Fraunhofer FEP

Fraunhofer Institute for
Organic Electronics, Electron Beam
and Plasma Technology FEP

Annual Report 2022/23

Content

Prof. Dr. Elizabeth von Hauff,
Director Fraunhofer FEP

Foreword

Dear partners of Fraunhofer FEP,
Dear readers,

In 2021, I took over the directorship of the Fraunhofer FEP and last year's annual report reflects our excitement and optimism towards new horizons, projects and plans. In 2022, as an institute we began to implement many of the planned steps, but also had to overcome some unexpected new hurdles. In February 2022, Prof. Kirchhoff handed over the baton of institute direction me, and I am grateful for the six months that we spent together leading the Fraunhofer FEP. In parallel, I started to establish the Chair of Coating Technologies for Electronics at the TU Dresden. This has already created a promising basis for future synergies and joint research, for example in the field of energy research and semiconductor technologies. The first employees have been recruited for the purpose of promoting the exchange and expansion of scientific excellence at the institute. Furthermore, the researchers at the institute contribute their expertise within various networks, such as the innovation cluster HZwo on the topic of hydrogen or the cluster of excellence CeTI of the TU Dresden on the tactile internet. I am particularly pleased that in 2023 one of our PhD candidates received one of the prestigious scholarships to conduct research in the field of hydrogen technologies at the TU Dresden within a project funded by the Boysen Foundation.

Despite initial uncertainties, which also accompanied us in 2022 due to the global pandemic situation, we succeeded in acquiring several major projects within the framework of public funding at the state, federal and EU levels. For example, the implementation phase of the »EdgeVision« project was approved as part of the federal government's RUBIN funding (Regional Entrepreneurial Alliances for Innovation). This is the cornerstone for the establishment of a regional network for the development of a high-performance ultra-low-power edge AI, visualization and sensor platform for secure IoT and human-technology interaction in Eastern Saxony.

Thanks to great efforts by our FEP scientists, we have succeeded in acquiring new projects with industrial partners from Germany as well as worldwide, which contribute greatly to the stable financing of the institute. In this context, the division Microdisplays and Sensors acquired the third largest industrial contract in the Fraunhofer-Gesellschaft in 2022.

To assure all necessary processes, especially in administration and project controlling, major challenges had to be mastered in the past year. The introduction of a fully comprehensive

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Thanks to the innovative power of our colleagues, we are working on groundbreaking technologies for the future using resource-efficient processes.«

Prof. Dr. Elizabeth von Hauff,
Director Fraunhofer FEP

SAP portfolio in January entailed a large number of changes and high additional workloads for the entire staff. All of the Fraunhofer FEP employees have my gratitude and admiration for their incredible patience, cooperation, willingness to learn and flexibility in finding short-term solutions to safeguard daily operations.

In the hot summer, after a long break, we were finally able to open our doors to the public again and to show our research to many interested visitors during the Dresden Long Night of Science. Afterwards, we restarted our presence at major trade fairs, e. g. at ACHEMA and electronica - the world's leading trade fairs for process industry and electronics, respectively. Fraunhofer FEP's new research results were also discussed live with great interest at several specialist conferences such as BIOEurope. Topics such as effective metal extraction with electron-stimulated microorganisms by bioleaching or the modular AR service platform for industrial manufacturing attracted a wide range of interest.

As a passionate cyclist, it was my particular pleasure to join our colleagues and all of Dresden's Fraunhofer Institutes in cycling to a respectable 6th place in the city cycling competition in the fall of 2022. But it is not only with our research – e. g. on thin-film technologies for the energy transition for smart windows – or by cycling that we want to contribute to a good climate. When we built our new laboratories on Bodenbacher Straße, great emphasis was put on the use of energy-saving technology and materials right from the start. Fraunhofer FEP is also the first institute in the entire research landscape in Germany with a certified energy management system!

In 2022 Fraunhofer FEP started a strategy process, and we will present the results in 2023 to an external committee. The goal was to engage a large number of colleagues from all departments in this process to define a roadmap for the next five years. We are focusing on the scientific divisions, as well as organizational topics ranging from IT to human resources. Our aim is to define sustainable approaches to prepare our institute for the future, and to establish a platform on which we can continually reorient ourselves according to the needs of our customers and partners, to changing external circumstances, with to the well-being of our employees.

Finally, I would like to thank all our employees as well as our funding bodies and industry and academic partners for their continued great trust, support, and cooperation!

In our annual report we go into depth on the highlights from the last 12 months. Enjoy reading and I look forward to continued good cooperation!

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Advisory Board

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Merck KGaA, Global Head of Group Corporate Sustainability
Chairman of the Board

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

Photo of the 33rd Advisory Board Meeting on May 10, 2022.

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Institut für Festkörperelektronik, Direktor

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Leibniz-Institut für Oberflächenmodifizierung e. V.

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3D-Micromac AG, Vorstandsvorsitzender

Dipl.-Ing. Michael Protzmann
ALD Vacuum Technologies GmbH, Technischer Geschäftsführer

Prof. Dr. Michaela Schulz-Siegmund
Universität Leipzig, Medizinische Fakultät, Institut für Pharmazie,
Lehrstuhl für Pharmazeutische Technologie

Pia von Ardenne
VON ARDENNE GmbH, Member of Executive Management

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Referatsleiter Technologiepolitik, Technologieförderung

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Fraunhofer-Gesellschaft, Institutsbetreuer

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Meyer Burger (Germany) AG, Head of Research and Development

Jörg Wittich
ALD Vacuum Technologies GmbH, Geschäftsführer

This list represents the status as of the board meeting in 2022. For an up-to-date version, please visit our website at:

https://s.fhg.de/NX2

Organizational Structure

Fraunhofer FEP

Director
Prof. Dr. Elizabeth von Hauff

Corporate Communications Annett Arnold	**Marketing** Ines Schedwill		**Administration** Veit Mittag
Information Technology Udo Gernandt	**Quality Management / Team Assistance** Sabine Nolting	**Protective Rights / Contracts** Jörg Kubusch	**Technical / Energy Management** Gerd Obenaus

Electron Beam Sources – Processes – Applications Dr. Burkhard Zimmermann	**Medical and Biotechnological Applications** Dr. Ulla König	**Plasma Technology** Dr. Nicolas Schiller	**Microdisplays and Sensors** Dr. Uwe Vogel	**Systems** Dr. Michiel Top	
Coating Metal, Energy Applications, Parts and Cleaning Dr. Torsten Kopte	**Hygienization** Dr. Gaby Gotzmann	**R2R Technologies** Dr. Matthias Fahland	**Organic Microelectronic Devices** Bernd Richter	**Mechanic Development** Henrik Flaske	**Materials Analysis** Dr. Olaf Zywitzki
Coating Metal and Energy Applications Dr. Torsten Kopte	**Biocompatible Materials** Dr. Ulla König	**R2R thermal evaporation and optical inspection** Dr. Jacqueline Hauptmann	**IC and System Design** Philipp Wartenberg	**Electronic Development** Rainer Labitzke	
Cleaning Frank-Holm Rögner	**Biotechnological Processes** Dr. Simone Schopf	**R2R High-Rate Vacuum Coating** Steffen Straach	**Microdisplay Cleanroom** Mario Metzner	**Prototyping** Mirko Kreusel	
Coating of Parts Dr. Fred Fietzke		**R2R Sputtering and PECVD** Dr. Cindy Steiner			
Sustainable Technologies for Energy and Electronics Dr. Christian May		**R2R Wet Coating and Electron Beam Curing** Dr. Steffen Günther			
Customized Electron Beam Systems and Technologies Prof. Dr. Gösta Mattausch		**S2S Technologies and Precision Coating** Dr. Jörg Neidhardt			
		S2S Sputtering and PECVD Dr. Kerstin Täschner			
		Dynamic Precision Coating Dr. Daniel Glöß			
		Static Precision Coating Dr. Hagen Bartzsch			
		Sputterepitaxy Technologies Dr. Alexander Hinz			

Division Department Group

The organizational structure shown represents the status as of 10/2022. 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 12.1 million € of new business from industry through direct contracts. Proceeds of 9.2 million € were obtained from public projects funded by the federal and state governments. A portion of these, amounting to 3.8 million €, was attracted through joint publicly funded projects with mid-cap companies. The expenditure of institutional capital ran to 7.1 million €.

Investment costs

Total expenditures from the operating and investment budget amounted to 28.4 million €. 1.2 million € was invested in equipment, construction and infrastructure during the period.

