

**ANNUAL REPORT  
2011/12**

**Key Topic:**

**RESEARCH FOR THE ENVIRONMENT**

Since the German Federal Ministry of Education and Research dedicated its Science Year 2012 to the »Project Earth – Our Future«, our Annual Report focuses on the activities in the business unit »Environment«.

One of many examples for the challenges that a steadily growing human population will have to deal with in the future is the safe supply of drinking water and hence a sustainable use of this very vital resource.

To symbolize this, our front cover shows one of nature's own tricks to this end: The microstructured surface of nasturdium leaves ensures that rain water and dew drops are transported to the roots with a minimum of evaporation losses after the water has served to clean these »solar panels« converting energy through photosynthesis in the plant's own »fuel station«.

But drinking water is not the only dwindling resource unevenly distributed over the world. Fraunhofer ISC is working on intelligent solutions for a sustainable use of both natural resources and secondary raw materials.

# ANNUAL REPORT 2011/12

Key Topic  
»RESEARCH FOR THE ENVIRONMENT«

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# PREFACE

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## **Dear Friends and Partners of Fraunhofer ISC, Ladies and Gentlemen,**

If you were to ask me what I consider to be the highlight of 2011, it would certainly be the foundation of the Fraunhofer Project Group Materials Recycling and Resource Strategies IWKS, based in Alzenau in the Bavarian Untermain region. Seldom has a single topic led so speedily to the foundation of a Fraunhofer research institution: namely, the issue of critical metals and minerals which are essential to most of our advanced technologies. It is becoming increasingly difficult to access sufficient quantities of these raw materials. This is attributable, on the one hand, to a steady rise in the world's population and rising demands for raw materials from a growing number of industrialized countries. On the other hand, deposits of crucial minerals and ores remain finite, making extraction ever more complex in the face of diminishing yields. These problems are compounded by the still unchecked squandering of key resources. In this situation, raw material deposits have increasingly become pawns in political and trade negotiations. These factors all contribute in their own way to frequently steep price increases and a shortage of supplies on world markets. If this trend continues, it will have serious repercussions on the technologies we use today as well as those we hope to develop in the future to assure our prosperity. This is particularly the case in Europe, given the continent's scant reserves of raw materials. Germany, for example, is almost completely reliant on imports from abroad, mostly from developing or emerging market countries.

Alleviating this dependency will call for either greater use of secondary sources of raw materials or a gradual transition to substitute materials. These topics are the focus of the Project Group IWKS, inaugurated in Alzenau on September 5, 2011 in the presence of the Bavarian Minister of Economic Affairs, Mr. Martin Zeil. The Bavarian Ministry of Economic Affairs, Infrastructure, Transport and Technology has allocated 5 million euros in initial funding to the Project Group for the period 2011-13, in the form of a grant towards operating budget

and investments. Federal government funding devoted to investments topped up the total to 7 million euros. The town of Alzenau is also supporting the Project Group, having donated park-like grounds complete with a suitable office building and enough space for further expansion. And then, in December 2011, the federal state of Hesse's Ministry of Higher Education, Research and the Arts approved another 24 million euro in initial funding – this time to build up a corresponding Project Group in Hesse. This made it necessary to delineate activities, so that questions of resource strategy and materials recycling are now being tackled in Bavaria, while work in Hesse will focus on substitute materials. The company Umicore, located on the Hanau-Wolfgang industrial estate, offered suitable premises to commence work in Hesse and these were rented from the beginning of 2012. In addition to the initial funding, both federal states declared their intention to provide funds for the construction and equipment of suitable institute buildings.

Leadership of the project group was entrusted jointly to Professor Armin Reller, Chair of Resource Strategy at the University of Augsburg, Professor Stefan Gäth, Chair of Resource Management at the University of Gießen, and Professor Oliver Gutfleisch, Chair of Functional Materials at the Technische Universität Darmstadt. Professor Rudolf Stauber, formerly of the BMW Group, has taken on the general management.

While the development of the Fraunhofer Project Group IWKS was in progress, the Bavarian Ministry of Economic Affairs, Infrastructure, Transport and Technology awarded 8 million euros over a period of five years towards the establishment of a Center for Applied Electrochemistry under the management of Fraunhofer ISC in Würzburg. The Center is the first of two building blocks of what is to become the Bavarian Electromobility Research and Development Center; the second facility is due to be established in 2012 on the premises of the Technische Universität in Garching, near Munich. The Bavarian Minister of Economic Affairs was again present in person for this occasion, handing over the official approval for the grant during a small ceremony held on October 7, 2011, attended by about 50 invited guests. The new Center will be led by Dr. Victor Trapp.



Contributing to research focused on the transition towards cleaner, more sustainable energy, the Center Smart Materials CeSMa was able to deliver a convincing proposal aimed at the generation of electricity through dielectric elastomer generators (DEG). Beginning in September 2012, corresponding research and development work will be funded, through Fraunhofer ISC, by a further 8 million euros over a five-year period from the Bavarian Ministry of Economic Affairs, Infrastructure, Transport and Technology.

As part of the ongoing expansion of the Institute, building work on the new Technikum III building at the Neunerplatz site in Würzburg continued in 2011. The shell of the building was completed in July, with extension work beginning immediately thereafter.

The first steps were also taken in 2011 to implement a concept drawn up in 2010, whereby the Project Group »Ceramic Composites« in Bayreuth, led up until now by Professor Walter Krenkel, was amalgamated into a Fraunhofer Center for High Temperature Materials and Design HTL, with effect from January 2012. The concept also foresaw the transfer to the Project Group in Bayreuth of two groups previously led by Dr. Friedrich Raether: »Polymer Ceramics« and »High-temperature Design«. A sound basis for further development and expansion has thus now been established. The foundation of the HTL Center is accompanied by a change of management, as the Center for High Temperature Materials and Design HTL will now be jointly led, beginning in 2012, by Professor Walter Krenkel and Dr. Friedrich Raether. To cover the costs of expansion incurred through the foundation of the HTL Center, the Bavarian Ministry of Economic Affairs, Infrastructure, Transport and Technology once again approved development funds totaling 7 million euros. Plans to house the Center HTL in its own new building were likewise approved.

Another very gratifying highlight this year was the award of the Joseph von Fraunhofer prize to Dr. Sabine Amberg-Schwab of Fraunhofer ISC and Dr. Noller of Fraunhofer IVV. It was awarded for the development of a barrier coating in conjunction with a roll-to-roll coating process for cost-effective encapsulation of

flexible inorganic photovoltaic cells. In 2011, this was incorporated into the production processes of our industrial partner, the Austrian company Isovoltaic AG.

The year 2011 was, then, once more a highly eventful and successful one for the Fraunhofer ISC in setting the course it intends to follow in the years ahead. The operating budget rose from 17.6 million euros in 2010 to a total of 18.5 million euros, a 5.1 % increase. An average of 315 people worked for the Institute in 2011, of which some 176 were permanent staff. Overall, performance for the 2011 financial year was once again positive. The substantial expenses incurred in founding the Project Group IWKS were borne by Fraunhofer ISC out of its base funding and considered an investment in the future. For this reason, the Institute's surplus fell significantly short of the outstanding figures for 2010.

May I take the opportunity at this point to express my sincere thanks to all staff at Fraunhofer ISC and the Department of Chemical Technology of Materials Synthesis – in recognition of their constructive support and excellent results in research and development, both of which are essential to the successes described here.

I should also like to thank the Fraunhofer-Gesellschaft, all industrial and institutional project partners, customers and advisors, the members of the Advisory Board and the Federal Ministry of Education and Research for the trust and confidence they have placed in us. My special thanks go to the Bavarian Ministry of Economic Affairs, Infrastructure, Transport and Technology for the faith they have shown in us, as witnessed in generous support for the expansion projects of Fraunhofer ISC.

Würzburg, June 2012

Prof. Gerhard Sextl



# PROJECT EARTH

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<http://www.isc.fraunhofer.de/publikationen.html>

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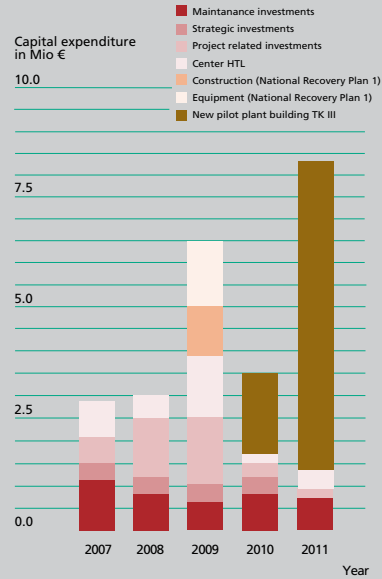
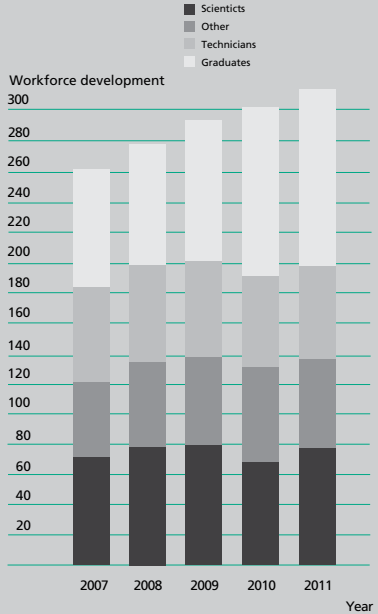
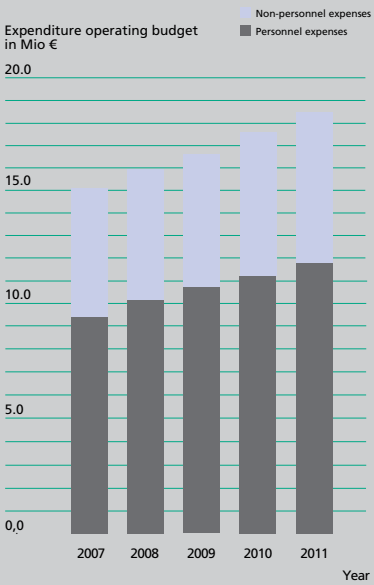
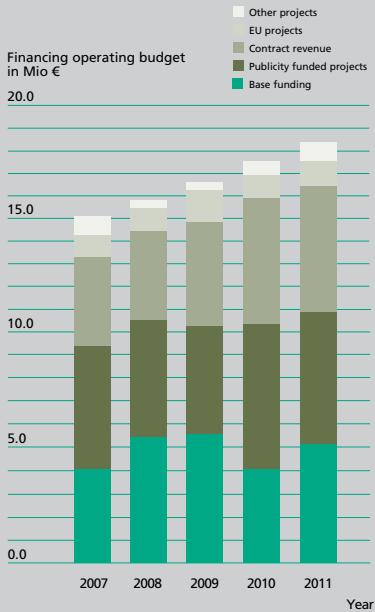


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# FACTS AND FIGURES



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## Key figures

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The German economy once again showed stable growth in 2011. Fraunhofer ISC benefited from this positive situation, reporting an increase not only in orders from industry but also in orders from major publicly-funded projects. Against the backdrop of a thoroughly satisfactory order book, the Institute's financial year ended on a balanced and successful note.

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## Growth in the workforce

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Given the sustained upturn in Germany's economy, Fraunhofer ISC was obliged to compete with many companies for highly qualified candidates. This meant that ongoing expansion at the Würzburg, Bronnbach, Bayreuth and Alzenau locations proceeded more slowly than had been hoped. Of a total of 315 employees, some 55 % (176) were full-time staff, and of these, 75 % were in permanent posts. Overall, the Institute's workforce was made up of a good balance of scientists, graduates and technicians. Moreover, Fraunhofer ISC offered many students an opportunity to work on their postgraduate theses and dissertations or to gain work experience while studying, thereby supporting materials sciences courses in the tertiary education sector.

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## Operating budget

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A series of new topics and project groups were set up or expanded at Fraunhofer ISC. These politically relevant research projects were each financed using public funds in their start-up phase. Fraunhofer ISC benefited from this growth, with its operating budget expanding in 2011 by some 5 % (€ 0.9 million) to reach € 18.5 million. The share attributable to the new project group IWKS was € 0.4 million. Personnel expenses (€ 11.9 million) and non-personnel expenses (€ 6.6 million) grew in line with the increase in business performance.

Basic financing from the Fraunhofer-Gesellschaft made up 28 % (€ 5.2 million) of Fraunhofer ISC's funding. The share coming from contract research amounted to 72 % (€ 13.3 million), of which public revenue made up € 5.5 million (30 %) and EU project revenue € 1.1 million (6 %). Revenue from industry and commerce came to € 5.8 million (31 %). Other revenues added up to € 0.9 million (5 %). A small net profit (+€ 26,000) was recorded.

For the financial year 2012, the Institute is expecting net profit for the year to be at least in line with the previous year. The combination of new public projects with those that have yet to be successfully completed will cause a shift in revenues from industry to public projects.

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## Capital expenditure

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In order to ensure success in scientific competition, there was a need for ongoing investments not only in highly qualified staff but also in technical equipment, office equipment and construction work. The Fraunhofer-Gesellschaft is investing a sum in the tens of millions in a new building and initial laboratory equipment at the Würzburg location. Over € 7 million was spent here in 2011 alone. This major infrastructure capital expenditure received federal, state and EU funding. But there was also investment in existing buildings, in new focal fields and in new technical equipment. The budget for these investments totaled € 1.3 million, funded 45 % from project revenues and 55 % from basic funding.

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# PROFILE

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## Specialists in new materials and resources

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If future products are to become established and successful in the marketplace, important drivers of their success will be not only the innovations they encompass and their inherent marketability but also the materials used and how these are produced, the substances they contain, and their overall quality.

Eco-friendliness and sustainability, recyclability and intelligent re-use are just some of the keywords for the additional challenges faced by manufacturers, industry and developers. That is why Fraunhofer ISC has spent decades working on new materials that achieve high added value in products. We are also refining the reliability, functionality and efficiency of established materials and the way they are produced and worked – extending to the design of suitable production-ready process technologies.

More than 300 employees are working closely with small and medium-sized companies and with large industry players to research new solutions to current and future challenges. In this way, the Institute is securing its partners' technological lead – and the associated jobs.

In 2011/2012 over 320 projects were successfully completed. In addition, more than 600 analyses were undertaken under contract. All projects serve the need to optimize materials, support quality assurance, and to evaluate instances of damage quickly and precisely so that practical solutions can be proposed.

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## Global network of industry and research

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Fraunhofer ISC is well networked across Germany and the world and is an active participant in a wide variety of platforms for dialog between the scientific and industrial communities. Within a year of its founding in 2010, the ISC

International, headed by Dr. Michael Popall, was able to significantly strengthen international contacts. Connections with new collaboration partners have been successfully built up in Asia in particular. In Europe, Dr. Johanna Leißner in Fraunhofer's Brussels office is supporting the Institute's activities. Thanks to these organizational measures, combined with greater efforts in public relations and intensive networking at the operational level through research projects, the Institute has managed to greatly expand its international presence in materials development.

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## Development trends and visions for the future

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Fraunhofer ISC carries out technology scouting and evaluates technological trends, thereby providing valuable ongoing stimuli to industrial partners.

The business unit New Business Development, headed by Dr. Karl-Heinz Haas, keeps up to date with key developments around the world and uses these to develop proposals for R&D at Fraunhofer ISC. Together with industry partners, the Institute has succeeded in positioning itself at the vanguard of contenders for the best innovations, products, and market share.

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## Expanding Fraunhofer ISC and raising its profile

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In order to secure Fraunhofer ISC's market position and that of its R&D partners, work has been done to raise the Institute's profile. Projects and research aimed at developing materials for eco-friendly products and applications, for efficient and safe energy use, and for individualized but affordable medicines have been brought together under the business units Energy, Environment, and Health.

In opening the Fraunhofer Project Group for Materials Recycling and Resource Strategies IWKS in Alzenau in September 2011, Fraunhofer ISC addressed one of the most important



*Biodegradable wound dressing based on silica-gel fiber fleece; approval for certain medical indications since October 2010*

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# PROFILE

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and pressing challenges faced by industry today: how to secure raw materials for high-tech applications when resources become more scarce in the face of growing global demand, which is causing prices to soar. To this end, working closely with industry, novel recycling technologies are developed along with opportunities for substitution, and strategies for securing supplies of raw materials. In this, Fraunhofer ISC enters into an important new area of applied research.

The founding of the Center for Applied Electrochemistry in October 2011 marked a further milestone in expanding the Institute's competencies in developing materials for energy storage and electrochemical applications.

On January 1, 2012, following five years of continuous development, the Fraunhofer Project Group Ceramic Composites in Bayreuth became the Center for High Temperature Materials and Design HTL; it is well on its way to becoming a Fraunhofer institute in its own right. So, Fraunhofer ISC now conducts materials research at five locations.

These include the centers in Bronnbach and Würzburg:

- Center of Device Development CeDeD
- International Convention Center for Cultural Heritage Preservation IZKK
  
- Center for Applied Analytics
- Center for Applied Electrochemistry
- Center Smart Materials CeSMA

The Bayreuth location is the seat of the

- Fraunhofer Center for High Temperature Materials and Design HTL

The Alzenau and Hanau-Wolfgang locations are home to the

- Fraunhofer Project Group for Materials Recycling and Resource Strategies IWKS

# HEALTH

# ENVIRONMENT

# ENERGY

## **Würzburg/Bronnbach**

Speciality glass development |  
Energy storage | Mobile energy supply |  
Microelectronics and polymer electronics |  
Nanotechnology | Diagnostics | Regenerative  
medicine | Dental and micro medicine | Func-  
tional fillers | Coating technology | Smart mate-  
rials | Environmental monitoring | Preventive  
conservation | Equipment construction

## **Alzenau/Hanau**

Recycling concepts  
Design for recycling  
Resource strategies  
Materials substitution

## **Bayreuth**

High-temperature  
lightweight con-struct-  
ion | Intrinsically safe  
ceramic  
processes

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# THE ADVISORY BOARD

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The Institute's management team is supported by an advisory body made up of prominent figures from the realms of industry, research and politics. In 2011/12, the Advisory Board consisted of the following members:

**Dr. Martin Bastian, SKZ – Süddeutsches Kunststoff-Zentrum, Würzburg**

**Prof. Dr. Peter Behrens, University of Hannover**

**Dr. Hans Dolhaine, Henkel AG & Co.KGaA, Düsseldorf**

**Dipl.-Ing. Hans-Michael Güther, SGL Brakes GmbH, Meitingen**

**Prof. Dr. Martin Jansen, Max Planck Institute for Solid State Research, Stuttgart**

**Dr. Roland Langfeld (Vorsitzender), Schott Glas, Mainz**

**Dr. Egbert Lox, Umicore NV/SA, Olen, Belgium**

**Henry Rauter, VITA Zahnfabrik H. Rauter GmbH & Co. KG, Bad Säckingen**

**Dr. Georg Ried, Bavarian State Ministry of  
Economic Affairs, Infrastructure, Transport and Technology, Munich**

**Prof. Dr. Martin Winter, CeNTech GmbH, Münster**

**Dr. Detlef Wollweber, Bayer Innovation GmbH, Düsseldorf**



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# CORE COMPETENCIES

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The main focus of Fraunhofer ISC's work is on the application-oriented development of non-metallic materials – from precursors to functional models.

**Core competencies are:**

- **Chemical nanotechnology**
- **Process engineering and characterization**
- **Glass chemistry and technologies**

**With key activities in**

**high-temperature lightweight construction, structural parts made of CMCs, high-temperature design, polymer ceramics,**

**nanochemistry, sol-gel materials, specialty glass development, smart materials,**

**energy storage, mobile energy supply**

**micro and polymer electronics, optics**

**diagnostics, regenerative medicine, dental materials, micromedicine**

**functional fillers, particle technology**

**coating technology and materials**

**environmental monitoring and conservation research**

**device and plant development**

**resource strategies, recycling concepts, design for recycling, materials substitution**

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# MATERIALS BASE

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## ORMOCER®

One of the Institute's key areas of research and development is the ORMOCER®\* class of materials. These inorganic-organic hybrid polymers developed by the Fraunhofer ISC are manufactured using chemical nanotechnology processes. The Institute's expertise in the sol-gel synthesis, functionalization and further processing of ORMOCER®s has steadily improved over the 25 years since this class of materials was first introduced. ORMOCER®s have now been implemented in a wide range of industrial applications.

By selecting the appropriate monomer or polymer starting components, it is possible to create materials and surfaces with a multifunctional property profile. This enables scientists to influence a whole range of factors including optical and electrical properties, resistance to wear and corrosion, adhesive properties, wettability and surface energy, barrier properties and biocompatibility. The range of applications for hybrid polymer materials is correspondingly diverse.

Many products have already been successfully launched in close collaboration with industry partners, including scratch-proof coatings for plastic magnifying glasses and lenses, dental filling materials, fissure sealants, bonding agents and protective coatings, as well as high-quality decorative coatings for household glassware. Light-sensitive hybrid coatings are used in dosimeters to determine the levels of light to which works of art and other objects of cultural significance are exposed. Hybrid materials are also used in the packaging and integration of electronic and optoelectronic components on printed circuit boards: Waveguides made from ORMOCER®s make it possible to produce highly sophisticated electro-optical circuits at a reasonable cost. Microlenses made from ORMOCER®s already feature in numerous electronic devices.

\*Trademark of Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e. V. in Germany

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## TECHNICAL SPECIALITY GLASS

Special types of glass with customized properties for engineering and optical applications are used in a variety of fields including metrology, microscopy, electronics, medical engineering, the automotive industry and the construction industry. The development and characterization of specialty glasses and glass ceramics has long been one of the Fraunhofer ISC's core areas of expertise.

Properties such as homogeneity, viscosity, bending strength and chemical resistance are painstakingly optimized to meet specific industrial requirements. For instance, in order to use glass as a highly temperature-resistant and chemical-resistant joining material, the melting point, expansion characteristics and wetting behavior must be adapted to suit the materials being joined.

The scientists use ultramodern, in-situ measuring techniques to characterize glass-forming melts as well as an automated glass screening system which is the only one of its kind in Europe.

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# MATERIALS BASE

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## SMART MATERIALS

Adaptive materials whose properties can be changed by electric or magnetic stimuli are known as »intelligent materials« or »smart materials«. In the future they will help to simplify complex mechanical and mechatronic systems while simultaneously allowing the implementation of new additional functions.

The Fraunhofer ISC has amassed extensive experience and considerable expertise in developing and designing magnetorheological and electrorheological fluids (MRFs and ERFs) and magnetorheological elastomers (MREs). These materials quickly and reversibly change their viscosity and elasticity if an electric or magnetic field is applied, making them the perfect choice for adaptive vibration damping or impact absorption and for haptic control systems.

Researchers are also working on materials which can be used to convert electrical signals into mechanical movements and vice versa. These materials – which include piezoceramics, electroactive polymers (EAP) and carbon nanotube composites (CNT) – are suitable for use as actuator and sensor components, including ultrasonic transducers for online structural health monitoring and for energy conversion (microenergy harvesting). Scientists select and combine the best materials based on the field of application and specified requirements in each case.

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# CERAMIC PROCESS ENGINEERING

Optimizing the production of premium high-performance ceramics while keeping energy consumption to a minimum can only be achieved by tailoring process parameters to suit individual processes. Fraunhofer ISC investigates and models key process steps such as shaping, debinding and sintering with the aim of achieving inherently reliable, low-cost production.

Homogenous structuring of the unfired blanks or »green bodies« plays a crucial role in the quality and reliability of the high-tech ceramics they are subsequently used to produce. State-of-the-art testing and measuring procedures are employed in order to determine and steadily improve the homogeneity of green bodies – for example creating high-resolution SEM images using terahertz-wave scattering, and measuring and modeling thermal conductivity and the Young's modulus to suit the respective application.

Thermo-optical measuring (TOM) methods developed at Fraunhofer ISC are used for non-contact in-situ monitoring of the debinding and sintering processes applied to the green bodies. By incorporating special evaluation software, the course of the ceramic manufacturing process can be accurately tracked and predicted for any desired temperature cycles under a variety of atmospheric conditions. The combination of modeling and in-situ measurement makes it possible to optimize the properties of ceramic materials and develop suitable process parameters.

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# MATERIALS BASE

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## COMPOSITE MATERIALS

Originally developed by the aerospace industry as an alternative to metallic materials, ceramic matrix composites (CMC) are lightweight, high-performance materials with excellent temperature stability which are increasingly finding their way into everyday applications – for example lightweight and highly wear-resistant CMC brake disks.

Fraunhofer ISC in Würzburg develops novel ceramic fibers with high temperature stability based on the Si-B-N-C and Si-C materials systems. Since SiC fibers reach their performance limits at very high temperatures, researchers are working on a SiBNC high-temperature ceramic designed for use at temperatures above 1,300 °C as well as developing economical manufacturing processes for SiC. For both systems, the team's work spans the entire process chain on a pilot plant scale, from the manufacture of ceramic precursors and the synthesis of spinnable polymers right through to fiber production.

The Fraunhofer-Center for High Temperature Materials and Design HTL in Bayreuth designs, manufactures and tests CMC materials. Thanks to the expansion of its facilities over the last few years, the Group is now able to carry out all the key processes from component forming and high-temperature treatment through to final quality inspection. Particular emphasis is placed on the application-specific development of structural components with high temperature stability made from oxide and non-oxide fiber composites. The team also devises simulation models based on detailed fault-analysis data, which can be used to produce reliable predictions concerning the expected lifetime of fiber-composite ceramics under real-life operating conditions.

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*From the Center for Applied Analytics*

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# COMPETENCE UNITS

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## COMPETENCE UNIT DENTAL AND MICROMEDICINE

This competence unit develops biofunctionalized and actively functionalized materials for dental conservation (restoration, prophylaxis, regeneration) and dental prostheses, as well as for use in bone cement and micromedical applications. Its core competencies include the development and synthesis of multifunctional precursors as well as application-tailored materials such as monomer-free resin systems, nano-hybrid and other composites, glass ionomer cements and customized self-etch, total-etch and other adhesives that provide an excellent basis for direct and indirect restoration (fillings, crowns, etc.). Development is accompanied by extensive and application-targeted chemico-physical characterizations. The unit employs a wide variety of processes for structuring solutions and for filler synthesis and application.

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## GLASS AND MINERAL MATERIALS

From the model-based development of new glasses and inorganic mineral materials over process engineering right through to the construction of prototypes – this competence unit covers all major steps involved in materials development. Its focus is on the development of specialty glasses and glass ceramics but also on materials for the construction industry, including bulk materials, fibers and coatings. An automated glass screening system – the only one of its kind anywhere in the world – is used for the development of specialty glasses. Glasses and preforms can be manufactured on request in quantities of up to 100 kilograms per year. In the field of mineral materials, the work is focused on the materials cycles of both natural resources and secondary raw materials. Another area of expertise is the functionalization of traditional building materials.

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## COMPETENCE UNIT OPTICS AND ELECTRONICS

This competence unit develops technologies (materials, processes, characterization) for applications in the fields of optics and electronics. Its core competencies lie in the development of coating, shaping and two-dimensional and three-dimensional structuring processes, including their adaptation to the production environment, with a particular focus on material classes developed at the Fraunhofer ISC such as (hybrid) polymers, glasses and ceramics. The competence unit also specializes in developing directly structurable hybrid polymers for optical and electronic packaging technologies and for micromedical applications.

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## COMPETENCE UNIT MATERIALS CHEMISTRY

The Materials Chemistry competence unit dovetails expertise from the departments of sol-gel chemistry, coating materials and particle technology. This opens up access to a wealth of synthesis methods for developing and optimizing materials and material components. Turnkey solutions are developed for key applications in the fields of engineering, health, energy, construction and the environment.

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# COMPETENCE TEAMS

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## COMPETENCE TEAM SOL-GEL MATERIALS AND PRODUCTS

Researchers in this department synthesize precursors for non-metallic, inorganic materials using the classic sol-gel chemistry route. These precursors serve as the basis for the chemical synthesis of inorganic coating solutions, fiber spinning melts, and mesoporous materials used in the development of multifunctional materials for applications such as building materials, architectural glazing and products in the field of regenerative medicine. Key areas of research include products for affordable health care in future markets and tailor-made technical solutions designed to enable the efficient use of solar installations in desert regions and other dust-laden environments.

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## COMPETENCE TEAM HYBRID COATINGS AND COATING TECHNOLOGY

Chemical nanotechnology processes are used to synthesize multifunctional hybrid coating materials. This involves the use of substrate-specific, material-specific and component-specific application and processing techniques tailored to specific production environments and processes, as well as modern curing methods for coatings. The team of researchers works on an array of properties and applications including a broad range of protective effects, adjustable permeability and migration barriers, catalytic effects, special chemical sensitivity, variable optical properties and switchable, active functions.

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## COMPETENCE TEAM CONSERVATION SCIENCES

Backed by many years of experience in the effects of corrosion on metal and glass, this competence team investigates the impact of environmental factors on endangered cultural heritage, especially made of glass, metals and ceramics. Measurements of environmental impact using specially designed glass and light dosimeters enable preventive measures to be taken to better protect artworks and items of cultural significance in situ, in display cases and in museum storage facilities. The team's services also include the development of new conservation methods and materials designed to protect historical and industrial monuments. Projects include the development of a special glass-in-glass solidifying agent designed to enable the gradual, gentle repair of micro-cracks in corrosion-damaged church windows, a project that was carried out in cooperation with the competence team on sol-gel materials and products.

