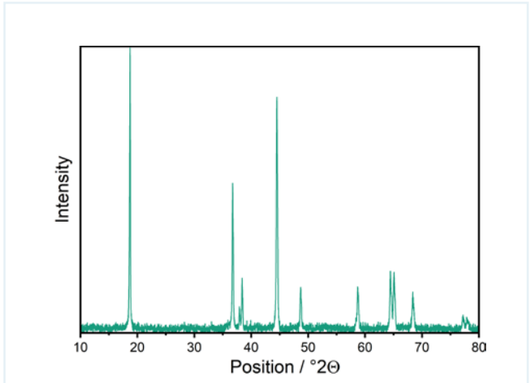
Many battery materials degrade upon contact with air, which restricts the application of analytical methods under atmospheric conditions. At the Fraunhofer IST, a transfer shuttle is available which makes it possible to prepare battery samples in a glovebox and then transfer them to a scanning electron microscope (SEM) under inert gas. This enables high-resolution imaging as well as chemical analyses of the uninfluenced materials. In cases where the utilization of a shuttle is, however, not possible, customized concepts are developed at the Fraunhofer IST in order to ensure measurement quality while simultaneously preventing contact with the air.

Material analytics for novel solid-state electrolytes

Solid-state electrolytes have the potential to replace liquid electrolytes and to thereby enable improved properties. Solid electrolytes facilitate the application of lithium metal anodes, for example, and can therefore significantly increase the energy density, amongst other things. Material analytics enables the targeted optimization of properties and is therefore essential for development. In particular, sulfide solid-state electrolytes can be analyzed in terms of their phase purity by means of Raman spectroscopy, for example. The particle morphologies and the electrodes produced on the basis of these solid-state electrolytes can be examined with the aid of an SEM. Furthermore, energy dispersive X-ray spectroscopy (EDX) enables precise analysis of the elemental compositions, whilst X-ray diffraction (XRD) can be applied to determine the crystallinity. Through the combination of these methods, a comprehensive material analysis is achieved that provides valuable insights into the properties and behavior of novel solid-state electrolytes.



The battery-cell voltage during cycling.



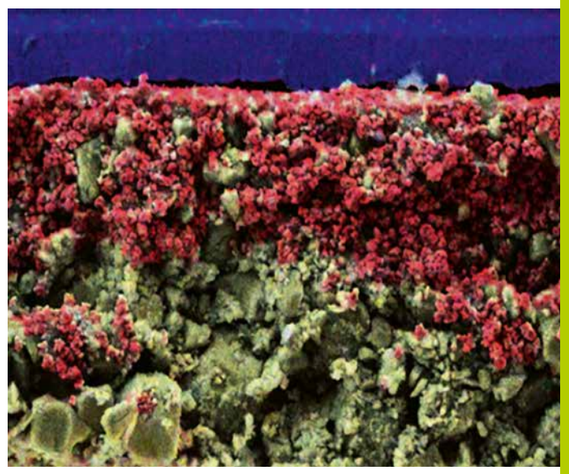
X-ray diffractogram of the active material of a cathode.

Electrochemical characterization

Whilst the analysis of the individual materials provides valuable information regarding their suitability for utilization in batteries, the actual functionality can only be assessed in practical application. By means of electrochemical characterization, the behavior of the battery during the charging and discharging process can be comprehensively characterized. Cyclization experiments are performed in order to evaluate not only the service life but also the charging and discharging properties of the battery cells. A detailed insight into the electrochemical processes can be gained through electrochemical impedance spectroscopy. This method allows the individual transport processes within the battery to be analyzed in detail and their influence on the overall performance to be understood.

Post-mortem analysis – Troubleshooting in the event of battery failure

In the case of defective batteries, identification of the cause of the failure is often of interest. Firstly, the electrochemical data recorded shortly before the defect can provide valuable information. Secondly, the opening of the cells and the subsequent analysis enables insightful information to be acquired regarding the cause of the fault. Furthermore, microscopic imaging methods in combination with elemental analysis can provide detailed information concerning interfaces and material alterations. This information can be validated using further analytical methods in order to gain a comprehensive understanding of the damage mechanisms and to prevent problems in the future.



An SEM-EDX cross-section of a cathode layer with a solid-state electrolyte on aluminum foil.

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Energy / photovoltaics

The future of solar-cell production

What are the biggest challenges in the photovoltaic industry?

"The challenges in the PV industry are manifold. Although photovoltaics is now the most affordable technology for the generation of electricity, there are still major hurdles to overcome. One of the key issues is insufficient grid integration and limited storage options. This situation makes it impossible to feed all of the created electricity into the grid, and the resulting increased grid fees have to be borne by the consumers. A further problem lies in the production chain: PV modules are predominantly manufactured in China. In order to strengthen Europe's resilience in this field, independent European module production is necessary. The associated higher costs would only have a minor impact on electricity generation costs – less than 0.5 Cent per kilowatt hour."

What does the Fraunhofer IST offer companies from the field of photovoltaics?

"Innovations in PV cell technology can contribute towards reducing the electricity generation costs. At the Fraunhofer IST, we develop processes and system technologies for the production of the most diverse functional layers for the latest tandem cell technologies in order to significantly increase cell efficiencies. One particular focus thereby lies on the adaptation of these to the G12 standard format for silicon solar cells (210 mm x 210 mm) and the demonstration of their scalability. One example of this is the development of a hybrid vacuum system for perovskite-silicon tandem cells. This system enables the precise and efficient deposition of several functional layers in succession – the passivation layers for the perovskite, the electron contact layers and the subsequent buffer layers – with high homogeneity and in high quality on the aforementioned dimensions."

Looking back and looking forward – what was your personal highlight in the reporting year and what can the industry expect from the Fraunhofer IST in the future?

"One particular highlight in the reporting year was the success of the Fraunhofer flagship project 'Materials for sustainable tandem solar cells with maximum conversion efficiency' (MaNiTU). Through the combination of theory and modeling, material screening, material selection, and cell development and analysis, six Fraunhofer institutes have succeeded in achieving a new cell-efficiency record of 32 % for perovskite-silicon solar cells cells using industry-compatible processes – while taking sustainability into account as a central aspect. These advances have so far been achieved on a cell size of 1 cm²; all the applied technologies are, however, capable of being scaled up to the G12 standard format. In the future, the Fraunhofer IST will provide companies with support in transferring the developed technologies into industrial applications, thereby significantly advancing the further development of photovoltaics."

Combination of linear evaporation and atomic layer deposition for the production of a large-area front-contact system (Al_2O_3/C60/SnO_2) for perovskite-silicon tandem solar cells in one single vacuum coating system.

By working in cooperation with us, you can benefit from:

- Development of innovative process and system technologies for the production of functional layers for novel solar-cell concepts
- Research into new cell concepts such as perovskite-silicon tandem solar cells
- Development and characterization of new materials for solar cells
- Transfer of the developed technologies to industry

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Pyrolysis as a key technology

Sustainable recycling of silicon photovoltaic modules

Photovoltaic modules have an average service life of 25-30 years. In addition to natural ageing, other issues that can lead to modules having to be replaced prematurely include economic factors or damage caused by environmental influences. With the rapid expansion of solar energy, the quantity of disused solar cells will therefore increase considerably in the coming years. This development presents a major challenge, as the raw materials incorporated into the modules, such as silver, glass, silicon, metals and polymers, are valuable resources that must be recovered efficiently. In this respect, pyrolysis offers promising approaches for sustainable and economical recycling.

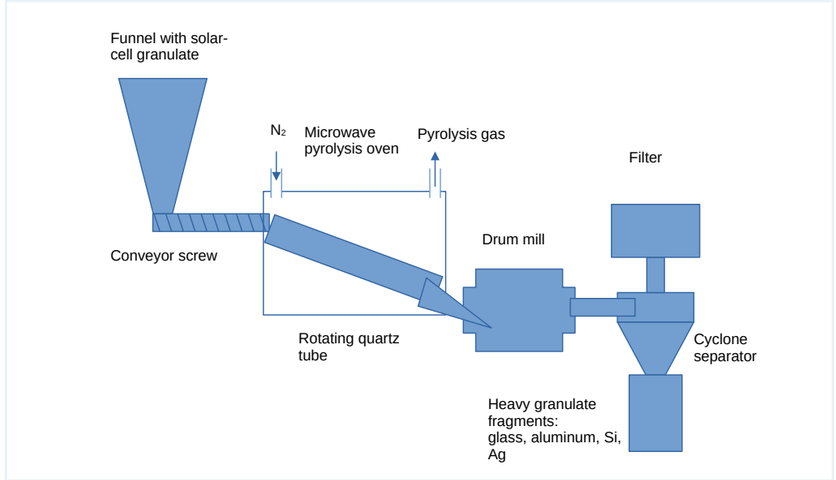
Microwave pyrolysis system developed within the "PV-Kreis" project.

Efficient recycling through microwave-excited pyrolysis

Conventional recycling processes have their limitations, particularly in the case of damaged or broken PV modules. The approach investigated at the Fraunhofer IST therefore relies on the thermal decomposition of the organic components by means of microwave-excited pyrolysis. This innovative method enables the efficient heating of the modules, which is necessary for the separation of the different materials. Simultaneously, the polymers contained in the modules can be recycled both materially and energetically in the form of pyrolysis oils and gases. This not only contributes towards the recovery of valuable raw materials, but also offers a sustainable solution for a resource-conserving circular economy.

Results

In a first step, the structure and material composition of various silicon PV modules were examined in detail. By means of thermogravimetric analysis (TGA), the temperature required for thermal decomposition as well as the composition of the gaseous pyrolysis products of granular PV modules were determined in particular. Based on these findings, a system concept was developed in collaboration with the project partners, which has since been implemented in a prototype plant.