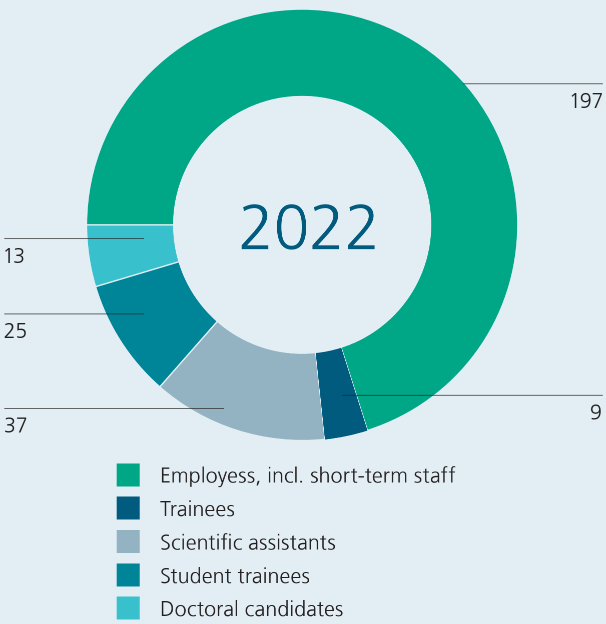
Staff and material costs

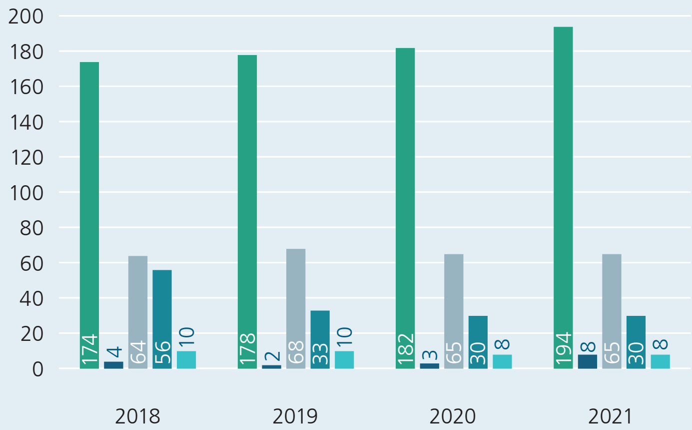
Personnel expenditures totaled 14.6 million €, representing 53.6 percent of the operating budget (27.2 million €). Material costs amounted to 12.6 million €.

Employee development

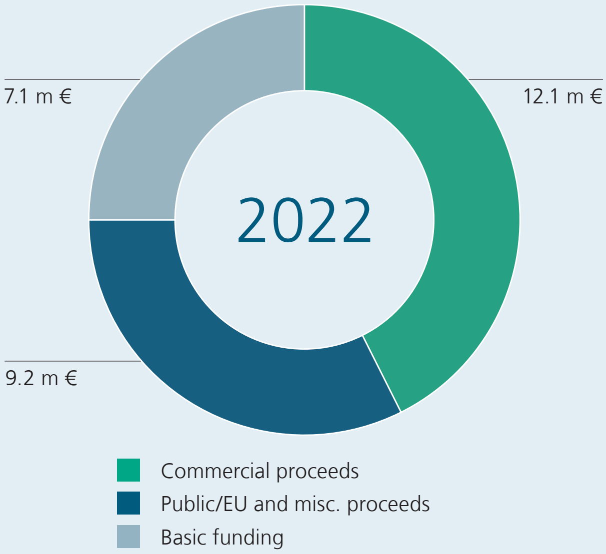
197 staff members were employed at the institute during the past year, of which 9 were trainees, along with 25 student trainees as well as 37 scientific assistants. Of the 75 staff members that were employed as scientists, 13 were additionally working on their doctoral degrees. The proportion of females in the scientific area amounted to 26 percent.

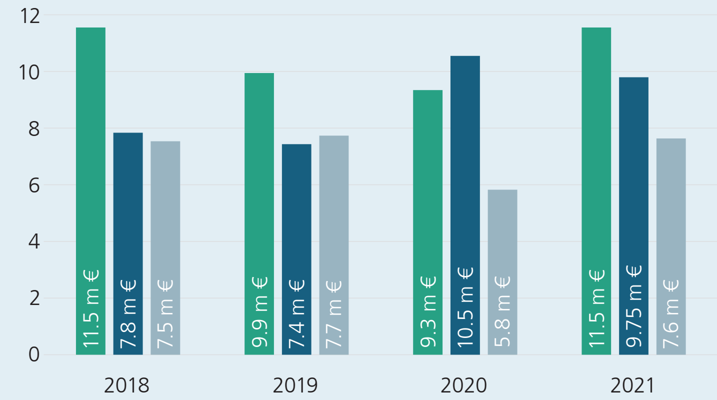
Employee development



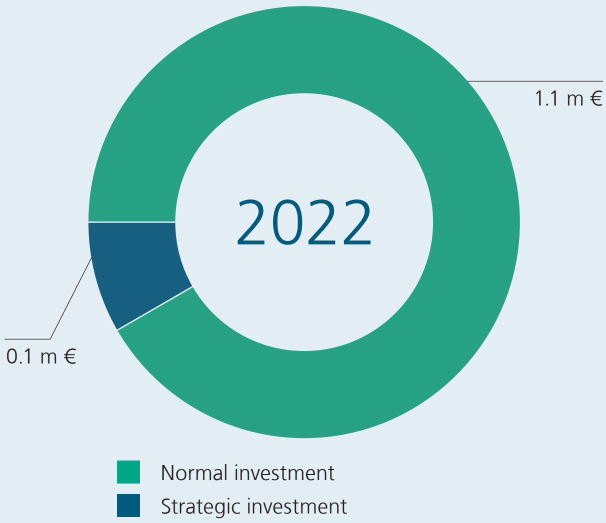


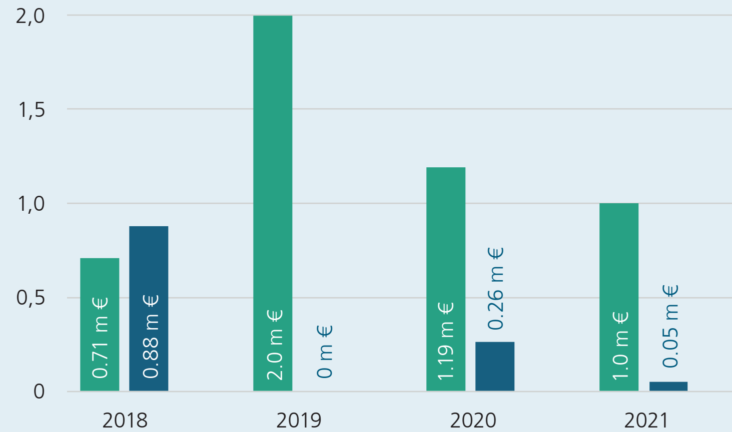
Financing



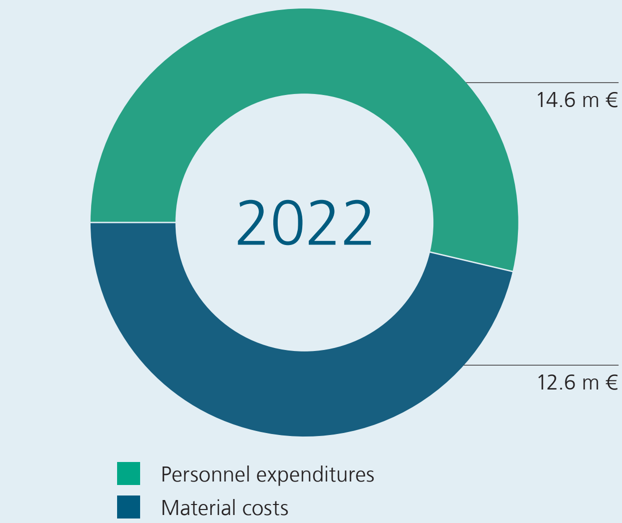


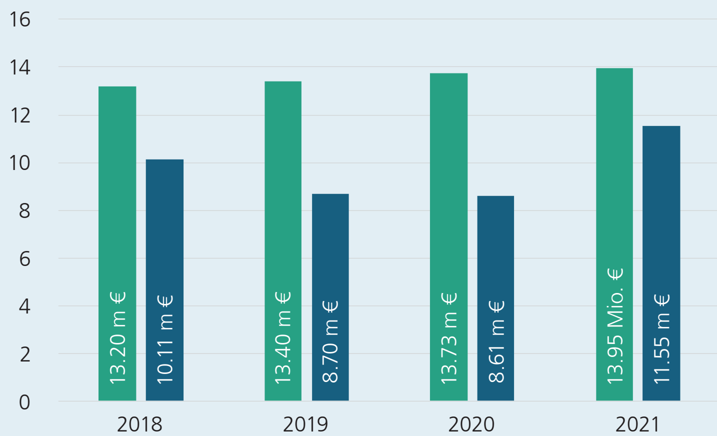
Investment costs





Staff and materials costs





Research News

Business Units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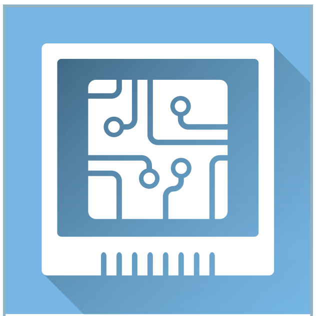

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Coating of Parts

The PVD coating of tools and components with friction and wear reducing layers as well as for corrosion protection has a long tradition at Fraunhofer FEP. For applications in consumer goods, energy and medical technology, coatings with specific optical and electrical properties, biocompatibility, scratch and abrasion resistance are also deposited. In this context, the adjustment of specific wetting properties such as complete coverage (superhydrophilicity) or their complete suppression (superhydrophobicity) is becoming increasingly important and requires unconventional solutions.

Another focus is the coating of small parts as bulk material, e.g. for the corrosion protection of fasteners or the functionalization of metallic, ceramic or glassy granulates and powders.

In addition to pulse magnetron sputtering in single, double and multiple source configurations, high-rate electron beam and thermal evaporation are also used as coating technologies. Another focus is the development and application of plasma sources for substrate pre-treatment as well as physical and chemical vapor phase deposition.

