Fraunhofer
MATERIALS

FRAUNHOFER GROUP FOR MATERIALS AND COMPONENTS – MATERIALS

... FOR TOMORROW.

Dear Readers,

In this brochure we use selected examples to give you an impression of the range of R&D covered by Fraunhofer MATERIALS – the Fraunhofer Group for Materials and Components. We hope to arouse your interest in a more intensive exchange of experience and ideas on one topic or another.

The availability of suitable materials and control of the corresponding materials technologies have always played an important role in technical, economic and social progress in industrial societies and are strong competitive factors. Relevant analyses prove this time and again. In Germany, for example, the processing industry currently accounts for around 20 percent of the gross domestic product. In this case, the share of material costs is 35-55 percent of the total costs. We can achieve considerable efficiency gains thanks to research and development and trigger innovation with new materials and substitution solutions, not only maintaining the competitiveness of Germany as a seat of industry but at the same time helping to make more meaningful and sustainable use of globally limited resources. The importance of materials research continues to increase as materials innovations keep diving new technologies, productivity and value creation.

With our application-oriented research in materials science and engineering and our solutions for materials-related problems of our collaboration partners, we also transform how materials are dealt with in industry and society. Currently, we work on the increased use of digital methods both for developing new materials and also increasing the efficiency of entire value chains. Our Materials Data Space® initiative also represents this. Our aim is to set global standards in the digitalization of materials and thus to enable German companies to take an excellent competitive position. We look forward to exchanging views with you about the many exciting topics involving advanced materials. Feel free to contact us any time!

Prof. Dr. Peter Gumbsch
Chairman of the Fraunhofer Group for Materials and Components – MATERIALS

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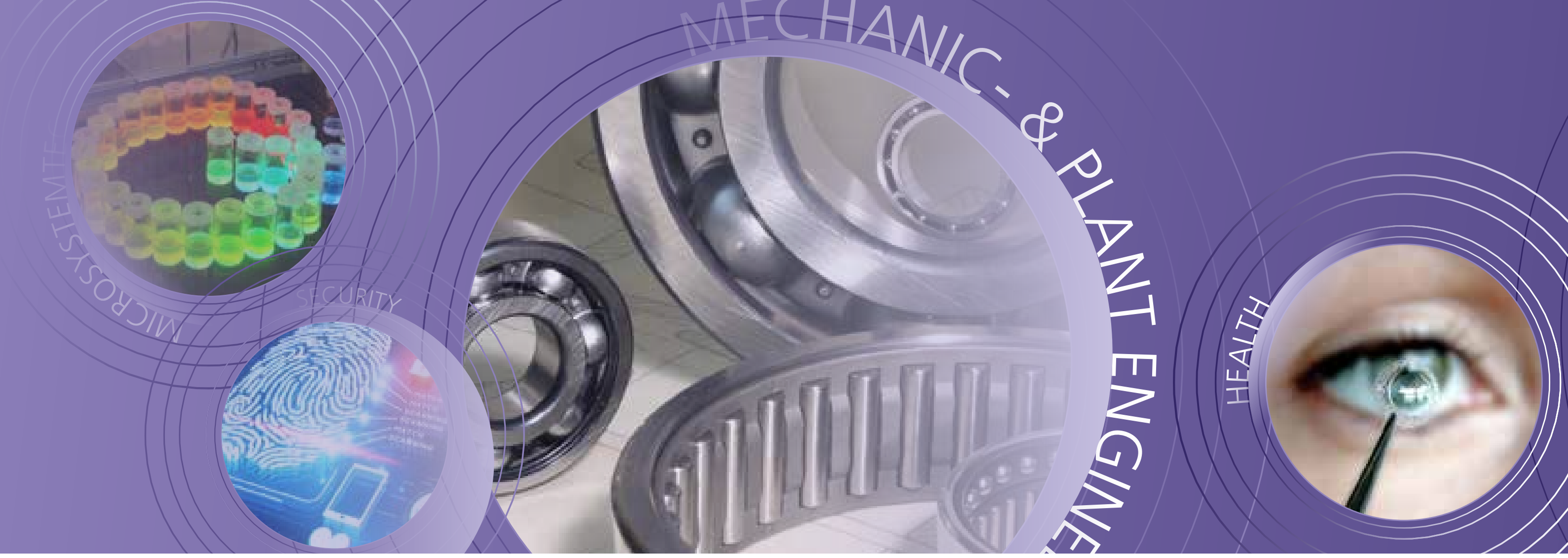

FRAUNHOFER MATERIALS – A STRONG GROUP

The institutes of the Fraunhofer-Gesellschaft are organized into eight thematically structured groups of institutes in order to strengthen professional cooperations and to offer joint and coordinated services.

Fraunhofer MATERIALS pools the expertise of 16 material science and engineering institutes of the Fraunhofer-Gesellschaft.

The Group applies its know-how primarily in the following economically significant **business areas** in order to realize system innovations by means of tailored material and component development:

- Energy and Environment
- Mobility
- Health
- Machinery and Plant engineering
- Construction and Living
- Microsystems technology
- Safety

The **core competencies** of Fraunhofer material research cover the entire value chain:

- Materials development
- Technology development
- Evaluation of application behavior
- Materials modeling and simulation

The Group covers the entire spectrum of materials from metals, polymers and ceramics to materials made from renewables. The overall budget of Fraunhofer MATERIALS was over 473,5 million euros in 2018. The Group currently has more than 4,600 employees, about 2388 of which are scientists.

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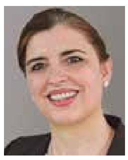
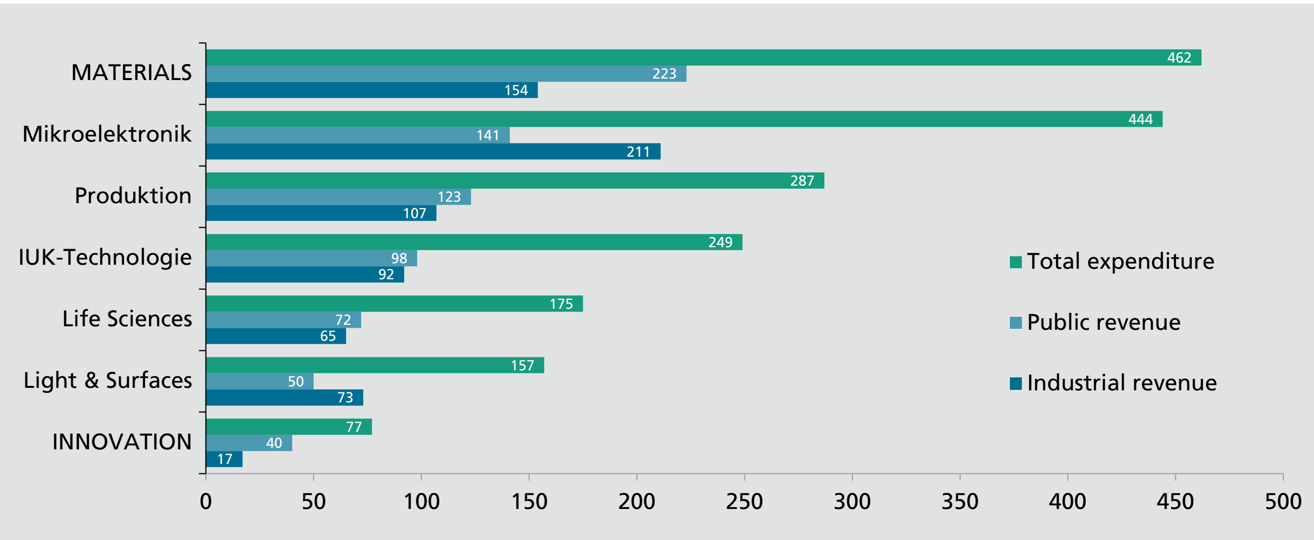


Tasks and Functions

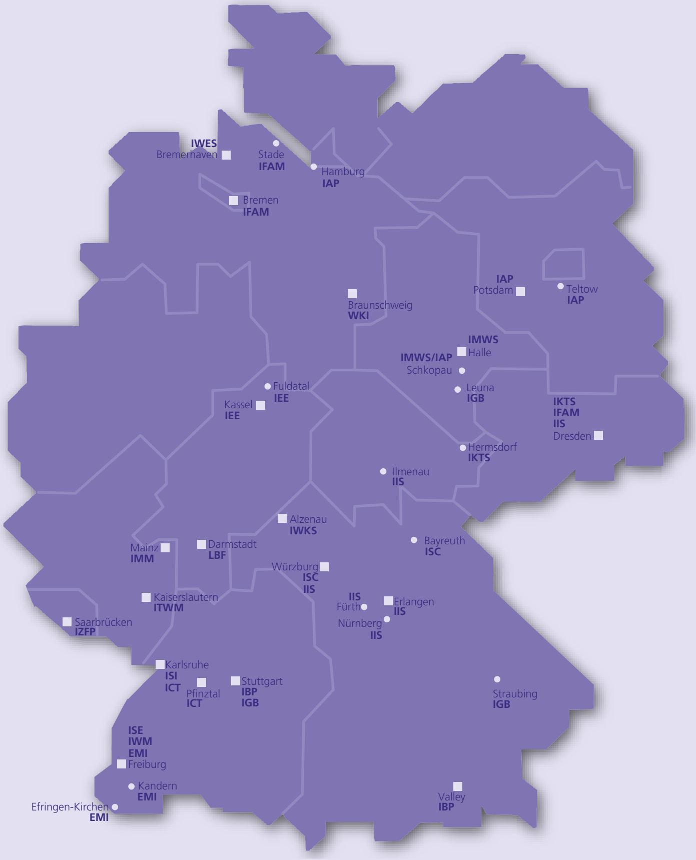
Materials research and technology at Fraunhofer encompasses the entire value chain, running the gamut from the development of new and improvement of existing materials, industrial-scale manufacturing technologies, characterization of properties to the evaluation of application characteristics. This applies to components made of these materials and their behavior within the system.

- Cooperative platform with contact to the market
- Coherent communication with the market
- Initialization and implementation of joint research projects and R&D cooperations
- Strategic pooling and further development of Fraunhofer competencies
- Coordination of internal Fraunhofer research programs
- Coordination of strategic investment planning of institutes in the group
- Advisory support for national and international R&D policies
- Advisory support and involvement in decisions made by the Fraunhofer executive board
- Implementation of decisions made by the executive board within the group
- Long-term, joint planning and strategic development

Fraunhofer Groups
Expenses and income in the performance area Contract research 2018 Mi €



FRAUNHOFER MATERIALS – ADDED VALUE WITHIN A NETWORK



■ main locations ● Subsidary locations with full-time equivalents > 20

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Fraunhofer Institute for High-Speed Dynamics
www.emi.fraunhofer.de

Fraunhofer IAP
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Fraunhofer IBP
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Fraunhofer IEE
Fraunhofer Institute for Energy Economics and Energy System Technology
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Fraunhofer IKTS
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Fraunhofer IMM
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Fraunhofer ISC
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Fraunhofer ISE
Fraunhofer Institute for Solar Energy Systems
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Fraunhofer IWES
Fraunhofer Institute for Wind Energy Systems
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Fraunhofer IWKS
Fraunhofer Research Institution for Materials Recycling and Resource Strategies
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Fraunhofer IWM
Fraunhofer Institute for Mechanics of Materials
www.iwm.fraunhofer.de

Fraunhofer IZFP
Fraunhofer Institute for Nondestructive Testing
www.izfp.fraunhofer.de

Fraunhofer LBF
Fraunhofer Institute for Structural Durability and System Reliability
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Fraunhofer WKI
Fraunhofer Institute for Wood Research
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Guest Institutes:
Fraunhofer IGB
Fraunhofer Institute for Interfacial Engineering and Biotechnology
www.igb.fraunhofer.de

Fraunhofer IIS
Fraunhofer Institute for Integrated Circuits
www.iis.fraunhofer.de

Fraunhofer ITWM
Fraunhofer Institute for Industrial Mathematics
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Fraunhofer ISI
Fraunhofer Institute for Systems and Innovation Research
www.isi.fraunhofer.de

01/04/2019

Changes in energy systems: increasing electrification due to new electricity applications in the heating and transport sector. © shutterstock/ArtisticPhoto; collage: Fraunhofer Energy Alliance

MATERIALS FOR A SUCCESSFUL ENERGY TRANSITION

Energy systems around the world are experiencing a period of change. Renewable energies, above all solar and wind power, are gaining major importance and in all likelihood will deliver the largest contributions to power generation and also to the overall energy supply by the middle of the century. The large proportion of volatile, non-controllable renewable energies for the generation of electricity requires a paradigm shift in the supply model, which is still heavily based on centralized power plants at present. The demand-based provision of energy by large power plants will be increasingly replaced by a system in which there is a constant balance between (volatile) provision and flexible use. This will give rise to a complex interplay between time-adjusted energy use, stronger linking of the electricity, heat and transport sectors, temporary use of flexible generating systems and the use of different types of storage systems. All of this not only gives rise to basic requirements for operation of the energy system but also for the components and functional materials used in their manufacture – from primary energy conversion, transport, distribution and storage to the demand side. Examples from photovoltaics include new production processes for silicon wafers and also new classes of materials such as perovskites or combinations of materials with different band gaps for multiple solar cells. Material issues in the field of energy storage systems are becoming very important. In lithium-ion battery cells it is all about new anode materials with a higher energy density, substitutes for cobalt on the cathode side and, in the medium term, the replacement of liquid electrolytes by ion-conducting solids. In the field of power electronics, advanced semiconductor materials may lead to significant leaps in the clock frequency and therefore power density.

Metal-organic framework materials may be used as highly porous materials with easily adjustable microstructures in a wide variety of applications, ranging from gas heat pumps and selective adsorbers for gas separation, e.g. for selective CO_2 storage, to solid storage systems for reversible storage of a variety of molecules such as those of synthetic energy sources. These are just a few examples of a wealth of promising research and development work that covers virtually all aspects of the energy conversion chains.

Added to this is another requirement: while the traditional power supply system is/was based mainly on the use of fossil fuel sources and all other materials in power plants and facilities have therefore played a comparatively subordinate role, the future energy system will be based primarily on renewable energies that, to all intents and purposes, are inexhaustible. However, it requires a massive increase in the use of a wide range of materials, from copper, steel and concrete to rare earths, for the many millions of systems used for conversion and storage. Therefore, issues of resource availability and the creation of closed resource cycles for these systems and components will play a key role in the future.

These and many other research questions are the focus of applied materials research at several Fraunhofer Institutes of the Fraunhofer MATERIALS Group. In addition to excellent equipment for material synthesis and characterization as well as expertise in basic material simulation, we are distinguished by including questions of industrial feasibility scale-up and cost analyses at an early stage.

The Fraunhofer MATERIALS Group creates a platform for Industrie 4.0-compatible materials. © Fraunhofer MATERIALS Group

MATERIALS DATA SPACE®

Industrie 4.0 relies on the right materials and engineered materials. The Fraunhofer MATERIALS Group creates a platform for this: The Materials Data Space® aims to provide cross-company digital data about materials and engineered materials along the entire value chain. This networking will enable shorter development times, learning manufacturing processes and completely new business models. It opens up enormous potential for material efficiency, production efficiency and recycling.

Materials Data Space® pools all the relevant information about materials and components in a digitalized and cross-company manner. With this »digital material twin«, it will be possible for developers and engineers to understand and utilize the engineered materials used in each development step as variable systems with adjustable properties.

Materials Data Space® intends to provide data about a material or component consistently over the entire life cycle. All process owners, from material developers and material, semi-finished product and component manufacturers to end users and recyclers, can access it if the rights are assigned accordingly. Dynamic material properties can be captured in real time and fed into the Materials Data Space® at every stage of the process. Thanks to the interconnectedness, it is possible for self-organizing, cross-company value networks to become established which can be optimized according to different criteria such as cost, availability and resource consumption. The information technology which forms the foundation for the Materials Data Space® is the secure data space of the Industrial Data Space.

Knowledge of the microstructure of materials is translated into digital material models which become starting points for integrated process chain simulations. At the same time, the dataset of the Materials Data Space® becomes the »memory of the material«. In addition to the information on the microstructure, the Materials Data Space® also contains information on materials and components which have sensory properties. They can detect their current condition themselves, for example the level of wear or stress. The materials pass on this data autonomously, according to specified rules, to production, processing and assembly machines which can then respond to it. At the same time the Materials Data Space® takes into account the data from adaptive components, which adapt based on the load system that is self-determined or signaled by the overall system. This results in learning manufacturing processes in which the processes are always optimally tailored to the properties of the materials used in each case. Last but not least, the data itself can become the basis for new business models

In several use cases, the institutes from the Fraunhofer MATERIALS Group, together with partners, are currently demonstrating the potential of this approach and are further developing the Materials Data Space®. These include projects in the field of fiber-reinforced composites/fiber-reinforced composite components, metal processing/metal forming as well as functional materials and intelligent recycling. There are already plans for further use cases, the examples being the value chains of aluminum and copper. The Center for Economics of Materials CEM, which is funded by the Fraunhofer IMWS and the Martin Luther University Halle-Wittenberg, analyzes the economic effects of digitalization processes along the entire value chain of the emerging Industrie 4.0 under the aspects of the circular economy and material economics.

Our aim is to set global standards in the digitalization of materials and to contribute significantly to the economy's competitiveness through our R&D.

Prof. Dr. Peter Gumbsch
Chairman of the Fraunhofer MATERIALS Group
Director of the Fraunhofer Institute for Mechanics of Materials IWM

MATERIALS FOR ADDITIVE MANUFACTURING

The necessity for resource efficiency on the one hand and consumer demand for individualized products on the other hand pose new challenges for the manufacturing industry in many sectors.

In recent years, additive manufacturing methods have become more and more interesting for industry. This is due to the growing economic importance of advanced materials, manufacturing and production methods for the manufacturing industry, and in particular due also to the possibility of using additive manufacturing methods to create novel component geometries and functionalities in addition to manufacturing prototypes and small batches without high tool costs.

In the meantime, there are a number of very well-developed processes (SLA, DLP, SLS, SLM, EBM, FFF and many more) and a correspondingly wide range of high-performance systems for additive manufacturing on the market. The processes and systems are each specialized in a generally narrow spectrum of usable materials. However, component and product characteristics are defined not only by the manufacturing process but also substantially by the materials used. The interaction of tailor-made materials and processes therefore opens up great technological and economic potential that has barely been exploited so far. One goal of the Fraunhofer MATERIALS Group is therefore to tap into and develop (new) materials for additive manufacturing. The increasing digitalization both in production (Industrie 4.0) and material development (Materials 4.0, Materials Data Space®) provides excellent conditions, particularly for additive manufacturing. Due to the associated options for decentralized manufacturing, for cost-efficient manufacturing even in small quantities (down to batch size 1) and for the individualization of products, these opportunities can be used very easily by innovative SMEs and startup companies.
The development of a broad portfolio of materials and semi-finished products is crucial to stronger penetration of the manufacturing industry with additive manufacturing processes, especially in the sectors of electronics, power engineering, medical technology and process engineering, but also in the aerospace industry, mechanical and automotive engineering as well as in safety engineering. These are materials with which the opportunities of additive manufacturing systems engineering can be fully exploited. Broadening the known materials portfolio will achieve this aim. In addition, further developing existing additive manufacturing technologies into an integrated multi-material approach is promising. This is the only basis for implementing tailor-made hybrid component concepts which are aligned precisely with the local requirements profile of a component and which meet this profile by means of a functionally adapted variation of the material properties (e.g. stiffness, electrical and thermal conductivity, etc.) in all three component dimensions.

Further development of additive manufacturing and in particular further development of the material combinations necessary for it could, in future, integrate conventional upstream and downstream production steps (such as shaping, functionalization and assembly) into a single process. In a large number of sectors, this would result in above-average economic leverage due to shorter development and production times, greater production flexibility and more efficient use of resources.

The Fraunhofer MATERIALS Group works in many R&D projects on suitable materials and processes for a wider use of additive manufacturing processes in the processing industry.

OUR CORE COMPETENCIES

Primarily institutes from the Fraunhofer-Gesellschaft that are specialized in material science and engineering have joined Fraunhofer MATERIALS. Also, additional guest institutes participate in the Group with expertise on systems and process engineering from their individual areas of application. In this manner, the Group pools together very wide-ranging knowledge and experience along the entire value chain and in all classes of materials.

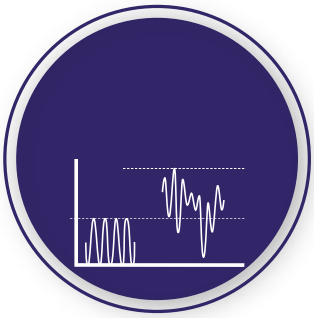
MATERIAL DEVELOPMENT

Materials play a special role in most product innovations. Material innovations either provide impetus for the development of a new product or the product development itself defines a specific profile of requirements for developing or improving new materials. According to studies made on the subject, approx. 70 percent of all new products are based on new materials. In addition, new materials are increasing in significance in terms of cost.

The institutes of Fraunhofer MATERIALS contribute extensively to innovation processes in the field of material development. Some examples for successful material development at Fraunhofer are high-performance polymer fibers for lightweight construction, ceramic fibers for high-temperature applications and matrix or composite fibers optimized for special areas of application. Further developments are found in nanoscale, semi-conductor, phase change or »smart« materials. Special ceramics also belong in the R&D range as well as functional polymers with specific properties (electric, electro-optical, optical and mechanical) or the specific adjustment of property profiles by means of new additives. Particular emphasis is placed on the development of bio-based and recycled materials.

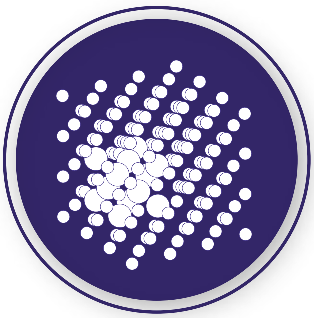
TECHNOLOGY DEVELOPMENT

Modern materials must meet the high standards in terms of their properties of characteristic profiles. Not only should they be light, resistant strong to loads, bio-compatible, durable, and »smart«, but also their manufacture, processing and disposal should be economic and resource- and material-efficient. In order to achieve these and similarly complex requirements, a wide spectrum of sophisticated material technologies is necessary in addition to the material development itself. The manufacture, treatment and processing steps are often decisive as to how efficient and competitive a material and the final product made from this material finally are in practice. With the development of advanced material technologies, the institutes of Fraunhofer MATERIALS make considerable contributions to meeting economic and societal challenges. Among the institutes' areas of operation are the development and the application of selected technologies for surface finishing, coating and the functionalization of materials as well as the further development and optimization of joining and processing techniques or the development of entirely new processes and methods such as in the area of polymer synthesis, microforming, rapid prototyping and recycling.



EVALUATION OF THE APPLICATION BEHAVIOR

Fraunhofer scientists are commissioned by their customers to develop materials and technologies suited to individual application purposes, whether for vehicle construction, medical technology, energy production, or for static or highly dynamic stress. In order for the material and the components made from this material to actually prevail in practice, the different stages of the development process are accompanied by the appropriate method of analysis, characterization, testing and, finally, quality control and field tests. The Fraunhofer institutes within the Group offer a comprehensive range of methods and tests for the testing and evaluation of the functionality of structural durability on the one hand, and system reliability on the other. A number of numerical and experimental methods – destructive as well as non-destructive methods – are available on the micro and macro scale during the entire material and product life cycle. This also includes the »intelligent« methods of structural health monitoring or the in-line monitoring of production processes, i. e. by means of computer tomography. By further developing materials and products, testing procedures and evaluation methods likewise form part of the innovation process.



MATERIAL MODELING AND SIMULATION

Modern materials are developed with regard to their future application in products. This is based on a clear definition of the target properties for the materials. These target properties can ideally be broken down to the microstructural scale. Fraunhofer scientists design new materials on computers using simulation technology and virtually test their properties on micro as well as on macro scale. They collect data, work on corresponding material models and roughly predict how a polymer composite will react in an injection molding process. They carry out computer-based research to determine whether the customized anti-reflex coating for solar cells maintains the required properties during application or how the safety-critical zones of a lightweight body will react upon impact with an obstacle. Using material modeling methods, suitable simulation instruments and corresponding expert knowledge, it is possible to reduce the extent of cost and time-intensive tests series and to considerably shorten development time. Modeling and simulation techniques are applied and are further developed for specific applications at institutes of the Fraunhofer MATERIALS Group.

OUR BUSINESS AREAS

Advances in materials science and engineering are essential for innovations in all fields of technology and often provide the necessary impetus. The availability of optimized materials and the related manufacturing and processing technologies are decisive factors for the competitiveness of economic areas. Fraunhofer MATERIALS deals with a multitude of challenges and works on tailored solutions in the following key areas.

ENERGY AND ENVIRONMENT

Energy and resource efficiency to ensure an affordable, reliable and at the same time environmentally-friendly energy supply for a growing world population is not conceivable without material innovations. The requirements for a transformation of the energy system with regard to energy production, transport, supply and storage are defined by particular challenges for materials and material technologies. The availability of certain raw materials for a number of high-tech applications also plays a key role. The development of efficient recycling methods and widely-available, efficient substitute materials are urgent research issues.

MOBILITY

An efficient transportation system is essential for a modern society, economic growth, employment and prosperity. In addition to electronics, materials are essential innovation drivers for mobility and transportation. Competitive material and system solutions for road- and rail-bound vehicles, in aviation and in shipbuilding must meet specific requirement profiles for resource- and energy-efficiency, lightweight construction, safety, system reliability and comfort. This applies to electric vehicles as well as to combustion engines or hybrids.

HEALTH

Demographic change, the spread of new types of diseases as well as increasing individual health consciousness create high demands on an efficient and affordable health care system. This results in a greater need for innovative material systems for prevention, diagnosis and therapy. Material innovations enable new approaches in drug research and increase the lifespan and bio-compatibility of medical products.

MECHANICAL AND PLANT ENGINEERING

The ratio of material expenses in Germany's manufacturing sector is considerable. Materials, processing and manufacturing techniques are closely intertwined. Coordinated modifications of material properties, processing and production methods are key to improving the performance of products. Optimized material application on the one hand and the product-ready development of new materials on the other can considerably increase productivity and quality. The modeling and integrated simulation of materials and processing steps together with a continuous flow of material data speed up the innovation process.

CONSTRUCTION AND LIVING

Housing is one of man's basic needs. In order to create affordable housing at a high standard of living while simultaneously realizing energy-efficient, sustainable construction methods requires a strategically intelligent application of materials and material systems. This applies to new constructions as well as to the renovation of old buildings. Important goals during the development of new materials and production methods are saving energy and reducing CO_2 emissions as well as the recycling and the recovery of raw materials.

MICROSYSTEMS TECHNOLOGY

The market for microelectronics and microsystems technology is highly dynamic. Innovation cycles are quite short and the added value of material application is extremely high. Further increase of the integration density, on the one hand, and the application of scarce, expensive or toxic raw materials on the other are central themes that require a very high functional and performance capability of the applied material systems. The decisive factor in many cases is their structure and composition on the atomic scale.

SECURITY

Protecting people, buildings and infrastructure from natural catastrophes, accidents or terror attacks is becoming an increasingly challenging task. Efficient materials within specific protection concepts can contribute considerably to greater security and damage control. The prerequisite for their development is an in-depth understanding of the behavior of materials, components and structures under extreme stress conditions such as impact or explosions.

Composite rotor blade: cross section (above) and shredded (below).
© Fraunhofer ICT

ENERGY AND ENVIRONMENT

Recycling of Large-Scale Composite Components – Rotor Blades

Composites made of reinforced fbers with thermosetting polymers as a matrix material have been the center of new material developments for a number of years, due to their enormous lightweight construction potential and high economic effciency. Composites are increasingly being incorporated into new products and, consequently, large quantities of these materials will need to be recycled in the future. In addition to fber-reinforced polymers, flling materials like balsa wood or polymer foam as a sandwich construction are applied to the rotor blades of wind turbines to save additional weight. The advantage of hybrid materials - that, with the right mix of materials in the composite, they can be adapted to individual requirements - has turned out to be a disadvantage with regard to disposal. The recycling of these composite materials, and in particular the separation of the components without forfeiting the desirable properties, is still an unresolved problem.

The development of an economical and ecological recycling solution for composites must take into account the entire recycling chain, from dismantling and treatment through to the provision of processable secondary raw materials. However, these steps prove to be diffcult, particularly with large-scale components like rotor blades. With today's state-of-the-art technology, dismantling only enables the transport of rotor blade segments that do not require authorization. It does not serve the purpose of separating them into individual fractions. Rotor blades currently requiring disposal are made of glass-fiber-reinforced polymers containing a polymer foam or basal wood sandwich construction. Large metal bolts are located at the fange, which connects the rotor, and copper lines are contained inside the blades to act as lightning conductors. Some manufacturers also integrate carbon-fber-reinforced polymers into particularly stressed areas in some of the latest generation of rotor blades. Current research work also focuses on the application of thermoplastic structures in rotor blades, which further contributes to the existing material mix.
A separation of individual fractions at the contact point would make the subsequent processing and material recovery more effcient. Up to now, the recycling process for rotor blade materials was a mechanical shredding of the entire composite, which was then used as a combustible or sand substitute in the cement industry, or for thermal recovery in waste incineration plants.

The use of energetic dismantling to separate rotor blade materials into different fractions, as well as the subsequent material-specifc processing, are being researched at Fraunhofer ICT within the framework of the ForCycle project on »Recycling of Composite Components made of Polymers as Matrix Material«. The objective of the project is the recovery of secondary raw materials for renewed, high-quality application. The technological possibilities for recovering fber material comprise mechanical, thermal and also chemical processes. In cooperation with the Technische Hochschule Nürnberg, the separation of fbers from the matrix material is researched in addition to the recovery of these resins and fllers, in order to achieve an ecologically and economically effcient recycling process. The sustainability of the new developments is shown in a final evaluation of the new processes and materials as well as through a comparison with the state of the art in the recycling of rotor blades.

The rotor blades of wind turbines contain large volumes of very light balsa wood which, following recycling, can be re-used in e.g. insulation materials. © Peter Meinlschmidt, Fraunhofer WKI

Portion of a rotor blade (above, © Peter Meinlschmidt, Fraunhofer WKI) and following homogenous separation of the balsa wood (below, © Manuela Lingnau, Fraunhofer WKI).

Recycling of Balsa Wood from Rotor Blades for the Production of Insulation Materials

Rotor blades of wind turbines have a service life of 10 - 20 years (Figure 1). After this, they are usually incinerated at a cement plant. A renewed material utilization of the components does not take place.

With a length of 40 m and a mass of approx. 26 tonnes, a rotor blade consists of approx. 24 t glass fiber-reinforced plastic (GRP), 1.3 t balsa wood and 0.5 t metal. With an average balsa wood density of 150 kg/m³, such a rotor contains around 8.5 m³ of valuable balsa wood, which is available for recycling processes. Subsequent to the first use in the rotor blade, the outstanding material properties of the balsa wood should then be used in a second application in insulation material, preferably through cascade utilization. In an innovative SME project at the Fraunhofer Institute for Wood Research WKI in collaboration with the Nuremberg Tech (TH Nürnberg) and seven small and medium-sized partner companies, suitable recycling and reutilization procedures for the accruing large volumes of balsa wood are to be defined.

The project partners are focusing on a holistic consideration of the recycling chain for the balsa wood. They thereby undertake rotor-blade dismantling in the field, mechanical material processing and the homogenous separation at the recycling depot as well as the development of recovery procedures – which form the main focus of the project.

Dismantling and Shredding of Rotor Blades

The renewed utilization of the balsa wood requires efficient dismantling and the targeted separation of the sandwich material. Within the framework of the project, water-jet cutting is being examined as the procedure which will minimize both wear on the cutting material and dust generation.