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## COMPETENCE TEAM PARTICLE TECHNOLOGY AND INTERFACES

With the growing functionality and complexity of materials and components, interfacial phenomena gain more and more importance. Wherever large surfaces come into play – for example in particle systems for diagnostics or in composite materials – the chemistry at the interfaces and boundaries is likely to determine their quality and even their key properties. Based on many years of experience in the field of wet-chemical synthesis of multifunctional particles for dental applications, surface functionalization and composite manufacturing, the team's expertise has steadily been expanded to include areas such as medical diagnostics/theranostics, drug encapsulation, targeted release and self-healing.

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# CENTERS

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*The Center for Applied Electrochemistry  
is funded by the Bavarian State.*

*Connecting a measuring cell in the multichannel test system.*

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# CENTER FOR APPLIED ELECTROCHEMISTRY

The Center for Applied Electrochemistry was founded at Fraunhofer ISC on October 7, 2011. As part of the Bavarian Electromobility Research and Development Center, researchers at Fraunhofer ISC will be working together with the Fraunhofer Project Group Electrochemical Storage in Garching, near Munich, primarily on improving energy storage for electric cars. Both centers see themselves as links between tertiary-level basic research and industrial application, and will therefore be looking to collaborate with industry on this work. In Würzburg, the focus is on developing new materials and components for various battery types and electrochemical double-layer capacitors along with the recycling and resource efficiency of these energy storage devices.

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## Focus on battery development

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Accordingly, the emphasis of current work is on developing materials for safer, higher-performance lithium-ion batteries as well as for hybrid systems composed of double-layer capacitors and batteries. A particularly promising innovation for improving the safety of lithium-ion batteries are the polymer electrolytes based on inorganic-organic hybrid polymers (ORMOCER®s), which were developed at Fraunhofer ISC. Specially adapted members of this class of materials are used as a lithium-ion-conducting separator layer to replace the flammable organic liquid electrolytes used up until now. On the one hand, these new electrolytes act as a low-flammability barrier layer in order to minimize the risk of fire. On the other hand, they possess sufficient ion conductivity to enable the rapid, controlled transportation of lithium ions. The inorganic polysiloxane structure of these hybrid polymers provides for high thermal, mechanical, and electrochemical stability and thus a particularly high level of safety. The molecular structure can be adapted to a variety of uses according to the specific requirements of an application.

For example, stable electrolytes with conductivities of just under 1 mS/cm have already been manufactured.

In addition to innovative polymer electrolyte systems, Fraunhofer ISC's synthesis know-how is also being applied to developing new electrode materials for lithium-ion batteries and electrochemical double-layer capacitors. The objective here is to synthesize materials with high specific capacities that permit high voltages and thus high energy densities during operation, but whose nanostructuring enables rapid charging and discharging and ensures that the energy storage devices have a high power density. Another important factor here is how well the individual components are coordinated with each other. At Fraunhofer ISC, both newly developed materials and those procured from external suppliers are processed into electrodes and cells and electrochemically characterized. Large multi-channel instruments are available for measuring long-term cycling under controlled temperature conditions and allow detailed information to be ascertained about the behavior of various anode and cathode materials as they interact with the electrolytes. Special methods such as scanning electrochemical microscopy (SECM) and impedance spectroscopy round off the portfolio of characterization methods.

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# CENTERS



Automated glass screening system

## CENTER OF DEVICE DEVELOPMENT (CEDED)

### Development and services

Principal focus of the Center of Device Development CeDeD is the development of scientific research systems for use in the characterization of new materials and in the quality control of production processes.

The Center offers the full range of expertise required for scientific development, planning and design as well as construction of research systems. It covers the entire line of development of research systems, from concept and design based upon the 3D design modeling software AUTOCAD Inventor to computer-controlled component manufacture in its workshop. CeDeD is the central point of contact for internal and external research groups as well as the direct partner to industry for plant-specific technical implementation of research findings. In close collaboration with Fraunhofer ISC research groups, CeDeD develops prototypes, demonstrators and pilot plants for the production and processing of newly developed materials and also research equipment for process control at the end of the value chain.

### Partner for industry and research

Particular emphasis is placed upon the development of thermo-optical measurement systems (TOM) used for in-situ characterization of materials during heat treatment. Measurements can be carried out in temperatures ranging from room temperature to over 2000 °C. Current enquiries come in particular from the speciality glass and high-tech ceramics industries as well as from companies working in further development of refractory materials. With the aid of vacuum engineering, laser technology and robotics, the newly developed processes are scaled up to systems suitable for industrial use. Thermo-optical measurement techniques are of course also relevant for further groups of materials which undergo heat treatment – including all powder metallurgy and injection molding. With ISO 9001:2008 accreditation and an annual audit of its quality management system, CeDeD guarantees reproduction of the complete process chain and is a reliable partner for organizations looking to develop new technologies.

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Chemical analytics

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## CENTER FOR APPLIED ANALYTICS

In its work for both internal and external customers, the Center for Applied Analytics serves as the central point of contact for analysis of the composition and properties of materials. Material composition analysis ranges from the centimeter scale down to the atomic level of granularity. A correlation between the identified microstructure and the material properties is then often possible. Materials analysis is the basis for the development of many materials and processes and is also of great importance in failure analysis. Failures occurring during production or even out in the field can often be attributed to material defects or the use of materials in environmental conditions which had not previously been taken into account. The Center for Applied Analytics offers a combination of the latest materials analyses and applied scientific consultancy. The aim is to understand analytical results and to implement specific measures accordingly. In order to meet the stringent quality requirements of industry, the Center for Applied Analytics is accredited according to DIN EN ISO/IEC 17025.

The Center's field of expertise focuses on chemical analysis methods for non-metallic materials, nanoscale analysis, failure analysis, the characterization of structural and surface properties – in product testing that includes the RAL or EUCEB testing of mineral wools, as well as interface and surface analysis. In addition to routine chemical analyses using X-ray fluorescence methods, resistance testing is carried out on various types of materials. Even a few millionths of a gram of a material in solution can be analyzed using inductively coupled plasma-atomic emission spectrometry (ICP-AES) or atomic absorption spectrometry (AAS). High-resolution scanning electron microscopes are used to analyze microstructural properties such as the surface topography and surface properties of samples. The Center uses an advanced ion-beam cross-section polisher which enables the artifact-free preparation of porous specimens for analysis. A scanning transmission electron microscope (S/TEM) is used to analyze material structure into the nanometer range. Using a focused ion beam (FIB), specific ultra-thin specimens are taken from the material being tested. X-ray photoelectron spectroscopy (XPS) is employed in the chemical analysis of surfaces. Fraunhofer ISC has at its disposal more than 50 different analysis techniques which facilitate correlation analysis. Should the Center need to employ further analysis methods, such as ToF-SIMS, synchrotron tomography and others, it can call on a network of service providers - some of which have similar accreditation - both inside and outside the Fraunhofer-Gesellschaft.

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## CENTER SMART MATERIALS (CESMA)

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### Mission

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CeSMA, Fraunhofer ISC's Center for Smart Materials, develops customized materials and components capable of performing specific functions by changing their properties in response to an electric stimulus. Their main applications are as sensors or actuators, in which mechanical energy is converted into electrical energy or vice versa. Because the changes are reversible, with a response time of a few milliseconds, and the underlying physical effects can be continuously controlled, such smart materials open the way to novel solutions that are simpler to implement than conventional mechanical solutions, provide new additional functions, and at the same time reduce the weight of the final product.

With its focus on implementing smart materials in components such as actuators, sensors, attenuators, clutches, energy harvesters and even »smart windows«, CeSMA enables its customers to rapidly integrate these new technologies in their products. CeSMA's activities have been growing steadily since its creation in May 2009, and the current planning figures indicate a continuation of this trend in 2012.

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### Materials – Functions – Components

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Smart materials, also known as adaptive materials, cover an extremely diverse range of materials including polycrystalline solid-state materials such as piezoelectric ceramics, electrorheological and magnetorheological fluids, dielectric elastomer actuators (DEA) and sensors (DES), and composites such as magnetorheological elastomers (MRE) which consist

of magnetically polarizable particles in a soft elastomer matrix, enabling them to reversibly change shape and/or stiffness when exposed to a magnetic field. Another class of property-changing materials is the metallo-supramolecular coordination polyelectrolytes (MEPE), which have so far been qualified for use in »smart windows« but are also strong candidates for use in other applications.

The process of selecting and optimizing materials for a particular application starts with an analysis of the case at hand. This enables the necessary forces, travel distances, dynamic parameters and temperature range to be specified. These data serve as the basis for deciding whether or not the material needs to be optimized, and if so in what way. The next stage involves designing a laboratory demonstration model in which the selected materials can be integrated and tested. These tests may include cyclic load tests and climate testing (according to DIN or EN standards), as required.

The following projects are typical examples of the development work carried out by CeSMA:

#### *Dielectric elastomer actuators (DEA)*

Targeted optimization of the material (including enhanced permittivity) resulted in a 40 % improvement in strain at the same field strength compared with the unmodified material. The expansion of the actuator remains unchanged with respect to the initial measurement through 100,000 cycles. Application: multilayer actuators.

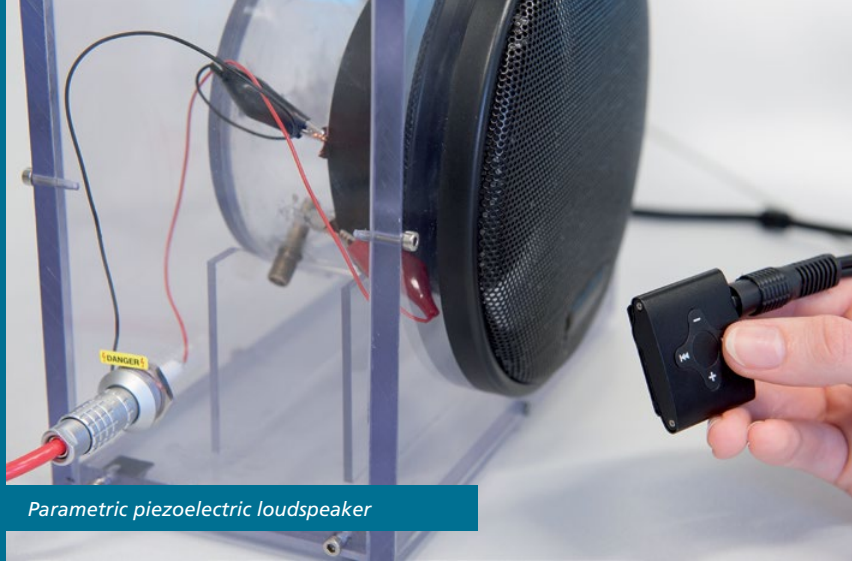
#### *Dielectric elastomer sensors (DES)*

Endurance tests have demonstrated that this type of sensor is capable of operating reliably through 150,000 cycles at temperatures ranging between -30 and +80 °C. Typical applications of these robust sensors include strain measurement in technical installations, smart textiles, and seat occupation detectors.





DES shoe sole



Parametric piezoelectric loudspeaker

### ***Magnetorheological fluids (MRF) with high temperature stability***

A new MRF formulation was developed that demonstrates no significant, measurable change in the switching coefficient or basic viscosity even after 24 hours of heat treatment at a temperature of 200 °C. The customer intends to use this material in space applications. An electronic control system for torque distribution based on an MRF clutch has been successfully tested at a torque of up to 500 Nm.

### ***A new parametric piezoelectric loudspeaker***

is capable of generating a sound beam with a length of 0.5 meters and a width of 0.6 meters. Work on the project is being continued with the aim of achieving a range in excess of 1 meter. Applications: directional audio systems for use in vehicles and multimedia museum displays.

### ***High-temperature ultrasonic transducer***

Ideal for condition monitoring in power generation plants and other facilities with high operating temperatures, where it has been proven that the novel ultrasonic transducer design is capable of generating and receiving acoustic signals at a temperature of 600 °C. Work on the project is being continued with the aim of establishing a monitoring system.

### ***Piezoelectric switches***

These switches consist of a thin film of piezoelectric material applied to a metal substrate, that only needs to bend through a distance of 10 µm in order to generate a switching signal (see illustration). Initial industrial implementation projects are in the pipeline.

### ***Smart windows***

that automatically modulate solar transmission: In a collaborative research project with the University of Würzburg, the Federal Institute for Materials Research and Testing (BAM) in Berlin, and the Institute of Materials for Electrical and Electronic Engineering (IWE) at Karlsruhe Institute of

Technology (KIT), sponsored by the German Federal Ministry of Education and Research BMBF, a new type of switchable glazing technology based on the electrochemical properties of metallo-supramolecular coordination polyelectrolytes (MEPE) has completed all project milestones this year (including reliability testing over 10,000 switching cycles). An industrial consortium is to take the project further and develop applications for architects and other users.

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### **Future activities**

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In addition to its ongoing work on applications of the materials and technologies listed above, CeSMA intends to add another highly promising line of research to its portfolio, in a project for which funding has been granted under the »Bavaria on the Move« government initiative. The subject of this research is dielectric elastomer generators (DEG), a new technology for converting mechanical energy into electrical energy. The advantages of DEGs, alongside their high energy efficiency, are that they are low-weight, produce no noise when operating, and do not require the use of rare natural resources, unlike other types of generator.

CeSMA is ideally placed to conduct a project of this type, given its existing advanced knowledge and skills in the field of dielectric elastomers. However, the project will require the input of additional expertise, especially in the fields of power electronics, electronic controls, and energy storage. For this reason, CeSMA intends to run this development project in collaboration with an experienced external partner.

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# CENTERS

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## INTERNATIONAL CONVENTION CENTER FOR CULTURAL HERITAGE PRESERVATION IZKK

The Fraunhofer ISC has been involved in the development and adaptation of restoration methods and materials designed for use in the conservation of cultural heritage for many years now, with very successful results. The Institute also carries out related work in the field of environmental monitoring by developing products and methods that are designed for tasks such as measuring and evaluating the environmental impact of industrial processes.

Reaffirming Bronnbach's importance in the field of cultural heritage preservation, the ISC decided in 2008 to establish the International Convention Center for Cultural Heritage Preservation IZKK in close collaboration with the Main-Tauber regional administration.

With its focus on promoting knowledge-sharing, research and the pooling of resources, the IZKK defines itself as an educational institute and contributes to the Fraunhofer-Gesellschaft's principles of sustainability. Housed in a living monument, Bronnbach Abbey, the Center aims to revive interest in our cultural heritage, and especially contribute to its preservation by disseminating the results of its research. The modern conference rooms in the historical 12th century abbey building enable the IZKK to offer a broad range of seminars, training courses and conferences to an international customer base. In 2011, for example, the IZKK was chosen to host the third edition of GLASSAC, an international conference on glass science in art and conservation.

The Center's target audience includes restorers, architects, master craftsmen, plasterers, artists, curators and other professions involved in cultural heritage preservation. In terms of its research activities, it fosters intensive cooperation and dialog with universities of science and applied science, research institutes, museums, and offices and agencies responsible for cultural heritage preservation.

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*Historic Church Window*

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# REVIEW

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## 2011 FRAUNHOFER PRIZE GOES TO ISC RESEARCHER <sup>1</sup>

It is only three years since the Joseph von Fraunhofer Prize was awarded to researchers from Fraunhofer ISC, yet 2011 saw the accolade once more headed for Würzburg. Together with her project partner, Dr. Klaus Noller of Fraunhofer IVV, Dr. Sabine Amberg-Schwab of the competence team Hybrid Coatings and Coating Technology was honored for the development of a flexible and transparent barrier film layer for photovoltaics applications; these films were successfully incorporated into industrial production processes in 2010. Among those attending the awards ceremony held at Fraunhofer ISC were Würzburg's first mayor Dr. Adolf Bauer and the president of the regional council of Lower Franconia, Dr. Paul Beinhofer

## RESEARCH PRIZE

**AWARDED FOR DEVELOPMENT OF COST-EFFECTIVE PRINTING PROCESS FOR SMART ACTIVE-MATRIX SENSORS**

As part of the EU-sponsored 3PLAST project, research institutions and industry have teamed up to develop new printing pastes and processes for printed electronics. By finding ways to reduce complexity, research collaborators succeeded in deriving a cost-effective production process for large-area organic electronics that uses only five different printing pastes. For this achievement, they were honored with the IDTechEx Printed Electronics Europe 2011 Academics R&D Award. The 3PLAST project is coordinated by project leader Gerhard Domann, staff member of Fraunhofer ISC in Würzburg.





## »RESEARCH FOR OUR HEALTH« 2

A SERIES OF TALKS FOR THE YEAR OF SCIENCE

In the course of a series of talks held in Würzburg town hall and hosted by the city's business development program, Fraunhofer ISC was invited three times to speak on current areas of medical research. For each talk, two renowned scientists were called upon to jointly lead an evening presentation, as representatives of various research and teaching institutes.

For the inaugural event on June 8, honored by the official presence of Mayor Rosenthal, Dr. Sofia Dembski of the competence team Particle Technology and Interfaces spoke on new avenues in cancer research. Dr. Jörn Probst, Head of the business unit Health, talked on September 29 about regenerative medicine, and on October 13 Dr. Herbert Wolter, senior manager of the competence unit Dental and Micro Medicine, gave a presentation on materials with bite – affordable and high-quality dental treatment for all ages.

## EXHIBITION SHIP MS WISSENSCHAFT COMES TO WÜRZBURG

Another of the events organized for the »Year of Science 2011 – Research for our health« was the arrival of the exhibition ship »MS Wissenschaft – New trends in medicine«, which paid a visit to Würzburg from June 11 through June 13. This year's exhibition once again featured a Fraunhofer ISC display. Entitled »Detecting cancer earlier«, it provided an interactive accompaniment to the earlier lecture given by Dr. Sofia Dembski at the opening ceremony.

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# REVIEW

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## SUCCESSFUL CENTER SMART MATERIALS WORKSHOP

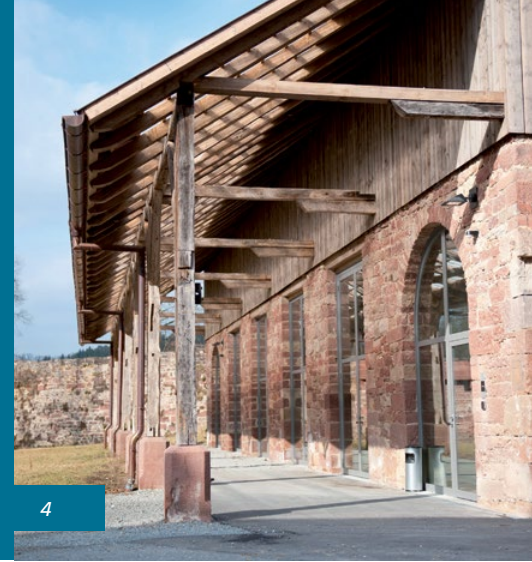
A one-day workshop on »Smart materials in cars« attracted over 40 participants from research and industry to Fraunhofer ISC. The workshop was held on May 4, 2011 in cooperation with the »New Materials« and »Mechatronics and Automation« clusters. The true potential of smart materials is particularly apparent in vehicle manufacturing – a cost-sensitive area where controllable properties could for instance be applied to resolve the conflicting demands of safety and comfort. Dr. Konstantinos Gkagkas of Toyota Motor Europe NV/SA and Rudolf Geiling of Geiling GmbH together with Lucien Johnston und Dr. Raino Petricevic of Fludicon spoke on behalf of suppliers and the automotive industry. This was the third such workshop organized by CeSMa and, once more, the audience was impressed by the unorthodox applications allowed by this type of material.

## OPEN DAY

The open day on September 28 was an out-and-out success. The first guests were already waiting outside when the institute opened its doors at 10 a.m. and, by the time closing came around at 5 p.m., over 1,000 guests had found their way both to Neunerplatz and to the branch in Friedrichstraße. Visitors were able to make use of 25 information stations to gain a comprehensive overview of the projects currently being worked on by researchers at Fraunhofer ISC, in collaboration with partners from business and industry. What's more, the high-tech laboratories – including the scanning electron microscope, fiber spinning machine and laser laboratory – were opened to guests. The lively interest at the Fraunhofer ISC careers booth also highlighted the importance of such events in getting young people interested in research and attracting new talent to the institute.



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## HISTORIC COACH HOUSE TO BECOME TEST CENTER <sup>3, 4</sup>

Following a year or so of building work, the redevelopment of the former coach house – part of a collection of historic buildings comprising the farm outhouses of the Bronnbach Abbey – was completed on March 16, 2011. It was a historic day for Fraunhofer ISC and for its Bronnbach office, which since 1996 has been located in the neighboring building, itself formerly a stable building belonging to the abbey.

Following the conversion of the abbey's Bursariat (treasury) into a conference center and renovation of the farm building and most recently the abbey forecourt, the idea of renovating the old coach house on the road to Reicholzheim took shape. The structure of the dilapidated 19th-century building was to be kept intact and, above all, restored to use. Fraunhofer ISC was approached and asked whether it might consider the coach house for an expansion of its site. While the Main-Tauber regional administration bore the costs of renovating and restoring the building, the Fraunhofer-Gesellschaft assumed the costs for technical equipment. The building has now been in use since March 2011 as a test center for the CeDeD – Center of Device Development.

Fraunhofer ISC is pleased to have been able to contribute to the preservation of this unique building in the beautiful Tauber valley and thanks Main-Tauber regional administration and all those involved in this renovation project.

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## CENTER FOR HIGH-TEMPERATURE MATERIALS AND DESIGN HTL

Against the backdrop of worldwide increases in raw material costs and ever scarcer resources, lightweight construction is becoming increasingly important and has long since extended its reach beyond the aerospace industry. Overall, there is an ever increasing demand for heat-resistant and damage-tolerant structural materials, where these are able to fulfill functions that are specific to the applications in which they are used. Ceramics play an important role in high-temperature lightweight construction due to their thermal stability and corrosion resistance, as well as their high specific rigidity. Ceramic composites combine the advantages of various ceramic components. By selecting the components, and determining how they are arranged or structured, these composites can be adapted to specific requirements, in terms of how they cope with certain mechanical, thermal, chemical or electrical loads. Applications for ceramic composites include aircraft and missile components that are exposed to extreme aero-thermal stress, high-temperature heat exchangers in modern combined cycle power plants, high-power gas turbines, or clutch and brake systems in automotive technology.

Founded in 2012, the Fraunhofer Center for High Temperature Materials and Design HTL combines Fraunhofer ISC's existing expertise in the field of ceramic materials with process know-how specific to the manufacture of high-temperature materials, the production of fibers, and industrial heat treatment. The Center's activities therefore span various aspects of materials science and production technology. Its current staff of 55 is organized into three Working Teams. One of these teams

can be traced back to the Project Group Ceramic Composites, which was originally set up in Bayreuth in 2006. Housed in the »New Materials Bayreuth« (NME) building in Wolfsbach, it develops ceramic matrix composite (CMC) materials and components in close cooperation with the Chair of Ceramic Materials Engineering at the University of Bayreuth. The second Working Team is developing precursors for ceramic fibers, coatings, and matrix materials, as well as fiber manufacturing processes. The third team makes material and process designs available to ceramic manufacturers through its development of in-situ measurement techniques and simulation methods. The HTL's existing expertise in lightweight ceramic materials, especially ceramic matrix composites (CMC), is unique in Germany. This is to be extended in the years ahead through targeted growth within the existing organizational structure and the establishment of new working groups.

A central issue of the HTL concerns the question of how to improve the energy efficiency of industrial processes at high temperatures. In response, the Center is developing materials for high-temperature applications, including fibers and foams for thermal insulation, energy-efficient kiln furniture, as well as materials for moving parts such as radiator valves or turbine components. The HTL is also working to optimize the parameters of industrial heat treatment processes in order to reduce energy consumption to a minimum. Two relevant projects are presented on these pages.

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### **Energy efficiency in the heat treatment of technical ceramics**

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During sintering of technical ceramics, the theoretical energy consumption is usually only about one-tenth of the energy consumption actually required for industrial production. Energy loss not only occurs through the imperfect insulation of furnaces and unfavorable temperature cycles, but also through the high heat absorption capacity of kiln furniture





Fraunhofer HTL's filament winding machine

that is heated up together with the material being fired. The HTL, working together with ceramic and kiln manufacturers in a joint project funded by the German Federal Ministry of Education and Research BMBF, was able to demonstrate how energy consumption can be reduced by at least 40 % during the production of technical ceramics.

To this end, the HTL used specially developed thermo-optical measuring techniques to gather data on the material during its heat treatment. This data provides the basic input for simulation of the reaction kinetics of thermal debinding and sintering of ceramic materials. Finite element simulations of the heat treatment make it possible to determine precisely the temperature distribution and energy loss occurring in industrial sintering, so that those process conditions requiring the least energy can be defined.

A great potential for energy savings during the production of ceramics also confronts the question of whether the unfired blanks, or 'green bodies', are sufficiently homogeneous. Microscopic inhomogeneities can occur when the pores are not evenly distributed on a local level, but they can also be caused by porosity gradients in the component itself. The former leads to an increased energy demand during sintering, the latter leads to a warp of the components which results in an increased energy demand during the finishing processes. The HTL has developed measurement techniques that can precisely determine the local and the macroscopic homogeneity of green bodies, thereby enabling targeted optimization of the ceramic forming process.

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### **Fiber enclosed steel pipes for high-temperature steam applications**

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In steam power plants, steam is routed under high pressure at temperatures up to 800 °C. The steel pipes used for this purpose today have reached their limits in terms of thermal

and mechanical stress. So-called tertiary creep, occurring at high temperatures and internal pressures, causes rapid wear of the steel pipe during its lifetime, and this significantly increases its probability of failure. This limits the capacity to operate steam power plants efficiently at higher temperatures.

In a joint project funded by the BMBF, the HTL is working together with the operator of a large power plant and a CMC manufacturer on an approach aimed at the development of completely novel solutions in the field of high-temperature pressure vessels, especially pipes. These are to be made of low-cost steel enclosed in a jacket made predominantly of ceramic fiber. This combination of steel and ceramics not only ensures that the walls of the steel pipes are gas tight; the ceramic fiber surrounding them also prevents creep deformation.

The combination of ceramic materials and metals – as tested in practice here – has great potential for other high-temperature applications in which the inherent strengths of each class of material compensates respectively for specific weaknesses of the other, paving the way to more energy-efficient processes.

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# BUSINESS UNITS

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## BUSINESS UNIT HEALTH

The medicine of the future will need new kinds of treatment to overcome the challenges of demographic change and the consequences of major endemic diseases. This calls for multifunctional materials that can diagnose, monitor and control physiological processes. One of the core tasks of the business unit Health is to develop these materials and find suitable ways of processing them and integrating them in existing systems.

With life expectancy increasing and health care budgets being slashed, the aim of achieving high quality yet affordable medical care has become one of the defining challenges of our time. Research into new materials and the technologies required to process them forms an essential part of developing new and improved diagnostic and treatment methods and innovative methods of preventive medical care.

At Fraunhofer ISC, researchers focus on developing customized material solutions on the basis of hybrid polymers, ceramics and glasses for regenerative medicine, dental medicine, medical diagnostics, and high-tech medical devices.

Working together with industry partners, ISC researchers help to take existing commercial products to the next stage of development and design new, multifunctional materials with specific properties. We can also meet complex custom specifications in many different formats, including bulk materials, composites, coatings, fibers, hollow fibers and particles.

Our work in the field of health care focuses on seeking solutions that address the following megatrends:

- Regenerative therapies
- Early diagnosis / theranostics
- Age-related medicine
- Personalized medicine
- Wellness / preventive medicine

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### SKIN HEAL – Wound healing from the bioreactor

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Chronic open wounds are one of the most prevalent medical conditions – and they cost the German healthcare system some eight billion euros a year. They are caused by common diseases such as diabetes and cancer, and they primarily affect the elderly. The number of cases and the costs involved are likely to increase in the future, in view of demographic change. To counteract this trend, researchers from five Fraunhofer institutes – ISC, IGB, IME, EMFT and MEVIS – have pooled their skills in a Beyond Tomorrow project known as »Skin Heal«. The core objective of the project, which is coordinated by Fraunhofer ISC, is to optimize the treatment of chronic wounds using an artificial wound model in order to help make health care more affordable.

The starting point for the research is an artificial 3D wound model for diabetic or cancerous skin which the researchers also hope to apply to other types of diseased skin at a subsequent stage of the project. This first stage of the innovation process has been entrusted to the Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB in Stuttgart and the IGB's Oncology project group in Würzburg, which has already gained recognition for its models of healthy skin. If the scientists succeed in generating an artificial wound, approved therapeutic wound dressings will then be integrated in the in vitro model and tested to determine how exactly they work. This step will include commercially approved dressings developed at the Fraunhofer Institute for Silicate Research ISC which are designed to be left in the wound and dissolve after a period of a few weeks.



»Skin Heal« – wound healing from the bioreactor © Fraunhofer IGB

This approach is intended to demonstrate that the artificial models are equivalent to the conditions and dynamics of real skin.