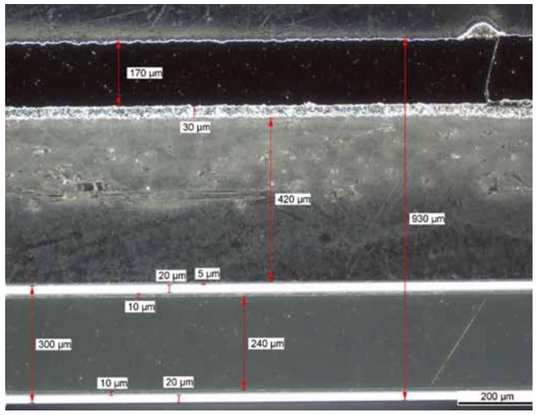


System concept for the microwave pyrolysis of PV modules.

This prototype plant represents an important step forwards in the practical application of microwave-excited pyrolysis and offers the possibility of further optimizing the efficiency and economic viability of the recycling process.

	Single-pane safety glass (ESG)	3250 µm
	Ethylene-vinyl acetate (EVA) - transparent	375 µm
	Si wafer	200 µm
	Ethylene-vinyl acetate (EVA) - transparent	425 µm
	Polyvinyl fluoride (PVF)	25 µm
	Polyethylene terephthalate (PET)	250 µm
	Polyvinyl fluoride (PVF)	25 µm

Determined material composition of an Si PV module.



Microscope image of the cross-section of an Si PV module.

Outlook: Optimization, emission control, and material expansion

In the further course of the project, the prototype plant will be put into operation and intensively tested in order to continuously optimize the process control. The primary focus will thereby be on the neutralization of toxic process gases – such as hydrofluoric acid – and the determination and minimization of the required energy input. Furthermore, plans are in place to integrate other composite materials into the recycling process in the future; these include glass-fiber- or carbon-fiber-reinforced polymers as well as electrical elements or electronic components.

The project

The work was funded within the framework of the BMBF joint project "Circular Economy menschengerecht gestalten" (Circular economy with human-oriented design, "PV-Kreis") under the funding reference 02L22C114.

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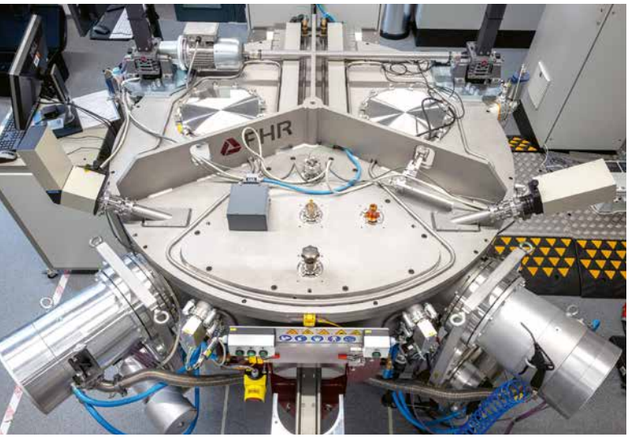
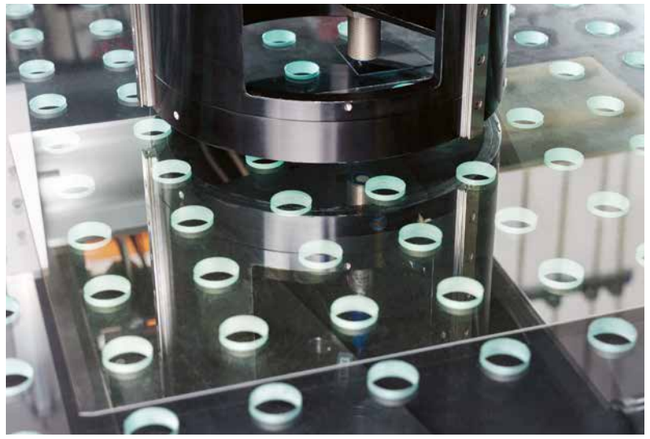


Application of inline measurement technology for the determination of layer-thickness dependence, e.g. of SnO_2 on C60, as well as for the analysis of the time lag occurring at the beginning of the SnO_2 deposition.

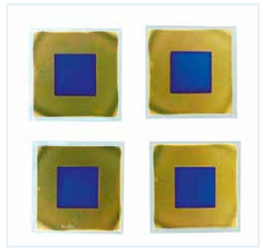


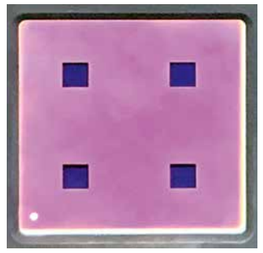
Large-area deposition of a C60/SnO_2-electron-contact coating system on glass.

Sustainable coating technologies and industrial manufacturing processes

Functional layers for highly efficient perovskite-silicon tandem solar cells

In addition to the solar absorber, functional layers within a solar cell are crucial for the production of highly efficient solar cells. This requires the development of electronically suitable materials that exhibit very low absorption and can simultaneously be produced over a large area with a high deposition rate. Within the framework of the Fraunhofer flagship project "MaNiTU", the Fraunhofer IST has been working in collaboration with five other Fraunhofer institutes over a period of five years on the research and optimization of perovskite-silicon tandem solar cells. The development of these innovative solar cells using stable materials and scalable production processes is a decisive step forwards for the next generation of photovoltaics.

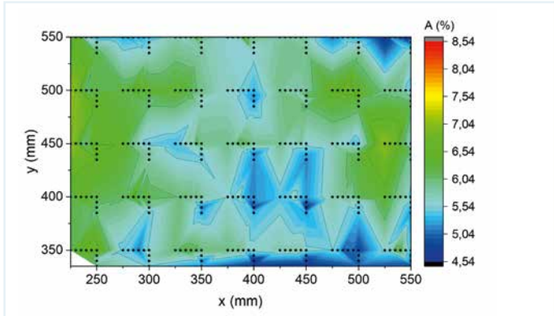




Above: Four 10 mm x 10 mm solar cells are shown, which were simultaneously coated with an IZO front contact. Below: The coated mount, whose homogeneity is evident from the uniform interference color on larger areas.

Progress in material development and process integration

During the Fraunhofer IST's flagship project "MaNiTU" (Materialien für nachhaltige Tandemsolarzellen mit höchster Umwandlungseffizienz – Materials for sustainable tandem solar cells with maximum conversion efficiency), the focus was directed towards the development of industry-oriented system components and coating technologies for high-performance contact materials. One challenge lay in the temperature sensitivity of the perovskite cell, which requires a processing temperature of below 100 °C. For this purpose, an innovative process chain was developed that combines ALD and evaporation processes in an SALD hybrid system and is supplemented by a concluding sputtering process.



From the transmission and reflection mapping, the absorption of the C60/SnO_2-electron-contact layer system can be depicted. The measurements were carried out on the black points.

Scalable manufacturing processes for functional layers

For efficient energy conversion, a variety of functional layers within the tandem solar cells play a decisive role. The Fraunhofer IST focused on the development and industrialization of the following layers:

Front contact
A central objective was the implementation of a transparent conductive oxide as a front contact that can be produced over a large area (> G12) with a high deposition rate. Through reactive sputtering of an inexpensive metallic InZn tube target with a length of around 750 mm, the researchers at the Fraunhofer IST were able to realize a process on the basis of indium zinc oxide (IZO) and to successfully test it on cells. Efficiency levels of over 28 percent were thereby achieved.

Passivation, electron-contact and buffer layer system
By combining thermal atomic layer deposition (ALD) and a new SALD hybrid system, it was possible to deposit metal oxides such as tin oxide (SnO_2) and aluminum oxide (Al_2O_3) over large areas and at low temperatures. These processes were successfully transferred from conventional methods to an industry-oriented hybrid system. In addition, a thermal PVD linear evaporator for C60 was developed and integrated into the SALD system. In future, this will enable the homogeneous coating of wafers in G12 format without vacuum breakage. Initial tests have shown promising passivation properties on perovskite layers.

Outlook

With the successful development and optimization of industrial coating and contacting technologies for perovskite-silicon tandem solar cells, the Fraunhofer IST has provided a significant contribution towards the further development of photovoltaics. The next step is to transfer the technology to industrial applications. In collaboration with partners from industry, the institute is working on establishing the developed processes for the economical and sustainable production of high-performance solar cells.

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Vehicle technology

Functional sustainable solutions for future vehicle concepts

What are the biggest challenges in the automotive-technology industry?

"From e-mobility, through car-sharing and autonomous vehicles, and on to the circular economy: The mobility industry is facing profound changes and requires innovative strategies for the development of durable products, sustainable functional interior concepts and resource-conserving processes – both in the production and in the recovery of materials. This is where the Fraunhofer IST comes in: We develop sustainable solutions for functional surfaces and technologies that support an efficient circular economy, enable the design of functional interiors, extend the service life of vehicles, and reduce CO_2 emissions."

What does the Fraunhofer IST offer companies from the industry?

"At the Fraunhofer IST, we work on customer-specific solutions that encompass the entire value chain of vehicle technology - from tribological and sensor surfaces for the production process as well as functional coatings and automated cleaning processes for the vehicle interior, through optical coatings for sensor systems, which play a central role in autonomous vehicles, and on to technologies for the automated reconditioning and dismantling of vehicles as well as recycling processes for feeding materials back into the cycle. All of our developments are evaluated from, in particular, the economic and ecological perspectives."

Looking back and looking forward – what was your personal highlight in the reporting year and what can the industry expect from the Fraunhofer IST in the future?