Completely wetting surfaces for novel heat pumps

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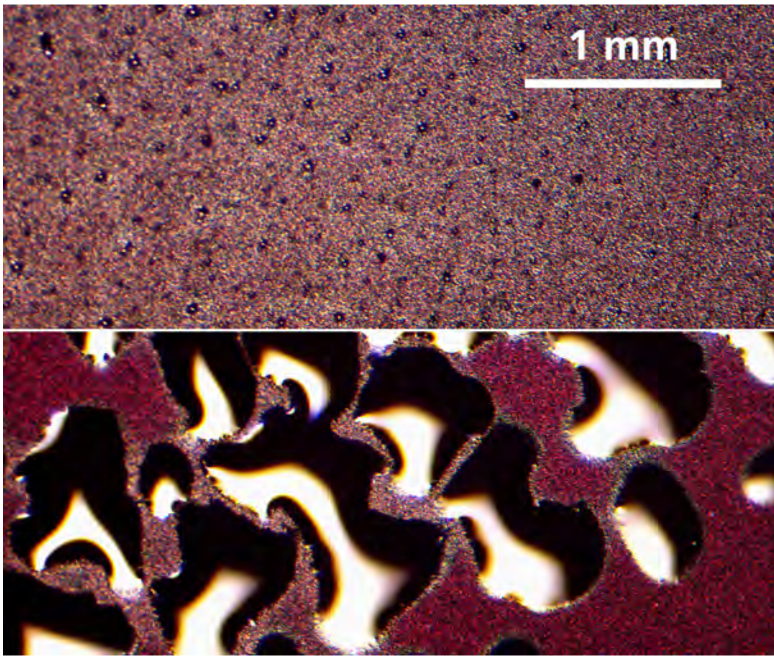
In the lighthouse project ElKaWe, six Fraunhofer Institutes are collaborating on the development of electrocaloric heat pumps for heating and cooling purposes. Fraunhofer FEP is involved in the development of wetting-enhancing coatings to ensure rapid heat transfer.

Heat pumps based on compressors are commonly used for heating and cooling purposes and have become the most frequently installed heating system in new single-family homes. However, the refrigerants used in these systems are often environmentally and health hazardous and are increasingly regulated by legislators. Solid-state heat pumps, on the other hand, operate with safe fluids such as water, are silent, and offer superior efficiency compared to compressor-based systems in the long run.

To promote this new technology, six Fraunhofer Institutes – IPM, IKTS, IAP, LBF, IAF, and FEP – have joined forces in the lighthouse project ElKaWe and are collaborating on the development of electrocaloric heat pumps. The basis for this lies in ceramic and polymer materials that respond to changes in electric field strength with an instantaneous temperature jump. The more effectively the generated heat can be dissipated, the more efficient the pump is.

In the patented concept for heat transfer, the working fluid evaporates or condenses periodically at the active surfaces to absorb or release heat. To achieve the desired performance range, this transition needs to occur up to ten times per second. This is only possible if wetting occurs through a full-surface, thin fluid film, maximizing heat transfer at the interface.

At Fraunhofer FEP, technological approaches have been developed for the treatment and coating of electrocaloric ceramic and polymer materials, ensuring their complete wetting within a very short time and maintaining this effect over extended periods (months to years). The key element consists of photocatalytically active materials with a defined adjustable surface structure. Static and time-dependent contact angle measurements, as well as microscopic examinations of wetting processes in various gas environments and pressure ranges, complement the investigations and contribute to a better understanding of the theoretical fundamentals of wetting dynamics in real solid-state materials.



Top: Light microscopic image of initial condensation nuclei on a superhydrophilic ceramic surface. Bottom: Residual wetting just before drying

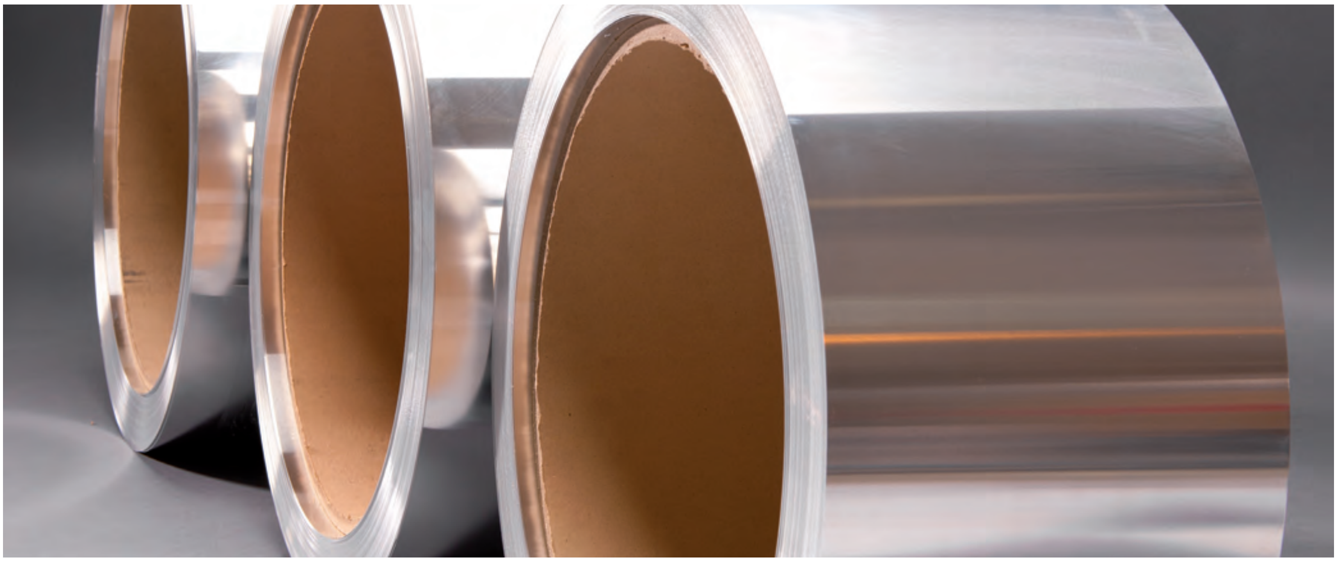
The project is ongoing and will continue until the end of 2024.

Funded within the framework of the Internal Programs of the Fraunhofer-Gesellschaft. Funding reference: 840 005.

Coating of Metal Sheets and Strips, Energy Technologies

The business unit comprises the vacuum coating of metallic sheets and strip for a wide variety of applications in the fields of mechanical engineering, architecture, packaging, transportation, lighting, and the environment. Anti-corrosion coatings based on zinc, tin, and aluminum represent one of our classic fields of activity in the area of steel strip coating. In the field of power engineering, we deal with various application areas such as photovoltaics, and the transport and storage of electrical energy. We develop technologies for depositing thin functional layers suited to high-performance solar cells, low-loss electrical cables, and electrical-energy storage systems.

Vacuum deposition processes are predominantly used in this business unit, as high areal throughput and extremely economical processes with high deposition rates are usually required for the coating of metallic sheets and strip. To improve the coating properties, special plasma activation processes for evaporation have been developed and adapted to coating large areas at these high deposition rates. The »MAXI« inline vacuum coating system for metallic sheets and strip is available as a prototyping and pilot-production system.



Upscaling of PVD and CVD methods for deposition of CNT for battery applications

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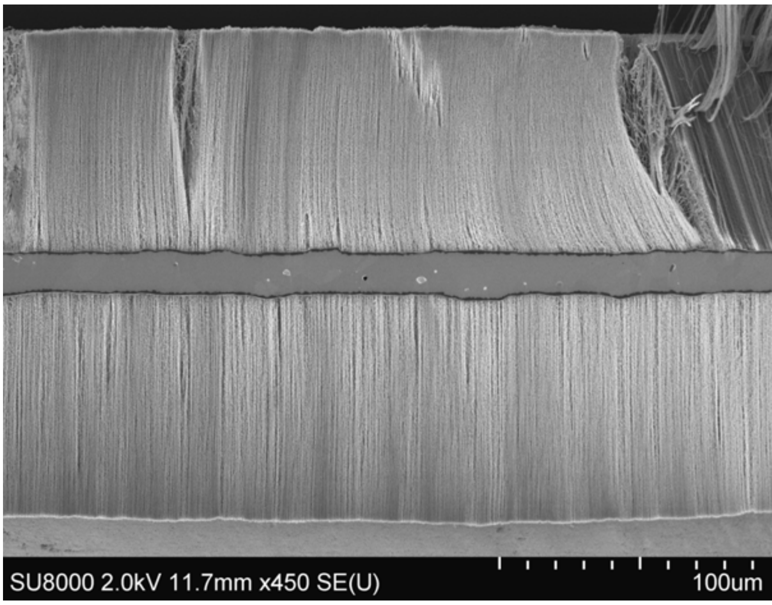
In the last three years, a close cooperation with the US start-up Zeta ENERGY Corp. has been established, which aims at the development of industrial processes for the deposition of carbon nanotubes (CNT) for battery applications.



Carbon nanotubes deposited on copper foil on both sides (partially damaged by preparation)

In 2019, the company Zeta ENERGY approached us with the task of depositing very thin metal and metal oxide layers on thin metal strips. These layers are used as a catalyst for the growth of carbon nanotubes (CNT), which form the anode in customer's novel battery concept. Magnetron sputtering and electron beam evaporation were to be comparatively evaluated as deposition technologies. Our in-line vacuum coating equipment for metal strips and sheets MAXI was used for the evaporation and the coating plant ILA 900 for the sputtering processes.