The third stage of the innovation process involves an analysis of wound fluid using technology developed by the Fraunhofer Research Institution for Modular Solid State Technologies EMFT, which uses characteristic biomarkers to draw conclusions on the status of the healing process. To achieve this, the bandage covering the wound incorporates microfluidic actuators and sensors which make it possible to convey the fluid out of the wound without having to change the bandage. Once the researchers have established the timing and the distribution of the substances that promote the healing process, the fourth stage will be to introduce immunotherapeutics into the wound at the right moment and in the right quantities. Commercially approved dressings will be modified for this purpose, for example by incorporating special silicates in the fiber matrix which encapsulate drugs at a molecular level. These drugs are then released during the wound healing process to promote faster healing. This stage involves close cooperation between the Fraunhofer Institute for Molecular Biology and Applied Ecology IME and the ISC, with the IME offering its immunological expertise and the ISC providing know-how in the field of silicate research.

The project also aims to develop simple, age-related therapies which will enable patients to administer much of their treatment themselves. This is the goal set for researchers at the Fraunhofer Institute for Medical Image Computing MEVIS in the fifth and final innovation stage. Their task is to develop ways of improving the fluorescence-based imaging techniques that are designed to help researchers – and ultimately patients – to decide whether a wound is healing as it should. To optimize optical imaging results, the researchers use luminescent nanoparticles developed at the ISC whose surface has been altered so as to bind to biomarkers characteristic of wound healing. The long-term objective would be for patients to keep an ongoing, long-term record of their wound situation, e. g. using

an iPhone application; this would enable doctors to document how well the wound is healing and alert patients if they need to make an appointment to see their physician. Demographic change will make this type of self-diagnosis an inevitable part of everyday life – in fact, it is likely to develop into an essential pillar of future medical care.

If the model developed in the project is successful, it could offer huge cost savings to cash-strapped health care systems: As well as cutting costs by offering more effective treatment which enables chronic wounds to heal more quickly, it could also significantly reduce inpatient hospital costs by shifting care to the realm of outpatient services and the home environment. It could also help to drastically pare down the cost of developing new drugs – and with new drugs currently notching up development costs of up to one billion euros each, this is an area that offers enormous potential to save money. Clinical trials are what drive these costs sky high: 90 percent of drugs fail to progress beyond this stage, in most cases because they do not significantly outperform a placebo effect or provide no added value in comparison to other remedies that are already available. The results of relevant in vitro preclinical testing could help scientists to plan clinical trials more effectively and reduce the level of animal testing to an absolute minimum.

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#### **MagElan – Smart materials stimulate biological cells**

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Electroactive polymers (EAPs) and magnetoactive polymers (MAPs) are a new class of elastomers that make use of an external magnetic field to modulate their hardness and Young's modulus. A project carried out in collaboration with the Regensburg University of Applied Sciences (magnetization system) and the University Eye Clinic Würzburg (cell biology evaluation) set out to develop a novel application for EAPs in the field of tissue engineering. Living cells are known to demonstrate a different growth behavior and a different protein expression depending on substrate elasticity.

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# BUSINESS UNITS

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By using silicon-based EAPs as a cell culture substrate, scientists have succeeded in creating a material which allows its surface Young's modulus to be controlled and modulated by applying a magnetic field. Based on this principle, it would appear to be feasible to steer the growth and properties of a cell complex or tissue based on one cell type in different directions. With this goal in mind, researchers investigated the growth and protein expression of human fibroblasts on MAP both with and without a magnetic field.

The MAP material consists of addition-crosslinked polydimethylsiloxane (PDMS) with a 30 percent content by volume of finely dispersed, spherical iron particles with an average particle size of approximately 5 millimeters. One of the challenges was to prepare an easy-to-handle, biocompatible material with a tissue-like hardness and a modulus of elasticity of 10 kPa. To this end, the researchers attempted to develop a network that would be as wide-meshed as possible while still retaining adequate stability. By linking together long chain vinyl terminated PDMS and high molecular crosslinking agents in combination with chain extenders, plasticizers and a compatible platinum catalyst system, they succeeded in producing and biologically validating an easy to handle MAP with a Young's modulus of around 10 kPa.

To ensure that the MAPs could be magnetically controlled, two different types of magnetization system were developed using 3D FEM simulations. The job of the first system is to achieve homogenous distribution of the Young's modulus on the surface, a task which required multiple basic magnet circuits to be established in combinations of individually magnetized permanent magnets. The second magnetization system uses a time variable magnetic field to generate actuating movements on the surface. To achieve this, the researchers developed a coil-based excitation system which generates the required fields. With the help of the first system, the researchers succeeded in inducing a homogenous distribution of the Young's modulus on the surface of the MAP and varying the Young's modulus in a broad range between 10 kPa and 600 kPa.

Characterization of the Young's modulus close to the surface was carried out using a micro hardness tester and a specially developed measuring system. In order to analyze these dynamics under a fluorescence microscope, the MAP surface was functionalized with fluorescent microparticles and then evaluated using image processing software.

Cells are connected to their surroundings and mechanically anchored in place by means of receptors. Integrins – specific receptor proteins that detect extracellular matrix molecules – play a particularly important role in this context. One of their functions is to transfer the mechanical stimuli emanating from the MAP substrate through the cell wall to the cytoskeleton. Thus, the elasticity of the cellular environment influences the differentiation, structure and protein expression of cells and has a significant impact on the development and preservation of tissues and organs. On rigid cell culture substrates, connective tissue cells (fibroblasts) differentiate into contractile myofibroblasts which are characterized by the marker protein  $\alpha$ -SMA ( $\alpha$ -smooth muscle actin). The MAPs were prepared for cell seeding by means of silanization and coating with collagen or fibronectin and were then populated with human fibroblasts. The expression of  $\alpha$ -SMA can be controlled due to the softness of MAP as a cell culture substrate. As a result, the system developed by the researchers is, in principle, suitable for use in cell biology research and tissue culture.

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## Photostimulable nanoparticles for medical diagnostics

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Molecular imaging is one of the biggest hopes in the field of tumor detection. By using innovative biomarkers that selectively bind to tumor cells, it is possible to obtain specific and sensitive tumor imaging results. Unlike conventional methods, which in many cases can only register anatomical and morphological changes that appear late in the progression of a disease, tumor-specific markers enable the visualization of deviations in biological processes on the molecular level at an early stage. Thus, the use of molecular imaging in combination





»MagEla« – Smart materials stimulate biological cells



Photostimulable nanoparticles for medical diagnostics

with established examination methods can make a significant contribution toward improving the diagnosis of malignant tumors.

Researchers at Fraunhofer ISC are working in this field to develop new nanoparticle (NP) probes based on photostimulable luminescent (PSL) materials. These PSL-NP probes are modified with highly specific antibodies or aptamers in order to guarantee their targeted and selective accumulation in tumor-like tissue. These probes can be administered as in vivo diagnostic agents, e. g. by injecting them into the bloodstream, from where they can make their way to the cancerous cells.

One of the advantages of PSL-NPs over conventional fluorescent substances is that they are »charged« with UV light *ex vivo* so that they can be excited by IR light to fluoresce in the visible spectrum when required. The energy can be stored in the particle for a considerable duration (minutes or hours) and then accessed at the precise time required by means of stimulation with IR light. This gives medical staff time to prepare the patient for surgery and gives the applied dose of NP probes time to accumulate in the tumor tissue. Due to the time gap between optical excitation and the detection of marked cells, it is possible to use substrate-free and scattered-light-free detection. In addition, excitation with IR light ensures greater penetration depth and reduces the risk of cell damage in comparison to UV light.

PSL-NPs can be synthesized on the basis of Mn<sup>2+</sup>-doped zinc silicate (Zn<sub>2</sub>SiO<sub>4</sub>:Mn<sup>2+</sup>), for example. This procedure involves firstly preparing the SiO<sub>2</sub> core using the Stöber process in order to grow a manganese-doped zinc silicate shell around the core using a modified Pecchini process. By adjusting the process parameters, modifications can be made to the particle size and morphology, the crystalline structure of the shell and the optical properties. Typical particle sizes for the target applications are between 55 and 220 nm, the charging of the particles is carried out *ex vivo* at a wavelength of 260 nm, excitation with IR light is performed at  $\lambda = 650$  nm, and the resulting emission

wavelength is  $\lambda = 520$  nm. A range of in vitro tests confirmed that the particles are biocompatible according to ISO 10993.

Potential areas of application include diagnostics during surgery for resection of malignant tumors. This would involve modifying PSL-NP probes with antibodies to ensure specific and selective accumulation in tumor-like tissue after injecting them. During the tumor resection, the surgeon would be able to localize the tumor and precisely delimit the boundaries of the resection by illuminating the relevant area of tissue with a suitable light source. This would also enable medical staff to detect small secondary tumors and check nearby lymph nodes for metastases. The result would be to reduce the duration of surgery, guarantee complete resection of the tumor and minimize damage to healthy tissue, particularly in the area of the lymph nodes. This would also enable a reduction in recurrence rates.

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# BUSINESS UNITS

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## ENERGY

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### The year of the German energy transition

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In the foreseeable future, over 10 billion people will be living on our planet and will have to be supplied with sufficient energy and other essential resources. How we deal with the energy question will largely determine whether humans succeed in putting their lifestyles and economic practices on to a sustainable development course.

This is the main challenge facing humanity along with climate change and scarcity of resources. The old energy supply model, which is heavily reliant on fossil fuels, has been stretched to its limits. Fossil fuels are finite, and the emissions released from burning them are having an increasingly destructive effect on the climate. And some supposed alternatives have also revealed their limits. The German government was quick to draw conclusions from the Fukushima nuclear disaster in March 2011, and on June 30, 2011, the German parliament approved a nuclear phase-out by 2022. The resulting paradigm shift in German energy policy is known as the »energy transition«. The centerpiece of this transition is the expansion of renewable energy, in particular wind power, hydroelectric power, solar power, bioenergy, and geothermal power. The plan is for these energy sources to provide an alternative in future not only to nuclear power but also to fossil fuels (oil, coal, natural gas).

An energy supply heavily based on renewables will be much more decentralized in nature than has been the case until now and will thus require different electrical network structures. In future, a large number of wind and solar installations will have to be coordinated with each other along with their generation and load profiles.

The irregular availability of these energy sources requires new storage, transmission, and control technologies. At the same

time, significant research and development efforts are needed in the areas of energy production and use.

However, a sustainable energy supply can only be obtained if there is further progress in energy conservation and greater energy efficiency. The technological leaps this requires can only be achieved by means of intensive cooperation between research institutions and industry. Across the range of its activities around the production, storage, and use of energy, from applied research to developing products with industrial applications, Fraunhofer ISC is making an important contribution toward bringing about a sustainable energy supply.

Our innovations are increasingly providing valuable support to the economy in terms of improved energy efficiency in production processes (systems technology, process control, raw materials and other materials, etc.) while also enabling many households to make considerable savings (building insulation, lighting, glazing, etc.). Moreover, Fraunhofer ISC was quick to recognize the importance of resource-conserving technologies and is also engaged in research into material substitution and recycling – factors which are closely related to energy – through its IWKS project group.

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### Electrochemical energy storage devices

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It has become impossible to imagine everyday life without electrochemical energy storage devices. Millions upon millions of them are in use every day in portable electronic devices such as laptops and cell phones, in every car, and in practically almost areas of modern life. Also in use alongside the various kinds of batteries are electro-chemical double-layer capacitors, which buffer little packets of electrical energy and so relieve the batteries. Whereas automobiles are often served by conventional lead-acid batteries, portable electronic devices are equipped with state-of-the-art battery systems based on lithium-ion technology. The lithium-ion battery, which was launched by Sony as recently as 1991, has now become



standard, replacing the old nickel-metal hydride battery. This success is down to the lithium-ion battery's high energy densities, which greatly exceed those of every other electrochemical energy storage device available today. Without these high energy densities, the long operating times of today's laptops and the large number of functions in smart phones would not be possible.

When it comes to supplying power in automobiles, however, the lithium-ion battery is not yet up to the task of adequately meeting the demanding requirements. Today over 90 % of all hybrid vehicles still use nickel-metal hydride batteries; lithium-ion batteries are at an early stage of market penetration here.

Until now electric vehicles have failed to gain wide acceptance – primarily due to their relatively short range, the high price of batteries, and the time it takes to recharge them. Also, public perception of the safety and reliability of electric vehicles has been largely characterized by skepticism as a result of a few high-profile incidents. Consequently, there are still quite a few hurdles to be cleared, particularly in the area of battery research, if we are to reach the German government's target of having a million electric vehicles on the nation's roads by 2020.

The same goes for developing battery systems that will allow greater use of renewable energy. To date there have been few technological alternatives in this field, and lithium-ion batteries have some drawbacks here too. There is also a need to improve or develop other battery types, which must be safe and affordable to gain wide acceptance in private energy-producing households.

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#### **Projects from the Center for Applied Electrochemistry**

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As a participant in the Fraunhofer-Gesellschaft's »Electromobility System Research« project, Fraunhofer ISC coordinated the »Materials Development« sub-project, in which eleven Fraunhofer institutes worked to increase the energy density

and safety of lithium-ion batteries. In addition, new types of batteries that could form the basis of future energy storage devices were investigated. Fraunhofer ISC's focus in this sub-project was on synthesizing inherently safe anode and cathode materials as well as non-flammable electrolytes for lithium-ion batteries. For the »Batteries of the Next Generation« work package, electrode supports with a high surface area were coated with materials capable of intercalation in order to develop hybrid concepts between battery and double-layer capacitor.

In the »EnergyCap« project, which is sponsored by Germany's Federal Ministry of Economics and Technology, Fraunhofer ISC is participating in a sub-project exploring the combination of desirable characteristics of lithium-ion batteries and double-layer capacitors in so-called hybrid capacitors. In addition to storing charges on a double layer, hybrid capacitors – like batteries – use a redox mechanism, allowing them to improve the low energy densities of double-layer capacitors. For this purpose, highly porous materials are used and coated with various battery materials in such a way that porosity is largely retained.

In the »Lithium-Ion Battery LIB 2015« innovation alliance, eight partners within the KoLiWin collaborative research project are jointly developing new materials concepts for electrochemical energy storage devices under the direction of Fraunhofer ISC. The objective is not only to speed up charging, but also to provide a greater quantity of energy than conventional battery types, while at the same time being considerably safer. With the collaboration of two further Fraunhofer institutes, the Fraunhofer Institute for Mechanics of Materials IWM and the Fraunhofer Institute for Ceramic Technologies and Systems IKTS, along with several universities, the KoLiWIN project will focus on collecting findings from solid-state chemistry and electrochemistry as well as from materials research.

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## Energy harvesting

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The Center Smart Materials (CeSMA) develops materials and components that essentially permit mechanical energy to be swiftly converted into electrical energy (energy harvesting). These new material systems can make it possible to create innovative products and technologies capable of improving the energy efficiency above all of industrial processes and installations. This process involves obtaining smaller electrical energy packets from energy sources such as vibrations or air currents and then either using them immediately or storing them. Another field of application is the provision of electrical energy for energy-autonomous sensors. For example, a metal substrate can be coated with a thin film of piezoelectric material; this only needs to bend through a distance of 10  $\mu\text{m}$  in order to generate a switching signal. Dielectric elastomer generators (DEGs) allow mechanical energy to be converted into electrical energy with greater efficiency. DEGs have a low density and do not require any scarce raw materials. Now that various kinds of preliminary work have been completed, work is to begin in earnest on using DEGs for energy production and for energy-efficient products and processes.

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## Smart windows save energy

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A long-cherished dream in air conditioning for buildings and vehicles is to develop windows with switchable transmission (smart windows), because they could achieve energy savings of up to 30 %. A new kind of electrochemically switchable smart window based on metallo-polyelectrolytes (MEPE) was developed at CeSMA. As part of a collaborative research project with the University of Würzburg, the Federal Institute for Materials Research and Testing (BAM) in Berlin, and the Institute of Materials for Electrical and Electronic Engineering (IWE) at Karlsruhe Institute of Technology (KIT), sponsored by Germany's Federal Ministry of Education and Research,

the results of the research were taken on by an international consortium in 2011 to develop applications for architects and other users.

In addition, further cost-efficient electrochromic coatings are being developed at Fraunhofer ISC. The use of wet-chemical coating techniques permits a significant reduction in manufacturing costs compared to physical sputtering and vapor deposition techniques. It is also possible to produce electrochromic film laminates from electrochromic elements based on conductive polymers that can be processed at a lower temperature. These laminates mean existing windows can be retrofitted in vaulted structures or in applications requiring low-weight materials such as aircraft windows. The fitting and retrofitting of electrochromic window panes in vehicles and buildings for energy-saving automatic shading will be able to make a big contribution to energy efficiency in the future.

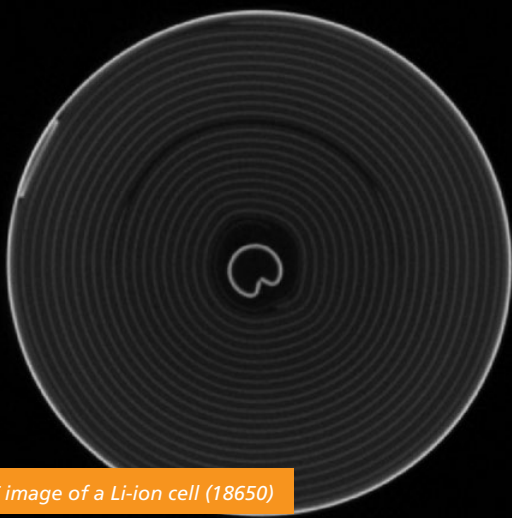
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## More efficient aircraft engines, power plants, and industrial processes

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To increase the efficiency of gas turbines and aircraft engines, the Fraunhofer Center for High Temperature Materials and Design HTL is developing modern lightweight materials and components with high damage tolerance. Researchers are investigating ceramics with fiber reinforcement and high thermal and mechanical performance – ceramic matrix composites (CMCs) – for use in combustion chambers and low-pressure turbines. Using these high-strength ceramic materials can bring about an increase in the thermal efficiency of aircraft engines. As a »side effect«, they could also result in significant reductions in the noise emissions produced by modern engines. In the bilateral project conducted in collaboration with MTU Aero Engines in Munich, researchers are working to determine test conditions and testing standards that closely reflect the real-life application of newly developed CMCs; they are investigating corrosion, creep resistance and fatigue behavior under realistic test conditions.





CT image of a Li-ion cell (18650)



Semi-automatic electrode production

At the same time, Fraunhofer ISC is developing processes for manufacturing the SiC fibers required for CMCs. In a joint project with the SGL Carbon Group, researchers are investigating the manufacturing parameters of SiC fibers made of silicon-rich polymers on a pilot scale. Their suitability for CMCs will be tested by other partners.

However, the use of CMCs can also play a big energy-saving role in power plants and in energy-intensive high-temperature processes, where they enable higher operating temperatures and a better exploitation of process heat.

At the same time, the thermo-optical measuring (TOM) instruments developed at Fraunhofer ISC's Center of Device Development CeDeD can test the resilience of these materials or conventional fireproof materials with unprecedented accuracy.

Conventional fireproof materials are often used in furnaces and glass tanks. Using our measuring instruments for testing allows optimization not only of the materials used there but also of the highly energy-intensive processes. The same applies to modern processes for producing energy from fossil fuels such as lignite and bituminous coal, in which TOM systems are used to enable the processes to be characterized online.

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### Modern solar cells

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In conventional photovoltaic cells and solar thermal collectors, 10 % of the incident light is not used for energy production. The majority (four-fifths) of this 10 % is reflected. Using special coatings developed at Fraunhofer ISC, the degree of reflection can be reduced significantly, thus improving the energy yield. This can increase the annual output of photovoltaic modules by 3.5 to 4 %; for solar thermal plants, the figure is as high as 7 to 8 %. This innovation has already been implemented on an industrial scale. Newly developed

coatings have made it possible for photovoltaic modules to have self-cleaning effects, enabling the efficient use of solar installations in dusty desert areas and in the arid regions of southern Europe.

Developments that have come about in the area of expertise of materials chemistry also play an important role in the latest photovoltaic systems. For example, light-scattering layers help to improve the efficiency of silicon-based thin-film solar cells. Organic photovoltaic systems require transparent barrier layers on films to protect the organic solar cells from environmental influences. These ultra barrier films were developed in the Fraunhofer POLO alliance coordinated by Fraunhofer ISC. The films are also very important in the manufacture of modern energy-saving organic light-emitting diodes (OLEDs).

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### Energy efficiency in buildings

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Energy efficiency in buildings is a very big factor in saving energy. One objective here is to reduce the amount of heating energy required in buildings, for example through using heat-insulating materials or thermal storage materials. Latent heat storage materials (also known as phase change materials, PCMs) offer a modern type of heat storage. During the transition phase when changing between aggregate states, PCMs store the supplied or dissipated thermal energy. PCMs fitted inside walls can significantly increase their insulating properties. Fraunhofer ISC is working on inorganic encapsulation techniques for PCMs, which should greatly increase the range of commercial applications for PCMs.

Together with the use of electrochromic window panes and important contributions to the manufacturing of OLEDs for energy-saving lighting systems, Fraunhofer ISC is doing its part to facilitate energy saving in buildings.

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## Resource management and recycling

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The ecological and commercially viable development of new processes for recycling critical materials is the task of the new Fraunhofer project group IWKS. A further objective is to work on the substitution of materials whose availability is classed as critical.

Fraunhofer IWKS's role is closely related to energy issues. For example, the energy transition in Germany will see special-glass recycling grow in importance, because special low-iron glasses have to be used in building the modules for photovoltaic systems or thermal solar collectors in order to keep the energy losses caused by their glass covers as low as possible.

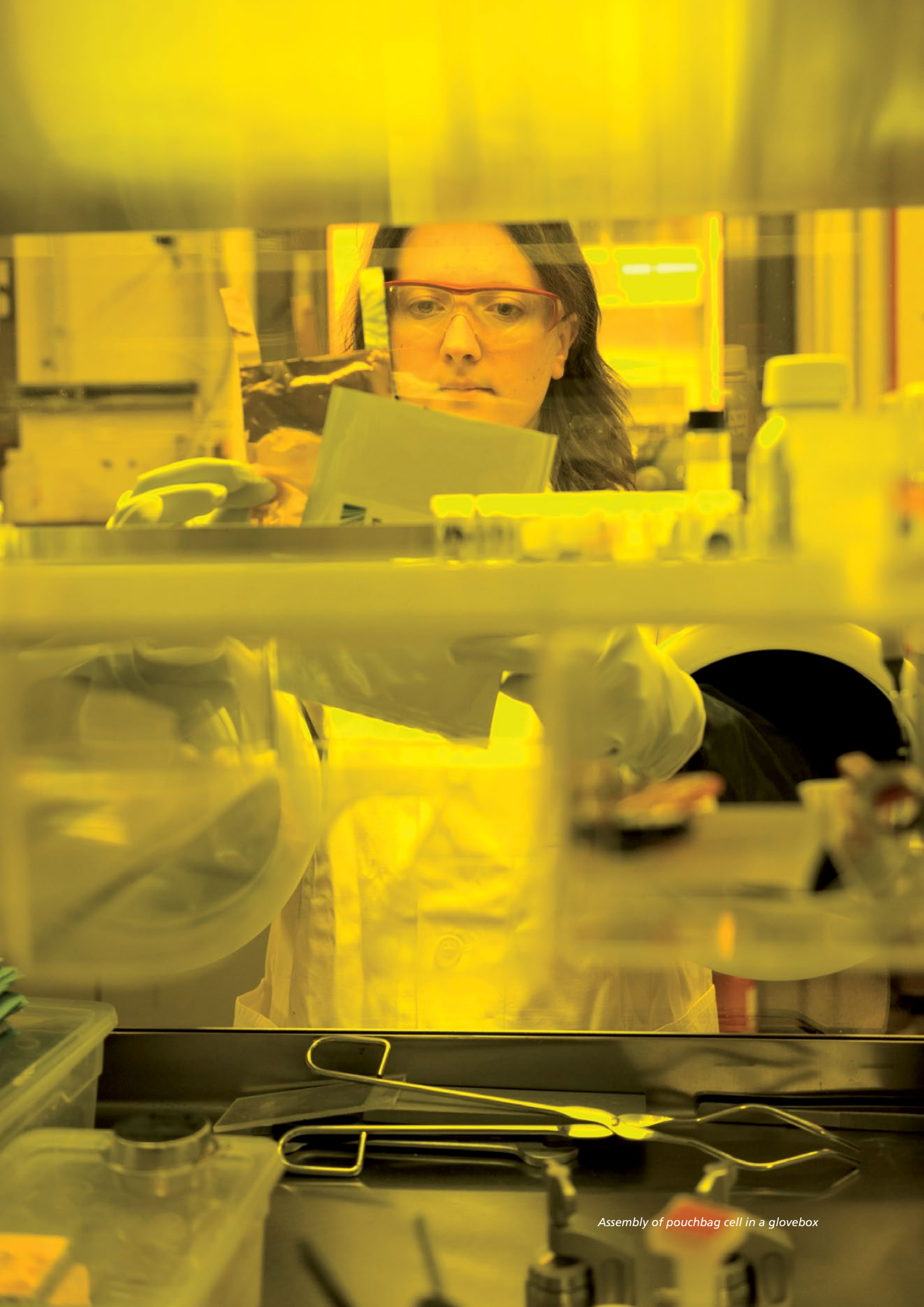
Electric motors, which are essential for electromobility, contain significant amounts of rare earths, the availability and prices of which have undergone dramatic changes in the recent past. Work is needed here both on new recycling techniques and also on the partial substitution of rare earths in order to make electric motors affordable and available in large quantities.

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*Assembly of pouchbag cell in a glovebox*





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# FEATURE TOPIC »RESEARCH FOR THE ENVIRONMENT«

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## BUSINESS UNIT ENVIRONMENT

- REPLACING MERCURY IN MEASURING AND CALIBRATION DEVICES
- ENERGY CONSERVATION AND CO<sub>2</sub> REDUCTION IN THE PRODUCTION OF CEMENT
- FLEXIBLE BENDING OF FLAT GLASS
- CORROSION PROTECTION WITHOUT HEXAVALENT CHROMIUM
- CLIMATE FOR CULTURE
- SENSOR SYSTEMS AND ENVIRONMENTAL MONITORING
- AIR PURIFICATION AND DECONTAMINATION
- SELECTIVE MAGNETIC PARTICLES FOR WASTEWATER TREATMENT AND THE RECOVERY OF RECYCLABLE MATERIALS
- HOW MULTI-FUNCTIONALITY REDUCES PROCESS COSTS AND SAVES RESOURCES

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# BUSINESS UNITS

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## ENVIRONMENT

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### Sustainable materials research

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An intact environment is essential to the survival of humanity. Over the long term, we will only be able to continue to exploit the air, water, soil, food, and raw materials for industrial production by employing sustainable approaches and closed-loop recycling. The recognition that there is ultimately no way around the reconciling of economics and environmental concerns has taken root in all modern industrial societies. One consequence of this awareness in Germany was the establishment of the FONA framework program by the Federal Ministry of Education and Research to promote research into sustainable development.

Environmental protection, resource conservation, new recycling strategies, ecodesign, environmentally sound disposal, and user-friendliness are all factors that manufacturers consider from the outset when developing new materials and components. Alongside a clearly defined high-tech strategy, sustainable product development has become a sine qua non of future materials research in industrial nations.

This perception forms the basis for the work on new material technologies by the Fraunhofer ISC business unit Environment. These especially efficient and eco-friendly technologies contribute to climate protection and the preservation of our natural resources. The business unit's activities focus particularly on the development and implementation of chemical synthesis procedures and processes which conserve resources in a sustainable and highly efficient manner.

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### An application-oriented partner for industry

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Chemical synthesis, often referred to as a bottom-up approach, is at the forefront of materials research at Fraunhofer ISC. This involves establishing a link between compatible processing technologies and highly-specialized (nano-) analyses. This unique combination has resulted in the development of a large number of new products, such as those grouped under wet-chemical material synthesis, which makes use of the sol-gel process. The hybrid materials made possible by these processes are a trademark of the Fraunhofer-Gesellschaft. ORMOCER®s, as they are known, have already been in use for some time as dental materials, where they are increasingly used to replace environmentally-damaging dental amalgam. Further examples of efficient material technologies include thin decorative color coatings for glass objects. These are based on aqueous-alcoholic solvents, making them a more environment friendly method of coloring glass than intensive melting processes based on toxic components (CdS, CdSe). New ultra-hydrophobic coatings applied to the rims of glass carafes (Drop Protect, manufactured by Zwiesel Kristallglas-fabrik AG) reduce the wettability of the glass surface. This prevents drops from running over the rim while pouring and makes the carafes easier to clean.

Great economic importance is attached to developing sustainable corrosion protection for metallic structural materials such as sheet steel and light alloys. Fraunhofer ISC is conducting research into substitute materials possessing a self-healing effect for use in coating systems and primers. These materials are set to replace hexavalent chromium, which, despite its widespread use to date, is hazardous to the environment and indeed is already banned in some places. Efforts are being made to microencapsulate corrosion inhibitors and coating components in order to prevent corrosion of exposed metal surfaces in the event of mechanical damage to the protective coating. This would significantly increase the service life of components – particularly in difficult-to-access places inside cavities.

Our development and application of ultra-thin layers with high levels of functional integration contributes significantly to the goal of resource conservation. This also applies to the films used in food packaging, for instance, where biopolymers are successfully functionalized as sustainable packaging materials through the use of ultra-thin silicon oxide layers and hybrid polymers, which create a barrier against both water vapor and oxygen. These multifunctional layer systems also endow packaging with new properties, such as antimicrobial effects and counterfeit protection.