"One outstanding project is 'DigiPro2Green', in which we have optimized and integrated thin-film sensors in order to be able to monitor injection-molding processes more efficiently and to make them more sustainable. This enables a greater utilization of recyclates in production processes. A further pioneering project is 'FutureCarProduction', in which the focus is directed towards the ecological and economic evaluation and the development of alternative processes to giga-casting in car-body construction. At the Fraunhofer CCEM in Wolfsburg, we are conducting research within the Joint Research Group (JRG) 'Sustainable Material and Surface Systems' on sustainable bio-based coatings that make sensitive natural materials more resistant, thereby enabling their long-term use in interiors. Furthermore, in the 'Circular Economy' future lab there, we are working on automated, material-friendly cleaning and repair methods that extend the useful life of components and, consequently, help to drive forward the sustainable transformation of the mobility industry. Recycling is a key topic for the future. We are therefore conducting research into both the automated dismantling of vehicles and innovative technologies for the mechanical and chemical recycling of materials."

By working in cooperation with us, you can benefit from:

- Smart sensor solutions for the monitoring of production processes
- Deposition of complex, multifunctional layer systems with the aid of the most diverse coating techniques
- Automated disassembly, cleaning and reconditioning processes
- Life Cycle Engineering
- Development of circular processes and products
- Innovative functional interior concepts

Circular manufacturing in vehicle technology: High-tech processes create the foundation for the sustainable mobility solutions of tomorrow.

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Innovative solutions for aerospace

Focus on precision, sustainability, and progress

What are the biggest challenges in the aerospace sector?

"The aerospace industry is currently faced with diverse and complex challenges. Strict environmental stipulations – such as the REACH regulation – are putting pressure on companies to replace critical substances such as chromium(VI) or cadmium with more environmentally-friendly alternatives. At the same time, the requirements regarding material diversity, process quality and resource efficiency are increasing. Innovative approaches are required in order to ensure the precise handling of complex component geometries, particularly with regard to new manufacturing technologies such as additive manufacturing. In space travel, optical technologies play a key role, for example in Earth observation, solar-system research and laser communication. Here, the demands placed on optical coatings are increasing in terms of quality, surface area, sharpness of filters and precision. In addition, hyperspectral measurement methods are constantly gaining in importance and necessitate highly specialized optical coatings."

What does the Fraunhofer IST offer to companies in the field of aerospace?

"At the Fraunhofer IST, we develop customized solutions that are specifically tailored to the requirements of the aerospace industry. In particular, materials such as polymers, light metals or CFRP are coated in order to achieve special functions such as corrosion and wear protection or electrical conductivity. In the field of aerospace, we offer high-precision optical and optical-functional technologies and coatings. Our range of services extends from optical filters in the UV to the LWIR infrared range, through electrochromic coatings, and on to special coatings that can actively remove dust deposits from their surfaces. A further focus is on special gradient filters, which are of crucial importance for hyperspectral spectral filtering in Earth-observation applications."

Looking back and looking forward – what was your personal highlight in the reporting year and what can the industry expect from the Fraunhofer IST in the future?

"One milestone was the development of a procedure for supplying energy on the Moon. A long-term secure energy supply is an important component for the future colonization of the Moon. This involves extracting iron from the lunar rock (regolith), burning it and then utilizing the resulting heat to generate electricity. The resulting iron oxide is electrochemically converted back to iron and oxygen. This process can also contribute towards the decarbonization of the energy supply on Earth.

A further highlight was the development of a multi-gradient coating. This coating contains an extremely compact bandpass filter that is applied directly to a CMOS chip. The central wavelength of this filter extends over a length of only 10mm and covers a very large spectral range from the blue range (400 nm) through to the infrared (1700 nm). For this development, 5 highly complex filter coatings, each with more than 200 layers, were necessary."

By working in cooperation with us, you can benefit from:

- Individual solutions: Customized pre-treatment and coating processes for specific requirements
- Sustainability: Development of resource-conserving and environmentally-friendly processes that are REACH-compliant
- Process digitalization: Increased efficiency through modular plant concepts with digital process control
- Material diversity: Expertise in the handling of complex geometries and hybrid materials
- Holistic life cycle assessment: Systematic environmental analyses throughout the entire life cycle

Metallized CFRP honeycomb structure.

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Mechanical engineering and production technology

Highly stressable thin-film sensors for in-situ measurement results

By working in cooperation with us, you can benefit from:

- Multisensory thin-film sensors for the measurement of force and temperature
- Customer-specific sensor design
- Utilization in tribologically highly stressed applications

What are the biggest challenges in mechanical engineering and production technology?

"In mechanical engineering and production technology, we face complex challenges in the field of sensor technology. Increasing digitalization and automation require precise data collection and evaluation in real-time. in real time. The integration of various sensors and systems is therefore crucial in order to enable comprehensive data analysis and the optimization of processes in real time. The demands thereby placed on sensor technology are high: The sensors must not only provide precise measurement data but also be compactly constructed and, at the same time, robust enough to function reliably even under extreme conditions. In addition, integration directly into the process zone is often necessary. Fulfilling these often contradictory requirements while simultaneously keeping costs at a reasonable level necessitates innovative solutions. Continuous research and development are therefore the key to further enhancing efficiency in production."

What does the Fraunhofer IST offer companies in the field of mechanical engineering and production technology?

"Advances in coating technology and microtechnology are decisive factors in mastering demanding measurement tasks in tribologically highly stressed process zones. As a result of our application-optimized sensor development, near-surface thin-film sensors (10-15 µm thick) can be directly applied to tool or component surfaces by means of vacuum coating processes. This technology opens up new possibilities for integrating sensor functions such as force, pressure, strain and temperature measurement into existing systems, tools and components, thereby allowing measurements to be taken in areas that were previously difficult to access and enabling improvements in process monitoring."

Sensory forging punch with temperature sensors for cold forging of steel.

Looking back and looking forward – what was your personal highlight in the reporting year and what can the industry expect from the Fraunhofer IST in the future?

"My personal highlight was the successful completion of our Industrial Collective Research (German: IGF) project 'Multisensory tools in cold forging'. For the first time, we were able to integrate temperature sensors directly into the contact zone on the forming punch during cup backward extrusion of steel, thereby validating the associated simulations. In addition, we have developed a thin-film-based force measuring disk that records deviations in concentricity and evaluates the data using AI. Thanks to the thin-film sensor system, the compact measuring disk records high forces and pressures and can be flexibly adapted for a wide range of applications.

In the future, we aim to further develop our sensor systems for highly demanding operating conditions – such as for continuous operation at high temperatures of 500 to 600 °C. At the same time, we are optimizing AI-supported data evaluation in order to monitor and control production processes even more precisely."

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From research

Thin-film sensors and PVD coating systems

1

Charging system for e-mobility based on a novel form of face contacting.

2

Sensory high-current contact partner with six thin-film sensors for temperature measurement.

3

Surface treated and PVD-coated copper contacts.

Innovative face contacts for extremely high-power energy transmission

In high-current applications such as e-mobility, temperature monitoring is prescribed by law in order to prevent damage resulting from excessive temperature and faulty behavior during the charging process. At the same time, it is necessary to specifically modify and coat the contact surfaces in order to minimize contact resistance for the transmission of extremely high-power levels. In cooperation with the Fraunhofer IVI and the Fraunhofer IWU, the Fraunhofer IST has developed a thin-film temperature sensor as well as optimized surface pre-treatments and adapted PVD coating systems for high-current electrical contacts, which are specially designed for use in charging connectors in megawatt charging systems (MCS).

High-voltage resistant thin-film sensors on electrical contact partners

In order to enable reliable temperature measurement at the high-current contact spots, a thin-film sensor system was developed. This was deposited directly onto a high-current contact partner made from electrical copper. A thin sensor layer was deposited on the electrically insulating base layer, which exhibits a high dielectric strength. Six microstructured sensors were positioned on the contact partner: three in the immediate vicinity and three at a defined distance from the contact spots. This arrangement of the sensors enables a temperature measurement with high spatial resolution. Finally, a top layer was applied which serves both as wear protection and electrical insulation of the sensor structures.

PVD coating systems for electrical contacts and optimized contact surfaces

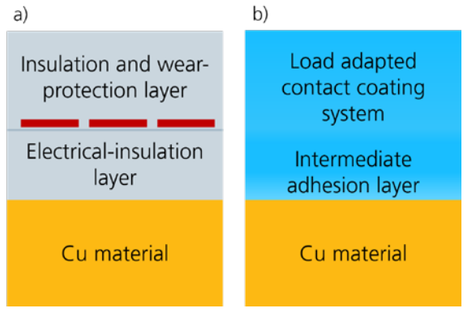
The redetachable contact partners in high-current transmission applications must combine very good electrical conductivity with high wear resistance. In addition, a high level of surface quality is advantageous for defined contacting. In order to fulfill these requirements, a treatment sequence consisting of special surface smoothing and an adapted PVD coating system was developed. An interlayer enables optimum adhesion of the functional layer to the copper contact component. The subsequent mechanically adapted intermediate layer and contact layer ensure minimization of the contact resistance and, consequently, minimal temperature development in the electrical high-current face contact.

Results and outlook

The results to date show that the thin-film sensors enable precise temperature measurement in the immediate vicinity of the electrical contact spots, as a result of which condition monitoring of the charging plug can be realized by means of these sensors. In addition, the treated and coated contact components exhibit low contact resistance even after more than a thousand contact cycles. In the future, the sensors and contact-coating systems are to be tested in the developed MCS charging plug under real conditions in order to validate their performance potential. Furthermore, the aim is to transfer these developments to similar applications such as CCS charging plugs and other high-current electrical applications.

The project

These developments were achieved within the PREPARE project “Neuartige Stirnkontaktierungen zur Energieübertragung extrem hoher Leistungen” (Innovative face contacts for the extremely high-power energy transmission) within the framework of the Fraunhofer-Gesellschaft’s internal programs in collaboration with the Fraunhofer Institute for Transportation and Infrastructure Systems IVI and the Fraunhofer Institute for Machine Tools and Forming Technology IWU.