Separation of the Balsa Wood from the Glass Fiber-Reinforced Plastic (GRP)

The partners at the TH Nürnberg carried out initial comminution tests on rotor blades, during which the parameters of comminution type, mass flow, particle size distribution and energy consumption were examined more closely. The first successful experiments on the separation of balsa wood and GRP were achieved with the aid of density differences (Figure 2). Over the further course of the project, the researchers validated these results industrially and compared them with other procedures, such as the zigzag sifter. They subsequently subjected the recovered balsa wood to various sieve analyses in order to determine the particle size.

Production of Insulation Materials from Balsa Wood

For the production of wood-fiber insulation materials, the recycled balsa wood was optimally defibrated in a refiner by means of thermomechanical pulping. Utilizing both conventional and newer binding agents, the scientists produced differing wood-fiber insulation materials with densities of 20 to 250 kg/m³. Via the pulping of the balsa wood in an atmospheric refiner, a wood-fiber/water mixture can be extracted which, through a foaming and subsequent drying process, can be applied as a pressure-resistant wood foam without synthetic binding agents.

Outlook

In further planned work, the researchers intend to use the balsa wood for the production of lightweight »wood polymer composites« (WPC) in order to reduce the usually very high densities of WPC (approx. 1 100 kg/m³) by half.

An ecological balancing of the reprocessing steps and the manufacturing procedures for the various insulation materials should ultimately lead to optimal recycling processes.

Example of magnetic scrap material.
© Fraunhofer IFAM

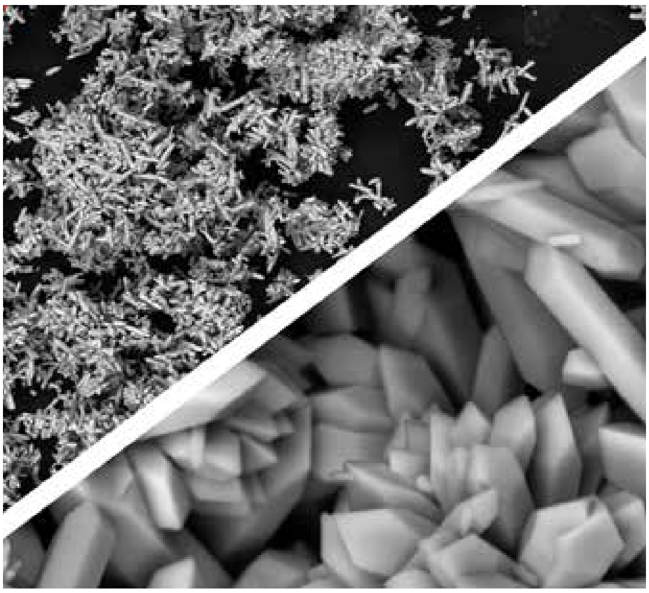
Recycling of Rare-Earth Magnets and Production Waste

Ever since China imposed export duties on certain rare earths in 2010 and 2011, an important economic strategy of the German government has been to decrease dependence on the import of these rare earths. The three most important options for achieving this goal are for Germany to develop its own primary deposits, the reduction and substitution of certain rare earths, and the recovery of secondary raw materials by means of recycling.

Although neodymium, praseodymium and dysprosium are the most economically signifcant of all rare earths due to their importance in the manufacture of high-performance NdFeb magnets, efforts, thus far, for a targeted recovery of these elements have been insuffcient. In particular, only few promising approaches exist for the processing of old magnets and magnet waste that, on the one hand, exploit the full potential of the already separated rare earth elements they contain and, on the other, are able to remove unwanted impurities (e. g. oxide, organic compounds).

This is where the hydrometallurgical recycling process developed by Fraunhofer IFAM Dresden comes in, achieving the targeted recovery of the elements neodymium, praseodymium and dysprosium from material mixes. The process is based on the idea that by skillfully exploiting physical correlations and by optimized process control it is possible to attain a selectivity high enough to eliminate a time-consuming and costly precision separation process of the rare earths involving ion exchangers or fluid-fluid extraction plants. However, for the production of new, higher-grade NdFeB magnets, it is essential that particularly samarium, which is contained in magnet material mixes, as well as oxide and organic impurities, are separated.

It could be shown in the framework of development projects that this necessary selectivity during the recycling of magnet material mixes can be realized on a laboratory scale, particularly by means of appropriate physical pretreatment and pre-separation as well as by means of a controlled hyd- rometallurgical process. A corresponding recycling process has already been registered for patent approval.



Product containing neodymium during the recycling process.
© Fraunhofer IFAM

The Fraunhofer Research Institution IWKS also researches and works with methods of material recycling, in order to retain the material in its composition and to use it as reprocessed recyclate for the production of new magnets. A unique pilot plant in Germany for the production of permanent magnets on a pilot plant scale is under construction.

Valuable raw materials can be recovered from different types of waste (example: electronic scraps, copper slag, tea fibers).
© Fraunhofer Research Institution IWKS

Efficient Recycling and Optimized Material Cycles for Sustainable Competitiveness

Scarcity of resources is a central theme for global economic and societal development. An improvement in the recycling of raw materials and an optimization of the material cycles is therefore not only important for environmental protection. An increase in the resource efficiency, recycling and reutilization of raw materials after usage as well as the substitution of rare and critical substances are the prerequisites for maintaining productivity and the competitive edge of the industrial location of Germany.

Recycling Valuable Materials, Replacing Critical Raw Materials

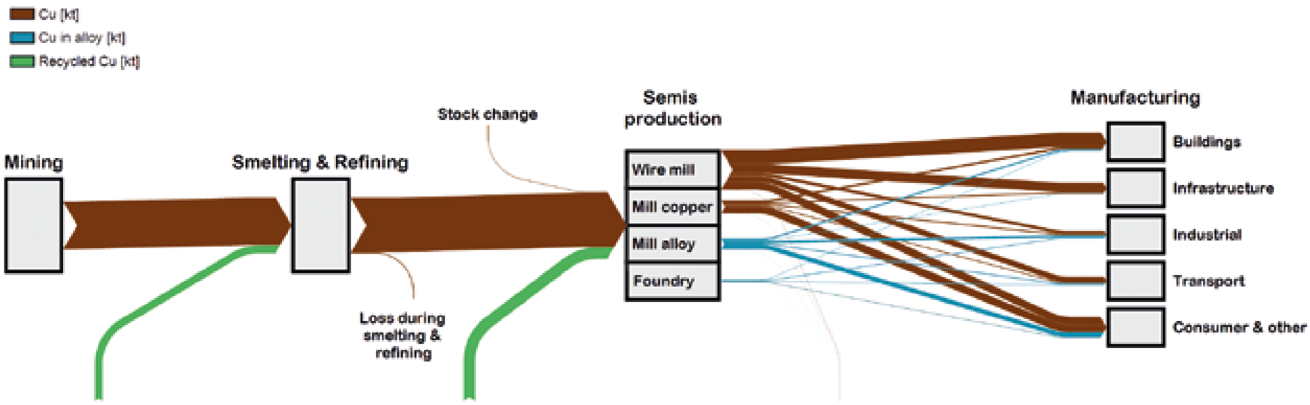
Within Fraunhofer MATERIALS, the Fraunhofer Research Institution Materials Recycling and Resource Strategies IWKS researches and develops new recycling technologies and substitutes for raw and processed materials. This type of closed cycle within the material flow management is especially aimed at critical supply elements and material systems. Concepts for the sustainable use of recyclable and waste material from glass manufacture, waste incineration and industrial production are developed and implemented for this purpose. The focal points of research work are glass, slag, ash, biomaterials and foods as well as the recycling of other materials such as production residue and former consumer goods.

Further emphasis is placed on the availability, recycling and substitution of raw materials in electronic components, parts and appliances. The focus is on material flow analyses of recycling processes, analysis and assessment of electronic appliances and the development of new types of fragmentation and sorting methods. The main point here is the development of innovative process chains and the closure of recycling cycles, for example, of electronic waste.

Particularly significant in the area of biomaterials and food products are composite materials, cellulose fibers, the use of food scraps and sustainability certifications. Analysis, pre-treatment and recycling methods for natural fibers are developed, value chains for biophenols are examined, and the resource efficiency of small and medium-sized companies in the food industry is improved in research cooperations.

Developing and Implementing Specific Strategies

The Fraunhofer Research Institution IWKS supports companies with comprehensive knowledge on criticality analyses, markets, trends and technologies that are important for meaningful recycling and for successfully operating recovery substance cycles. In terms of methods the advisory concept ranges from analysis of the situation and strategy development to concepts for measures and implementation. The advantage for contracting companies is that they work together with scientists on strategic as well as technological and organizational recommendations and on their implementation. Among other things, this is founded on concept and feasibility studies, profitability assessments, system analyses for increasing raw material and energy efficiency, optimization of waste and resource management, and improvement of all relevant process steps along the value chain. New recovery substance cycles can thus be defined and implemented.



Global copper flows (2017)

© Fraunhofer ISI

Evaluating and Improving the Reliability of Raw Material Supply

A reliable supply of raw materials is necessary for the EU and especially for German industry. To be able to react appropriately to the challenges posed by changing international raw materials markets, both an understanding of the challenges and an evaluation of potential solutions are necessary. An important step in this assessment is the identification of critical raw materials, where both the likelihood of a supply shortage and the consequences of such a shortage are seen as high. Fraunhofer ISI has supported this identifcation process particularly at the EU level by playing a key role in the compilation of the lists of raw materials for the EU in 2010 and 2014. These analyses had - and still have - an important infuence on the actions of the EU for improving the supply of raw materials, including EU research funding.

Future developments are also important for a successful positioning in changing markets. Fraunhofer ISI supports this positioning with studies on the demand of raw materials for emerging technologies, with the creation of (technology) road maps and with modeling tools that incorporate increases in effciency, substitution, recycling and the contribution of primary raw materials. This makes it possible not only to estimate the effect of individual developments but also to consider the multiple facets of raw material extraction and usage. This includes, for example, miniaturization and recycling technologies as well as new materials and products, which can in part substitute for others, as well as changes in the relevant policy framework. By determining together with its clients the most important research issues for each project, Fraunhofer ISI can provide relevant information and tailored analyses for governments, industrial associations and individual companies.

Dynamic Modeling of Anthropogenic Material Cycles

The material basis of modern economies can be better understood, evaluated and optimized by using dynamic material fow modeling applied to global, regional and national material fows. Particularly in view of conserving fnite resources, dynamic material fow models based on historical data can help identify worthwhile approaches to improving recycling systems. In the case of copper, Fraunhofer ISI has been commissioned by the industry to develop global and regional models with which robust statements are possible regarding copper stocks and recycling worldwide and in selected regions. The results from the global model are included in the yearly World Copper Factbook of the International Copper Study Group (ICSG).

The sound system description and plausible future scenarios of dynamic material fow models also make them an important source of information for strategic decisions. In the Fraunhofer Lighthouse Project »The Criticality of Rare Earths«, for example, researchers estimate the expected demand for neodymium and dysprosium, differentiated according to sectors and product groups, as well as their future occurrence in manufacturing scrap and end-of-life products using a global and a German model. These estimations support decisions for technology development (in which areas can greater savings be achieved with more effcient technologies or alternative materials?), necessary collection systems (what amount of which end-of-life products should be collected in the future?) as well as investments in (recycling) facilities (what type of facility and capacity will be needed?).

Manufacture of a new magnet alloy in an electric arc furnace.
@ Fraunhofer Research Institution IWKS

Substitution of Critical Raw Materials – New Permanent Magnets for the Change in Energy Policy

With its research work, the Fraunhofer Research Institution for Materials Recycling and Resource Strategies IWKS has set itself the goal of contributing to securing raw materials that are economically significant for Germany. The availability of strategic metals such as the metals of rare earths is increasingly becoming the focus of politics and industry. With the aid of new approaches to raw materials strategies, recycling and possible substitution materials, production costs can be reduced, supply reliability improved, and also a decisive contribution to protecting the environment can be made. Rare earth metals play a particularly significant role in high performance magnets. Neodymium iron-boron-magnets have by far the highest energy density of all currently known permanent magnets and make up about two thirds of market turnover worldwide. Minute quantities, for example, are used in loudspeakers and hard drives as well as in wind turbines (> 600 kg/MW).

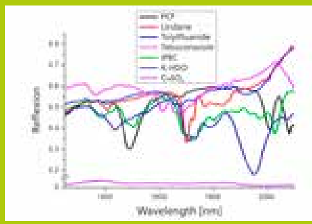
Particularly the rising numbers of hybrid and electrovehicles in the automobile industry have increased the demand for rare earths. Magnet systems have, for this reason, become a work priority of the IWKS Research Institution. The main focus lies on the substitution of metals that are classified as critical. Theoretical predictions and proposals are made on the basis of simulations for new types of ferromagnetic phases without neodymium (Nd) and dysprosium (Dy) but with equivalent magnetic properties. The predictions serve as a basis for the synthesis of new magnet materials. Here, the IWKS can draw on cutting-edge equipment and diverse synthesis routes that include electric arc furnaces, the method of rapid solidification and sintering. The latest method for the manufacture of high-performance magnets is directed at nanocrystalline structures, e.g. by hot pressing and hot forming, among others.

In addition to the actual substitution of materials, the efficient application of raw materials also plays a major role. With the development of manufacturing methods for the final product shaping, it is possible to eliminate costly and, therefore, material-intensive post-processing and thus, effectively, save material. In addition, the Fraunhofer Research Institution IWKS is working on optimizing the microstructure in order to more selectively distribute particularly critical elements like Dy within the structure, but most importantly, on parts where it optimally influences the properties of the magnet. These measures can reduce the application of Dy by up to 50 percent.

Which Branches of Industry Benefit?

High-performance magnets play a prominent role particularly in the area of generators and electronic motors. Electromobility, the automobile industry and wind turbine plants especially benefit from more readily available replacement materials. These technologies are predicted to grow strongly in the future, and an enormous rise in the demand for Nd and Dy is expected. High-performance magnets play an important role in the electronics and computer industry as well as in medical science. Uncertainties about raw material supply could slow down developments in future technologies.

Figure 1: NIR sorting facility for the determination of organic wood preservatives. © Fraunhofer WKI / Manuela Lingnau



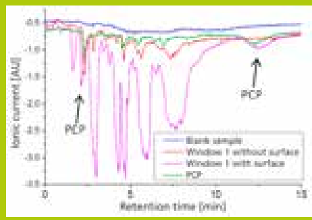


Figure 2: GC-FAIMS and the associated spectrum showing the detection of PCP in treated wooden windows before and after surface decontamination. © Fraunhofer WKI / Peter Meinlschmidt

Molecular Sorting for the Recycling of Waste Wood

The rising demand for fresh wood and the increased use of firewood are currently leading to declining timber volumes in the whole of Europe. The use of »waste wood« is therefore becoming increasingly important for the European wood-based materials industry.

The material usage of approx. 8-10 Million tons per year waste wood in Germany currently takes place almost exclusively in the particleboard industry. Countries such as Italy have already increased their proportion of waste wood in particleboard to over 90 percent.

The reasons for the low utilization in Germany are the restrictions imposed by the Waste Wood Ordinance and the existing high incineration capacities for the generation of energy. Within the framework of the »Molecular sorting« project, the Fraunhofer WKI and its partners have developed procedures and technologies in order to significantly increase the quantities of pure wood fraction which can be separated and materially utilized in the future. The detection, comminution, separation, sorting and purification procedures thereby developed help to considerably improve the homogeneity of the obtained products.

Techniques for Detection and Sorting at the Molecular Level

At the Fraunhofer WKI, the employees developed and tested various detection techniques at the molecular level for the »Demonstrator for Waste Wood Cascade«. Detection techniques include X-ray fluorescence analysis (XRF), near-infrared spectroscopy (NIRS) and field asymmetric ion mobility spectrometry (GC-FAIMS).

With XRF, fast and reliable statements can be made concerning the type and quantity of inorganic wood preservatives as well as various coatings. Near-infrared spectroscopy (NIRS) captures the molecular vibrations following absorption of the incident infrared radiation (Figure 1). This enables the simple and safe detection of widely varying plastics and many organic wood preservatives.

Ion mobility spectrometry (IMS) can be applied in the analysis of vaporizable ionizable substances (Figure 2). If the IMS separation effect is not sufficient enough to adequately separate complex organic wood-based materials or wood preservatives, the method can be coupled with gas chromatography (GC-FAIMS).

Detection of Wood Preservatives

Many organic wood preservatives could be detected with both NIRS and GC-FAIMS technology. Particularly with NIRS, the active substances were often not directly analyzed, but instead the altered structure of the cellulose, the hemicellulose and the lignin. The scientists were also able to verify the influence of the wood moisture and the solvent used in the treatment.
The wood preservative active agents investigated with GC-FAIMS belong to the SVOC group and exhibit comparatively low vapor pressures. At temperatures as low as 80 °C, they evaporate in quantities which are sufficient for their detection. Based on this knowledge, wood preservatives such as PCB (Figure 2), dichlofluanid and lindane could be detected. Furthermore, the project participants were able to show that by removing a 5 mm-thick surface layer from wooden window frames, the wood preservative active agents could be removed.

Outlook

Mithilfe der drei beschriebenen Detektionstechniken, die auf molekularer Ebene chemische Verbindungen detektieren, konnten die Wissenschaftler sowohl anorganische als auch organische Holzschutzmittel, Biozide und auch verschiedene Kunststoffe nachweisen. Eine deutlich höhere Altholz-Recyclingquote ist damit auch in Deutschland denkbar.

Fraunhofer expertise in the sorting of heterogeneous building rubble, to produce homogeneous building products and secondary raw materials.
© Fraunhofer IBP

BauCycle

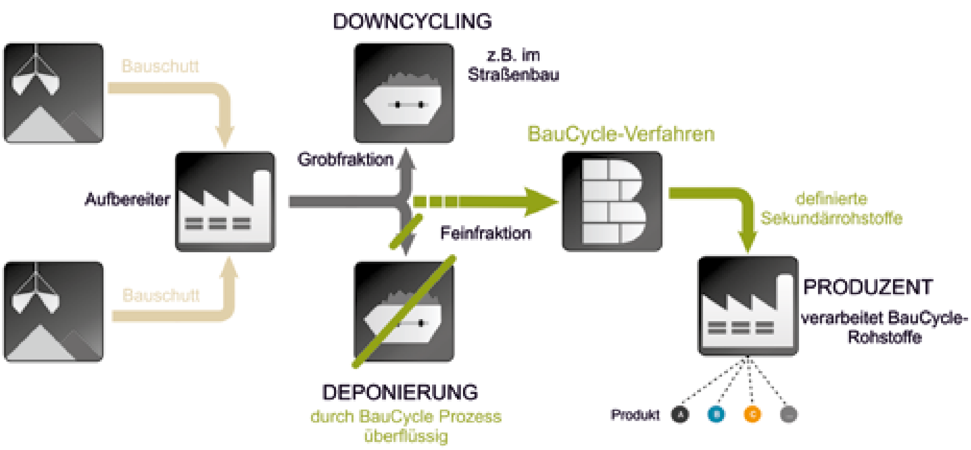
The German saying »as the sand of the sea«, which literally means »a ten a penny« has lost its validity. In many countries in the world the valuable resource sand is disappearing continuously. The main reason therefor is the boom construction sector which consumes vast quantities of concrete comprising mostly of sand and gravel. Every year around 40 billion tons of sand and gravel are consumed and on the other hand around five million tons of fine grained construction waste accrue in Germany every year. Until now this waste has been used as landfill or road construction material. Different Fraunhofer institutes (IBP, IML, UMSICHT, IOSB) have set themselves the task to process the construction waste in a way to generate a new sustainable material. The big goal of the project »BauCycle« is to reuse the construction waste below two millimetre particle size and to cover the whole value chain from developing innovative sorting processes and high-quality construction materials up to the development of a dynamic virtual commodity exchange.

Ideally four different pure mixtures can be reused for example for producing autoclaved aerated concrete (AAC). AAC is a lightweight construction material with excellent insulation properties, which is highly suitable for both load-bearing walls and insulation material in the interior. Experiments showed that mixtures of concrete and sand-lime bricks are suitable for the production of AAC and the best results could be generated with a mixture of 80 percent waste sand-lime bricks and 20 percent waste concrete.

The experiments also showed that a mixture of waste bricks and waste concrete can be used to produce geopolymers. Geopolymers are a cement-free construction material with similar characteristics to concrete regarding the strength and acid resistance. Furthermore geopolymers achieve a significantly better balance in terms of CO2.

Besides the AAC samples of different composition the scientists could also develop a geopolymer-based façade plate and a sound-absorbing plate showing an open porosity structure with the same absorbing properties as products which are already available on the market.

Within the Project »BauCycle« Fraunhofer IBP is responsible for the utilisation of the sorted construction waste and in particular for the development of innovative and sustainable new materials, such as functional construction elements, sound-absorbing plates and cement-free binders.



BauCycle-Process
@ Fraunhofer IBP

Prof. Bernd Meyer is developing a new gasification reactor that can cleanly utilize carbon-containing waste and use it to produce synthetic gas. © TU Bergakademie Freiberg / IEC

Processing module with integrated ultrasonic sensors for complete removal of pharmaceutical residues. © Fraunhofer IKTS

CarbonDemonstration Pilot Plant: Waste becomes Raw Material

Climate protection and energy transition imply a structural change for the German industry that encompasses far more than the end of power generation via lignite and fossil fuels. A long term prospect is to base the entire supply of raw materials on sustainable sources. Therefore, the Fraunhofer IMWS is establishing a pilot plant together with partners to convert carbon carriers such as plastic waste and leftovers from biomass into products that can be used as a raw material for the chemical industry. This is an important contribution to the low-emission carbon recycling economy. After a planning phase, the CarbonDemonstration pilot plant shall be available from 2021 in the Leuna chemical park.

Synthetic gases consisting primarily of hydrogen and carbon monoxide are an important raw material for companies located there. Most of these gases are currently petroleum-based. By contrast, the pilot plant in Leuna will use different carbon carriers, for instance carbonaceous residues. These will not be incinerated as before, but gasified. Core of the underlying conversion technique is a process in which carbon-containing raw materials are treated with oxygen and water vapour under heat generation at temperatures above 1000 °C. By adding hydrogen, a sustainable syngas can be produced after further processing and purification. The electrolysis platform that is currently emerging in Leuna as another Fraunhofer IMWS pilot plant will provide the hydrogen and oxygen necessary. Here the elements are produced through electrolysis, using electricity from renewable energies. CarbonDemonstration thus ultimately performs chemical recycling and closes the carbon cycle: carbon is not burned in order to pollute the environment as CO^2, but used for other material compounds.

Complete Elimination of Trace Substances from Waste Water

Pharmaceutical residues in waste water pose new challenges for municipal water treatment. Usually, they are difficult to remove with conventional sewage plant and water treatment technology. With the help of electrochemical processes, pharmaceutical residues can be completely degraded. They are electrochemically converted at the anode of an electrolysis cell, leaving only carbon dioxide. However, the anodes made of boron-doped diamond are extremely expensive.

Fraunhofer IKTS is pursuing two approaches in order to manufacture the electrodes more cost-efficiently and increase the degradation rates. On the one hand, an alternative noble-metal-free anode material of semiconducting mixed-oxide phases was developed. On the other hand, the waste water is induced to oscillate by means of ultrasound in order to intensify the mass transport at the electrode and thus reach even higher degradation rates. This is achieved by minimizing the thickness of the diffusion layer on the anode. The layer acts as a kind of reaction barrier and thus slows down their destruction. Not only is the process combination sophisticated, but also the design of the corresponding electrode-sonotrode module. The innovative approach consists of pressing the ultrasonic sensors directly onto the ceramic electrode so that it vibrates like a spring. This greatly improves material transport to the electrode. In the future, the electrode-sonotrode module will also be used in other sectors, such as the destruction of nitroaromatics, plasticizers, herbicide residues or other toxic substances in commercial waste water.

Electro-chemical process laboratory. © Fraunhofer ISC

Electro hydraulic fragmentation device at IWKS: phase selective separation of recycling goods. © ImpulsTec GmbH

Energy Storage – from Material Development to Recycling

The efficient and secure storage of electric energy is a major technical challenge and an important prerequisite for the sustainable success of portable and stationary energy supply systems. These, for example, are necessary for the expansion of regenerative energy usage and electromobility. The development of new materials for high-performance batteries and work on efficient battery concepts play an important role. Moreover, established and cost-effective systems such as lead-acid batteries also have a great potential for stationary energy storage and automotives (start-stop automatic and mild hybrid vehicles) by improving their lifespan and performance, e.g. with dynamic loading and in partially charged conditions. Intelligent recycling methods and the reprocessing of certain components (»second life«) are additionally increasing in significance with regard to the efficient use of raw materials. Competent contact persons from the Fraunhofer R&D Center of Electromobility of the Fraunhofer ISC and the Research Institution Materials Recycling and Resource Strategies IWKS are available for all aspects on the topic of energy storage.

Battery Materials and Components

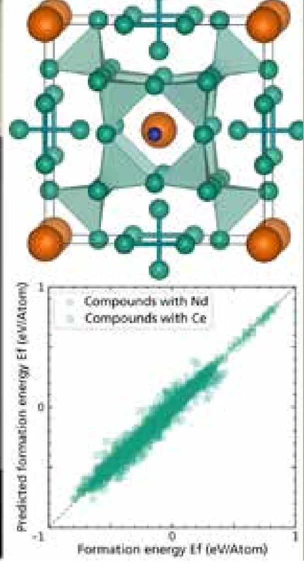
In the field of material research the focus is on the development of components for energy storage of current and future generations, as well as the manufacturing and processing of these components up to pilot plant scale for electrochemical energy storage systems such as:

- Lithium-ion batteries (LIB) – including the modification of high-energy cathodes (lithium-rich layer-oxides) and anodes (silicon-based), solid electrolytes
- Metal-air batteries – including catalyst development, boundary layer design
- Lead-acid batteries – including additives for electrode masses
- Solid state batteries
- Double layer capacitors – LIB supercapacitor
- Sodium-based technologies – including sodium-air cells
- Material characterization and testing

The performance and resistance of battery components and systems are examined in an excellently equipped electrochemical test environment. This enables, among other things, battery charging and unloading cycles on over 200 channels from the femtoampere up to the kiloampere range under controlled climate conditions. Aging processes that lead to a decrease in performance can thus be simulated under defined conditions and used for material optimization. A specialized post mortem analysis, as well as electron microscopy accredited according to DIN EN ISO / IEC 17025-2005 with a unique micro laboratory in the scanning electron microscope, enable precise analysis on micro and nano levels.

Battery Recycling

The Research Institution IWKS within Fraunhofer MATERIALS is developing new and intelligent methods for the appropriate and energy-efficient recycling of electrochemical energy storage systems, particularly for lithium-ion batteries. The safe and efficient fragmentation and separation of the individual components are particularly important. The materials should not just be recovered on an elemental level but preferably in the form of an already synthesized compound. Either an equivalent or an even better functioning of the recycled material is required for this process along with cost neutrality compared to conventional raw materials and greater environmental friendliness and economic efficiency compared to common metallurgical methods.



With the aid of the »MagnetPredictor« tool, magnetic material properties of combinations of rare earth elements, transition metals and other elements can be predicted. © Fraunhofer IWM

cerenergy® – Environmentally friendly and cost-efficient ceramic batteries for stationary energy storage. © Fraunhofer IKTS

Material Property Prediction with the Aid of Machine Learning

There is an infinite range of possibilities: if a tiny amount of a material is replaced with another element, it can fundamentally change the material properties. Nevertheless, the resulting properties obey the laws of physical interrelationships, making it possible to »sound out« materials for the properties that are required – an extremely time-consuming enterprise with the trial-and-error method that has been until now used as the standard.

A machine learning tool developed by the Fraunhofer IWM is now making it possible to predict the ferro-magnetic crystal properties of material compounds easily and quickly to, for example, develop magnets. Permanent magnetic materials are required for electric automobiles and windmills with only small proportions of rare earth metals. The »MagnetPredictor« high-throughput simulation method systematically checks a multitude of conceivable material variants in relation to the question »are these materials suitable as permanent magnets?« This approach results in some very promising compounds and reduces the number of experimental investigations. The information required here is straightforward: it relates to the crystal structure of the material and the chemical elements contained within. The results have been verified using familiar magnetic materials: the simulation determines the magnetization and magnetic anisotropy of a new material extremely accurately. The procedure works not only for magnetic characteristics, but in principle for other material properties, too.

In addition, it is possible to apply the procedure in reverse, as it were, and specify the minimum requirements of a desired material. For example, magnetization and »preferably cheap copper rather than scarce cobalt«. An optimization algorithm then delivers the best possible elemental composition for the material in the context of the »machine learning« material model.

cerenergy® – Environmentally friendly and cost-efficient Stationary Energy Storage

Successfully transforming and advancing our energy supply system to make it sustainable is one of the most important tasks in the 21st century. The growing global energy demand and ever-increasing peak loads make reliable solutions necessary. Cost-efficient energy storage can help renewable and non-renewable energy production methods to converge and provide affordable long-term supply security. The ceramic high-temperature battery cerenergy®, developed by Fraunhofer IKTS, was optimized for series production capability and low costs by modern ceramic methods.

Batteries based on sodium nickel chloride were seen as early as the 1980s, in applications for electric vehicles. In the search of cost-efficient, long-lasting and reliable stationary energy supply solutions, researchers from Fraunhofer IKTS are now revisiting and re-evaluating this technology. The characteristic feature of this type of battery is that it uses exclusively local raw materials, such as nickel, alumina and common salt. This makes the batteries ecologically sustainable. Furthermore, the researchers were able to reduce the costs significantly. The key for this remarkable development is found in the core of the high-temperature batteries – the ceramic electrolytes from beta aluminate, whose design and manufacture determine the technology's cost and functionality. The Fraunhofer IKTS' ceramic production and synthesis route includes preparing the ceramic powder and processing the beta aluminate, thus achieving a fully ceramic technology ready for large-scale production – for a truly modern form of energy storage.

Redox low battery.
© Fraunhofer ICT

Redox Flow Batteries for the Storage of Renewable Energy

Energy provided by sun and wind rarely corresponds to the actual demand at a given point in time. This is the reason why the storage of electrical energy, particularly for large-scale application, has become one of the greatest challenges in energy technology. A better adaptation of stored reserves to changing needs is economically possible, particularly when decentralized storage facilities with a cost-effcient battery capacity are implemented.

The power output and energy of redox flow batteries can be individually scaled, enabling decentralized energy storage in the range of a few kilowatts up to several megawatts. The advantages of this type of battery are the large and fexible storage capacity, potentially low storage costs as well as a long lifespan. The current state of the art is the storage of surplus energy in lead accumulators. However, these only last for a limited number of cycles and usually have to be replaced after three to fve years. Depending on the chemistry, redox flow batteries have a comparable energy density; however, their life span is several times greater than that of lead accumulators.

