Fraunhofer FEP

Fraunhofer Institute for Electron Beam and Plasma Technology FEP

Annual Report 2024/25

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.

Annual Report 2024/25

Content

Foreword

Prof. Dr. Elizabeth von Hauff,
Director Fraunhofer FEP

2024 was a year of change, innovation, and forward-looking developments for the Fraunhofer Institute for Electron Beam and Plasma Technology FEP. The strategic and organizational adjustments that shaped the year underscore the willingness and ability of the institute and our employees to dynamically adapt to changing requirements and opportunities. The beginning of the year was marked by extensive restructuring, with the microdisplays and sensor technology business unit successfully transferred to the Fraunhofer Institute for Photonic Microsystems IPMS in January. This restructuring will enable both institutes to focus on further developing and strengthening their portfolios in their respective areas of expertise.

Fraunhofer FEP is committed not only to cutting-edge scientific research, but also to promoting the next generation of technicians and scientists. Particularly noteworthy is the commitment of our employees to the "Schüler experimentieren" (Pupils Experiment) competition in March. Three pupils investigated the resistance of electrochromic coatings on windows to acids and bases. The results of the Flex-G 4.0 project, in which such films are used as retrofit solutions in windows to regulate heat input and light incidence, were incorporated into this project. With the support of our scientists, their results earned them first place in the chemistry category of the regional competition and they also competed in the state competition.

Another milestone was the inauguration of the new RESET building complex in April, which was attended by high-ranking guests from politics, science, and industry. This modern building complex represents an important expansion of our infrastructure and offers ideal conditions for advancing new research initiatives in the fields of electronics and surface technology.

With the aim of making scientific findings accessible to a broad audience, Fraunhofer FEP opened its doors to the Long Night of Science in Dresden in June. Thousands of visitors – from interested amateurs to experts – took the opportunity to learn about our innovative technologies in an open and inspiring atmosphere. Also in June, Fraunhofer FEP participated for the first time in the Manufacturing World trade fair in Tokyo. The presentation of our developments in electron beam technology for coatings and electron beam sources met with great interest and led to valuable new collaborations and the strengthening of our long-standing network in Japan.

Further project meetings took place over the summer, including the conclusion of the EU project FlexFunction2Sustain, in which we acted as project coordinator. The project focused on the development of sustainable, scalable coating technologies for flexible electronics and resource-saving, recyclable technologies. This resulted in successful use cases, which are currently being transferred to production by players in the region.

In August, we welcomed three new trainees who will complete their training as microtechnologists and mechatronics engineers with us over the coming years. Promoting young talent is important to us, and our new colleagues benefit from practical training in our modern laboratories and facilities.

A particular highlight was the award presented to one of our former trainees by the Dresden Chamber of Industry and Commerce as the best exam graduate of his year. We are delighted that he will continue to support our team in the prototyping department after completing his training. We would also like to thank his trainer, who is deeply committed to the quality of training at Fraunhofer FEP.

Our educational initiatives continued in September with the Photonica Summer School, which stopped in Dresden again this year. Over twenty students took the opportunity to visit our laboratories and participate in workshops and experiments on topics such as optical emission control and spectroscopy.

Our researchers presented the latest results of their research at numerous conferences. These included an efficient method for coating surfaces with graphene using electron beam technology and the further development of perovskite solar cells and organic photovoltaics through improved high-barrier layers. Milestones were also achieved in the development of thin films to improve heat transfer in electrocaloric heat pumps. These successes were accompanied by investments in new equipment, such as a new pilot cleaning plant for industrial parts cleaning.

In addition to these events, Fraunhofer FEP placed great emphasis on deepening and expanding our scientific partnerships. In the 2024/2025 winter semester, we will once again be offering a course in conservation and restoration at the Berlin University of Applied Sciences (HTW), which will be supplemented by an excursion in January 2025. We will also be offering lectures at HTW Dresden again, while our cooperation with TU Dresden will be further strengthened, in particular through the Chair of Coating Technologies for Electronics. Our team received special recognition with the appointment of Prof. Simone Schopf as visiting professor at BTU Cottbus in July, which further strengthens our links with academic partners.

Looking ahead to the coming year, Fraunhofer FEP will continue to pursue strategic research areas and developments. A particular focus will be on the expansion of hydrogen technologies and forward-looking areas such as smart building and sustainable packaging technologies. The further development of our networks and collaborations with academic and industrial partners is also at the heart of our agenda.

On behalf of the entire team, we would like to thank all employees, partners, and supporters who made 2024 a successful and eventful year. We look forward to continuing our collaboration and working together on the challenges and opportunities of tomorrow.

News from the institute

Opening of the Research Center for Resource-Efficient Energy Technologies (RESET)

In April, the Fraunhofer Institute for Electron Beam and Plasma Technology FEP opened the »RESsourcenschonende Energie-Technologien (RESET)« research center on its expanded campus in Dresden.

With state-of-the-art laboratory facilities for sputter epitaxy, biomedical applications, and electron beam technologies, the institute aims to set new standards in research. Strategic research priorities in the building include the development of innovative process technologies, for example for the generation, storage, and processing of hydrogen (Power-to-X) and for the deposition of high-precision gallium nitride (GaN) layers on silicon wafers.

The grand opening of the building complex was attended by many invited guests from industry and politics, as well as institutions involved in the construction, and the Fraunhofer FEP Advisory Board.

Institute Director Prof. Elizabeth von Hauff then gave Saxony's State Secretary Prof. Thomas Popp and the Mayor of Dresden Dirk Hilbert a tour of the new premises and provided insights into the institute's new research priorities.

Afterwards, all other guests had the opportunity to take part in building tours to gain a closer insight into the topics covered by Fraunhofer FEP.

Delivery of the »ISABEL« pilot plant

For decades, Fraunhofer FEP has been successfully working on technologies for the chemical-free treatment of seeds using accelerated electrons. The institute is a leader in the development and implementation of innovative plants and contributes to sustainable agriculture.

With the delivery of an advanced high-throughput pilot plant »ISABEL«, another successful technology transfer to an industrial customer has been achieved. The plant can treat up to 25 tons of seeds per hour. Once again, application-oriented research has been brought to the customer!

More details and information on electrons as a sustainable alternative to chemical seed treatment can be found here:

https://s.fhg.de/SY2U

In-service training course »BeSTeR«

In September 2024, the first round of the newly designed and exclusive advanced training course to become a “Professional Specialist (m/f/d) for Industrial Parts Cleaning – BeSTeR” began. The course started with a week of classroom training for three participants in Dresden, followed by phases of three hours of online instruction per week and self-study phases.

Participants can expect comprehensive training that addresses the increasing relevance of industrial parts cleaning for the entire process chain and focuses on a sound understanding of the fundamentals of industrial parts cleaning and the practical mastery of relevant skills, because even the smallest contaminants on components can significantly impair the functionality of subsequent products.

The second week of classroom instruction took place at the end of November 2024, followed by two weeks of practical training – one in Dresden in January and one in Stuttgart in February. After further practical training and project work at the participants' companies, they will then obtain the IHK certificate at DQR level 5 by summer 2025, with final exams in June and August.

The training program is an innovative collaboration between Fraunhofer FEP and SBG Dresden.

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Advisory Board

Chairmen of the Board

Prof. Dr. Herwig Buchholz
Chairman of the Board

Dipl.-Ing. Ralf Kretzschmar
Belimed Life Science AG, Chief Executive Officer
Deputy Chairman of the Board

Photo of the 35th Advisory Board Meeting on April 17, 2024.

Members of the Advisory Board

MRin Dr. Annerose Beck
Saxon State Ministry for Science, Culture and Tourism,
Head of Division "Bund-Länder-Forschungseinrichtungen"

Dr. Bernd Fischer
DR. JOHANNES HEIDENHAIN GmbH,
Head of "Anlagenbau Teilungen"

Dr. Ulrike Geiger
Federal Ministry of Education and Research
Head of Division "Quantentechnologien; Quantum Computing"

Prof. Dr.-Ing. habil. Gerald Gerlach
TU Dresden, Faculty of Electrical and Computer Engineering,
Institute of Solid State Electronics, Director

Dr. Ulrike Helmstedt
Leibniz Institute of Surface Engineering e. V.
Head of Barrier and Precision Coatings

Marcel König
Meyer Burger AG, Head of Research and Development

Dipl.-Ing. Peter G. Nothnagel
former Saxon State Ministry of Economic Affairs, Labor and Transport, former Head of Division

Prof. Dr. Michaela Schulz-Siegmund
Leipzig University, Faculty of Medicine, Institute of Pharmacy,
Head of Pharmaceutical Technology

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 "Industry"

Guests of the Advisory Board

Dr. Patrick Hoyer
Fraunhofer-Gesellschaft, Institute Liaison

Dr. Ran Ruby Yan
GLOBALFOUNDRIES Dresden Module One LLC & Co. KG
Director Human-Machine-Interface

This list represents the status as of the board meeting in 2024. For an up-to-date version, please visit our website at:

https://s.fhg.de/NX2

Organizational Structure

Fraunhofer FEP

Institute management
Prof. Dr. Elizabeth von Hauff
Deputy: Dr. Burkhard Zimmermann

Communications – Annett Arnold

Business Development – Dr. Christian May

Information Technology – Udo Gernandt

Protective Rights / Contracts – Jörg Kubusch

Electron Beam Sources – Processes – Applications – Dr. Burkhard Zimmermann (Division)
- **Coating Metal and Energy Applications** – Dr. Stefan Saager
- **Cleaning and Hygiene Technologies** – Frank-Holm Rögner
- **Coating of Parts** – Dr. Fred Fietzke
- **Biocompatible Materials** – Dr. Ulla König
- **Customized Electron Beam Systems and Technologies** – Prof. Dr. Gösta Mattausch (Department)

