

Activity report 2025

About Fraunhofer FEP

The Fraunhofer Institute for Electron Beam and Plasma Technology FEP works on innovative solutions for vacuum coating and the treatment of surfaces, liquids and gases.

Based on our core competencies electron beam technology, magnetron sputtering and plasma-assisted surface processes, Fraunhofer FEP develops resource-saving and efficient process technologies for the strategic fields of energy and sustainability, life science, environmental technologies, smart building and digitalization.

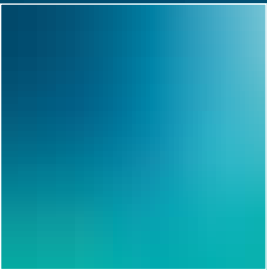
Fraunhofer FEP offers a broad range of research, development and pilot production capabilities for the development and scaling of both corresponding processes and customized hardware systems.

Together with our partners, we develop customized and industry-ready solutions and processes for future-oriented coating solutions.

Our aim is to tap into the innovative potential of technologies for new production processes and products of the future and make it available to our customers.

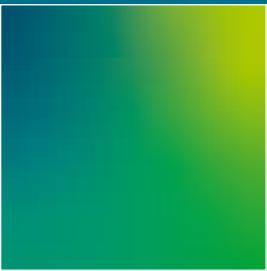
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Welcome Message



**International networking,
new forms of cooperation,
and sustainable technology
development were the key
priorities in 2025.«**

Prof. Dr. Elizabeth von Hauff,
Director Fraunhofer FEP

The year 2025 presented Fraunhofer FEP with a wide range of challenges, shaped by a dynamic geopolitical and economic environment. Yet it is precisely in times like these that difficult conditions often provide the most fertile ground for new ideas and innovations. Over the past twelve months, we have further refined our strategic focus and made targeted investments in our infrastructure and in expanding the institute's expertise – with the clear goal of setting the course for successful and future-oriented development and continuing to meet the needs of our partners and customers.

In 2025, we aligned the topics from the strategy process audited in 2023 with the direction of new research policy agendas, such as the High-Tech Agenda for Germany and the 10th EU Framework Program for Research and Innovation. As a result, we have grouped our core competencies into overarching pillars:

- Decarbonization, climate-neutral energy, and mobility
- Biotechnology, biomedicine, and the circular economy
- Microelectronics
- Security and resilience, aerospace

In this issue, we present the scientific highlights from these new research areas. We demonstrate how microstructured polymer films can be used to fully integrate photovoltaic modules into building façades.

The versatility of low-energy electron beam technology is demonstrated in the articles on the antiviral functionalization of environmentally sustainable nonwoven fabrics for respiratory masks, our new hybrid technology in the form of bioreactors with built-in low-energy electron beam sources, and innovative approaches to the synchronized pulsing of electron beams and atmospheric-pressure plasma. The range of topics is rounded out by our newly developed mushroom-shaped source for seed treatment.

In the field of microelectronics, we showcase the digitization of complex coating processes to increase efficiency in transferring laboratory results to the market. In the article on sputter epitaxy, we highlight the sustainable, large-scale production of epitaxial sputtered nitride layers for power electronics.

Finally, we present innovative coating solutions for corrosion protection, conductivity, and shielding for the aerospace and defense industries.

For us, 2025 was also marked by international networking and new forms of cooperation. Internationally, we were represented at events including InterBattery in Seoul and, once again, at Manufacturing World in Tokyo. My participation in a K-FAST delegation trip to South Korea and the expansion of our memorandum of understanding with the Korean Technology Promotion Agency (TIPA) underscore our commitment to sustainable, international collaborations.

We also made our mark on the national level: My presentation at the Saxon Innovation Conference, our participation in the Saxon Transfer Award, and our contribution to the Day of German Aerospace Regions demonstrate the breadth of our expertise – from sustainable coatings to solutions for the mobility of the future.

A highlight of the year was the continuation of our own “pro flex” conference in May, through which we successfully created a platform for exchange between science and industry for the eighth time.

With the new “Innovation Week” format, we gave companies and research institutions the opportunity to work with us to further develop forward-looking ideas directly within an industrial research environment. The positive response and the resulting collaborations confirm the value of this approach.

A special highlight was the 25th anniversary of our MAXI inline vacuum coating system, which we celebrated as part of the V2025 tutorial. Here, we impressively demonstrated how sustainability can be implemented in surface technology.

I would like to thank all our employees, partners, and supporters for their tremendous dedication. We now look forward with confidence to the developments ahead and are excited to shape the future together with you.

Prof. Dr. Elizabeth von Hauff
Director of Fraunhofer FEP

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Advisory Board

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Chairman of the Board

Dipl.-Ing. Ralf Kretzschmar

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Nothnagel – Beratende Ingenieure, CEO



Photo of the 36th Advisory Board Meeting on April 9, 2025.

Prof. Dr. Michaela Schulz-Siegmund

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Institute for Pharmacy, Director

Carsten Utikal

Saxon State Ministry for Science, Culture and Tourism
Secretary, Division 43, Bund-Länder-Forschungseinrichtungen

Pia von Ardenne

VON ARDENNE Holding SE & Co. KGaA, CEO

Jörg Wittich

ALD Vacuum Technologies GmbH, Managing Director

MR Christoph Zimmer-Conrad

Saxon State Ministry of Economic Affairs, Labor and Transport
Head of Division 36 "Industry"

Kuratoriumsgast

Dr. Patrick Hoyer

Fraunhofer-Gesellschaft, Head of University Cooperation,
Appointment Management, and Scientific Awards

This list represents the status as of the board meeting in 2025. For an up-to-date version, please visit our website at:

 <https://s.fhg.de/NX2>

Organizational Structure



The organizational structure shown represents the status as of 11/2025. A current version can be found on our website at:

 <https://s.fhg.de/5a3>

The Institute in Figures

Financing

Fraunhofer FEP was able to bring in 7.0 million € of new business from industry through direct contracts. Proceeds of 3.7 million € were obtained from public projects funded by the federal and state governments. The expenditure of institutional capital ran to 11.3 million €.

Investment costs

Total expenditures from the operating and investment budget amounted to 22.0 million €. 1.5 million € was invested in equipment, construction and infrastructure during the period.

Employee development

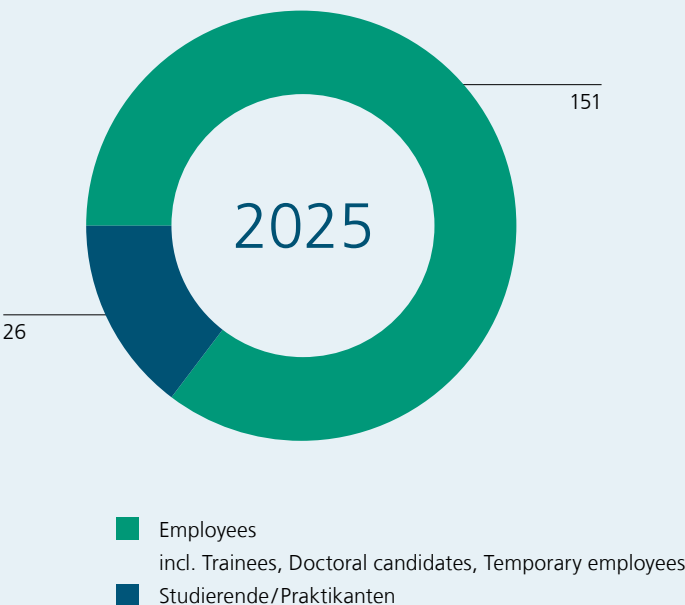
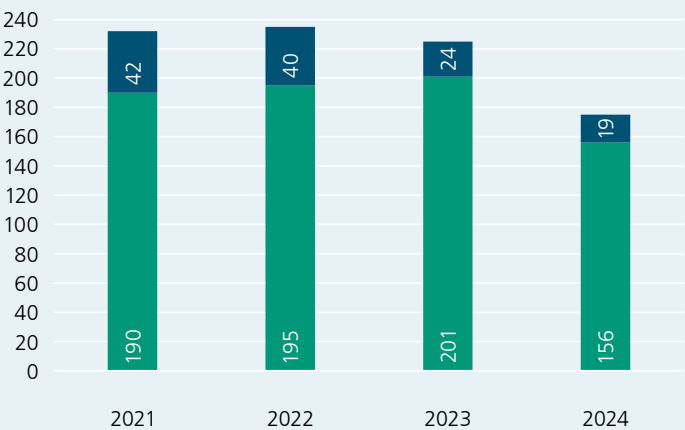
Last year, an average of 151 employees (including 4 trainees) and 26 research assistants/interns worked at the Institute. Of the 54 staff members that were employed as scientists, 11 were additionally working on their doctoral degrees. The proportion of females in the scientific area amounted to 25.3 percent.