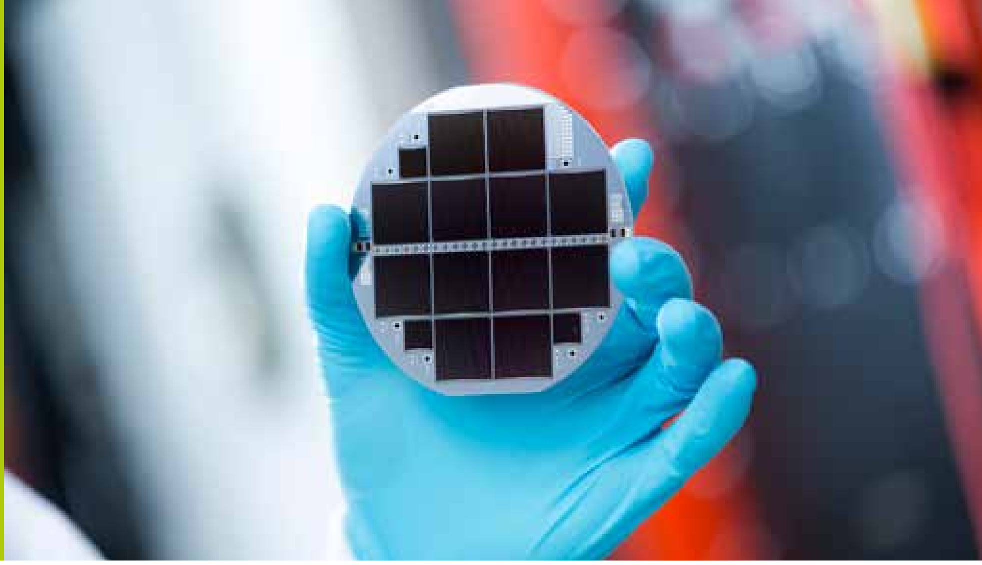
The principle of redox flow batteries is the storage of chemical energy in dissolved redox pairs in external tanks. Power conversion takes place in a separate power module. During discharge the electrodes are continuously supplied with the solutions from the storage tanks, and the resulting product is discharged into the same tanks. Charging can be carried out by simply reversing the direction of the current. This type of storage could be used for hourly storage in large applications of several megawatts, since the storage capacity is largely determined by the amount of electrolyte solution, and the effciency is over 75 percent.

Redox flow batteries have been developed and researched at Fraunhofer ICT since 2006. In the area of materials, research focuses on active substances such as electrolyte formulations as well as the modifcation of electrodes and membrane material. In order to manufacture cell stacks more economically, high- performance carbon-polymer composites for electricity conductors - so-called bipolar plates - are developed at Fraunhofer ICT. In addition to the membranes, these materials are the current cost drivers of flow batteries. In addition, methods are being developed for the characterization and classifcation of materials. This enables the comparison of different redox flow batteries and their materials in one installation, in order to evaluate the advantages and disadvantages of each system.

The objective of the large-scale RedoxWind project is the practical implementation of a redox flow battery within an existing electricity network, for the storage of fuctuating energies from wind or photovoltaic parks. A redox flow battery with a performance of 2 megawatts and storage capacity of 20 MWh is being developed at the institute for this purpose. A 2-megawatt wind turbine with a hub height of 100 meters is being built directly next to the large battery to supply electricity. This system will be integrated into the institute’s network to supply different consumers.

Advances achieved by Fraunhofer ICT compared to the state of the art:

- Modular concept of a large-scale storage system in megawatts / megawatt hours
- Cell frame design and production in polymer injection molding suitable for large-scale use
- Cost-optimized, highly conductive polymer carbon composites as bipolar plate materials for new production technologies (e. g. 2-component injection molding)
- Flow battery certifcation according to IEC standards
- Optimized electrolyte formulations for vanadium and bromine systems; development of specifcations and special analytics
- Development of demonstrators for special applications, e. g. hybrid storage as an uninterruptible power supply (UPS) with low self-discharge.



Multi-junction solar cell made of III-V semiconductors and silicon. The record cell converts 33.3 percent of the incident sunlight into electricity.
© Fraunhofer ISE/Dirk Mahler

High Efficiency Solar Cells based on Silicon or III-V Semiconductors as well as Tandem Solar Cells

Silicon Solar Cells

Silicon solar cells dominate the photovoltaic market today. Research and industry are continually working to optimize the cell efficiency and are moving increasingly closer to the theoretical efficiency limit of the material. Fraunhofer ISE holds the current world record of 22.3 percent for multicrystalline silicon solar cells. The key to this achievement was the holistic approach, enabling the optimization of all steps from the crystallization up to the singular solar cell processing. An optimized plasma texture and a so-called Tunnel Oxide Passivated Contact Technology (TOPCon) developed at Fraunhofer ISE for back side contacting played an essential role. With the TOPCon technology the electrical contacts are applied over the entire rear surface of the cell without patterning. This reduces charge-carrier losses and leads to much higher conversion efficiencies.

For monocrystalline silicon solar cells, Fraunhofer solar cells achieved a first-time efficiency of 25.7 percent of a both-sides contacted silicon solar cell, due to the TOPCon technology.

III-V Solar Cells

Fraunhofer ISE also holds the international record for the highest photovoltaic efficiency overall of 46.1 percent for its III-V concentrator multi-junction solar cells. This record cell is based on a combination of different III-V semiconductor compounds, e.g., gallium-indium-phosphide (GaInP), gallium-indium-arsenide (GaInAs) or germanium (Ge). Each semiconductor converts a different wavelength range of sunlight into electricity. Working together the sub-cells achieve an extremely high cell efficiency. Originally III-V multi-junction solar cells were used in space for supplying power to satellites, an application that Fraunhofer ISE is still working on today. On Earth, large concentrator power plants, which combine III-V solar cells with concentrating optics are a typical application.

Tandem Solar Cells

To create even more efficient solar cells, researchers at Fraunhofer ISE forged new paths in combining their expertise in silicon and III-V materials research. They succeeded in creating a silicon-based multi-junction solar cell with 33.3 percent efficiency with a simple front and rear contact. The high conversion efficiency of the silicon-based multi-junction solar cell was achieved with extremely thin 0.002 mm semiconductor layers of III-V compound semiconductors, bonding them to a silicon solar cell. The visible sunlight is absorbed in a gallium-indium-phosphide (GaInP) top cell, the near infrared light in gallium-arsenide (GaAs) and the longer wavelengths in the silicon subcell. In this way, the efficiency of silicon-based solar cells can be significantly increased.

The photovoltaic researchers used a well-known process from the microelectronics industry called »direct wafer bonding« to successfully transfer III-V semiconductor layers, of only 1.9 micrometers thick, to silicon. After plasma activation under high vacuum, the surfaces were bonded together under pressure. The atoms on the surface of the III-V sub-cell form bonds with the silicon atoms, creating a monolithic device. The complexity of its inner structure is not evident from its outer appearance: the cell has a simple front and rear contact just as a conventional silicon solar cell and therefore can be integrated into photovoltaic modules in the same manner.

In-situ filling of a printed perovskite solar cell at Fraunhofer ISE. The perovskite is filled into the solar cell as a molten salt and then crystallized in the solar cell. The amount shown in the photo (2 ml) is sufficient to produce a module of four square meters.
© Fraunhofer ISE

Organic und Perovskite Solar Cells

Organic Solar Cells

Organic semiconductors are used to convert sunlight into electricity. These materials can be applied to flexible substrates in a continuous process at low temperature with high-throughput. The manufacturing costs are almost exclusively dictated by the material costs. The singular layers of the cells have a thickness of 100 nm, therefore the material demand remains below ca. 1 gram pro m². With upscaling, a large potential for cost reduction is to be expected. In spite of efficiencies of over 11 percent, further advances are still necessary. Fraunhofer ISE has set the following goal: The ITO used for the transparent electrode shall be substituted by another material, which also brings high efficiencies, is cost-effective and remains stable over a long period of time. The material shall also be compatible with roll-to-roll processing.

Perovskite Solar Cells

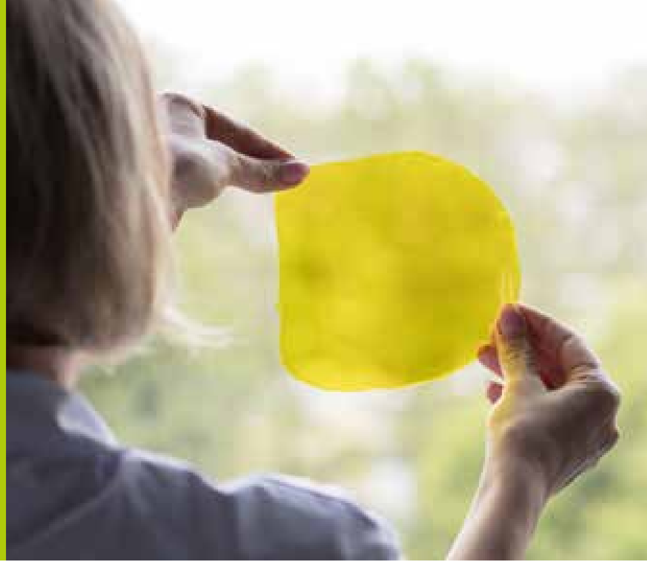
An innovative approach to fabricate solar cells even more resource-friendly is to reduce the number of production steps by reversing the manufacturing process. For this purpose, Fraunhofer ISE developed the in-situ concept for printed Perovskite solar cells. With a record efficiency of 12.6 %, an important milestone has been achieved for printed photovoltaics. Being able to control the deposition process of the perovskite crystallites within the nanoporous electrode, made of metal oxides and micronized graphite, is a decisive factor for the cell efficiency. New is the process used by the Fraunhofer researchers to fill the otherwise completed cell with perovskite and the subsequent crystallization.

Fast and cost-effective Testing Device for Potential-induced Degradation in Solar Modules

Potential-induced degradation (PID) is one of the most common causes of performance deficits in solar modules based on silicon solar cells. This severe defect particularly occurs when solar modules are operated in a damp environment with high voltage. At Fraunhofer IMWS, the physical processes were investigated until the root cause of the defect mechanism was understood: Crystal defects cause short-circuits (shunts) in the silicon, which occur in PID. These crystal defects are called stacking faults. They are only a few micrometers long and are only one atom layer thick. Due to the penetration of sodium atoms, they become electrically conductive, so that short circuits occur. Based on this fundamental understanding of the PID effect, a test method at cell level was developed at Fraunhofer IMWS and patented. The test procedure and the device that derived from it generate PID in the lab, so that its influence on solar cells or encapsulation materials can be investigated. Freiberg Instruments further developed this test method to »industrial maturity« as a licensee. The »PIDcon« device can now be used to check solar cells for their susceptibility to PID in a simple procedure, with significantly less material, energy and cost than in the conventional test method. Freiberg Instruments also supported Fraunhofer IMWS in developing »PIDcheck«. This mobile device makes it possible to efficiently test for PID in modules that are already installed. With the goal of quantifying possible power losses under the influence of PID for operators of solar power plants, Fraunhofer IMWS works on the use of »PIDcheck« in the field for predicting future degradation and evaluating countermeasures.

Quantum dots produce extremely brilliant colors. © Fraunhofer IAP / Till Budde

The novel proton-conducting membranes can be used in the decentralized, electrochemical production of hydrogen peroxide. © Fraunhofer IAP



High efficiency cadmium-free Quantum Dots for QD-LEDS and Solar Cells

Quantum dots (QD) and quantum rods (QR) are a class of nanomaterials that utilize quantum effects to emit light. This enables them to be used to efficiently generate extremely brilliant colors. Their absorption and emission properties can be uniquely adjusted by altering particle size or shape. The surface of the particles can be modified in order to adapt them to the chemical environment. The materials can be produced so that they emit both in the visible and infrared spectrum. These extraordinary properties enable them to be used in a wide variety of applications, for example as phosphors in display technology, to convert light to higher wavelengths in photovoltaics, as sensor materials, or as security features on banknotes.

Until now, QDs have contained cadmium which is a toxic heavy metal. The Fraunhofer IAP therefore synthesizes cadmium-free QDs that are just as powerful as the QDs containing cadmium and which achieve high quantum yields. They are based, for example, on environmentally friendly indium phosphide or zinc sulfide and can be used as fluorescent materials for LEDs, as an emitter material in QD LEDs, as color filters in displays and for the LED backlighting of LCDs. Infrared active QDs based on copper indium phosphide can also be deployed as solar concentrators to increase the efficiency of solar cells.

Continuous flow reactors allow up to several grams of QDs to be produced per hour. These can then be inkjet printed onto solid and flexible substrates using ink formulations. The Fraunhofer IAP has both a »printer farm« and a pilot plant for producing QD LEDs and solar cells.

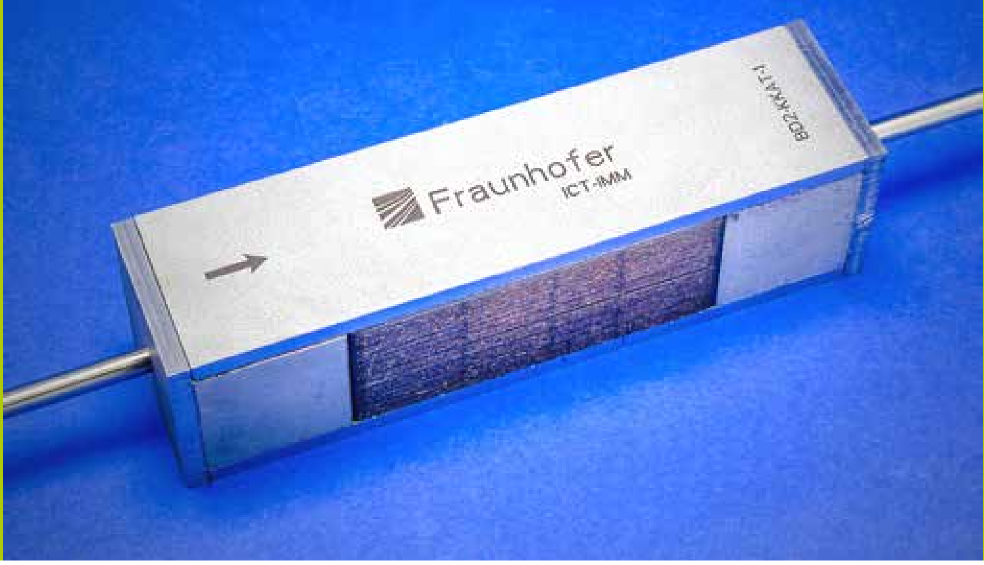
Environmentally friendly Proton-Conducting Membrane for Electrolysis and Fuel Cells

Using electrochemical processes to produce basic chemicals allows a long-term reduction in costs and enables the energy system to be tied to chemical production. Ion-conducting polymer membranes are an important component of electrolysis and fuel cells. Perfluorinated polymers, such as Nafion®, have some drawbacks: high costs, loss of proton conductivity over time at temperatures above 80 °C, issues with oxidation stability and thermostability, and the problem of fluorine escaping into the environment.

The Fraunhofer Institute for Applied Polymer Research IAP has developed a completely new concept for producing inexpensive and environmentally friendly ion-conducting membranes for electrolysis and fuel cells. The membranes can be used, for example, in the decentralized, electrochemical production of hydrogen peroxide.

Based on polyphenylquinoxalines, new block copolyphenylquinoxalines (BPPQs) have been produced by way of polycondensation which subsequently undergo sulfonation. The sulfonated BPPQs display excellent solubility in organic solvents and excellent thermostability. The membranes can be produced on a laboratory scale and are mechanically very stable. They also exhibit high oxidation stability and have state-of-the-art proton conductivities of 1 mS/cm. Compared to Nafion® (over 70 percent fluorine), the fluorine content has been drastically reduced to about 5 percent.

The membrane was developed by IAP researchers as part of the Fraunhofer's lead project »Electricity as a Raw Material«, which seeks to develop new electrochemical processes and to optimize existing processes for the production of important basic chemicals.



Reactor for biodiesel synthesis under supercritical reaction conditions. © Fraunhofer IMM

Manufacture of Biodiesel in a Supercritical Process – New Process Promises increased in Efficiency, Environmental Benefits and Cost Reduction

In this project, which is financed by the Energy and Climate Fund of the Federal Government via the Agency of Renewable Resources (FNR), the usual transesterification of vegetable oils that takes place during the manufacture of biodiesel is carried out using supercritical methanol. Instead of the homogeneous catalysts used otherwise, Fraunhofer IMM relies on innovative heterogeneous catalysts that are applied as a coating in microscale reactors.

Supercritical defines the thermodynamic state of substances at and beyond of a specific constellation of temperature and pressure, in which the properties of liquids and gases merge without phase separation.

A small laboratory plant is to be tested that manu- factures biodiesel from different vegetable oils at considerably higher reaction rates. Due to the supercritical process management the reaction time is reduced. At the same time, several process steps such as the recovery of the homogeneous catalyst become redundant. Thanks to the new concept, transesterification rates are being increased, while the reactor size as well as water consumption are reduced. The sensitivity of the process against traces of water in the raw material decreases.

Besides this, the lower demand of methanol, the higher purity of the by-product glycerin and the long-term stability of the catalyst are expected advantages. When replacing methanol by ethanol, the already improved environmental compatibility can be increased even further. Although the process takes place at high pressures and temperatures, process optimization ensures a total energy consumption which is significantly lower compared to conventional methods. The supercritical process offers great economic potential.

Demonstration plant © Fraunhofer IMM

Leading Edge Protection

The rotor blade tips of a wind turbine reach speeds in excess of 300 km/h in full load operation. At this speed, raindrops act on the surface like sandpaper. Even slight damage causes the surfaces to become rough at certain points, which reduces the aerodynamic efficency and thus affects the economic efficiency and the service life of the whole turbine.

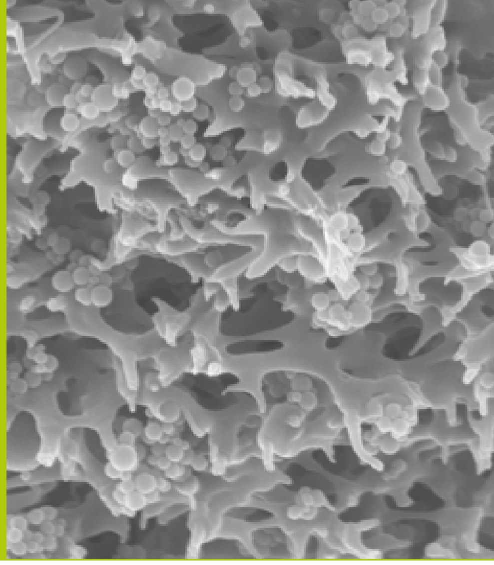
The parts which are very seriously affected such as the leading edge of the wind turbine blade are therefore equipped with special protection systems, for example films or coatings – known as Leading Edge Protection (LEP). The problem: there is still no protection system which can survive rain, hail, temperature fluctuations, UV light, and humidity over the whole service life of a turbine. Hence, Fraunhofer IWES has been operating a rain erosion test bench since 2015 to better understand damage processes and derive effective protection measures. On the rain erosion test bench, substrates with different coatings are tested under a variety of conditions. The number and size of the drops, the point in time and frequency of the impacts, the temperature, and the UV irradiation can be controlled very precisely.

A droplet impact system that can detect the position and the impact energy of the droplet strikes is currently under development. The complete test bench will be reproduced in a CFD simulation and the damage events will be documented with a laser-based inspection system and a high-speed camera. Also documented are the topology of the samples, and damage in the micrometer range. Developing a suitable material and damage model makes it easier to understand the processes on the material level. The results assist suppliers providing material for the rotor blade production to achieve optimum adaptation of their products to the practical demands. In 2018, the erosion test bench was expanded such that ice accretion tests can be carried out with a high degree of reliability.

Equipment: Max. speed: 550 km/h, Temperatures: 4°C to 40°C, Variable drop size: 1.5 to 5.5 mm © Jan Meier

Test bench lighthouse »Alte Weser« with corrosion samples in the coastal shipping sector. © Fraunhofer IFAM

Mixed-matrix membrane adsorber. © Fraunhofer IGB (guest institute)



The Sea and the Rust: Coatings for Maritime Technologies

The maritime environment places high demands on technical surfaces. Constant humidity in combination with a high salt content, intensive UV radiation and changing temperatures poses a particularly aggressive corrosion load for all protective systems. Incomplete corrosion protection leads to limited service life or premature failure of the component or structure, resulting in cost-intensive repairs. Based on many years of development work, the experts at Fraunhofer IFAM have sound knowledge and practical experience in the field of corrosion protection.

The know-how comprises not only special expertise on corrosion types and phenomena, but also on the application of suitable, preventive protective measures. High demands are placed on these corrosion protection measures. The specialists at Fraunhofer IFAM provide comprehensive advice and practical support through technical services and application-oriented research. The technical contacts are certified according to FROSIO or DIN CERTCO and their expertise is recognized both nationally and internationally.

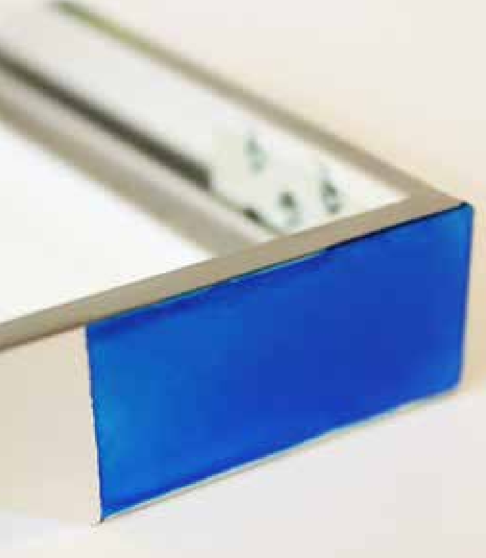
In addition to corrosion, the colonisation of surfaces by marine organisms such as bacteria, algae, mussels and barnacles leads to further functional restrictions of surfaces and the destruction of materials. In order to meet these challenges competently, Fraunhofer IFAM offers extensive possibilities for investigations and tests in the laboratory and in the field. These include atmospheric outdoor weathering and a static fouling test rig for the storage of samples in the sea to test the anti-fouling properties of coatings.

Membrane Adsorber for the Separation of Micropollutants and Metal Ions

If filtration and adsorption are combined in one unit, a so called membrane adsorber results. This concept was introduced mainly for downstream processing in biotechnology to separate low concentrations of small molecules by microfiltration, where only small pressure must be applied. Our aim is to transfer this concept for the treatment of water to separate low concentrations of micropollutants and to close material cycles within production processes.

Our concept is the development of nanoparticles with specific binding sites for different substances. Tailor-made membrane adsorbers can be designed by embedding such particles in membranes. We prepare such particles by miniemulsion polymerization. For the separation of metal ions we developed particles with ion exchange capabilities, Sulphur containing thiourea groups and chelating groups. With such membrane adsorbers valuable metals such as silver, copper or rare earth can be separated.

Adsorption experiments with micropollutants showed that particle-loaded membranes have a higher adsorption capacity in comparison to the blank membranes. In addition, it was demonstrated that the membranes are completely regenerated by a pH shift and therefore can be used multiple times. The prepared membranes show a flux rate as microfiltration membranes and have the capability to selectively adsorb substances with different physico-chemical properties in one step. This concept will be further advanced and will be combined with an additional coating of the porous structure of the membrane to come to an improved flexibility and an increased selectivity. This will be done in the project POLINOM funded by BMBF.



Interior aluminum surfaces can be cost-effectively coated with potato starch-based paints. © Fraunhofer IAP

Production of high-quality biowaxes from biogas using Fischer-Tropsch synthesis. © Fraunhofer IKTS

Coatings and Paints based on Potato Starch

Until now, coatings and paints that use biobased binding or film forming agents have been too expensive or unable to meet application requirements. Researchers at the Fraunhofer Institute for Applied Polymer Research IAP and the Fraunhofer Institute for Manufacturing Engineering and Automation IPA have developed a cost-effective coating based on potato starch. Research has focused on coating metal, for example aluminum, that is used in interior applications such as fire doors, computer cases and window frames.

In its natural form, however, starch has some properties that prevent it from being used as a film forming agent: for example, it is neither soluble in cold water nor does it form coherent, non-brittle films. Therefore, the starch had to be modified. First the starch was degraded which improved its solubility in water and the subsequent solid content of the starch in water, as well as its film-forming capabilities.

Next the starch was esterified. The starch esters were water dispersible, formed cohesive films and adhered well to glass and aluminum surfaces. In cooperation with the Fraunhofer IPA, the esterified starch was then chemically crosslinked which further reduced the coating's sensitivity to water. Stability tests were also carried out at the Fraunhofer IPA to test its long-term stability.

The investigations have shown that starch esters are set to become a possible alternative to petroleum-based film forming agents in the coating industry thanks to their good film formation properties and excellent adhesion to various materials.

Waxes from Biogas for the Cosmetics Industry

Biogas is usually converted into electricity or biomethane and fed into the respective grids. Since the feed-in rates are determined mostly by the prevailing funding policy, the 8000 existing biogas plants in Germany have strong incentives to find new ways to operate profitably without having to rely on state funding.

The use of biogas to produce high-quality chemical products is one potential alternative. Biogas consists of methane and carbon dioxide. Until now, carbon dioxide has mostly been classed as a waste product, although it can also be used to synthesize various kinds of waxes. The pertaining process involves producing syngas at very high temperatures and with the help of ceramic-based catalytic converters. Using a Fischer-Tropsch synthesis, the syngas is then used to synthesize high-quality, organic-grade wax.

Thanks to their high purity, theses waxes are of particular interest for the cosmetics industry. They enable lucrative potential applications, in particular for the natural cosmetics sector. Furthermore, biowaxes can also be used as lubricants. The purity of these waxes means that a defined product composition – and thus reliable product properties – can be guaranteed at all times, to a degree not offered by petroleum-based lubricants.

The three-year project, funded by the development bank SAB, was an in-depth investigation of this promising approach. The focus was, in particular, on the design and operation of a demonstration plant for wax production connected to a biogas plant. The process data received were used to evaluate and prove the economic viability of the approach.

Rotor blades, solar modules and winter sports articles can be equipped with anti-icing coatings. © Fraunhofer IGB (guest institute)

Flexibly configurable test rig to characterize and investigate single-tank storage concepts based on molten salt for temperatures up to 550°C. © Fraunhofer ISE/Dirk Mahler

Anti-Ice Coatings

The icing of surfaces is a widespread problem. The Fraunhofer Institute for Interfacial Engineering and Biotechnology uses plasma technology to apply water resistant micro- and nano-structured coatings to polymer films made of impact and shockproof polyurethane (PU) or other material surfaces for effective anti-icing.

The coatings, only a few nanometers thick, change the wetting process of surfaces in that the water is repelled from the surface. This way the water remains fluid on the coated surfaces even at temperatures below zero degrees since the coatings prevent the formation of crystal nuclei, thus leaving the water in a super-cooled state.

In ice chambers at temperatures of minus 30 degrees it can be seen that the anti-ice coating reduces the adhesion of ice by more than 90 percent. The coating is weather-resistant, dirt repellent and easy to clean in addition to being environmentally friendly and inexpensive to manufacture.

Flat materials like textiles and three-dimensional moldings up to a certain size with surfaces made of different materials like lacquers, metals and polymers can be directly coated.

Even the anti-icing of outdoor and winter sports articles such as ski goggles, winter sportswear and tents or rucksacks is possible with this method.

Functionalized films can be applied to aircraft wings, rotor blades of wind turbine plants, solar modules, overhead electric lines, buildings parts and facades, and even on sports equipment such as skis and snow boards. Anti-ice films can also be easily applied to cooling units or in refrigerators and can be replaced any time.

Single Tank Molten-Salt Storage Saves Space as well as Costs

Solar thermal power plants coupled with high-temperature storage allow the decoupling of solar radiation and power generation, thus providing a dispatchable electricity generation and supply. The energy generated during the day can be dispatched during peak consumption which occurs in the evening.

Fraunhofer ISE developed a single-tank molten-salt storage system based on the stratified layer principle, as an alternative to the two-tank system, the current standard in solar thermal power plants. The single-tank system saves both costs and space. In particular, saving space is interesting when storing waste heat from industrial processes. In comparison to other storage media such as thermal oil, molten salt is cheap and can be stored unpressurized up to 600 °C depending on the mixture.

The Fraunhofer researchers investigated the stratification behavior and the effect of different factors. A large density difference promotes the separation into hot and cold fluid layers. The relative density difference for molten-salt systems is significantly higher than for hot water systems. This can lead to a good storage performance. To achieve further cost reductions, the use of cost-effective filler materials and their compatibility with the salts will be investigated.

This technology was implemented in the new MATS power plant installed in Borg El Arab, Egypt. The 1 MW solar thermal power plant has a collector field of 10,000 m². A particular feature of the MATS plant is the single-tank storage. Both hot and cold (290°C) salt are stored in stratified layers in a single tank. The steam generator is integrated in the storage tank, which reduces the investment costs. The plant meets the electricity demand of more than 1000 people and provides water desalination up to four hours after sunset.

Figure 1 The new high-speed helicopter Racer.
© Airbus Helicopters

MOBILITY

Bird-Strike Simulations for the New High-Speed Helicopter »Racer«

At the Paris Airshow, Airbus Helicopters presented a model of its new high-speed helicopter »Racer« on June 17, 2017 (Figure 1). The Racer demonstrator is being developed within the EU aviation program Clean Sky 2 and is scheduled for its first flight in 2020. Racer, which is short for Rapid And Cost-Effective Rotorcraft, will incorporate several innovative features for attaining a very wide cruising radius and a high cruising speed of over 400 kilometers per hour at very low fuel consumption. This new type of high-speed helicopter is supposed to be deployed for search and rescue missions, emergency medical services as well as public and private supply and transportation flights.

Fraunhofer EMI provides Basis for Flight Permit

For Racer's first flight in 2020, a flight permit is required, for which Racer has to meet the demands according to EASA standard CS-29. Inter alia, you have to ensure the safe progression of the flight or safe landing after collision with a bird of mass 1 kilogram. Statistical data substantiate the necessity of this: Every year, several 10,000 collisions of birds with aircraft occur worldwide. They cause high economic losses and can sometimes even lead to safety risks, as the New York incident in 2009 shows, when an A320 had to carry out an emergency landing on the Hudson River. Because of the lower flight level, helicopters are more often affected by bird strikes than airplanes.

Fraunhofer EMI conducted the simulations necessary to provide this evidence. Airbus Helicopters provided the relevant data, and from these, a finite-element model (FEM) of Racer was generated. Using this model, it is possible to simulate bird strikes at various locations of the helicopter and estimate their effects.

Creating the Numerical Model

For realistic simulations of bird-strike impact, a validated model of a bird had to be created. This happened in a simplified manner as the exact numerical reproduction of the animal would have been a quite considerable effort. Details of the bird body only play a minor role for damages caused by impact, anyway. That is why birds are usually modeled as simple geometrical

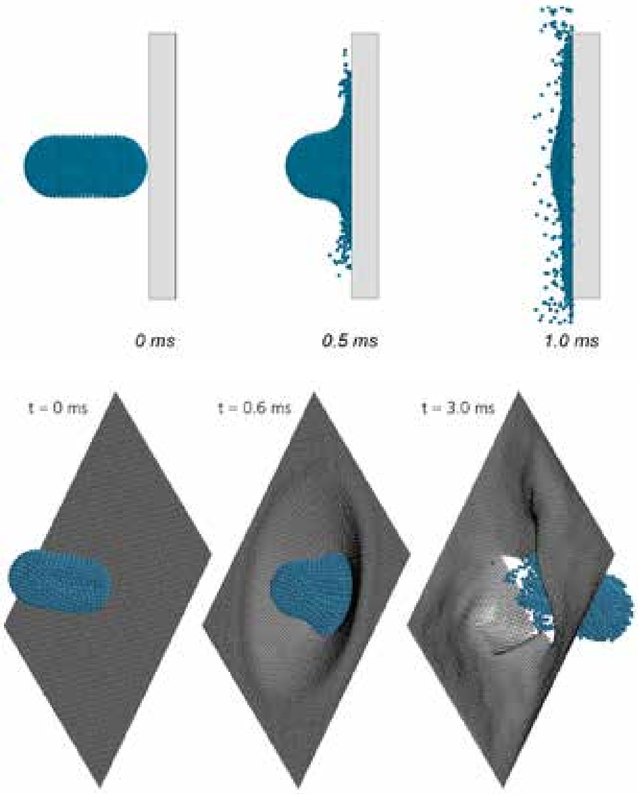


Figure 2 Simulation of a bird impacting onto a steel plate (top) and a polycarbonate plate (bottom) for the validation of the SPH (smoothed particle hydrodynamics) bird model. © Fraunhofer EMI

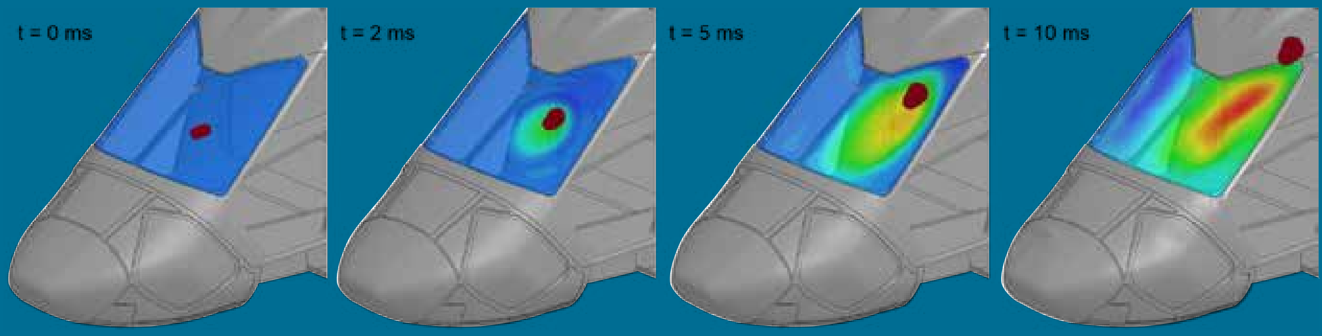


Figure 3 Simulation of a bird colliding with a polycarbonate windshield at 460 kilometers per hour. In the red area, the shield deforms up to 17 centimeters without breaking. © Fraunhofer EMI

forms such as spheres or ellipsoids. Simulation at EMI resorted to the common form of a cylinder with semispherical ends. The bird model was discretized by the SPH method (smoothed particle hydrodynamics). Given the high deformations occurring at impact, this method shows many advantages over classical FE methods with regard to stability and computing time. When subjected to high velocities relevant during a bird-strike event, the material strengths are exceeded by far implying that the material can be modeled by assuming a simple fluid such as water.