Plasma Technology – Dr. Nicolas Schiller (Division)
- **R2R Technologies** – Dr. Matthias Fahland (Department)
- **R2R thermal evaporation and optical inspection** – Dr. Matthias Fahland
- **R2R High-Rate Vacuum Coating** – Steffen Straach
- **R2R Sputtering and PECVD** – Dr. Cindy Steiner
- **R2R Wet Coating and Electron Beam Curing** – Dr. Steffen Günther
- **S2S Technologies and Precision Coating** – Dr. Jörg Neidhardt (Department)
- **S2S Sputtering and PECVD** – Dr. Kerstin Täschner
- **Dynamic Precision Coating** – Dr. Daniel Glöß
- **Static Precision Coating** – Dr. Hagen Bartzsch
- **Sputterepitaxy Technologies** – Dr. Jörg Neidhardt

Systems – Jens Drechsel (Division)
- **Mechanic Development** – Henrik Flaske
- **Electronic Development** – Rainer Labitzke
- **Prototyping** – Mirko Kreusel

Materials Analysis – Dr. Olaf Zywitzki (Department)

Biomedical Laboratory Unit – Dr. Simone Schopf

Administration – Almar Schulz-Coppi (Department)
- **Occupational Safety** – Maik Schober
- **Quality Management** – Grit Köckritz
- **Controlling** – Nicole Raymund
- **Purchasing** – Stefanie Pfoh
- **Shipping / Export / Devices** – Claudia Rockstroh
- **Technical / Energy Management** – Gerd Obenaus

Divison | Department | Group

The organizational structure shown represents the status as of 12/2024. 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 8.5 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. A portion of these, amounting to 0.8 million €, was attracted through joint publicly funded projects with mid-cap companies. The expenditure of institutional capital ran to 11.0 million €.

Employee development

Last year, an average of 156 employees (including 9 trainees) and 19 research assistants/interns worked at the Institute. Of the 56 staff members that were employed as scientists, 12 were additionally working on their doctoral degrees. The proportion of females in the scientific area amounted to 25 percent.

Investment costs

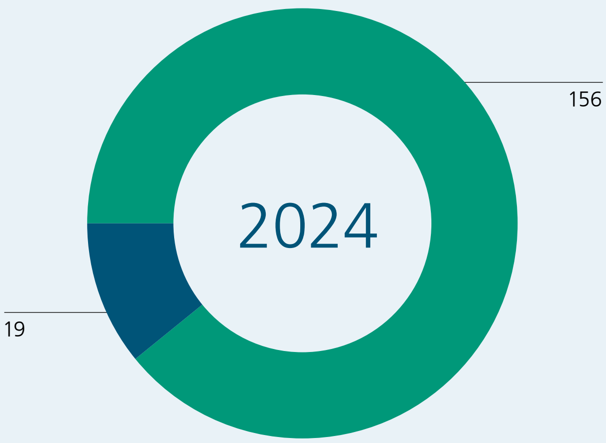
Total expenditures from the operating and investment budget amounted to 23.3 million €. 1.0 million € was invested in equipment, construction and infrastructure during the period.

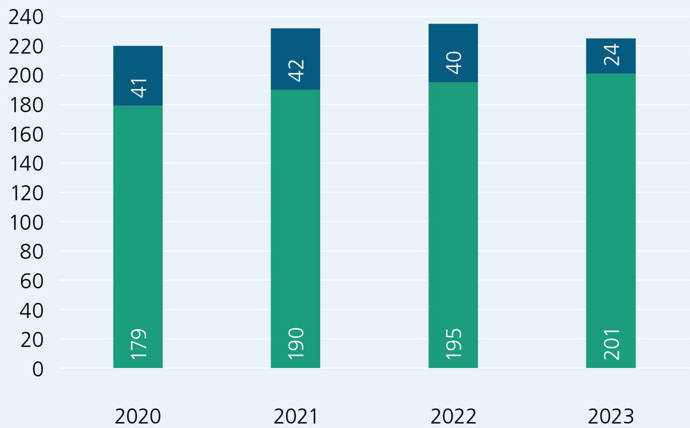
Staff and material costs

Personnel expenditures totaled 12.2 million €, representing 54.5 percent of the operating budget (22.4 million €). Material costs amounted to 10.2 million €.

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

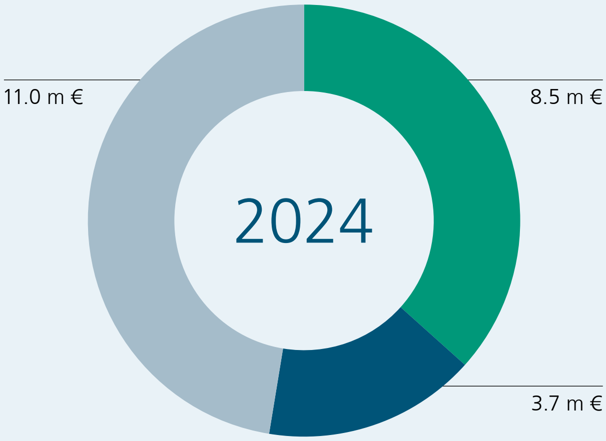
Employee development

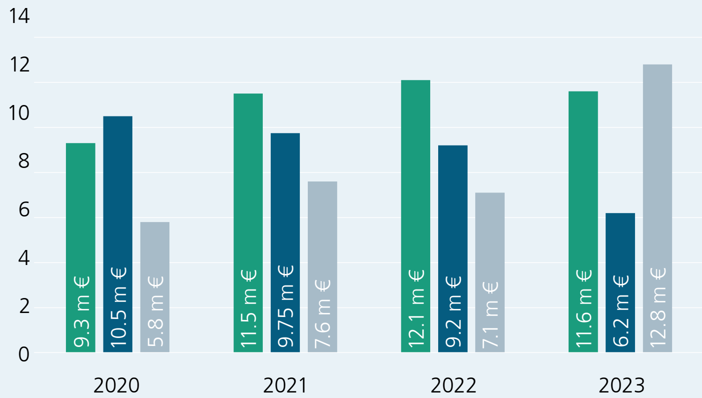




Employees
incl. Trainees, Doctoral candidates, Temporary employees
Students/Interns