Staff and material costs

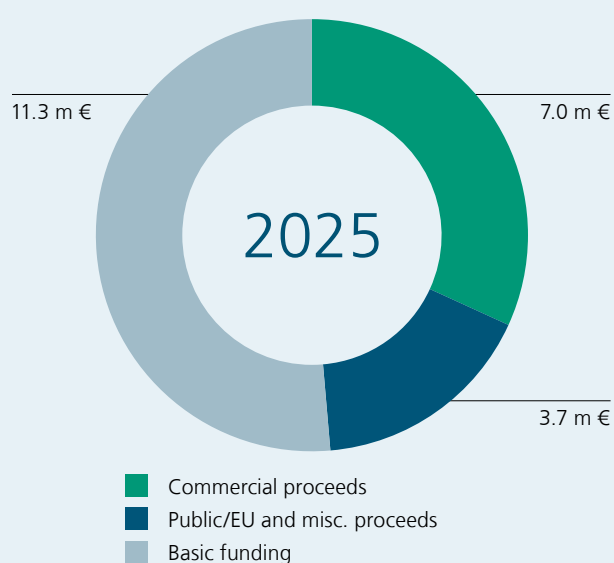
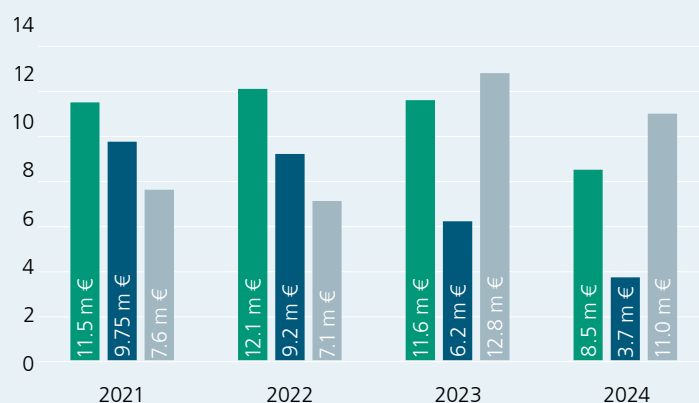
Personnel expenditures totaled 12.3 million €, representing 60.0 percent of the operating budget (20.5 million €). Material costs amounted to 8.2 million €.

The figures for the comparative period 2020 – 2023 include the the former Division "Microdisplays and Sensors".

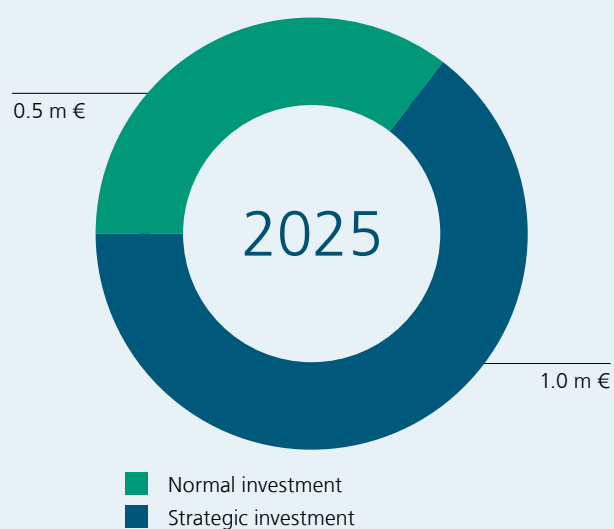
Employee development



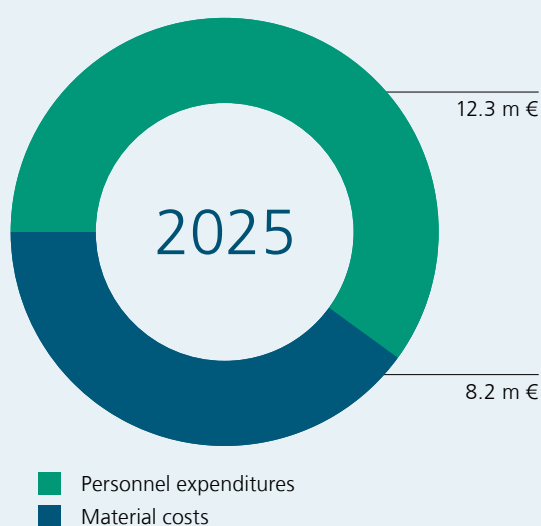
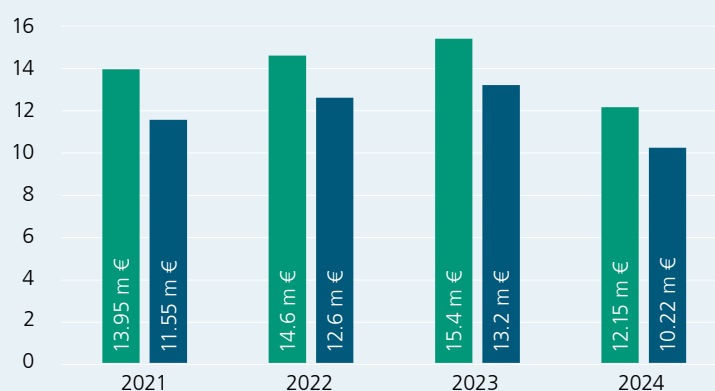
Financing



Investment costs



Staff and material costs



Industry Solutions



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Cultural Heritage Management 15



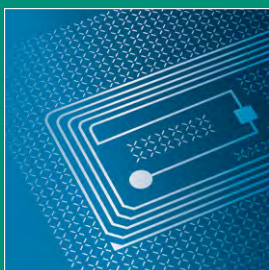
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Energy and Sustainability



The Fraunhofer FEP offers innovative technologies and solutions in the field of energy and sustainability that contribute to increasing efficiency and conserving resources.

In the field of photovoltaics, the institute develops advanced coating processes to optimize solar cells and modules. For hydrogen technology, precise thin-film depositions for electrolyzers are used to increase the efficiency of hydrogen production. We also develop customized coatings for battery technologies to improve the performance and service life of energy storage systems.

The Fraunhofer FEP is also working on intelligent solutions for energy management to support sustainable and efficient energy systems.

Cultural Heritage Management



The Fraunhofer FEP offers a wide range of innovative technologies and services for the preservation and maintenance of cultural assets. Our expertise ranges from the characterization of thin films and surfaces to the reconstruction of historical mirrors and plasma-activated high-rate evaporation processes.

We also offer advanced solutions for the cleaning and pre-treatment of surfaces as well as the development of thin film corrosion sensors. With state-of-the-art technology and in-depth scientific knowledge, we support research and development, quality assurance and the restoration of historical objects.

Our aim is to offer the best possible solutions for the preservation of valuable cultural artefacts through continuous innovation and adaptation of our processes.

Life Sciences



The Fraunhofer FEP offers a broad spectrum of technologies for the optimization of materials and surfaces for the life sciences sector.

Our core competences lie in the development of biofunctional coatings and the targeted modification of surface properties, for example to improve the biocompatibility of implants and medical technology products. With our processes for germ reduction and sterilization using low-energy electron beams, we contribute to the safe and efficient reprocessing of medical devices and packaging.