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a) Diagram of a thin-film sensor system
b) Diagram of a PVD coating system for high-current electrical contacts

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Slurry pot with abrasive medium in artificial seawater (3.5% NaCl solution).

From research

Interactions of wear and corrosion

Investigation into tribocorrosive stresses

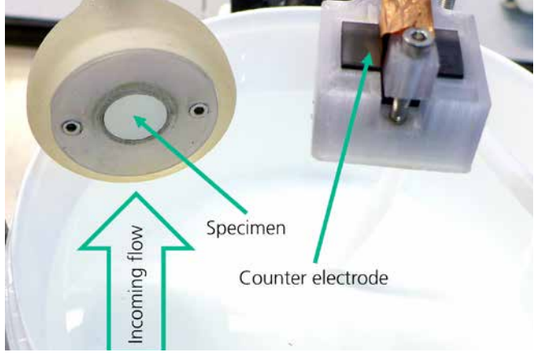
Tribocorrosive stresses occur in numerous applications – from the water and energy industries, through medical technology, and on to production engineering – for example in the extrusion of new materials. The tribological investigation of such stresses is a core area of expertise at the Fraunhofer IST. It enables the evaluation of application-specific loads and forms the basis for targeted adjustments to the surfaces and edge layers of components and tools. Through the expansion of this expertise to include the analysis of tribological interactions under additional corrosive stress, the Fraunhofer IST is able to exploit new fields of application. The in-depth investigation into tribocorrosion also opens up the potential for a unique selling point in industry-related stress analysis.

Combined wear and corrosion on components and tools

In tribocorrosive environments, corrosion and mechanical wear act simultaneously and have a mutually reinforcing effect, which significantly influences the degree of damage. Conventional test methods that only consider either wear or corrosion individually are therefore inadequate. As tribocorrosive processes often progress slowly, time-scalable test methods are necessary in order to realistically model the damage mechanisms and to systematically investigate new material concepts.

Pilot model test bench for the investigation of tribocorrosion

With the aid of an in-house-developed test bench, the test environment at the Fraunhofer IST enables the realistic and accelerated recording of wear under increased corrosion conditions. The high flexibility of the test bench allows customized test sequences - from fundamental investigations to determine mass loss all the way through to detailed analyses of individual tribocorrosive components.



Electrically contacted specimen paired with counter electrode during testing without mechanical wear component to detect corrosion induced wear.

Significant parameters, such as the angle of incoming media flow and the composition of the abrasive media and electrolytes, can be adapted to specific application conditions in order to simulate the stress as realistically as possible. In addition to the tribocorrosion parameters determined (derived from the mass losses and current-density potential curves), the scientific documentation for the client (customer) also includes high-resolution images of the altered topography of the material samples. This enables a comprehensive evaluation of the influences of the respective application environment. Taking the material 1.4404 as an example, an increasing current density can be detected as an indicator of an increased corrosion rate as soon as additional mechanical stress occurs.

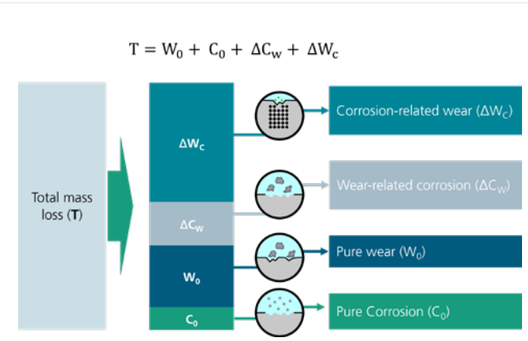
Test conditions for application-specific investigations

In order to accurately map the application environment, defined framework conditions must be fulfilled to use the test bench:

- Sample materials:
  The materials to be analyzed should have conductive properties. We have acquired particular expertise in the analysis of diffusion-treated steels (austenites) and nickel-based alloys (Alloy 718).
- Sample holder:
  This can be customized by means of 3D printing, but requires clear geometric specifications. Previously investigated round specimens had diameters of 30 to 35 mm and a height of 4 to 10 mm.
- Abrasive media:
  The range of utilized abrasive media is diverse and can be adapted to the respective application conditions. Defined types of sand and coarser abrasive media (e.g. barrel-finishing media) up to a size of approx. 1 cm³ are deployed.
- Electrolytes:
  These are adapted to the specific application conditions. Experience has been acquired with 3.5% NaCl solutions. In addition, defined contents of sulphuric acid (H_2SO_4) or alkaline solutions (NaOH, KOH) are possible.
- Extension of the range of investigations:
  In future, gaseous environments (CO_2) and temperature control up to 70 °C are also envisaged.

Construction of a series test bench

The test bench developed in-house has already successfully confirmed in pilot tests that the elaborated test routines provide substantiated information on hybrid wear stress and on the evaluation of different material conditions. On this basis, the test bench is being further developed in terms of design and technology in order to make it usable as a series test bench with the established investigation routines. To increase efficiency, parallelization of the sample processing will be implemented. In addition, sensors are being integrated to facilitate the recording of significant test parameters. The acquired data will be digitally recorded and stored in a database in order to enable complete documentation and further investigations.



The tribocorrosive mass loss (T) is comprised of the specific wear values for the individual effective components used in the application.

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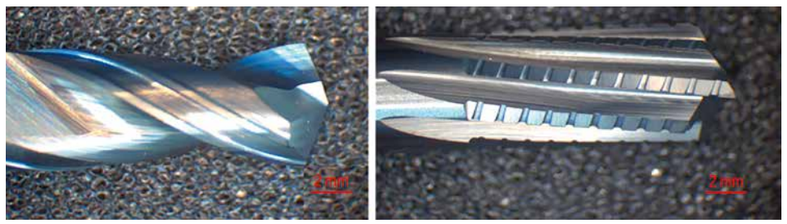
Complex tool geometries coated with an intermediate layer.

From research

Substitution of chemical pre-treatment through intermediate-layer systems

CVD diamond coatings for machining

CVD diamond-coated tools are used in particular in the machining of high-strength and highly abrasive materials. The decisive factor for the service life of the tools is the adhesive strength of the diamond coating on the tool, which is usually comprised of WC-Co carbide. For cobalt-containing carbides, intermediate layers constitute a promising approach for overcoming current challenges.



Tools coated with an intermediate layer and a CVD diamond layer.

Intermediate layers as an alternative to pre-treatment by etching

CVD diamond coating of WC-Co carbides is challenging due to, amongst other things, diffusion processes. Although etching preparation of the tool edge zone leads to a reduction in the cobalt content, it can also weaken it. One alternative is presented by intermediate layers that act as a diffusion barrier and can be deposited without pre-treatment.

Development of high-adhesion coating systems

One focus of current work at the Fraunhofer IST is the development and optimization of mutually compatible and, therefore, highly adhesive coating systems consisting of an intermediate layer and a CVD diamond layer. In a concluded joint project, comprehensive coating system screenings were carried out on test specimens with differing cobalt contents. On the basis of these investigations, promising coating systems were identified and transferred to tools with complex geometries.

Testing in machining trials

In addition to standardized sandblasting tests, machining tests were also performed in order to evaluate the coating systems developed. The coated tools were thereby utilized both for drilling in an aluminum-silicon alloy and for milling carbon-fiber-reinforced plastic (CFRP). At the end of defined tool lives, the devel-oped coating systems produced very good results which, in many cases, already attained the level of the reference tools pre-treated by etching. The wear behavior is particularly worthy of mention: The coated tools exhibited continuous wear, and large-scale coating failure did not occur.

Outlook: Application to carbides with a high cobalt content

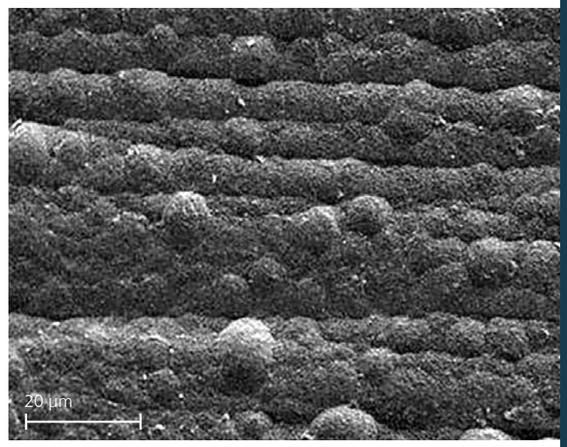
One exciting next step is the transfer of the findings to WC-Co carbides with higher cobalt contents (> 12 %). The investigations to date show that etching pre-treatment can be avoided and that CVD diamond coatings can be applied with good adhesion. Future investigations of tools with cobalt contents > 12 % could further extend the utilization limits and demonstrate the potential for ap-plications beyond the field of machining.

The project

The presented work was carried out as part of the KMU-innovativ project "DIA-MAX", funding reference 03XP0391C, funded by the BMBF, via Project Management Jülich, with the duration 08/2021 to 04/2024.

Collaboration partners:

- WEMA Zerspanungswerkzeuge GmbH
- Weber Technologies GmbH



Scanning electron micrograph of a CVD diamond-coated intermediate layer.

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By working in cooperation with us, you can benefit from:

- High-precision optical coatings for maximum performance from your components
- Innovative production processes for the optimization of efficiency and quality
- State-of-the-art simulation methods for the shortening of development times
- Coating processes for excellent coating quality, high reproducibility and long service life of optical components
- International networking, e.g. through the research innovation platform in Taiwan, that opens up access to new markets and technologies
- Support from simulation, through development, and on to industrial implementation
- Future-proof solutions for demanding applications in the optics industry

Optics

Precision and innovation: Optical technologies for the future

What are the biggest challenges in optical technologies?