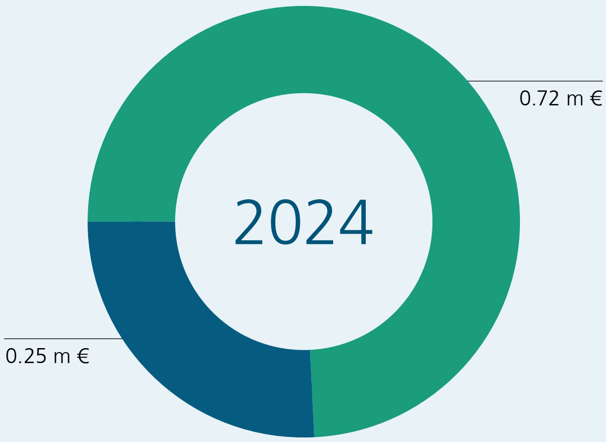
Financing

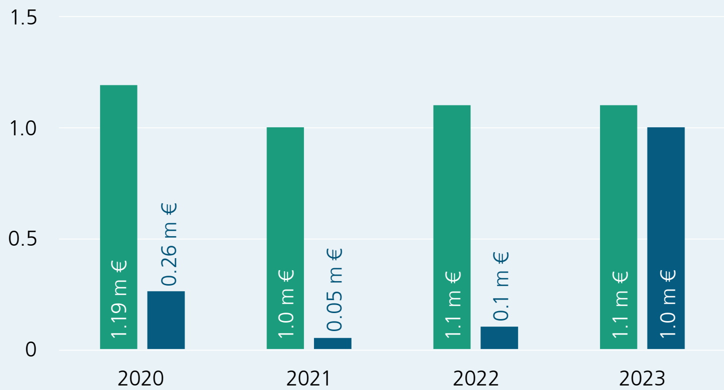




Commercial proceeds
Public/EU and misc. proceeds
Basic funding

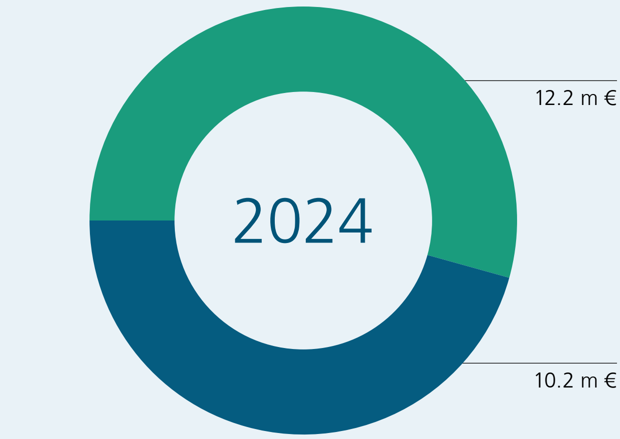
Investment costs





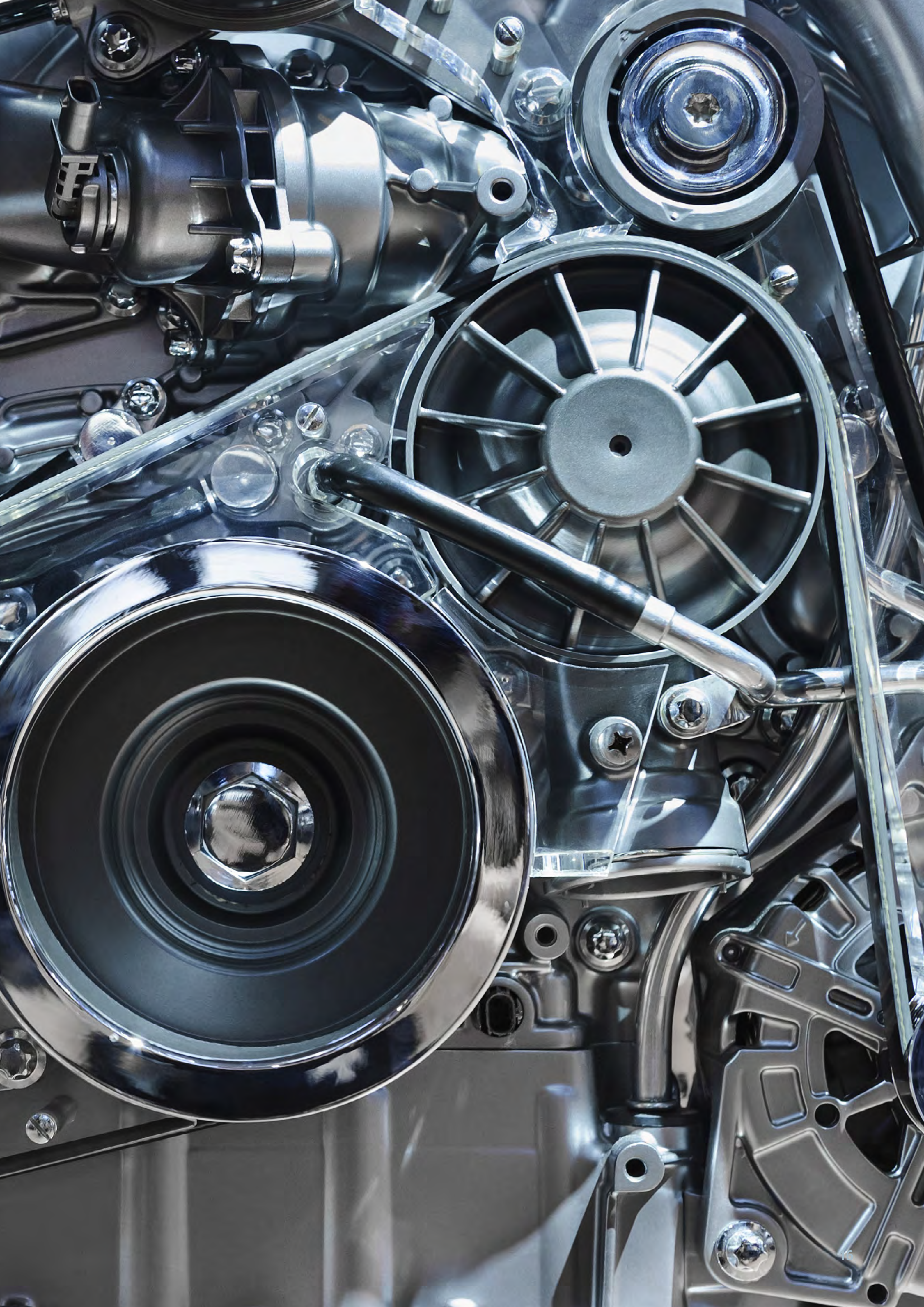
Normal investment
Strategic investment

Staff and material costs



Personnel expenditures
Material costs

Industry Solutions



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 electrolysers 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.

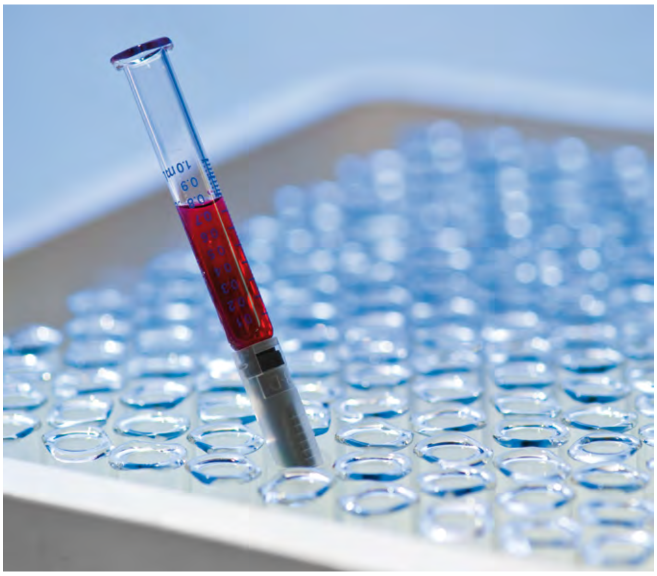
Cultural Heritage Management

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.

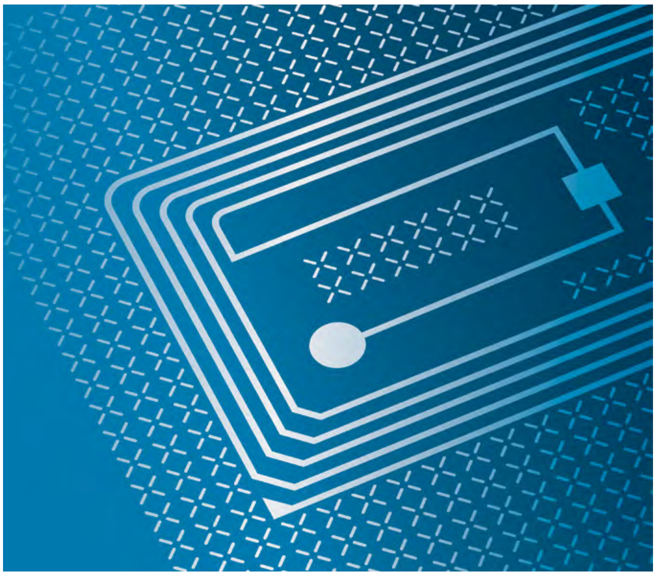
Mobility

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.

Smart Farming

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 smart farming, 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.

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.

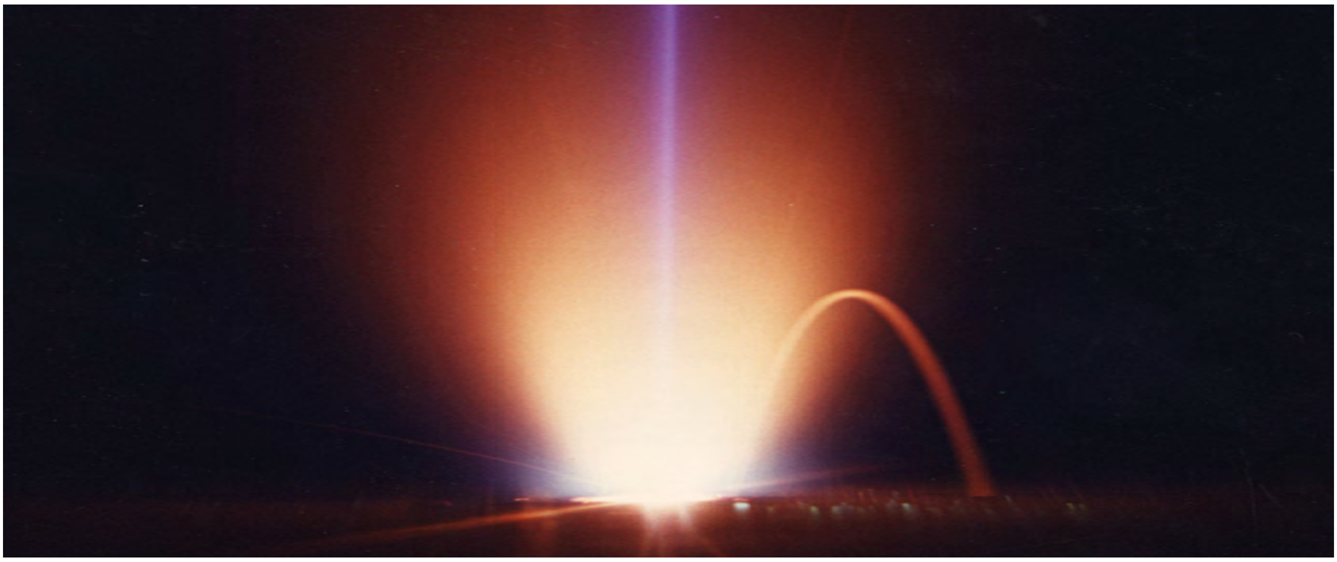
Research News

Division Electron Beam

Electron beams are extremely versatile tools for materials processing, environmental technology, surface treatment, medical and technical imaging, process control, and analysis. They combine a wealth of physical, chemical, and biological effects with high energy efficiency, excellent precision, and technological flexibility.

In the field of electron beams, the surfaces of solid bodies such as metal strips and plates, 3D-shaped components and bulk materials, as well as textiles and biological tissues, are treated, functionalized, cleaned, joined or coated. Various physical and chemical vapor deposition (PVD/CVD) processes and electron beam welding in a vacuum are used, as well as cleaning techniques, electron beam treatment, and grafting at atmospheric pressure. On the other hand, biomedical liquids or waste water as well as industrial exhaust gases or chemical gases are cleaned, inactivated or subjected to specific conversion reactions using electron beams. To this end, not only processes but also customer-specific electron beam and plasma sources are developed and transferred. The aim is to provide our customers with application-ready complete solutions – technologies and systems from a single source.