To validate the generated model, in a first step, open-access data published by the Air Force Materials Laboratory during the 1970s were used. Experiments in those times included real chickens as well as surrogate bodies made of gelatin impacting on a steel plate where the occurring pressures were measured. In a second step, Airbus Helicopters supplied EMI with recent measurements. In this case, gelatin birds were shot against polycarbonate plates. Both types of experiment were emulated in simulation (Figure 2: top: steel plate; bottom: polycarbonate plate) using the bird model. The computed pressures, forces and damages show high agreement with the experimental data.

Next, the FE model of the helicopter was prepared. For this sake, geometric data were cleaned up, simplified and connected. Then, the materials involved were modeled and the layer structure of the composite materials, the contacts and the boundary conditions were defined. In its final version, the FE model of Racer consists of more than half a million shell and hexahedron elements with edge lengths of about 10 millimeters to 15 millimeters. In spite of this high number of elements, the simulation of one bird strike takes only a computing time of about one to two hours on 16 central processing units.

Evaluation of Bird-Strike Resistance

The generated model made virtual bird-strike analyses for the high-speed helicopter Racer possible. Figure 3 shows, for example, the deformation of a polycarbonate windshield at collision and subsequent sliding-off of a bird with a relative velocity of about 460 kilometers per hour. Despite strong deformation, the shield stays intact.

The great advantage of using simulations is that it is easily possible to carry out adjustments on the computer concerning materials, wall thickness of components or change of collision point and velocity of the bird. Thus, various scenarios could be analyzed with regard to bird-strike resistance. Evaluation criteria included, for example, the potential perforation or breaking of components, the number of damaged layers of composites, the potential failure of adhesive layers or the residual velocity and the deviation of the bird toward critical structures. These analyses are essential for the preliminary design of the new helicopter. Fraunhofer EMI could identify vulnerable components and make suggestions for improvements. Thus, the work done by EMI is a valuable contribution to the development process of Racer and serves Airbus Helicopters to prove Racer fulfills the requirements for the flight permit.

For further information, visit www.airbus.com

Clean Sky 2

This project is funded by the European Union

This project has received funding from the Clean Sky 2 Joint Undertaking under the Europeans Union Horizon 2020 research and innovation programme under grant agreement No. CS2-Air-GAM-2016-2017-05.

Gesture-controlled prototype of a utility vehicle seat.
© Isringhausen GmbH & Co. KG

Gesture Control – Intelligent Man-to-Machine Interfaces

Modern utility vehicle seats help drivers to concentrate and drive long distances without tiring, while pneumatic vibration systems help protect them from damaging vibrations. The ergonomic shape and design as well as the correct positioning of the seats are important for optimal comfort. The Center Smart Materials CeSMa of Fraunhofer ISC has developed a contactless gesture control for the driver seats of trucks, with which it is possible to adjust the optimal seating position using only hand gestures.

Intuitive Contactless Communication

Research on professional truck drivers shows that individual seat positions can only be correctly made if the driver is familiar with all of the settings and if he can operate them intuitively. The new type of gesture control enables a number of intuitive adjustment and comfort functions with which the seat position as well as sections of contour configurations can be adapted to the individual needs and physical requirements of the driver. The seat simply follows the natural movement of the hand – there is no need to learn special gestures. If the seat needs to be elevated, the hand moves up; if it has to be moved forward, the hand moves forward. Further diagonal upward or downward gestures adjust the backrest and thigh support. A man-to-machine communication has thus been realized that is easy to learn and easy to operate. Operating errors can additionally be excluded electronically.

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Cost-effective Manufacture and Freedom in Design

An additional benefit: Factors like switches and buttons that can be damaged or soiled in daily operation are eliminated. This means a simplification of the seat structure and, therefore, lower production costs. In addition, individual seat positions of different drivers can be saved with simple movements and retrieved at any time when needed. The large-surface, buttonless control panel is located in an easily accessible area on the side of the driver seat – invisible under a covering. It is dirt resistant, robust and can be operated when wearing gloves. This opens up whole new areas of possibilities for the designers of seats and vehicles: Since all the components are located behind the plastic side cover of the driver seat, the outer shape and design of the side cladding for the operating side can be freely selected.

Hand Movements Trigger Switch Function

The side covering is furnished with electrodes for capacitive proximity sensors based on charge-transfer principles for the contactless gesture control of the vehicle seat. If a hand or finger come near the sensor field under the covering, the capacity changes and a switch function is triggered. The sensory information is recorded, processed and transferred in switch commands with hard and software developed by Fraunhofer ISC. The application of this operating concept is not limited to truck seats. The sensors are also suitable for seats in cars, trains or aircraft. The man-to-machine technology is also conceivable in housing technology, such as in the operation of window blinds or household appliances, or even in the operation of robots and machines via motion patterns in production technology.

Realized TRANSFORMERS trucks Hybrid-on-demand trailer (left), Load-optimization trailer. (right) © www.transformers-project.eu

TRANSFORMERS: Configurable Trucks for efficient Transport

The increasing freight traffic on Europe's roads requires improvements in truck efficiency. In the EU research project TRANSFORMERS, an international consortium has taken on this task. As part of the collaboration, Fraunhofer LBF developed a sensor system for measuring the load volume and a battery housing to supply an electric auxiliary drive in the trailer.

The TRANSFORMERS trailers enable a reduction in the fuel consumption of up to 25 percent, particularly for palletized goods. This is achieved by the mission-specific adaptation of the structure, an electric auxiliary drive installed in the trailer, an adjustable loading capacity and holistically optimized aerodynamics.

Load-Optimization Trailer

The Van Eck load-optimization trailer has an electric roof height adjuster, a load volume sensor and a double floor system. For example, if the maximum permissible mass of the trailer is reached without its volume being fully utilized, the roof can be lowered to reduce the aerodynamic drag. The current utilization is determined in each case by the sensor system developed by LBF for measuring the load height.

If, however, the maximum permissible mass has not yet been reached, pallets can be loaded one top of one another using the double floor system to fully utilize the maximum load height and thus increase transport efficiency.

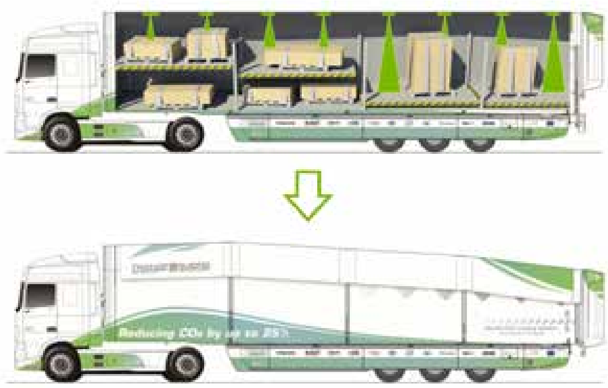
Hybrid-on-Demand Trailer

The Schmitz Cargobull hybrid-on-demand trailer has a manual roof height adjuster and a hybrid-on-demand drive with energy recovery. Similarly to the load-optimization trailer, the trailer's roof height can be adjusted to the actual load height to reduce the aerodynamic drag.

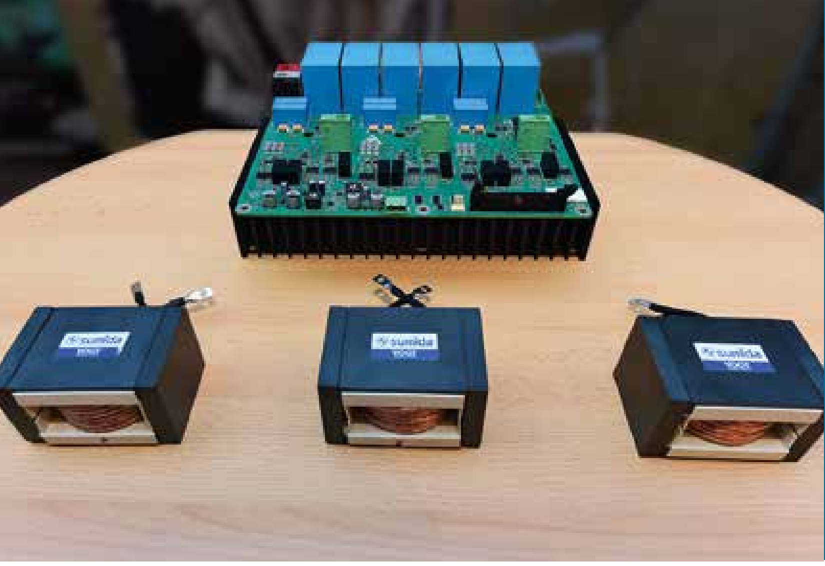
As a commonly named hybrid-on-demand system, the electric drive-train installed in the trailer ensures additional power is available at short notice, e.g. for overcoming uphill gradients or when starting. Similarly, braking energy which is otherwise lost can be recovered on downhill sections of the journey.

The battery with associated power electronics and the necessary cooling system must be securely fastened to the underbody of the trailer during operation and must be protected from environmental impacts (e.g. stone-chipping) in harsh everyday use. The robust housing necessary for this has been designed and constructed at Fraunhofer LBF and constitutes a mechanically reliable connection to the trailer.

The benefits of the concept lie in reduced fuel costs per ton-kilometer for the operator as well as lower CO2 emissions and a reduction in the risk of traffic jams on uphill gradients and in urban traffic.



Determination of the load height (above) and adjustment of the roof height (below) image: Fraunhofer LBF



Demonstrator of a 30 kVA photovoltaic inverter with SiC semiconductors, which can reduce the system's total weight by up to 50 %.
© Research project PV-LEO / Fraunhofer IEE

Save Materials by using Silicon Carbide Semiconductors

The physical properties of silicon carbide power semiconductors (SiC) make it possible to realise very fast and low-loss unipolar component concepts, such as MOSFETs or Schottky diodes, even for high blocking voltages, such as in photovoltaic inverters.

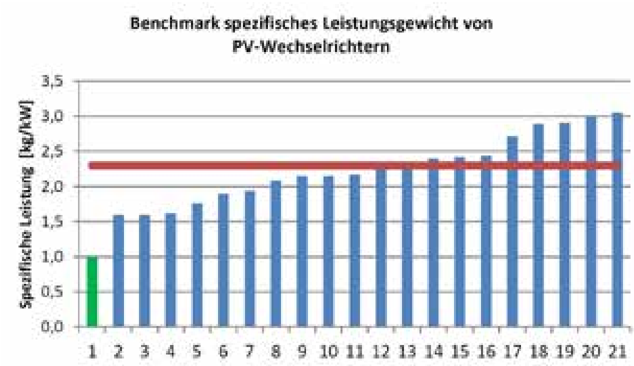
These properties allow for using inverter circuits with considerably higher clock frequencies while at the same time reducing losses. In the case of photovoltaic inverters, a significantly higher power density can be achieved, because the weight- and cost-determining magnetic elements can now be designed much smaller. The dimensions of the heat sink, as another volume-increasing element, can be reduced as well.

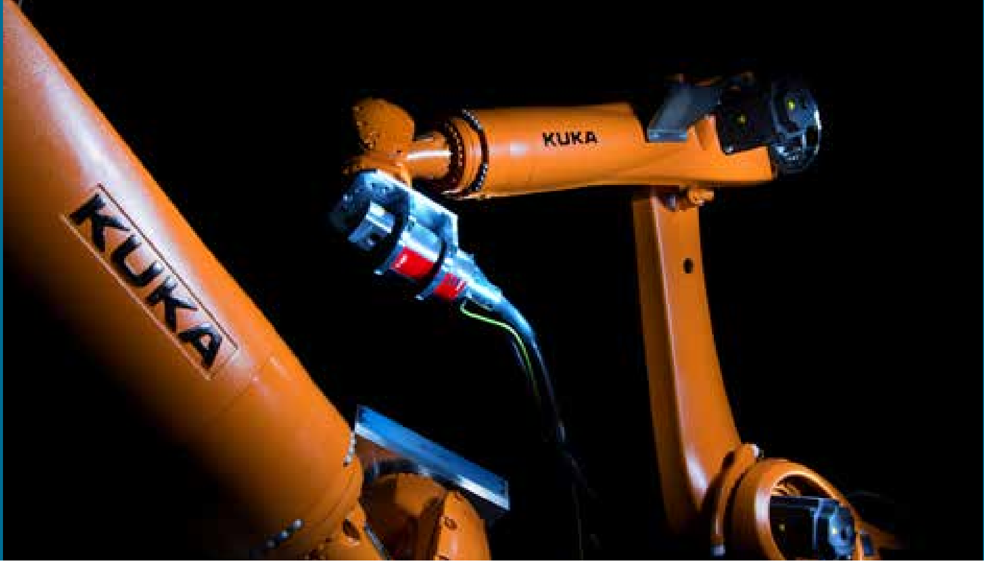
In collaboration with partners from the industry, Fraunhofer IEE in Kassel has developed a demonstrator of a PV inverter with 30 kVA power, which illustrates the advantages of semiconductors in practical application, as part of the PV-LEO research project funded by the BMWi and the BMBF.

In conventional inverter systems, typically operating at clock frequencies of 17 kHz, the choke components and the cooling account for up to 50% of the system's total weight. By increasing the clock frequency to 50 kHz, the weight of the choke components was roughly halved. Due to the smaller size of the chokes, however, additional heat dissipation measures need to be taken during assembly to prevent hotspots within the components.

The newly developed system achieves a power-to-weight ratio of 0.93 kg/kW. Hence, the use of SiC semiconductors allows for a significant weight reduction compared to the state of the art (2.3 kg/kW on average).

Despite considerably higher expenditures for SiC semiconductors, an improvement in the cost position for the manufacturer of these systems can already be achieved at system level. Therefore, the new SiC technology is expected to rapidly gain acceptance within this area of application.





© Paul Pulkert

»RoboCT«: Robots for Cognitive Sensor System

The use of robots in non-destructive testing offers a decisive advantage over conventional industrial CT systems: test positions on complex shaped objects, such as vehicle bodies, can be reached this way. In practice, several cooperating robots that are carrying the imaging components such as e.g. X-ray source and detector correspondingly, move around the test object. This way, the system is capable of conducting three-dimensional CT with detail recognizability in the size range of a human hair. The object can be inspected down to the last detail using this technology with the utmost precision, without damaging it. Previously, the specimen for such an analysis had to be disassembled or even sawed out and analyzed in a separate CT system.

Common industrial X-ray CT systems are capable of analyzing objects of about 30 centimeters in diameter and thus to acquire 3D information about all external but also hidden internal structures. These CT images can be virtually disassembled and analyzed in the computer e.g. as stack of sectional images. To achieve resolutions of less than one micron, extremely precise hardware components are required. With large industrial robots – here with ranges of three meters and more – it is possible to reach sections, so-called »regions of interest ROI«, on much larger and complex shaped objects. The particular challenge is to algorithmically correct geometrical inaccuracies of the robots directly from the recorded measurement data. The most precise industrial robots of this size only achieve accuracies of ½ to ¼ millimeter throughout their entire working area – while CT requires at least 1/20 millimeter depending on the application. The solution to this problem is the basis for using this technology productively today.

Robot-assisted CT, as has become reality today as a result of these developments, is only the beginning of a larger idea. In the long term, the aim is to not simply measure material data indiscriminately or completely, but to acquire only the relevant data. And what is relevant data, this so-called cognitive sensor system will decide for itself. Customers are supplied with some kind of highly flexible black box. They do not have to deal with the system and do not have to have NDT know-how. Parts of this box are, for example, robots that have access to different, self-adapting sensor systems and then in the broadest sense decide for themselves which methods they use and how. The robot applies an X-ray system, an air ultrasound system or even a thermography system to solve a specific defined task and not just to test something. Through the application of artificial intelligence, RoboCT can assist people in a variety of tasks by proposing optimal parameterization in terms of accessibility and recording parameters as a black box, depending on the task at hand.

Ready for nondestructive testing with »3D SmartInspect«: An augmented reality system for manual testing of complex components or large surfaces. © Fraunhofer IZFP

3D SmartInspect – Intelligence in Inspection and Quality Control

Many safety-relevant components and structures in industrial environments are under high mechanical and/or thermal loads. Even small defects such as internal corrosion, material fatigue, or cracks in welds can be a decisive factor for the failure-free operation or malfunction of such systems and plants. Major quality assurance methods, which have been established for ages and used to this day, frequently rely on manual nondestructive inspection concepts basing on handheld ultra-sound or eddy current sensor systems; if necessary, additional electromagnetic testing procedures can also be applied.

In conventional testing, the component to be examined is selectively scanned with a probe moved along a grid pattern. The measuring signal is displayed on the test instrument in a simple format and directly interpreted by the testing engineer during the inspection. The test log is mostly handwritten, and often the deviations found are but labelings on the components. During this process, the testing engineer does not receive any technical support: Interpreting the measured values continuously and correctly, checking for complete coverage of the inspection area, and generating the test log require a high level of expertise from the testing engineer.

This is where the complete and correctly collected data acqui-sition enabled by a modern display and simultaneous digital data analysis can open up enormous potential. The test design, which is based from the ground up on digital, intelligent data collection and online analysis, as well as on digital information presentation that is condensed to the relevant data, provides an enormous innovation boost for nondestructive testing: The 3D SmartInspect test assistance module developed at the Fraun-hofer IZFP ushers in a new era for modern and highly flexible human-based manual testing. »3D SmartInspect« is an example for a pioneer NDT 4.0 technology in the context of integration of and into digital environments.

The digital recording of the manual testing and handling process by cameras, tracking of the probe position, automated measuring signal analysis and the generation of digital test logs result in a new class of inspection systems that significantly facilitate the performance, analysis and control of manual tests. At the same time, due to its integration into and merging with the virtual world (Augmented Reality), this assistance can also be performed by non-specialized personnel.

The Fraunhofer IZFP has implemented the first prototype of the 3D SmartInspect assistance system based on eddy current and ultrasound sensors. The system interactively supports inspectors in manual testing processes and enables the automated simultaneous documentation of the testing process including the electronic transmission of the resulting data.

All that needs to be done before the test is setting up the camera system in a suitable location that allows the visual capturing of the area to be tested; then the tester can begin to perform the test. The tracking module will detect and track the movements of the probe and log the test positions and measured signals. These signals will be automatically analyzed and merged with location coordinates in the live image. Using Augmented Reality (AR), the tested areas and registered defect indications (e.g., internal defects) will be displayed for the tester on a display (laptop or tablet). In addition, the test result can be inspected by means of a head-mounted AR display (MS Holo-Lens) and transmitted electronically to a server or a datacenter »anywhere in the world«.

Thus, 3DSmartAssist sensors are step-by-step becoming an integral part of the Internet of Things. The data, which have been further processed to extract relevant information, can simply be transmitted to the digital product and material memory and stored in a suitable manner. A combination with collaborative robotics will open up completely new applications in Human-Machine Interaction (HMI) for use in industry.

Test setup for X-ray test at Fraunhofer EMI in Efringen-Kirchen. © Fraunhofer EMI

Battery test bench for dynamic tests of loaded cells. © Fraunhofer EMI

X-ray diagnostics in Crash Tests

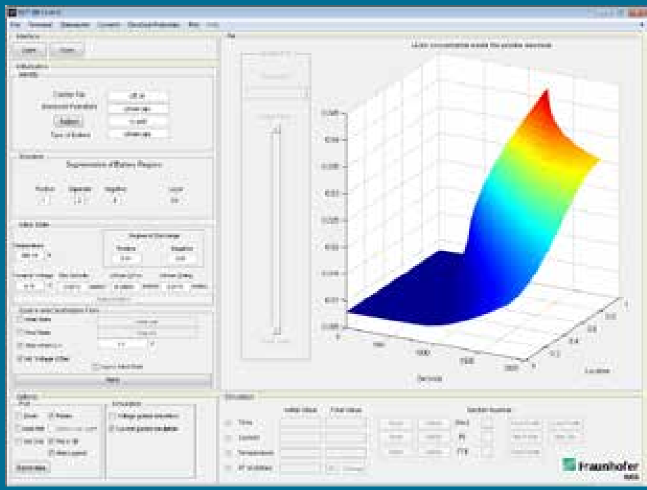
Modern, lightweight vehicles are produced of ever more complex materials and structures. To understand the constitution of these structures, X-ray and computed tomography have become established in research and development. Up to now, X-ray was mainly restricted to static investigations. With the technology of X-CC, the Fraunhofer-Institute for High-Speed Dynamics, Ernst-Mach-Institut, EMI, for the first time combines X-ray with the high-dynamic deformation processes under crash conditions. This enables to understand how inner structures of a vehicle, which are not visible from the outside, behave during crash. Based on these gained insights, materials and numerical models can be optimized. X-raying is an established material research technology, which in the industrial sector has thus far been restricted primarily to static and quasistatic analyses.

With the X-CC technology, Fraunhofer EMI combines X-ray technology with the highly dynamic deformation processes under crash conditions and thereby contributes to the overall understanding of the behavior of inner car structures during a crash. The results are included into the simulation for the optimization of structures, structural components or materials. The long-term goal is to obtain an X-ray video of the crash tests. This business branch of Fraunhofer EMI, which has developed into a large, successful research field, has sparked growing interest in industry and research. EMI develops new methods, simulations and fields of application, conducts industrial projects for notable clients and plans the continuous development of test setups for future studies.

Mechanical Behavior of Batteries Under Dynamic Loading – Battery Test Bench

The call for an increase in electric vehicles on our roads requires the application of efficient mobile sources of energy. As a result, electric energy storage systems are growing in importance in the field of mobility. However, as energy density and the overall capacity of available energy storage continually increase, so does their risk potential. A special test bench for the characterization of lithium ion cells at Fraunhofer EMI allows for the destructive testing of charged battery cells at different load modes from the static to the dynamic range with load velocities of up to 10 meters per second and loads of up to 50 tonnes. Different cell types can be examined with this apparatus with respect to their deformation behavior under various conditions.

A further effective possibility of researching batteries that have undergone compression, crushing or other types of destruction is by computed tomography (CT). This allows the visualization of the interior of a cell before and after a test and enables the analysis of damage.



User interface of the "BaSiS - Battery Simulation Studio" © Fraunhofer IEE

Simulation Software Accelerates Development of Battery Systems

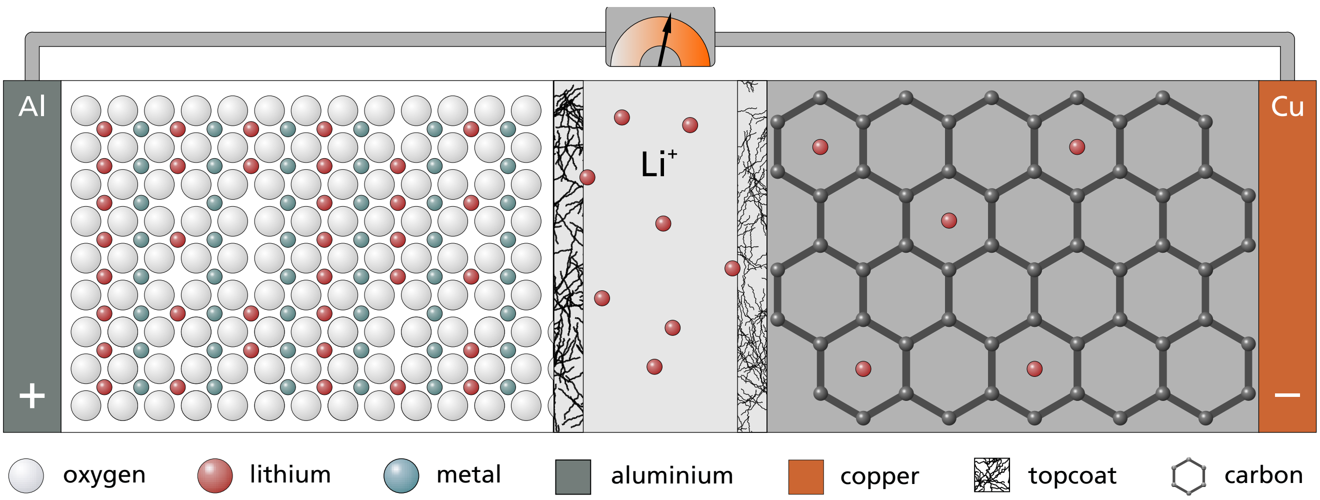
In recent years, the use of batteries has increased significantly in many industry sectors. The efficient use and smart system integration of batteries are crucial factors for the usability and success of products and systems. This applies not only to aerospace, power and utility vehicles as well as power tools, but also to our little electronic companions in everyday life, such as smartphones, tablets, vacuum cleaners and lawnmowers.

The "BaSiS - Battery Simulation Studio" developed at Fraunhofer IEE over the last 20 years provides a tried-and-tested tool for the reliable, safe and precise simulation of batteries in common development environments, helping to optimise development processes. The software models the behaviour of batteries with high precision on a physical and electrochemical level and can easily be integrated into MATLAB® / SIMULINK® for complete system simulations. Moreover, BaSiS can be used to study the behaviour of various design parameters of a battery.

The system is employed in the development and optimisation of cell materials, battery cells and packs, battery management systems as well as battery-powered devices, plants, vehicles and air-/spacecraft. Battery simulations save costly laboratory measurements and accelerate development processes.

Virtual batteries in hardware-in-the-loop systems

The real-time module of BaSiS can be used to model the terminal behaviour of real batteries in hardware-in-the-loop test benches. BaSiS enables fast, cost-efficient and reproducible hardware testing, for example of battery management systems (BMS) and complete systems, such as vehicles. In contrast to real batteries, such a test bench can additionally provide all internal quantities of the battery for the overall system development.



The hybrid lightweight rear axle developed by Fraunhofer LBF reduces axle weight by around 40 percent compared to conventional metal designs. © Fraunhofer LBF

PAN fibers are the perfect precursor material for producing carbon fibers. © Fraunhofer IAP

Lightweight Solutions with defined Properties

For more than 80 years, scientists at Fraunhofer LBF have been researching intelligent lightweight construction solutions for load-bearing structures. The hybrid rear axle developed by LBF scientists is an example of this lightweight design competence. It contains a number of innovative solutions, including the so-called T-Igel® connection – an innovative connecting element between the metal and fiber composite component that enables a form-fit, low-notch-stress connection between the two components – and on the other hand, the optimization of the fiber orientation of the carbon-fiber-reinforced component with regard to the multi-axial load from the driving operation.

In the course of the »epsilon« project funded by the European Union, the new lightweight rear axle was designed using the finite element method in several iteration steps. Parameter studies and design variants were carried out, which finally led to significant weight savings and a result consisting of two metallic side-parts and a middle part made of fiber-reinforced plastic. This hybrid design simplified the design of the connection points to the vehicle structure and accelerated the manufacturing process.

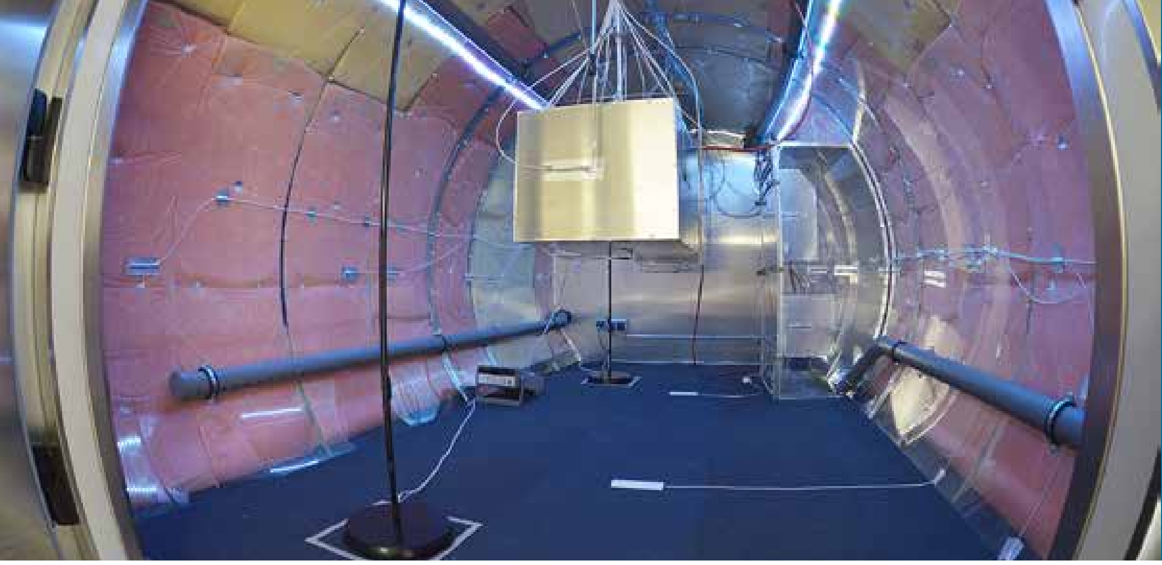
At Fraunhofer LBF, the complete development process was mapped from concept development to numerical calculations, prototypical production, and component testing. The resulting weight reduction compared to the corresponding conventional chassis components is around 40 percent for the rear axle. The reliability of the lightweight rear axle was confirmed in real driving tests.

Cost-effective Carbon Fibers for Light-Weight Applications

Whether they are used in aircraft, racing cars, and bicycles - carbon fibers are the most advanced reinforcement fibers for extremely lightweight composites. Nevertheless, it remains difficult to penetrate mass markets, like the automotive and construction industries, as well as other industries that currently use glass and natural fibers. One of the main reasons is the high production costs of today’s carbon fibers. The ComCarbon® technology developed at the Fraunhofer Institute for Applied Polymer Research IAP will make it possible in the future to produce carbon fibers for the mass market at low cost.

Approximately half of the cost of producing conventional carbon fibers is incurred in the production of the precursor: polyacrylonitrile fiber (PAN). This so-called precursor fiber cannot be melted and is therefore produced using an expensive solution spinning process. The Fraunhofer IAP has developed an alternative PAN-based precursor technology that can save about 60 percent of the costs incurred by the precursor, i.e. about 30 percent of overall costs to produce the carbon fiber. It is based on a low-cost melt spinning process using special meltable PAN copolymers developed at the institute specifically for this purpose. Once they are converted to an unmeltable state, these cost-effective precursor fibers can then be processed into carbon fibers in the same way as conventional precursors using established production routes.