"The biggest challenges still lie in increasing the efficiency, precision and durability of optical systems, despite the fact that enormous progress has been made in these areas. In coating technology, the production of high-precision optical coatings requires innovative approaches, as even minor variations in coating thickness or material composition affect the optical performance. In addition, coatings can cover a broad spectrum from UV through to long-wave infrared and must be able to withstand harsh environmental conditions. At the same time, it is important to minimize defects and contamination, as they can impair the quality and service life of the coatings. Furthermore, production processes must not only be technically superior, but also highly scalable for industrial applications, whereby modern processes such as magnetron sputtering are becoming increasingly important. Lastly, the seamless integration of new coatings into existing optical systems also poses a challenge. Particularly demanding in this context are CMOS direct coatings, which must be extremely precise and compatible with semiconductor processes in order to enable high-performance optoelectronic systems."

What does the Fraunhofer IST offer companies in the field of optics?

"We develop customized solutions for innovative optical coatings and their production processes. The cross-sectional nature of optical coatings is reflected in their broad range of applications: from classic optical components, through medical technology and sensor technology, and on to aerospace applications. Through advanced processes such as magnetron sputtering by means of EOSS® and MOCCA+®, high-precision coatings with optimized mechanical, optical and functional properties can be created. This enables, for example, extremely precise laser protection filters, anti-reflective coatings for planar or shaped optical components, and filters for specific wavelength ranges. Our customers benefit not only from application-oriented research, but also from the possibility of further developing new coating technologies that meet their specific requirements."

Looking back and looking forward – what was your personal highlight in the reporting year and what can the industry expect from the Fraunhofer IST in the future??

"One highlight was our entry into the development of optical filters for the long-wave infrared range. To achieve this, we are researching a new class of materials – fluorides and sulfides, which fulfill the highest requirements for transparency and durability in the long-wave IR spectrum and enable new applications. The opening of a research innovation platform in Taiwan was also a milestone. This initiative promotes technological solutions in the field of optical systems and applications – in particular for the benefit of German and European SMEs. Companies benefit from the intensive networking with Asian markets, new research results and optimized production processes. The Fraunhofer IST will continue to be an important innovation partner in the future, particularly as regards high-precision optical coatings, new material systems and the integration of state-of-the-art technologies into industrial applications."

Linear variable interference filters have a wide range of applications in hyperspectral imaging in the fields of agriculture, the environment, and analytics. Innovative design and state-of-the-art process technology at Fraunhofer IST enable particularly compact manufacturing across large spectral ranges.

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From research

The key to smart agriculture

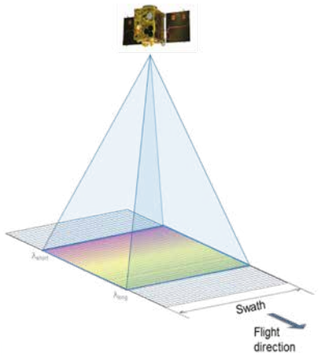
Compact hyperspectral filters

Climate change and the growing world population create enormous challenges for agriculture. Declining yields, more frequent extreme-weather events and pest infestations threaten global food security. Simultaneously, the sustainable utilization of resources necessitates a more targeted management of agricultural land. The application of hyperspectral imaging offers new solutions here: by supplying valuable information, it enables, for example, more precise fertilization and irrigation. In the RAINBOW project, the Fraunhofer IST is working on a new approach to hyperspectral remote sensing.

RAINBOW utilizes compactly integrated satellite-based imaging in order to offer farmers a cost-effective solution for the acquisition of detailed information regarding the condition of their fields. Although existing multispectral approaches already provide valuable insights into various areas of the visible and near-infrared spectrum, they do not capture all the spectral absorption bands that are necessary for a comprehensive analysis of a plant's condition. RAINBOW closes this gap by means of high-resolution hyperspectral sensor technology.

Innovative filter technology for precise agricultural analysis

The heart of the RAINBOW hyperspectral instrument is formed by an innovative bandpass filter which was developed at the Fraunhofer IST on the basis of filter-on-chip technology. This enables the integration of more than 30 spectral bands in a compact and cost-effective format. The elaborate bandpass filter covers a spectral range from 400 to 1700 nm and allows the precise recording of specific biochemical parameters of plants. As a result, general observations are replaced by quantitative assessments – an important step forwards for precision agriculture.



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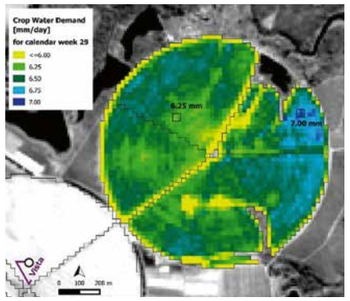
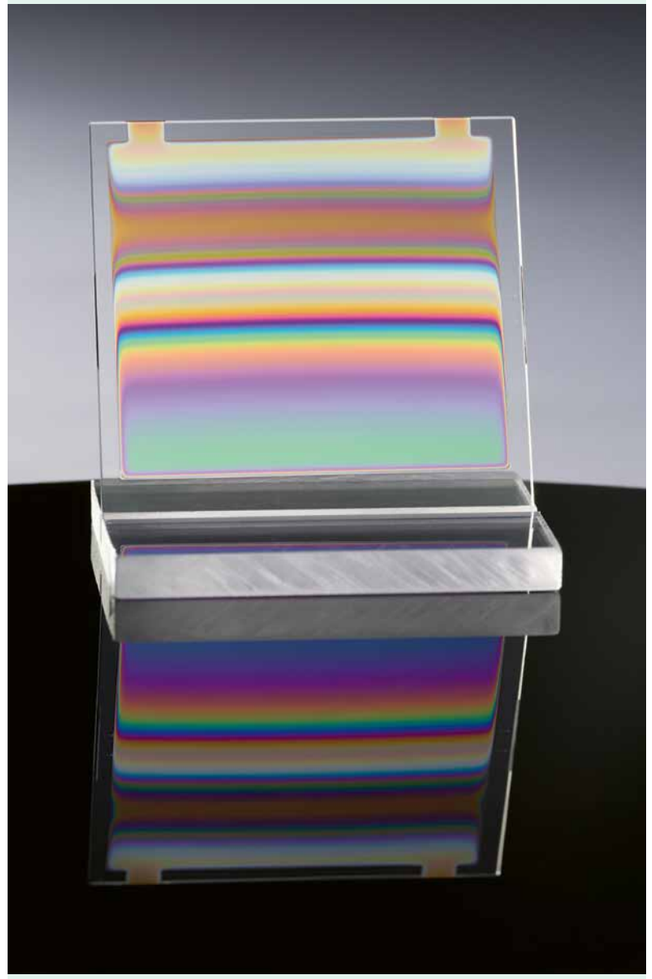


2

Each pixel in the image can be assigned a complete spectrum in the visible and near-infrared range, which is recorded during the flyby (Figure 1). This allows more precise information to be collected regarding agricultural areas, e.g. areas with increased water demand (Figure 2).



The extremely compact hyperspectral filter unites three linearly variable bandpass filters on a substrate that is only 10 mm in size. In the finished instrument, this filter sits directly in front of the camera chip and enables high-precision spectral analyses.

Compact integration through microstructuring

In order to accommodate the wide spectral range, RAINBOW utilizes three linearly variable bandpass filters that are monolithically integrated on a single glass substrate with a size of only 10 mm. This integrated solution requires a particularly strong spectral variation of the bandpass filter of more than 122 nm or more than 27 percent per mm. For the separation of the bandpass filters in the intended substrate areas, microstructuring techniques such as photolithography and lift-off processes were applied.

Hyperspectral data for the future of agriculture

With the development of the filter and the demonstration of the process chain, the Fraunhofer IST is taking a decisive step forward in cost-efficient hyperspectral imaging for small satellites. The RAINBOW approach and the integration of the filter-on-chip technology therefore provide an important contribution towards sustainable agriculture and global food security.

The project

In the RAINBOW project, funded by the European Space Agency ESA within the framework of the InCubed+ program, the Fraunhofer IST is developing compact multigradient filters for hyperspectral satellite-based imaging. Further project partners are Airbus Defence & Space, VISTA Geowissenschaftliche Fernerkundung GmbH and the Fraunhofer IOF.

Additional information on the project:
incubed.esa.int/portfolio/rainbow

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Medical and pharmaceutical technology

Coating and surface technology for medical technology and pharmaceutical systems

What are the biggest challenges in the medical technology and pharmaceutical sectors?

"Both the medical technology and the pharmaceutical sectors are subject to strict regulations that are associated with long and cost-intensive development processes. Legal changes such as the planned PFAS ban or the packaging ordinance necessitate adjustments, for example in the selection of materials. These and other regulatory requirements – intensified by the new version of the Medical Device Regulation (MDR) – pose considerable challenges, in particular for the medical-technology sector, which is dominated by SMEs. Simultaneously, the focus in patient care is increasingly shifting towards patient-specific solutions, resulting in the need for innovative design concepts, the utilization of new material combinations, and precisely coordinated combinations of active ingredients and excipients."

What does the Fraunhofer IST offer companies from the fields of medical technology and pharmaceuticals?

"Coating and surface technology opens up a diverse range of application possibilities for medical products. A central aspect is the targeted control of adhesion at different levels – whether by promoting or preventing the adhesion of biological molecules such as cells, microorganisms or proteins. Furthermore, plasma techniques enable the processing of new materials and material combinations in medical technology. This encompasses, for example, the modification of packaging materials or disposable products to improve barrier properties or migration blockers as well as the targeted chemical functionalization of surfaces. In pharmaceutical process engineering, thin-film technology plays an important role, particularly for system components or tools. Here, wear-resistant non-stick coatings and corrosion-protection layers form a particular focus in order to optimize the longevity and efficiency of these systems."