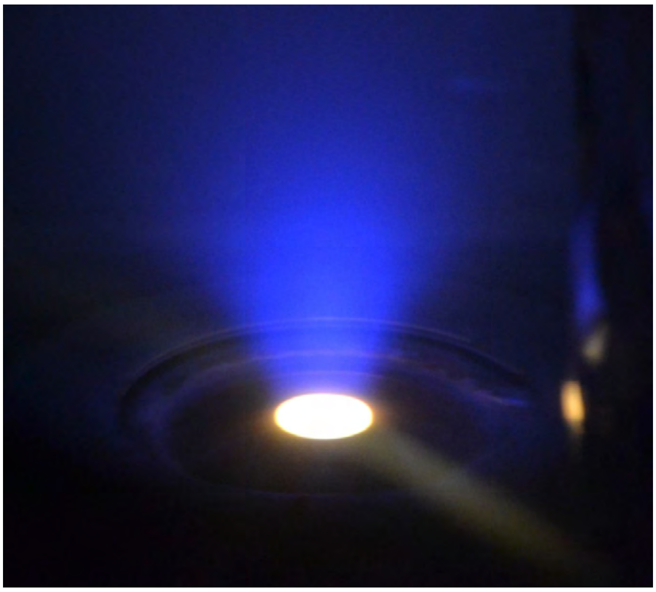
Current projects focus on energy applications (coatings for batteries, hydrogen technologies, heat storage, photovoltaics), aviation (corrosion protection, thermal barriers on turbine components), chemical applications (power-to-chem processes), and environmental and life sciences (treatment of seeds, wastewater, and exhaust gases, stimulation of microbiological processes).



ta-C coatings using anodic arc evaporation

Contact: Dr. Bert Scheffel | Phone +49 351 2586-243 | bert.scheffel@fep.fraunhofer.de

Anodic arc evaporation of graphite enables the deposition of high-quality, droplet-free and smooth ta-C coatings with application potential for hard coatings, in particular. Deposition rates of up to 18 nm/s have been achieved.



Process photo of the anodic arc evaporation of graphite

Tetrahedral amorphous carbon (ta-C) is one of the most promising modifications of 'diamond-like carbon' materials. Hydrogen-free ta-C coatings are chemically inert and are characterized by high hardness, thermal stability, thermal conductivity and low coefficients of friction. These properties open up a wide range of applications, in particular as wear-resistant coatings for tools, components and automotive parts, and as diffusion barriers in hydrogen technology.

Various processes have already been established for the deposition of ta-C coatings. In arc-based processes, however, characteristic droplets or particles are emitted and embedded in the coatings. These impair the coating properties and can only be reduced using complex filter techniques.

The Fraunhofer FEP has developed a physical vapor deposition process that uses a hollow cathode arc discharge as an electron source and enables the anodic arc evaporation of graphite for the deposition of hydrogen-free carbon layers. By applying a bias voltage, the particle energies can be increased and the layer properties customized. The layers deposited on steel substrates with thicknesses of 500 – 800 nm were analyzed using nanoindentation, Raman spectrometry, FE-SEM, AFM and spectroscopic ellipsometry. The analyses show a high proportion of tetrahedral sp^3 bonds of 70 – 88 %. The energies of the vapor particles are high enough to achieve high hardness values of 61 – 75 GPa and a Young's modulus of 588 – 685 GPa at substrate temperatures below 200°C, even without bias voltage. The coatings are droplet-free and are characterized by low surface roughness. The deposition rates of 4 – 18 nm/s are exceptionally high for ta-C coatings, which emphasizes their suitability for industrial applications. The ta-C coatings with high hardness and smooth surface are very well suited for wear-resistant surfaces.

The innovative coating process can be easily scaled in terms of coating width by arranging several evaporator modules in a row. The process is also suitable for other materials and applications, such as the low-damage deposition of transparent conductive oxides.

Plasma-treated Liquids: Opportunities for sustainable and chemical-free cleaning and sanitation

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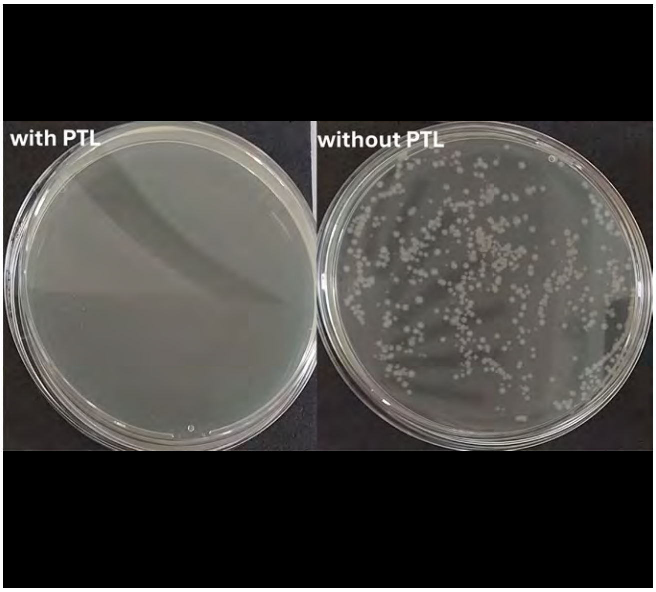
Plasma-treated liquids have the potential to reduce the use of conventional cleaning and disinfecting agents.
Research at Fraunhofer FEP focuses currently on the relationships between cleaning and sanitizing effects as well as the shelf life.

Plasma-activated water (PAW), also called plasma-treated liquid (PTL), is known for its antimicrobial effect. Plasma-treated liquids are produced by introducing ionized gas from atmospheric pressure plasma sources into liquids, causing the reactive nitrogen and oxygen species generated by the plasma source to dissolve in the liquid or react with liquid components. Due to the variety of different reactive species, as well as the associated low pH and high redox potential, these liquids show an antimicrobial effect. The high reactivity of PTL additionally offers a potential for their use as cleaning agent. As part of our research activities, we are investigating the hygienic and the cleaning effect of PTL, as well as the suitability for combined use for cleaning and disinfection. Relationships between the effectiveness of PTL and the effect of the various reactive species are investigated to optimize the production technology and to allow an economically attractive and reproducible industrial use of PTL.

In our investigations, different model microorganisms are investigated to evaluate the sanitizing effect considering varying production conditions of PTL and environmental conditions. For example, a reduction of 99.9% was achieved on bacterial contamination with Escherichia coli after a short treatment time of only 5 minutes (see figure). One example of application for the investigation of the cleaning performance is the gentle removal of graphite residues on porous quartz surfaces.

In addition to the cleaning and sanitizing effect, the shelf life of PTL is an important point for industrial use. In initial investigations we were able to show that the liquids retain their reactivity for over 10 months.

Our further research focuses on the relationships between the plasma source and the properties of reactive species and their content in the generated PTL, as well as suitable monitoring methods for easy quantification of relevant reactive species enabling reproducible industrial implementation.



Growth of Escherichia coli bacteria after treatment with PTL (left) and without treatment (right). Vital bacteria grow as white colonies on the nutrient agar.

»LinTR – Industrial Cleaning Learning Lab« as part of further training in the field of technical cleanliness

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The LinTR learning laboratory for industrial parts cleaning at Fraunhofer closes a gap in further training in parts cleanliness, combines theory and practice and promotes interdisciplinary communication.

6-chamber ultrasonic teaching system REDESO

The importance of technical cleanliness in industrial production is increasing in more and more sectors. Cleaning processes are crucial in order to guarantee the quality requirements of a component. Nevertheless, there is a lack of practical training opportunities to learn and master complex process chains in relation to part cleanliness. To close this gap, the LinTR "Learning Lab for Industrial Parts Cleaning" was created. This innovative learning laboratory is designed to offer a flexible, modular concept that combines theoretical knowledge and practical skills, thus playing a key role in further training and professional qualification.

Supported by the Fraunhofer Academy, the Fraunhofer Institutes FEP, IWS, IVV and IPA are working on the development of the learning lab. Not only are the technical possibilities being expanded, but a new methodological and didactic concept is also being developed. This concept is based on typical process chains and can provide participants with a comprehensive understanding of industrial parts cleaning through practical training in various laboratories. A two-part, dismountable model component was developed for this purpose, which enables problem-based teaching through a combination of different geometries and standardized contamination.

Interdisciplinarity is a central element of the LinTR learning laboratory. Participants learn to understand the complex influences along a process chain and to recognize the importance of effective cooperation. This not only deepens their technical knowledge, but also trains their ability to solve problems in groups.

Another important milestone in the learning lab is the commissioning of our REDESO training cleaning system. This 6-chamber ultrasonic system for aqueous cleaning has a very wide range of adjustable process parameters, enabling practical cleaning tests to be carried out on a wide variety of components and production processes. In future, in addition to demonstrating cleaning effects, the system will also be used to analyze errors in the cleaning process, for example by deliberately setting some parameters unfavorably in order to enable training participants to systematically search for errors.

Overall, the LinTR learning laboratory will be established as an integral part of further training in the field of technical cleanliness at Fraunhofer and will thus make a decisive contribution to ensuring quality in industrial production.

Plasma treatment of polymer surfaces for use in electrocaloric heat pumps

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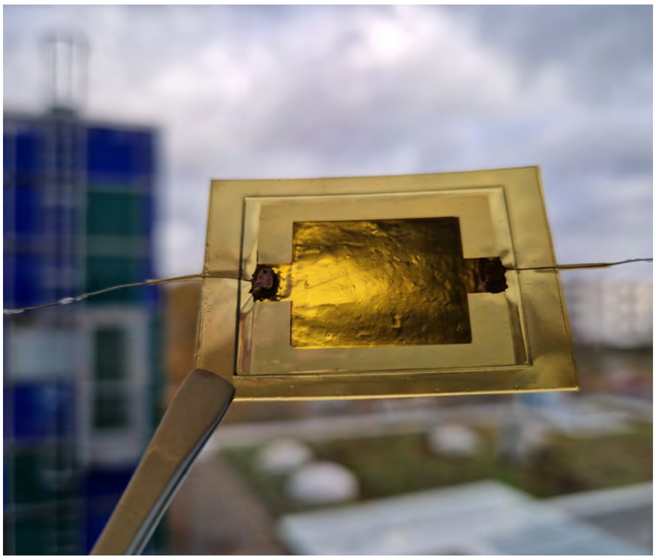
In the lighthouse project ElKaWe, six Fraunhofer Institutes have worked for several years on the development of electrocaloric heat pumps. The Fraunhofer FEP was involved with wetting-promoting surfaces on ceramic and polymer components.