Melt spinning has enormous economic and ecological advantages over solution spinning. No environmentally-harmful solvents are involved, which therefore do not have to be recycled at great expense. One ton of spinning mass directly supplies one ton of precursor fibers and the spinning speeds are many times higher than with solution spinning.



Fraunhofer IBP scientists perform experimental tests in the Thermal Test Bench cabin demonstrator to examine indoor climate and thermal comfort conditions.
© Fraunhofer IBP

Thermal Test Bench

Aviation is going to be more environmentally friendly: by 2020 jets are intended to cut their carbon dioxide emissions by 50 percent (compared to the aircraft fleet in 2000), reduce nitrogen oxide output by 80 percent and noise emission by another 50 percent. In addition, it is envisaged to develop innovative solutions in the areas of design, production, maintenance, and recycling, as well as to optimize the aircraft lifecycle.

These are the ambitious goals targeted by the EU project »Clean Sky«. The largest European technology initiative to date was launched in 2008. In the scope of »Clean Sky« the order for developing, constructing, and commissioning the Thermal Test Bench was placed. This test facility allows validating the thermal performance of innovative aircraft architectures and devices as well as new engineering tools - quite successfully, actually: since the demonstrator was put into operation in 2014, it has reliably passed all functionality tests. By using the demonstrator it has become possible to check the architecture of entire business jet sections with regard to thermal efficiency and functional performance, which is becoming increasingly important in view of the transition to »More Electric Aircraft« architectures.

For these purposes, three mock-ups are being used:
Composite cockpit:
The composite cockpit allows analyzing the thermal performance of composite structures.

Cabin segment:
The cabin segment enables the researchers to examine the cabin climate and the indoor comfort, as well as underfloor installations and the tank's usability as a thermal storage device.

Aft fuselage segment:
This segment is mainly used for testing avionics bay architectures and for integrating systems characterized by extreme heat release.

These three fuselage sections can be exposed to environmental conditions that occur both on the ground and in flight situations, which allows secure testing of in-flight conditions without taking off. Precisely controllable air-conditioning systems are used for conditioning the cabin climate: These AC systems allow to provide a wide range of air temperatures, air humidities, and air volume flow rates for cabin ventilation. Moreover, Fraunhofer IBP scientists developed and optimized control and regulation mechanisms for the Thermal Test Bench. The result: The required test conditions were ensured in a very accurate and uniform quality, thus enabling tests to be performed in accordance with aviation standard DO 160. In the scope of the test campaign for the »Heat pipe« technology demonstrator such an investigation could be implemented for the first time. In parallel, the Fraunhofer Indoor Environment Simulation Suite (IESS) was further developed and validated using the Thermal Test Bench. For designing indoor climate applications, spatially resolved temperature distributions are required. To date, classical calculation procedures employed in the design process have failed to provide this data. At this stage, even sophisticated simulations for advanced design purposes - such as Computational Fluid Dynamics (CFD) - do not solve the problem. In the case of large spaces, they reflect chaotic flow characteristics, creating only little added value for practical applications while taking a lot of computing time.

In contrast, the IESS developed by IBP scientists subdivides the space into several zones (typically 20 to 500), which interact in terms of air exchange. This model allows to define heat sources, ventilation openings, walls and windows, which can be connected to adjacent zones. The model also considers the impact and interaction of thermal radiation from all surfaces involved, as well as the influence of solar radiation, depending on place and time. This approach reduces computing time by factor 1000 to 10 000, while rendering results of comparable significance. When designing a new aircraft, engineers are now able to compare a great variety of different architectures and identify the most promising solutions. The Thermal Model

Fraunhofer ISE mini-plant for methanol production from CO_2 and H_2. © Fraunhofer ISE

Generation Tool and the Ecolonomic Analysis Tool ensure that this process is automated.

But are the results really representative of realistic applications? This must be verified before introducing this tool chain in aviation design. The climatic conditions are extreme, the geometrical structures are complicated, and it takes highly complex air-conditioning systems to control the climate inside an aircraft. Fraunhofer IBP's Thermal Test Bench enables engineers to carry out representative tests already on the ground. The predictions created by the Thermal Model clearly range in the scope of the required accuracy and can be validated. Compared to CFD calculations that were done in parallel, the predictions generated by the thermal model were found to be much closer to reality, as was proved by test campaigns performed using the cockpit and cabin and aft mock-up.

The underfloor area of the cabin demonstrator provides various options to perform thermal tests, using so-called equipment simulators.
© Fraunhofer IBP

Production of Sustainable Fuels and Chemicals from CO_2 und H_2

The Power-to-Liquid (PtL) technology - the conversion of CO_2 with sustainable H_2 (e.g., generated through water electrolysis) to liquid compounds, such as methanol - offers numerous advantages: seasonal energy storage, a chemical buffer for provision of fluctuating renewable energies and reduction of CO_2 emissions. Others are the generation of alternative fuels with improved combustion properties and valuable platform chemicals, importantly based on a sustainable and reliable energy / feedstock supply. The PtL technology uses carbon dioxide from exhaust flows, biomass processes and air as feedstock for fuels and the chemical production. Thus, the PtL concept has the potential to reduce the dependency on crude oil and natural gas, whilst simultaneously facilitating large scale renewable energy storage and reducing GHG emissions (e.g. in the mobility sector).

At Fraunhofer ISE a fully automated mini plant to synthesize liquid fuels like methanol from carbon-rich gases and hydrogen is being tested and further developed. The key to a successful development of PtL technology is the energy efficient synthesis of methanol based on a direct hydrogenation of CO_2. The Fraunhofer researchers are working to better understand the synthesis process, to develop more active, selective and stable catalysts and to improve the processing technology, including the optimization of the overall production system (i.e. electrolysis, methanol, synthesis).

The KraussMaffei Berstorff UD tape line at Fraunhofer PAZ opens up new dimensions in terms of processing speed and width range.
© KraussMaffei Berstorff

Injection-molded components can be produced at Fraunhofer PAZ almost on industrial scale.
© Fraunhofer IMWS / Sven Döring

Thermoplastic Lightweight Construction for Mass Production

Polymer composites are nowadays crucial especially to mobility applications. Alongside the further optimization of the mechanical properties at low density, the profitability is increasingly getting into focus of developments. The Business Unit Polymer Applications at the Fraunhofer IMWS is specialist in diagnostics and optimization of polymer materials and is working on the development of novel thermoplastic semi-finished products and lightweight solutions for mass production. The Fraunhofer IMWS adresses questions of the use of polymeric materials from the selection of raw materials to the processing technology and the resulting processing-structure-property-relationships right up to the desired performance of components. In the field of fiber reinforced thermoplastics the entire value chain is covered: the material's microstructure, compounding and manufacturing of semi-finished products, up to tailor-made components that are fit for mass production.

At the Fraunhofer Pilot Plant Center for Polymer Synthesis and Processing PAZ, a joint unit of Fraunhofer IMWS and the Fraunhofer Institute of Applied Polymer Research IAP, a machine park with state-of-the-art facilities is available. New and easily applicable solutions are developed and explored here, together with partners from the industry and research. For example, the UD-tape system developed jointly with KraussMaffei Berstorff, offers processing speeds up to 20 m / min and tape widths of 500 mm and is designed for high-volume production. Reinforcing fibers of carbon, glass or other materials like basalt can be embedded in different thermoplastic matrices by melt impregnation. On the basis of this unidirectional continuous fiber reinforced tapes (UD tapes), material-efficient and stress-resistant laminates can be produced. Hybrid injection molding process for thermoforming and back molding of the tape-based laminates are available on top of that, which allows the economical production of lightweight structures in short processing cycles in the range of one minute.

Another research focus of the Fraunhofer IMWS includes the development of semi-finished organosandwich products and the according processing technologies on an industrial level. ThermHex Waben GmbH is key partner in this. Semi-finished organic-sheeting sandwich products are named for their layered quality: sandwiched between two very thin layers of thermoplastic fiber composites (organic sheeting), there is a thermoplastic honeycomb core. This design, which does not require additional reinforcement ribs, combines cost effectiveness and good component rigidity with minimal weight.

Another area of expertise is bio-based materials. Natural fibers are examined as well as bio-based matrices in compounds and continuous fiber reinforced tapes. This contributes to the production of highly sustainable semi-finished products and components that are also easy to recycle. Processes are complemented by the Fraunhofer IMWS using non-destructive methods such as X-ray, CT or thermography to perform mechanical and microstructural analyzes of materials. Evaluations of semi-finished products and components, for example in terms of fiber orientation and pore formation, are important to characterize the local properties such as stiffness, strength or durability and product quality.

Formed organosandwich structures with a thermoplastic honeycomb core and coatings made from UD tape laminates.
© Fraunhofer IMWS/Sven Döring

Carbon and hemp fiber-reinforced component. © Fraunhofer WKI / Manuela Lingnau

New Natural Fiber-Reinforced Hybrid Composites

Companies in the automotive and aerospace industries are increasingly utilizing fiber-reinforced composites in order to produce lightweight, high-strength and functionalized components. Which specific material combinations are thereby used depends on the subsequent application. Whilst the use of carbon fibers is technically very expedient in many areas, it is often not absolutely necessary. From an economic and ecological point of view, various bio-based materials are also conceivable.

Researchers at the HOFZET© Application Center at the Fraunhofer Institute for Wood Research combine natural and carbon fibers in a single work step within a textile semi-finished product. Through the so-called multilayer technology, the technically high-grade carbon fibers can be applied precisely where they are needed within the component. Simultaneously, polymer fibers can be integrated into the fabric so that thermoplastic processing is directly possible.

The result: The components are cost-effective, have a very high strength, good acoustic and vibration-damping properties, and are considerably more ecological than pure-carbon components.

Special coatings on the yarns and/or fabrics ensure that the natural fibers bond optimally with the plastic matrix. Such a pretreatment, which is optimized from a materials technology point of view, is largely new territory for textile fibers. With optimum fiber-matrix adhesion, the strength of the material thereby increases by up to 50 percent compared to a poor interface quality.

The researchers are also investigating how the processing operations for the new materials can be implemented on an industrial scale. Prior to beginning their research, they also take into consideration how the developed hybrid materials can be reprocessed or how individual material components can be recovered for a new application. Depending on the material composition, they pursue differing physical, thermal and chemical recycling approaches. As the conclusion, an ecological, economic and technical evaluation of the entire process chain is performed.

Conventional and bio-based fiber composites. © Fraunhofer WKI / Manuela Lingnau

Manufacture of structural components for automotive lightweight construction. © Fraunhofer ICT

Process Development for the Sequential Preforming of Semi-Finished Products

Climate change and its consequences are pushing societies worldwide to adopt a more energy- and resource-effcient lifestyle. Global warming can only be curbed in the long term if the emission of greenhouse gases is greatly reduced over the next years. Since the energy consumption of vehicles directly determines the amount of pollutants that are emitted, the strategic relevance of lightweight construction in the automobile industry will increase in the future.

Fiber-reinforced polymers are being used with greater frequency in addition to established lightweight construction materials. These polymers have great potential due to their density-specifc material properties. High-performance composites with a high fiber volume are of special interest because of their excellent mechanical properties. In particular anisotropic layer constructions, oriented according to the load path, enable the production of high-strength structural components suitable for lightweight applications. Automated, robust and quality-assured manufacturing technologies are needed in the future in order to successfully introduce this material system to large-scale automotive production.

The Technology Cluster Composites (TC^2) focused, among other things, on the industrialization of RTM process chains for the manufacture of structural components for automotive lightweight construction. An outstanding feature of TC^2 was an integrated approach to technological challenges that was not based on individual problems but focused on connections and interactions within continuous process chains.

The cost structure of the RTM process chain is a strong argument for the implementation of automated preforming. The automatization of handling operations as well as the reshaping process (draping) within the preforming proce- dure can drastically reduce production cycle times, which leads to a signifcant reduction in overall RTM production costs. At the same time, the reproducibility of component quality increases as the degree of automation becomes greater which, in turn, results in a noticeable decrease in the rate of production waste.

Fundamental draping and fixation strategies for preform manufacturing were developed and validated within the framework of TC^2 by the participating group partners Fraunhofer ICT, the Institute of Aircraft Design of the University of Stuttgart (IFB), the Institute of Textile Technology and Process Engineering Denkendorf, the Institute of Production Science (wbk) and the Institute of Vehicle Systems Technology of the Karlsruhe Institute of Technology. The sequential reshaping of entire layer constructions using a multiple-stamp mold has proven to be the best method for the automated manufacture of components with complex geometries. In this method, the layer constructions are locally prestressed. The local application of reactive binding systems has proven to work best for fxing the shape and position of textile semi-fnished products. Dieffenbacher GmbH created a PreformCenter at Fraunhofer ICT for automated preform manufacturing on the basis of this preliminary work. The new technology makes it possible to investigate the complete preform manufacturing process from layer cutting and the application of binders through to shaping. The individual processing steps are linked by a handling technology consisting of selected grippers acting as robot end effectors.

Functional filaments for the 3D printing. © Fraunhofer IFAM

Functional Polymer Composites for Innovative Functional Integration

Equipping new components or materials with additional functions has been a trend in product development for years. The Fraunhofer IFAM in Bremen is responding to the current demand for more functional integration with the material class of »functional polymer composites« developed there.

The material concept is based on thermoplastic polymers, in their classic characteristics or as soft-flexible elastomers. Innovative compounding techniques, combined with the desired fillers, generate high-performance plastic composites for a wide variety of applications. Both metallic microfibers and powders of various types can be used as fillers. In the appropriate case, these can be combined with low-melting alloys. Furthermore, all carbon-containing as well as ceramic additives can be compounded into the respective matrix polymers. Filler contents of over 80 % by weight can be easily achieved with this technology and lead to functions in the plastic that come very close to the properties of the corresponding fillers.

Electrical conductivities of high 106 S/m can be achieved as well as thermal conductivities of more than 10 W/mK. A further large area of application is the functionalisation of the material with regard to its use in the field of EMC protection. Here an analogue damping behaviour can be achieved over a very wide frequency range in comparison to purely metallic materials. In addition to the physical properties, the »functional polymer composites« show further special features. Despite of their high possible contents, the materials still exhibit a good spectrum of mechanical properties as well as processing behavior. The composites can thus be processed with the established production technologies of the plastics industry, with minor adjustments in the process.

By means of extrusion or injection moulding (especially with multi-component injection moulding or extrusion), function-integrated components can be produced efficiently and at minimum cost. The processing portfolio of composite materials is currently being supplemented by FFF printing. In terms of technology, a special production line for highly filled polymer composites has been created on which the various material variants can be processed into a correspondingly printable filament.

Functional polymer composites make it much easier to integrate additive functions into a component. Thus, new applications can lead to new or improved product ideas, and good technical solutions can be developed if necessary.

Filled plastic granules as starting material for production of the 3D printing filaments. © Fraunhofer IFAM

Some of the tracked routes superimposed onto a solar irradiance map of Europe. © European Union, 2012 PVGIS (Karte)/topae/ shutterstock (truck)

Improved roll resistance ' with the same grip - possible by optimizing the filler networks in tires. © istock / santiphotois

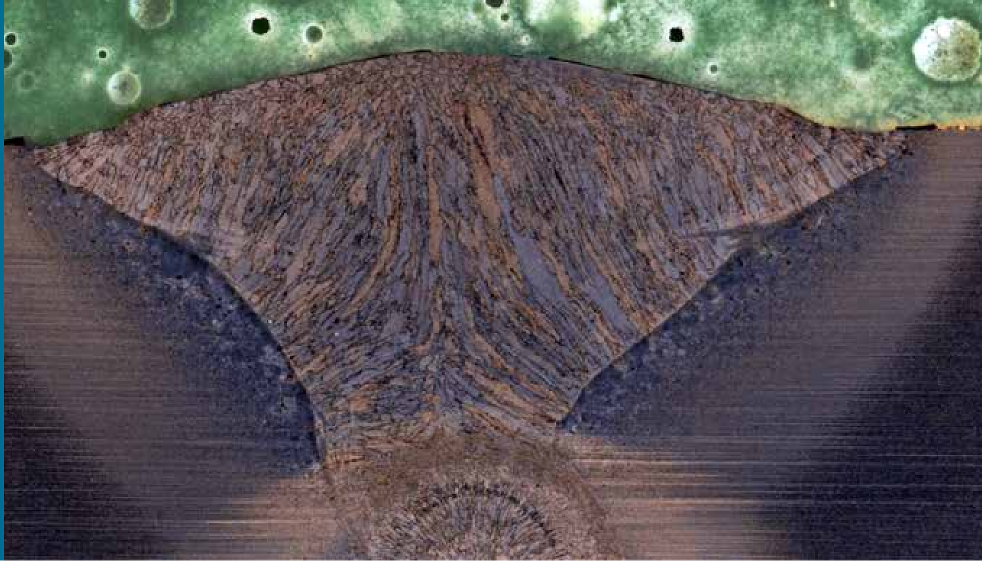
Photovoltaics on Commercial Vehicles: New Challenges and Potentials

In the past years, photovoltaics have become increasingly attractive for use in the transport sector due to rapidly falling costs and new innovations in the cell and module technology. The large roofs of commercial vehicles are particularly suitable for the application-optimized, flexible and light-weight PV modules. For this application, new materials are being tried and tested. The solar electricity produced during driving reduces the diesel consumption, the CO2 emissions and the driving costs. Fraunhofer ISE, with support from Fraunhofer CSE in Boston and in cooperation with three freight companies, investigated the potential of PV on commercial vehicles. Six trucks were equipped with special equipment to measure one-minute averages of irradiation, temperature and speed. Over a period of up to 15 months, comprehensive data were acquired along real transport routes in Central and Southern Europe as well as in North America.

From the data, it became evident that PV operation on commercial vehicles occurs under significantly different conditions to those experienced in conventional rooftop or ground-mounted systems. For example, the average module temperature was 22.6 °C (compared to over 60 °C for fixed PV modules). Measurements allowed the positive effect of airflow on the module temperature to be quantified. The highest yield potential was a calculated to be between 5297 and 7395 kWh/a. Converted to diesel equivalent, these values amount to savings ranging from 1513 to 2113 liters per year for a 40 ton trailer-truck. Together with partners in the transport sector, Fraunhofer ISE is working on the targeted development and qualification of PV technology for applications on vehicles.

Microstructural Characterization of Energy-Saving and Wear-Resistant Tire Materials

Rubber-based composites, as used for tire treads, are complex materials containing not only rubber but many additives. While the rubber content of the material provides rubber-typical properties such as high elasticity, the addition of nanoscale fillers such as carbon black or silica has a huge impact on other essential features such as hardness or abrasion resistance. These parameters can be determined by the filler type and filler content. In tire composites the filler content is so high that a solid filler network develops that dominates the mechanical characteristics of the tire. A detailed understanding and targeted adaptation of the filler network are therefore crucial when it comes to developing optimized tire compounds. Detailed investigations at the microstructural level at Fraunhofer IMWS have shown: The filler network does not only contain the filler particles themselves, but also viscoelastic elements that are formed from immobilized, vitreous rubber segments on the filler surface. Although these immobilized segments provide for only about 1-3 percent of the total rubber volume in the composite, their influence on the mechanical properties is dramatically significant. Vitreous rubber bridges emerge between the filler particles, which can successively soften, for example by a temperature rise, and thus halve the elastic modulus of the entire composite material. This results in an increased rolling resistance and fuel consumption. This process emphasises the significance of microstructural analyzes of the filler network for the optimization of composites for tire treads, as performed at Fraunhofer IMWS.



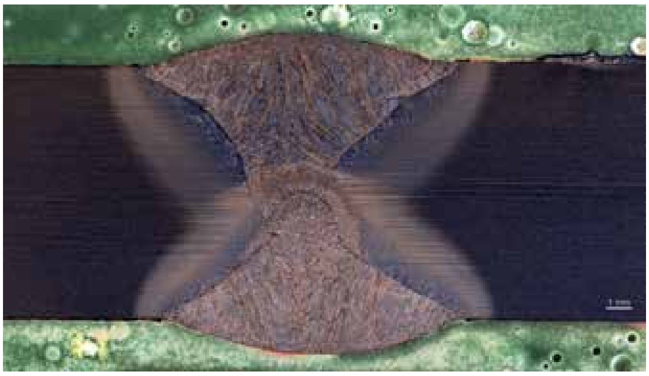
Assessing the risk of hydrogen embrittlement: cold Ccacking in high-tensile steels

High-tensile strength steels play a key role in lightweight engineering components. If these
steels are welded during the production of components, mobile hydrogen can cause problems in the material: the hydrogen collect in areas of the components with high residual stresses and can enhance the risk of embrittlement. The consequence are so-called cold cracks that can make components unusable.

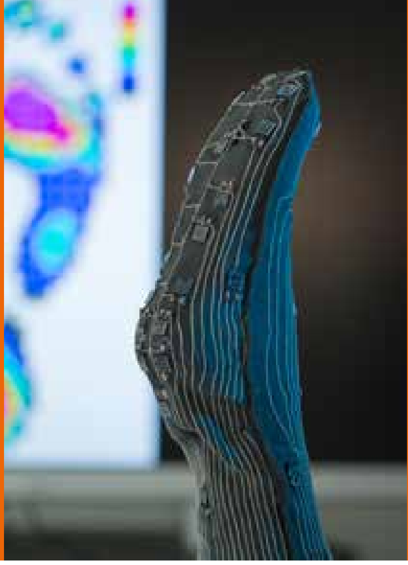
In order to help component manufacturers to reduce the reject rate for high-tensile steel components sustainably, the Fraunhofer IWM has further developed numerical welding simulation methods which are already in use in industry. It is therefore now possible to simulate all factors concerning hydrogen cold cracking in welded areas of components regarding the very rapid change from room temperature to melting temperature and back to room temperature.

The development over time of the factors affecting the cold crack formation and their interactions can now be observed in virtual reality in a very precise way – hardening structures, for example, residual and external stresses and the local hydrogen concentration. The distinctive feature of the new method is that the effect of so-called hydrogen traps can be taken into account which can act as sources as well as sinks to diffusible hydrogen.

The simulation results are used as the basis for optimizing the process parameters in laser-welding processes: laser process parameters, more precise preheating and post weld heat treatment temperatures as well as the exact heating time can thus be determined. The simulation technique is also useful in planning components: the data allows more cost-effective component shapes to be identified that improve the local residual stress and thus prevent cold crack formation.



Optical microscope image of the weld structure of a welded joint.
© Fraunhofer-Institut für Werkstoffmechanik IWM



Pressure measurement stocking with integrated elastomer sensors – trade fair demonstrator without a second outer textile layer. © Fraunhofer ISC

HEALTH

■ Preventive Wound Protection – Pressure Monitoring Stockings for Diabetics

Diabetes is one of the most widespread diseases and can lead to serious consequences. According to the German Health Report on Diabetes 2014 of the German Diabetes Association, statutory health insurance companies estimate that approx. 20 percent of their annual costs are spent on the treatment of diabetes. In the advanced stages of the disease, many diabetics no longer have feeling in their feet and, therefore, cannot register pressure or temperature signals. They do not notice it when there is too much pressure in certain areas of their feet. Even small uneven spots or shoe pressure can cause open wounds or tissue damage, which can lead to chronic wounds, if noticed too late. As a result, many diabetes patients have to have their toes or feet amputated. A new type of pressure monitoring stockings can prevent this. A sensor system integrated into the stocking warns the person wearing it of pressure sores.

Smart Phones Evaluate Signals

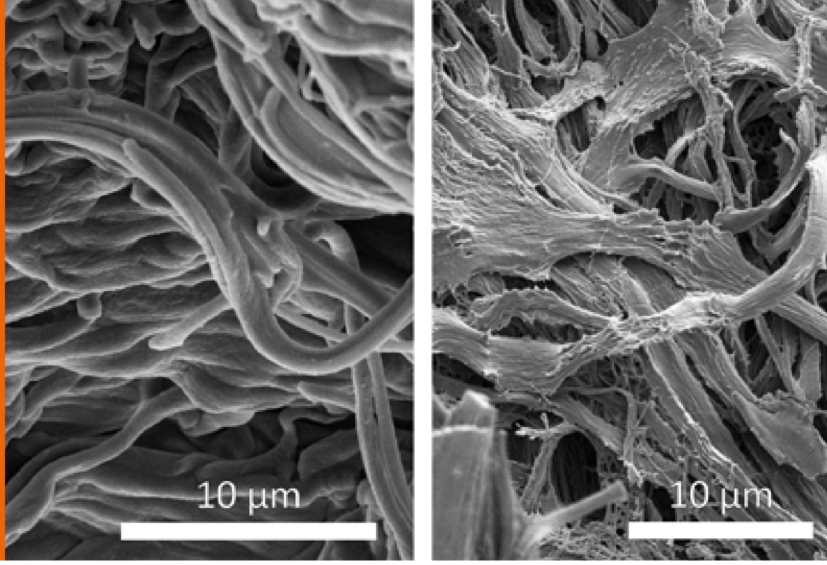
The sensors are made of a very elastic, soft silicon film. This makes them easy to integrate into textiles without disturbing the wearer. The film is coated with highly flexible electrodes on both sides. If the film is deformed by pressure or stretching, its density decreases and its surface simultaneously expands. The result: The electric capacity increases. The change in the capacity of the 40 sensors is transmitted by conductive and elastic threads to an electronic evaluation unit. The evaluated data is transmitted wirelessly to a smartphone or tablet, which shows the diabetes patient whether he/she should change his/her foot position or weight distribution. This way the patient can react quickly and protect himself/herself from dangerous pressure sores.

Outlook

In order to guarantee washability, the project partners are now developing stockings from which the electronics can simply be removed like a Velcro fastener. However, commercial disinfectants already allow a hygienic treatment of the pressure monitoring stocking. An additional area of application for sensors integrated into textiles is the area of fitness. Joggers, for example, would be able to check their running style and foot position when wearing the socks. It is also possible to manufacture gloves with sensors to equip robot grippers or prostheses. Further future developments make it possible to measure a person's posture in order for example, to prevent biomechanical stress due to prolonged sitting.

Malaria causes many deaths worldwide. The Fraunhofer ISC is working with project partners on a rapid test based on biologized fluorescent nanoparticles to simplify the reliable diagnosis.
© Fraunhofer ISC

Scanning electron microscope pictures of the skin's elastin fibres of a 6 (l.) and a 90-year old (r.) test subject.
© Fraunhofer IMWS



Nanoparticles for Early Malaria Diagnosis – New Rapid Test in Development

Malaria diseases are widespread in the tropics and subtropics. According to the Robert Koch Institute, around 600,000 people worldwide die as a result every year. Malaria tropica – the most severe malignant disease – is caused by Plasmodium falciparum, one of the five typical malaria parasites. If left untreated, this disease will, in most cases, result in death. An early and reliable diagnosis is crucial for the success of the treatment.

In order to detect an infection and be able to determine the type of pathogen correctly, conventional diagnostic procedures require specific laboratory equipment and a very well-trained and experienced staff. The Fraunhofer Translational Center for Regenerative Therapies at the Fraunhofer Institute for Silicate Research ISC, together with the Fraunhofer Institute for Molecular Biology and Applied Ecology IME and the University of Tübingen, is developing an easy-to-use diagnostic rapid test to determine this type of malaria. Specifically, functionalized fluorescent nanoparticles are coupled with highly sensitive antibodies that recognize the protein of the malaria parasite.

To detect the pathogens in a blood sample, time-resolved fluorescence resonance energy transfer (TRFRET) is used. For this, the fluorescence properties of the nanoparticles are adjusted by the Fraunhofer ISC so that the autofluorescence of the blood does not distort the measurement result. The new process will be analyzed and evaluated under real conditions in terms of process parameters, sensitivity, specificity and feasibility, in collaboration with the Center for Recherches Médicales de Lambaréné (CERMEL) in Gabon. If the diagnostic test proves to be suitable under these conditions, a prototype of a low-cost manufacturable medicament should be produced, which can also be used without specific laboratory equipment.

Like Balsam on a Wound: Bio-based Composite Materials for the Skin

The care of badly healing skin injuries, for example in chronic wounds or burn wounds, requires resorbable wound covers, that is materials that can be degraded by the human body itself during the healing process. To develop materials fit for that purpose, researchers at Fraunhofer IMWS are focussing on the unique properties of the natural fiber proteins elastin and collagen. So far, scaffold structures made of synthetic polymers are used as wound covers when treating poorly healing skin injuries. However, these materials can stay only temporarily on the wound and are not as elastic as healthy skin: this results in contractions and tensions. This is not just unpleasant for the patient, but also increases the risk of the healing process not functioning properly.

That is why research at Fraunhofer IMWS is targetting the development of innovative biomaterials for dermal applications. The natural fibre proteins elastin and collagen set the parameter. The fact that skin, lung tissue, blood vessels or cartilage are equally elastic, robust and resistant to cope with a lifetime worth of stress, is primarily due to the interaction of these two proteins: collagen fibres show an extremely high level of tensile strength and in this way lend stability to tissues. Elastin also has complementary properties and is a main component of the elastic fibres responsible for elasticity and tensile strength of many tissues. At the Fraunhofer IMWS, composites are being developed which are based on these and other natural materials and, for example can serve as semi-finished products for medical applications. The new composite materials are produced via electrospinning and combine immunological compatibility, durability and biodegradability with favorable mechanical properties.

Investigations into bacterial load. © AdobeStock

Infection control with antibacterialbone implants. © Fraunhofer IGB (guest institute)

No Opportunities for Resistant Bacteria

There is a high risk of infection during surgical procedures, and surgical implants in particular can lead to severe bacterial infections. Furthermore, multidrug-resistant bacteria and the decreasing number of effective antibiotics add to the significant danger to the patient. The aim of the internal Fraunhofer project "Synergy Boost" is to make a significant contribution to the development of strategies against infection, in particular against multidrug-resistant pathogens.

In order to suppress implant-associated infections, in this research project the synergistic effect of antibiotics and silver is utilized and transferred to the implant surface. The effectivity of antibiotics can be increased by a factor of 10 to 1000 through the presence of silver ions. This strengthening effect against various bacteria – including multidrug resistant bacteria (MRSA) – has been demonstrated under laboratory conditions at the participating institutes. This combination offers the advantage that less antibiotics need to be used and less side effects can be expected. In addition, even antibiotics to which resistance has already developed can be used again in combination with silver, whereby the resistance threshold of the pathogens can be overcome due to the increased effectiveness.

In order to prevent post-operative infections it is essential that an antibiotic is available at the implant site in the right form and for the right length of time. To this end, so-called release layers have been generated which can locally release the material combination of antibiotic and metal ions in defined amounts. Hereby, metal-containing porous coatings are applied using various methods to the implant surface. The antibiotic is then only introduced immediately before the operation, whereby an implant with the "Synergy Boost" technology is individually impregnated according to the antibiogram of the patient. To evidence a successful development, the results from the laboratory are tested on an infection model, then the process is scaled up and the process feasibility is demonstrated. To ensure the usability of the results, the basic requirements for the documentation of developments in medical technology are met.

Protection Against Infection Using Antibacterial Bone Implants

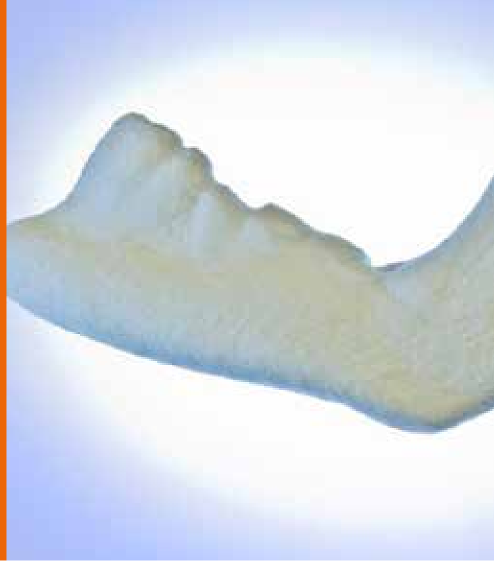
During implantation of bone material, it may happen that germs penetrate the body. Infections of the bones are particularly problematic since antibiotics, which are conveyed by blood, only reach the implants in very low concentrations. The best protection would be to avoid infections all together. In cooperation with the French CIRIMAT Carnot Institute in Toulouse, the Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB has developed bone substitutes with integrated protection against infection.