The ability to monitor mechanically-stressed components with piezoelectric sensors, to detect complex pollutant mixtures with gas and fiber sensors, or to monitor the climate and environment with dosimeters all depend on functional materials and active surfaces that possess new, previously unobtainable combinations of characteristics as a result of their chemical composition, microstructure, or how they were processed (material design through chemical nanotechnology). This paves the way for new, simplified processes with less material input, also in the field of microsystems engineering.

Rounding off the materials portfolio are new glasses, glass ceramics, nanocomposites, sustainable building materials, secondary raw materials, and – in future – renewable raw materials. The degradation and avoidance of pollutants through the use of meso- and microporous materials are hot topics in materials science. Research in this area is focused on creating a livable future in our homes and in tomorrow's (mega-) cities, as these foreseeably take shape, particularly in Asia and the Middle East.

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## Our vision

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Restricting climate change and its effects is one of the major social challenges of our time. Germany has set itself ambitious climate objectives and has legally committed itself to a dramatic reduction in CO<sub>2</sub> emissions. Achieving these goals

will require new raw material strategies and material-efficient technologies that lead to sustainable development.

In moving towards our vision of an environment which is utilized in a sustainable manner, remaining intact and livable for future generations, we work systematically in our role as research partners on developing new materials and material technologies that incorporate renewable raw materials and fully recyclable components. The following technologies play a particularly prominent role here: CO<sub>2</sub>-neutral building materials, biopolymers, meso- and microporous pollutant absorption systems, catalytically active surfaces and coatings, and encapsulation technologies.

When deciding where we will next focus our development efforts, ecodesign in material and component development shares equal importance with considerations pertaining to sustainability over the entire lifetime of a manufactured product (life cycle analysis). Our objective here is to contribute to the further development and strengthening of the market for environmental technologies while also expanding Germany's role as the global leader in this field.

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## REPLACING MERCURY IN MEASURING AND CALIBRATION DEVICES

KARL J. DEICHMANN

### Developing a mercury-free precision thermometer

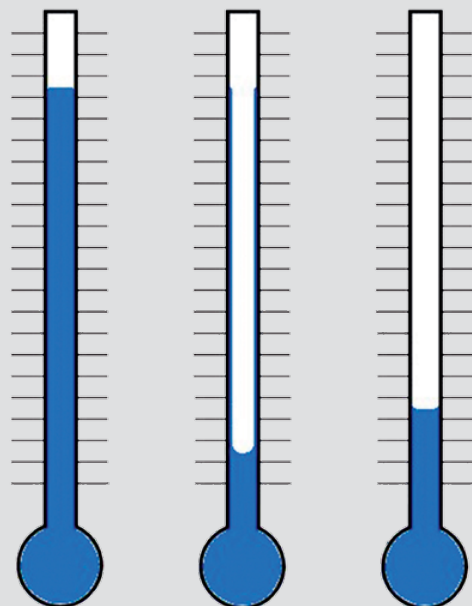
Efforts are being made to reduce the use of mercury to an absolute minimum due to the very high risk of water contamination (fish toxicity) and, in particular, the dangers posed by mercury vapors. Under the European chemicals legislation REACH (EC No. 1907/2006 Annex XVII, 18a), the use of mercury has now been restricted to measuring devices for industrial and scientific use. According to this legislation, mercury-containing measuring instruments should no longer be used as far as this is technically and economically feasible. It is left to the member states of the EU to enforce even stricter measures.

Precision thermometers (calibratable, graduation  $\leq 0.2$  °) are used in many fields of science and technology. When it comes to choosing an easy-to-use precision thermometer, liquid-in-glass thermometers containing mercury have typically been the dominant option. In addition, precision liquid-in-glass thermometers (containing mercury) are still a mandatory requirement for performing many standardized tests and analyses in conformance with DIN, ISO and ASTM. Efforts to find alternative liquids to replace mercury in precision thermometers have primarily been thwarted by the fact that most liquids (with the exception of liquid metals) wet and cling to the glass of the thermometer, causing reading errors when the thermometer cools down. The problem of wetting means that it is often necessary to wait several hours before the liquid has returned to its original state, as illustrated by the diagram on the left. The thermometer on the far left is warm and is showing the correct temperature. The thermometer in the middle shows the reading immediately after the

thermometer has cooled down: The liquid retained on the capillary wall causes an incorrect temperature to be displayed. The thermometer on the right shows the reading a few hours later. The liquid that was originally left on the capillary wall has run down the glass, and the thermometer is now displaying the correct temperature.

The aim of the project, which was funded by the German federal ministry of economics and technology (BMWi) through the Allianz Industrie Forschung (AIF, Industrial Research

*The problem of wetting when replacing mercury by other liquids*







No wetting – no waiting



Inner coating of thermometer capillaries

Alliance), was to develop a novel, mercury-free precision liquid-in-glass thermometer. The intention was to achieve this using a combination of a thermometer capillary surface with the lowest possible surface energy and a thermometer liquid with the highest possible surface tension.

#### Advantages over electronic thermometers

Liquid-in-glass thermometers have a number of advantages over electronic thermometers:

- They do not require any power (e. g. batteries) to function, which means that they are always ready to use.
- The fact that they do not require batteries means they are environment friendly, provided that they are mercury-free.
- In contrast to electronic thermometers, it is easy to determine whether they are working properly (no further devices are required to check this).
- They are significantly cheaper while offering the same degree of accuracy.

#### Inner coating of thermometer capillaries

In order to provide thermometer capillaries with an inner fluorosilane coating, the researchers developed a method and a coating technique. These ensure that the surface energy of the capillary inner surface is permanently reduced to below 10 mN/m as a basic condition for preventing wetting. The coating solution consists of two components which must be mixed in the same volume ratio one day prior to use. One component contains the fluorosilane and the other component contains the water required to hydrolyze the fluorosilane together with the hydrolysis catalyst. To achieve the optimum and most complete coating of the capillary inner surface, the researchers determined that the glass surface should first be activated through treatment with an acid. Acetone was chosen as a

solvent due to its low viscosity, which enables the coating to be applied even to narrow thermometer capillaries (from approx. 60  $\mu\text{m}$ ).

#### The search for a suitable thermometer filling liquid

The choice of suitable thermometer filling liquids that have a high surface tension is very limited. Some ionic liquids have a wide existence range of the liquid phase while simultaneously offering high surface tension. However, the use of this class of materials, which initially appeared promising, was ruled out due to the high viscosity of the apparently suitable ionic liquids. Rapid cooling of thermometers filled with these ionic liquids very quickly leads to thread breakage, which renders the thermometer useless.

Following intensive research, the scientists finally identified propylene carbonate as a suitable thermometer filling liquid. Thermometers which have capillaries coated with fluorosilane and are filled with propylene carbonate behave in a similar fashion to mercury thermometers with regard to reading accuracy and response time. The absence of a meniscus actually means that these thermometers are even quicker to read than mercury thermometers. The only disadvantage in comparison to mercury thermometers is the limited measuring temperature range. However, their temperature range of  $-30\text{ }^{\circ}\text{C}$  to  $150\text{ }^{\circ}\text{C}$  means that it would be possible to replace approximately 90 % of mercury thermometers. This would eliminate a large portion of the 4.5 tons of mercury which are used each year in the EU for measuring devices – and which ultimately end up in the environment.

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## ENERGY CONSERVATION AND CO<sub>2</sub> REDUCTION IN THE PRODUCTION OF CEMENT

DR. JÜRGEN MEINHARDT

In the interest of achieving a resource-friendly cement production that is low in energy consumption and CO<sub>2</sub> emission, the on-going project »ECO Cement« (funded by the Federal Ministry of Economics and Technology BMWi) is looking into the extent to which early strength of cinder or slag sand cement can be enhanced so that building contractors do not suffer any disadvantages in the scheduling and costs of construction in comparison with the use of clinker-based varieties. Cinder sand could then be employed in the domain of bulk cement. Provided that an accelerated early hardening can take place, these varieties of cement would not only offer a wide range of practical advantages in building construction (such as high chemical resistance, low build-up of hydration heat, fair-faced concrete surface), but also improve eco-efficiency and the sustainability of the concrete construction. It would also be possible to conserve natural resources that are normally consumed during cement production. Critical to eco-efficiency is the degree by which the clinker content of the concrete can be lowered in favor of cinder sand. This is because the production of clinker in furnace aggregates results in CO<sub>2</sub> emissions from fuel, as fuel energy is transferred to process heat, as well as from raw materials during the limestone neutralizing process. In contrast, cinder sand is a waste product of iron extraction and in no way affects the eco-balance. The total CO<sub>2</sub> content of CEM I cement with 0 % slag sand is 1011 kg/t. If a CEM III/A with 50 % slag sand could be used, the CO<sub>2</sub> content would be reduced to 539 kg/t, and using a CEM III/B with 75 % cinder sand would even reduce that figure to just 300 kg/t.

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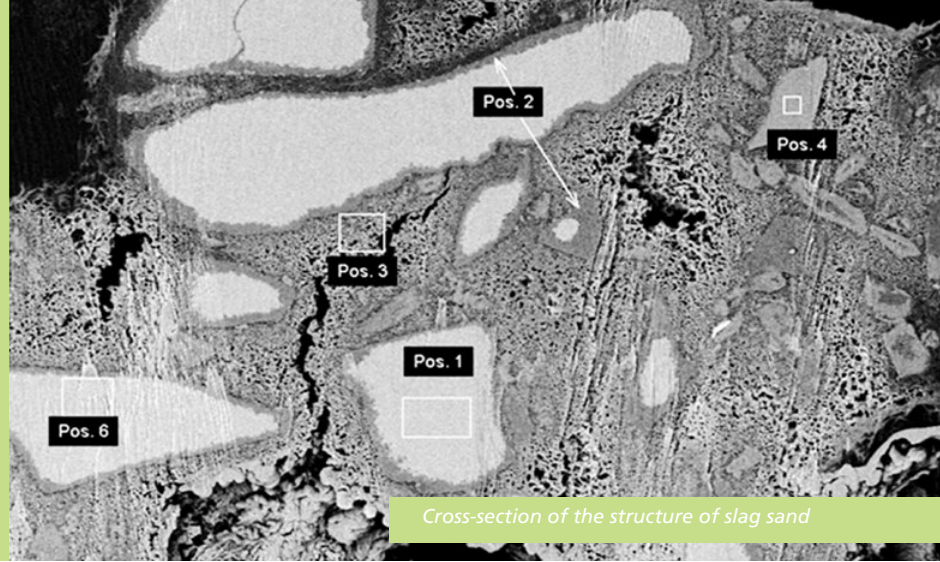
### Development of analytical processes

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Cinder or slag sand is an almost completely amorphous, that is to say vitreous, silicate material. For decades, Fraunhofer ISC has been concerned with the development and the corrosion of silicate materials, including cement. Within the project, special attention is paid to the hydration behavior of slag sand in aqueous and cement-related conditions. In order to find what is behind the reduced early strength of slag sand cement, it is necessary to assess the appropriate analytical methods.

Most of the published analyses are derived from macroscopic investigations, including the chemical composition of pore solution using ICP, or of microscopic tests using a raster electron microscope. The latter involves so-called »Environmental Scanning Electron Microscopes (ESEM)« or »Variable Pressure Microscopes (VP)«. In both cases it is possible to work under air pressures of several millibars in the test chamber whilst maintaining a high level of humidity. This ensures that the hydrate phases, which occur during hydration of the clinker and slag sand, are not destroyed. Nevertheless, the high pressure in the chamber hinders high resolution, as the electrons of the gas molecules are dispersed. Under the raster electron microscope, chemical element analysis is impaired even more severely, as the dispersal of primary electrons from the gas molecules produces the so-called »skirt effect«, resulting in a noticeably poor spatial resolution of several micrometers.

This explains why research in recent years has moved more towards using cryogenic methods, which allow us to freeze cement under high pressure before examining it under the



microscope. The high pressures are necessary to prevent the formation of polycrystals in the ice. Ideally, this results in amorphous freezing, which maintains volume or prevents structures that contain water from bursting during freezing. During the so-called cryogenic analysis under the raster electron microscope, it is possible to work in a hard vacuum, which means the electrons of gas molecules are not scattered and very high resolutions can be achieved. Work is carried out in a so-called low kV mode, meaning that the acceleration potential has a value of no more than 1 kV. In this mode it is possible to avoid an electric charge, obviating the need to sputter the non-conductive cement with a thin metallic layer, which would mask the smallest surface structures. Nanoscale resolutions are achieved. A drawback of this method is not being able to analyze the cross-section of the material, since the surfaces being examined are inevitably fractured. This prevents a genuine analysis of how the internal structure of the cement is formed and the various stages involved, particularly the analysis of diffusion profiles. In any case, despite the hard vacuum in the testing chamber, in the case of chemical element analysis there are still no satisfactory spatial resolutions available.

In recent years, Fraunhofer ISC has therefore tested an ion beam preparation on cement. Techniques have been developed, which, while not yet able to guarantee the preservation of morphology in the hydrate phases, allow a cross-section preparation without mechanical damage and which do not lead to artifacts regarding chemical element dispersal in the matrix. Figure 1 shows a cross-section of the structure of slag sand that was stored for 30 days in an aqueous NaOH solution with a pH value of 13. The cross-section was produced using argon ion beams. The raster electron microscopic image was achieved using a special high-resolution, material-sensitive detector. Differences in the gray value can be traced back to actual changes in material composition. A dark fringe on the edge of the slag sand grains is clearly visible. Here, chemical element analysis using EDX establishes a significantly higher,

over-stoichiometric oxygen content. Although hydrogen cannot be detected through EDX, the oxygen content indicates the presence of water ( $H_2O$ ), which means the dark border represents the hydration depth of the slag sand. Between the grains of slag sand a gel matrix has formed, which probably surrendered its free water during preparation, leading to a highly porous structure.

Despite this success in preparation and analysis technology, some questions remain unanswered. One such question concerns the site-specific chemical composition. The quantitative evaluation by EDX spectra are based on mathematical models that are geared towards homogenized, dense matrices, and are therefore unsuitable for highly porous varieties. It is also not possible to determine EDX spatial resolution in highly porous matrices. This may be in the range of several micrometers, depending respectively on the acceleration potential, the material in question or porous structure. When tests are to be carried out in the micrometer, or more importantly the sub-micrometer range, the qualitative and quantitative chemical analyses are less than conclusive. This led to the development of suitable preparation techniques based on the Focused Ion Beam (FIB) technique, which can produce lamellae that are approximately 100 nanometers thin for use with the transmission electron microscope (TEM). Here a lamella is cut out of the highly porous cement matrix using a gallium ion beam focused to within a few nanometers. The advantage of a transmission electron microscope over a raster electron microscope is that no extensive scattering of electrons from the sample atoms takes place due to the greatly reduced thickness of the sample. In this way, chemical analysis by way of EDX can be achieved a spatial resolution of just a few nanometers. This allows the diffusion profiles, especially beyond the outer surfaces of the grain and into the matrix, to be measured. It is then possible to draw conclusions about the interaction between the grains and the pore solution, while benefiting at the same time from images with sub-nanometer resolution. Analyses of the crystal structure are also made possible due to electron diffraction. In

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order to rule out the creation of artifacts, further investigation into the interaction of cement-related hydrate phases still has to take place using gallium ions.

The figure shows the STEM (Scanning Transmission Electron Microscopy) image of the cross section through the edge of a slag sand grain that has been corroded in an aqueous medium. One can recognize on the outside of the grain the morphology that is typical for an aqueous attack on glass, as well as in the formation of a gel layer. The pale layer on top of the gel layer is a result of the platinum sputtering process used during preparation of the lamella. To prevent damage to the surface by gallium ions, it is protected by a platinum coating.

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## Conclusion

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Cement-related structures can now be analyzed in high resolution, chemically as well as morphologically, thanks to the development of new preparative approaches using ion beam techniques and the application of scanning transmission electron microscopy. In particular, high-resolution diffusion profiles can be measured, allowing to investigate just how slag sand, clinker and pore solutions interact. This has established the analysis requirements with which to ascertain the causes of reduced early strength in slag sand cements.

## Contact

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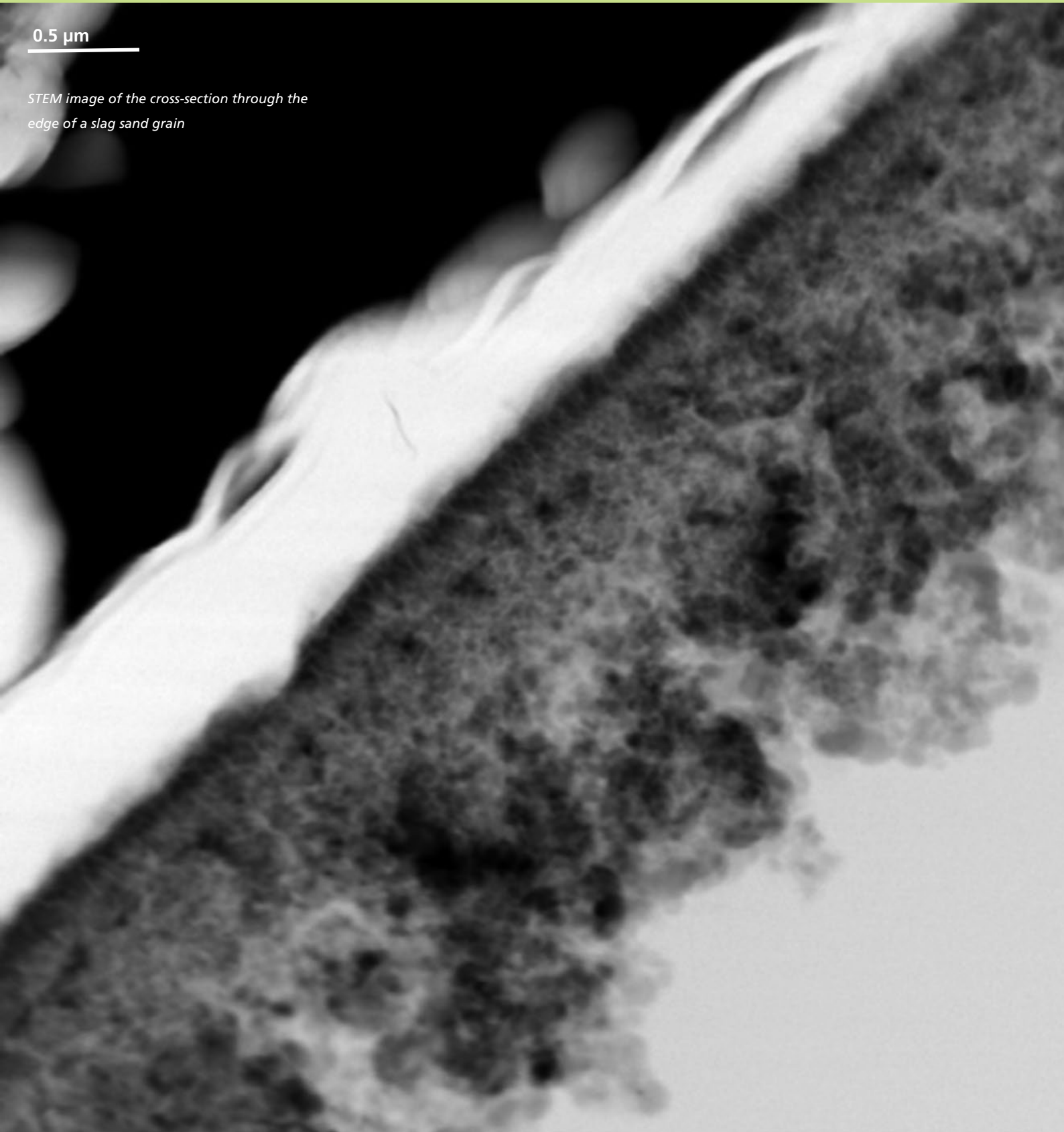
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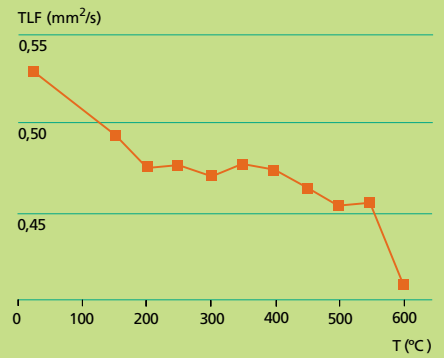
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*STEM image of the cross-section through the edge of a slag sand grain*





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2 Temperature conductivity of soda lime silicate flat glass plotted against temperature measured using the laser-flash method (CO<sub>2</sub> laser)

## FLEXIBLE BENDING OF FLAT GLASS

DR. MARTIN KILO

### Introduction

In collaboration with industrial partners and the Fraunhofer IWM, Fraunhofer ISC managed the joint development project »Flexible Flat-Glass Bending Technique« (FFB) as part of the conceptual framework »Research for the Production of Tomorrow«, which was funded by the German Federal Ministry of Education and Research (BMBF). This collective project has resulted in the development of an innovative bending technique for manufacturing curved glass products out of flat glass, including prestressed glass in certain applications. The following requirements were placed on this technique: high level of automation, material-specific process workflow, more energy-efficient and faster process times than the state of the art, high product quality in relation to contour accuracy and surface finish, permanent and detailed process monitoring, and reproducible process workflow. The previous state of the art for bending flat glass in applications being dealt with in the project – involving small to medium quantities and complex contours – tends to be based on manual processes (hand-finishing) that involve a great deal of time/effort, low quality, and high costs.

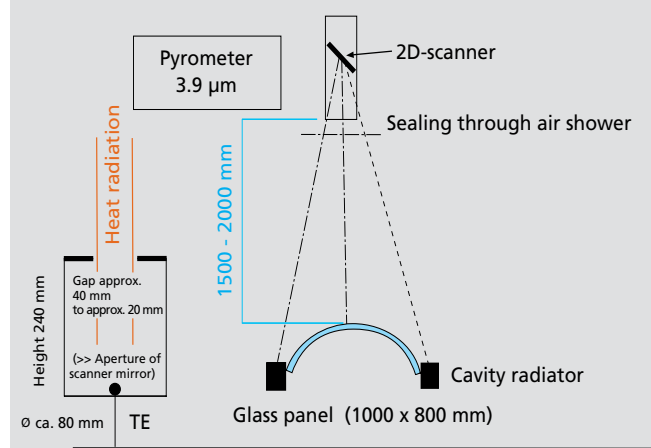
### Objectives and work packages

The Fraunhofer ISC's tasks in the project were to provide material data on the thermal behavior of glass and to devise metrology for online temperature monitoring during the glass forming process. The Fraunhofer ISC utilized its existing thermo-optical measurement techniques to provide the material data, modifying these techniques to obtain data required for

simulation of the forming process at the Fraunhofer IWM. This called for data on viscosity, thermal conductivity, coefficient of thermal expansion, surface tension, and infrared absorption in the range of the forming temperature. Investigations were carried out on soda lime silicate float glass, which served as an exemplary reference. The research also focused on the effect of temperature on the bonding behavior of glass with various contact materials that are relevant to forming.

To monitor the bending process, a temperature measurement technique was developed based on existing know-how. This technique can measure the glass temperature in the forming area with an accuracy of approx.  $\pm 1$  K and was initially tested in the Fraunhofer ISC lab before being transferred to the pilot plant set up at the Fraunhofer IWM. The pyrometric temperature measurement is based on the periodic scanning

1 Schematic diagram of pyrometric temperature measurement with flat glass bending.





Bended flat glass panel © Fraunhofer IWM

of the glass surface using a scanner mirror and a periodic temperature comparison with a reference radiation source and experimentally determined correction data (Fig. 1). To manufacture curved toughened safety glass, the glass is transferred to a second furnace chamber and blown with cold air from both sides.

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## Results and outlook

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Precise local pyrometric temperature measurement during the process was set up and integrated into the pilot plant. The influence of precise local heating (hot air, laser) on contour accuracy was illustrated in the simulation and verified in the experiment.

The technique developed in the project can virtually eliminate tooling times when switching products thanks to technical measures that control the mold and which do away with the need for individual molds. The time for producing a curved glass panel is therefore substantially reduced since the individual process steps of heating, forming, and cooling can be spatially separated. This results in a substantial saving in energy consumption in producing the individual glass panel. Viewed overall, the devised process makes a substantial contribution to improving product quality, lowering waste, reducing material consumption while, in turn, increasing energy efficiency.

The project has paved the way for a field-tested, efficient technique and process solution to economically manufacture small quantities of curved and, where necessary, tempered quality flat glass.

The temperature conductivity of the soda lime silicate flat glass was determined in the Fraunhofer ISC's thermo-optical measuring system (TOM) using laser-flash methods at various

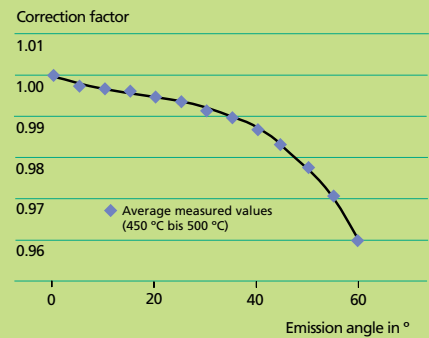
temperatures (Fig. 2). The glass samples were investigated as freestanding individual panels, as plane-parallel double panels, and as drops lying on a thin metallic film. The measurements on the drop were carried out using in-house customized software which supports inverse simulation of the heat transport.

The specific heat capacity  $c_p$  of soda lime float glass was also determined. The glass transition of the test sample was determined at a temperature of 567.1 °C at a change of specific heat capacity of 0.275 J/g\*K.

The thermo-optical contactless measurement principle can be used to determine the transformation temperature ( $T_g$ ) and Vogel-Fulcher-Tammann (VFT) points of glass. Apart from determining  $T_g$ , fiber-elongation and beam bending techniques are also used.

A special test-sample holder was constructed for load experiments, with glass test samples mounted on movable rollers so that no transverse forces are produced. To achieve temperature distribution that is as even as possible, the glass bar within the furnace was also placed in a separate container made of insulating fiber material with viewing windows. The viscous deformation under defined pressure was determined using bar-shaped flat-glass test samples made out of soda lime silicate glass. The measurement covered viscosities from 109 to 1015 dPa\*s – equivalent to measurement temperatures of around 900 to 400 °C. The bar-bending technique and the fiber-elongation test make it possible to reproduce results to within 2 K: the same range achieved when determining the transformation temperature. The thermo-optically determined values provide a good match with the values calculated using the Vogel-Fulcher-Tammann equation.

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*3 Measurement of the distance and angle dependency of the pyrometrically measured temperatures, measured values, and compensation function (values = standardized averages of multiple measurement series ( $\pm \phi$ ) at 450 °C or 500 °C)*

A separate test bench was set up to develop the pyrometric temperature measurement technique for bending. This test bench was used to conduct model experiments on hot float-glass panels. Fig. 3 shows that heat radiation barely changes at an angle between 0° and  $\pm 40^\circ$ . Across this angle range, the temperature can therefore be measured in the bending apparatus.

Since the measurement distance changes during the bending process, the influence of the distance between scanner mirrors and flat-glass panel on the temperature measurement signal was determined. At angles between 110° and 130° no significant temperature change occurs as a function of the glass/pyrometer measurement distance.

Experimentally determined temperature-dependent emissivity values of the glass are used to determine the glass temperature using the pyrometer.

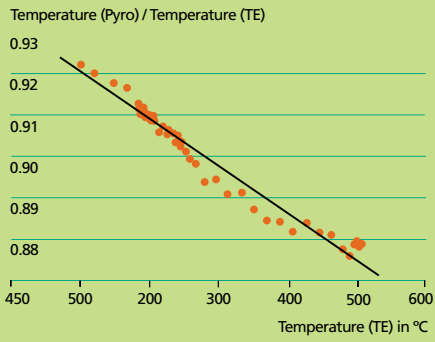
The ISC developed the program for contactless temperature recording of glass panels during the bending process. The program directly controls a pyrometer and a scanner. To increase measurement accuracy, the temperature of a black-body radiator is measured pyrometrically inside the furnace, and additionally for reference with the help of a thermocouple. These data are applied online to correct the exclusively pyrometric recording of glass temperatures, thus allowing measurement aspects of dynamically changing circumstances (contamination, etc.) to be taken into account during the glass bending process.

Another correction factor takes account of the angle of heat radiation recorded pyrometrically as a function of the mounting position of the scanner and the glass coordinates being measured. The requisite temperature- and angle-dependent calibration data were determined at the ISC during the project and are managed by the furnace control program. A correction algorithm ensures the directly recorded temperature data are corrected.