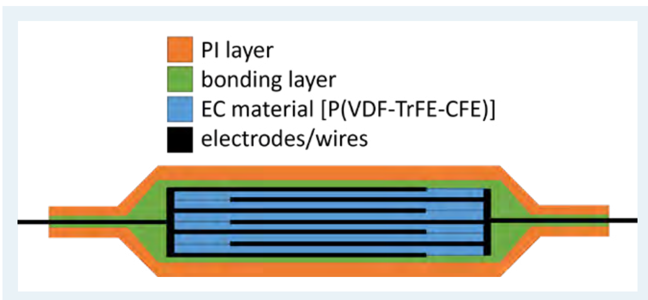
Polymer EC component

Heat pumps are a key element of the energy revolution in Germany. They are currently the most commonly installed type of heating system, particularly for supplying newly built single-family homes. However, the classic compressor-based heat pump has a number of disadvantages, such as the use of refrigerants that are potentially harmful to the environment and health, as well as significant noise emissions.
For this reason, six Fraunhofer Institutes – IPM, IKTS, IAP, LBF, IAF and FEP – have joined forces in the lighthouse project ElKaWe to help a new technology achieve a breakthrough. These are electrocaloric heat pumps based on ceramic or polymer materials that can convert electrical energy directly into thermal energy.

In the underlying principle of heat transport, the working fluid periodically evaporates or condenses on the active surfaces in order to absorb or release heat. The faster this process takes place, the more efficient the pump is. However, especially for polymeric materials with their water-repellent (hydrophobic) surface, it is difficult to achieve rapid, complete wetting of the components with a thin film of liquid.

The breakthrough here came from a form of plasma treatment in vacuum, in which the surface of a polymer is bombarded with high-energy oxygen ions and a thin, open-pored layer of titanium-silicon oxide is deposited at the same time. The result is a nanostructure that enables full-surface wetting of the surface (superhydrophilicity). The effect is stable over the long term (months to years) and does not require reactivation.
Since the limited thermal resistance of the electrocaloric material prohibits direct plasma treatment, an alternative approach was chosen: the structuring of a thermally resistant encapsulation film and the subsequent combination of this film with the electrocaloric material to form a usable component.

For use in polymer-based electrocaloric heat pumps, 12.5 µm thin polyimide films were treated at the Fraunhofer FEP using the process described and then laminated onto pre-processed multilayer stacks of electrocalorically active terpolymer at the Fraunhofer IAP. Tests carried out proved that the finished components functioned satisfactorily. These are currently being assembled into demonstrator assemblies, which will prove the performance of the resulting technology and serve to acquire new projects.



Schematic cross-section of a polymer EC component

Bacteria as material producers: Electron beam-assisted microbial production of biogenic limestone

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The growing demand for climate-neutral building materials requires new manufacturing processes. The DeCaBio project is researching innovative electron beam-assisted processes for increased biogenic limestone synthesis to support the decarbonization of the cement industry.

SEM image of the crystalline structure of biogenic limestone ($CaCO_3$)

Due to growing demands for sustainable and resource-efficient processes to achieve climate targets, the need for bio-based substitution processes is also increasing in the construction industry. Cement, the world's most widely produced material, is indispensable as a binding agent, but its current production causes high greenhouse gas emissions. The decarbonization of the cement industry is therefore a promising strategy that will enable the development of low-carbon bio-based building materials in the future.

Microorganisms are everywhere and have been influencing the Earth's environment for over 3.5 billion years. In addition to decomposition and degradation processes, specific microorganisms are also capable of binding carbon dioxide from the atmosphere through photosynthesis and subsequently converting it into stable limestone deposits. The microbial synthesis of biogenic limestone has many advantages and the potential to significantly reduce environmental impact compared to conventional manufacturing processes when integrated into industrial processes.

This is where the internal bilateral Fraunhofer project DeCaBio comes in, which is being carried out in cooperation between the Biocompatible Materials group at Fraunhofer FEP and the Mineral Materials and Building Materials Recycling department at Fraunhofer IBP. In order to further reduce the carbon footprint of cement formulations in the future and gradually replace fossil limestone as a primary resource, the DeCaBio project focuses on increasing the biogenic production of climate-positive limestone with the help of phototrophic microorganisms, cyanobacteria. The project is investigating the dose-dependent biopositive effect of low-energy, non-thermal electron beam processes on the metabolic processes of phototrophic microorganisms in order to improve the effectiveness and economic efficiency of limestone synthesis. The microbial production process involves several reaction steps and usually occurs when cyanobacteria grow in a suitable environment with excess calcium ions (Ca^{2+}) and CO_2 (carbon dioxide). The biogenic limestone obtained can then be used as a filler for concrete or as a cement grinding agent for composite cements. To ensure a high level of sustainability in terms of process circularity, construction waste fractions and food waste are to be reused or recycled as calcium sources through upcycling in order to establish additional resource-saving recycling processes.

Division Plasma

The division plasma technology is characterised by three development directions:

- Roll-to-roll processes for flexible materials, such as the coating of plastic films or ultra-thin glass
- Coating of large-area, flat or slightly curved materials, such as optical coatings on glass or plastic sheets
- Coatings for optical or electronic applications, e.g. semiconductors on silicon wafers

These development directions are based on the surface and thin-film technologies of Fraunhofer FEP, such as magnetron sputtering, electron beam technology or plasma-assisted evaporation. At the centre of our work is the task of adapting the processes to the requirements of the respective application, on the one hand with regard to coating and surface function, and on the other hand with regard to production costs.

For our development work, we have a wide range of equipment at our disposal, from laboratory systems to industrial-scale systems.

The development work for customers follows several paths: development of the basic process, piloting of the process using demonstrators and pilot production, transfer of the process to the customer's systems. The transfer of the technology is often linked to customised key components developed by us.

Biomimetic surfaces – roll-to-roll structuring using nano-imprint lithography and electron beam crosslinking

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Inspired by nature, we have developed roll-to-roll nano-imprint lithography to transfer unique surfaces onto various materials.
Our technology enables large-scale, high-resolution structures and covers applications from photovoltaics to medical systems.

Inspired by nature, from peach skin to butterfly wings and lotus leaves, we have taken on the challenge of transferring their unique surface properties onto other materials. We achieved this through the development of roll-to-roll nano-imprint lithography (NIL) combined with electron beam crosslinking.

This process utilizes special lacquer formulations, which are applied to flexible substrates using slot-die coating, continuously shaped through a mold, and simultaneously crosslinked. This allows for large-scale structures with resolutions from millimeters to a few nanometers to be transferred onto substrates such as polymers, paper, textiles, metals, and metal-coated films. These innovations were made possible through funded projects like Convert2Green, Design-PV, and FlexFunction2Sustain, focusing on decorative-haptic structures on photovoltaic modules and anti-reflective surfaces for car displays. In the PERSEUS project, we are looking to the future, aiming to develop optical layers to enhance the efficiency of perovskite solar cells.

The key to our technology is electron beam crosslinking, which occurs within milliseconds. Our machine, the atmoFlex 1250, ensures high productivity with a material width of up to 1250 mm and speeds of up to 100 m/min.

The fields of application are diverse: they include Fresnel structures for light bundling in photovoltaics, decorative surfaces for facades, anti-fouling structures for maritime applications, anti-glare surfaces for displays, haptic structures for furniture, flow-optimized surfaces for watercraft, and microfluidic structures for medical lab-on-chip systems.

We offer comprehensive consulting on structuring, mold selection, lacquer formulation, and structure design. Additionally, we conduct research in the field of mold manufacturing using 3D printing and their surface modification. Besides localized structure investigations using WLI and SEM, we utilize Fraunhofer FEP's own roll-to-roll inspection system WILMA for a 100% surface analysis of NIL-structured substrates.

Leather texture, produced using NIL technology on a PET film

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Antipathogenic touchscreen polymer films

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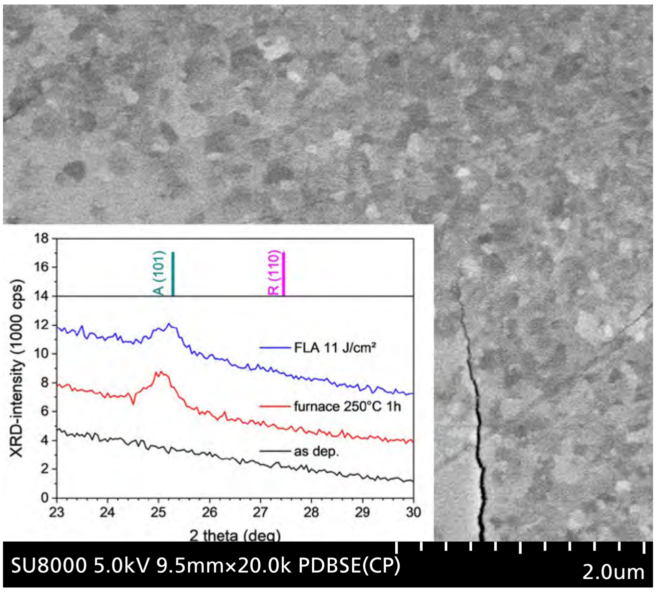
The aim of the "SanFlex" project is to reduce healthcare-associated infections by developing antipathogenic coatings based on crystalline TiO_2 thin films enhanced by a super-acidic surface, applicated on flexible substrates for touchscreens and displays.