Johanna Reus, PhD student in the Research Training Group RNApp, at work in the biolab. The focus of her work is on the further development of the packaging possibilities for and the storage stability of RNA therapeutics.

Looking back and looking forward – what was your personal highlight in the reporting year and what can the industry expect from the Fraunhofer IST in the future?

"Last year, we were able to launch the 'RNApp' Research Training Group. Under the leadership of the Medizinische Hochschule Hannover (Hanover medical university, MHH) and in collaboration with partners, we are researching innovative technologies for RNA-based therapeutic approaches within the framework of 12 doctoral projects. The focus of the Fraunhofer IST is thereby directed at the development of new concepts for primary packaging materials, in particular with regard to the control of adhesion. The project offers great potential for close networking with regional partners from Hanover, Braunschweig and Göttingen, thereby strengthening the interdisciplinary cooperation. In addition to this collaboration, we were able to utilize our coatings to develop sample solutions for various project partners in the pharmaceutical industry; these are now being tested in close-to-production trials. If successfully implemented, these coatings could contribute towards increasing the yield in pharmaceutical production processes and the more efficient utilization of resources."

By working in cooperation with us, you can benefit from:

- Personalized solutions:
  Customized solutions for adhesion control, independent of the substrate material
- Material diversity:
  Modification of different materials and complex geometries
- Sustainability:
  Process development for gas-phase-based modification of surfaces for increased functionality and improved processability
- Sampling:
  Provision of samples or small series for customer-specific applications

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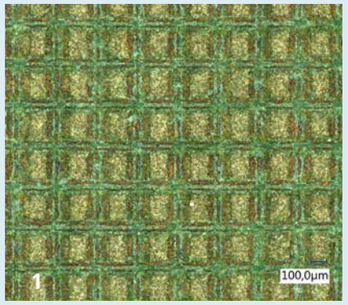
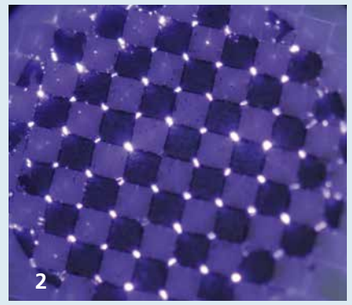
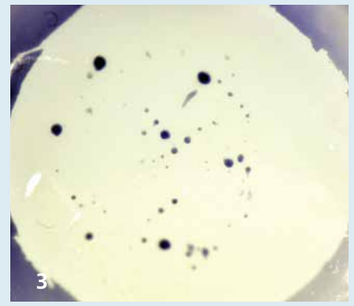
Via the side-mounted nozzles, a multitude of powders can be introduced into the plasma jet.



Via the creation of metallic layers (here: Cu) followed by selective laser ablation, structures can be produced on the ceramic surface.



Used for the production of plasma electrodes, the structuring ensures the formation of a controlled-filament dielectrically impeded discharge.



In skin samples, the plasma discharge creates microscopic pores that can be detected by the reactive oxygen and nitrogen species generated in the plasma.

From research

Low-energy plasma spraying for plasma-mediated drug delivery

Administration of medication: Efficient and gentle

The administration of medicines via the skin offers numerous advantages, including improved bioavailability and a reduction in systemic side effects. One promising technology for the creation of microscopic pores in the skin is cold atmospheric-pressure plasma. In order for this method to be used therapeutically, both the plasma generation and the associated effects must be reproducible and stable. This poses a major challenge for its targeted use in medical technology.

Structured plasma electrodes for precise application

In the "KaPlaTech" project, plasma electrodes are specifically structured in order to create a homogeneously filamented discharge pattern. This ensures a consistent and reliable treatment that fulfills the therapeutic requirements of the patients. The Application Center of the Fraunhofer IST uses low-energy plasma spraying in order to structure ceramic dielectrics. Through the creation of metallic layers, followed by selective laser ablation, user-defined structures are created that can be optimized in terms of their effect. With the aid of the structured electrodes, a reproducible quantity, distribution and energy density of plasma-discharge filaments can be created on skin samples. This enables the efficient formation of skin pores.

New prospects for medical technology and the pharmaceutical industry

The results obtained from the project should make it easier for medical-technology manufacturers and pharmaceutical companies to integrate plasma technology into innovative therapy concepts. As a result, the therapeutic potential of cold atmospheric-pressure plasma can be used even more extensively. In particular, this technology could revolutionize the pain-free administration of novel active substances and, consequently, contribute towards improved patient care.

Project

Erforschung von Kaltplasmapartikeltechnologien und Anwendungen (engl.: Research into cold-plasma particle technologies and applications)

Duration

01.03.2022 - 31.08.2026

Funding body

Bundesministerium für Bildung und Forschung BMBF
(Federal Ministry of Education and Research)
Funding reference 03FHP179B

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KaPlaTech

By working in cooperation with us, you can benefit from:

- Support and advice on sustainable management strategies tailored to companies and their sectors
- Support in the implementation of the Sustainable Development Goals (SDGs) and the acquisition of relevant sustainability certificates
- A range of training courses and learning concepts on sustainability-related topics (e.g. LCA, LCE, CSRD)
- Analysis of sustainability trends, materiality, resource efficiency and circular economy practices across various sectors
- Development of customized assessment tools for companies to holistically optimize products and processes
- Support in calculating CO_2 and water footprints and the development of decarbonization roadmaps

Sustainability management and Life Cycle Engineering

Enhancing the sustainability of German industry through application-oriented solutions

What are the biggest challenges for companies in the field of sustainability management and Life Cycle Engineering?

"In addition to climate change, circular economy and resource scarcity play a central role in the sustainability strategies of businesses. Closing the material loop to return materials into the cycle at consistent quality is only possible in a few cases today. This is precisely where we come in – with the Fraunhofer Center Circular Economy for Mobility CCEM in Wolfsburg. We develop single-source technologies for circular materials, analyze and evaluate these materials and processes with regard to their sustainability performance, and derive from this the technical targets for further process and product optimization."

What does the Fraunhofer IST offer companies through its expertise in the field of sustainability management and LCE?

»Fraunhofer IST offers customized solutions for promoting circular economy for companies across various sectors. This includes the development of new technologies and business models that enable high-quality recycling. Furthermore, the institute specializes in developing analytical tools for assessing environmental impacts and supports companies in obtaining external sustainability certificates for their products and processes. Through sustainability assessments, Life Cycle Engineering approaches, and cost-efficient solutions, Fraunhofer IST contributes to the establishment of closed material cycles."

In the Sustainability Management and Life Cycle Engineering Department, we apply data-assisted methods in order to drive sustainability, innovation and circular economy in technologies and the industries.

Looking back and looking forward – what was your personal highlight in the reporting year and what can the industry expect from the Fraunhofer IST in the future?

"Over the past year, we have established comprehensive and cooperative networks consisting of industrial and research partners within the EU and internationally. In the 'SuSteelAG – Sustainable Steel from Australia and Germany' project, for example, Fraunhofer IST is working hand-in-hand with companies from the ore-extraction, steel-production, and transport sectors as well as with research institutes and universities in Germany and Australia, on a holistic evaluation and optimization of the entire process chain for green steel production. This close cooperation provides ideal conditions for research results that are highly mature from a technical, economic, and environmental perspectives, thereby enhancing the future competitiveness of companies."

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Fundamental development for a Europe-wide harmonized, generally accepted and applied approach to life cycle analyses for zero-emission vehicles.

From research

Holistic analysis of the environmental profile of vehicles throughout their life cycle

The transition to zero-emission vehicles is essential for the achievement of our climate targets; it is, however, associated with major challenges. Current methods of life cycle analysis (LCA) are generally not standardized, which leads to results that are not comparable. This makes it difficult for manufacturers, political decision-makers and consumers to incorporate information on emissions into their decisions.

In addition, the integration of real data and the consideration of environmental, social, and economic aspects presents a complex task that requires a harmonized approach. Within the scope of the TranSensus LCA project, Fraunhofer IST, in collaboration with partners from industry and research, is developing a standardized LCA framework for zero-emission transport.

This approach integrates sophisticated data-collection processes, modern analysis tools and stakeholder-consensus initiatives in order to provide recommendations for action for the European Union. The harmonized LCA framework forms the basis for the establishment of comparable life cycle assessments for vehicles and provides solid foundations for effective regulation and reliable information for consumers..

Additional information on the project:

Project
Towards a European-wide harmonized, transport specific LCA Approach

Duration
01.01.2023 - 30.06.2025

Project partners

- Fraunhofer Institute for Structural Durability and System Reliability LBF
- Sphera
- Swedish Environmental Research Institute IVL
- Commissariat à l'énergie atomiqueet aux énergies alternatives CEA
- Bureau de Recherches Géologiques et Minières BRGM
- Électricité de France SA
- Universiteit Leide
- Ricardo PLC
- Bayerische Motoren Werke AG
- Renault Group
- Northvolt AB
- STMicroelectronics NV
- Rheinisch-Westfälische Technische Hochschule Aachen
- UMICORE N.V./S.A.
- Scania AB
- Université de Bordeaux
- Technische Universität Braunschweig
- Valeo S.A.
- Volkswagen AG
- Universiteit Gent

Funding body
Horizon Europe

The "TranSensusLCA" project covers a wide range of topics that also address aspects of the circular economy.

This year's General Assembly of the project team took place at CEA in Grenoble, France.