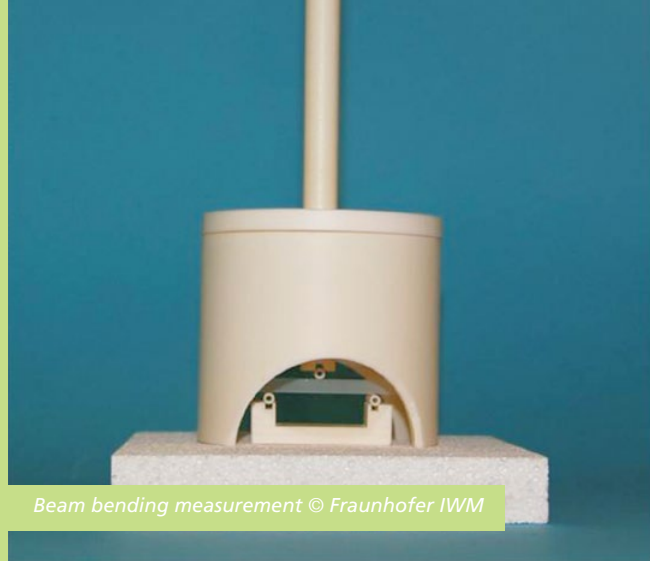
Measurements were taken using the pyrometer system, together with thermocouples mounted on the panel, to investigate the temperature distribution inside the furnace (Fig. 4). This revealed a temperature gradient of approx 10K across the bending zone. A temperature variation is also discernible in the area of the door.

The temperature measurement was integrated into the furnace control system (IPC) from Eckelmann AG. Temperature measurements on glass panels were conducted and analyzed during a series of operating tests. The temperature measurement was verified using cavity radiators and thermocouples. The inclusion of the superficial in-situ temperature measurements helped substantially improve the furnace control system. The precise determination of the bending temperature revealed the ideal processing window for the particular glass in order to suitably control the bending process.



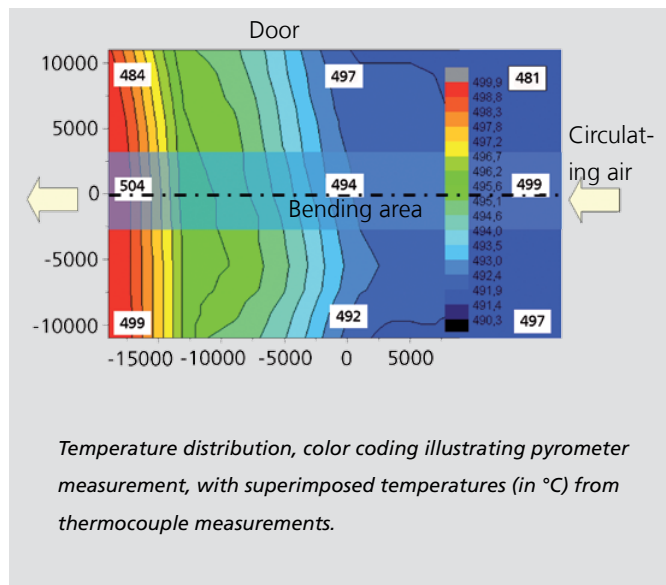


4 Temperature dependency of emissivity  $\varepsilon(T)$  for float glass



Beam bending measurement © Fraunhofer IWM

The project has paved the way for field-tested, efficient techniques and process solutions to economically manufacture small quantities of curved and, where necessary, tempered quality flat glass. The technique therefore makes a major contribution to reducing materials consumption and improving the associated energy efficiency



Temperature distribution, color coding illustrating pyrometer measurement, with superimposed temperatures (in °C) from thermocouple measurements.

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## CORROSION PROTECTION WITHOUT HEXAVALENT CHROMIUM

MARIE-LUISE RIGHI, DR. JOHANNA KRON

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### The need for action

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The corrosion of metals costs the economy billions each year. By current reckoning, the cost for developed countries is around 6 % of national GDP once the associated costs of decreased production or operational failure have been taken into account. In Germany alone, the figure stands at around 150 billion euros each year. How to prevent corrosion, then, is a crucial question in keeping production effective over the long term. Established methods such as chrome plating, where metal surfaces are treated with hexavalent chromium, are now only permitted in exceptional circumstances because of the risks they pose to health, and a blanket ban covering even these special instances should not be ruled out. In the light of increasingly strict environmental regulations worldwide and rising quality expectations, companies are being forced to make appropriate adjustments in the way they deal with corrosion protection. Correspondingly, alternatives to chromium(VI) are being sought the world over. Fraunhofer ISC is working hard on various wet-chemical processes that might allow the effective corrosion protection properties of chrome plating to be combined with a sol-gel coating with no adverse effects on health.

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### Property profile for chrome plating

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There is a long history of using chrome plating as a pre-treatment on aluminum, iron or even magnesium prior to the application of a final coating. This is due to the excellent corrosion protection properties of the method and its easy

integration into established metal-processing techniques. A replacement technique must, therefore, do justice to both these aspects if it is to be recognized and employed as an economically and ecologically worthwhile alternative.

Key properties with regard to the treatment of metals:

- Galvanic-technical processing in the roll-to-roll process
- Forming consistency in standard molding techniques, for instance deep drawing
- Spontaneous healing in the event of minor damage – with corrosion protection left intact

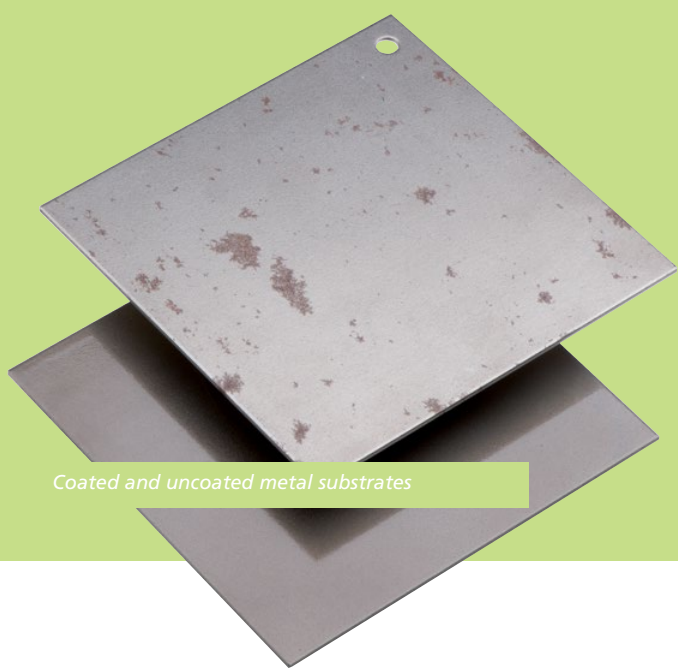
However, hexavalent chromium compounds are listed as toxic and carcinogenic in the EU's Dangerous Substances Directive, and are on the list of top toxic substances as issued by the U.S. Environmental Protection Agency. In accordance with the EU Directive on End-of-Life Vehicles, as of 2007 car manufacturers have been obliged to offer products completely free of chromium(VI). Furthermore, the EU Directive on Waste Electrical and Electronic Equipment governs the recycling of electronic and electrical equipment. As of July 2006, EU member states have been obliged to ensure that new electronic goods introduced into the market no longer contain hexavalent chromium, among other dangerous substances.

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### Passive corrosion protection on a hybrid sol-gel base

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In a project sponsored by the German Federation of Industrial Research Associations (AiF), sister institute Fraunhofer IWU and the Institute for Corrosion Protection Dresden collaborated with Fraunhofer ISC to develop new ideas for a corrosion protection system that would be applicable to many



Coated and uncoated metal substrates



Salt spray test

metals and provide an eco-friendly alternative to chrome plating. Possible areas of application include steel and zinc-coated steel as well as aluminum and magnesium alloys. Coatings were designed to suit commercially available technical finishes and various top-coat systems, among them polyester powder, a bilayer EP/PUR liquid coating and a single-layer PUR liquid coating; this was done to achieve the best possible adhesion and anti-corrosion effect. Hybrid polymer nanocomposites developed at Fraunhofer ISC were used as substitutes for chromium(VI).

Apart from the immediate corrosion protection properties of the coatings, researchers kept a particularly close eye on the formability of metal sheets that had been provided with a nanocomposite and top-layer coating. In this instance, the nanocomposite coating also assumes the role of an adhesion promoting primer for the top coat. Following attempts to form the sheets by bending and deep drawing, it could be shown that nanocomposite coatings possess the requisite adhesive strength.

As subsequent corrosion tests proved, the nanocomposite systems selected offered effective protection against corrosion on a variety of metal surfaces when used in combination with a top coating. As a result, the ISC's nanocomposites can be considered suitable for use as an eco-friendly, multi-surface alternative to chromium(VI) pre-treatment finishing. The only notable differences in the level of protection offered against corrosion were in the reaction to an artificial fault following exposure to salt fog. Here, the performance of the nanocomposites under investigation was not quite as strong as that of the chrome-plated controls.

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### Active corrosion protection with self-healing effect

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The ASKORR project, a collaborative in-house research project between two Max Planck institutes and two Fraunhofer institutes coordinated by Fraunhofer ISC, is looking to develop a sol-gel solution that will allow the self-healing of a coated surface. Scientists from the two renowned research institutions have approached the problem by combining various active layers and applying them onto steel surfaces at risk of corrosion. These layers contain active agents in the form of nanocontainers. Then, if the surface suffers mechanical damage, the active agents contained within the layers are released and are able to »heal« the damage. The effect, as far as corrosion protection is concerned, is thus similar to that observed in chrome plating, where nearby chromates also gather at the site of mechanical damage, so sealing the scratch.

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### Outlook

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The advantage of both techniques outlined above is that they use wet-chemical processes that can be more easily integrated into strip processing for metal finishing than, for instance, can vacuum-supported techniques for surface treatment. While passive corrosion protection does not yet offer ideal performance in the event of damage to the protective coating, the use of coatings with active nanocontainers looks very promising in the effort to create a comprehensive and easily usable replacement for chrome plating. In developing this, Fraunhofer ISC has made a great step forward in finding coating materials for corrosion protection that are both eco-friendly and not harmful to health.

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## CLIMATE FOR CULTURE

DR. JOHANNA LEISSNER, KATRIN WITTSTADT, MARIE-LUISE RIGHI

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### The effects of climate change

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The worldwide climate change we are witnessing today will have a multifaceted and dramatic impact on the development of our societies. In Europe it is expected that periods of drought and a succession of gales and heavy rains will accompany a general rise in average temperature. Such changes will affect many, if not all areas of our lives, from food production, logistics and transportation to tourism, construction/manufacturing as well as the energy industry.

The EU project »Climate for Culture«, which is due to continue into 2014, is investigating one particular effect of these climatic changes within the regions of Central Europe, having recognized that climate change presents an equally significant challenge within the field of heritage conservation. Historic buildings are just as vulnerable to shifts in microclimate as are museums or gallery exhibits, themselves often highly sensitive to changes in temperature and air humidity.

Against this background, the »Climate for Culture« project combines for the first time ever high resolution regional climate models with whole building simulation models in order to assess climate projections until 2100 and the impact on the indoor climates of historic buildings and their collections. This will allow coordinated conservation measures to be put in place as early as possible. 27 partners are collaborating on this project across Europe and Egypt. Fraunhofer ISC with its expertise in the field of cultural heritage conservation is contributing to setting up and assessing the corrosive impacts of the projected future climate by glass sensors developed at the institute within a previous European research project.

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### Reliable forecasts thanks to validated modeling and environment sensor technology

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The project is based on two climate scenarios taken from IPCC reports AR4 and AR5, both highly detailed from a climatic perspective as well as in terms of the areas they cover. From these scenarios project collaborators worked out projections for different climate indices including temperature and humidity. In order to test the models, acquired data was entered into various building simulation programs alongside real recorded measurements. The next step was then to apply the model outputs to calculate changes in room temperature and air humidity levels in a historic building for which relevant parameters were already known.

Simulation results for recent and past observation periods were compared with actual climatic data from the interior and exterior of the building. This data had already been collected over an extended period, allowing the accuracy of the simulation to be evaluated. We were able to prove that figures generated by the models in some cases closely matched the recorded measurements, so that a sufficient level of accuracy can be assumed. Initial projections into the future, covering the same period as the IPCC scenarios from 2085 to 2100, showed a rise in average room temperatures. It seems that on an average even the room temperature of an unheated building in winter would no longer fall below freezing point during the forecast period. Further steps planned to improve the simulation will take air humidity and other factors into account, including periodic cyclical fluctuations, such as day and night, dew and frost.



Sensors in climate chamber

However, these changes will not only have an impact on building structure and fixed installations but also on paintings and movable items. This issue marks the beginning of the next phase of the project, in which the Fraunhofer ISC will use the glass sensors, temperature and humidity sensors and climate simulations to measure, analyze and reconstruct the effect of climate change on paintings, murals, decorated glass and other objects. These experiments aim to facilitate the forecasting of potential damage to real artifacts, in order to determine the exact causes of this damage and thereby develop effective protection and conservation strategies.

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## Outlook

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The positive correlation between recorded and computed climatic data demonstrates that simulation techniques can also be used to forecast the evolution of indoor environments. Alongside further modeling and studies into the effects of these micro climatic changes on building structure, as well as on movable and fixed inventory, it will be possible to predict what measures should be undertaken to limit the effects of climate change, whether this involves the air conditioning of historical buildings or the immediate preservation of culturally significant objects. Those entrusted with conserving cultural heritage are therefore leading the way in evaluating the impact of climate change on the building sector. No less than three per cent of existing buildings in Germany have listed status and are particularly affected.

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## SENSOR SYSTEMS AND ENVIRONMENTAL MONITORING

DR. KLAUS ROSE, DR. PAUL BELLENDORF

### Sensor technology tackles a broad range of environmental issues

Demand for sensor systems that are capable of detecting concentrations of both hazardous and non-hazardous substances continues to rise. This can be attributed to the gradual tightening of standards in the fields of occupational health and safety and environmental protection, the increasing complexity of control systems in industrial production processes, and the detection of compounds in medical technology. Sensor systems can also be found in an increasingly broad range of other applications – for example in the structural monitoring of buildings, production plants, building components, machines and vehicles.

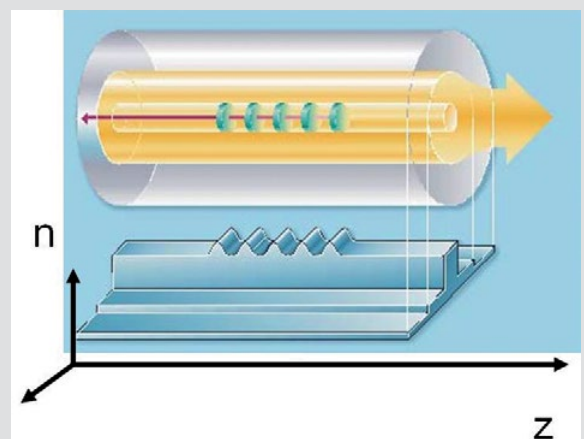
Rapid advances in the miniaturization of electronic components initially led to a surge in the use of electrically based systems. Recently, however, optical measuring techniques have gained significant ground, largely because of the major advantages they offer over electrical systems:

- no voltage or power required;
- not affected by electromagnetic interference, high voltage or high temperatures, and resistant to chemicals;
- do not require an external reference signal;
- offer a broad wavelength range for detection (UV to IR).

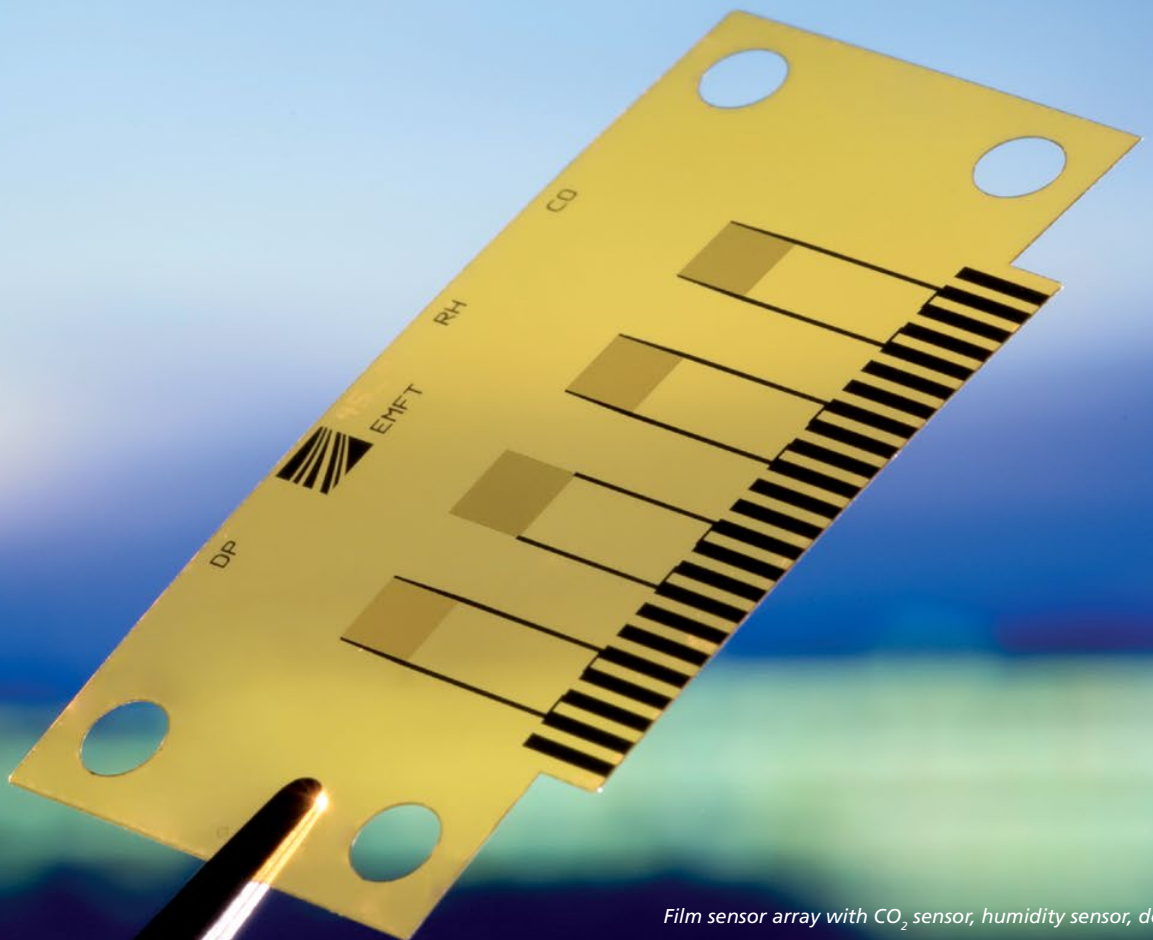
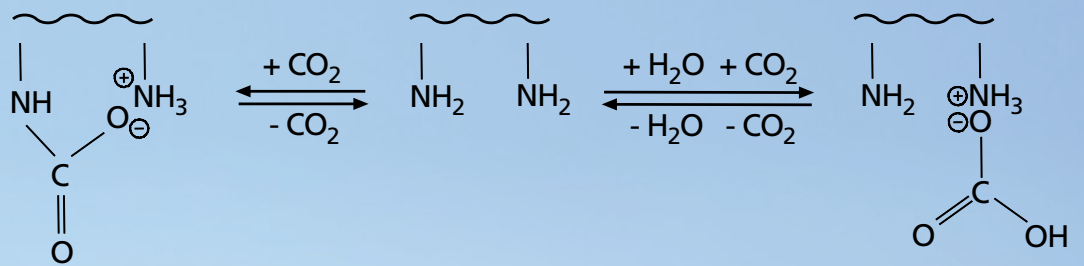
Sensor systems have long been a major area of research and development at Fraunhofer ISC. Examples include the development of gas-sensitive coatings for CO<sub>2</sub> sensors; these coatings

can be used in optical fiber sensors and interdigital capacitors. Researchers have also succeeded in developing an optical glucose sensor in the field of biosensors, and a coating for the fiber Bragg grating sensors used for optical strain measurements. All these types of sensor make use of hybrid-polymer coating systems (ORMOCER®s).

*Schematic drawing of a fiber bragg grating sensor  
(Source: IPHT)*







Film sensor array with CO<sub>2</sub> sensor, humidity sensor, dew formation and temperature sensors

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## How sensor coatings work

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Measurement data and substance properties are read by a sensitive component which registers a change in a physical quantity. This change is converted into an electrical or optical signal. In many cases, the components are not produced from a sensitive material and therefore require a sensitive medium, i.e. the transducer – the sensitive coating.

Sensitive coatings can be used to detect chemical substances in the environment being monitored: The functional elements integrated in the coating interact with substances in the environment or form a new reaction product. In the case of an optical sensor, for example, the refractive index of the coating changes, which means that the light propagation in the conductor (e. g. an optical fiber) also changes through the interaction with what is known as the evanescent field of the light traveling in the optical fiber. In the case of electrical sensors, the same sensor coating reactivity leads to changes in conductivity or capacitance, or a change in the electrical work function. The sensitivity of the CO<sub>2</sub> sensor coating developed at Fraunhofer ISC is based on the reversible reaction of gaseous CO<sub>2</sub> with amino groups that are integrated in the coating.

A completely different detection principle is used to develop an optical biosensor for the determination of glucose concentration. The enzyme glucose oxidase, which oxidizes glucose to gluconate, is a component of the sensor coating. Another component that is integrated in the coating is a metal-organic ruthenium complex which acts as an oxygen sensor. The measuring principle is based on the fact that the fluorescence of the ruthenium complex is quenched in the presence of oxygen. Thus, fluorescence spectroscopic determination of the oxygen content provides information on the O<sub>2</sub> consumption in the enzymatic glucose oxidation which occurs at the coating surface. Glucose in this case is determined by an indirect means which requires two completely different sensor components to be integrated in the active coating.

Optical fiber technology enables the writing of fiber Bragg grating structures in optical fibers. These grating structures reflect light within the optical fiber, and the reflection wavelengths respond very sensitively to external mechanical influences. This enables optical fibers to be used e. g. as strain and deformation sensors for monitoring structural components and buildings, with the fiber itself playing the role of the sensitive element. The primary task of the coating is to protect the sensitive optical fibers and to ensure that the force of any mechanical load is transferred to the fiber without damping.

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## Applications and uses

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Monitoring of the indoor climate of buildings and vehicles is an important environmental issue, with CO<sub>2</sub> concentration representing a key factor. Progress continues to be made in miniaturizing the measurement systems used in this field, improving their energy consumption and even integrating them as self-sufficient devices and in novel electronic complete systems. The CO<sub>2</sub> sensor coating described above has now been further developed to modify its use, transferring interdigital capacitor structures on glass surfaces to structures on polyamide film, in which the CO<sub>2</sub> sensor forms part of a film sensor array.

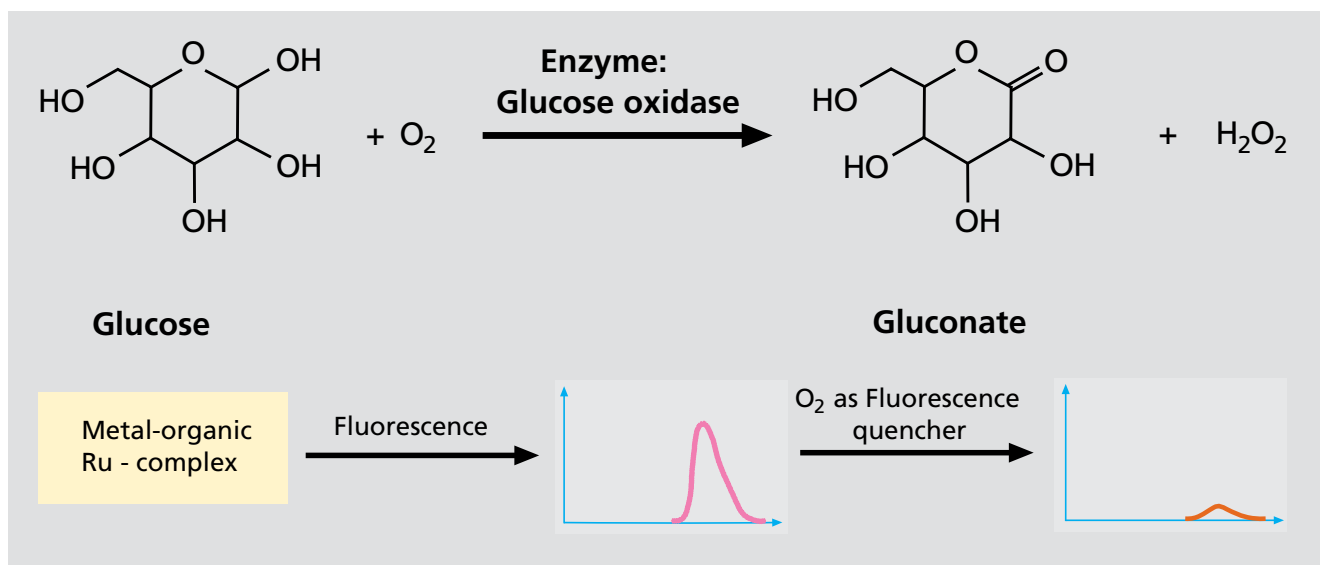
The monitoring of biotechnological processors in the production of food, drinks, pharmaceuticals and biofuels is also increasingly being performed using biosensors. To make this application possible, researchers developed a method of integrating sensitive biomolecules – such as glucose for example – in an ORMOCER® sensor coating. An online optical glucose sensor makes it possible to permanently detect the glucose concentration in a bioreactor without having to take samples and send them away for costly analysis at an external facility. The time this saves represents a significant factor in the production process.



Optical sensor fiber with grating (Source: IPHT)

The measurement of strain, pressure and temperature was previously the domain of electrical systems (strain gages). The advantages of optical fiber Bragg grating sensors have now significantly expanded the potential scope of applications for this type of sensor. Thanks to its excellent adhesion to the optical fiber, its ability to withstand high thermal and mechanical loads and its stable transmission of force, the ORMOCER® fiber

coating developed for this purpose makes a key contribution to this technology. Furthermore, the geometry of the optical fiber and the chemical variability of the coating enable the sensor fiber to be bonded directly in the component or directly in the structure of a laminated material.



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# ENVIRONMENT

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## **New dosimeter to detect pollutants in museums**

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The primary task of museums is to preserve artworks and cultural heritage objects permanently and securely while utilizing the opportunity to display selected pieces to the general public. The complexity of this task varies depending on what materials the collected items are made of. For example, significantly more care must be taken when storing and exhibiting paper and textiles than relatively robust items made of stone. It is essential to carefully tailor environmental parameters such as temperature, relative air humidity and light to the sensitivity of each category of objects, as well as ensuring blanket protection against a range of harmful gases. Continuous monitoring of all these parameters would be an overwhelming task for those in charge of running a museum if it were necessary to measure all these factors not only for each room, but also for every display case, every storage cupboard and every crate – especially bearing in mind the cost and complexity of much of this measuring technology. One solution is to use small, cable-free dosimeters which can be used to monitor the environment at locations in the museum that are at particular risk and/or exposed to particularly high levels of pollutants.

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## **Why use dosimeters?**

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In contrast to conventional measuring techniques, a dosimeter does not simply record current conditions at a fixed point in time at a particular museum location. Instead, it provides information on the integrated effects of one or more parameters over a longer measurement period, which could be anywhere from several weeks to one year. This long measurement duration means that dosimeters are even capable of detecting the effects of low concentrations of pollutants. This is particularly useful for detecting harmful agents in small to medium volumes of air – such as in packaging crates and museum display cases – since the opening of these sealed containers to install measuring equipment causes air to be exchanged between

the inside and outside of the container. This air exchange causes a sudden and significant change in the concentration of harmful substances, such as formaldehyde from chipboard for example. If measurements of the pollutant gases are taken directly after opening the container, the result cannot be representative of the enclosed space since the pollutants have not yet had time to accumulate. Dosimeter studies are therefore intended for longer-duration exhibitions, since they allow time for the steady accumulation of pollutants from construction materials (chipboards, adhesives, joint sealants, varnishes, etc.), display devices (material holders, support structures, etc.) and even the exhibited artworks themselves (preservatives, pesticides, etc.), which then triggers a response from the dosimeters.

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## **The MEMORI dosimeter**

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The MEMORI dosimeter will draw on two existing commercially available museum dosimeters (the Fraunhofer Glass Slide Dosimeter (GSD) and the Early Warning Organic dosimeter developed by NILU) to create an easy-to-use, portable device. Combining the strengths of the two existing products, the new system will be sensitive to both VOCs (volatile organic compounds) and inorganic and oxidizing acids. A novel handheld reader will enable in-situ evaluation of the results produced by the MEMORI dosimeter, thereby eliminating the need to return individual dosimeters to the laboratory for analysis, a step that is currently required for both of the existing systems.

A special website has been developed to allow users to compare their own measurements with the results obtained by other dosimeters users, either anonymously or by creating an account. The website will also offer background information on the various damage parameters, thereby enabling users to obtain key information on the possible causes of pollutants.



Artwork from the MEMORI project (University of Arts »George Enescu« Iași, Romania)

Development of the MEMORI dosimeter is being carried out in tandem with an extensive series of scientific studies investigating the potential of organic acids and other pollutants to damage artworks and cultural heritage objects (e. g. painting varnishes, pigments, leather and parchment, cellulose materials and textiles). The researchers will also be determining recommended threshold levels for exhibiting different materials under specified conditions.

The new dosimeters and the research studies into the sensitivity of different types of materials to pollutants will help to further reduce the risk of damage to artworks and cultural heritage objects in the future.