The modern biomedical laboratory complex of the Fraunhofer FEP with safety level S1 consists of laboratory units for microbiology, cell biology, bioanalytics as well as for surface chemistry and biotechnological reaction processes. This enables us to carry out interdisciplinary and industry-orientated research and development for a wide range of life science applications.

We look forward to evaluating with you how our technologies can qualify your surfaces for contact with biological media.

Mechanical Engineering



Optimized surfaces are the basis of many innovations, especially in mechanical engineering. Coatings that make products and components resistant to corrosion, wear and scratches are of enormous economic importance: damage caused by corrosion alone amounts to billions of euros worldwide every year. Friction-reducing coatings also make a considerable contribution to reducing energy and material consumption.

At Fraunhofer FEP, we develop highly productive vacuum processes and technologies to clean flat surfaces and components and improve their properties by applying a wide variety of coatings and coating systems: Using sputtering technology, plasma-activated high-rate vapour deposition and high-rate PECVD, we efficiently apply functional coatings. Together with the Fraunhofer Cleaning division, we can also offer you a comprehensive portfolio of cleaning technologies.

We use the electron beam as a versatile tool for welding components, hardening surfaces or specifically modifying their properties. Scaling up all processes for industrial production conditions is an important focus of our work.

Mobility

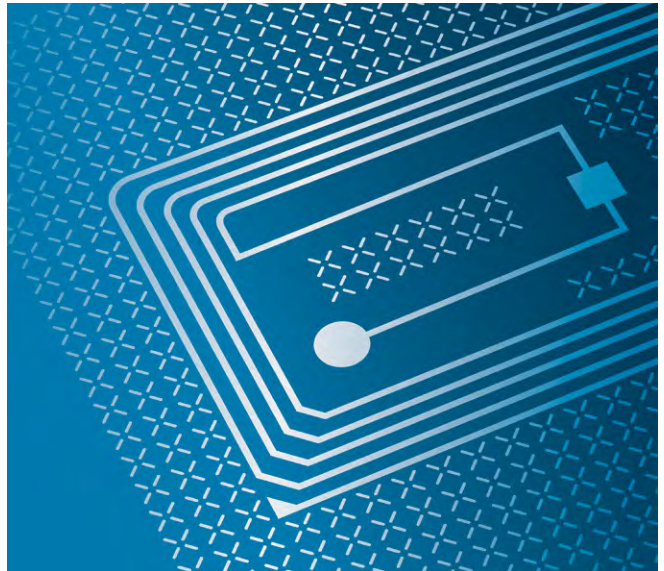


Our tailor-made industrial solutions for the mobility sector include cutting-edge and customer-specific technologies for optimizing surfaces in the automotive, rail and aerospace sectors.

The specially developed coating solutions improve both the durability and performance of vehicle components and help to reduce emissions. In the field of exhaust gas purification, advanced technologies are developed for the efficient reduction of pollutants in maritime applications. In addition, we offer the development of coating solutions and surface treatments for rail vehicles, which are used in the passenger area as well as on technical and mechanical components.

Through precise research and development, we create innovative solutions for sustainable and high-performance mobility.

Optics, Sensors and Electronics



The Fraunhofer FEP offers advanced technological solutions for the growth sectors of optics, sensor technology and electronics. Our coating technologies are becoming increasingly important as they both optimize existing products and enable new product innovations.

With our many years of experience and state-of-the-art system technology, we are able to apply electrical, optical, acoustic and magnetic coatings precisely and homogeneously to large surfaces.

Our vacuum processes ensure high coating rates, accuracy and reliability, which guarantees the productive and cost-effective manufacture of sophisticated products. The use of electron beam technology also enables us to weld sensitive material combinations with extreme precision, particularly in the field of sensor technology, and to create solutions that would not be possible with other processes.

Smart Building



Functional surfaces for façades and roofs are playing an increasingly important role in the construction industry and architecture. They not only contribute to aesthetic design, but also fulfil crucial technical functions.

Smart building technologies integrate innovative solutions such as thermochromic and low-E coatings that increase energy efficiency and comfort in buildings. These intelligent surfaces enable effective regulation of temperature and light, which significantly reduces energy consumption. They thus set new standards for sustainable and future-orientated construction.

The Fraunhofer FEP has many years of expertise and a wide range of possibilities in process and layer development on flexible materials such as films and thin glass as well as on flat glass. This can be done in roll-to-roll and sheet-to-sheet processes in a vacuum or in an atmosphere.

In addition, with our expertise in electron beam, sputtering and plasma technology, we offer solutions for coating various components for heat storage systems of the future, such as electrocaloric heat pumps or zeolite heat storage materials.

AgriTech



Agriculture is facing major challenges resulting from climate change and the scarcity of natural resources. Innovative approaches are needed to increase yields, reduce costs and minimize environmental impact at the same time. This is where smart agriculture comes in, ushering in a new era of sustainability through the use of state-of-the-art technologies.

In the field of AgriTech, the Fraunhofer FEP focuses on advanced electron beam and plasma technologies that offer numerous advantages. Our technologies not only help to increase the efficiency of production, but also significantly reduce the environmental impact.

The reduction in the use of chemicals and the improved utilization of resources create the basis for a more sustainable future in agriculture.

Environmental Technologies



Innovative solutions for environmental technologies make a decisive contribution to conserving resources and reducing emissions.

We develop processes, for example to stimulate bioleaching processes for the environmentally friendly extraction of metals or technologies for the sustainable purification of waste water and waste gases.

Plasma-activated water ensures environmentally friendly purification. Low-energy electrons can break down persistent micropollutants, e.g. pharmaceutical residues, in wastewater and thus significantly improve the efficiency and range of biological treatment processes. For waste gas treatment, we use low-energy electrons to efficiently eliminate pollutants.

In the field of energy storage and the utilization of renewable energies, we offer, for example, the development of thermal barrier coatings for turbine blades and special coatings for fuel cells. The generation of chemical energy storage from renewable energy using electron beam-based plasma synthesis processes is another important research focus.

We are also working on solutions for material recycling in order to enable sustainable reutilization through modern coating processes.

The phytosanitary treatment of seeds with low-energy electrons is a purely physical process that does not require the addition of chemical additives and can therefore be particularly environmentally and socially friendly.

Packaging



The packaging sector is subject to enormous cost pressure: packaging material must not usually cost much, but is very important for the quality and shelf life of the end product.

In addition, the demand for packaging materials is constantly increasing. In contrast, the amount of materials based on fossil raw materials must be reduced in order to contribute to a sustainable future. The proportion of renewable, bio-based materials for packaging products must increase in order to avoid environmental pollution, e.g. through microplastics.

Technologies for vacuum coating and surface modification with electrons from the Fraunhofer FEP are ideally suited to this task due to their high productivity and the very good surface properties that can be achieved.

Based on our technological expertise, we offer in particular the functionalization of bio-based and biodegradable films as well as monomaterials, for example for permeation barriers to extend the shelf life of the product. We also use electron beam technology to modify the surface of plastics or to cure printing inks or lacquer-based functional layers.

We support you with the development of highly productive technologies and processes for the finishing of your packaging!

Future Topics

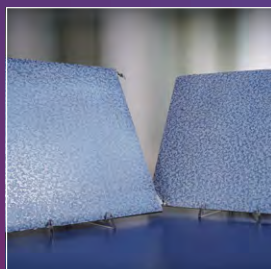


The future topics to which the Fraunhofer FEP is committed and which will determine the direction of the institute's work in the coming years are technologically groundbreaking and should make a significant contribution to overcoming global challenges. Energy-efficient and sustainable solutions, innovative life science applications and the digitalization of industrial processes are essential for sustainable development and the well-being of society.

- Digitalization
- Sputter epitaxy
- Plasma chemistry

Through its research work, the Fraunhofer FEP makes a decisive contribution to the innovative strength and competitiveness of the German and European economy.