In the further course of the project, the low-pressure CVD technology developed by Zeta in the laboratory for the deposition of CNTs was to be scaled up using the pilot plant MAXI. For this purpose, the first step was to develop the concept for a CVD module that could be integrated into the MAXI. During this phase, a close, trusting cooperation with the customer evolved. Weekly online meetings and regular on-site discussions at the Fraunhofer FEP quickly became established. The CVD module was designed and manufactured in the Fraunhofer FEP's systems department. It was ready for assembly in the MAXI at the beginning of 2022.

The module was then taken into operation together with experts from Zeta. The parameters found at Zeta in the laboratory were transferred and very soon the first CNT were successfully deposited in the MAXI plant.

Systematic investigations of the influence of the process parameters on the growth of CNT followed. In this way, it became possible to understand and to control the growth processes of the CNT better and better. A decisive factor in this was also the very committed participation of the Analytical Department of Fraunhofer FEP. High-resolution electron micrographs provide an impressive view on the grown CNT. Ultimately, it was possible to deposit approx. 80 µm long, vertically oriented CNT on both sides of a 15 µm thick copper foil and to image them in cross-section.

The collaboration with Zeta is to be continued. The focus will be on the transition to roll-to-roll deposition, with the aim of significantly increasing productivity. We look forward to overcoming new challenges in close cooperation.

Development of Electron Beam Systems and Technologies

Electron beams are exceptionally versatile tools for the processing of materials, surface refinement, environmental technology, medical as well as technical imaging, inline process control and analytics. They combine a wealth of physical, chemical and biological effects with high energetic efficiency, excellent precision and outstanding technological flexibility.

The intense, locally and temporally precisely controlled heating of solids by focused electron beams can be used to advantage for welding, micro-structuring and evaporation (at the highest rates technically achievable) as well as for additive manufacturing and machining of complex components. Chemical effects bring about energy-efficient and highly productive curing of paints, modification of plastics, plasma-chemical syntheses, and pollutant removal in wastewaters and exhaust gases. Antimicrobial and fungicidal actions of electrons represent biological use effects. In this way, medical products such as tools and packaging can be safely sterilized. The chemical-free disinfection of seeds is another application example with high ecological relevance. Furthermore, electron treatment facilitates the biocompatible functionalization of implants and the stimulation of biotechnological processes.

In this multifaceted business field, we develop electron beam sources as well as their control and supply systems optimized for different customer requirements and tasks, but also qualify new electron beam processes for innovative applications in research and production. The aim is to provide our customers with application-ready integrated packages – advanced technologies and systems from a single source.

Test plant TABEA: EB Technology for Cleaning of Exhaust Gases and Wastewaters as well as PtX Plasma Synthesis

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As a strategic investment of Fraunhofer FEP, the mobile test plant TABEA was realized with the company CREAVAC for the cleaning of exhaust gases and wastewaters as well as for plasma-chemical PtX synthesis processes based on various electron beam technologies.

Delivery of the TABEA container at the research complex for »Resource-Saving Energy Technologies« (RESET) of the Fraunhofer Institutes Center Dresden in November 2022.

Effective climate protection is a major challenge of our time and, in the medium term, requires a general shift away from the exploitation and use of fossil carbon deposits, not only as energy sources but also as raw materials for the chemical industry. When transforming the energy supply to regenerative sources, highly efficient storage technologies are required on a large scale, in particular to compensate for seasonal fluctuations. Chemical energy storage systems are indispensable for this purpose. A defossilized raw material supply requires the development of a carbon cycle economy, in which the material use of CO_2 as an educt of chemical syntheses will play a major role. In this context, Fraunhofer FEP has set itself the goal to evaluate the conversion of carbon dioxide, e. g. with (future green) hydrogen, in atmospheric electron beam plasmas and to proof the advantageous energy efficiency and conversion degree of this novel, industrially scalable PtX process. (PtX = Power-to-X stands for production of chemical energy storage and product raw materials using electrical energy from renewable sources.)

The conceptual approach is based on the fact that the excitation required to overcome the energetic or kinetic inhibition of exothermic reactions, as well as the energy supply for endothermic reactions, is not only possible thermally, but in plasmas also by directly and selectively influencing the binding states of molecules.
The key to superior energy efficiency is that the plasmas are thermodynamically in non-equilibrium, which allows the global temperature in the plasma to be kept low despite effective excitation of the chemically active species. Atmospheric electron beam plasmas are also characterized by their uniform energy density and volume filling, which simultaneously promises high conversion degrees.

Electron beam (EB) technologies can also make valuable contributions to environmental technologies, such as the cleaning of exhaust gases and wastewaters. Here, fast electrons interact with the constituents of the gases or liquid mixtures and form various excited species as well as ions and highly reactive radicals, which ultimately lead to the chemical degradation of the pollutants. The energy transfer takes place primarily into electronic bonding states, not into heat. This is associated with low energy losses and, like the reactions initiated in this way, is an extremely fast process. A very short residence time is therefore sufficient in the reactor, which can thus be designed to be compact despite the high flow velocity of the treated fluids.

As a platform for all these technological EB applications and financed by a strategic investment of Fraunhofer FEP, the container-integrated, modularly equipped test plant TABEA was developed and built jointly with the company CREAVAC GmbH. The container is mobile, so that even highly explosive gases can be processed at external locations or pilot tests can be offered to industrial users and carried out directly on site.

Flexible Products

Flexible materials can be found in many applications. The decisive reasons for their practical use are often the freedom in shaping, the low thickness, associated with the low weight, or a high mechanical robustness of the materials.

The core activity of the business area is the modification of the surface properties of flexible materials. Fraunhofer FEP has a wide range of processes at its disposal for this purpose. Roll-to-roll coating has a prominent position in this regard. This is a highly efficient manufacturing principle that is essential for the low-cost production of many products. Examples of this can be found in various industries. Representative examples are food packaging and flexible organic electronics.

Depending on the application and basic technology, the coatings are applied either in vacuum or under atmospheric pressure. They aim to adapt precisely the surface properties to the user scenario. The conductivity of the surface, the optical properties, the diffusion properties for gases and various other properties can be subject of modification. Often, the right combination of several features is also important.

Fraunhofer FEP is uniquely positioned to accompany development projects with industrial customers. This may include the conception, feasibility studies or pilot production and process transfer to the project partner. For this purpose, a highly motivated team of employees is available, as well as extensive equipment for coating and characterization of the materials.

Multimodal X-ray and hyperspectral thin-film nano-material evaluation and quality imaging – nanoQI

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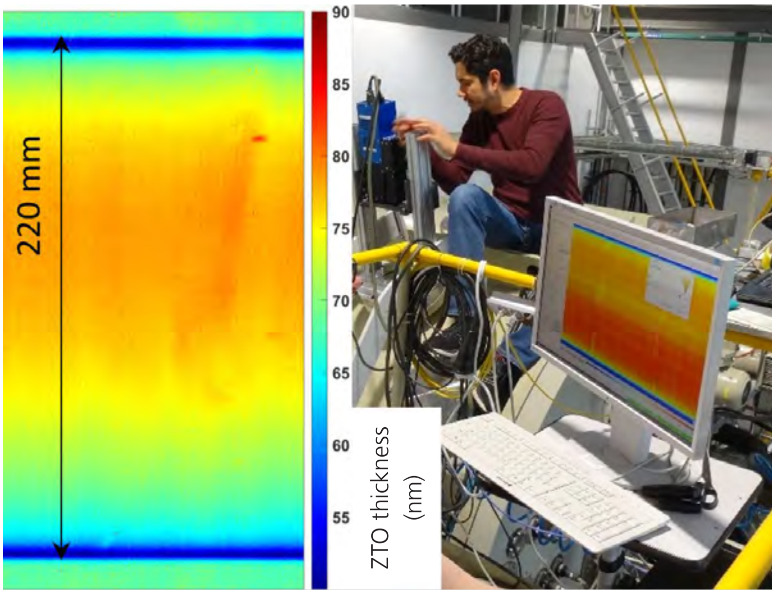
nanoQI creates an industrial-scale, real-time technology for in-line characterization and quality control of nanoscale thin film properties on large surfaces, based on hyper-spectral imaging.



Thickness distribution of an oxide layer on PET substrate and commissioning of the hyperspectral measurement setup at the coFlex® 600 R2R pilot coating plant at Fraunhofer FEP together with project partners from Fraunhofer IWS and Norsk Elektro Optikk.

Since 2020, the Fraunhofer FEP has been coordinating the EU project »nanoQI«. The aim of the project is to establish a technology for quality control of thin film properties such as layer thickness, density, and chemical composition on large substrate surfaces on an industrial scale. This technology is crucial for optimizing and further developing modern thin film technologies in terms of material quality, reproducibility, productivity, and the technology transfer of these processes to industry.

To achieve this goal, X-ray measurement methods such as X-ray reflection (XRR) or X-ray diffraction (XRD) are combined with hyperspectral imaging (HSI) in the VIS-NIR spectral range and integrated into various process systems at the three partner sites Fraunhofer FEP, Fraunhofer IAP, and TNO Eindhoven. The necessary components, such as XRD/XRR prototypes (Bruker AXS), spectral cameras and optics (Norsk Elektro Optikk, NEO), HSI light sources (Fraunhofer IWS), as well as the software for HSI data acquisition, evaluation, and visualization (Fraunhofer IWS, NEO, Fraunhofer FEP), were developed in close cooperation within the consortium.

Machine learning models are being developed for in-line quantification and visualization of layer properties using HSI, which will be trained initially with the results of XRD/XRR measurements. After implementation of the models in the HSI software at the systems, it can independently determine layer properties from the generated HSI raw data during the coating process for process control and monitoring.