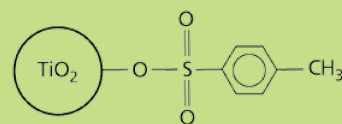
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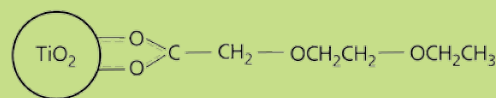
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# ENVIRONMENT



aromatically stabilized



aliphatically stabilized

## AIR PURIFICATION AND DECONTAMINATION

DR. KLAUS ROSE

### Cleaning – a Time and Cost Factor

Various industrial and public sectors presently face the problem of complying with increasingly stringent standards in product purity, hygiene, or industrial safety and environmental protection. These demands can often no longer be met, despite the steadily rising complexity of prevention strategies, or of cleaning and decontamination procedures.

Providing surfaces with easy-to-clean or self-cleaning properties, or with antimicrobial protection, is now of increasing importance for applications in medicine, hygiene and the environment, and thus for all aspects of the working and home environment. Conventional antimicrobial layers often tend to lose efficacy over time as the surfaces to which they are applied change or become soiled; they may also contain biocidal components, which are then successively released by the surface. In many fields of application, however, migration into the environment or into the product itself is not acceptable. Equipment and instruments in the pharmaceutical and medical sector, for example, must be elaborately sterilized during cleaning or before they can be re-used, and the conditions required to achieve this are often a determining factor for the lifetime of such products.

Looking further afield, at manufacturing, and at the handling of annoying or harmful substances, there is a need to protect both humans and the environment by ensuring appropriate treatment of the exhaust air. The need to optimize filtration and air purification in buildings and in vehicles is assuming an ever more important role in the wake of the increasing sealing and insulation, caused by the concomitant demands to reduce energy consumption.

One problem here is the removal of gaseous air components, as these are not captured by filters. While it might be possible to absorb or adsorb these via appropriately treated surfaces, efficiency in this case is determined by the finite absorption capacity. Permanent degradation of pollutants directly in the filter systems can help improve this situation considerably.

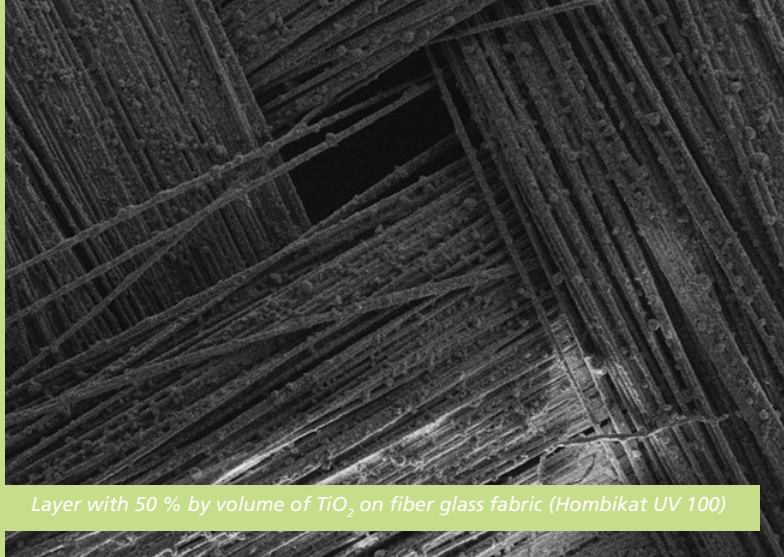
According to survey results, self-cleaning properties are currently among the most sought-after features for surface coatings, also in Germany.

### Photocatalytic Cleaning Using Light and TiO<sub>2</sub>

In photocatalysis, organic substances are decomposed by anatase modification of crystalline titanium dioxide, using UV-A light. Photocatalytically active layers containing titanium dioxide are thus suitable for the removal of microbial and chemical contamination on the surface, hence improving the indoor climate and increasing workspace safety, operational readiness and cleanliness of technical and medical devices.

The current range of processes used for the production of photocatalytic layers comprises the generation of crystalline TiO<sub>2</sub> layers via plasma spray, CVD, PVD or sol-gel coating methods. In order to achieve crystalline layer growth, temperatures above 500 °C are the state of the art, thus limiting its use to thermally stable substrates. These processes are both costly and limited to a few fields of application and selected thermo stable substrates.





Layer with 50 % by volume of TiO<sub>2</sub> on fiber glass fabric (Hombikat UV 100)

The second possibility involves the immobilization of TiO<sub>2</sub> particles by embedding them in a matrix. Photocatalytic TiO<sub>2</sub> particles are already being used in facade paints, for example. Photocatalytic decomposition of the binder has been observed in corresponding layers based on purely organic binders, as well as decomposition of the substrate surface of organic polymeric substrates, resulting in layer delamination. The commercially available particles used, even if they consist of nanoscale primary particles, cannot be processed without agglomeration, so they cannot be used on substrates that have to keep transparent.

At the Fraunhofer ISC, the route chosen involves incorporating photocatalytic titanium dioxide into a hybrid ORMOCER® matrix, which – due to its inorganic basic structure – has a much higher inherent stability against photocatalytic decomposition than an organic binder. At the same time, special surface-modified TiO<sub>2</sub> nanoparticles of anatase modification were developed. Since these nanoparticles are agglomeration-free, they can also be used on transparent substrates. The binders based on ORMOCER® are either curable at low temperatures or through exposure to UV light, which also makes them suitable for use on temperature-sensitive substrates.

### TiO<sub>2</sub>-Particles for Incorporation in Layers

TiO<sub>2</sub> nanoparticle production is based on a multistage process with resulting particle sizes in the range of 10 nm. In order to achieve monomodal distribution and to ensure agglomerate-free dispersibility, the nanoparticles were stabilized with organic complex ligands.

Particle distribution in hybrid layer matrices was very homogeneous and uniform for all particle/layer combinations. Overall, particle concentrations in the binder were as high as 50 % by volume. Significant photocatalytic activity is achieved at 20 % by volume of nano-TiO<sub>2</sub>.

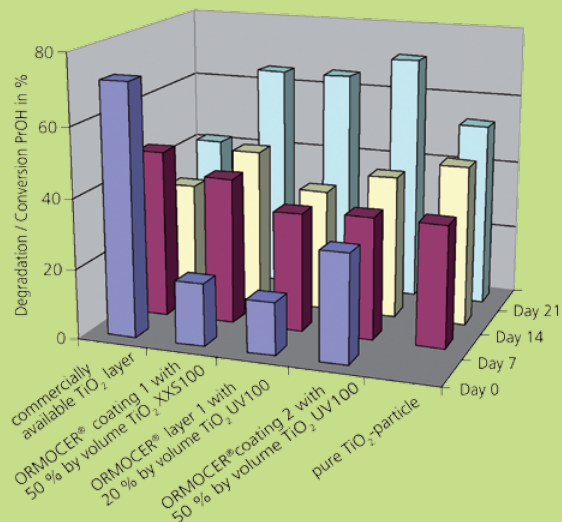
The photocatalytic effect is based on direct contact of the active TiO<sub>2</sub> with the substance to be degraded. In the case of the incorporated particles, a thin hybrid polymer film and/or complex ligands will initially cover the particles and prevent their direct contact with the substance to be degraded. Over the course of the photocatalytic reaction, in the first instance under the influence of UV light, both the film and the surface modification are slowly degraded, which means that photocatalytic reactions can only develop with time. In many cases, this kind of activation by intense UV irradiation is therefore carried out in advance. In order to test these reactions, increasing hydrophilicity of the surface layer is measured, which in the best case leads to a state of superhydrophilicity, i. e. contact angle about 0° towards water.

With irradiation in the UV-B/C- spectrum, at a dose of 170 - 340 J/cm<sup>2</sup> (30 min - 60 min), superhydrophilicity was determined in the treated layers after 30 minutes (Table). This activation method was chosen for further photocatalysis studies.

Layer	Proportion Nano-TiO <sub>2</sub>	Contact angle change
Ak_Q	20 % 50 %	49° → ~ 0° 55° → ~ 0°
G_PA_AI	20 % 50 %	72° → ~ 0° 74° → ~ 0°
G_PAF_AI	20 % 50 %	104° → ~ 0° 104° → ~ 0°

*Table. Superhydrophilicity of TiO<sub>2</sub>-based layers after 60 min UV- activation*

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For applications in which transparency of the layer was not required, commercially available TiO<sub>2</sub> powders were also used. The particles used had primary particle sizes of 10 nm (Hombikat® UV 100) and/or 25 nm (P25), but were not usable without agglomeration and therefore resulted in rough, non-transparent layers. The mode of action during activation / hydrophilization and for the photocatalytic activity, however, is comparable with that of the nanoparticles.

## Reducing Pollutants

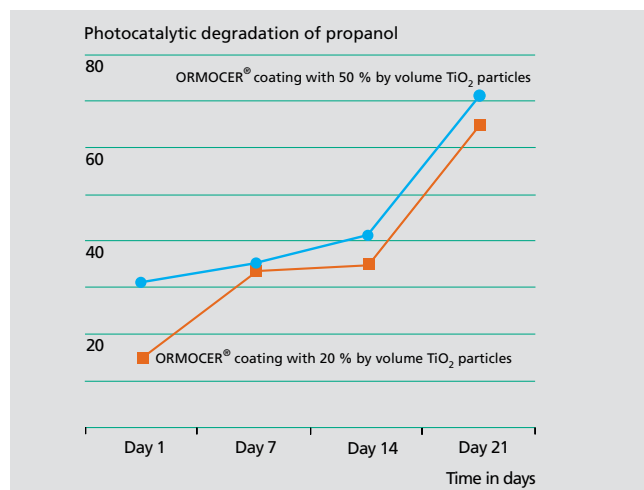
As a preliminary test, and complementary to studies with application-specific substances and contaminants, the degradation of methylene blue dye on TiO<sub>2</sub>-based layers was chosen. In this case, a first indication of the photocatalytic activity is discernible through the discoloration of the dye, either when dissolved in the form of an aqueous solution, or as a dried film after being applied onto a TiO<sub>2</sub>-based surface. Decomposition of substances of practical relevance was examined in various projects, depending on the intended application.

In the PlasKat Project, funded by the Federal Ministry of Education and Research, our partner institute IUTA (Institute for Energy and Environmental Technology, Duisburg) selected a variety of pharmaceutical active ingredients consisting of antibiotics and cytostatics that display a wide range of relevant physical and chemical properties. Results showed that different types of substances are degradable in different ways by photocatalysis when coming into contact with nano-TiO<sub>2</sub>-based ORMOCER® layers, which is attributed to the different and complicated structures of biochemical molecules. Nevertheless, at least some substances, such as methotrexate (MTX), cyclophosphamide and etoposide, were nearly completely decomposed. There was a noticeable trend towards higher degradation rates for more polar substances. In addition to degradation of substances on TiO<sub>2</sub>-based layers, photocatalytic activity also led to significantly reduced colonization by bacteria. In tests by project partner Iba Heiligenstadt it was found

that layers containing 20 % nano-TiO<sub>2</sub> led to an 80 % reduction of *Staphylococcus aureus* and *Staphylococcus epidermidis* colonization.

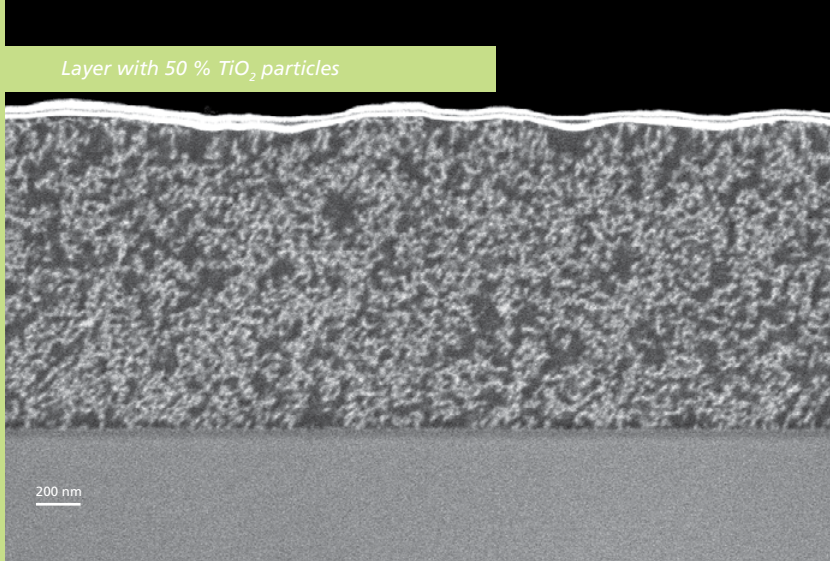
An ORMOCER® spray coating was also developed at the Fraunhofer ISC that can be applied over conventional aircraft paints. It contains commercially available, photocatalytically active titanium dioxide nanoparticles (Aeroxid® TiO<sub>2</sub> P25). The photocatalytic activity of the novel coating has been demonstrated by the degradation of chitosan, a derivative of chitin.

The Oxifilter Project, also funded by the Federal Ministry of Education and Research, aimed at developing coatings for photocatalytic air purification. Degradation of propanol and the formation of the degradation product acetone were chosen as a first model reaction. (Project partner IUTA). The hybrid TiO<sub>2</sub>-based layers applied on filler pads initially demonstrated lower photocatalytic activity, although this was observed improve over time, until reaching a peak after 21 days. On day 21, photocatalytic activity of the hybrid layers was even significantly higher than that of the control samples, such as layers consisting of pure TiO<sub>2</sub> particles, even though hybrid layers with embedded TiO<sub>2</sub> actually contain less TiO<sub>2</sub> per unit of surface area. This reaction can be attributed to the fact that the samples, as has been observed in previous studies,





Laboratory work place  
© Berner



Layer with 50 % TiO<sub>2</sub> particles

initially undergo an activation phase under UV light before demonstrating a sufficient level of photocatalytic activity.

### Projects and Applications

Transparent nano-TiO<sub>2</sub>-based layers are mainly designed for use on external and exposed surfaces, such as surfaces in work areas. For surfaces that are not visible, such as on the inside of equipment, larger sized particles can be used, provided that the esthetic quality of the layer is of secondary importance.

Photocatalytically active surfaces, like those developed in the work described for the PlasKat project, play a special role. Here, no release of active ingredients is required, and the layer in principle remains active permanently. It was possible to demonstrate that photocatalytically active layers are suitable for eliminating chemical and microbial contamination. They thus serve to improve indoor climate and increase operational readiness and cleanliness of technical and medical equipment.

Directly relevant applications include:

- structural elements and work surfaces in laboratories
- medical implants and components that are introduced intermittently into the body, such as tracheal catheters

The need to remove impurities from air or waste air, in particular those occurring in gaseous form which cannot be extracted by conventional particle filters, is an increasingly important factor in many industrial and commercial, public or private buildings and vehicles. In addition to the non-eliminable gaseous pollutants, particulate substances deposited on the filters present a problem when they accumulate or escape back into circulation. The complex replacement, separation and transport of the contaminated filter elements that would be required are also significant cost factors.

The ORMOCER® binders specially developed within the »Oxifilter« project – which are applied onto fiberglass fabric and contain TiO<sub>2</sub> particles – are making an important contribution towards being able to capture and remove circulating components from the air flow so that they can be degraded through photocatalytic reactions.

In the aviation industry, soiling on the exterior of an aircraft is not only an esthetic issue; it may also represent a safety problem, which is why considerable effort is put into cleaning processes. Chitin residues from insects prove to be particularly persistent. A coating that automatically decomposes this kind of organic residue could dramatically reduce the effort on cleaning. The »Nano Base« project was investigating the incorporation of titanium dioxide nanoparticles into ORMOCER® coatings and developing suitable compositions for exterior aircraft paint. Previously used aircraft paints do not contain any active photocatalytic ingredients.

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## SELECTIVE MAGNETIC PARTICLES FOR WASTE-WATER TREATMENT AND THE RECOVERY OF RECYCLABLE MATERIALS

KARL-SEBASTIAN MANDEL, DR. FRANK HUTTER,  
DR. CARSTEN GELLERMANN, DR. PAUL BELLENDORF

The constantly growing demand for raw materials, especially those of industrial importance, has emphasized the necessity of recycling. The majority of raw materials required by industry are obtained from non-renewable sources, and it is becoming increasingly difficult to find new deposits of mineral resources that can be profitably extracted. The necessary investments are so high, and the engineering and environmental challenges so complex, that there is a high risk of short- or medium-term supply disruptions. This supply problem is further aggravated by the growing economic strength of emerging industrial nations such as China or India. As regards Europe, it is an acknowledged fact that the future of European industrialized nations will depend to a large extent on the long-term availability of key resources. Whereas in 1980 the production of high-tech materials required no more than 12 (chemical) elements, the number of elements needed to produce advanced multifunctional materials had shot up to nearly 60 by the year 2000. Countries like Germany that are poor in natural resources urgently need to develop new methods and processes that will prolong the lifecycle of the available raw materials by recycling them through the »production – use – reuse« stages as many times as possible (through improved utilization of secondary raw materials) without significant loss.

Another vital resource that can benefit from a sustainable, responsible approach to recycling is water. Naturally occurring, geological and anthropogenic inputs to the aquatic ecosystem can lead to elevated levels of heavy-metal pollution. This is

the case, for instance, in many Asian countries, where the concentration of highly toxic arsenic in the drinking water supply represents a health hazard to millions of people. Fraunhofer ISC and its Project Group Materials Recycling and Resource Strategies IWKS are currently working on a novel approach involving the use of nanotechnology with the aim of developing an innovative materials-based solution to the recycling of diluted chemicals present in wastewater and to water purification in general.

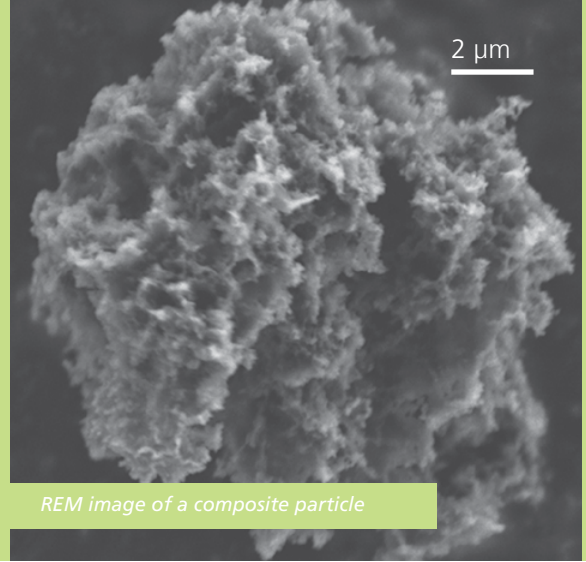
The first step is the synthesis of magnetic nanoparticles with a diameter of approx. 10 nm using a simple, low-cost process. In its macroscopic form, the iron oxide known as magnetite ( $\text{Fe}_3\text{O}_4$ ) acts as a relatively good permanent magnet, hence its common name. But if the material is produced in the form of extremely small particles, these particles »forget« their initial magnetic properties as soon as the external magnetic field is removed (a phenomenon known as superparamagnetism). The input of thermal energy at room temperature is sufficient to cancel out the particles' intrinsic magnetic moment, in other words their remanent magnetism is neutralized and measurements produce a result of zero. Unlike permanent magnets, these particles have no magnetic attraction between them, and can therefore be dispersed in a fluid without agglomerating. If a stable sol is produced using these superparamagnetic particles, it becomes a ferrofluid that can be manipulated by means of an external magnetic field. The individual particles cannot be magnetically isolated from the ferrofluid solution.





*Synthesis of magnetic nanoparticles*

# ENVIRONMENT



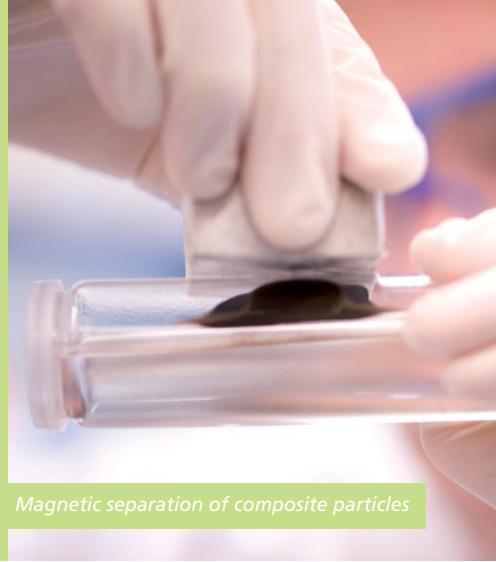
REM image of a composite particle

Any gradients in the concentration of particles are eliminated by the effects of Brownian motion. But it is possible to »bend« the fluid by applying a magnetic field. If a number of superparamagnetic nanoparticles are bound together in a solid non-magnetic matrix to form larger particles with a diameter greater than 10 μm, Brownian motion ceases to have the aforementioned effect, and it becomes possible to isolate the composite particles from the fluid by applying a magnetic field (see image sequence). But they nonetheless retain their superparamagnetic properties, and behave in the same way as ordinary, non-magnetic suspended particles in water when the magnetic field is removed. If a way can be found to modify the surface of these composite particles so as to enable them to bind selectively and reversibly with specific substances dissolved in water, a new process can be developed for water purification and the recovery of recyclable materials. In basic terms, the particles can be isolated by applying a magnetic field, the bound substances can be removed and disposed of safely or reused, and even the magnetic particles themselves can be reused.

In a project funded by the Baden-Württemberg-Stiftung, work is under way to establish a process of this type for the recycling of phosphate. Phosphate is an important industrial raw material, but it is estimated that known reserves will be exhausted within the next few decades. 80-85 % of all mined phosphate rock is used as a non-substitutable ingredient in fertilizers. The world-market price of phosphate ore rose sharply in 2007, from 50 to 350 US dollars per ton. Moreover, the extracted phosphate rock is frequently contaminated with heavy metals (such as cadmium), as the mining companies are increasingly having to exploit low-grade deposits. Considerable economic benefit could therefore be derived from a solution that enables phosphate to be recovered from wastewater or other waste flows. It would also help to combat the problem of eutrophication, a phenomenon in which aquatic ecosystems such as freshwater lakes are starved of oxygen as the result of excessive concentrations of phosphate arising from the overuse of fertilizers on agricultural land.

In collaboration with the Institute for Sanitary Engineering, Water Quality and Solid Waste Management (ISWA) at the University of Stuttgart, a solution has already been found that enables phosphate to be separated from water by means of functionalized magnetic particles, as proved in experiments on real waste flows that have been artificially enriched with an increased phosphate payload. Further research is under way to modify the surface properties of the magnetic particles, so as to improve the efficiency of the separation process and permit the recovery and reuse of the magnetic particles. Related experimental research aiming to improve the selectivity of the new depollution methods has produced promising results. With only minor process modifications, it has been demonstrated that the novel particles are capable of magnetically removing toxic arsenic compounds ( $\text{AsO}_4^{3-}$ ) from liquid media, and that they can be easily separated from the arsenic-containing solution and regenerated for reuse.





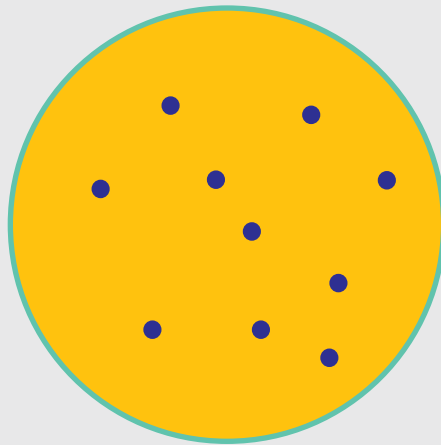
Magnetic separation of composite particles

*Schematic drawing of a magnetic composite particle*

**SUPERPARAMAGNETIC  
NANOPARTICLES**

**MICROPARTICLE MATRIX**

**SELECTIVE SHELL**



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# ENVIRONMENT

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## HOW MULTI-FUNCTIONALITY REDUCES PROCESS COSTS AND SAVES RESOURCES

DR. RUTH HOUBERTZ

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### Challenges – Integration and miniaturization

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Integrated passive and active elements serve as key components in today's and tomorrow's IT systems. Research aimed at developing electronic, optical, or mechanical components on a micro- and nanometer scale for various applications has been ongoing for over a decade. A host of different materials and processes can generally be found in a single component, as the quest continues to achieve still higher integration density in devices with ever greater complexity and functionality.

The use of nanoscale materials (bottom-up) complements the development of components on a micro- and nanometer scale using suitable processing techniques (top-down). Both approaches can potentially reduce costs while meeting the aforementioned requirements. However, such savings are not only achieved by implementing solutions in miniaturized components with increased integration density, but also by employing processes that are cost-effective and environmentally friendly. New materials are often required for both approaches, which can be adapted to the processes on a broad scale and/or are intrinsically multifunctional.

On the one hand, material multifunctionality may under certain circumstances significantly reduce the number of materials used in a single component. This reduction of critical interfaces in the components makes them less prone to failures, leading to higher yields and greater reliability. At the

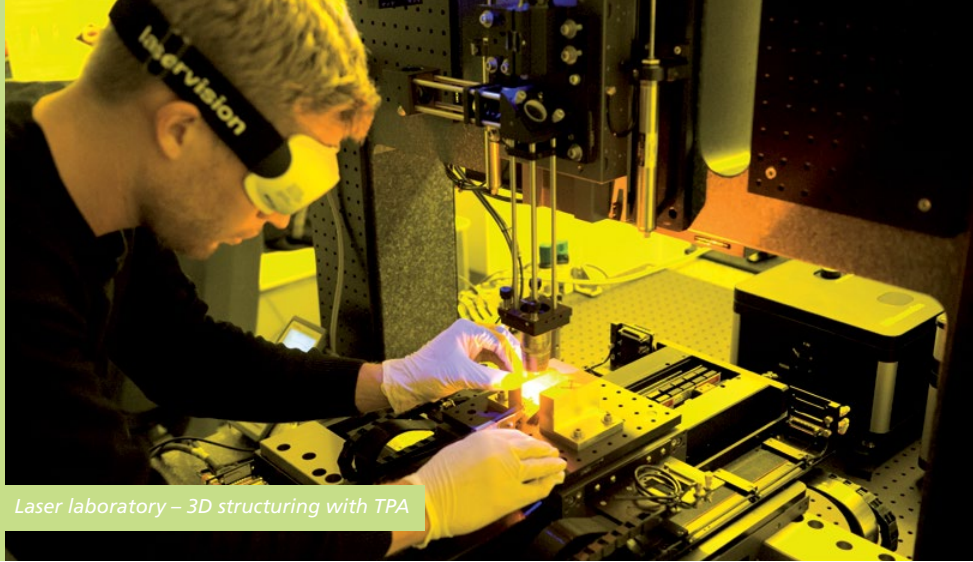
same time, significant resource savings can also be made, in the solvents and the energy consumed (as part of material synthesis and/or in the processing of components, for example), or through material substitution in components. These options all serve to reduce manufacturing costs while lessening the burden on the environment.

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### ORMOCER®s – a material class in their own right

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As a material class, inorganic/organic hybrid polymers (ORMOCER®s) provide an opportunity to confront these challenges; ORMOCER®s represent excellent alternative materials to the often highly complex solutions in some cases that have been used until now. They are capable of resolving various issues in micro- and nanotechnology, pertaining to microsystems engineering in general, and medical technology in particular. Thanks to suitably controlled chemical synthesis processes, ORMOCER®s support the implementation of intrinsic multifunctionality – a major advantage over conventional materials. As a result, various functions can be performed in a single component using material tailored specifically to the customer's requirements. This also paves the way for low-cost manufacturing processes capable of being scaled up to industrial standards. Sensitive substrates or components can also be processed using non-destructive techniques due to low-temperature syntheses (room temperature up to 80 °C) combined with low process temperatures (up to 150 °C).



Laser laboratory – 3D structuring with TPA

### Example application – Optical interconnects

While microprocessors are already highly sophisticated and run at very high internal clock rates, data transmission speeds of up to 10 Gbit/s over transmission routes of 2 to 20 cm will be feasible in future without a major shielding overhead. Electrical data transmission, however, suffers from limitations such as fluctuating transmission quality, lower data rates, and insufficient bandwidth. Over the past few years, optical data transmission technologies have revolutionized the ICT sector. High-speed data transmission rates combined with constantly falling costs, low optical attenuation, and high immunity to interference as well as a highly flexible design and integration of optical transmission paths have turned these kinds of optical data transmission technologies into a compelling proposition for a host of applications: from in-car data networking, through access networks, to usage in data centers and supercomputers.

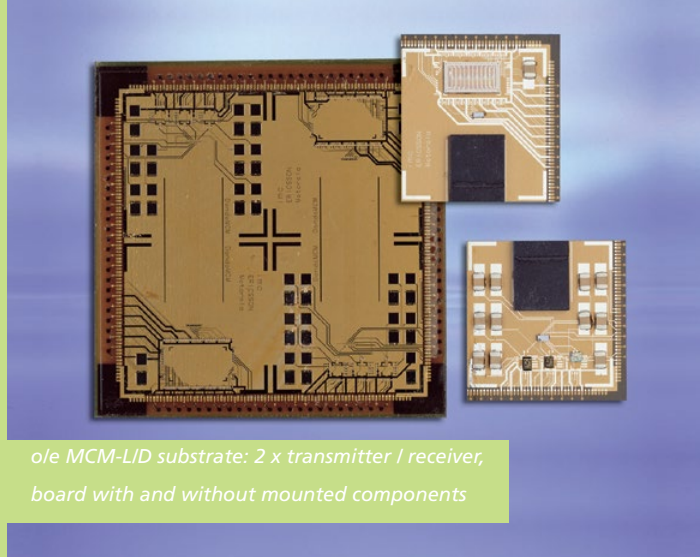
Optical interconnects thus represent a key technology for future communications technologies. The high bandwidth requirement of complex applications calls for the usage of optical data links on various packaging levels (chip to chip, chip to board, board to board), since copper connections are pushed to their limits at high data rates on account of phenomena such as frequency-dependent signal delay and crosstalk. Optical links can be used without complicated shielding designs to substitute a large number of copper links and hence save resources: compared with today's widespread electrical data links, optical signal transmission is unrivaled when it comes to data speed, range, immunity to interference, and energy consumption. In addition, optical mounting and connection technologies support a very high degree of integration related to their resistance to interference – a characteristic that also helps promote ongoing miniaturization.