Every year, approximately 4 million people acquire healthcare-associated infections in Europe[1]. Pathogens spread quickly via surfaces such as handrails, handles or touchscreens. To reduce the spread of pathogens, particularly in hospitals but also in public buildings, the EU-funded project SanFlex is researching on photocatalytic titanium dioxide coatings that are additionally modified by a super-acidic surface.

In the future perspective, the coatings shall be used on protective films for user interfaces such as touchscreens. The challenge is to produce the anatase-crystalline TiO_2 layers required for functionalization on flexible substrates. To this end, Fraunhofer FEP is pursuing the approach of depositing the layers in the amorphous state using an established large-area inline magnetron sputtering process and afterwards crystallizing them in a post-annealing step using large-area inline flash lamp annealing (FLA). On the crystalline TiO_2 facetes, inorganic acid groups are adsorbed via a photo fixation step, making the surface super-acidic. This modified surface has an antipathogenic effect in two respects: the attachment of pathogens is initially prevented and at the same time microorganisms on the surface are eliminated.

The proof of principle has been realized on rigid glass substrates. Therefore, the relationship between the layer deposition, the crystallization process by inline FLA and the photo fixation of the inorganic acid groups has been studied. The investigated process steps are characterized by an inline capability, which shall enable the production in a roll-to-roll process in the future. Based on the gained knowledge, the project is now in the transfer phase from rigid to flexible substrates. Initial successes have been achieved in the crystallization of TiO_2 layers on temperature-stable polymer films.



Scanning electron micrograph of a crystalline TiO_2 thin film on a temperature-stable polymer film, produced by inline magnetron sputtering and flash lamp annealing.
Inset: X-ray-diffractograms of the TiO_2 thin film after magnetron-sputtering (black curve, X-ray-amorphous), after furnace annealing (red curve, anatase-crystalline phase) and after flash lamp annealing (blue curve, anatase-crystalline phase).

Current work is focused on the correlation between the degree of crystallization and the photo fixation process. The thermal management of the crystallization process is also in the focus of investigations.

[1] *C. Suetens et al., "Prevalence of healthcare-associated infections, estimated incidence and composite antimicrobial resistance index in acute care hospitals and long-term care facilities: results from two European point prevalence surveys, 2016 to 2017", Eurosurveillance, 2018, vol. 23/46.*

New Generation of Key Components for Wireless, Optical and Quantum Communication by Tunable Ferroelectric Nitrides

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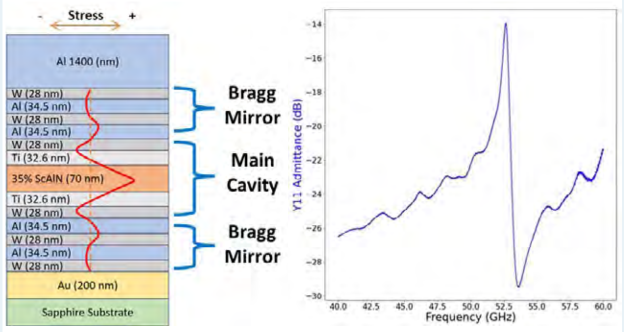
In the project, novel high-frequency filters and electro-optical converters are being developed together with the project partners from Carnegie Mellon University (CMU). These are based on piezoelectric and ferroelectric aluminum scandium nitride layers that are deposited at Fraunhofer FEP.

The basis for the targeted devices is the development of an industrially suitable, stable and reproducible deposition technology for piezoelectric AlScN layers with good thickness and composition homogeneity over 150 and 200 mm wafer diameters at high deposition rates of 3 nm/sec. An effective piezoelectric coefficient $d_{33,f}$ of 12 pm/V was measured on AlScN films deposited by reactive magnetron sputtering of sputtering target from an AlSc alloy with 35% Sc content. Ferroelectric polarization was possible at electric field strengths of ±3.8 MV/cm.

In the field of mobile communication, increasingly large data volumes require the transition to ever higher transmission frequencies. This requires new concepts for components such as frequency filters. One example is the so-called Overmoded Bulk Acoustic Resonator developed in the project. The design of these resonators for frequencies of 50 GHz was carried out at the partner CMU, the layer deposition of the piezoelectrically active layer and the acoustic resonator at FEP. Processing into a device and characterization was again carried out at CMU[1]. A kt² value of 5.5% and a Q value of 108 were measured. With these parameters, the application in future components is already foreseeable.

Photonic components are currently mainly based on lithium niobate due to its advantageous electro-optical properties. However, this material is not compatible with other semiconductor manufacturing processes. The aim is to produce equivalent components based on AlScN, which is CMOS-compatible and thus enables the integration of photonic components into microelectronic circuits. A first step in this direction was the production and characterization of AlScN waveguides. It was shown that the optical losses are low (five times lower than the state of the art), so that optical components based on AlScN waveguides can be realized. Furthermore, a first functional electro-optical modulator based on AlScN has already been demonstrated.



Design and measured characteristic response of the acoustic resonator

[1] J. Baek, S. Barth, T. Schreiber, H. Bartzsch, G. Piazza: 52 GHz 35% Scandium Doped Aluminum Nitride Overmoded Bulk Acoustic Resonator, 2024 Ultrasonics, Ferroelectrics, and Frequency Control Joint Symposium

[2] B. Friedman, S. Barth, T. Schreiber, H. Bartzsch, J. Bain, G. Piazza: Measured optical losses of Sc doped AlN waveguides, Vol. 32, No. 4 / 12 Feb 2024 / Optics Express 5252

Division Systems

The division “Systems” is a cross-sectional department of the Fraunhofer FEP and supports the research work of the physics and technology departments. We develop and manufacture key technological compo-nents for electron beam technology, sputtering technology and plasma surface technologies. These key components are used both in the Fraunhofer FEP test facilities as well as part of “integrated packages” at our industrial partners. They are usually not available on the market and are offered to our partners as tailor-made solutions based on customer-specific requirements. We are able to cover the entire value chain from the initial idea, through design and development, to the realization of prototypes or the finished product.

The development and production portfolio includes plasma and electron beam sources in a wide variety of designs, as well as technological power supplies specially adapted to these devices and the associated analog and digital control technology. Device technology for focusing, centering and deflecting the electron beam and pulsed power supplies with intelli-gent, fast arc switch-off for controlling atmospheric pressure plasmas complete our develop-ment and manufactur-ing expertise.

Hvdirect – High voltage power supply for electron beam processes

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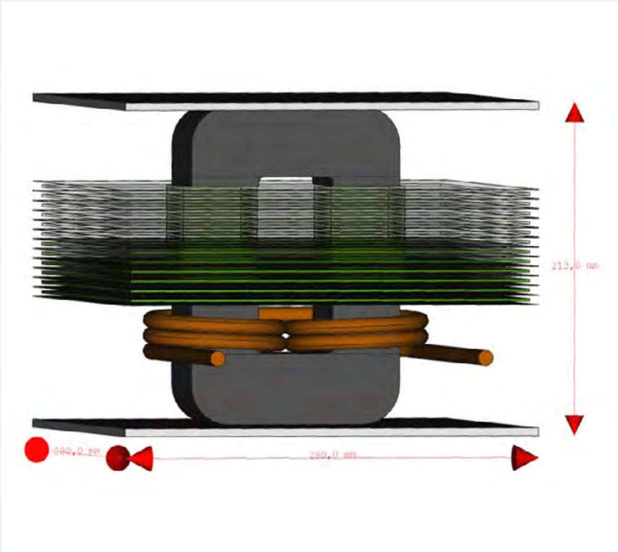
Fraunhofer FEP has developed a modular high-voltage power supply for electron beam processes that is compact and cost-effective. The prototype achieves 15 times the power density of conventional devices and can be scaled up to 600 kV.

Electron beam modules for innovative applications and current technological development projects at Fraunhofer FEP require a powerful, compact, flexibly configurable and cost-effective high-voltage technology. Commercially available high-voltage power supplies (HVPS) currently only meet these requirements to a limited extent.

The aim of the “HVdirect” project was to develop a modular HVPS that is designed for high-voltage applications up to 600 kV and can be integrated into an electron source. In addition to maximum compactness, minimal energy storage is required in the output circuit of the HVPS and in the connecting elements to the electron source in order to reduce damage caused by high-voltage flashovers (arcs) and undesirable process interruptions. Known HVPS concepts were initially evaluated for suitability and optimisation potential. The concept of the insulated core transformer proved to be the most promising.

Using modern simulation tools such as FEM, all high-voltage components (secondary winding of the transformer, magnetic flux compensation, rectification and frequency-accurate voltage measurement) were integrated directly onto PCB boards. Each board supplies 100 mA @ 10 kV and can be stacked in series as modules, depending on the voltage requirements of the application. A compact, modular demonstrator with 120 kV × 100 mA was constructed and combined with a resonant converter. Tests were carried out using a water resistor, which was also realised and proved to be a cost-effective and safe tool suitable for highly dynamic measurements. Good robustness was achieved through optical signal transmission, precise and fast power management using SiC semiconductor switches and FPGA control. The HVPS realised in this way achieves 15 times the power density of conventional devices.