Research News



DesignPV – Aesthetic and efficient building-integrated photovoltaics 23



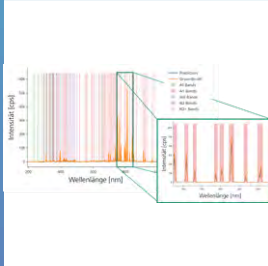
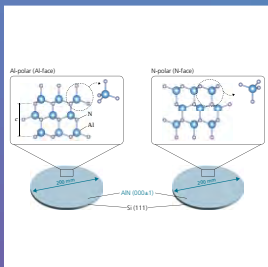
Sustainable protective textiles achieved by electron beam-assisted functionalization with humic substances 24



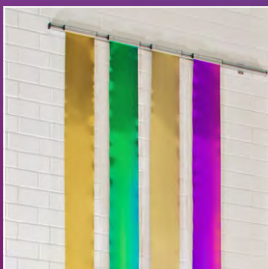
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DesignPV – Aesthetic and efficient building-integrated photovoltaics

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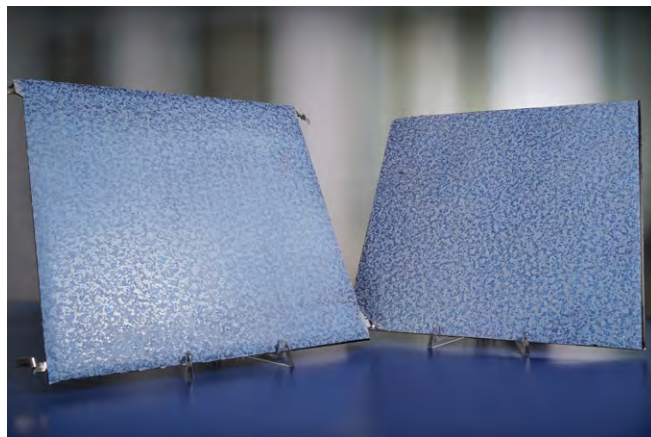
The DesignPV project, funded by the Federal Ministry for Economic Affairs and Energy as part of the 7th Energy Research Program, aims to advance building-integrated photovoltaics (BIPV) through innovative technologies and appealing design. The focus is on developing cost-effective, durable, and visually appealing solutions to harness previously unused façade areas for energy generation.

A key aspect of the project is the integration of decorative films onto both PV-active and non-active façade elements to enable a uniform appearance. The decorative films are based on ETFE substrate films, which are already well-established in architectural applications due to their excellent weather resistance. However, because ETFE's low surface energy makes it difficult to apply decorative layers, Fraunhofer FEP developed a plasma process that roughens the films on a nanometer scale, significantly improving the adhesion of those layers.

The decorative films are patterned using roll-to-roll nanoimprint lithography (NIL). This process enables the large-area patterning of films with feature sizes ranging from a few nanometers to millimeters. In this process, a patterned master roller is pressed into a coating layer while the coating is simultaneously cross-linked by electron beam irradiation. This continuous technology allows for highly productive manufacturing with web widths of up to 1,250 mm and process speeds of up to 100 meters per minute. In addition, it allows for the integration of pigments and particles to create surfaces that closely replicate the tactile and visual properties of natural materials.

Initial Results

At the project's midpoint, several decorative patterns were initially applied to PET films and successfully installed and tested on both PV-active and non-active façade elements. The results show that the decorated PV modules are visually almost indistinguishable from conventional façade elements and – depending on the decorative pattern – achieve an output of up to 80% of that of the uncoated reference modules. This represents significant progress, as aesthetic considerations are often seen as a barrier to the acceptance of BIPV solutions.



Freely combinable façade elements with decorative film – on the left, a PV module and, on the right, a sheet metal façade element without PV functionality.

Outlook

In the next step, the results obtained will be transferred to ETFE substrate films. In addition, testing of further decorative patterns and color variations, as well as comprehensive investigations into long-term stability and weather resistance, are planned. The goal is to further increase the integration of BIPV in architecture and to make the technology usable for the energy-efficient retrofitting of existing buildings. With DesignPV, Fraunhofer FEP is making a significant contribution to the energy transition and to the sustainable design of urban spaces.

Project Partners

FLACHGLAS Sachsen GmbH
Fraunhofer Institute for Electron Beam and Plasma Technology FEP
Institute for Solar Energy Research GmbH Hamelin
Ronge GmbH
SURTECO GmbH
TOMASIC Engineering GmbH



*Funded by the German Federal Ministry
for Economic Affairs and Energy.
Funding reference: 03EN1084A*

Sustainable protective textiles achieved by electron beam-assisted functionalization with humic substances

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The use of low-energy, non-thermal electron beam processes results in biohybrid textiles with specifically adjusted surface properties. The finalized project HuminTex shows how bio-based materials can be further developed into functional mask components using natural substances with antiviral properties, called humic substances, and transferred to industrial production.

Sustainability is becoming increasingly important in both medical technology and personal protective equipment. In addition to the protective function, the focus is shifting to material origin, environmental compatibility, and end-of-life concepts. Particularly, disposable products such as respiratory masks require new approaches that combine functionality with resource-saving materials and processes. Within this context, the HuminTex joint project addresses the development of antiviral, bio-based protective textiles for medical applications.

In this project, Fraunhofer FEP's approach was based on low-energy, non-thermal electron beam technology for the selective modification of textile surfaces. The two-stage electron beam-assisted grafting enables precise, substrate-specific surface functionalization and coating of textile substrates with low thermal stability. At the same time, process-induced heat stress can be avoided entirely, eliminating the need for additional chemicals, such as surfactants, that are typically used in standard textile finishing.

This allows tailored functional property profiles to be created while maintaining the structural integrity of the textiles. One focus was on the stable electron beam-induced immobilization of naturally occurring humic substances on biodegradable nonwovens made of polylactide (PLA). The covalent bonding of the functional humic acid molecules was confirmed spectroscopically. Additional investigations confirmed the high resistance of the coating to process- and usage-related stresses. The introduction of a bio-based chitosan layer as an adhesion promoter further improved both the bonding of the humic substances and the long-term stability of the functional layer. The selected humic substances were shown to be effective against viruses using plaque assays with specially established bacteriophage models.



PLA nonwoven fabric with applied humic substances for the electron beam-assisted grafting process (left) and comparison of two FFP2 PLA respirator masks – one unmodified and one functionalized with humic substances (right)

The results showed remarkable reduction in viral activity both in the pure natural substances and in the PLA textiles functionalized with humic substances. Overall, these data confirm that surfaces containing humic substances have the potential to effectively inactivate viral particles.

The final functional PLA nonwoven fabrics were successfully integrated as an intermediate layer in the standard design of FFP2 respirators. In collaboration with project partner STFI e.V. and industry partners Zschimmer & Schwarz GmbH and Sentias GmbH, the serial production of biodegradable FFP2 respirator masks was realized. Thus, the research work at Fraunhofer FEP demonstrates the high application potential of low-energy, non-thermal electron beam processes for the precise and selective surface engineering of textile substrates. This enables the development of application-specific and resource-efficient protective textiles for future medical technology applications.

The HuminTex joint project (funding code 16PS104004) was financed by the Innovative Protective Equipment funding program of the German Federal Ministry for Economic Affairs and Energy.



*Funded by the German Federal Ministry
for Economic Affairs and Energy.
Funding reference: 16PS104004*

Innovative electron beam technology for biotechnological processes

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By commissioning a new system combining a low-energy electron beam source and a bioreactor, Fraunhofer FEP is breaking new ground at the intersection of electron beam technology and biotechnology. This new technology enables specific influence of biological processes in liquids using accelerated electrons, forming an important basis for innovative applications in the bioeconomy and environmental technology.

This technology is based on one of Fraunhofer FEP's core competencies: electron beam technology. Coupling this with a bioreactor creates a flexible, scalable platform that can treat different volumes of liquid in an energy-efficient manner. The dose, dose rate and penetration depth of the electron beam can be precisely controlled. Its compact, safe and modular design means it can be used in sensitive environments and transferred to larger reactor systems in the future. Thus, the technology contributes to the implementation of the National Bioeconomy Strategy by optimizing bioprocesses and making biological resources more efficient.