The novel bone implants are made of calcium phosphate apatite crystals, which are very similar in composition and structure to natural bone material. In order to reduce or suppress the growth of bacteria on calcium phosphate crystals, different materials and combinations were examined, such as silver, copper and zinc ions as well as antimicrobial enzymes and peptides. Antibiotics were not used since their application is problematic due to the development of bacterial resistance.

Samples of specially modified and antibacterially functionalized apatite crystals were infected in the laboratory with bacteria including typical hospital germs like several species of Staphylococcus. After cultivation for several days the functionalized apatite crystals were examined for antibacterial properties and cytotoxicity. With different metal ions, the amount of bacteria in the immediate vicinity of the apatites was reduced by more than 90 percent. A peptide coating proved to be equally effective for inhibiting the growth of bacteria on the surface of apatite pellets and granules.

Powder injection-molded Shoulder anchor made of iron Tricalcium phosphate composite. © Fraunhofer IFAM

Additively manufactured mandible bone. © Fraunhofer IKTS



Removable, Load-bearing Implants – New Material Development for Human Beings

The improvement of the implant restoration is a continuous process to increase the quality of life of humans. In order to avoid operations to remove implants after healing, to save patients further stress and to reduce the costs for the health care system, degradable implant materials are increasingly attracting the attention of medical technology research and development.

For this progress, a materials and technology platform for the manufacture of novel load-bearing bone implants is being set up within the framework of the Fraunhofer internal project »DegraLast«. To this end, materials with specifically adjustable mechanical properties and degradation behavior are being developed for use in orthopedics and traumatology. The central challenge here is to ensure the mechanical stability of the overall system consisting of implant and bone during the entire duration of implant degradation and bone healing. To meet this demand, the project group is researching innovative composite materials based on biodegradable metals and bioceramics.

Modern generative and shape-bound procedures are used to manufacture the implants. The Fraunhofer Institutes IFAM, IGB, ILT and IBMT, however, also addressed other aspects: In order to ensure the usability of the new materials for implants, is simultaneously being applied to biological test systems, which enable the analysis of the ingrowth behaviour of bone and the degradation behaviour of implant materials at the cellular level in physiological media. In addition, monitoring systems based on optoacoustic imaging will be developed for later clinical use to track implant degradation and bone healing.

Ceramic Materials for Additive Manufacturing

Difficult ceramic components were previously injection molded requiring an intensive use of tools, or manufactured with high material losses from isostatically pressed moldings. New additive manufacturing technologies open up a whole new path for ceramics. With the aid of these technologies, components can be manufactured tool-free and with highly complex geometries, which was not possible with any other shaping method so far. What was exclusively possible in the plastics and metal industry so far, Fraunhofer researchers now utilized for the production of complicated geometries of long-term stable, temperature-, wear- and corrosion-resistant ceramics.

Solely from CAD data, free-form surfaces, undercuts, inner channels or hollow structures are built in layers to an adapted individual component. Simultaneously, small series for jewelry industry, micro-reaction or instrument technology, or medical technology can be realized quickly and in a cost-efficient manner. For example, efficient patient-specific implants are produced, which are adapted in their respective form and texture to individual requirements.

Furthermore, researchers developed customized tools for the minimally invasive surgery which can prospectively combine several functions in one step due to integrated fluidic, sensor or thermal elements.

Research currently also focuses on developing material systems for multifunctional components from material and shape combinations. Thus, parts made of porous, permeable components with dense shell structures could soon be joined. Thus, the individual bone structure can be modeled accordingly to produce targeted implants for bone cancer patients.

Printable (bio)polymer solutions.
© Fraunhofer IGB
(guest institute)

A brushing machine is used to investigate the mechanical impact of dental cleansers on teeth.
© Fraunhofer IMWS/Sven Döring

3D Bioprinting: Materials for the Implants of the Future

The medicine of the future is biological. And the future has already begun: Biomolecules are already used as active ingredients and first cell-based implants are fully integrated into the organism.

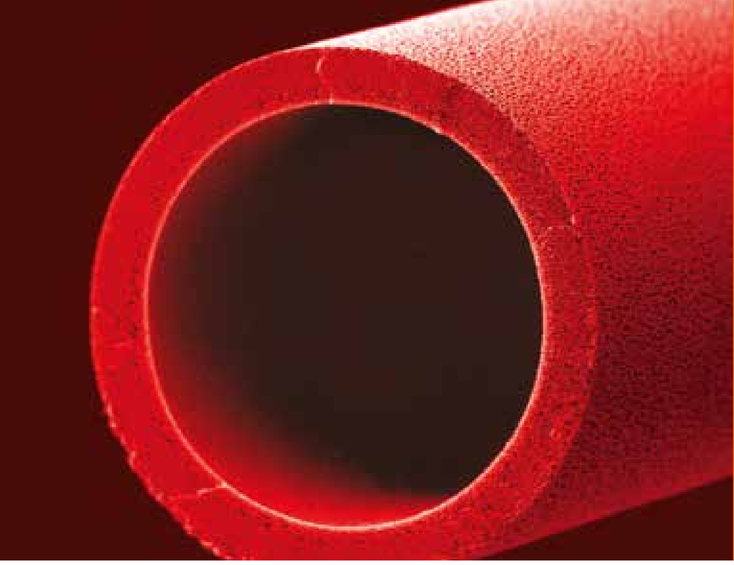
In order to turn the concept of biological replacement tissue into tangible reality, scientists at Fraunhofer IGB are optimizing biological materials for processing with 3D printing techniques. They use the molecules that are derived from the natural matrix of biological tissues such as hyaluronic acid or gelatin. By chemical modification of the biological molecules the viscosity and the gelling behavior can be controlled and crosslinkable groups can be introduced. Biopolymer solutions are provided that are particularly suitable for liquid handling and are used in printing and dispensing processes, such as low viscous gelatin solutions that can be processed at temperatures up to 10°C without gelling.

By means of a photo stimulus, stable hydrogels can be produced from these biomolecule solutions by cross-linking. Depending on the crosslinking density, the mechanical and biological properties of these hydrogels can be adapted to those of native tissue. This modular system of modified biopolymers is increasingly being tested for the construction of three-dimensional model tissue, so-called bioprinting, and for pharmaceutical formulations.

Material Science Assessment of the Performance of Oral and Dental Care Products

»Twice a day, at least two minutes« - every child in Germany knows this motto for dental hygiene. The Fraunhofer IMWS is approaching this topic, which for decades was investigated mainly from a bioscience and dental point of view, intensively at the material level, with highly exciting results: With their expertise in microstructural investigations, the scientists in Halle could evaluate, for example, the influences of the bristle geometries of toothbrushes on the cleaning result or explain the discoloration processes caused by mouthwashes.

Latest works focus on the common phenomenon of hypersensitive teeth and successful treatment options. The industry is looking for models to evaluate active ingredients and formulas already during the development phase and before complex clinical tests. Most existing products against hypersensitive teeth aim at a closure of the channels in dentin at the exposed tooth necks, to interrupt the transmission of pain impulses to the tooth nerves. The researchers of the Fraunhofer IMWS were able to establish a model in which the closure is imaged and characterized chemically. The test procedure can be combined with a flow measurement on dentin. It also allows the integration of mechanical and acid attacks and thus offers excellent opportunities for the evaluation of analgesic products.



Regioselectively equipped hollow fiber membrane for blood cleansing. © Fraunhofer IGB (guest institute)

Germ-killing contact lenses could fight an acanthamoeba infection. © Fraunhofer IAP

Regioselectively Equipped Hollow Fiber Membrane for Blood Purification

A specially developed plasma process enables the manufacture of hollow fiber membranes allowing one-step dialysis, for example, in the case of sepsis: The filtering of blood cells and the purifcation of blood plasma take place in a single step.

The hollow fibers are regioselectively functionalized – i.e. only in the pores: Sensitive blood cells are washed through the unmodifed lumen of the hollow fibers without being affected (they cannot pass through the membrane pores because of their size). The blood plasma, on the other hand, is filtered through the nanoscale membrane pores. Their inner surface and the outside of the membrane are functionalized in such a way that inflammatory endotoxins like lipopolysaccharides (LPS) adhere to them. The purified blood plasma is reunited with the blood cells after passing through the membrane.

To achieve such a selective membrane structure, the nanopores have been provided with functional groups in a dry plasma chemical process and equipped with bioactive molecules in a subsequent wet chemical treatment.

In this case, plasma functionalization took place with amino groups, whereby a functionalization density of around 50 plasma µmol/g fiber was achieved. The functional groups are only located either on the inside or outside – this selectivity cannot be attained with wet chemical methods! However, the processes are not only limited to amino groups. Customized membrane structures can be used for different applications beyond the field of medicine as well.

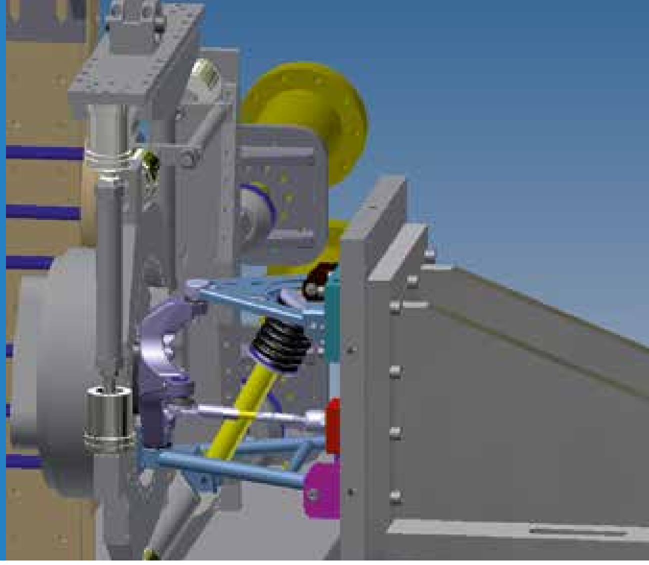
Non-invasive Treatment of difficult-to-cure Corneal Inflammation caused by Acanthamoeba

Corneal infections are a major cause of reduced visual acuity worldwide. They are usually caused by corneal inflammation triggered by germs such as bacteria, fungi, yeasts, viruses and acanthamoeba. Ophthalmologists are particularly concerned about acanthamoeba as this form of the disease often fails to respond to medication. Current therapies using disinfectants in combination with antibiotics have severe side-effects and damage the cornea.

Improperly cleaned soft contact lenses are regarded as the main transmission medium for the pathogens in 88 percent of cases. Researchers at the Fraunhofer Institute for Applied Polymer Research IAP and the Department of Ophthalmology at the University of Heidelberg are therefore investigating novel, non-invasive treatment concepts that do not require the use of antibiotics.

Plasma-treated antimicrobial contact lenses could represent a promising alternative. Plasma is known to reduce germs. In order to achieve the desired germ-killing effect, the researchers produced plasma-activated water (PAW) in which the contact lenses were swollen. The contact lenses were made of a soft hydrogel-based biomaterial patented by the Fraunhofer IAP. This biomaterial stores the PAW but does not react with it.

The antibacterial potential of the plasma-treated lenses was confirmed in all in vitro experiments – with the PAW hydrogels displaying strong antimicrobial effects. In upcoming clinical trials, the research team will be working with ophthalmologists to determine how long PAW-treated lenses can be used in order to achieve full treatment success without damaging the cornea.



With the use of digital methods in test engineering, the Fraunhofer LBF accompanies innovative product developments in industries where the focus is on reliability.
© Fraunhofer LBF

MECHANICAL AND PLANT ENGINEERING

Modeling and Parameterization of a servo-hydraulic Test Bench

Getting the test bench into the computer – this is an important step on the way to the digitized product development process. Digitization requires not only the creation of digital twins of products, but also of test environments that ensure their functionality and durability. This is the only way to virtually record the interaction of the test object and the test system, the feasibility limits in the test, and the achievable accuracies in comparison to the real application even before the actual test.

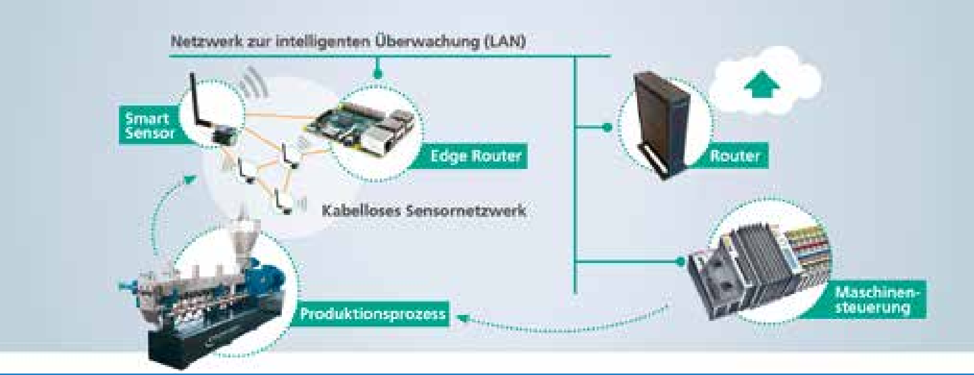
Of particular importance is the digital twin of the test bench for active systems in vehicles, such as those increasingly used in the chassis area. For example, in the development of a mechatronic roll stabilizer iARC (intelligent Active Roll Control), experimental testing is a decisive part in the product development process. There are clear differences in the test requirements for different applications. In order to implement tests more efficiently in terms of time and costs, a numerical simulation model of the test bench is being developed at Fraunhofer LBF. Together with a virtual test object model, it is possible to clarify to what extent the test requirements can be implemented on the test bench and which optimization potentials exist – even before the actual tests begin. This allows test bench occupancy times to be significantly shortened and experimental iterations to be minimized.

The test bench model comprises the non-linear system dynamics of the hydraulics, their control, as well as the kinematics. It is identified and parameterized on the basis of a test program specially tailored to the respective requirement. With regard to the interpretability of the model, a consistently physically-motivated white-box modeling approach can be chosen. The generated model is also able to map the resulting control deviations as well as the performance limits of the test system. The very high quality of the results enables a wide range of applications of the model, e.g., in sensitivity analysis and feasibility analysis.

The sensitivity analysis examines the influence of different model parameters on the simulation result. On the one hand, this provides information regarding the required modeling depth of comparable test benches and, on the other hand, shows possibilities for reducing the control deviation.

The feasibility analysis examines to what extent a test requirement can be implemented on the test bench and which limits of the system dynamics have a limiting effect.

By using the standard integration of a virtual test with the help of the digital twin in the run-up to the experimental test, significant increases in efficiency can be achieved, as obstacles can be identified early and their causes identified. This approach is of particular relevance for automotive suppliers, since testing in the vehicle is usually only possible at a very late stage in development, and the test bench is therefore the essential tool for validation.



The monitoring and optimization system developed at Fraunhofer LBF using the example of a twin-screw extruder consists of intelligent sensors with integrated sensor-data preprocessing as well as a multifunctional gateway for data preparation and process feedback. © Fraunhofer LBF

Spray suspension made of fine ceramic or hardmetal particles for thin high-performance layers with extremely low roughness. © Fraunhofer IKTS

Intelligent Sensors Monitor and optimize Industrial Processes 4.0

Cyber-physical systems (CMS) are the silent heroes of »Industry 4.0«. Forecasts indicate that they will determine global production. Intelligent sensors for monitoring and controlling production processes ensure that networked, autonomous work processes can run reliably.

With its newly developed monitoring system, Fraunhofer LBF offers companies a universal platform, for example, in condition monitoring or maintenance planning. Together with manufacturers and users of machines and systems, the Fraunhofer experts can flexibly transfer the modular, adaptable system to different processes and machines in companies. Networking the data via a data pool, for example, in a cloud service, facilitates status monitoring for the respective specific application across all machines and operations. By combining existing data from the machine controller with selected, additionally-recorded sensor data, critical operating states or material fluctuations can be detected, and faulty batches or machine failures can be minimized. Standardized interfaces are used to enable simple, subsequent integration into existing company networks (retrofitting).

In addition, the researchers have implemented signal preprocessing that allows measurement data to be reduced in the sensor node. Non-measurable process data can be calculated based on models in the new system. In order to avoid critical system states and reduce wear, optimization algorithms provide a direct condition-based feedback effect on the process control.

Suspension Spraying for robust and functional Surface Refinement

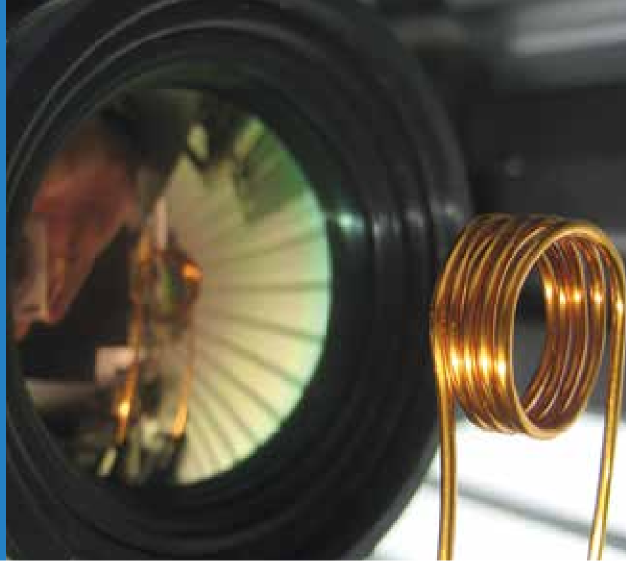
Ceramic coatings can provide a significant contribution to the surface resistance and quality of machine components with regard to wear protection, non-stick effect or insulation behavior. Thermal coating methods based on ceramic or metal powders are among the most common solutions. Although the powder particles used are fine and the coatings thin, these surfaces are very rough. In order to achieve the desired surface quality, the coated components therefore often require extensive finishing or sealing. To remove the need for such steps, the Fraunhofer Institutes IKTS and IWS have developed further a specific thermal coating method: Instead of powders, a suspension is sprayed, which contains much finer particles than the typical spray powders. This makes it possible to produce thin (< 100 µm) and dense layers with very smooth surfaces, and it also helps save on raw materials.

The layer properties are determined first by the parameters prevalent in the thermal spraying process, and second by the suspension properties. Materials with a homogeneous particle size distribution and high purity are particularly suited for producing suspensions. Using electroacoustic, rheological and sedimentation measuring technologies, the suspension properties can be adjusted and optimized with regard to solid particle content, grain size distribution, and viscosity.

In addition to ceramic materials, such as chromium oxide, alumina or zirconium oxide, it has now become possible to spray hardmetals thermally while avoiding defects. Furthermore, the technology enables graded layer systems, which allow, among other things, for the combination of different thermal and mechanic properties.

Demonstrator for active thermography on rail wheels. © Fraunhofer IZFP

Copper coil. © Fraunhofer IZFP



Tracking Down Minute Cracks – Active Thermography with Inductive Excitation

In many branches of industry safety-relevant components have to undergo a one hundred percent check in order to exclude surface cracks during manufacture. In the future, all procedures that do not require special surface treatment, that work reliably and objectively and that enable a fully automatic examination of components are given a competitive edge.

Inductively excited thermography permits surface inspections for cracks without surface treatment; it is fast and nondestructive. It is an objective procedure that provides reliable test results and additionally makes it possible to determine the location of the defect (crack depth). Thus it is suited for fully automatic test facilities that carry out a one hundred percent testing of components in industrial production lines.

Fraunhofer IZFP has a comprehensive range of technical equipment for different variations of active thermography:

- optical impulse and »lock-in« excitation (periodic excitation)
- ultrasonic excitation
- inductive excitation by electromagnetic alternating felds
- noncontact infrared measurement technology with infrared camera system for close, medium and long-wave infrared radiation area with temperature resolutions up to approx. 15 mK and image frequencies up to 20 kHz (time resolutions up to 50 µs) at image resolutions up to 1024 x 768 pixels
- robots and linear adjustment units for fast automated testing with integrated thermographic systems
- software for testing system control, and data processing and measurement data evaluation as well as for automatic defect detection and defect reconstruction
- theoretical and experimental tests concerning the physical principles and application possibilities of different active thermal testing technologies

Range of services

- test measurements and feasibility studies for industrial applications
- tests based on the accreditation of the institute's test and application center
- conception, planning and construction of mobile test systems
- conception, planning and construction of fully automated test facilities for the online testing of components in the production line, including robot-assisted test systems

Advantages

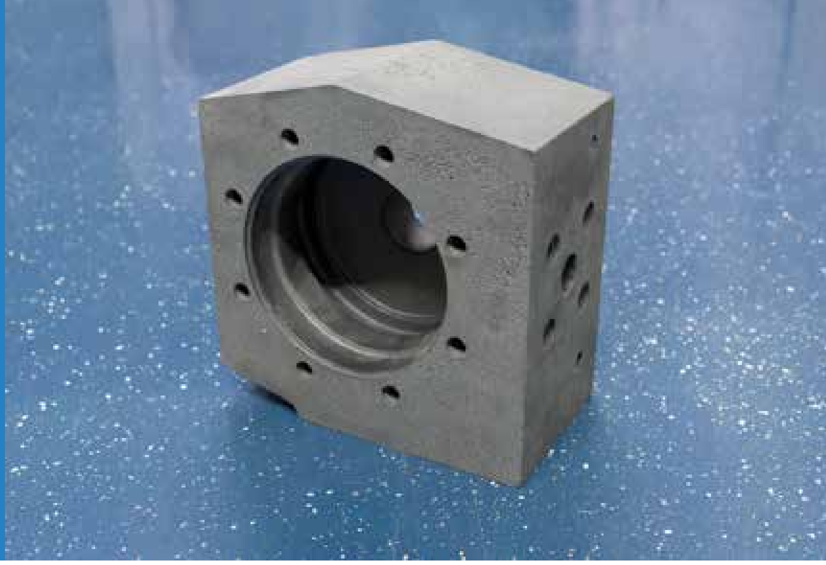
- contactless and fast examination method for surface crack testing
- testing of components with complex geometries
- possibility of determining crack depths
- possibility of verifying hidden defects
- objective and reliable testing of components in industrial manufacture
- capacity for easy automation without greater mechanical effort
- suited for fully automated testing facilities for one hundred percent testing of components in industrial production lines

Applications

- crack detection on forging parts
- in-process crack detection on long products made of steel
- tests for surface cracks on railway tracks and wheels
- detection of delamination in metallic material compounds
- replacement for magnetic particle inspection
- crack detection in photovoltaic cells
- crack detection in turbine components
- detection of fiber breakage in CFRP

Modular high-temperature reactor for the continuous synthesis of nanoparticles. © Fraunhofer IMM

Pump housing (SICcast Mineralguß GmbH) with an inner coating made of superhard diamond ceramics. © Fraunhofer IKTS



Modular, High-Temperature Reactor for the Continuous Synthesis of Nanoparticles

Fraunhofer IMM has developed an innovative modular reactor for continuous flow synthesis that is designed for the synthesis of nanoparticles at elevated temperatures. The reactor is able to withstand liquid-phase reactions of up to 400 °C. Standard hot injection synthesis protocols for the synthesis of nanomaterials can be transferred from a batch to a continuous process. The central part of the reactor is a microfuidic mixer developed by Fraunhofer IMM and a temperature-controlled delay element. Integrated optical flow-through cells allow for in-situ optical detection at different positions and at high temperatures on location and thus lay a foundation for on-line process monitoring.

The modular design of the reactor allows it to be adapted to specifc needs, since both the design and the construction are carried out at Fraunhofer IMM. Because of its compact size, the reactor module takes up little space in the laboratory or fume hood and can be integrated into already existing set-ups. Its design enables the transfer of batches to continuous processes, especially synthesis paths for nano-particles that require higher temperatures and fast mixing (hot injection). These conditions are usually available in high quality during the synthesis of monodisperse nanoparticles. Examples for this are organometallic syntheses such as those used for CdSe quantum dots, Pt and other metallic nanoparticles or oxide metals.

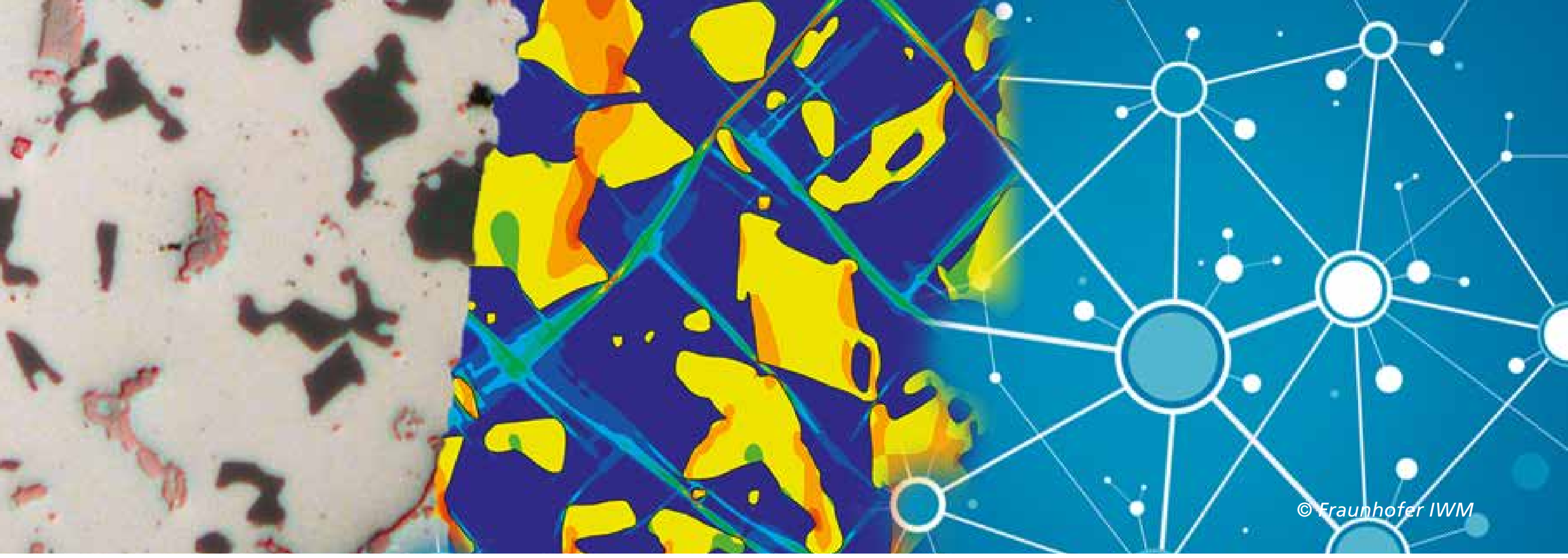
With our knowhow in continuous flow chemistry, microreaction technology and plant engineering, this reactor represents the centerpiece of a complete, customized system in laboratory scale for the synthesis of nanomaterials. We offer tailored services with regard to the design and construction of prototypes or feasibility studies while taking customer needs and specifcations into consideration.

Superhard Diamond Ceramics for Deep-Sea and Offshore Mining

In deep-sea or offshore mining for oil and gas, the durability and freedom from maintenance of all deployed machines over timespans of 10 to 30 years is essential. Achieving this is next to impossible with conventional materials – specifically, for example, with regard to wear components in pumps, pipe segments or nozzles. For this field of application, Fraunhofer IKTS, in collaboration with its Fraunhofer AdvanCer Alliance partners, is developing superhard, wear- and corrosion-resistant diamond ceramics.

In contrast to commercial diamond materials, these novel diamond ceramics can be manufactured in a cost-efficient manner and in complex geometries using conventional ceramic technologies – on the one hand as compact components and on the other hand as layers of 300 to 500 µm thickness in highly stressed component areas. Thereby, the diamond preform is infiltrated with liquid silicon. During the infiltration, a three-dimensional framework is formed in which the diamond is chemically integrated. This SiC bonding results in higher strength of 450 to 500 MPa and a high corrosion resistance. In addition, tribological tests show that the wear resistance of the developed diamond ceramics is 10 times higher than that of commercial boron carbide materials and they have a wear behavior similar to that of superhard polycrystalline diamond (PCD).

The microstructures of the materials can be adjusted across a wide range allowing for the production of components with customized properties. The developed diamond ceramics open up new possibilities for manufacturing wear- and corrosion-resistant components cost-effectively for applications beyond the deep-sea area as well.

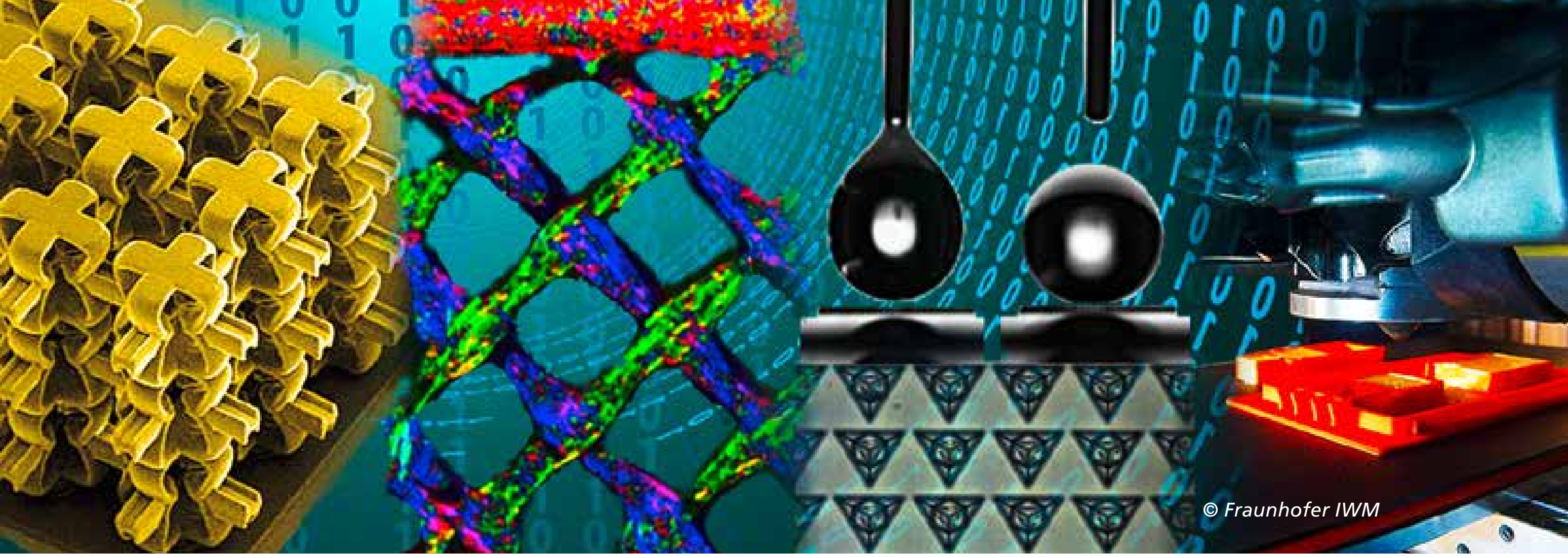


Digitalization of Materials for better Products and Processes

Industrial production and modern information technology are being combined in the context of Industry 4.0 with the aim of optimizing value creation chains and component functions. This requires relevant material properties that change with location and time to be taken into account in individual process stages. The challenge: the data is very heterogeneous and must be derived from inline sensors or indirectly from a large number of material experiments and process simulations.