In the final phase of the project, the demonstration and industrial validation of the methods and technologies developed so far is the main focus. The nanoQI solutions will be used under realistic operating and production conditions to develop strategies for upgrades and optimizations, but also for detailed cost-benefit analysis to pave the way for commercial exploitation.

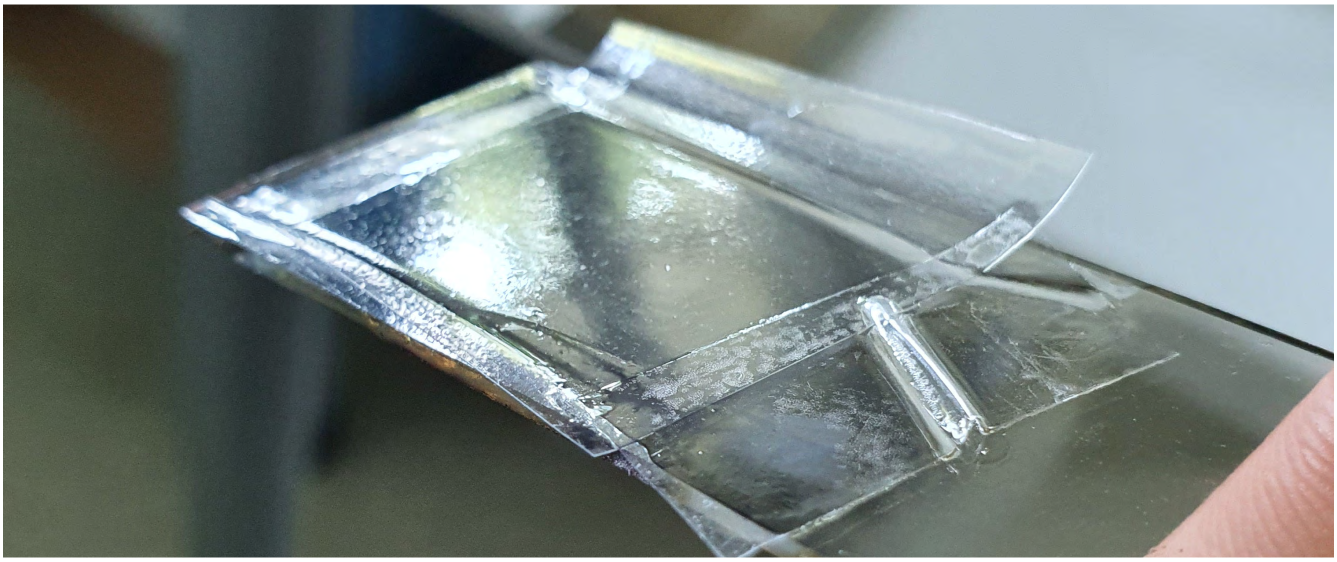
For example, at Fraunhofer FEP, in-line HSI quality control of <100 nm thin barrier and contact layers, deposited by roll-to-roll magnetron sputtering on polymer films up to 600 mm wide and several hundred meters long, is being implemented. For oxide layers on PET, a layer thickness accuracy of a few nanometers with a spatial resolution of less than 1 mm and a web speed of several m/min has already been demonstrated.

Medical and Biotechnological Applications

The societal and political challenges of our time also shape the R&D activities of the business unit. We strive to develop sustainable processes for various applications in the life sciences and environmental sectors using the core competencies of FEP. The economical use of resources, recycling, the future development of new raw material sources, as well as environmentally friendly and demand-oriented extraction methods are strategic research topics.

At Fraunhofer FEP, an interdisciplinary consortium is working to close the technological gap in low-energy electron beam processes of liquids by establishing hybrid technology, integrating a cost-effective, miniaturized electron beam source into a bioreactor. Initial studies indicate a biostimulating effect of low-dose electrons on bacteria, which can accelerate microbial leaching and make it more effective for the recovery of metals. In addition to raw material extraction or recycling processes, hybrid technology can also be used for water treatment, production of green hydrogen, or in the pharmaceutical or food industries.

Low-energy electron beam technology (Ebeam) as a multifunctional tool is explicitly suitable for substitution processes. For example, Ebeam grafting offers the opportunity to coat materials with selective surface functions without the use of additional chemical cross-linking agents, so that biocidal, biocompatible, or antifouling surface properties can be achieved depending on the application profile.



Development of living building materials of the future through carbon dioxide uptake and carbonate mineralization by phototrophic microorganisms

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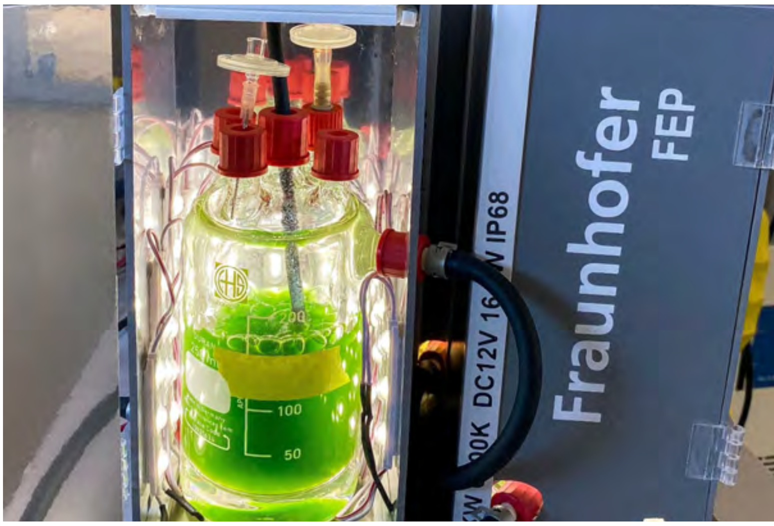
In the SME project BioCarboBeton, a process for biogenic material production through carbonate mineralization was developed using phototrophic microorganisms to produce a novel climate-neutral building and construction material.



Modular cultivation system for phototrophic microorganisms for the production of secondary lime

Concrete is probably the most widely used building material of our time due to its versatile application possibilities. With the global population growth, urbanization, and increasing infrastructure development, the global demand for the main component of concrete, cement, is estimated to increase by 12–23% by 2050. Cement production alone contributes to an annual carbon dioxide emission of more than 20 million tons in Germany. With the efforts of the federal government to achieve complete climate neutrality by 2045, the cement industry is facing an enormous challenge. Climate neutrality in this area can only be achieved through alternative approaches such as the use of renewable raw materials or the recycling of cement.

Another approach is pursued by the Fraunhofer internal SME project BioCarboBeton through the development and specific shaping of Living Building Materials – »Living Building Materials« (LBM) in collaboration with Fraunhofer IKTS. The focus of the project work in the Medical and Biotechnological Applications division of Fraunhofer FEP is the biogenic material development of secondary lime (biomineralization), including complementary analytical process monitoring and microbiological evaluation, as well as the optimization and scalability of the biomineralization process to address large-scale application possibilities.

The production of a living building material aims to achieve targeted uptake of atmospheric or industrial carbon dioxide with subsequent conversion into calcium carbonate as secondary lime. This process of carbonate mineralization is induced by phototrophic microorganisms (cyanobacteria) embedded in a special (bio)polymer composite matrix with mineral aggregates, contributing to the creation of a mechanically stable and future-oriented building material. Unlike conventional materials, it is based on a climate-neutral production process, is recyclable, and can reduce environmental impact by using waste from other industries. By establishing a new cultivation system and regulating individual microbial growth parameters, an increase in biomass productivity and the ability to biomineralize has already been achieved.

Funded within the framework of the Internal Programs of the Fraunhofer-Gesellschaft. Funding reference: SME 840 131.

Microdisplays and Sensors

The business unit “Microdisplays and Sensors“ is offering R&D addressing component/device design and manufacturing technologies based on organic and inorganic semiconductors, e.g., organic light emitting diodes (OLED), photodetectors, inorganic µLED, that become integrated with silicon CMOS and MEMS backplanes. Therefore we focus on the supply chain from CMOS-IC design (backplane), wafer supply with commercial Silicon Foundries, up to frontplane definition and processing (e.g., emitters, absorbers), providing prototypes and pilot-fabrication. So far most important technology is OLED-on-Silicon, providing the basis for OLED “microdisplays”. For “sensor” applications it is often combined with additional sensing layers (e.g., material- and ion-sensitive dyes), to enable detection of e.g., pH, oxygen or carbon dioxide concentrations in gases or liquids.

Though we focus on components and their manufacturing technologies, knowledge on system integration (e.g., smart glasses) and applications (e.g., motorcycle helmet head-up display) remains vital for provident development of innovative features (e.g., luminance, color space, lifetime, resolution, response time, spectral sensitivity). This experience enables tight collaboration with application, system integration and supply chain partners.