Countless international research institutes and companies have been investigating various concepts for more than 15 years in a bid to integrate optical waveguides at board level. All the concepts share one thing in common: the waveguide being integrated consists of at least two materials with different refractive indices. These materials form the waveguide core and the waveguide cladding; the refractive indices of the two materials need to be different. Furthermore, additional planarization materials and dielectrics also tend to be required; up to four different materials can be used to manufacture the optical interconnects. However, only two materials are required when using ORMOCER®s for this application as they boast very good optical properties in the data and telecommunications wavelength range (850, 1310, and 1550 nm) along with customizable dielectric and excellent planarization properties. The number of process steps for manufacturing components typically ranges between 9 and 13 (for ORMOCER® waveguides), and more than 17 (for other materials).

Optical links can be integrated at board level in various ways. While optical backplanes, which are based on integrated glass or polymer fibers, are already available commercially, they are extremely expensive. Polymer waveguides can, for instance, be integrated by structuring optical waveguides from the optical polymers using processes such as photolithography, laser ablation, replication or imprint lithography, or standard laser direct writing. All the aforementioned manufacturing processes are characterized by the usage of a host of different processes which consume resources such as energy (temperature), process chemicals, and time.

The variants for integrating the waveguides are as diverse as they are complex as regards the materials, the manufacturing processes, and the coupling/decoupling solutions. While implementation of the actual optical waveguide structures no longer poses a substantial challenge thanks to the availability of different manufacturing processes, the international re-

# ENVIRONMENT



ole MCM-LID substrate: 2 x transmitter / receiver, board with and without mounted components

search community has not yet managed to resolve two critical challenges satisfactorily: on the one hand, the performance of the materials used in the case of polymer waveguides – the solution of choice to date – and, on the other hand, the alignment of the optoelectronic components for coupling/decoupling of light into and out of the waveguides. The alignment, in other words the exact active or passive positioning of the waveguide ends in relation to the light-emitting surface of the light emitter, or in relation to the detection surface of the light receiver, continues to pose a major technical problem resulting in high costs. Conventional solutions rely on mirrors, prisms, gratings or lens systems, which are designed to connect the waveguides with the optoelectronic components mounted on the surface of the printed circuit board. In all these cases, complex active alignment of the interface systems is required if high coupling losses are to be avoided.

This contrasts with the relatively simple process for manufacturing optical waveguides out of an ORMOCER® at board level using a genuine 3-D structuring technique. Femtosecond

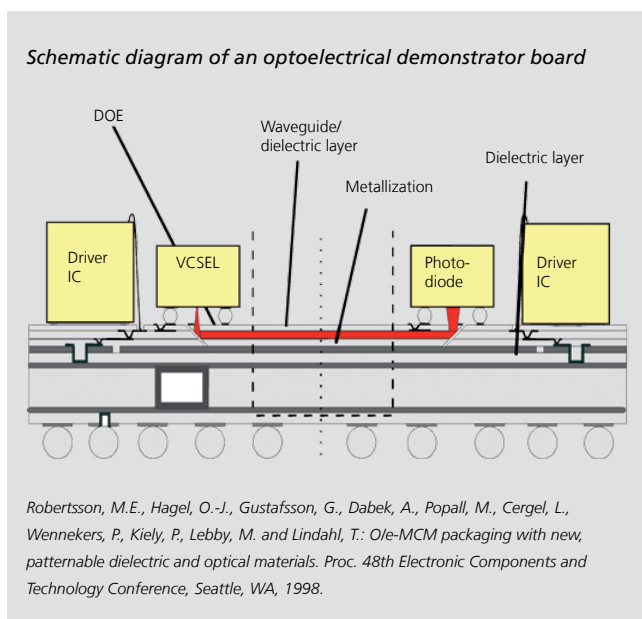
lasers initiating two-photon absorption (TPA) are used to focus the laser light onto the material being structured; the focus is computer-controlled, allowing it to be moved in any spatial direction. The intensity is only sufficient in the focal area to trigger the two-photon absorption; the ORMOCER® is then organically cross-linked by photochemical means (two-photon polymerization or 2PP). Multimode waveguides, for instance, can be written on prefabricated boards containing optoelectronic components.

This requires just three process steps, with the final process step already an integral part of the PCB production process. The process has demonstrated that optical interconnects can be implemented at board level in just a single ORMOCER® system, with a data rate of up to 7 Gbit/s and a BER (bit error ratio) of approx.  $10^{-9}$ , depending on the optoelectronic elements used.

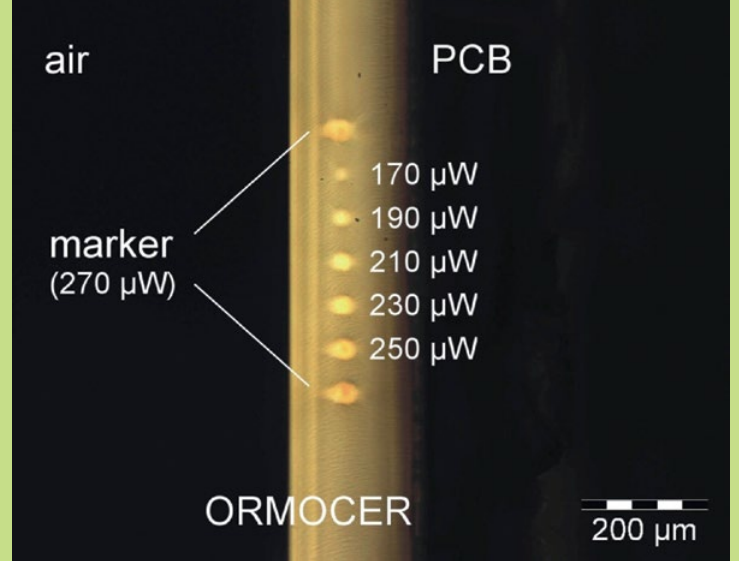
The advantages of this process for manufacturing optical interconnects are obvious:

- No complex alignment of the optical components in relation to the waveguides
- High freedom of design and integration density for implementing three-dimensionally arranged optical interconnects
- Usage of just one multifunctional material for waveguide core and cladding, for planarization, and as an electrical dielectric
- Manufacturing involves just three process steps
- Solvent-free processing

This list highlights that the number of process steps and the number of materials can be substantially reduced by using a multifunctional material. Substantial quantities of resources are saved as a result, which feeds through into a significant reduction in process costs.



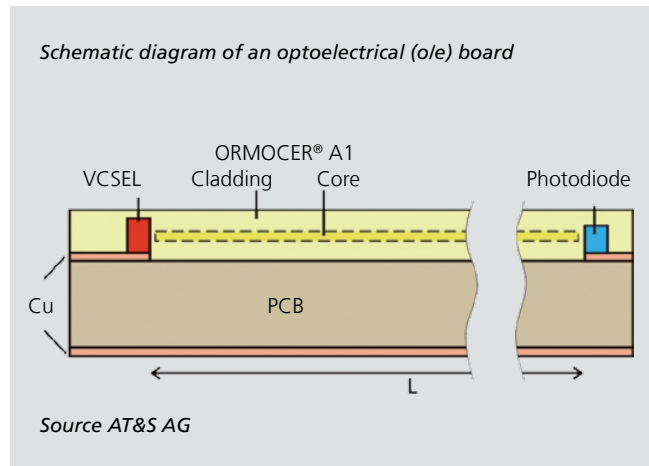
Cross-section through multimode waveguides  
 written using TPA in one and the same  
 ORMOCER® on an ole board  
 © Joanneum Research



The basic research into process control paves the way for  
 usage on an industrial scale.

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**Acknowledgements**  
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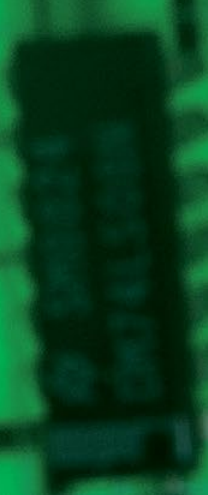
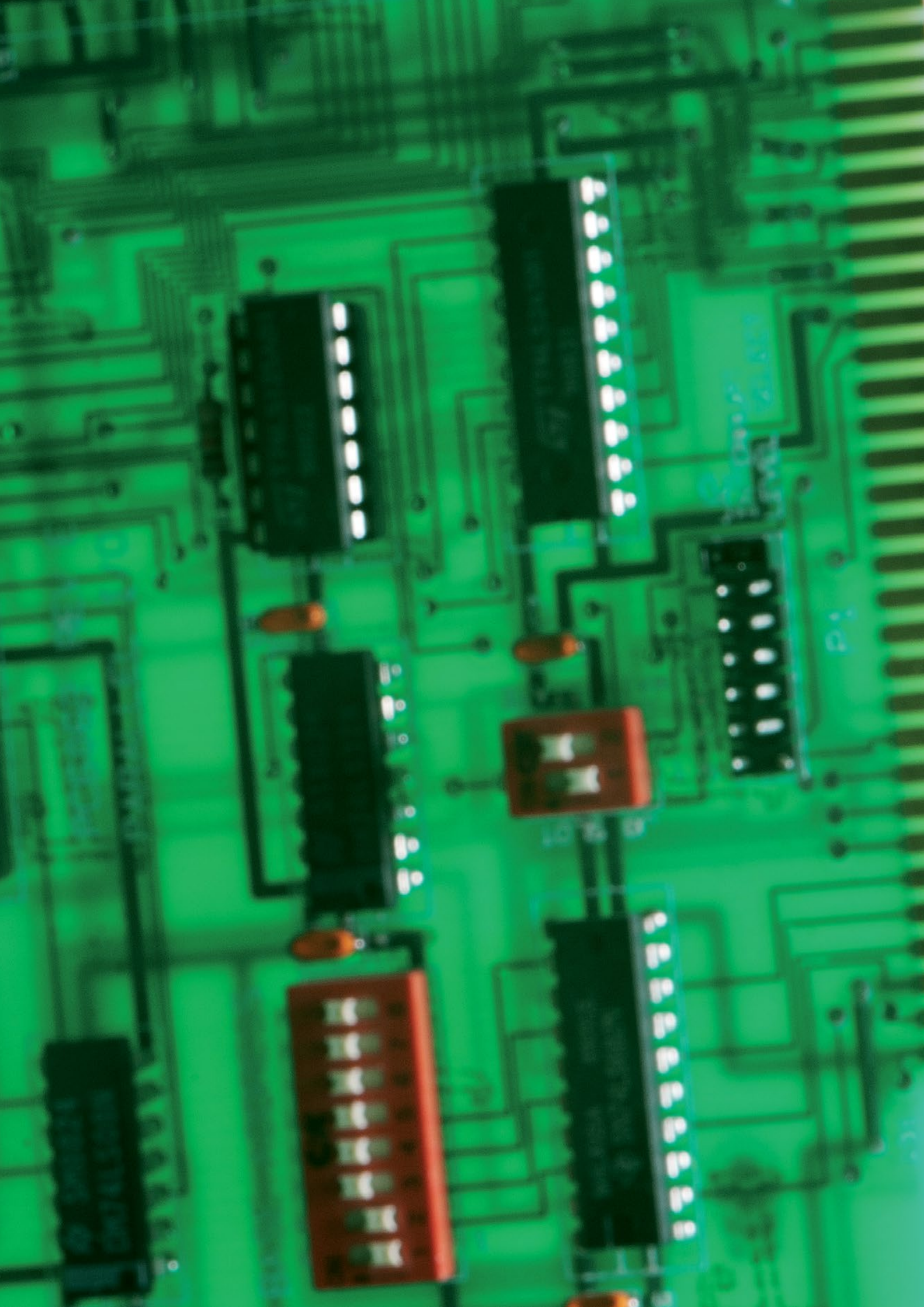
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# FRAUNHOFER PROJECT GROUP MATERIALS RECYCLING AND RESOURCE STRATEGIES IWKS

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- ON THE FOUNDING OF THE NEW PROJECT GROUP
- HISTORY AND MILESTONES OF THE IWKS
- THE MOLECULAR SORTING COOPERATION PROJECT

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# FRAUNHOFER PROJECT GROUP IWKS

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## ON THE FOUNDING OF THE NEW PROJECT GROUP

MARIE-LUISE RIGHI

Not only is demand rising steadily for raw materials – such as copper, nickel, iron, oil, coal, etc. – their prices are climbing upward too. In 2010, the Index of World Market Prices of Commodities (denominated in euro) compiled by the Hamburg Institute of International Economics shot up by more than 30 percent. Despite the economic crisis, dynamic growth in emerging and developing economies is expected to accelerate demand for raw materials by several orders of magnitude over the long term.

Demand for precious metals and rare earths is growing especially fast. Although the materials are often present in existing products, bringing them back into the materials cycle is difficult. »And this is exactly where the work of the Fraunhofer Project Group Materials Recycling and Resource Strategies IWKS begins«, explains Prof. Gerhard Sextl, director of the Fraunhofer Institute for Silicate Research ISC. The institute played a major role in initiating the foundation of the group together with partner companies from the Materials Valley e.V. association. »The group will first compile and analyze verified data on global materials cycles as a basis for developing resource strategies. These activities will be accompanied by the ecological and commercially viable development of new processes for recycling critical materials.«

This briefly describes two of the three fields in which the IWKS intends to get down to work. Materials Recycling and Resource Strategies deal with the need to analyze material flows and create resource strategies, so that bottlenecks can be predicted and subsequently avoided or balanced out. In Recycling Technologies, scientists are focusing their efforts on

reclaiming as many materials as possible, while simultaneously adhering to strict commercial criteria.

The ideal approach to the latter field begins with the design of the product, where the desire to reuse or recycle constituent materials is facilitated by how the product is constructed in the first place. Prof. Dr. Armin Reller, Head of the Division Resource Strategy, also sees huge potential in the area of renewable energy: »When you consider the boom in new energy technologies – solar and wind power generators – we should really already be thinking about how to reuse, remanufacture, or recycle the functional materials used in them. It's very often worthwhile to reclaim them for further use.«

The Fraunhofer project group IWKS will also be devoting attention to how raw materials can be substituted, the third focus of its activities. Here scientists aim to identify and develop materials, processes, and products that improve how efficiently raw materials are used, on the one hand, and that provide substitutes for critical raw materials on the other. »Critical« in this context refers to materials that are already scarce or becoming so, because their sources are either finite or located in conflict areas. The project group aims to develop alternative materials that are both commercially and ecologically viable, and which serve to ensure that the manufacturing sector has a secure supply of raw materials in the long term.

[www.iwks.fraunhofer.de](http://www.iwks.fraunhofer.de)



*The inauguration of the project group took place at Fraunhofer IWKS's Alzenau location on September 5, 2011. In the spirit of the state government's »Bavaria on the Move« initiative, the Bavarian Minister of Economic Affairs Martin Zeil insisted on personally delivering the official approval for start-up funding totaling € 5 million, thus underscoring the importance attached to the issue at a political level. On behalf of all those involved in founding the project group, keynote speakers at the opening ceremony took yet another look at the path so resolutely followed in turning the idea into a practical reality. Even allowing for the high degree of motivation shown by all involved, it is no mean feat to establish in such a short timespan what will one day serve as the foundation for a new Fraunhofer institute.*



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# FRAUNHOFER PROJECT GROUP IWKS

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## HISTORY AND MILESTONES OF THE IWKS

AS REFLECTED BY ITS FOUNDING FATHERS

The Fraunhofer Project Group for Materials Recycling and Resource Strategies IWKS, based in Alzenau, was founded in September 2011. The ground for this precursor to a new Fraunhofer institute, in which the local business community and political supporters are placing great expectations, was prepared in an intensive effort by the Fraunhofer ISC in a minimum of time. The primary objective of the new research institution is to devise solutions that will enable European industry to meet its long-term need for raw materials in a manner that is both economically and ecologically viable. This interview with Dr. Wulf Brämer of the industrial association Materials Valley e. V., Hanau – one of the initiators of this project –, ISC director Prof. Dr. Gerhard Sextl, and Prof. Dr. Armin Reller, one of the heads the new project group and Chair of Resource Strategy at the University of Augsburg, provides the background that led to the creation of the IWKS.

### INTERVIEWER

*What was the motivation behind the idea of creating a Fraunhofer research group dedicated to securing access to natural resources?*

### DR. BRÄMER

The decisive trigger, in my opinion, was the absence of Fraunhofer institutes in the Rhine-Main region – a situation that local industry found more and more difficult to accept. In the years from 1970 to 2000, we failed to encourage the establishment of Fraunhofer institutes here, not only those specializing in recycling but also with respect to the Fraunhofer organization as a whole, which has a great deal to offer to our local industries who cover a wide range of activities, from polymer chemistry to metalworking.

### PROFESSOR SEXTL

Up until the mid-1990s, most of the large industrial companies in the region relied on their own research departments, which were so productive that they saw no need for calling on the services of external research partners.

### DR. BRÄMER

At the time, they had no need of such assistance, because they were determined to go it alone. Their views have changed radically, especially now that they are facing increased competition from other regions. Saxony took the lead in this respect, and was one of the first regions to offer government support for the establishment of Fraunhofer research institutions – a development that our own politicians have been following with interest.



In the course of the debate on the availability of raw materials, which has been growing in intensity during the past year or two, the question arose of whether it might be possible to develop separate solutions for different categories of materials. The members of the Materials Valley association have been discussing these issues to determine the priorities and needs from an industry viewpoint. The only research organization that seemed to fit all requirements for a partnership of this nature was the application-oriented Fraunhofer-Gesellschaft.

#### PROFESSOR RELLER

I think it is important to mention that, precisely owing to the fact that recycling involves such a wide variety of materials from plastics to metals, it has become increasingly clear that it will be a major challenge to develop all the new technologies needed to process so many different materials.

#### INTERVIEWER

*So it was the Materials Valley association that set the ball rolling. How did you go about finding and bringing together the right partners?*

#### DR. BRÄMER

Fraunhofer ISC was already a member of the association. With its strong focus on materials science, and also because we had some very good contacts there, the ISC was the obvious choice of partner within the Fraunhofer-Gesellschaft for dealing with the concrete issues at hand.

#### PROFESSOR SEXTL

Dr. Brämer approached me with the idea of creating a specialized project group, and together we presented it to the Fraunhofer executive board, who agreed that this was a topic of major interest and gave me a free hand to launch the necessary activities for the creation of this project group. The next step was to find someone to help us define the new group's structure, someone who would later be able to take over as a director. This is where Professor Reller came in. We had first met in February 2010 at a meeting of the German Society for Chemical Engineering and Biotechnology (Dechema), where I head the working group on inorganic-technical chemistry.

#### PROFESSOR RELLER

At that meeting, I had presented a paper on functional materials for renewable energy applications, and afterwards Gerhard Sextl came up to me and invited me to give a similar lecture at the ISC. The talk took place in March 2010. That was also how I came into contact with Materials Valley.

#### INTERVIEWER

*Professor Reller, in your academic work as Chair of Resource Strategy you have been dealing with the topics of resource flows and resource strategies for quite some time. What contribution will you be able to make to Fraunhofer, and in what areas do you see the most opportunities?*

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# FRAUNHOFER PROJECT GROUP IWKS

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## PROFESSOR RELLER

In my research, I have had a lot to do with solid-state chemistry, and I noticed that it involves a very large number of metals, some of which are very rare. I took an interest in the question of where these metals come from, and we drew up the first maps showing this information. It's a matter of visualizing the entire life cycle assessment in a spatial and temporal context – not just for metals, but for all industrial materials and resources, as Mr. Brämer rightly points out. This means looking beyond the phase of actual use to consider what happens afterwards. What happens to all these devices and materials after the end of their useful life? Can we recover them or are they irretrievably lost? And can we substitute critical materials?

## INTERVIEWER

*What do you mean by substitution in this context?*

## DR. BRÄMER

By substitution we do not only mean replacing one material with another but also the possibility of using entirely new technologies to replace those that have become too expensive or detrimental to the environment. Mr. Sextl always illustrates this point with an excellent example, namely the transition from wet chemical film to digital photography.

## PROFESSOR RELLER

Another thing we have to do is to decide what systems and technologies we will need in the future. We need to create a sense of urgency with regard to the necessary resources, because when we look at today's consumption trends and the distribution of raw materials, we can already obtain a relatively clear picture of the resources that we need, those that are soon likely to be in short supply, and the areas where we will need to find substitutes or generate new material functions.

## INTERVIEWER

*Do you have a pertinent example?*

## PROFESSOR RELLER

One of the most talked-about subjects at the moment is electromobility. Manufacturers have only just started to define the metals and functional materials that will be required for large-scale implementation. It is not surprising that the automotive industry has been relatively slow to launch major development projects. One of the problems is the time factor, because it simply isn't possible to get hold of sufficient supplies of lithium, cobalt, or rare earth metals from one day to the next. This is another of the challenges that the project group IWKS will be working to solve.





#### **DR. BRÄMER**

It doesn't help matters that, as we are all aware, the political powers and opinion-makers have a tendency to gloss over the complexities and often make people believe that a solution has already been found as soon as the public's attention has been drawn to a particular issue. But that is far from being the case.

#### **INTERVIEWER**

*The ability to provide a rapid response is no doubt crucial. Indeed, it was one of the main discussion points when the project group was founded. How did you approach this?*

#### **PROFESSOR SEXTL**

I can at least say that the industrial community in Hanau was quick off the mark. By the end of the first discussions in January 2010, they had already produced an interest matrix comprising six large companies, accompanied by a declaration of support.

#### **DR. BRÄMER**

We wrote to the Hessian Ministry of Science in February 2010 asking for support with our plans to set up a Fraunhofer Institute in Hanau. The letter was signed by the CEOs of numerous renowned industrial companies. The ministry welcomed this initiative and referred us to its project funding program. To enable us to start work as soon as possible, we decided together with Mr. Sextl to extend our fund-raising efforts to Bavaria.

#### **PROFESSOR SEXTL**

In September 2010, we approached the President of the Regional Council of Lower Franconia, Dr. Beinhofer, who suggested that we should contact the council member for Aschaffenburg, Dr. Reuter. Reuter immediately wrote an official letter to the Bavarian State Government and two months later the cabinet ministers passed a resolution granting initial funding for the creation of our project group and the establishment of the first working groups. We meanwhile continued to negotiate with the Hessian Ministry of Economics, and were eventually granted generous support from this source too, enabling us to implement all of the planned working groups.

#### **DR. BRÄMER**

Once we had been assured of the support of local government and the Fraunhofer-Gesellschaft, we at Materials Valley organized two »Industry meets Fraunhofer« events to gather more broadly based information on the needs of industry in the Rhine-Main area and the Lower Main region of Bavaria, with the aim of developing our concept in line with their interests. Of the resulting 70 project proposals, a certain number were grouped by theme and elements of the research content were prepared for the launch of the project group, including the thematic areas of special glass, polyurethane, and magnetic materials.

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# FRAUNHOFER PROJECT GROUP IWKS

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## INTERVIEWER

*Professor Reller: Dr. Brämer has touched on the subject of material flows. What experience have you been able to gather in this area in your academic research?*

## PROFESSOR RELLER

One of the biggest problems is that we have to deal with a mixture of materials, and until now we have only recovered the components that can actually be reused, such as gold and silver, for which the companies UMICORE and HERAEUS operate an efficient precious-metal recycling process. Moreover, many of the components incorporated in industrial products are delivered by outside suppliers, with the result that companies often do not know exactly what materials are contained in the end product. The functional elements are incorporated to specification, and the final material composition is unknown. This obviously makes recycling very difficult, especially when certain materials are only present in infinitesimally small quantities, as is the case with thin-film technology or microelectronics. We need to focus our search for solutions on situations where there is a risk of losing metals. These milligram amounts of metals such as palladium or silver in the products are dissipated in the biosphere without the slightest chance of being recovered. In my view, the development of solutions to such problems is one of our most important future challenges.

## DR. BRÄMER

The decisive factor for industry is that the processes should be cost-efficient. Whatever the material we aim to recycle, we need to be able to calculate the bottom-line result. Cost-efficiency happens to be a very important goal of the work done by this institute, without which we simply cannot succeed.

## PROFESSOR RELLER

This is an aspect that is going to require some serious thought. It is pretty obvious that the price of certain metals is going to rise astronomically in the next few years. In Switzerland, the idea has even been contemplated of stockpiling industrial waste until it becomes economically viable to recover certain metals. It could be a solution, but not in the immediate term, for the investments that it would require today will not pay off for another ten years or so.

## DR. BRÄMER

Another important factor in a successful recycling strategy is the question of waste collection. This is a political and a legislative issue. The example of PET bottles shows just how well this can work: It takes hardly any effort for consumers to deposit their empty bottles in a reverse vending machine, and their cash deposit is returned on the spot. We need a similarly efficient system for consumer electronics and other end-of-life products, in which an advanced recycling fee is charged to the purchaser, reimbursable when the device is brought to a collection point. But this requires a legal and political incentive – precisely one of the areas where the IWKS can step in by providing its advice to support the relevant decision-making processes.

#### INTERVIEWER

*If you take all these aspects into consideration, i.e. the political framework and the need for a rapid return on investments, when does recycling become a viable proposition, and what can organizations like the IWKS do to provide the maximum of support?*

#### PROFESSOR RELLER

Without hesitation: the key aspect is toxicity, because the ecological burden plays a very significant role. We need to close the materials cycle, especially in processes involving heavy metals. For example, we still need to find a way of recycling the rare earth metals and mercury contained in energy-saving lamps. And in the longer term we will also have to deal with the disposal of the huge number of photovoltaic panels currently installed around the world. We will be faced with some highly exotic compounds, such as cadmium-telluride. We urgently need to find a means of preventing this substance from being dispersed as a toxic dust all over the environment. There is huge potential for material-specific recycling strategies in this respect.

#### DR. BRÄMER

All manufacturers of photovoltaic systems are today bound by the obligation to take back their products for recycling. This legal obligation affects the whole solar industry in Germany.

#### PROFESSOR RELLER

In a sense, the legislative authorities are supporting the efforts of companies with transparent operations. But the problem is that it is not always possible to apply these laws in certain areas of the low-cost production sector. What is needed is a universally applicable set of laws that lays down the basic principles to be respected throughout production.

#### PROFESSOR SEXTL

This is where it is important for the IWKS to become an active member of lobbying networks, and to repeatedly draw companies' attention to emerging problems. For supply chains are often anything but transparent. Social change and new political initiatives can only be effective if they are based on a broad public consensus and supported by industry.

It is all very well to aim for cost-effective solutions, but the break-even point for different technologies depends on the availability of the necessary raw materials. A solution that might be rejected today on cost grounds could well be profitable in a few years' time. Following this reasoning, the establishment of the project group was urgently required, because it will enable us to offer suitable processes at the right time.

#### INTERVIEWER

*What role do phosphates play in the IWKS's plans?*

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# FRAUNHOFER PROJECT GROUP IWKS

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## PROFESSOR RELLER

Phosphates are absolutely essential to food production. But they also play an important role as additives in the production processes for many advanced materials. The majority of naturally occurring phosphate deposits are contaminated with heavy metals. So sooner or later it will be necessary to extract the heavy metals from these excavated minerals, which is why the recycling and reprocessing of phosphates is an issue high on our research agenda. We are members of a worldwide research network dedicated to this subject.

## INTERVIEWER

*Where do you see possibilities for collaboration and interaction between IWKS and ISC?*

## PROFESSOR RELLER

First of all, in the area of materials science: We have many overlapping interests in the field of silicate materials. Moreover, the ISC's growing emphasis on electrochemistry takes in a substantial number of materials that could be of direct use in our recycling and substitution processes. The ISC's laboratories in Würzburg are well equipped, and we have been able to use their facilities for many productive analytical tests.

## PROFESSOR SEXTL

I can imagine that, as the parent institute in Würzburg, we might continue to perform analyses and operate laboratory-scale wet-chemical processes for the IWKS. This would save the IWKS the expense of investing its own funds in the necessary complex equipment. But when it comes to setting up chemical separation processes on a larger scale, I would prefer to see that done at the new location in Hanau-Wolfgang, where there is an existing production-adapted chemical infrastructure.

## INTERVIEWER

*To conclude, I would like to come back to the choice of location for the new institute. There were a number of possible options: what factors motivated the final decision?*

## PROFESSOR SEXTL

It was evident from the start that we were looking for a location in the Bavarian Lower Main region or the Rhine-Main area, due to the proximity to the local companies who, after all, had provided the original impetus. With the help of the local administration in Aschaffenburg, we were able to identify a handful of possible sites. After evaluation of each location's advantages with respect to the proposed research activities, Alzenau quickly emerged as the most suitable location for our Bavarian partners. In September 2011, the Bavarian economics minister Martin Zeil came to Alzenau in person to hand over the grant for the first years of operation. With the support of the Hessian Ministry of Economics, it was possible to establish the ties to Hanau-Wolfgang, a major site in chemical processing, so that, as of this year, the IWKS will be able to take up business at the two sites, Alzenau und Hanau-Wolfgang, in all three working groups: resource strategies, recycling technologies, and materials substitution.