The aim of the MaterialDigital project of the state of Baden-Württemberg under the leadership of the Fraunhofer IWM is to ensure that the materials being processed are part of the continuous digital value creation chain. A materials data space has been set up for digital mapping of process and material history. In addition to pure management of the data in the knowledge graphs, the Fraunhofer IWM is developing interfaces for data entry and output and search tools that are as generic as possible. An ontology for cast aluminum materials - likewise as generic as possible - is also being drawn up. The Fraunhofer IWM is feeding sensor data from a casting and heat treatment process for an AlSi10Mg alloy being measured by the institutes involved into the new materials data space.

The Fraunhofer IWM is supporting test specimen development with structural mechanical calculations and investigations. At selected points in the casting and heat treatment process chain, the Fraunhofer IWM generates digital material twins of the test specimens from the material data space: these describe, in particular, the material state at critical points that have been defined in advance. A process control system that can be used in-line is also being developed that makes it possible to obtain information about the local casting structure (and the casting defects contained within).



Programmable Materials for Future Systems with Integrated Functions

The development of programmable materials is turning our use of materials upside down: a single material can replace an entire system of sensors, controllers and actuators by integrating their functions. The aim of the Fraunhofer Cluster of Excellence Programmable Materials, which is led by the Fraunhofer IWM, is to use materials of this sort to reduce the complexity of current systems and reduce the consumption of resources. The focus is on programmable transport characteristics on the one hand and mechanical properties on the other. One example of a formally and functionally dynamic material of this sort is plastic coating for the inside padding of a prosthetic leg: the structured polymer is soft at first, to protect the stump of the leg. If the person lifts something heavy, then a higher load is applied to the coating and it hardens a little so that the sensitive stump does not press against the hard prosthetic material.

Desirable functions of this sort are achieved by designing the internal material structure for the function required in accordance with various scales. This is only possible due to a deep technical understanding of the mechanisms and fabrication of programmable materials. The various programs are fundamentally developed, characterized and presented in the form of demonstrators in the Fraunhofer Cluster of Excellence.

All the expertise of the Fraunhofer IWM, IAP, IWU, ICT and IBP is brought together to design, implement and produce a function of this sort and materials and processes are monitored from the molecular to the macroscopic scale.

The Peel$^{PLAS®}$ release film can be easily removed leaving a contaminant-free cured component. © Fraunhofer IFAM

The new low pressure plasma plant at Fraunhofer IFAM enables the coating of up to 2.4 meter wide polymer films. © Fraunhofer IFAM

Contaminant-Free FRP Component Manufacture Using Peel$^{PLAS®}$ Release Film

The release agent free manufacture of large fiber reinforced plastic (FRP) structures, such as those used for aircraft and wind turbine construction, would mean that process steps such as applying release agents to molds and removing release agent residues from cured components could be avoided. To realize this goal, the experts in the Plasma Technology and Surfaces department and Automation and Production Technology department at the Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM have developed Peel$^{PLAS®}$ release film, a film suitable for deep-drawing processes and functionalized with plasma technology.

The special feature of the release film is its very thin (less than 0.3 microns), adherent plasma-polymer layer that was developed by Fraunhofer IFAM. This allows easy demolding and leaves behind no residues at all on the component surface. The Peel$^{PLAS®}$ release film can be stretched with little force and can even withstand extreme elongation up to 300 percent and temperatures up to 180 °C without functionality impairment. This is ideal for fold-free application, even on curved and structured molds. In order to apply the release film it is first secured in place and sealed with butyl rubber tape or a reusable, automated seal that is under development at Fraunhofer IFAM. A vacuum is then applied between the release film and mold, causing it to be applied like a second skin, even over complex surface contours. The films can also be used for the release agent free manufacture of very large FRP components.

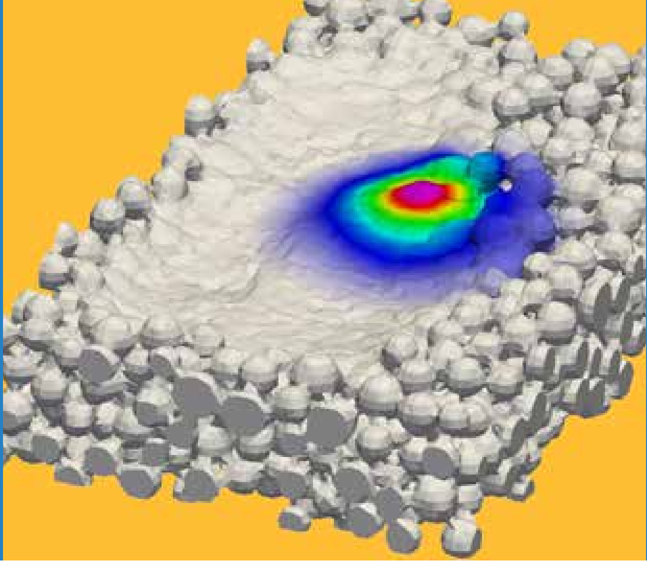
The innovative Peel$^{PLAS®}$ release film is not only suitable for use with prepreg technology but can also be used for other manufacturing processes such as the (vacuum) infusion process, the hand lamination process, or resin transfer molding (RTM). Furthermore, the releasing properties of the flexible release film are not solely limited to carbon fiber and glass fiber matrix resins.

In addition, the new technology allows in-mold coating of fiber composite components, whereby the component is coated by integral application of a gel-coat to the film. The matt effect of the coated surface can be adjusted via the roughness of the Peel$^{PLAS®}$ release film that is employed. This coating technique significantly lowers the risk of coating defects.

This enables FRP to be coated, without release agent residues having to first be removed. If the film remains on the component to the end of the process or up to delivery to the final customer, then it also serves as a protective film.

Besides removing the need to coat the surfaces of molds with release agent, the use of Peel$^{PLAS®}$ release film also increases the productivity of various other steps in the process chain. For example, there is no longer a need to thoroughly clean the molds to remove release agent residues. This means that the mold service life and availability are considerably increased.

Due to the great research potential and the positive response of industry, Fraunhofer IFAM has invested in the construction of an innovative low pressure plasma plant that enables up to 2.4 meter wide polymer films to be applied even more effectively with the plasma-polymer release layer in a roll-to-roll process.



Simulation of melting and solidification of a powder layer. © Fraunhofer IWM

3D powder-printed and sintered hardmetal drawing die with internal cooling channels. © Fraunhofer IKTS

Simulation of Melting and Solidification Dynamics in Additive Production Processes

The reliability of components produced by additive manufacturing is not yet sufficient for their use in lightweight structural elements but such components could help to further reduce weight and increase functionality. Highly complex parts with mechanical properties customized on a computer could be manufactured in a powder bed laser melting process. However, there are currently no established simulation tools for application dependent design of additive manufactured components.

The Fraunhofer IWM is developing and refining its particle-based SimPARTIX® software to provide tools of this sort. The packing densities created during the powder spreading process - crucial for the subsequent melting process - are simulated. In this process, the powder is described on the scale of grains including their physical interactions. Powder bed inhomogeneities can thus be found and avoided. In addition, simulation of the melting and resolidification processes in the actual laser melting procedure allows predictions of part properties, such as porosity and surface roughness, which ultimately provide indicators for the strength of the resulting component. Local heating by a laser, heat conduction in the material and flow in the melt pool are calculated for this purpose.

The results help to find processing windows for a given powder and to adjust the process parameters accordingly. In addition, the suitability of powders for the laser melting process can be evaluated. The simulation also supports development of new materials such as alloys, as the number of experimental development cycles required can be reduced.

Complex Hardmetal Tools from the 3D Printer

Hardmetal is a powerful material, characterized by its high degree of hardness, wear resistance and toughness. The complexity of hardmetal components is currently limited by conventional shaping processes. Only relatively simple geometries can be realized. However, modern tools often require much more complex geometries, such as helical or meandering cooling channels inside the component. These geometries need to be produced in time-consuming and cost-intensive processes by cutting and grinding hardmetal blanks with diamond tools or through eroding methods. Therefore, the researchers of Fraunhofer IKTS are developing complex hardmetal tools by using 3D printing methods. The quality of the products obtained is fully up to par with high-performance tools manufactured with conventional methods.

In the binder-jetting printing method used, the starting powders or granulates are wetted locally and bound with an organic binder through a print head. The heat treatment, which needs to be adapted specifically to the composition, drives out the binder in a first step before compacting the component through high temperature and pressure. By optimizing the process chain, the researchers successfully obtained components which are fully sealed and come with a perfect hardmetal microstructure and excellent mechanic properties. By precisely varying the binder matrix, it is possible to adjust bending strength, toughness and hardness – the lower the binder content within the hardmetal, the harder the component will be. The prototypes manufactured at Fraunhofer IKTS have a binder content of 12 or 17 weight percent and a microstructure that is similar to that obtained through conventional production routes.

The mobile machining robot at the Hannover Messe 2018 in the context of integration into a digital production environment. © Fraunhofer

The world's most precise 6-axis industrial robot on the AGV machines the vertical tail plane of an Airbus 320 . © Fraunhofer IFAM

Mobile Robots for the Versatile High-precision Machining of Large Lightweight Components at Favorable Cost

Large lightweight components such as those used for aircraft manufacture are usually made of carbon fiber reinforced plastic (CFRP) or aluminum alloy. The size of such components presents a special technical challenge. These components have relatively large and differing deviations from the ideal geometry due to the manufacturing process and stiffness. However, the subsequent machining and assembly require that very strict dimensional variation be met. Permissible deviations from the design optimum are often just ± 0.2 millimeter, and sometimes even less. Meeting these boundary conditions was the goal of the ProsihP 2 project carried out by the Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM in Stade, namely to replace existing portal systems for contour milling of large CFRP shells with a more efficient and more favorable-cost technology with improved versatility.

The most promising concept involves replacing a portal system with three mobile robots with no increased space or investment requirements. This would increase productivity by ca. 40 percent. An additional benefit of the mobile robots – even after end-effector change – is their use elsewhere for other tasks.

The challenge for the project partners was to develop a system comprising an automated guided vehicle (AGV) and industrial robots that can individually measure components and machine them with the required precision. As neither robots having the required absolute precision nor AGVs having the required stiffness were commercially available, it was decided to design a new AGV and to modify a commercial robot with the necessary controls, motors, and sensors.

The cost-effective AGV is made from standard components and is suitable for interchangeable heavy-duty robots from all manufacturers having a weight up to 2.6 tonnes. For the machining work it is firmly positioned on the floor with the aid of three legs. This so prevents destabilizing effects of the AGV running gear. Three extendible wheels give the AGV total freedom of movement and it can even turn on its spot.

The project team equipped the kinematics of the robot with a Siemens CNC system, incorporated compatible motors, and added output-side angle measuring systems on each axis for correcting positional deviations. Prior to the start of the process the robot is calibrated using a procedure based on the replacement of the kinematic robot model with an individually parameterized model. In addition, cameras or laser trackers register the actual position of the robot, so allowing real-time correction by comparison with target data. This joint project has not only realized a unique mobile machining robot to meet the requirements of the aircraft manufacturing industry – it has developed the world's most precise machining robot.

The system received the ROBOTICS AWARD 2018 at the Hannover Messe and is designed for components of up to 30 meters in length. It can, for example, be used for various primary aircraft structures such as wing and fuselage sections. Furthermore, with minor modifications the mobile robot system can be used, for example, for machining wind turbine rotor blades or for large components for shipbuilding.

The project was funded by the State of Lower Saxony and involved the following partners: Aicon 3D Systems GmbH, Airbus Operations GmbH, Artis GmbH, CTC GmbH Stade, Fraunhofer IFAM, IPMT of TU Hamburg, Ludwig Schleicher Anlagenbau GmbH, Mabi AG – Robotic, mz robolab GmbH, Siemens AG, and Volkswagen AG.

The flexible polymerization pilot plant in the Fraunhofer PAZ synthesis center enables the synthesis of sample quantities up to the ton scale.
© Fraunhofer IAP / Till Budde

The Fraunhofer PAZ evaluates the use of long-fiber reinforced thermoplastic components for lightweight applications.
© Fraunhofer IMWS / Sven Doering

Ton Scale and Series Production – Polymer Synthesis and Processing on an Industrial Level

Scale-up is a decisive step in the commercialization of new technologies and products. Both the materials and the manufacturing processes must be adapted for industrial use. The Fraunhofer Pilot Plant Center for Polymer Synthesis and Processing PAZ in Schkopau provides the plants, infrastructure and experience to do this. In order to meet the requirements of its customers in the plastics and automotive industries, the Fraunhofer PAZ develops a range of polymer synthesis processes and processing methods on a scale that can be used by industry. The range of services extends from the production of monomers and polymer synthesis on a pilot plant scale to plastics processing for large-scale production. It also processes lightweight and biobased materials.

The Fraunhofer PAZ is a joint initiative of the Fraunhofer Institute for Applied Polymer Research IAP in Potsdam-Golm and the Fraunhofer Institute for Microstructure of Materials and Systems IMWS in Halle. The Pilot Plant Center unites the expertise of both institutions - Polymer Synthesis (IAP) and Polymer Processing (IMWS) - in a unique way. This cooperation, which combines the technical capabilities on a pilot plant scale with high plant flexibility, creates a unique selling point on the European R&D market.

Polymer Synthesis up to Ton Scale

The polymerization pilot plant is designed as a flexible multi-product plant. A wide range of polymerization processes relevant to industry can be simulated on various synthesis lines, for example (anionic) solution polymerization, emulsion polymerization, suspension polymerization as well as polycondensation and catalytic polymerization. Reactor volumes of the main reactors range from 50 to 1000 liters and both discontinuous and continuous operation is possible. Reaction pressures range from a vacuum of less than 1 mbar to 100 bars and temperatures range from room temperature to 300 °C.

New, customer-specific processes can be implemented by flexibly combining equipment from different production lines. Project goals include scale-up from lab scale to pilot plant scale, as well as the development of technology and preparation of sample material, e.g. for product development and application testing. One field of activity is expansion and process development in the area of synthetic rubber.

Polymer Processing up to Series Production

Polymer processing focuses on investigating thermoplastic-based lightweight fiber composites and innovative rubber composites for use in large-scale production.

The range of services extends from customer-specific material development to the development of fiber-reinforced semi-finished products as well as component and technology development for lightweight thermoplastic-based structures. Particular attention is placed on the relationship between processing and structure and between structure and properties.

The Pilot Plant Center is able to provide its customers with sample production up to a ton scale, technical capabilities to quickly produce sample tools, pilot scale production, and the complex analysis of components and materials.

Another research focus is microstructure analysis using non-destructive testing techniques and online testing methods. The properties of thermoplastic components are optimized by predicting crystallization processes and controlling crystallization states.

Bridge as an example of an infrastructure construction. © Fraunhofer IZFP

CONSTRUCTION AND LIVING

Cognitive Sensor Platform – Permanent Condition Monitoring at the Push of a Button

Aging infrastructure systems, especially in the traffic sector, pose major challenges to technological progress and steadily increasing mobility. For example, bridge refurbishment is often not carried out until the end of the bridge´s projected lifetime, sometimes when the bridge is already in danger of collapsing. In the worst case this could lead to its demolition. Fraunhofer IZFP researchers are concerned about ensuring timely inspections and refurbishments and for this purpose, they have developed a modular monitoring platform for fast and cost-effective repair.

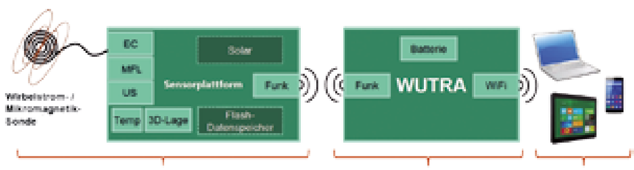
The technical safety of traffic structures can only be guaranteed by reliable condition monitoring and evaluation. Accidents caused by structural weaknesses or by late condition assessment can be avoided by permanently monitoring a structure's condition, which enables a timely assessment. Manual inspections are too costly and time-consuming and they are often carried out too late. As well as bridges, the safety of funiculars, the requirements of power plant technology and the chemical industry as well as high masts and traffic lights in city centres can also be cited as evidence of this. In all these areas, there are known to have been incidents which were caused by material aging and corrosion which were either not discovered or discovered too late.

Modular, self-powered and cost-effective Infrastructure Measurement Systems

At Fraunhofer IZFP in Saarbrucken, a cognitive sensor platform was developed as a system which is able to meet the demand for permanent, modular infrastructure monitoring easily and cost-effectively. This means that expensive server structures and the need for regular maintenance of failure-prone systems will soon be a thing of the past. The possibility of connecting sensors, which have been specially adapted to suit the inspection task, to the structure provides tailor-made solutions and enables permanent monitoring of the structural condition.

Miniaturized Sensors permanently search for Cracks and Changes in the Building Fabric

The sensor platform consists of tiny sensors permanently attached to the construction, which detect the smallest changes in its structure. Each of these sensors contains a long-term data memory, which can be read out telemetrically at any time via a radio interface and which offers the prerequisites for a comprehensive condition evaluation of the building. The sensor platform is designed for a decade of operation without maintenance or replacement; for this reason its power supply comes from a renewable, permanently available energy source. Fraunhofer IZFP has adapted the existing non-destructive testing methods for this novel monitoring system and made them suitable for series production.



Principle Cognitive Sensor Platform © Fraunhofer IZFP

At close proximity to the module, the solar cells can be seen under the colored cover glass. © Fraunhofer ISE

Detailed view of the adsorption heat exchanger with zeolite. © Fraunhofer ISE

Colored Photovoltaic Modules based on the Morpho Butterfly

In order to realize zero or plus energy buildings, PV modules are often installed in the façade as well as on the roof. Architects and building owners not only demand a good price to performance ratio but also require modules that are aesthetically pleasing and offer a variety of design options. There is a large demand for modules in different colors with high saturation and a homogenous appearance.Conventional methods to color solar cells or cover glass offer a limited selection of colors and have a decisive disadvantage: Namely they cause comparatively high energy losses. Inspired by nature, Fraunhofer ISE developed a new procedure to produce colored modules with minimal transmission losses, thus reducing energy losses to a minimum.

A phenomenon observable in the morpho butterfly provided the starting point for the work. The fascination of the morpho butterfly lies in its brilliant blue wing color. The reason this fascinating blue color is so noticeable, is not because of pigments on the wing surface as with other butterflies, but rather due to a three dimensional surface structure with lamellae in the nanometer range. The miniature lamellae, which can only be seen under an electron microscope, cause light to diffract and interfere. The many lamellae reflect light of a specific wavelength, in this case blue. The reflections reinforce one another so that a truly brilliant color is achieved. The special highlight of this structure is that it remains transparent for the other wavelengths. Therefore, it is excellently suited for producing brilliant colors while maintaining a high light transmission. The reflected color can be specified by adjusting the distance between the lamellae.

Fraunhofer ISE demonstrated the feasibility of producing such a color-giving three dimensional surface structure on large area cover glass for PV modules. The developed coating is made of a dielectric material enabling high color saturation as well as good incident angle stability. The color is individually adjustable. In comparison to uncoated cover glass, the colored modules exhibit a relative power loss of only 7 percent.

Adsorption Development: Adsorption Heat Pumps and Chillers

In the area of thermally driven heat pumps and chillers, Fraunhofer ISE is working on compact adsorption heat exchangers. Standard heat exchanger concepts are combined with a newly developed metal composite material.

Heat dissipation during the adsorption process is very important for operation of the adsorber. The power density of the adsorber is dependent on the amount of sorption material per volume. One possibility to optimize the adsorption process is to apply porous metal carrier structures with a high specific surface area and good thermal conductivity.

An adsorption module was produced and measured in a cooperative project with Fraunhofer IFAM and industry partners. The heat exchanger structure is based on flat pipes made of aluminum that are manufactured in an extrusion molding process and coated with soldering agents. One considerable advantage of this type of construction is the large surface contact of the composite material with the heat-exchanger surface, enabling the heat to dissipate from the active material over short distances. The power density could be increased by at least a factor of five compared to state-of-the-art technology, which makes wall-mounted adsorption heat pumps conceivable, for example.

Further developments on composite materials and their integration into standard heat exchanger concepts are currently underway. Alternative carrier materials such as wire mesh or foams as well as new classes of adsorption materials like metal organic frameworks are promising future candidates.

Façade profiles during the SBI test.
© Fraunhofer WKI / A. Schirp

Adsorber-based coating with zeolite sorption material on an industrial-scale air-air-heat exchanger for the air conditioning of buildings.
© Fraunhofer ISE

Flame-retardant Wood-Polymer Composites (WPC) for Façade Profiles

In collaboration with industrial partners, researchers at the Fraunhofer Institute for Wood Research WKI have developed flame-retardant WPC for application as façade profiles. The project was funded by the BMEL via the FNR. WPC is composed of around 50 - 70 % wood particles and around 30 - 50 % thermoplastically processable polymers, in particular polypropylene and polyethylene. As a result of its high durability, WPC is primarily used to manufacture products for outdoor applications. With the development of flame-retardant WPCs which comply with building regulations, the range of applications can be extended significantly.

For the production of the façade profiles, high-density polyethylene (HDPE) was utilized and both the wood flour and the polymer were equipped with suitable flame retardants. Important material properties of the WPC, such as water absorption, swelling and strength, should thereby remain unaffected. The developed formulations were subsequently processed on an industrial scale. Testing of the material in the Single Burning Item test (SBI) showed that pre-treatment of the wood flour with a flame retardant leads to a better classification of the produced WPC. In further experiments, WPC profile types with a higher wood content (55 %) and with PVC as the matrix were produced. With the higher wood content, the researchers were able to achieve a very good classification in the SBI. For the formulation with 42 % pre-treated wood flour and HDPE as matrix, they achieved the same classification as for the PVC-matrix variant without the addition of flame retardants.

The partners achieved the production of flame-retardant bonding agents through the development of long-chain phosphoric acid esters. The synthesized products exhibited a good adhesion which, in some cases, was even better than that of the reference bonding agent MAPP. As regards the flame-retardant effect, however, room for improvement still remains.

Highly Porous Coatings for Thermal Cooling Units and Heat Pumps

Thermally powered cooling units are an alternative to regular air conditioners. They evaporate liquids, such as water at low pressure and thereby extract warmth from the air. Fraunhofer ISE is working on new types of sorption materials that can absorb a particularly high amount of water. The researchers use metal organic frameworks (MOFs) for this purpose. These consist of a metal complex and an organic part. They typically have an inner surface of up to 4000 m^2 per gram and can bind up to 1.4 grams of water per gram of material. Up to now, MOFs have been used as a filling. However, a filling made of MOF granulates prevents thermal conduction. But if the material is used in a thin layer on metal slats, heat dissipation is increased and, as a result, the performance of the appliance as well.

Researchers have developed two complementary methods for coating heat exchangers and other components with highly porous metal organic frameworks – a direct crystallization method and a binder-based coating. These enable the application of different MOFs or adsorbents such as silica gels, zeolite or silica-aluminum phosphates to components.

This is not only interesting for application in buildings but also in areas in which reversible chemistry or physical reactions take place with heat transformation. Chemical processes often use catalysts with large inner surfaces. A coating of MOF or zeolite can improve the flow rate or temperature stabilization.

The wood foam developed at the Fraunhofer WKI is comprised of 100 percent renewable raw materials.
© Fraunhofer WKI / M. Lingnau

Wood Foam – From Tree to Foam

Foams are usually comprised of plastics on a petrochemical basis. At the Fraunhofer Institute for Wood Research WKI in Braunschweig, researchers have developed a new foam material: It consists of 100 percent renewable raw materials, is climate-friendly and recyclable. In the long term, wood foam could replace conventional petroleum-based foams, whether for thermal insulation, packaging or lightweight construction materials.

The researchers at the WKI developed procedures for producing foam from wood particles. To create the foam, the wood is first ground into fine particles with a high water content until a viscous mass is formed. The researchers foam this suspension chemically or physically by means of internal or external gas generators. The mass subsequently hardens in the drying oven. The cohesion of the foam is achieved through the wood's own binding forces. A possible health hazard through emissions from adhesives does therefore not exist. The result is a lightweight base material with a porous, cellular structure and a low bulk density. Foams made from beech wood, for example, can be specifically produced within a density range of between 40 kg/m³ and 280 kg/m³. The material can be further processed as hard foam board or elastic foam material and, like other wood-based materials, is easy to saw or mill. The product thereby creates very little dust and is odorless.

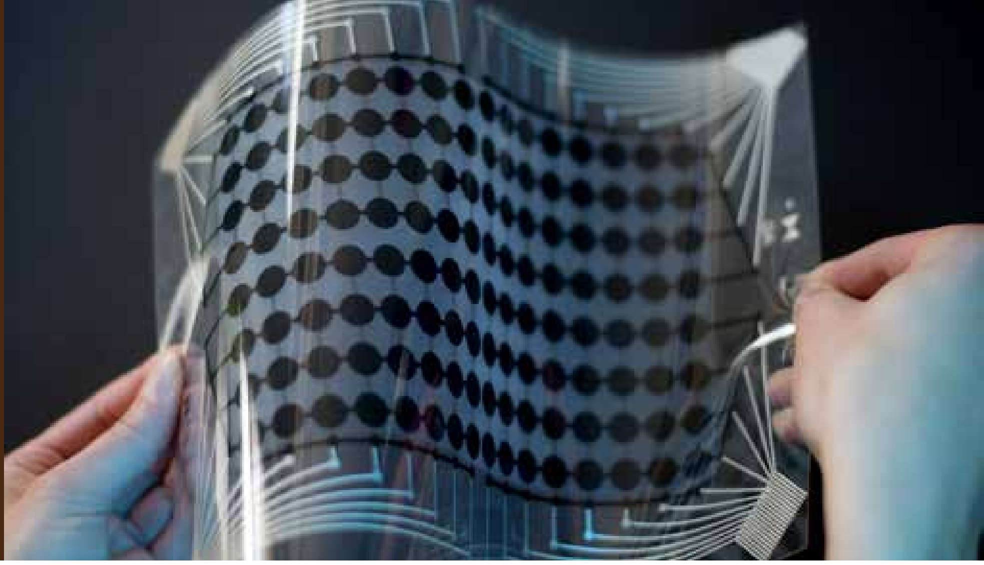
Wood foams are particularly suitable as insulation material for buildings. Whilst wood-based insulation materials already exist, these have the disadvantage that they are less dimensionally stable than insulation materials made from plastic. The wood foam developed at the WKI, however, can compete with classic plastic foams. The foam products have already been tested in accordance with the standards applicable to insulation materials. For both the thermal insulation properties and the mechanical and hygric properties, highly promising values have been obtained. The compressive strengths at 10 % compression are, depending on the thickness, 40 - 210 kPa. At low densities (0.038 w/m·K), the thermal conductivities lie between those of polystyrene and wood-fiber insulation panels. The thickness swelling after 24-hour water storage is <1 percent. The fire behavior is similar to that of natural-fiber insulation materials: they burn and smolder, and in some cases the flame extinguishes independently. Potentially necessary additives can be easily and efficiently mixed with the fibrous material during the production process.

A further advantage: In contrast to conventional foam, the wood foam can be unproblematically recycled. If it has been used as packaging, for example, the consumer can simply dispose of it via the waste-paper system.

Scientists are currently experimenting with different types of wood. Within just a few years, products made from wood foam will be manjaufactured industrially on a large scale and available on the market.

The enormous potential of this innovative material is reflected in the awards which the wood foam has already received. The development was nominated for the Deutsche Rohstoffeffizienz-Preis (German raw material efficiency award) in 2014, and won both the Interzum award »Best of the Best« and the GreenTec Award in the category »Construction and Living« in 2015.

The starting materials for the wood foam: Wood fibers and water are ground to a suspension and foamed.© Fraunhofer WKI



Sensitive, flexible film for touch displays. © Fraunhofer ISC

MICROSYSTEMS TECHNOLOGY

New Sensor Materials Enable Flexible and Light Touchscreens for Displays

Although flexible and cost-effective printed touch displays are still a vision of the future, they are predicted to have a wide range of application. Their advantage is freedom of design their easy adaption since it is possible to roll out, so to speak, the display film. In addition, the cost-effective manufacturing process has low material costs compared to other methods while maintaining the good sensor characteristics. The material can also be produced on a large scale. Last, but not least, the polymer-based touch displays are lighter and more robust than the conventional hard glass-based displays available today.

A new material development from Fraunhofer ISC takes the flexible display technology one big step forward. Printable sensor materials applied to a film can register deformations and transmit their signal directly and in high resolution to a computer. Combined with a flexible display, both tablet PCs and smartphones will not only be operable via virtual switches and buttons but also by means of bending and moving the film.

Signal by Means of Deformation

The sensors that were developed within the framework of the EU project »Flashed« are made from innovative piezoelectric printing pastes. They can be extensively applied to a flexible polymer film and allow for the installation of electronic printing sensors with a simple printing process. The sensitive surface of the film – when it is connected to a display, for example – measures the deformation when touched. The resulting signal can be digitalized and spatially depicted. The new touch sensor technology will fundamentally change the operation of mobile end devices since the new types of sensors enable a more intuitive control – without switches, buttons or swiping function.

Not only Pressure but also Temperature Sensitive

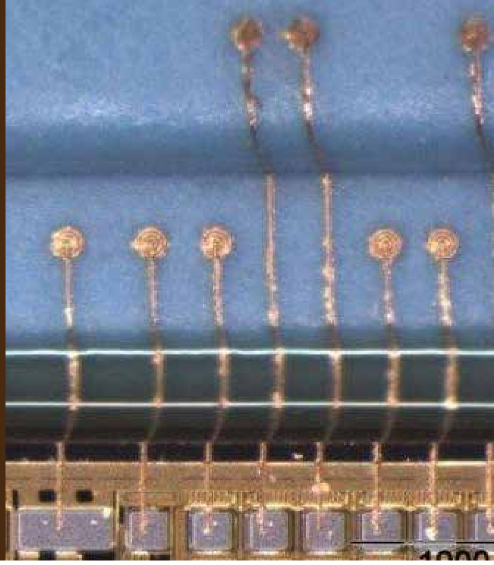
The sensors, which are inexpensive to manufacture, register not only changes in the mechanical pressure – for example when the flexible display is bent and moved – but also changes in temperature. This also makes them applicable as proximity sensors. Even the smallest change in temperature – such as when a hand approaches the sensor – triggers a corresponding signal. However, this effect can also be suppressed by the developers, if it is not needed. In the case of the FLEX SENSE display, it is advantageous to completely switch off the temperature sensitivity in order to attain a higher local resolution. In addition, the sensors can also be used as actuators to enable haptic feedback. The combination of sensor characteristics with haptic feedback can improve the user-friendliness of many applications and increase the range of functions.

Lead-free in the Future

Lead titanates have been used in sensors up to now. This material, which has been classified as harmful to health, is to be eliminated in the future. Therefore, an important goal is to replace piezo materials containing lead with other materials without losing too much of the sensitivity. New ferroelectric particle matrix systems are being developed within the framework of the project and are being adapted to current screen printing processes.