Power-saving OLED microdisplays for body temperature screening via thermal imaging

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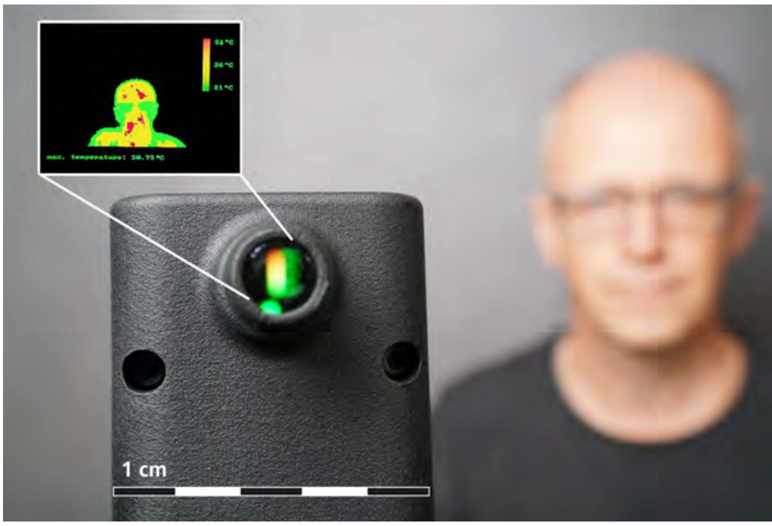
Within EU-funded project INNO4COV-19 Fraunhofer FEP has developed a prototype of a hand-held thermal camera system with integrated, low-power microdisplays for early and contactless detection of persons with elevated body temperature.



Portable system for the display of thermal images via power-saving OLED microdisplays

Thermal imaging cameras provide important information about differences in temperature in the vicinity. Depending on the application, they can, for example, visualize the body temperature of patients and visitors in hospitals from a distance or reveal problems with the thermal insulation of houses. Rapid and accurate temperature screening of elevated body temperatures, for example, can make an important contribution to the control of epidemics or pandemics and prevent the spread of infections at an early stage. The use of thermal imaging cameras to detect suspected cases is already an established method in public places, hospitals or train stations.

The INNO4COV-19 project started at the height of the Corona pandemic in late 2020 and aimed to efficiently and rapidly commercialize new products to control the COVID-19 pandemic and its consequences, and to combat future pandemics. Beside electron beam technologies for the sterilization of textile materials on large surfaces, a portable system for continuous monitoring of body temperature for the earliest possible detection of infected persons was realized using OLED microdisplay technology.

The result is now a handheld device with an integrated thermal camera. The basis of the system is a tiny OLED microdisplay, which is extremely power-efficient due to its intelligent backplane architecture, and is used to visualize the data. We combined the display with an infrared sensor to create a thermal imaging camera that both measures body temperature and displays the result directly via an near-to-eye visualization.

The system converts the 2D information of the uncooled thermal camera into a color image, which is displayed on the ultra-low power microdisplay in a resolution of 320 × 240 pixels, with a display diagonal of 0.19 inches. A button can be used to set the displayed temperature range in single-hand operation. The core components of the system can easily become embedded in lightweight smart glasses, headgear, caps, personal face shields or protective equipment. Applications in disaster relief, firefighting or even troubleshooting in industrial plants benefit here from the power-saving displays and thus long battery life.

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme.
Funding reference: 101016203

Precision Coating

Precision surface functionalization is essential for a wide range of applications. This requires very good homogeneity of layer thickness (less than ±0.5%) over extended substrate width and precise adjustment of mechanical, optical, electronic, and other layer properties. Core competencies in this area include adapted magnetron sputter sources, adapted in-line system concepts, process understanding for wafer and glass coating, dynamic apertures, energy-efficient flash lamp annealing and novel process technologies for ultra-thin glass. These competencies enable developments from »feasibility demonstration« to prototypes and »scalability demonstration«.

Examples of applications include:

- Large-area optical layer systems, also laterally or vertically graded
- Adapted transparent conductive contact layers including in-line flash lamp annealing
- Piezoelectric and ferroelectric layers for microsystems, high-frequency filters, ultrasonic microscopy, non-volatile storage, and micro-energy harvesting
- TiO_2 layers with photocatalytic, antimicrobial, and superhydrophilic properties
- Epitaxial AlN and GaN layers for power and RF electronics as well as LEDs.

Energy-efficient in-line flash lamp annealing of tailored coating systems in vacuum

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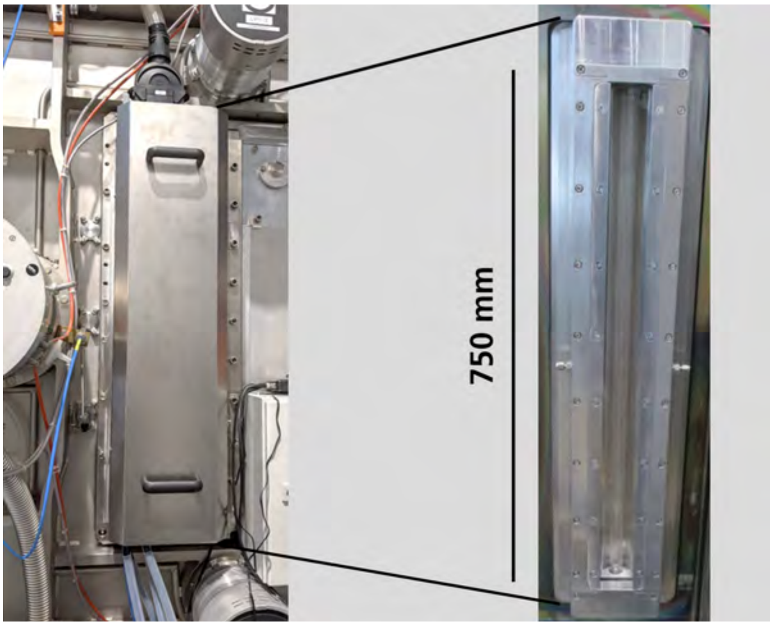
Flash lamp annealing (FLA) device integrated into a vertical in-line vacuum coating system for demonstration of an industrial scale of 1200 × 600 mm^2 surface treatment as part of the publicly funded project INNOFLASH.



Flash lamp module on the ILA 900 vertical in-line vacuum coating system

As part of the publicly funded technology project INNOFLASH by the Saxon State Ministry for Economic Affairs, Labor and Transport, the technology of flash lamp annealing (FLA) in vacuum has been successfully scaled. The aim was to provide an energy-efficient method for effective short-term annealing of large substrates using xenon flash lamps, which heat treats only the very surface region without thermally stressing the entire substrate. This was achieved through the use of 750 mm flash lamps that span the entire substrate width, and by providing sufficient energy densities, for example for the recrystallization of ITO thin films with proven industrial relevant lamp lifetimes.

The key was the development of an innovative power supply concept together with our project partner Rovak GmbH, which ensures the following parameters:

- High energy density > 25 J/cm$_2$
- Adjustable pulse duration (between 1 ms and 10 ms)
- High repetition (flash) frequency (up to 2 Hz)
- Long-term stable and reproducible FLA process (1 million flashes)

This new power supply concept reliably handles the high currents and voltages that occur in the millisecond range in the FLA process and enables precise and effective process control, as required for the use of FLA in industrial large-scale in-line applications, e. g. for:

- Activation of dopants for transparent conductive oxides such as ITO: The sheet resistance of unsintered ITO films with a thickness of 150 nm on float glass was reduced by FLA from 600 µΩcm to 215 µΩcm while increasing the transmission by 10% to 87% (TVIS according to DIN EN410)
- Crystallization of thin films, e. g. for thermochromy (vanadium oxide) or crystalline optical or photocatalytic coatings (TiO_2)
- Controlled in-vacuo de-wetting of thin metal island layers (e. g. Cu and Ag) for biozidic applications

Compared to conventional annealing, FLA offers higher energy and process efficiency, resulting in lower investment and operating costs for surface technologies.

FLA is also suitable for treating sensitive or innovative substrate materials, such as temperature-sensitive polymers or ultra-thin flexible glasses with their special heat conduction properties, offering a high potential for a variety of applications in the future.

Diese Maßnahme wird mitfinanziert durch Steuermittel auf der Grundlage des vom Sächsischen Landtag beschlossenen Haushaltes.

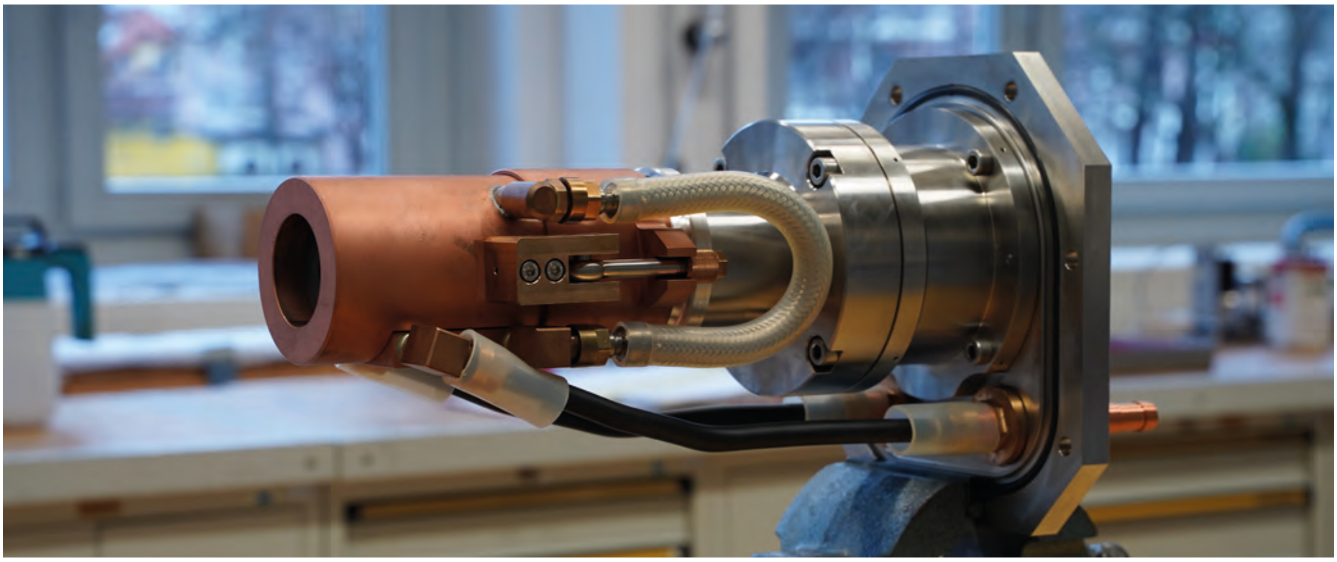
Funded by the Saxon State Ministry for Economics, Labour and Transport. Funding reference: 100349243/3698

Systems

Technology and hardware development go hand in hand at Fraunhofer FEP. Electron beam and plasma components required within the institute are often not available in the market and are specifically modified and further developed to meet application requirements. The development and implementation of this hardware takes place within the »Systems« department. Equipped with mechanical and electronic development as well as the associated sample production, we are able to map an idea from conception to development to implementation.