Structure of a high-voltage power supply (HVPS) for 120 kV × 100 mA

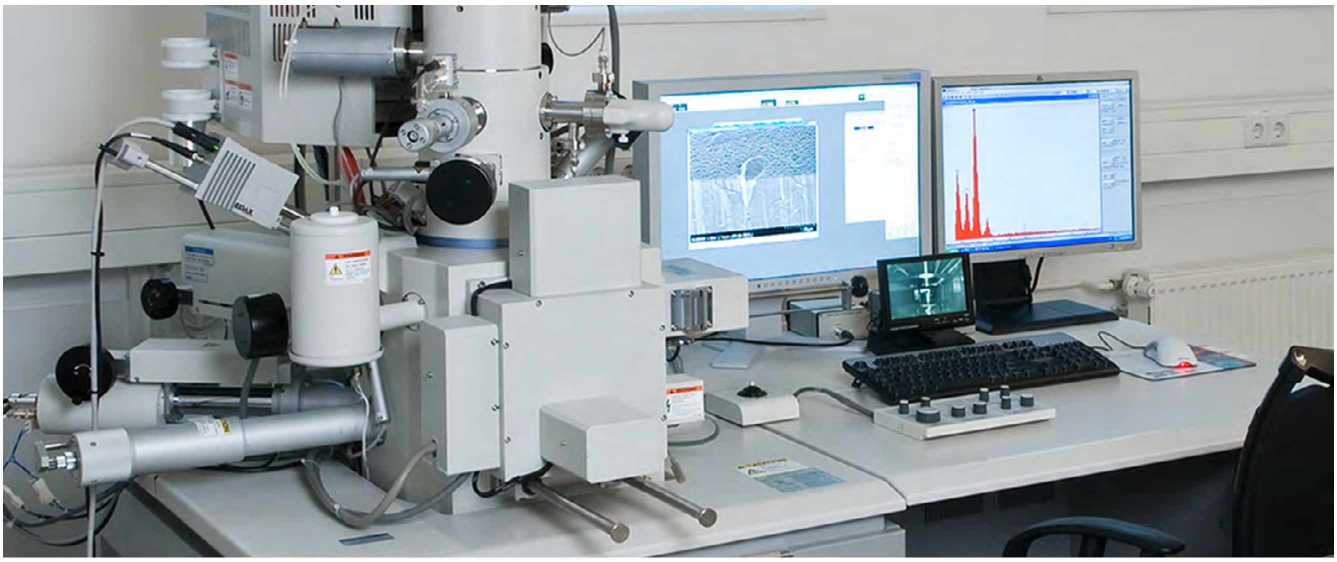
Following further practical tests, the HVPS is ready for use as an independent system component in the low-energy range. The development result will be marketed with the FEP technologies as part of the Fraunhofer FEP's “Integrated Packages”.

Materials Analysis

The Materials Analysis department has a variety of methods available for characterizing the structure and properties of thin films. The analytical methods and the extensive experience of our staff are applied in research projects and are also offered to our customers as services.

A high-resolution field-emission scanning electron microscope (FE-SEM) and an X-ray diffractometer (XRD) are available for characterizing of structure and microstructure of thin films. Polished cross-sections of multilayer systems can be prepared using an ion beam preparation technique, facilitating high-resolution FE-SEM examination in both material contrast mode and crystal-orientation contrast mode. Chemical composition is analyzed by energy-dispersive spectrometry of X-rays (EDS) and by glow-discharge optical emission spectrometry (GD-OES).

Many other measurement methods are available at the Fraunhofer FEP for determining the optical, mechanical, and electrical properties of thin layers. These include UV, VIS, and NIR spectrometry, spectroscopic ellipsometry, and nanoindentation. We have further extensive experience in the field of permeation barrier measurements for water vapor and oxygen through coated polymer films.



Analyses of chemical depth profiles by glow discharge optical emission spectrometry (GD-OES)

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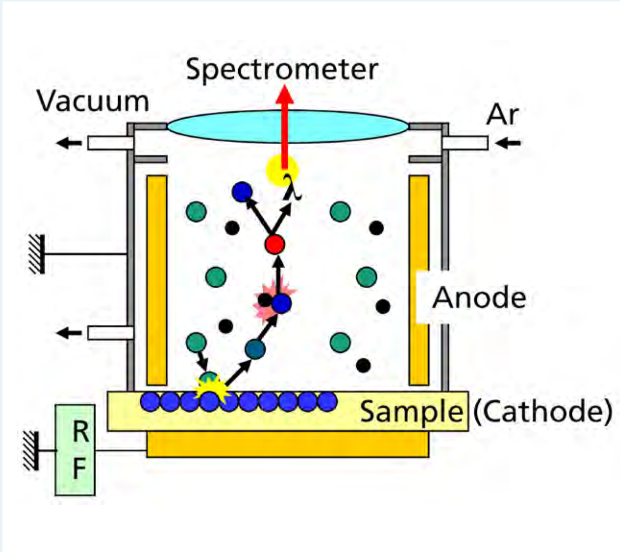
The determination of chemical depth profiles is of great importance for applications in the fields of optics, electronics, photovoltaics and battery technology. Glow discharge optical emission spectrometry is a very efficient method in terms of detection limits and depth resolution.



Glow discharge optical emission spectrometry (GD-OES)

The combination of a radio frequency glow discharge with optical emission spectrometry (RF-GD-OES) enables the analysis of chemical depth profiles on both electrically conductive and non-conductive samples. For the analyses, the sample is sputtered as the cathode of an RF glow discharge on a spot diameter of 4 mm, atomic layer by atomic layer. Simultaneously, an excitation of the sputtered atoms takes place in the plasma of the glow discharge, which is associated with an emission of optical spectral lines of the chemical elements present in the sample. The intensity of the optical emission lines is then recorded for the different chemical elements with a spectrometer as a function of the sputtering time. By additional use of reference materials, quantitative concentration-depth profiles can be calculated from the measured qualitative intensity-sputtering time profiles of the emission lines.

The detection range of the concentrations reaches from 10 ppm to 100% for many elements. A depth resolution of a few nanometres is possible for smooth substrates. The intensity of the optical emission lines of 45 chemical elements including hydrogen can be registered simultaneously. By using a pulsed RF discharge, temperature-sensitive samples such as coated polymer films or coatings on glass substrates can also be analysed.

Typical applications at Fraunhofer FEP are the analysis of the chemical composition of oxide or nitride coatings for optical and electronic applications. Another important application is the analysis of impurities at the interface to the substrate, which have an influence on the adhesion strength of the coatings. GD-OES analyses are used on thin-film solar cells to determine concentration gradients which influence the absorption of sunlight. At the same time, doping profiles or possible impurities in the individual layers can be analysed. GD-OES analyses are also very interesting for battery applications, as the method can also be used to analyse lithium-containing layers.

GD-OES analyses are successfully used at Fraunhofer FEP in various projects to optimise our coating technologies and are also offered as an external service.

Biomedical Laboratory Complex

The Biomedical Laboratory Complex is a multimodal research and service facility equipped with microbiological, cell biological, bioanalytical, biotechnological, and chemical equipment. One of Fraunhofer FEP's core competencies is electron beam technology, which has been used and optimized for numerous innovative applications for many years. Non-thermal electron beam technology can induce a variety of chemical and biological reactions at room temperature and under normal atmospheric conditions, as well as under protective atmospheres or in a vacuum.

By combining Fraunhofer FEP's core technological competencies with biological expertise, we are able to develop bio-based, environmentally friendly processes that meet the demands of the bioeconomy and the circular economy. We develop innovative processes and sustainable practices to ensure the efficient use of natural resources.

Our services include conducting feasibility studies, supporting our customers from the concept phase through to implementation. In addition to applying standardized methods, we develop customer- and project-specific test setups in accordance with, or based on, current DIN standards. Our laboratory complex meets all criteria for operation at biological safety level 2. A highlight of 2024 was our move to the newly opened RESET research centre, which is equipped with state-of-the-art laboratory facilities.

Biology meets technology for sustainable processes

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The laboratory complex provides innovative and sustainable solutions to complex problems faced by our customers. With a wide range of methods and equipment, interdisciplinary and industry-oriented research and development projects are carried out.

Among other things, the Biomedical Laboratory Complex focuses on using microorganisms to produce basic chemicals in a cycle-oriented way for the chemical, pharmaceutical, agricultural and environmental industries. We are focusing more and more on using phototrophic microorganisms for CO_2-neutral, chemical-free production processes. Furthermore, we are investigating electron beam-treated seeds as a chemical-free alternative to conventional seed dressing.

Various bioreactor systems are available for biomass production and optimization of product synthesis on a laboratory scale. Scaling up to a 50-liter pilot plant scale is possible We have established various detection systems for cell analysis to assess viability, proliferation, differentiation, and membrane potential. We can prepare and modify various tissues using electron beam technology without the use of chemicals.

The services offered by the laboratory complex include

- Laboratories for microbiology, cell biology, biotechnology, materials and bioanalytics, chemistry
- Microscopy pool
- Testing of the biocompatibility and biofunctionality of materials, cytotoxicity tests
- Cell analysis: assessment of viability, proliferation, differentiation, changes in cell count, cell cycle and membrane potential
- Sterility testing and bioburden testing
- Micro- and cell biology analysis systems, e. g., for recording growth curves
- Biotechnological process control
- DNA and protein analysis
- Materials and surface analysis

We are developing an innovative small-scale bioreactor system with an integrated, low-energy electron beam source to serve as a demonstrator

A project funded by the Fraunhofer Gesellschaft (SME BioIntElekt, funding code: 601 015) focused on the development of a demonstrator consisting of a low-energy electron beam source in combination with a stirred laboratory bioreactor With the development of the demonstrator, the project aimed to combine electron beam technology and biotechnology in order to develop a process for the more efficient implementation of biotechnological processes in liquids. This was demonstrated using the example of microbial ore leaching in which special iron- and acid-loving bacteria are used to convert metals from their insoluble ores into water-soluble salts. This allows the metals to be extracted from the ore. The demonstrated the biopositive, stimulating effect of low doses of low-energy electrons on the microbial leaching of copper ore.