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TranSensusLCA

The Fraunhofer IST in networks

The Fraunhofer-Gesellschaft at a glance

The Fraunhofer-Gesellschaft, headquartered in Germany, is one of the world's leading organizations for applied research. Since its founding as a nonprofit organization in 1949, Fraunhofer has held a unique position in the German research and innovation ecosystem. With nearly 32,000 employees, the research organization operates 75 institutes and independent research units across Germany. The Fraunhofer-Gesellschaft plays a major role in innovation by prioritizing research on cutting-edge technologies and the transfer of results to industry to strengthen Germany's industrial base and for the benefit of society as a whole.

Fraunhofer's primary customer base consists of large and medium-sized companies that utilize its expertise to boost their competitiveness with new technologies. For years, Fraunhofer has been one of the most active patent applicants in both Germany and Europe. Its extensive international patent portfolio is the basis for technology transfer through research projects, spin-offs and licensing. Moreover, Fraunhofer addresses societal goals in key technology sectors through interdisciplinary and international partnerships in specific markets. Examples include developments in microelectronics, artificial intelligence (AI), quantum computing, healthcare, the circular economy, new materials, energy systems, critical infrastructure security and defense.

Fraunhofer is an attractive and established partner in publicly funded joint projects with industry partners. The Fraunhofer-Gesellschaft is also instrumental in strengthening Germany's innovation and industrial base and ensuring its viability. Its activities create jobs in Germany, increase public-sector investments, give companies competitive edges and foster public acceptance of advanced technology. International partnerships with leading research partners and companies around the world ensure direct contact with the most influential research communities and economic areas.

Fraunhofer's annual business volume is €3.6 billion, €3.1 billion of which is generated by contract research — Fraunhofer's core business model. Unlike other public research organizations, base funding from the German federal and state governments is merely the foundation for the annual research budget. This serves as the basis for groundbreaking precompetitive research that will become important for the private sector and society in the years ahead.

Fraunhofer's distinctive feature is its large share of industry revenue, guaranteeing close collaboration with the private sector and industry and the consistent focus of Fraunhofer's research on the market. In 2024 alone, industry revenue accounted for €867 million of its total budget. Fraunhofer's research portfolio is augmented by competitively acquired public-sector funding, pursuing the right balance between public-sector and industry revenue.

Highly motivated employees are the most important factor behind Fraunhofer's success. The research organization therefore fosters an environment that encourages independent thinking, creativity and goal-driven work. It supports career development in both research and industry by providing targeted programs for professional and personal development.

The Fraunhofer-Gesellschaft is a recognized nonprofit organization named after Joseph von Fraunhofer (1787–1826), a Munich-based scholar who enjoyed equal success as a scientist, inventor and entrepreneur. His legacy continues to inspire the organization's spirit of innovation to this day.

Last updated: April 2025

The Fraunhofer-Gesellschaft celebrated its 75th anniversary on March 26, 2024.

Headquarters of the Fraunhofer-Gesellschaft.

Synergies through networking

Networks within the Fraunhofer-Gesellschaft

Within the framework of its research and development activities the Fraunhofer 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.

Fraunhofer-Gesellschaft, the Institute has been contributing its expertise in the Fraunhofer Group for Production, which consolidates the specialist knowledge of the Fraunhofer-Gesellschaft for the "production of the future".

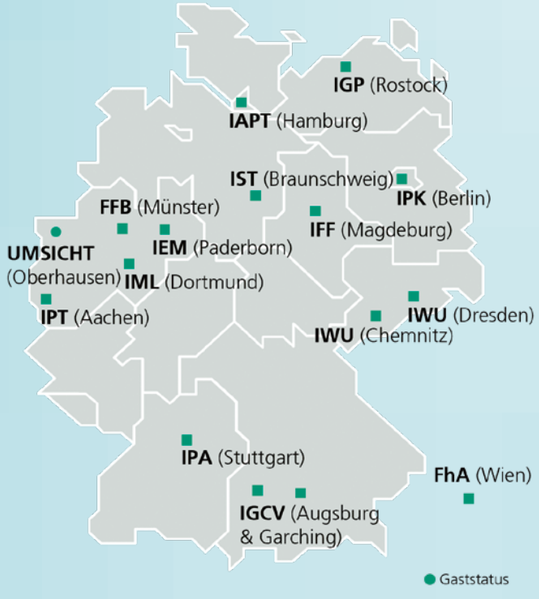
Furthermore, the Fraunhofer IST participates as a guest member in the Fraunhofer Group for Light & Surfaces, as well as in various alliances, business sectors, research and competence fields, and networks. The objective is to offer customers and partners optimum solutions for their tasks, including cross-technological options. In addition, the Fraunhofer IST is actively involved in the Fraunhofer Centers for Energy Storage and Systems ZESS and Circular Economy for Mobility CCEM 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.

Der group in figures

Operating budget[1]:
379 million Euro

Economic revenue[2]:
30,3 %

Employees[3]:
approx. 3000



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

#WeKnowProduction

Fraunhofer Group for Production

The Fraunhofer Group for Production was founded in 1998 as part of the Fraunhofer-Gesellschaft, the largest organization for application-oriented research in Europe. Today, 13 Fraunhofer institutes and establishments pool their expertise within this group, and offer innovative and sustainable system solutions from the broad field of production technology and logistics for German and international companies.

The Fraunhofer Group for Production focuses on the optimization of the entire value chain, thereby utilizing the latest findings from the disciplines of production science, engineering and computer science as a basis. This enables close and interdisciplinary collaboration between the research institutes and industry, through which the production methods of tomorrow can be designed. The Group offers a wide range of technologies, services and infrastructure in order to equip companies for the challenges and opportunities of future production. The Group offers a wide range of technologies, services and infrastructure in order to equip companies for the challenges and opportunities of future value creation.

Member institutes

The Fraunhofer Group for Production is the leading location network for applied manufacturing research in Europe and, together with its partners, forms an excellent network for comprehensively meeting industrial needs.

Competency portfolio

As a production-technology network, the consolidated expertise of the member institutes encompasses all areas along the value chain and is constantly being expanded, in an application-oriented manner, through a wide range of research and development projects:

- **Production Machinery and Facilities**
  Our expertise extends from factory planning, through machine tools and robot systems, and on to maintenance. As a result, we are able to guarantee the optimization and long-term availability of production capacities.
- **Manufacturing Technologies and Process Technologies**
  We combine comprehensive knowledge in the field of production technology, in particular in subtractive and additive manufacturing. Further focal points include process engineering as well as precision engineering and surface technology.
- **Product Development**
  Through integrative solutions in the fields of system-, software- and virtual-based engineering, we provide support in the development of new products – from the initial idea through to market launch.
- **Production Control, Automation and Measurement Technology**
  The Group for Production is driving forward the automation of industrial processes. Through smart sensor technology and the networking of systems, we enable precise, efficient and adaptive control of production processes, in particular with the targeted implementation of artificial intelligence and digital assistance systems.
- **Business and Value-Added Management**
  We support companies in the development of forward-looking strategies and business models. Our comprehensive expertise in innovation and technology management helps to promote the digital transformation of value-creation processes.
- **Logistics and Supply Chain Management**
  With our solutions, we are shaping the logistics of the future. Intelligent material-flow systems and modern ICT software architectures create resilient, transparent and sustainable value chains. The Group for Production develops holistic concepts for the optimization of logistics processes and actively contributes towards digital transformation in supply chain management.

Collaboration and future topics

The Fraunhofer Group for Production offers a multitude of services ranging from technology consulting and collaborative research through to the solving of requirements and challenges via collaborative implementation projects. In addition to “quick wins” from potential analyses and innovation workshops, feasibility studies and bespoke system developments and integrations are among the frequently implemented formats for successful cooperation with industry. The Group thereby designs and optimizes technologies, processes and products through to the production of prototypes and small series. In addition, the experts offer advice on the selection of the right solutions and continuously empower people in dealing with new innovations in production and logistics.

Businesses benefit from the versatile collaboration offered by the Group for Production - from individual orders through to major international projects. By means of strategic partnerships, such as Enterprise Labs or Joint Innovation Platforms, we strengthen the innovative power of our partners on a long-term basis. Our collaborations offer access to the latest technologies, interdisciplinary expertise and a powerful network comprised of business, science and politics. Whether through the integration into networks and innovation clusters that promote the exchange between business, science and politics, or through the targeted support of spin-offs and start-ups that develop innovative ideas to market maturity: the Group for Production offers businesses practical solutions in order to make their processes more efficient, more resource-conserving, and future-proof.

From the concrete challenges of industry all the way to innovative solutions - through our application-oriented research, we drive forward strategic research topics specifically for the benefit of industry. The Group for Production is involved in various publicly and industrially funded research projects, including in the following areas:

- Industrial data ecosystems
- Smart maintenance
- Generative AI in the production environment
- Human-robot collaborations
- Additive manufacturing
- Battery cell production
- Resilient circular value creation

We warmly invite you to initiate contact with us so that together, we can begin the development of forward-looking solutions.