The internal development of our hardware allows for close coordination with process engineers throughout the entire development process. This enables iterative processes and allows us to quickly achieve our goal: transfer to the industry. Supporting activities in process development enable continuous improvement of the key components of Fraunhofer FEP.

Plasma and electron beam sources for a wide range of applications are part of our technological key component development portfolio. Our key components are already widely used in industry together with the technologies developed at Fraunhofer FEP.



Coating tools directly from the 3D printer

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As part of an in-house research project, we were able to develop, manufacture and successfully test a functional sputtering magnetron using additive manufacturing on one of our coating systems.

Magnetron sputtering source produced with additive manufacturing processes

There are many requirements for the materials used in a magnetron. They must withstand and dissipate the heat generated at the target, withstand the pressure gradients within the system, and be able to isolate high voltages. These requirements are well-known for parts when produced by machining. For additive manufacturing, these properties are often still unknown and depend highly on the printing parameters. In the course of the project, various methods such as stereolithography, selective laser sintering, as well as laser and electron beam powder bed processes, were compared and evaluated.

After comparing the individual methods and evaluating different test specimens, a small magnetron was designed and produced using additive manufacturing. The production was carried out in collaboration with local companies and other Fraunhofer institutes. For the final demonstrator, all metallic parts, all insulators as well as most of the magnets were printed. We were able to not only make the magnetron even more compact, but also reduce the number of parts by, for example, directly integrating cooling channels into the main body. The use of additive manufacturing also led to a drastic reduction in production time. The post-processing of the individual parts took place in-house.

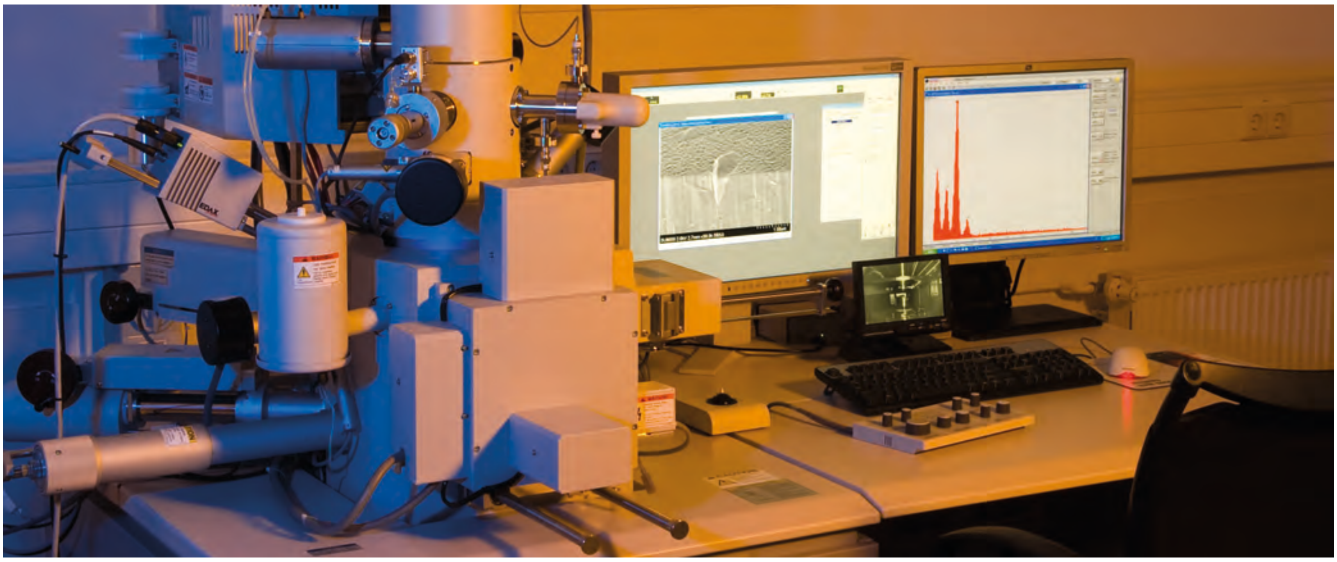
The project was completed with a practical test, where we were able to successfully deposit copper. We want to continue using the new possibilities of additive manufacturing in the future to incorporate further functionalities into our key components, such as highly efficient cooling structures, complex magnetic geometries, and many more.

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.



Ion beam preparation of cross sections for high resolution FE-SEM investigations of thin film solar cells

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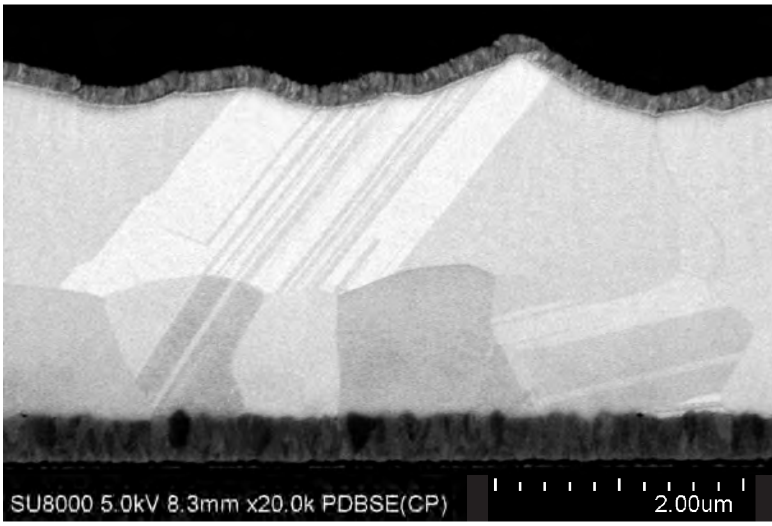
The efficiency of thin film solar cells is substantially affected by structure and interfaces between absorber layer, front contact and back contact. High resolution FE-SEM investigations are able to make an important contribution for the further optimization.



FE-SEM micrograph of an ion polished cross section of thin film solar cell in crystal orientation contrast

Ion polished cross sections can be prepared through the whole layer stack of thin film solar cells by means of broad ion beam (BIB) technique available at Fraunhofer FEP. Thereby it is possible to investigate structure and interfaces between absorber layer and different thin films of front and back contact of the solar cell by high resolution field emission scanning electron microscopy (FE-SEM).

The imaging of ion polished cross sections is carried out with backscattered electrons in material and crystal orientation contrast. The microstructure of polycrystalline absorber layer can be characterized in respect of present lattice defects as grain boundaries, dislocations and twins. Simultaneously the interfaces between absorber layer, front and back contact layers can be investigated at high resolution.

The present interfaces are potential recombination centers for charge carriers and have to be optimally adapted in respect of structure and doping.

An enhancement of the absorption of the solar radiation in short and long wavelength range is achieved by chemical gradients within the absorber layer which can be analyzed by energy dispersive spectrometry of x-rays (EDS). By optimization of this chemical gradients the band gap of the absorber material can be adjusted that high quantum efficiencies can be achieved for a broad spectral range.

The influence of microstructure of polycrystalline thin film solar cells on the separation and diffusion of photo generated charge carriers can be evaluated by FE-SEM imaging and simultaneous registration of the signal distribution of electron beam induced current (EBIC). This enables for example a direct investigation of the effect of grain boundaries on the local EBIC signal distribution.

Additionally, the analysis of the EBIC signal distribution enables the evaluation of the position of the pn junction and of the mean diffusion length of the charge carriers.

The comprehensive analytical opportunities provide an important contribution for further enhancement of the efficiency of thin film solar cells.