Appendix

The Fraunhofer-Gesellschaft

The Fraunhofer-Gesellschaft, headquartered in Germany, is one of the world's leading organizations for applied research. It 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. 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 across 75 institutes and legally independent research units in Germany, Fraunhofer operates with an annual budget of €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, industry revenue accounted for €867 million of its budget. Fraunhofer's research portfolio is augmented by competitively acquired public-sector funding, pursuing the right balance between public-sector and industry revenue.

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

- 75 institutes and research units
- Around 32,000 staff
- 3.6 billion euros annual research budget totaling

www.fraunhofer.de

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

Fraunhofer Institute for Physical Measurement Techniques IPM

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Phone +49 761 8857-269

www.light-and-surfaces.fraunhofer.de

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.

THE CLEANING EXPERTS

Central Office

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01277 Dresden, Germany

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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 Zeitz und Mitteldeutschland
  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
  www.forschungsallianz-kulturerbe.de
- Fraunhofer Academy
  www.academy.fraunhofer.de
- 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.dekubiPhonede
- International Council for Coatings on Glass ICCG e. V.
  www.iccg.eu
- International Irradiation Association
  www.iiaglobal.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

TECHNISCHE UNIVERSITÄT DRESDEN

Prof. Dr. Gösta Mattausch

West Saxon University of Applied Sciences Zwickau

Production and properties of nanostructures and nanolayers

WHZ Westsächsische Hochschule Zwickau
Hochschule für Mobilität

Frank-Holm Rögner

University of Applied Sciences Berlin

Conservation and Restoration 3:
Historical Methods and Current Developments

htw Hochschule für Technik und Wirtschaft Berlin
University of Applied Sciences

Dr. Stefan Saager

University of Applied Sciences Dresden

Electron and laser beam technology

HTW Hochschule für Technik und Wirtschaft Dresden
University of Applied Sciences

Prof. Dr. Simone Schopf

Brandenburg University of Technology Cottbus-Senftenberg

Environmental Biotechnologies

Biological processes for biomass and waste treatment

b-tu Brandenburgische Technische Universität Cottbus - Senftenberg

Theses

Dissertations

Author	Title	University
J. Szelwicka	Roll-to-Roll sputtering of thermochromic VO_2-based coatings onto ultrathin flexible glass	Technische Universität Dresden

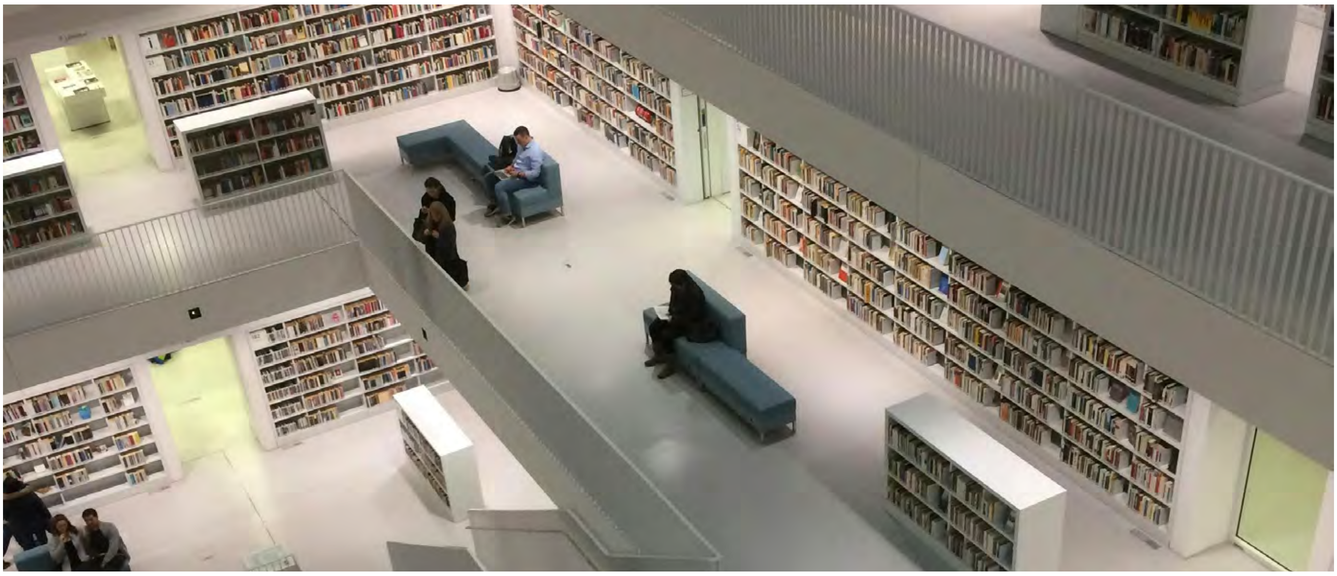
Master thesis

Author	Title	University
E. Kutschke	Entwicklung eines recycelbaren Monomaterials für flexible Verpackungen durch elektroneninduzierte Modifikation	Hochschule Mittweida
L. Elfeld	Funktionalisierte Poly(2-oxazoline) für die Oberflächenbeschichtung	Technische Universität Dresden

Bachelor thesis

Author	Title	University
P. Saavedra	Einfluss der Reaktivgaszusammensetzung auf die Schicht-eigenschaften von piezoelektrischen AlScN-Dünnschichten beim Puls-Magnetronsputtern	Technische Universität Dresden
U. Witzgall	Untersuchungen zur Validierung der Simulationssoftware Virtual Coater mit Hilfe von Daten eines Sputterprozesses	Hochschule Coburg

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 2022 114 434 B4	Ringförmige Vorrichtung zum Erzeugen von beschleunigten Elektronen	G. Mattausch, B. Meyer, H. Flaske, B. Zimmermann, R. Blüthner, J. Kubusch, L. Dincklage, L. Lorenz, S. Dominok, M. Top	08.06.2022	11.01.2024
US 11,918,979 B2	Method for activating a photocatalytically active outer layer deposited on a composite	G. Gotzmann, U. Vogel, D. Glöß, J. Schönfelder, P. Wartenberg	27.01.2021	05.03.2024
JP 7446818 B2	Multi-Layer Functional Film and Production Method thereof	J. Fahlteich, N. Prager, M. Fahland, O. Zywitzki, V. von Morgen, R. Eveson	26.12.2019	11.03.2024
JP 7431843 B2	Method for increasing the strength of a glass substrate	J. Westphalen, W. Langgemach, M. Junghähnel, T. Preußner	13.08.2021	15.02.2024
US 12,005,515 B2	Method for Smoothing a Component Surface Region	B. Graffel, F. Winckler, S. Fritzsche, B. Kieback, B. Klöden, T. Weißgärber	01.03.2021	11.06.2024
EP 4 214 348 B1	Vorrichtung und Verfahren zum Abscheiden harter Kohlenstoffschichten	B. Scheffel, M. Tenbusch, S. Saager	16.09.2021	03.07.2024
EP 3 468 622 B1	Verfahren zum Beaufschlagen einer Flüssigkeit mit beschleunigten Elektronen	J. Schönfelder, F.-H. Rögner, J. Portillo, J. Kubusch	08.06.2017	30.10.2024
DE 102023 109 753 B3	Vorrichtung zum Beaufschlagen von Schüttgut mit beschleunigten Elektronen	S. Weiss, R. Blüthner, H. Flaske B. Zimmermann, J. Kubusch, G. Mattausch, B. Meyer, M. Top, F. Schade, F. Winckler, M. Herzog, T. Weicht, E. von Hauff, T. Teichmann	18.04.2023	02.10.2024
CN 112789349 B	Method for stimulating the growth of biomass in a liquid inside a bioreactor	G. Gotzmann, A. Weidauer, V. Kirchhoff, C. Wetzel, J. Kubusch, J. Schönfelder	01.04.2021	25.10.2024
CN 113840731 B	Method for smoothing a component surface region	F. Winckler, B. Graffel, S. Fritzsche, B. Klöden, B. Kieback, T. Weißgärber	12.03.2021	25.10.2024

Highlights

Visit from the federal and state parliaments: Thomas Jarzombek, Dr. Markus Reichel and Dr. Frank Kromer at the Fraunhofer FEP

Prof. Holger Hanselka, President of the Fraunhofer-Gesellschaft, visits the Fraunhofer FEP as part of the Dialogue Tour

Opening ceremony of the coordination office »K-FAST – Korea Fraunhofer Office of Science and Technology« in Berlin

Elisabeth Ewen, Member of the Fraunhofer Executive Board, honoring Daniel Wohlfarth as best apprentice

Ceremonial inauguration of the Fraunhofer Research Center REsource Efficient Energy Technologies (RESET)

Industry workshop »The Future of Sustainable Packaging«

Winner of the »Hans Pulker Award« at the International Conference on Coatings on Glass and Plastics

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

Trade Fair Participations

SPIE. Photonics West

San Francisco, USA
27.01. – 01.02.2024

PSE 2024

Erfurt, Germany
02.09. – 05.09.2024

SPIE. AR|VR|MR

San Francisco, USA
29.01. – 31.01.2024

32. Fachtagung Industrielle Teilereinigung

Dresden, Germany
11.09. – 12.09.2024

Girls' Day

Dresden, Germany
25.04.2024

Smart Farming Netzwerktreffen

Dresden, Germany
16.09. – 17.09.2024

67th Annual SVC TechCon

Chicago, USA
06.05. – 09.05.2024

glasstec

Düsseldorf, Germany
22.10. – 25.10.2024

HZwo Workshop

Dresden, Germany
16.05.2024

IWMSE

Dresden, Germany
29.10.2024

Manufacturing World

Tokio, Japan
19.06. – 21.06.2024

Elmia Subcontractor

Jönköping, Sweden
12.11. – 14.11.2024

ICCG 14

Dresden, Germany
24.06. – 26.06.2024

Micro-Optics Summit

Amsterdam, Netherlands
02.12. – 03.12.2024

Imprint

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