Scanning acoustic microscopy offers a wide range of applications in Microelectronics.
© Fraunhofer IMWS

Printed precious metal contact.
© Fraunhofer IKTS



New failure analysis Methods for the 3D Integration of Microelectronic Systems

To further improve the packing density and performance of microelectronic components, many manufacturers rely on the utilization of the third dimension with stacked chip structures. These new component architectures with newly developed connection technologies result in enormous technical challenges along the production chain. Amongst other things, new defect images are to be investigated. A group at the Fraunhofer IMWS in Halle specializes on this work and the development of suitable analysis techniques

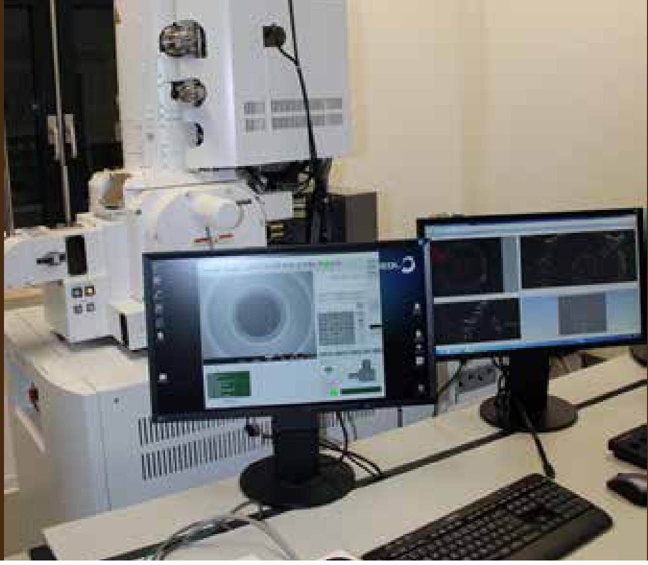
As a nondestructive method, scanning acoustic microscopy is a major tool for their defect analysis. Together with the device manufacturer PVA Tepla Analytical Systems GmbH, the Fraunhofer IMWS developed a globally unique, scanning acoustic microscope for the high frequency range up to 2 GHz. This opens up new areas of application for acoustic microscopy and offers great new possibilities of defect analysis in thin-film systems, the metrological acquisition of mechanical parameters as well as a very high lateral and depth resolution in single digits Micrometer range. In cooperation with the Belgian Research Center IMEC, the GHz scanning acoustic microscope was successfully used for detecting and locating defects in innovative 3D contacts in microelectronic chips - Through Silicon Vias (TSV).

Together with PVA Tepla and other partners from industry and Fraunhofer, further fields of application for the device are to be explored in the future, while continuously improving the performance of acoustic microscopy.

Precious Metal Inks for Microelectronics

The manufacture of functional materials through digital printing offers great potential for the production of electronic and sensor components. Methods, such as inkjet and aerosol printing, are highly adaptable, fast and scalable. In contrast to traditional semiconductor technology, these electronics production methods require material inks in order to print the circuitry components directly onto the target substrate. This trend has already led to a large number of innovative applications, such as flexible electrical circuits, miniaturized and cost-efficient sensors and wafer/chip rewiring and contacting.

With the aim of tapping into the potential of these and other applications, researchers at Fraunhofer IKTS are developing custom material inks based on gold, silver, platinum, palladium, rhodium, copper, as well as carbon and glass. The technical challenges are immense – the inks need to be compatible with existing printing technologies while being suitable for new types of substrates, such as polymers. Unlike ceramic substrates, polymers are burnt at temperatures significantly below 180 °C, which means that the sintering properties need to be adjusted with high precision.
The researchers have developed inks with particle sizes significantly below one micrometer, using a special nanoparticle synthesis, suitable solvents and organic additives. In addition to the small particle size, the inks are characterized by low viscosity and surface tension while at the same time boasting high electric conductivity. This means they can be separated with very fine and thin structure widths, significantly reducing the use of costly materials.



The resolution capacity range of the new microscope is under a hundred nanometers.

X-Ray View of Semiconductor Structures

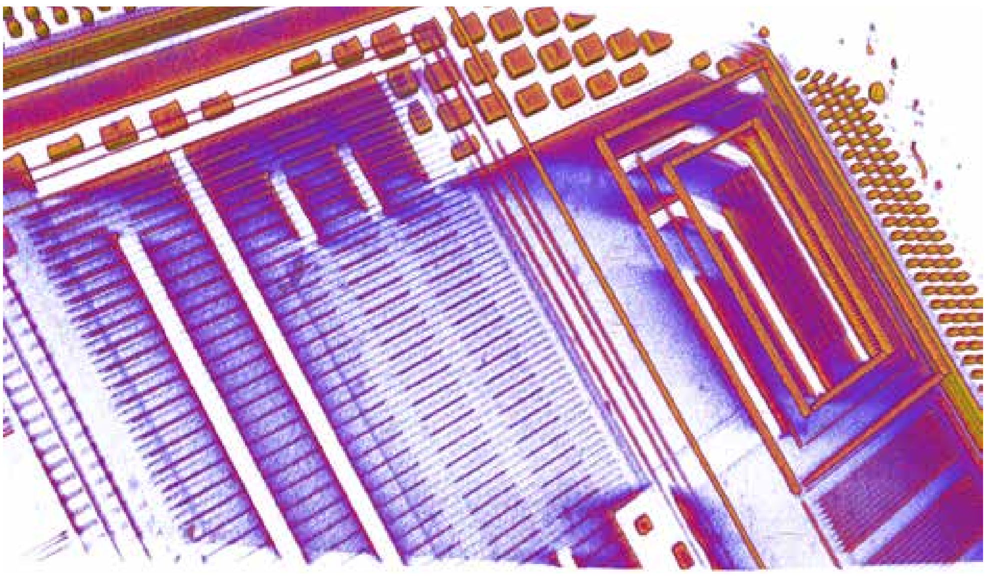
Integrated semiconductor structures (ICs) carry out fundamental work in the area of microelectronics. They have a three-dimensional structure, some of the conducting paths only measuring a few nanometers. With the development of the high-resolution Nano-CT, researchers at the Fraunhofer Development Center X-Ray Technology EZRT and the Fraunhofer Institute for Nondestructive Testing IZFP have made an important contribution to the nondestructive characterization and analysis of integrated semiconductor structures. In the future, this can be used not only to examine the design of microstructures but also to detect production errors at an early stage.

The resolution capacity range of the new XRM-II nano-CT-system is under a hundred nanometers. This is ten thousand times greater than that of a medical CT-system. In this size scale not only the conducting paths in integrated semiconductor structures are visible, but three-dimensional images of the mineral components of stone and the microstructure of metal alloys can also be seen.

The microscope, which was financed in the framework of the DFG large-scale equipment program, was put into operation in 2018 by researchers from the Fraunhofer Group NanoCT Systems NCTS at the Saarland University. Using the XRM-II Nano-CT, radioscopy- and CT-scans with resolutions of down to below 100 nm as well as measurements with a high-resolution scanning-electron microscope (0.8 nm) for the correlative analysis of materials can all be carried out by just one device.

In addition to this, a Micro-CT unit equipped with the new Talbot-Lau interferometry technology is also in use in Saarbrücken. This technology facilitates the simultaneous spatial representation of

X-ray attenuation, phase contrast and small angle scattering in components with a length of several centimeters. The Talbot-Lau interferometer is portable and its place can be exchanged with an in-situ tension-compression-load unit with which micro-CT-scans can be carried out on materials under load.



The XRM-II Nano-CT was put into operation in 2018 by researchers from the Fraunhofer Group NanoCT Systems NCTS at the Saarland University.

Sensor platform.
© Fraunhofer IMM

SECURITY

Finding the Right Escape Route with the New Sensor Platform

One of the worst situations subway passengers can imagine: A fire breaks out in a subway station, there is smoke everywhere, and the only thought is to »get back up to the surface where there is fresh air«. But what is the safest escape route for passengers to use in a subway station or tunnel without endangering themselves? Usually there are not that many alternatives, and when these escape routes simultaneously are the flow paths for smoke and other toxic gases, the passengers may soon find themselves caught in a deadly trap. In the MAusKat project funded by the Federal Ministry for Education and Research, researchers from Fraunhofer IMM have, together with other partners, developed a measurement and analysis system with which the propagation paths of gaseous hazardous substances can be traced in complex building structures. Emergency and escape routes can only be planned efficiently if this information is available. There have been a number of terror attacks in subway systems in the past, like the sarin gas attack in Tokyo in 1995 with 13 dead and thousands injured, or at the Domodedowo Airport in Moscow in 2011 (36 dead, 152 injured) but also fires in high-rises (Shanghai in 2010 with 53 dead) that have shown how complex the task of planning escape routes in fact is. Thus it is clear that it cannot be carried out adequately and comprehensively enough solely on the drawing board. Infrastructure operating organizations and emergency personnel require precise and reliable information before an incident occurs. This is where the measurement and analysis systems developed by Fraunhofer IMM in the MAusKat project come into play: the heart of the project is a mobile and infrastructure-independent sensor platform. In a test situation, a non-toxic tracer gas, usually SF6, is introduced into existing buildings and then the flow, distribution and concentration of the gas is registered at different measurement points. Based on this data, the flow and concentration are computed in a simulation and the danger zones within the building are identified. Existing escape routes can then be scrutinized and, based on the results, new emergency and escape routes can be planned.

Sensor Platforms Register SF6 and Climate Data

The sensor platform developed by Fraunhofer IMM is equipped with sensors and, in addition to the concentration of the SF6 tracer gas, also collects climate variables like temperature, humidity, air pressure and wind speeds in the x, y and z directions.

Sulfur hexafluoride is a synthetic gas – an inorganic, chemical compound made up of a single sulfur atom that is bound to six fluorine atoms (SF6). Under normal conditions, it is colorless and odorless, extremely inert, non-flammable and non-toxic. Because of its physical properties, SF6 is primarily used as an insulation gas, for example in medium- and high-voltage technology. Since the background concentration in the earth's atmosphere is very low (approx. 0.005 ppb) and because of very good traceability with reliable gas sensors, SF6 is also used as a tracer gas to register and evaluate air streams. However, the problem with using SF6 is that it has an immense global warming potential (GWP) of 22,800. For the sake of the environment, it is better to apply and emit only small concentrations of the SF6 gas. In contrast to

earlier tests in which samples were obtained manually in complex and expensive processes and had to be examined in a laboratory with a gas chromatograph, the measured variables can be automatically processed and saved in an interval of one second with the sensor platform. Because seconds are decisive in measurements, a high-precision clock with an accuracy of ± 3.5 ppm was installed that marks the individual measurement data with a time stamp in order to allow comparison between the data of the individual platforms. At the end of the measurement cycle, the stored measurement data can be saved on a USB stick or, depending on the setup, transferred wirelessly to the analysis system. The device is equipped with a network-independent power supply, which guarantees operation of 24 to 48 hours.

In the MAusKat project, tests were carried out, among other places, in department stores, lecture halls and, of course, subway systems. The results showed that with the help of the new analysis system, a more precise and timely representation of the climatological conditions is possible even in complex infrastructures over a long period of time. The personnel expenditure is limited to the installation of the measurement system and the subsequent evaluation of the measurement data. This reduces the costs of an examination many times over compared to the costs incurred for manual sampling and analysis in the laboratory.

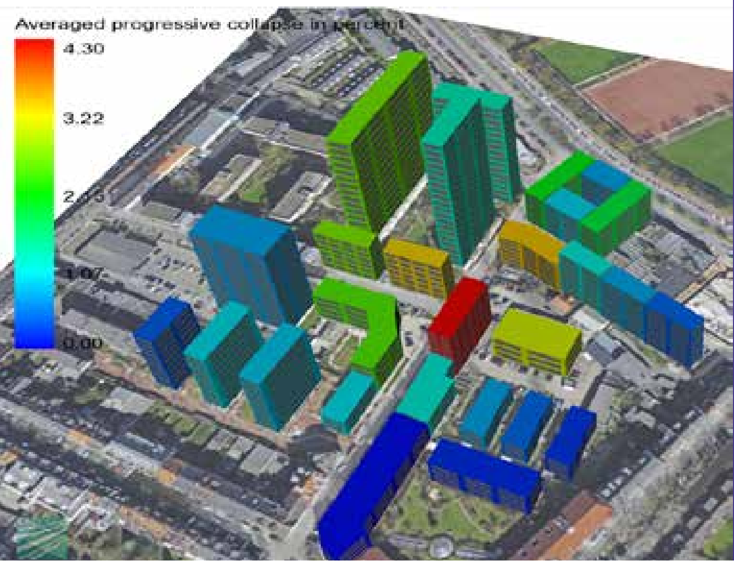
Smallest Amounts in the Lower PPM range

In view of the described cases and environmental policy aspects, it becomes clear that the gas sensors must be particularly sensitive to be able to record even the smallest amounts in the lower ppm range. A robust and highly sensitive SF6 sensor was developed by the company smartGAS Mikrosensorik GmbH in Heilbronn with which tracer gas can be detected in the sub-ppm range on a long-term basis in a stationary, power grid independent and time-resolved setting. According to Christian Stein, Managing Director of smartGAS, a number of practice tests and comparisons with gas chromatography have shown that reliable SF6 tracer gas concentrations from 50 ppb (0.05 ppm) can be detected with a resolution of 10 ppb.

As many Areas of Application as Sensors on the Market

A particular strength of Fraunhofer IMM is to develop systems in such a way that they are perfectly suited to the customers' requirements or projects while being modular and flexible. The application of sensor platforms as a leak detection appliance, for example, is possible in all application areas of SF6. »SF6 serves as a cooling agent in transformer stations but also as insulation in high-voltage power lines or it is used in AWACS aircraft«, Dr. Potje-Kamloth adds.

When it is permanently installed, the sensor platform can serve as a continuous surveillance / control system. As mentioned earlier, the sensor could particularly serve to protect the public from terror attacks. In 2011 the OrGaMir project funded by the Federal Ministry for Education and Research already showed how the sensor platform could be used as a prognosis and decision-making tool for the operator and emergency personnel on-site. When installed in a subway system and equipped with sensors to detect gases and vapors that are identified as particularly critical, in the event of an emergency the system quickly shows whether and where toxic gases have been released and how they are currently spreading



Weighted vulnerability of a city area considering all possible sources of danger (position, intensity).
© Fraunhofer EMI

Transparent ceramics as ballistic protection.
© Fraunhofer IKTS

■ The Licensed Software "VITRUV"

The licensed software VITRUV (Vulnerability Identification Tools for Resilience Enhancements of Urban Environments) enables the direct inclusion of safety and security aspects into city planning processes. This makes it possible to plan cities more sustainably and robustly already in the development stages and, additionally, to identify weak spots in urban areas.

In cooperation with potential users like city planners, architects and the police, a user-friendly software was developed in the EU project VITRUV. The graphic user interface (GUI) contains a three-dimensional visualization of the city areas and uses common data formats (JPEG, DXF, CityGML). The city under consideration can be quickly reproduced with retrievable, pre-defined building types.

Different approaches are integrated into the vulnerability analysis of urban areas. As the first step, an empirical risk analysis enables an evaluation of the predisposition of certain areas by processing historical data. Statistical frequencies (susceptibilities) are visualized depending on the type of danger, endangered object, region and exposure. Possible damage can then be computed with the aid of a validated physical engineering model within the framework of a quantitative risk analysis.

Different performance criteria like the number of affected persons, structural or monetary damage are retrievable for buildings and traffic infrastructure elements. Different protection measures are implemented and enable an increase in the urban resilience, i.e. the robustness of cities to disturbances. These measures additionally provide decision makers with a basis for cost-benefit analyses.

Further information at www.vitruv-tool.eu

■ Transparent Ceramics as Ballistic Protection

Ceramic materials are constantly under development; they now offer properties that were unheard of only a few years ago. This is largely thanks to more and more specialized manufacturing processes and customized raw materials. Transparent ceramics are among the most challenging materials for any manufacturing technology with regard to the required purity, freedom from pores and defects, and homogeneity. However, with the special optical parameters they can provide, they represent interesting alternatives and offer more innovative potential than the more traditional optical glasses. For instance, transparent protective ceramics make it possible to provide civilian and military personnel, vehicles and equipment with a maximum degree of ballistic protection while being very light-weight.

Fraunhofer IKTS has for years been a global leader in the production of transparent ceramics with finely crystalline microstructures and outstanding mechanic parameters. For the manufacture of ceramic-backing compounds, protective ceramics are bonded to a metal backing before the outside is covered by an anti-splinter protection. In the case of transparent safety windows, the backing is made of glass. In the event of a hit, the impact will break the ceramic material itself, but the projectile will then be worn away by the sharp-edged ceramic fragments. Even a few millimeters of sintered ceramics provide more protection than thick armor steel or 10 cm thick bullet-proof glass with a weight of 150 kg per square meter. Compared with such traditional protection, the combination of ceramic material and backing reduces the system's overall weight by nearly 50 percent – with obvious advantages as to the mobility, range and safety of vehicles and passengers.

Textiles with InnoSolTex® coating.
© Fraunhofer ISC

InnoSolTEX® – Functionalized Textiles

Textiles today must meet a number of high requirements. They are not only used for clothing but, as high-tech materials, also fulfill technical or protective functions. The manifold areas of application pose new challenges since there are specific standards protective clothing must meet in accordance with their area of application. Depending on what is required, the textiles must offer protection from mechanical influence, heat or flames, moisture, chemical substances as well as microorganisms and also contain anti-static function. Protective clothing can be designed in a number of different ways to protect against one or several of these influences.

Six Functions in one Textile Coating

Since fibers and textile structures cannot fulfill all requirements, they have to be processed. Up to now, it has not been possible to include all protective properties in one product. Together with its cooperation partner, Fraunhofer ISC has now developed a new hybrid coating sol based on inorganic-organic hybrid polymers.

The InnoSolTex® coating system enables six functions to be combined. The basis for the coating is the ORMOCER® inorganic-organic hybrid polymer class of materials developed at Fraunhofer ISC. The properties of these polymers can be varied in accordance with requirements. They fulfill hydrophobic, flame-resistant and wash-resistant functions and simultaneously provide an anti-static surface, improved wear resistance and an antimicrobial effect. The coating properties can be specifically arranged with a modular system according to customer requirements.

Only one Step in the Production sequence

The new coating can be applied either on the yarn or on the finished material. An additional benefit: Already existing production facilities can be upgraded with the system. It is also possible to coat the textiles in only one production step. The new InnoSolTex® lacquers can be diluted with water and stored for several weeks without any problem at a temperature of 6 °C.

In parallel to these material developments at Fraunhofer ISC, the production of its partners was scaled up to manufacture batch sizes of 30 kilograms. First industrial tests show that the coated yarns can be excellently processed to flat textile fabrics. They do not stick or tear and can be easily unwound from the spool, even at higher machine speeds. The textiles can be washed with mild detergents or disinfectants, keep their shape even after several washing cycles and maintain their antimicrobial function.

The new InnoSolTex® coating system thus combines several advantages: fewer process steps during production, lower energy and production costs and a high-performance product that can be processed in conventional industrial facilities without any problem.

© Fraunhofer ISC

The One World Trade Center in New York – DUCON® was applied here for more safety. © Fraunhofer EMI

DUCON®: A High-Performance Material in the Face of Dynamic Effects

In cities increasing numbers of people live in close proximity to each other. The danger resulting from extreme situations such as natural catastrophes, accidents and terrorist attacks increases as a result. During the construction of large apartment buildings or critical infrastructure, new materials can contribute to making buildings safer in the face of such extreme conditions. A prominent example for this is the One World Trade Center in New York City, which was completed on Ground Zero in 2013.

Safety aspects also played a large role in the selection of building materials. The high-performance material DUCON®, which was developed and optimized by Fraunhofer EMI and the company DUCON, was applied there.

This material is a composite material, in which a micro steel reinforcement is imbedded in a highly resistant concrete matrix. It provides a high amount of protection under dynamic influences. With a compressive strength of over 150 megapascals and a high tensile strength of more than 6 megapascals, the concrete matrix is also characterized by an optimized microstructure with low porosity. This leads to an excellent composite with the steel reinforcement, which is essential to achieving the desired properties. The use of high-performance components and the addition of fine supplements lead to an optimization of the packing density. The low porosity but also the high strength properties can considerably enlarge the application range of the concrete materials.

The use of reinforcements in the form of micro steel mats not only has the effect of reducing brittleness but also improves the behavior at maximum loading and leads to a considerable increase of the fracture energy.

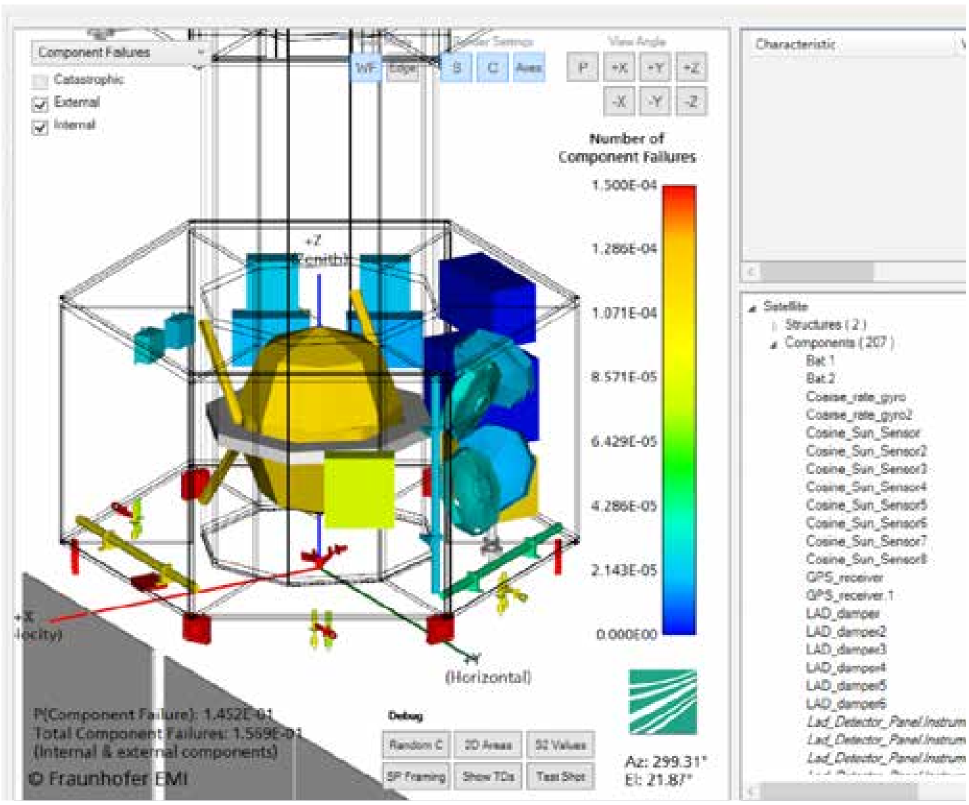
Because of its special microstructure, DUCON® is also suitable for application in aggressive environments such as sea water. Tests at Fraunhofer EMI have shown that the application of the material in critical building components provides a significantly higher level of protection.

The One World Trade Center in New York City. © Fraunhofer EMI

Satellite Vulnerability Analysis Software PIRAT

Space debris is a generic term for objects in the earth's orbit that represent a danger to spacecraft. Space debris occurs, among other things, as waste products at rocket launches, when the upper stages separate, when satellites are released or when spacecraft are disassembled by the explosion of residual fuel or batteries and also when objects collide with each other in low-earth orbits. An additional cause is burnt fuel from solid-fuel motors. Space debris can destroy satellites and damage other objects.

The relative velocity between space debris and a spacecraft can amount to 16 kilometers per second in low-earth orbits. Collisions with space debris particles as small as one millimeter can have serious consequences for satellites. Particles from this size range can penetrate satellite walls and crash into parts like pressure lines and tanks, fuel tanks, cables and electronic equipment, dama-



PIRAT software tool from EMI for examining the vulnerability of satellite components to impact from space debris and micrometeoroids.
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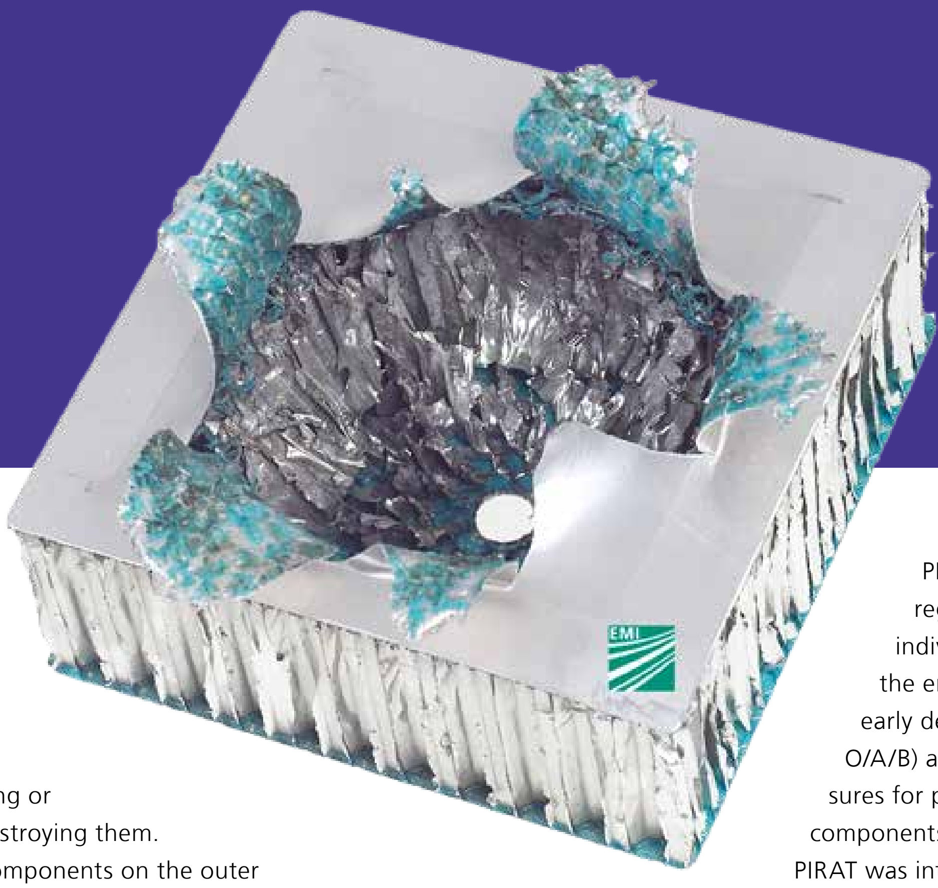


Aluminum structural wall for satellites after impact of an aluminum pellet.
© Fraunhofer EMI

ging or destroying them. Components on the outer side of the satellites are particularly affected by impact but are hard to protect.

The probability of the parts of a satellite being destroyed by space debris could only be estimated up to now. With the recently developed vulnerability analysis software PIRAT (Particle Impact Risk and Vulnerability Assessment Tool), it is now possible to compute the probability of failure due to space debris and micrometeoroid impact for every individual component of the spacecraft. The software developed at Fraunhofer EMI helps to quantitatively calculate the danger to spacecraft from increasing space debris pollution in the low-earth orbit.

PIRAT makes it possible to register the vulnerability of individual components as well as the entire spacecraft system during early development stages (phases O/A/B) and to include protection measures for particularly exposed spacecraft components early enough in the design. PIRAT was introduced to the Concurrent Design Facility of the European Space Agency (ESA) in 2014 as a software tool to support ESA engineers during the O/A phases of the spacecraft design. PIRAT is also a method for both examining the effects that occur as a result of the impact of space debris particles and micrometeoroids and predicting them at the system level in satellites.

Licenses for the PIRAT software are available at Fraunhofer EMI.

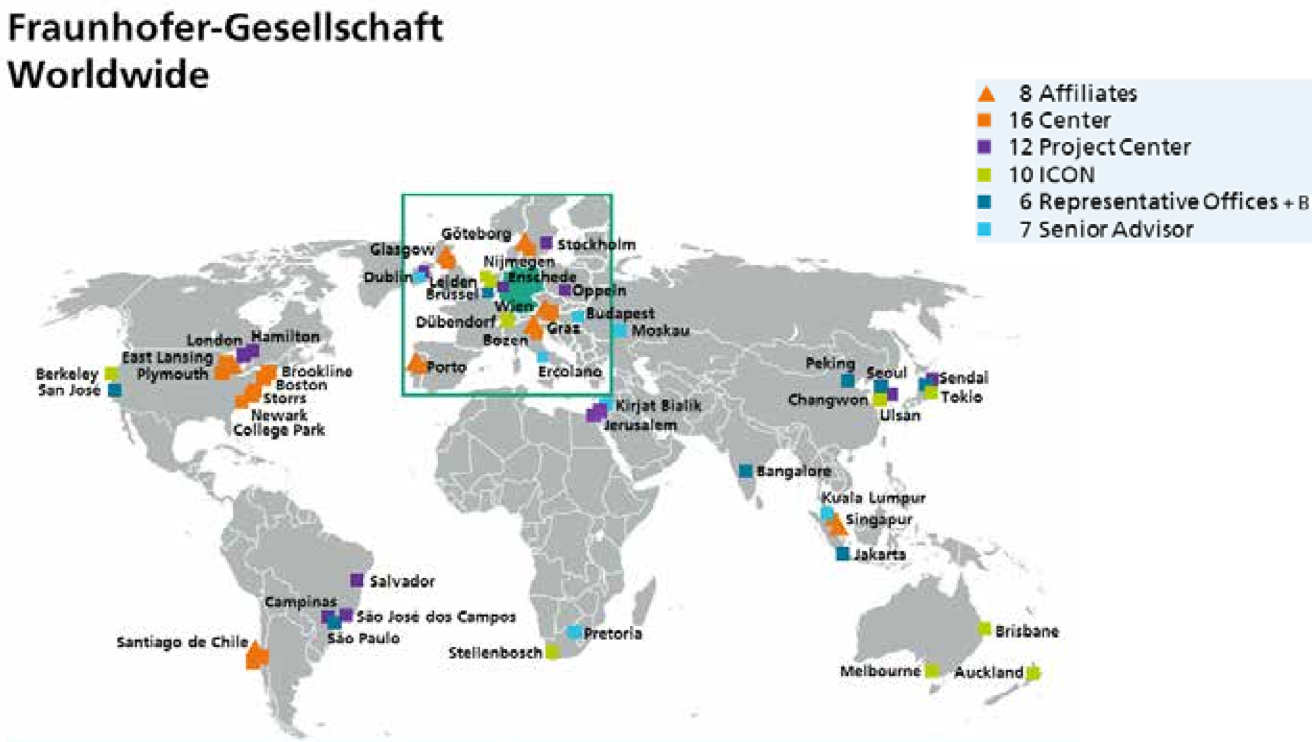
FRAUNHOFER-GESELLSCHAFT

Research of practical utility lies at the heart of all activities pursued by the Fraunhofer-Gesellschaft. Founded in 1949, the research organization undertakes applied research that drives economic development and serves the wider benefit of society. Its services are solicited by customers and contractual partners in industry, the service sector and public administration.

At present, the Fraunhofer-Gesellschaft maintains 72 institutes and research units. The majority of the more than 26,600 staff are qualified scientists and engineers, who work with an annual research budget of 2.6 billion euros. Of this sum, 2.2 billion euros is generated through contract research. Around 70 percent of the Fraunhofer-Gesellschaft's contract research revenue is derived from contracts with industry and from publicly financed research projects. Around 30 percent is contributed by the German federal and state governments in the form of base funding, enabling the institutes to work ahead on solutions to problems that will not become acutely relevant to industry and society until five or ten years from now.

International collaborations with excellent research partners and innovative companies around the world ensure direct access to regions of the greatest importance to present and future scientific progress and economic development.

With its clearly defined mission of application-oriented research and its focus on key technologies of relevance to the future, the Fraunhofer-Gesellschaft plays a prominent



FRAUNHOFER-GESELLSCHAFT

The Fraunhofer-Gesellschaft is a recognized non-profit organization that takes its name from Joseph von Fraunhofer (1787–1826), the illustrious Munich researcher, inventor and entrepreneur.

role in the German and European innovation process. Applied research has a knock-on effect that extends beyond the direct benefits perceived by the customer: Through their research and development work, the Fraunhofer Institutes help to reinforce the competitive strength of the economy in their local region, and throughout Germany and Europe. They do so by promoting innovation, strengthening the technological base, improving the acceptance of new technologies, and helping to train the urgently needed future generation of scientists and engineers.

As an employer, the Fraunhofer-Gesellschaft offers its staff the opportunity to develop the professional and personal skills that will allow them to take up positions of responsibility within their institute, at universities, in industry and in society. Students who choose to work on projects at the Fraunhofer Institutes have excellent prospects of starting and developing a career in industry by virtue of the practical training and experience they have acquired.

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