[1]Budget 2024 / [2]Result 2024 / [3]Projection 2/2024 (sci./techn./adm. personnel)

Contact

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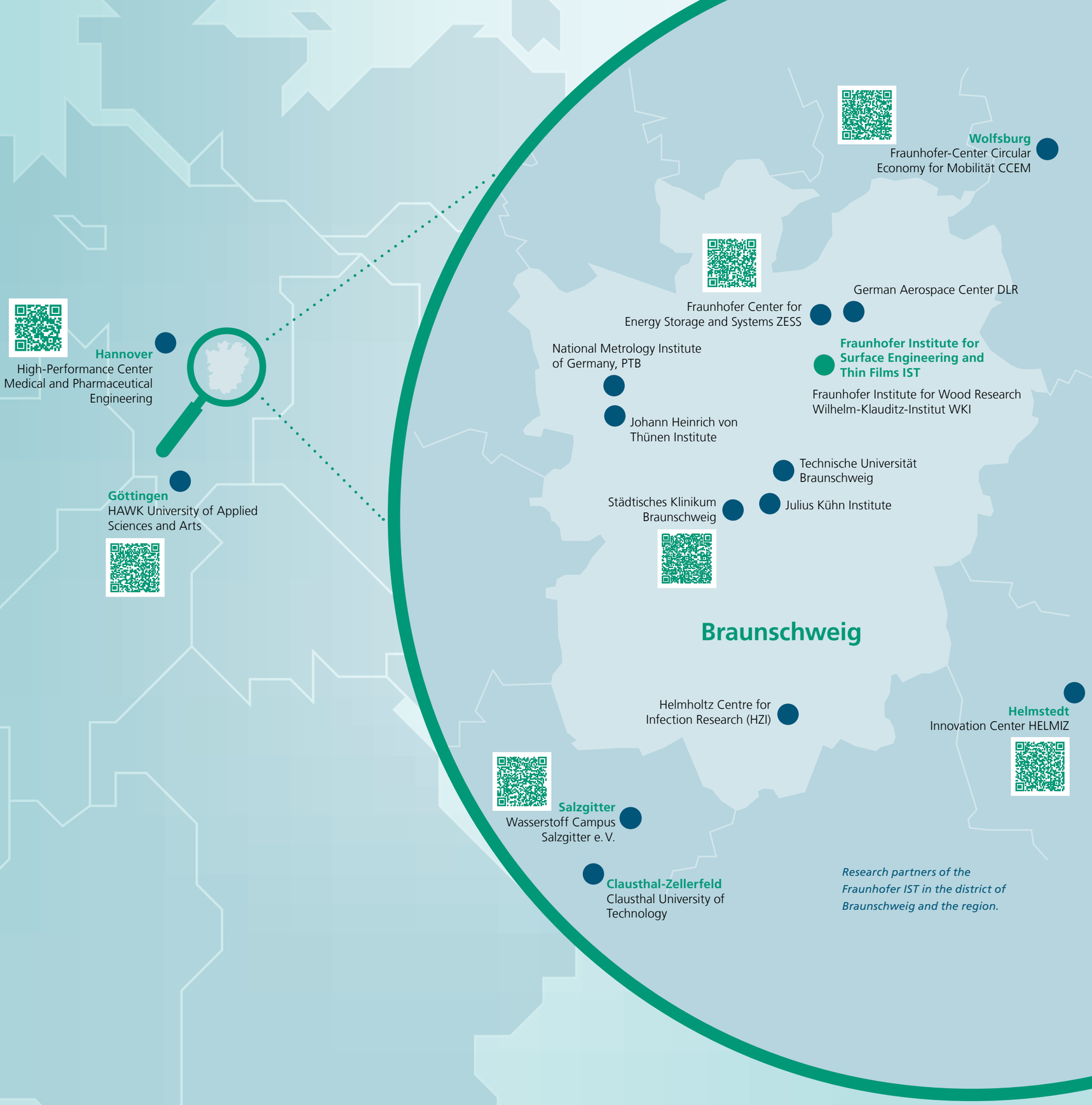
Regional and nationwide networking

31 institutions – 70 locations – 19,600 employees:
In order to network knowledge, sustainably promote innovation and strengthen the leading position of the Braunschweig science region, diverse scientific institutions in South-East Lower Saxony have joined forces to form the ForschungRegion Braunschweig e.V. Included among them are universities, colleges, federal research institutes, Helmholtz institutes, Fraunhofer institutes, Leibniz Association research establishments, museums, libraries and the Klinikum Braunschweig. Cooperation and partnerships already exist between many of these members and the Fraunhofer IST. The institute is also networked throughout Germany, beyond the ForschungRegion Braunschweig. The map shows examples of our network:



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

General Meeting at the Dortmunder OberflächenCentrum.

The Competence Network Industrial Plasma Surface Technology e.V.

INPLAS

The Competence Network Industrial Plasma Surface Technology e. V. INPLAS pursues the goal of further publicizing the potential of plasma technology and supporting, promoting, and moderating developments in the numerous fields of application. 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 for Cluster Management Excellence. INPLAS currently has 52 members from industry and science with around 200 active persons. 75 percent of the INPLAS members come from industry.

In 2024, INPLAS organized a diverse range of activities relating to the topics of surface technology. Highlights are presented below:

INPLAS working groups

In February 2024, both the 27th meeting of the "Tool Coatings" WG, headed by Hanno Paschke (Fraunhofer IST), and the 4th meeting of the "Digitalization and AI" focus group, headed by Marija Lindner (IWF of the TU Braunschweig), took place. Topics of the "Tool Coatings" WG encompassed increasing the service life of micro-cutting tools, DLCPlus coatings, hybrid PVD coatings for difficult-to-machine materials, and CVD diamond for coated carbide tools. The focus group addressed the accelerated design of surfaces for press tools, AI applications and automation in non-destructive testing as well as simulation-aided design for PVD/CVD processes.

The "Novel Plasma Sources and Processes" WG, led by Dr. Anke Hellmich (Applied Materials GmbH & Co. KG), Matthias Nestler (scia systems GmbH) and Dr. Ulf Seyfert (Von Ardenne GmbH), devoted its 32nd meeting in June 2024 to the principles of plasma-assisted propulsion in space and the diagnostics applied there, UHF-ECR plasma and ion sources, and quantitative plasma diagnostics for industrial processes. The fall meeting focused on plasma applications in industrial exhaust-gas purification, the conversion of CO_2 to synthesis gas, and the status quo and new developments in the field of high-power impulse magnetron sputtering (HIPIMS).

The spring and fall meetings of the "Combined Surface Technology" joint committee, headed by Prof. Dr. Petra Uhlmann from the Leibniz Institute of Polymer Research, addressed alternatives to perfluorinated and polyfluorinated alkyl compounds (PFAS).

Circularity Days

At the Circularity Days, an event that combines the Future Automotive Production Conference and the Materials Symposium – two conferences under one roof – (INPLAS provided support in recruiting speakers and promoting the event), the major focal points were innovative and smart production, Life Cycle Engineering, AI-based optimization, factories of the future, design and simulation for circular components, functional and innovative components as well as sustainable materials. Furthermore, within the framework of a pitch session, start-ups were provided with the opportunity to present themselves and their activities in the field of the circular economy. The Circularity Days took place in Wolfsburg in May 2024.

52 INPLAS members

INPLAS member overview (status: 2024).

Erfahren Sie mehr über unsere Mitglieder:

www.inplas.de

14th HIPIMS conference

In June 2024, the 14th International Conference on Fundamentals and Industrial Applications of HIPIMS took place in Sheffield. One focus was on the expansion of the traditional application areas for HIPIMS plasma and coating technology through comprehensive technologies for plasma coating, plasma surface treatment and advanced surface engineering.

INPLAS joint stand at the 19th International Conference on Plasma Surface Engineering (PSE) 2024

From 2 - 5 September 2024, the 19th PSE took place in Erfurt with around 550 participants and 62 industrial exhibitors. In the accompanying exhibition, the following partners presented themselves on the INPLAS joint stand: Advanced Energy Industries GmbH, Fraunhofer FEP, Fraunhofer IST, HAWK University of Applied Sciences and Arts Hildesheim/Holzminden/Göttingen, Hiden Analytical Europe GmbH, W & L Coating Systems GmbH and INPLAS e. V.

19th INPLAS General Meeting

In 2024, the 19th INPLAS General Meeting was held at the Dortmunder OberflächenCentrum. The agenda included the activities in the reporting period, the introduction of a new member and planned activities. One highlight was the guided tour of the plasma coil-coating facility at thyssenkrupp Steel Europe AG.

The team at the INPLAS joint stand at the PSE in Erfurt.

We would like to thank all members for their commitment and enthusiastic support.

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Memberships

Publications

Dissertations

Thewes, Alexander (2024). Grundlagenuntersuchungen zum Eigenschaftsprofil mehrphasiger Ti-Si-B-C-N Dünnschichten.

Wacker, Christian (2024). Methoden für den Handhabungsprozess mit vakuumbasierten Granulatgreifern.

Patents granted

Duckstein, R.; Abraham, T. G.; Moustafa, E. (2024): Kombination aus mikrobieller Elektrolyse (Anode) und Elektrosynthese in ionischen Flüssigkeiten (Kathode). DE 102023202271

Vergöhl, M.; Rademacher, D.; Zickenrott, T. (2024): Verfahren zur Herstellung optischer Schichtsysteme und Vorrichtung zur Herstellung. EP3058400

Neubert, T.;Abraham, T. G.; Lachmann, K.; Thomas, M. (2024): Vorrichtung und Verfahren zur in-situ Oberflächenmodifizierung bei additiv gefertigten Bauteilen. EP 3058400

Conference contributions

Bandorf, Ralf: Immersion infrared reflection-absorption spectroscopy studies on diamond-like carbon surfaces. II. Reactions of electrophilic groups on surfaces of sputtered a-C films. PSE Erfurt, 2.-5.9.2024 - Poster.

Bandorf, Ralf: Thin Film Coating Solutions for Hydrogen Economy. PSE Erfurt, 2.-5.9.2024 - Talk.

Bandorf, Ralf; Ehiasarian, Arutium: C-333 »Practice and Applications of High Power Impulse Magnetron Sputtering«. 67th Annual SVC Technical Conference, 4.-9.5.2024 - Talk.

Bandorf, Ralf; Gabriel, Herbert: Surface Engineering for the Hydrogen Economy. 67th Annual SVC Technical Conference, 4.-9.5.2024 - Talk.

Bandorf, Ralf; Gerdes, Holger: C-338 »Application of Reactive Sputtering«. 67th Annual SVC Technical Conference, 4.-9.5.2024 - Talk.

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