One key area of application is bioleaching, i. e. the microbial extraction of metals from ores and industrial waste materials. Specialized microorganisms can be used to extract metals such as copper, indium and vanadium from poorly soluble metal sulfides, using significantly less energy and producing fewer toxic or climate-damaging emissions than conventional processes. Preliminary research at Fraunhofer FEP indicates that electron beam irradiation can enhance the efficiency of copper bioleaching approximately 10 percent without hindering bacterial growth. The yield of dissolved copper is higher than in untreated samples, which is an important step towards the more economical and sustainable recovery of valuable metals from low-grade ores and recycled materials.

In addition to metal extraction, hybrid technology has the potential to be used for other applications, such as wastewater treatment, biopolymer production, and the sterilization of sensitive products.

Fraunhofer FEP supports industry and research partners in adapting and implementing this technology, providing assistance with everything from feasibility studies and the development



Development of hybrid technology for treating liquids with electrons

of suitable test regimes and microbiological validations, to investigating the effect of electrons on various biological systems. The new facility provides a powerful platform for collaborating with partners to develop innovative solutions for conserving resources, ensuring raw material security, and protecting the environment.

ELBION: Development of a compact electron source for cost-efficient phytosanitary seed treatment

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The ELBION project aimed to combine the phytosanitary treatment of seeds with electrons and biological agents, and to make the methods economically attractive also for seed producers with smaller annual volumes. To this end, Fraunhofer FEP developed a compact and cost-effective cylindrical electron source, while RAUSSENDORF GmbH designed a mobile, modular small-container system and investigated the effects of various bioactive substances.

The phytosanitary treatment of seeds with accelerated electrons offers a purely physical, environmentally friendly alternative to chemical dressing. While pathogens on and within the seed coat are reliably inactivated by this method, the embryo remains unaffected. This is possible because the penetration range of the electrons can be precisely tuned by the acceleration voltage of the beam generator. Depending on the seed variety, tailored recipes make sure that the recommended amount of energy is applied with appropriate surface uniformity and depth distribution. The ecological advantages as well as the phytosanitary efficacy of the electron treatment have been proven in long term studies together with German Federal Authorities and by decades of field experience in practical farming. To integrate the electron treatment into seed production workflows, Fraunhofer FEP has developed and transferred several container-based units (called "ISABEL") over the past years. They are being operated as stationary installations in large-scale facilities or as mobile plants at various locations of smaller enterprises. These existing units are highly productive and can treat (depending on the seed type) up to 25 metric tons per hour, but they also require significant investment.

Therefore, the main objective of the ELBION project was to make the electron treatment economically appealing even for customers with smaller annual volumes (below 5,000 tons) thereby increasing its market share.

In close collaboration with RAUSSENDORF GmbH, a mobile and modular small-scale container system was designed for this purpose, which, following electron treatment, also allows for the application of bioactive substances. These typically contain organic fertilizers or beneficial bacteria and fungi that promote plant growth, enhance nutrient uptake or protect against soil-borne pests and diseases.



Novel cylindrical electron source for cost-effective seed treatment on test rig in high-voltage laboratory of Fraunhofer FEP

As a key component for this concept, Fraunhofer FEP has developed a novel cylindrical electron source which emits electrons into atmosphere radially outwards to treat the surrounding curtain of falling seed, facilitating a throughput of about 10 metric tons per hour, which fits the typical productivity of upstream and downstream processes in commercial seed processing plants well. Like the linear sources previously available, this source is designed for acceleration voltages up to 150 kV and a rated power of 30 kW. However, by housing all the components of electron generation and acceleration inside the cylinder, significant savings are achieved in terms of space requirements and manufacturing costs. A prototype of this new, patented source was successfully commissioned on a test rig of Fraunhofer FEP and used to treat seed samples for field trials. It shall be integrated with controls and supplies and installed into a mobile, production-ready container in the next development phase.



This project is co-financed from tax revenue on the basis of the budget adopted by the Saxon State Parliament.

*Funded by the European Union and the Free State of Saxony.
Funding reference: 100690165*

Digitalization of coating processes

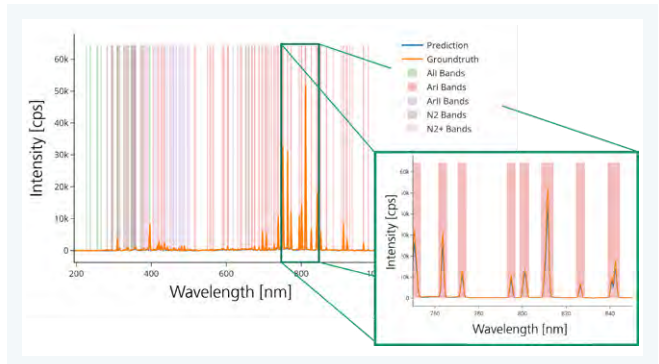
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The DigiMatUS project advances the digitalization of coating processes. A basis for machine learning is established by correlating process parameters and thin film properties for the synthesis of piezoelectric AlN/AlScN thin films for ultrasound microscopy. This enables a more effective development of new coatings or tailored coating properties as well as a more efficient transfer of technology between different machine platforms.

Piezoelectric thin films play a significant role in medical technology, microelectronics, and sensors, e. g., as active layers in lenses for ultrasound microscopes. These microscopes enable the examination of small structures, such as semiconductor components or biological tissue. To achieve the superior imaging quality, highly oriented and homogeneous piezoelectrically active layers are mandatory. The requirements for the quality of these layers increase as the dimensions of the features to be examined become smaller. The properties of the thin films and ultrasound transducers result from the complex interplay of numerous process parameters and factors.

In the DigiMatUS project ("Digitalization of materials research on thin-film materials using the example of high-resolution piezoelectric ultrasonic sensors"), the efficient development of coating technologies is being advanced through a digital representation of the deposition processes, the development of a process and film ontology (a formal representation of knowledge, entities, their properties, and relationships), and machine learning methods. For this purpose, the synthesis of piezoelectric aluminum nitride (AlN) and aluminum scandium nitride (AlScN) thin films is carried out at Fraunhofer FEP across a broad range of parameters. This includes, for example, the variation of sputter power, process pressure, or gas flows, as well as the consideration of other influencing factors, like the underlying coatings of the electrode structures. Through enhanced optical in-situ process monitoring and layer diagnostics, as well as extensive characterization of the layers, the project aims to establish the process-parameter / thin-film-property relationships in more detail.

The combination of an ontological description of the processes and the incorporation of existing expert knowledge forms the basis for meaningful predictive models for machine learning utilizing a comparatively small data set.



Optical emission spectrum of the plasma of an AlN process with color-coded bands of the individual species. Comparison of the measured spectrum (ground truth, blue) and the predicted spectrum (prediction, orange).

The development and training of the predictive models is carried out by the project partners at Otto-von-Guericke University Magdeburg. As a result, an initial predictive model has already been created that predicts plasma spectra based on process parameters. Current and future work at Fraunhofer FEP will focus on further advancing the thin film ontology, continuing experiments for additional training, and validating the developed models.

In addition to developments for ultrasound sensors, the results of the project open up new opportunities for other applications based on thin film technologies. The digital representation of material and process data through the thin film ontology and AI models will be adapted for other relevant coating processes and materials. This will significantly accelerate research and development of new materials in the future.