Appendix

The Fraunhofer-Gesellschaft

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

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

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

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

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

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

Customers and contractual partners are:

- Industry
- Service sector
- Public administration

Key figures at a glance

- 76 institutes and research units
- 30,000 staff
- 2.9 billion euros annual research budget totaling
- About two-thirds of the Fraunhofer-Gesellschaft's contract research revenue is derived from contracts with industry and from publicly financed research projects
- International cooperation through affiliated research centers and worldwide representative offices

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

- Organic Electronics, Electron Beam and Plasma Technology FEP
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- Laser Technology ILT
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- Applied Optics and Precision Engineering IOF
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- Optronics, System Technologies and Image Exploitation IOSB
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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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Memberships

- AK Glasig-kristalline Multifunktionswerkstoffe
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  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
- Deutsches Flachdisplay Forum e. V.
  www.displayforum.de
- Dresden-concept e. V.
  www.dresden-concept.de
- Energy Saxony e. V.
  www.energy-saxony.net
- EPIC European Photonics Industry Consortium
  www.epic-assoc.com
- Europäische Forschungsgesellschaft
  Dünne Schichten e. V. (EFDS)
  www.efds.org
- Fachverband für Mikrotechnik IVAM
  www.ivam.de
- Forschungsallianz Kulturerbe
  www.forschungsallianz-kulturerbe.de
- Forum MedTech Pharma
  www.medtech-pharma.de
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  für Maschinen- und Anlagenbau
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  www.light-and-surfaces.fraunhofer.de
- Fraunhofer-Wasserstoff-Netzwerk
  www.wasserstoff.fraunhofer.de
- FutureSax Sächsisches Transfernetzwerk
  www.futuresax.de/transfer/saechsisches-transfernetzwerk
- HZwo e. V.
  www.hzwo.eu
- Informationsdienst Wissenschaft
  www.idw-online.de
- International Council for Coatings on Glass ICCG e. V.
  www.iccg.eu
- International Electrotechnical Commission IEC,
  TC 110 Electronic Displays, WG 12
  www.iec.ch
- International Irradiation Association
  www.iiaglobal.com
- International SOS GmbH
  www.internationalsos.com
- KIC CCI – ICE-Konsortium Innovation by Creative Economy
- Kompetenznetz Industrielle Plasma-Oberflächentechnik
  INPLAS e. V.
  www.inplas.de
- Kompetenznetz Plasma Germany
  www.plasma-germany.org
- Kompetenzzentrum Luft- und Raumfahrttechnik
  Sachsen/Thüringen e. V. (LRT)
  www.lrt-sachsen-thueringen.de
- MicroLED Industry Association
  www.microledassociation.com
- 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
- Smart^3 materials – solutions – growth
  www.smarthoch3.de
- SmartEEs v.z.w.
  www.smartees.tech
- Space2Health
  www.space2health.eu
- VDE Verband der Elektrotechnik – Bezirksverein Dresden e. V.
  www.vde-dresden.de
- VDE Verband der Elektrotechnik – DKE-Liste »Fachkreise«
  www.vde.com
- VDMA Organic Electronics Association (OE-A)
  www.oe-a.org
- Verband Deutsches Reisemanagement e. V. (VDR)
  www.vdr-service.de/der-verband/der-vdr

Theses

Diploma Theses

Author	Title	University
M. Hanke	Einführung eines Energiemanagements am Fraunhofer-IZD Dresden	TU Dresden
F. Schuster	Universelle Testplattform komplexer elektro-optischer SoCs am Beispiel eines OLED Mikrodisplays	TU Dresden
M. Ehrhardt	Optimierung von Zink-Zinn-Oxid Barriereschichten für organische Photovoltaikanlagen durch Variation des Beschichtungsprozesses	TU Dresden
M. Bredemeyer	Untersuchungen zur Eignung lichthärtender Polymere für die Stabilisierung fragiler historischer Papierobjekte	TU Dresden
M. Herold	Anwendung der additiven Fertigung zur Herstellung einer Magnetron-Sputterquelle	TU Dresden
V. Heiser	Herstellung von kristallinem Titandioxid im Rolle-zu-Rolle-Prozess auf Dünnstglas mittels Hochleistungsimpulsmagnetronsputtern und unipolar gepulstem Magnetronsputtern	TU Dresden

Master Theses

Author	Title	University
A. Fritscher	Implementierung einer digitalen Mikrodisplay Ansteuerung in einer 28 nm CMOS Technologie	TU Dresden
L. Kahounova	Etablierung einer matrixschonenden Trocknungsmethode für bovines Perikard, Teilschritt eines neuen Aufbereitungsverfahrens für biologische Herzklappenprothesen	Hochschule Zittau/Görlitz
S. Bronder	Bewertung der Resistenz von Rinderperikard gegenüber Kalzifizierung nach Aufbereitung durch das innovative modulare SULEEI-Verfahren	Universität Bayreuth
M. Rietscher	Effects of low Energy Electron Irradiation on in vitro Cell Cultures	Brandenburg University of Technology
T. Rüger	Konzeptualisierung kundenseitiger, sozialer Kosten als Preisbestandteil bei nachhaltigem Konsumverhalten aus der Perspektive einer jungen Zielgruppe	TU Dresden
R. R. Nayak	Optimization of piezoelectric energy harvester using multi-physics finite element modelling	Universität Duisburg Essen

Publications

Authors	Title	Place of publication
F.-H. Rögner, M. Pfeilschifter	Market and Trend Analysis in Industrial Parts Cleaning 2020	Fraunhofer FEP, ISBN: 978-3-00-069602-2, 2022
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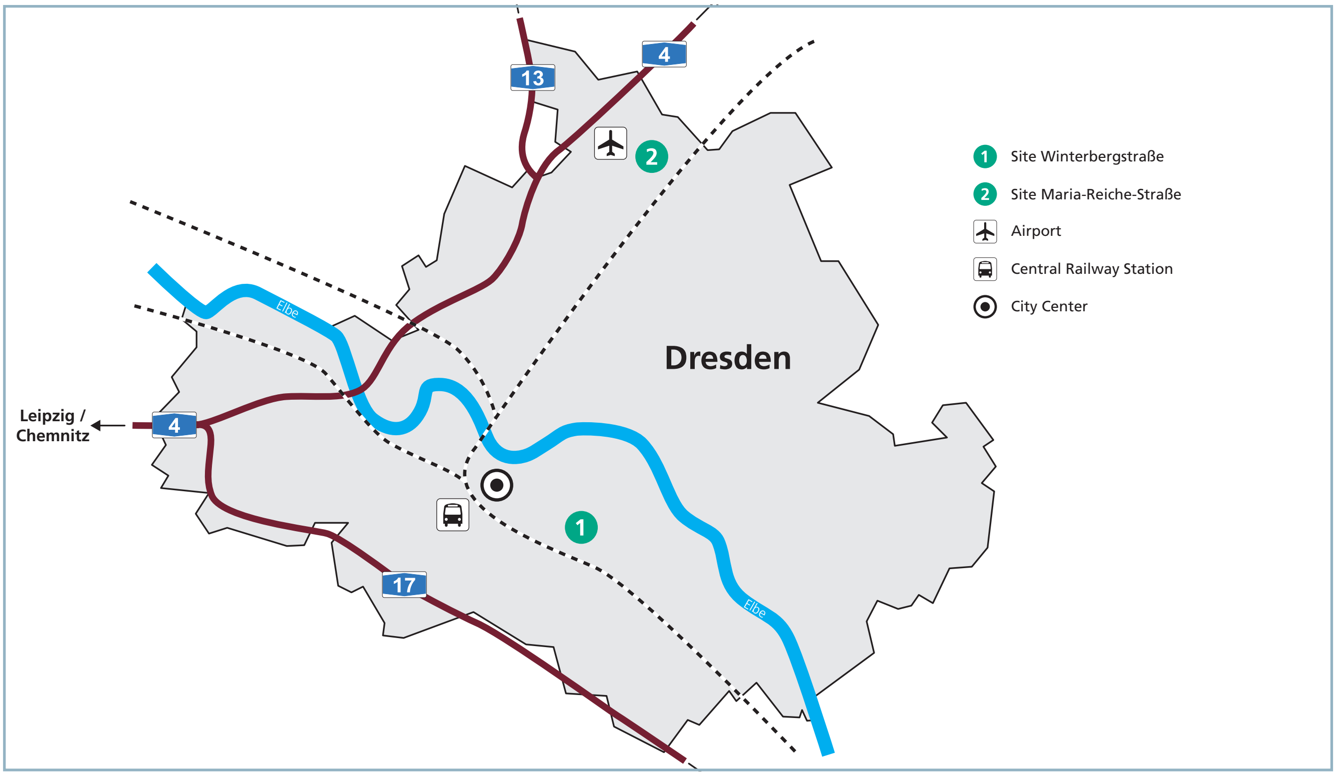

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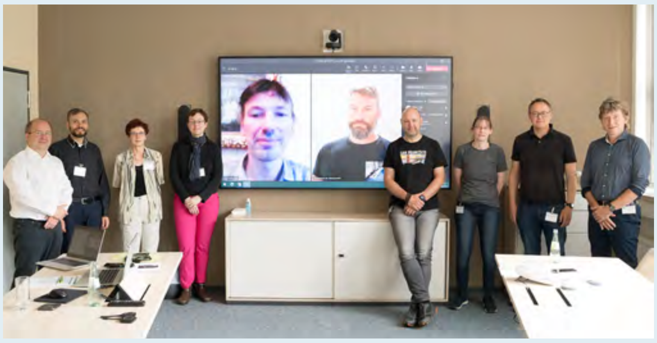

Project meeting „Biosynth“

Visit of the European Commission

IAEA Technical Meeting
„Advanced electron beams for industrial applications“

33rd Advisory Board Meeting of Fraunhofer FEP

Long Night of Sciences, Press tour with Mayor Dirk Hilbert

Certified Energy Management at Fraunhofer FEP

Award ceremony for 1st place „Product of the Year“
in the category „Optoelectronics and Displays“

Participation in the 5 km company run „REWE Team Challenge“

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Thus, Fraunhofer FEP offers a wide range of possibilities for research, development, and pilot production, especially for the processing, sterilization, structuring and refining of surfaces as well as OLED microdisplays, organic and inorganic sensors and optical filters.

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