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Magnetron Sputter Epitaxy: A Technology for the Future of GaN Power Electronics

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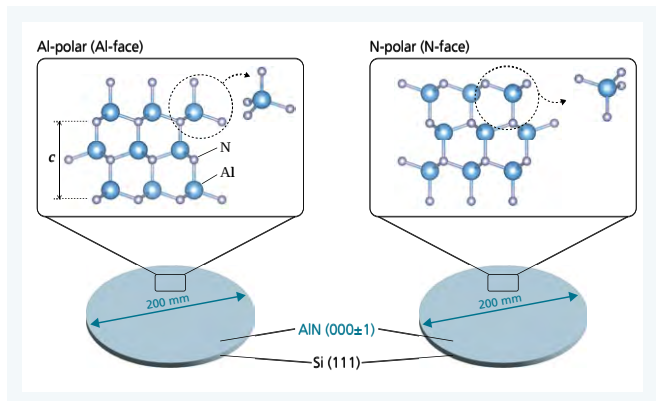
Magnetron Sputter Epitaxy (MSE) at Fraunhofer FEP represents an innovative technology for resource-efficient deposition of high-purity, crystalline III-nitride semiconductors such as Gallium Nitride (GaN) and Aluminum Nitride (AlN). These semiconductors are crucial for the development of future microelectronic devices. III-nitrides have a variety of applications, including in energy-efficient power converters for renewable energies, in frequency converters for e-mobility, in radar and wireless technologies, as well as in optoelectronic LED and laser systems.

Fraunhofer FEP is developing MSE as a complementary approach to synthesising III-nitride semiconductors more efficiently. Compared to traditional metalorganic chemical vapor deposition (MOCVD), which is the industrial standard for complex III-nitride devices, MSE produces crystalline layers via plasma-assisted deposition. This allows operating at decreased temperatures and helps circumventing the drawbacks of expensive and toxic organometallic precursors. Through the development of MSE technology, resource-efficient deposition of high-purity AlN- and GaN-layers at temperatures below 1000°C has been successfully realized.

The fabrication of AlN templates on silicon substrates with a 200 mm diameter provides a scalable foundation for the subsequent epitaxy of active devices, for example via MOCVD. MSE's lower process temperatures (800°C is targeted, compared to MOCVD at around 1100°C) minimize mechanical stresses and could enable direct integration of the epitaxy into the Si-CMOS frontend. In the mid-term, it is intended to directly deposit active devices using MSE.

So far, only with the Double Ring Magnetron (DRM) technology developed by Fraunhofer FEP it has been possible to directly control polarity of AlN (Al- or N-polar) on 200 mm silicon wafers and on 100 mm sapphire wafers through the epitaxy process itself, enabling new device architectures.

The stable reactive MSE deposition of GaN requires a solid-state gallium target (melting point of Ga $\approx$ 29°C). Thus, the DRM at Fraunhofer FEP has been further developed and equipped with an innovative evaporative cooling system.



Schematic representation of a 200 mm silicon wafer with an AlN layer in Al- and N-polarity. The upper portion of the image illustrates the geometric arrangement of Al and N atoms relative to the growth direction. By precisely controlling the symmetry of the epitaxial AlN layer, novel devices can be developed.

In 2026, Fraunhofer FEP will commission its new epitaxy tool »EpiLab« specifically designed for MSE. It will enable confocal deposition of AlGaN layers as well as AlN/GaN superlattices on 200 mm wafers, and the investigation of novel dopant approaches. This investment in infrastructure (including an ISO-3 cleanroom) provides the foundation for developing active layers for GaN-based devices and positions Fraunhofer FEP as a leading player in sustainable semiconductor technology.



Funded by the German Federal Ministry of Research, Technology and Space.

Funding reference: 01QE2533C (PAGaN)



*Funded by the internal program of the Fraunhofer-Gesellschaft.
Funding reference: Attract 40-00848 (EpiTakt)*

Lighter, less pollutant and yet safe: Coatings for the aviation industry

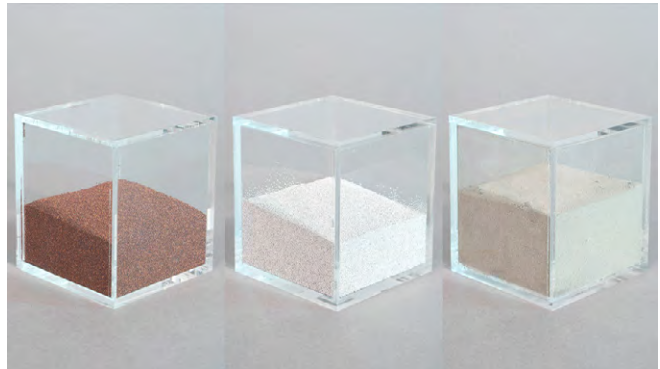
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In the aviation industry, material innovations and efforts to conserve resources serve to ensure safety for global mobility and to remain competitive on the international stage, while also taking environmental impacts into account. Thermal barrier coatings, non-toxic corrosion protection, and materials with specifically adjustable absorption and reflection characteristics across the electromagnetic spectrum are examples of how Fraunhofer FEP contributes to the overarching goal of safe and resource-efficient aviation through its coatings.

Aviation is a key driver of our globally interconnected economy and will continue to grow for the foreseeable future, enabling and supporting achievements such as the global flow of goods and the expansion of air travel. To help shape these developments in an environmentally responsible manner, a wide range of efforts are underway in Fraunhofer's research fields. These range from studies on alternative fuels and concepts for securing new, additional transportation networks, to technical developments such as ultra-lightweight materials, miniaturized sensors, or high-energy-density storage systems, to name just a few examples.

At Fraunhofer FEP, we develop coating technologies and coating structures, some of which are specifically designed for aviation applications. These include thermal barrier coatings applied to turbine blades using electron beam technology. New challenges in this area stem from the requirements posed by new fuels such as hydrogen or synthetic fuels (e. g., Sustainable Aviation Fuels, SAF).

Another area of focus is the development of new solutions for non-toxic corrosion protection for high-strength aerospace steels and aluminum alloys. As part of the German Federal Aviation Research Program »LuFo«, corrosion protection coatings based on aluminum with suitable alloying elements have been investigated in the »ProAlu« project; these coatings can ensure effective corrosion protection for the base material even if the coating is damaged, thanks to self-healing effects. The goal for industrial implementation is to eliminate cadmium as a corrosion protection agent on high-strength steels in aircraft construction.



Glass beads and lightweight fillers coated in bulk

We also apply high-rate deposition of aluminum layers to microglass beads using a bulk processing method. The challenge of handling particle batches increases as particle size decreases. While technological studies are currently still being conducted with glass beads of at least 200 µm in diameter, we plan to expand the scope of application to smaller and even lighter, free-flowing particle batches. Their embedding in matrix materials to achieve an EMC shielding effect in filled plastic components for ultralight construction appears to be an attractive prospect given increasing electrification and simultaneously high requirements for immunity to interference. Even in coatings that, in addition to providing color, must meet specific absorption characteristics in the electromagnetic spectrum, metallized lightweight particles could save weight compared to solid metal particles or flakes as a conductive component.

To ensure that existing research findings are incorporated into industrial manufacturing and that visionary ideas can be tested, we are always interested in collaborative projects with industry partners.



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for Economic Affairs and Energy.
Funding reference: 20W1921F*

MAXI as a research platform: Sustainable surface technology for the future

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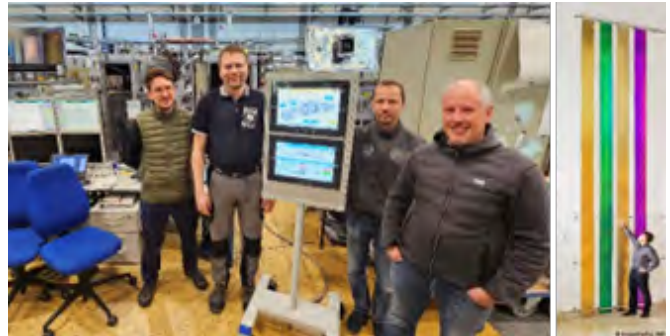
For 25 years, the multifunctional MAXI coating line at Fraunhofer FEP has shown how sustainable surface solutions can be developed efficiently. Today, upgraded electronics, enhanced inspection tools, new plasma-assisted processes and close cooperation with HIB I Automation GmbH are preparing MAXI for the next decades.

Sustainable surface technology is a key lever for conserving resources in industry. Functional coatings extend product lifetime by improving corrosion resistance, wear behavior and surface functionality, while the environmental footprint of the coating processes themselves must be kept low. Fraunhofer FEP addresses both aspects with environmentally friendly processes and multifunctional pilot equipment – above all with its in-line vacuum coating equipment for sheets and metal strips – MAXI.

Commissioned in 2000, the MAXI was conceived as a flexible long term platform rather than a single purpose tool. The modular and unique system with eight chambers supports both sheet to sheet and roll to roll processing of metal strips, plates, plastics, glass and ceramics. Different steps such as heating, ion etching, high rate EB PVD, pulsed magnetron sputtering, other PVD and PECVD processes as well as thermal post treatment can be combined in variable sequences. Integrated in situ analytics, including X-ray fluorescence and optical layer thickness monitoring, enable robust and reproducible processes.

This multifunctionality itself contributes significantly to sustainability. Existing infrastructure – vacuum pumps, power and gas supplies, cooling, process control and metrology – is continually reused across a wide range of projects. Instead of building new special purpose equipment, Fraunhofer FEP reconfigures the MAXI tool for changing R&D demands. This reduces investment and ramp up times, saves materials and energy and minimizes waste.

Over the years, MAXI has enabled a broad spectrum of applications: ZnMg based corrosion protection layers on steel strip, transparent and decorative SiO_2 and Al_2O_3 based coatings, hard and tribological TiN and TiAlN films, high surface area powders for capacitors, thick aluminium alloy layers for modern bearing shells, back contacts for solar cells, coatings for battery and fuel cell components as well as inline processes for graphene and carbon nanotubes.



Left: The HIB team during commissioning of the new plant control system at the MAXI plant

Right: Metallic strips with functional coatings

After 25 years of reliable operation, the MAXI tool is being comprehensively modernized. The control electronics and automation are renewed, the XRF inspection system is upgraded and the platform is prepared for new plasma assisted coating methods, including anodic arc evaporation for diamond like carbon films. A key element of this upgrade is the collaboration with HIB I Automation GmbH, which contributes advanced control and automation solutions. In this way, MAXI will remain a central platform for developing sustainable surface technologies under near industrial conditions in the years to come.

Appendix



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The Fraunhofer-Gesellschaft

The Fraunhofer-Gesellschaft, headquartered in Germany, is a leading organization for applied research. It plays a pivotal role in innovation by focusing on cutting-edge technologies and transferring research results to industry in order to strengthen Germany as a business location and benefit society. Since its founding as a nonprofit in 1949, Fraunhofer has held a unique position in the German research and innovation ecosystem.

With more than 30,000 employees at 74 institutes and independent research units in Germany, Fraunhofer operates with an annual budget of 3.6 billion euros. Contract research, Fraunhofer's mainstay, generates 3.2 billion of this budget. Unlike other public research organizations, institutional funding from federal and state governments accounts for no more than one-third of Fraunhofer's contract research budget. Institutional funding is thus merely the base of Fraunhofer's main business model and serves as the foundation for ground-breaking pre-competitive research that will become important for industry and society in the years ahead.

What truly sets Fraunhofer apart is its high share of industrial revenue, which ensures close collaboration with the private sector while keeping Fraunhofer's research focused on the market. Fraunhofer raises at least two-thirds of its contract research budget competitively from private-sector contracts and public project funding. In 2025, industrial revenue alone accounted for 966 million euros.

The Fraunhofer-Gesellschaft is a recognized non-profit organization named after Joseph von Fraunhofer (1787–1826), an illustrious researcher, inventor and entrepreneur hailing from Munich.

Customers and contractual partners are:

- Industry
- Service sector
- Public administration

Key figures at a glance

- 74 institutes and research units
- Around 30,000 staff
- 3.2 billion euros annual research budget totaling



Fraunhofer Group for Light & Surfaces

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

Members are the Fraunhofer institutes for

- Electron Beam and Plasma Technology FEP
www.fep.fraunhofer.de
- Laser Technology ILT
www.ilt.fraunhofer.de
- Applied Optics and Precision Engineering IOF
www.iof.fraunhofer.de
- Physical Measurement Techniques IPM
www.ipm.fraunhofer.de
- Material and Beam Technology IWS
www.iws.fraunhofer.de
- Surface Engineering and Thin Films IST
www.ist.fraunhofer.de (associated)
- Telecommunications, Heinrich Hertz Institute HHI
www.hhi.fraunhofer.de (associated)
- Optronics, System Technologies and Image Exploitation IOSB
www.iosb.fraunhofer.de (associated)

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

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

Chair of the Group is Prof. Karsten Buse (Fraunhofer IPM) and Dr. Heinrich Stülpnagel has been head of central office.



Central Office

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Fraunhofer-Business Area Cleaning

The Fraunhofer-Business Area Cleaning combines the expertise of 9 different Fraunhofer Institutes in the field of industrial surface cleaning and thus offers a very broad spectrum of technological competence and industry relevance. With its own website, regular newsletters and social media activities, and as a specialist partner of the leading international trade fair parts2clean, it achieves a high international reach. The

Fraunhofer-Business Area Cleaning makes a decisive contribution to the development and industrial use of cleaning technologies. Small and medium-sized companies in particular, but also large companies, receive competent support. They benefit from the comprehensive expertise in the field of analytical and experimental development of cleaning methods and processes as well as analytical methods and procedures for process monitoring and quality assurance.

Various further training formats, from special seminars at individual member institutes to IHK-certified advanced qualifications, are an essential, complementary pillar of knowledge transfer.

The office is currently located at the Fraunhofer FEP. Frank-Holm Rögner is the elected spokesperson.



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Phone +49 351 2586-242

 www.cleaning.fraunhofer.de

Memberships

- AK Glasig-kristalline Multifunktionswerkstoffe
www.ak-gkm.bam.de
- AMA Fachverband für Sensorik e. V.
www.ama-sensorik.de
- biosaxony e. V.
www.biosaxony.com
- BioZ – Biobasierte Innovationen aus Zeit und Mittel-
deutschland
www.bio-z.de
- Building 3D e. V.
<http://building-3d.de>
- Bundesverband Der Mittelstand BVMW e. V.
www.bvmw.de
- Deutsche Gesellschaft für angewandte Optik
www.dgao.de
- Deutsche Glastechnische Gesellschaft
www.hvg-dgg.de/home/dgg.html
- Deutscher Industrie-Reinigungs-Verband
www.dirv.org
- DIN Normungsausschuss Reinigung und Sauberkeit von
metallischen Bauteilen im Herstellprozess
www.din.de
- Dresden-concept e. V.
www.dresden-concept.de
- Energy Saxony e. V.
www.energy-saxony.net
- Europäische Forschungsgesellschaft Dünne Schichten e. V.
www.efds.org
- European Sustainable Nanotechnology Solutions Association
www.esna-assoc.eu
- Fachverband für Mikrotechnik IVAM
www.ivam.de
- Fachverband industrielle Teilereinigung FiT
www.fit-online.de
- Forschungsallianz Kulturerbe
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- Fraunhofer Geschäftsbereich Reinigung
www.reinigung.fraunhofer.de
- Fraunhofer Netzwerk Smart Farming
www.fraunhofer.de
- Fraunhofer Smart Maintenance Community
bei Fraunhofer-Allianz Produktion
www.produktion.fraunhofer.de
- Fraunhofer-Allianz Batterien
www.batterien.fraunhofer.de
- Fraunhofer-Verbund Light & Surfaces
www.light-and-surfaces.fraunhofer.de
- Fraunhofer-Verbund Mikroelektronik
www.mikroelektronik.fraunhofer.de
- Fraunhofer Wasserstoff-Netzwerk
www.fraunhofer.de
- FutureSax Sächsisches Transfernetzwerk
www.futuresax.de/transfer/saechsisches-transfernetzwerk
- HZwo e. V.
www.hzwo.eu
- Informationsdienst Wissenschaft
www.idw-online.de
- Innovationsnetzwerk Forum MedTech Pharma
bei Bayern Innovativ GmbH
www.medtech-pharma.de
- Innovationsnetzwerk CleanHand
www.cleanhand.de
- Innovationsnetzwerk DekubiTel
www.dekubitel.de
- International Council for Coatings on Glass ICCG e. V.
www.iccg.eu
- International Irradiation Association
www.iia-global.com
- KIC CCI – ICE-Konsortium Innovation by Creative Economy
www.ice-germany.de
- Kompetenznetz Industrielle Plasma-Oberflächentechnik e. V.
www.inplas.de
- Kompetenznetz Plasma Germany
www.plasma-germany.org
- Kompetenzzentrum Luft- und Raumfahrttechnik Sa/Thü e. V. LRT
www.lrt-sachsen-thueringen.de
- Netzwerk »Dresden – Stadt der Wissenschaften«
www.dresden.de
- R2RNet
www.r2r-net.eu
- SenSa Sensorik Sachsen
www.sensorik-sachsen.de
- Silicon Saxony e. V.
www.silicon-saxony.de
- Space2Health
www.space2health.eu
- VDE Verband der Elektrotechnik – Bezirksverein Dresden e. V.
www.vde-dresden.de
- VDMA Organic Electronics Association (OE-A)
www.oe-a.org
- Verband Deutsches Reisemanagement e. V. (VDR)
www.vdr-service.de/der-verband/der-vdr

Lectures



Prof. Dr. Elizabeth von Hauff

Technical University Dresden

Plasma Technology



Prof. Dr. Gösta Mattausch

West Saxon University of Applied Sciences Zwickau

Production and properties of nanostructures
and nanolayers



Frank-Holm Rögner

University of Applied Sciences Berlin

Conservation and Restoration 3:
Historical Methods and Current Developments



Dr. Stefan Saager

University of Applied Sciences Dresden

Electron and laser beam technology



Prof. Dr. Simone Schopf

Brandenburg University of Technology Cottbus-Senftenberg

Environmental Biotechnologies

Biologische Verfahren der Biomasse- und Abfallbehandlung



Theses

Diplom thesis

Author	Title	University
Xiaoming Shen	Entwicklung von Schutzschichten für Hochbarriere-Schichten auf Polymerfolie	Technische Universität Dresden

Master thesis

Author	Title	University
Jonathan Desa	Non-Stick Modification of the Surface of an Embossing Roller	Technische Universität Chemnitz
Haseeb Badar	Investigation of the influence of the biopositive effect of low-energy accelerated electrons to optimize sustainable biogenic limestone production	Rheinland-Pfälzische Technische Universität Kaiserslautern-Landau
Carolin Barth	Untersuchungen zur Abscheidung von Titan-Dünnschichten auf Komposit-Bipolarplatten	Hochschule für Technik und Wirtschaft Dresden

Publications



Our publications in the field of electron beam and plasma technology offer comprehensive insights into current developments, technological innovations and industrial applications. They cover topics such as precision machining, material modification, surface treatment and coating technologies.

You can find a current overview of our publications at:



www.fep.fraunhofer.de/publications

Protective Rights

Patent number	Title	Inventor(s)	Registration	Grant
DE 10 2023 207 810 B3	Verfahren und Vorrichtung zur Ermittlung einer Strahlungsdosis, die eine wässrige Flüssigkeit durch Elektronenstrahlung erfährt	S. Schopf, U. König, J. Besecke, J. Kubusch	14.08.2023	13.02.2025
BR 112021006089-8	Método para estimular o crescimento de uma biomassa que é misturada com um líquido dentro de um biorreator	J. Schönfelder, C. Wetzel, G. Gotzmann, V. Kirchhoff, A. Weidauer, J. Kubusch	29.03.2021	08.04.2025
US 12 362 141 B2	Apparatus and method for depositing hard carbon layers	B. Scheffel, M. Tenbusch, S. Saager	17.03.2023	15.07.2025
US 12 274 971 B2	Apparatus and method for applying accelerated electrons to gaseous media	G. Mattausch, R. Blüthner, A. Weidauer, B. Zimmermann, J. Kubusch, R. Labitzke, F.-H. Rögner, V. Kirchhoff	03.08.2022	15.04.2025
US 12 350 387 B2	Method for inactivating biologically active components in a liquid	J. Schönfelder, V. Kirchhoff, G. Gotzmann, C. Wetzel, A. Weidauer, J. Kubusch	02.04.2021	08.07.2025
EP 4 331 002 B1	Hohlkathodensystem zum Erzeugen eines Plasmas und Verfahren zum Betreiben eines solchen Hohlkathodensystems	G. Mattausch, B. Zimmermann, H. Flaske, B. Meyer, R. Labitzke, S. Weiss, J. Kubusch, V. Kirchhoff	30.08.2023	30.04.2025
US 12 291 705 B2	Method for stimulating the growth of a biomass, contained in a liquid, inside a bioreactor	J. Schönfelder, G. Gotzmann, C. Wetzel, V. Kirchhoff, A. Weidauer, J. Kubusch	02.04.2021	06.05.2025
JP 7687564 B2	Selbstdesinfizierendes antivirales Filtermaterial, dessen Herstellung und Anwendung, sowie Luftfiltereinrichtung mit dem Filtermaterial	M. Hoffmann, H. Böttcher	09.02.2023	26.05.2025
US 12 385 134 B2	Barrier layer system and method for producing a barrier layer system	E. Törker, F. Selbmann, C. Keibler-Willner, M. Baum, M. Wiemer	23.09.2022	12.08.2025
KR 10-2814648 B1	Method for stimulating the growth of a biomass, contained in a liquid, inside a bioreactor	J. Schönfelder, G. Gotzmann, C. Wetzel, V. Kirchhoff, A. Weidauer, J. Kubusch	04.05.2021	26.05.2025
IN 571141	Method for inactivating biologically active components in a liquid	J. Schönfelder, V. Kirchhoff, G. Gotzmann, C. Wetzel, A. Weidauer, J. Kubusch	27.03.2021	25.09.2025
JP 7775334 B2	Hohlkathodensystem zum Erzeugen eines Plasmas und Verfahren zum Betreiben eines solchen Hohlkathodensystems	G. Mattausch, B. Zimmermann, H. Flaske, B. Meyer, R. Labitzke, S. Weiss, J. Kubusch, V. Kirchhoff	27.10.2023	14.11.2025
JP 7794809 B2	Apparatus and method for depositing hard carbon layers	B. Scheffel, M. Tenbusch, S. Saager	16.09.2021	04.12.2025

Highlights



Participation in the Fraunhofer joint booth at the »BAU 2025« in Munich



Kickoff Meeting for the European Union-funded »CELLAGRI« project in Dresden



Introductory Seminar on Cleaning Technology at Fraunhofer FEP



Participation at InterBattery 2025 in Seoul, South Korea



Participation in the German Aerospace Regions Day at Dresden Airport



Conference proflex 2025 – Roll-to-roll coating of flexible materials



Visit by State Secretary Prof. Dr. Heike Graßmann from the Saxon State Ministry of Science, Culture, and Tourism



Participation in the 5 km company run »REWE Team Challenge«

Trade Fair Participations



bau-muenchen.com

BAU

Munich, Germany
13.01. – 17.01.2025



SVC TechCon

Nashville, USA
19.05. – 22.05.2025



Innovation Week

Dresden, Germany
#1 27.01. – 31.01.2025
#2 24.02. – 28.02.2025



Technologieworkshop

Dresden, Germany
05.06.2025



maintenance

Dortmund, Germany
19.02. – 20.02.2025



Manufacturing World

Tokyo, Japan
09.07. – 11.07.2025



InterBattery

Seoul, South Korea
05.03. – 07.03.2025



Tag der Deutschen Luft- und Raumfahrtregionen

Dresden, Germany
04.09.2025



ICE Europe

Munich, Germany
11.03. – 13.03.2025



parts2clean

Stuttgart, Germany
07.10. – 09.10.2025



Hydrogen Days

Prague, Czech Republic
19.03. – 21.03.2025



V2025

Dresden, Germany
13.10. – 16.10.2025



pro flex 2025

Dresden, Germany
06.05. – 07.05.2025



IWMSE

Dresden, Germany
11.11. – 12.11.2025

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EVOLUTION OF SURFACE AND LIGHT.