#### INTERVIEWER

*If we look ahead over the next couple of years, how will the IWKS have evolved by then?*

#### PROFESSOR SEXTL

We already have a staff of 10 employees. The next planned step is the construction of an industrial building for our recycling plant in collaboration with the municipality of Alzenau. At around the same time, in June 2012, we set up laboratories in Hanau-Wolfgang, on the premises of our cooperation partner UMICORE. With these facilities, we will be able to continue on our growth course, and expect the number of employees to rise to approximately 15 for each site by the end of 2013. We also intend to set up a joint user center with Aschaffenburg University of Applied Sciences: the necessary approval has already been granted. It will focus on the subject of »design for recycling«.

#### INTERVIEWER

*Apart from Aschaffenburg, what other contacts do you have to universities, and how will the project group be networked on a scientific level?*

#### PROFESSOR SEXTL

To head up our three working groups, in addition to Professor Reller from the University of Augsburg, we have been fortunate to recruit two other reputed scientists: Professor Oliver Gutfleisch from the Technische Universität Darmstadt and Professor Stefan Gäth from the University of Gießen.

#### DR. BRÄMER

A strong management team, motivated employees, geographical proximity to industrial partners with an interest in our work, financial support from state governments – what better conditions could you have for starting out on a new venture? Now is it our turn to bring the ideas to life.

#### INTERVIEWER

*That sums up everything perfectly. Many thanks to you all for this interview.*



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# FRAUNHOFER PROJECT GROUP IWKS

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## THE MOLECULAR SORTING COOPERATION PROJECT

DR. JÜRGEN MEINHARDT

*»We have to act to ensure a steady supply of raw materials to our industry ... We need fair conditions in markets outside Europe, we need conditions that will enable us generally to improve the long-term utilization of European raw material sources, and we need greater resource efficiency and more recycling.« (former Vice-President of the European Commission Günter Verheugen).*

An increasing variety of materials go into modern products. This is accompanied by a decline in the quantities of materials available. From a technical perspective, the increased scarcity of large flows of high-value materials is creating recycling challenges which have not yet been resolved. As a consequence, more mixed and/or contaminated material flows are being used. All the while, recycling quotas are becoming more stringent.

All this has given rise to the »Molecular Sorting« project, in which six different Fraunhofer institutes have teamed up to form a research group. The goal of the project is to develop material separation processes on a volume scale that has never before been attempted, and to demonstrate these processes through exemplary applications. »Molecular sorting« is defined as separation at as small a level as is required to enable a material to be recycled. This innovative approach is to replace the outdated standard »bulk sorting«.

The objective of the research project is to close high-value material cycles through a combination of identification and analysis processes, through processing techniques for secondary material flows, and modifications to manufacturing pro-

cesses. This will enable materials to be recovered and recycled after manufacture/use by means of separation processes that go all the way down to the molecular level.

The basic approach of the project is to investigate the economically relevant material flows of minerals (siliceous raw materials), metals, and biogenic (wood) and other organic raw materials (polymers). In case studies, a combination of analysis and process engineering is to be applied to these material flows with the aim of generating recycled materials that can be put to the exact same uses as primary raw materials.

The project is based on an expanded conception of »urban mining«, one concerned not only with recovering raw materials from disposal dumps, landfills and similar facilities or existing infrastructures, but also with exploring anthropogenic solid, liquid, and gaseous material flows, such as waste flows (target materials: wood, metals, polymers, minerals) or wastewater flows (target materials: metals, minerals). Methods and technologies are to be made available through the project which can be used to pursue different approaches to urban mining. Six demonstrator projects will demonstrate the results in relevant applications.

### Clear glass demonstrator: Turning used flat glass into highly-transparent glass

How does material separation work at the molecular level? That's what Fraunhofer ISC and the IWKS Materials Recycling and Resource Strategies Project Group want to demonstrate using glass. Future technologies such as photovoltaics and solar thermal energy require glass which is ultra-transparent and therefore as pure as possible. The most common impurity is iron, even small quantities of which are enough to significantly reduce the translucence of glass. However, these future technologies are growing at such a rate that neither the natural iron-free raw material sources, nor the volumes of recycled highly-transparent glass from decommissioned PV modules, are sufficient to meet the demand for highly-transparent flat glass over the coming decades. A potential raw material source here is conventional flat glass, which until now has been »downcycled« into cheap container glass or mineral wool. However, the high iron content poses a problem.

Fraunhofer ISC in Würzburg and the affiliated IWKS project group in Alzenau are working together to develop processes that separate iron from glass at the molecular level and convert any tiny residual amounts of iron into a type of iron that does not affect the transmission of light. Material separation is performed at around 1500 °C in the glass furnace. The advantage of recycling cheap flat glass is the lower costs and ready availability of low-iron glasses compared to iron-free raw materials, which have become expensive and very scarce.

Securing the long-term availability of raw materials for the manufacturing sector is the goal of the Fraunhofer IWKS. In pursuit of this goal, the group's efforts focus on three main areas: the fundamentals of material recycling and development of raw material strategies for industry and government policymakers; technologies for raw material production, recycling, and product design for recycling; replacing critical raw materials by developing alternatives as substitutes.

These are the three cornerstones of activities planned for the Fraunhofer Institute Material Recycling and Substitution, which was founded in September 2011. The Project Group is jointly led by Dr. Armin Reller, Professor of Resource Strategy at the University of Augsburg, Dr. Stefan Gäth, Professor of Resource Management at the University of Gießen, and Dr. Oliver Gutfleisch, Professor of Functional Materials at the Technische Universität Darmstadt. In the »Molecular Sorting« project, the IWKS project group has taken on the task of investigating issues of cost-efficiency. It will also play an important role in developing technology.

[www.molecular-sorting.fraunhofer.de](http://www.molecular-sorting.fraunhofer.de)



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# FRAUNHOFER

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## The Fraunhofer-Gesellschaft

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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 more than 80 research units in Germany, including 60 Fraunhofer Institutes. The majority of the more than 20,000 staff are qualified scientists and engineers, who work with an annual research budget of € 1.8 billion. Of this sum, more than € 1.5 billion is generated through contract research. More than 70 percent of the Fraunhofer-Gesellschaft's contract research revenue is derived from contracts with industry and from publicly financed research projects. Almost 30 percent is contributed by the German federal and Länder 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.

Affiliated international research centers and representative offices provide contact with the regions of 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 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.

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.



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# INHALTSVERZEICHNIS – ANHANG

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# INFORMATIONEN ZU DEN GENANNTEN PROJEKTEN

## Geschäftsbereich Gesundheit

### **EAP mit magnetisch steuerbarer Elastizität zur Interaktion mit Bindegewebszellen (MagEla) – Teilvorhaben: Etablierung bindegewebskompatibler magnetoaktiver Polymere**

BMBF gefördertes Projekt

FKZ 13N10573

Partner: Universitätsklinikum Würzburg, Augenklinik und Poliklinik; Fachhochschule Regensburg, Fakultät Elektro- und Informationstechnik

Laufzeit: 1.7.2009 – 30.09.2011

### **Photostimulierbare Nanopartikel für die operationsbegleitende Diagnostik bei der Resektion von Mammakarzinomen (ResCare)**

Ein mittelstandsorientiertes Eigenforschungsprojekt der Fraunhofer-Gesellschaft

Partner: Fraunhofer IGB

Laufzeit 1.7.2011 – 30.6.2013

### **Entwicklung und Evaluierung neuer Therapieformen für chronische Hauterkrankungen (SkinHeal)**

Ein »Märkte von übermorgen«-Projekt der Fraunhofer-Gesellschaft

Partner: Fraunhofer IGB; Fraunhofer IME; Fraunhofer MEVIS; Fraunhofer EMFT

Laufzeit: 1.5.2011 – 30.4.2013

## Geschäftsbereich Energie

### **Entwicklung und Charakteristik nanoskaliger Elektroden-Komposite für EnergyCap: Hochleistungsspeicher für Anwendungen im Bereich der erneuerbaren Energieversorgung, mobiler Bordnetze und Traktionsanwendungen (EnergyCap)**

BMWi gefördertes Projekt

FKZ AZ0327822B

Partner: BMW Forschung und Technik GmbH, München; Freudenberg Vliesstoffe KG, Weinheim; Liebherr-Werk Biberach GmbH; Merck KGaA, Darmstadt; RWTH Aachen; Siemens AG, München; SGL Carbon GmbH, Meitingen; WIMA Kondensatoren GmbH & Co. KG, Berlin, ZSW, Ulm

Assoziierter Partner ohne Förderung: ENERCON GmbH, Aurich

Laufzeit 1.7.2009 – 31.3.2012

# INFORMATIONEN ON PRESENTED PROJECTS

## **Fraunhofer Systemforschung Elektromobilität (FSEM), Schwerpunkt 3 – Energiespeichertechnik, Teilprojekt Materialentwicklung für Li-Ionen-Batterie (MALION)**

BMBF gefördertes Projekt im Konjunkturprogramm II  
Laufzeit: 1.5.2009 – 30.6.2011

## **Konzeptstudien für neuartige Lithium-Ionen-Zellen auf der Basis von Werkstoff-Innovationen »KoLiWIN« Teilvorhaben: Elektrodenbeschichtung, hybride Elektrolyte und elektrochemische Charakterisierung**

BMBF gefördertes Projekt  
FKZ 03SF0343A  
Laufzeit: 1.7.2009 – 30.6.2012

## **Geschäftsbereich UMWELT**

Das Forschungsvorhaben 14413 N »Untersuchungen zur Entwicklung eines quecksilberfreien Präzisionsthermometers« sowie das Fortsetzungsvorhaben 16197 N »Fortführung der Untersuchungen zur Entwicklung eines quecksilberfreien Präzisionsthermometers« der Forschungsgemeinschaft Technik und Glas e. V. Bronnbach wurde im Programm zur Förderung der »Industriellen Gemeinschaftsforschung (IGF)« vom Bundesministerium für Wirtschaft und Technologie BMWi über die AiF »Otto-von-Guericke« e. V. gefördert.

## **Energieeinsparung und CO<sub>2</sub>-Minderung bei der Zementproduktion durch die Herstellung hüttensandreicher Hochofenzemente mit verbesserter Anfangsfestigkeit (ECO-Zement)**

BMW gefördertes Projekt  
FKZ 0327477B  
Partner: SCHWENK Zement KG Karlstadt; BASF Bauchemie, Trostberg; Bergakademie Freiberg  
Laufzeit: 1.1.2009 – 31.12.2011

## **Flexibles Flachglas-Biegeverfahren (FBB) – Teilvorhaben: Thermooptisches Messverfahren**

BMBF gefördertes Projekt  
FKZ 02PU2295  
Partner: Glaser FMB GmbH & Co. KG; Fraunhofer IWM; ELINO; Eckelmann AG  
Laufzeit: 1.3.2008 – 31.12.2011

# PROJEKTINFORMATIONEN ZU DEN GENANNTEN PROJEKTEN

## **Aktive Schichten für den Korrosionsschutz (ASKORR)**

Ein Kooperationsprojekt der Fraunhofer-Gesellschaft und der Max-Planck-Gesellschaft

Partner: Fraunhofer-Institut für Angewandte Polymerforschung, Max-Planck-Institut für Polymerforschung, Max-Planck-Institut für Eisenforschung

Laufzeit: 2010 – 2013

## **Climate for Culture**

EU-Förderprojekt

FKZ 226973

Laufzeit: 2009 – 2014

[www.climateforculture.eu](http://www.climateforculture.eu)

## **MEMORI – Measurement, Effect Assessment and Mitigation of Pollutant Impact on Movable Cultural Assets**

EU-Förderprojekt

FKZ 265132

Laufzeit: 1.11.2010 – 31.10.2013

[www.memori-project.eu](http://www.memori-project.eu)

## **Innovative Plasmatechnik zur Erzeugung photokatalytisch aktiver, hybrider Schichten (PlasKat)**

BMBF gefördertes Projekt

FKZ 13N9313

Partner: Unitec Helmsdorf GmbH; Pfeleiderer Holzwerkstoffe GmbH; Primed Halberstadt Medizintechnik GmbH; Berner International GmbH; 4H Jena; iba e.V. Heiligenstadt; Institut für Energie- und Umwelttechnik e. V. (IUTA); FH Anhalt; FEP; [MAT PlasmaTec, Bayer Material Science – während der Laufzeit aus dem Projekt ausgeschieden]

Laufzeit: 1.9.2007 – 28.2.2011

## **Untersuchungen zur Beschichtung von Glasfasergeweben mit photoaktiven Nanomaterialien zur Realisierung gaszersetzender Eigenschaften von Filtersystemen (OXIFILTER)**

FKZ 03X0065D

Partner: Likusta Umwelttechnik GmbH; Sachtleben Chemie GmbH; Institut für Energie- und Umwelttechnik e.V. (IUTA)

Laufzeit: 1.3.2009 – 31.8.2012

# INFORMATIONEN ON PRESENTED PROJECTS

## **Neuartige Schutzschichten und katalytisch aktive Oberflächen auf Basis funktionalisierter Nanopartikel für die Elektro- und Verkehrstechnik (NanoBase)**

BMBF gefördertes Projekt

FKZ 03X0023F

Partner: ALTANA Pharma AG, Singen; Aucoteam-Ingenieurgesellschaft für Automatisierungs- und Computertechnik mbH, Berlin; EADS Deutschland GmbH, Ottobrunn; Forschungszentrum Jülich GmbH, Jülich; ItN Nanovation GmbH, Saarbrücken; Siemens AG, Fürth; Süd-Chemie, Moosburg; Rockwood Clay Additives GmbH, Moosburg

Laufzeit: 1.6.2006 – 31.5.2009

## **Biomimetisch hergestellte superparamagnetische Partikel für das Wertstoffrecycling (BioSuPaWert)**

Förderung im Rahmen des Programms »Umwelttechnologieforschung« der Baden-Württemberg-Stiftung

Laufzeit: 1.11.2010 – 30.10.2013

## **Molecular Sorting for Resource Efficiency**

Ein »Märkte von übermorgen«-Projekt der Fraunhofer-Gesellschaft

Laufzeit: 1.7.2011 – 30.6.2014

# PROJEKTÜBERSICHT

## **Aktuelle Forschungsschwerpunkte** **Current Frontline Research Topics**

### **Anlagen- und Geräteentwicklung** **Device development**

MUHOPF – Aufbau eines multiplen Hochtemperatur-Prüffeldes für Materialuntersuchungen unter kontrolliertem Sauerstoffeinfluss (Innovationscluster Metall, Keramik, Kunststoff und Oberflächentechnik des Ministeriums für Wirtschaft, Verkehr, Landwirtschaft und Weinbau und des Europäischen Feuerfestzentrum ECREF)

Untersuchung zur Entwicklung eines quecksilberfreien Präzisionsthermometers (AiF)

Ofenbau im Bereich Sonderanlagen

Prototypen-Anlagenbau

Robotik

Softwareentwicklung im Bereich Mess-, Steuerungs- und Automatisierungstechnik

Volumenmesstechnik

Zertifizierter Standardgerätebau im Bereich Volumendosierung, Laborglasjustierung und thermooptischer Messverfahren

### **Energiespeicherung und mobile Energieversorgung** **Energy storage and mobile energy supply**

EnergyCap – Hochleistungsspeicher für Anwendungen im

Bereich der erneuerbaren Energieversorgung, mobilen Bordnetzen und Traktionsanwendungen; Teilvorhaben: Entwicklung und Charakterisierung nanoskaliger Hybridelektroden und dafür abgestimmte Elektrolytsysteme für (BMBF)

Konzeptstudien für neuartige Lithium-Ionen-Zellen auf der Basis von Werkstoff-Innovationen – Koordination und Teilvorhaben: Elektrodenbeschichtung, hybride Elektrolyte und elektrochemische Charakterisierung (BMBF)

Verbundprojekt Fraunhofer Systemforschung Elektromobilität – Schwerpunkt 3: Energiespeichertechnik – Koordination und Teilvorhaben: Materialentwicklung für Li-Ionen Batterien (BMBF)

Autarke Energieversorgung über intelligente Piezogenerator/ Polymer-Supercap/Lithium-Polymerakku-Mikrosysteme (BMBF)

### **Forschungen zur nachhaltigen Sicherung von mittelalterlicher Kirchenverglasung** **Sustainable conservation of medieval church windows**

Conservation materials for stained glass windows – assessment of treatments, studies on reversibility and performance of innovative restoration strategies and products (EU)

Craquelée Schäden: Anwendung innovativer Restaurierungsmaterialien und -methoden zur Sicherung und Konservierung craquelierter Glasmalereien, modellhaft angewendet an Glasfenstern des 19. Jahrhunderts im Kölner Dom (Weltkulturerbe) (DBU)

### **Bau** **Building and construction**

Multi-source energy storage systems integrated in buildings (EU)



# PROJECT OVERVIEW

Kalthärtende Keramik durch nanotechnologische Gefügeoptimierung (BMBF)

Baustoffe auf Basis von porösen Glasflakes für das Klimamanagement (Bayer. Forschungstiftung)

Zeolithe mit absorberkatalytischer Wirkung für Formaldehyd in Holzwerkstoffen (FhG)

## Smart Materials

Einsetzbare adaptronische Module zur Kompensation von Echtzeitfehlern (thermisch und Schwingungen) und zur supergenauen Positionierung in rekonfigurierbaren Hochpräzisions-Werkzeugmaschinen (EU)

Entwicklung von Hochtemperatur-Ultraschallwandlern zur On-line-Strukturüberwachung heißer Dampfleitungsrohre (EU)

Hierarchical and Adaptive smaRT COmponents for precision production systems application (EU)

The integrated safe- and smart-built concept (EU)

Erforschung betriebsfester und langlebiger Materialsysteme von dielektrischen Elastomeraktoren – Teilvorhaben: Organisch modifizierte Silikonmaterialien für dielektrische Elastomeraktoren (BMBF)

Innovatives Condition Monitoring System zur nachhaltigen Überwachung sicherheitsrelevanter Komponenten (BMBF)

Integration neuartiger Funktions- und Konstruktionswerkstoffe und deren Anwendung in einem miniaturisierten Ventilsystem (BMBF)

Modellgestütztes Structural Health Monitoring für Rotorblätter von Windenergieanlagen (BMBF)

Smart Windows auf Basis von Metallo-Polyelektrolyten (BMBF)

Verbundprojekt Fraunhofer Systemforschung Elektromobilität (FSEM) - Schwerpunkt 4, Teilprojekt B: Technische Systemintegration, gesellschaftspolitische Fragestellungen und Projektmanagement, AP 5: Magnetorheologische Motor-Generator-Kupplung (BMBF)

Entwicklung von multifunktionellen Sensoren zum Nachweis der Glasbruchentstehung und zur Ansteuerung von Facility-Management-Systemen (BMWA)

## GESUNDHEIT HEALTH

### Diagnostik Diagnostics

Untersuchungen zur Speicherung von Ladungsträgern in Nanopartikeln und Entwicklung von Infrarotlicht-stimulierten Markern für die Bioanalytik und Diagnostik (DFG)

BioDots für biomedizinische Anwendungen (FhG)

Nanopartikelbasiertes multimodale In-vivo-Diagnostik (FhG)

Verfahrensentwicklung zur schonenden Kapselung von Wirkstoffen (FhG)

### Regenerative Medizin Regenerative medicine

EAP mit magnetisch steuerbarer Elastizität zur Interaktion mit Bindegewebszellen (BMBF)

# PROJEKTÜBERSICHT

Mikroverkapselung von Wirkstoffen (ZIM)  
Physiologisch degradierbare, mittels Zwei-Photonen-Absorption (TPA) strukturierte Hybridwerkstoffe für die Regenerative Medizin (FhG)

## **Dentalmedizin** **Dental medicine**

Entwicklung einer innovativen Werkstofflösung für Zahnkronen (ZIM)

Innovatives dentales Füllungskonzept (ZIM)

Chairside-Kronen (FhG)

Dentale Glaskeramiken

Neuer Halt für Zähne – einfach applizierbare regenerative Paradontalmaterialien (FhG)

## **Keramische Fasern und inhärent sichere Keramikherstellung** **Ceramic fibers and intrinsically safe ceramics production**

SiBNC-Werkstoffe für Produktions-, Energie- und Verkehrstechnik (BMBF)

Simulationsbasiertes Prozessdesign für die Entwicklung innovativer Keramik-Hochleistungsfasern (BMBF)

Entwicklung und Upscaling von Chemie und Technologie für SiC-Fasern (STMWIVT)

Oxidische Ceramic Matrix Composites (BMWi)

C/SiC-Kupplung – Kupplung mit Keramikreibpaarung (StmWIVT)

Herstellung großformatiger Bauteile aus Nichtoxidkeramik durch Einsatz optimierter Formgebungsverfahren und Mikrostruktur-Eigenschaftssimulation (StmWIVT)

Thermoschockbeständiges Keramik-Kompositmaterial für die Wärmetechnik; Materialentwicklung des Keramik-Matrixmaterials (BMWi)

Mikrostrukturentwicklung und Sintern bei Co-Firing von keramischen Mehrschichtsystemen (DFG)

Kontinuierliche Silizierung von Bremsscheiben (Bayerische Forschungstiftung)

## **Kundenspezifisches Spezialglas** **Customized special glasses**

Flexibles Flachglas-Biegeverfahren (BMBF)

Laserstrahl-Glasfrit-Bonden zum Packaging temperaturempfindlicher Glas- und Siliziumbauteile (BMBF)

Entwicklung der Prozesskette zum thermischen Wiederziehen komplexer Mikrokomponenten aus hochbrechenden Glaswerkstoffen (BMWi)

Entwicklung von Schmelzscreening-Verfahren (Bayerische Forschungstiftung)

## **Mikro- und Polymerelektronik** **Micro and polymer electronics**

Entwicklung der Grundlagen für eine polymere Low-Cost-Elektronik (FhG)

Nanoparticles and layers of semiconductors and dielectrics, ferroelectrics, piezoelectrics of AIST in and on multifunctional

# PROJECT OVERVIEW

OC-matrices and layers including relevant thin-film and micro-technology of ISC (FhG)

Photoinitierte Mikrostrukturierung von piezoelektrischen Werkstoffen für die Medizintechnik und die Mikrosystemtechnik (FhG)

## **NANOTECHNOLOGIE NANOTECHNOLOGY**

Economic foresight study on industrial trends and the research needs to support the competitiveness of European industries around 2025

NANORUCER – Mapping the Nanotechnology innovation system of Russia for preparing future cooperations between EU and Russia

## **(Nano)poröse Materialien (Nano)porous materials**

Entwicklung einer Technologieplattform für die Herstellung multifunktionaler Hybridschäume (FhG)

## **Optische Aufbau- und Verbindungstechnik Optical packaging**

Functionalized Advanced Materials Engineering of Hybrids and Ceramics (EU)

Nanochemistry and self-assembly routes to nanomaterials (EU)

Optische Transceiver-Module mit in-situ definierbaren spektralen Eigenschaften für optische Zugangsnetze (BMBF)

Optisch erzeugte Sub-100 nm-Strukturen für biomedizinische und technische Applikationen: Materialien und Technologien

zur Erzeugung kleinster Strukturen mittels Femtosekundenlaser-induzierter Mehrphotonenpolymerisation (DFG-SPP)

Thermop – Maßgeschneiderte Einstellung thermo-optischer Koeffizienten in anorganisch-organischen Hybridmaterialien für energieeffiziente optische Bauelemente

## **Ressourcenschonung Sustainable consumption and production**

Effiziente Entbinderungs- und Sintertechnik in der Keramikherstellung; Teilprojekt: Entwicklung effizienter Optimierungsmethoden für die Entbinderungs- und Sintertechnik (BMBF)

ECO-Zement – Energieeinsparung und CO<sub>2</sub>-Minderung bei der Zementproduktion durch die Herstellung hüttensandreicher Hochofenzemente mit verbesserter Anfangsfestigkeit (BMW i)

## **SCHICHTEN COATINGS**

Oxide Materials towards a matured post-silicon electronics era (EU)

MEM-OXYCAL Membranen für die Kraftwerkstechnologie – Teilvorhaben: Entwicklung, Charakterisierung und Test nanoskaliger, dichter Membranschichten für die Sauerstoffabtrennung (BMW i)

## **Aktive, schaltende Schichten Active switchable coatings**

Innovative switchable shading appliances based on nanomaterials and hybrid electrochromic device configurations (EU)

Entwicklung von Klebstoffen mit Hochbarriereigenschaften auf Basis nanoskaliger Hybridpolymere (BMBF)

# PROJEKTÜBERSICHT

Flexibles Energieversorgungssystem für energieautarke Mikrosysteme (BMBF)

Innovative Gradientenschichten mit nanoskaligen Hybridpolymeren (BMBF)

Funktionalisierung von Vliesstoffen für die Tiefenfiltration mit wasserbasierten anorganisch-organischen Beschichtungssolen (AiF/BMBF)

Korrosionsschutz durch hybride Nanomaterialien zur Substitution Chrom(VI)-haltiger Systeme (AiF/BMBF)

Aktive Schichten für den Korrosionsschutz (MGG/FhG)

Entwicklung, Erprobung und inline-Qualitätssicherung von flexiblen Ultrabarierefolien im Pilotmaßstab für die Anwendung in fotoelektronischen Systemen (FhG)

## **Saubere / leicht zu reinigende Schichten** **Self-cleaning / easy-to-clean surfaces**

Atmospheric Plasmas for Nanoscale Industrial Surface Processing (EU)

Erhöhung der aktiven und passiven Sicherheit von Fahrzeugen durch neuartige multifunktionelle Nanobeschichtungen (BMBF)

Herstellung von organisch-anorganischen Nanokompositbeschichtungen für Bildschirm- und Mobiltelefonoberflächen zur Selbstreinigung von Fingerabdrücken (BMBF)

Permanente Trennmittelbeschichtung auf Basis hybrider Nanokomposite (BMBF)

Innovative Plasmatechnik zur Erzeugung aktiver, hybrider Schichten (VDI/BMBF)

Hybride Nanokomposite für die elektrolytische Abscheidung (FhG)

## **Optisch-funktionale Schichten** **Optical functional coatings**

Entwicklung abriebbeständiger Antireflexschichten für hochtransparente Verglasungen im Baubereich (BMBF)

Innovative Beschichtungssysteme für optische Spezialfasern (BMBF)

T-Rex – Transparente, kratzfeste Schichten mit niedrigem refraktivem Index sowie hoher Transmission im sichtbaren, UV- und IR-Bereich (BMWl)

UV-härtbare Digitaldruckfarbe auf Hybridpolymerbasis zur Bedruckung von Glas (FhG)

## **Barrierschichten** **Barrier coatings**

Development and integration of processes and technologies for the production of organic low cost and large-area flexible Electronics (EU)

Plasmaaktivierung und plasma-unterstützte Beschichtung von Kunststoff-Folien für Anwendungen in der Elektrotechnik (BMBF)

Entwicklung der Grundlagen für eine polymere Low-Cost-Elektronik im Rahmen der marktorientierten Vorlauftforschung (FhG)

Multifunktionale Membrankissenkonstruktionen (FhG)

# PROJECT OVERVIEW

## **Umweltmonitoring und präventive Konservierung** **Environmental monitoring and preventive conservation**

Climate for Culture: Damage risk assessment, macroeconomic impact and mitigation strategies for sustainable preservation of cultural heritage in the times of climate change (EU)

MEMORI: Measurement, Effect Assessment and Mitigation of Pollutant Impact on Movable Cultural Assets.

Dom zu Merseburg – Konzept der konservatorischen und restauratorischen Maßnahmen an Metallsarkophagen in der Fürstengruft des Domes zu Merseburg (KUR)

Entwicklung und modellhafte Erprobung von energetisch optimierten Schutzverglasungen für anthropogen umweltgeschädigte historische Verglasungen am Beispiel des Xantener Domes (DBU)

Wege in die Moderne – Schadenspotential von Licht auf Museumsartefakte (SAW)

Plasmatechnologie Kulturerbe: Plasmatechnologie - eine innovative Technologie zur Konservierung und Restaurierung von Kulturgütern und öffentliche Präsentation der Forschungsallianz Kulturerbe (FhG)

Entwicklung transparenter Lacke zur Konservierung von Glas, Metall, Industriedenkmalen etc.

Klimamessungen im Innen- und Außenraum (Industrie und Denkmalpflege)

Klimasimulation und Schadensanalytik für Industriekunden

Lichtdosimeter zur Bestimmung der Gesamtmenge Licht, die auf ein Objekt/Exponat fällt, z.B. während einer Museumsausstellung

Umweltmonitoring: Umweltwirkungsmessungen, »preventive conservation«, Glassensoren

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Nanoscale Transparent Barrier Layers.  
25<sup>th</sup> OE-A Working Group Meeting,  
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Bellendorf, P., Leissner, J.:

Die Erhaltung unseres kulturellen Erbes in Zeiten des SUPER  
GAUs, globalen Wandels und der Finanzkrise - Luxus oder  
Notwendigkeit?  
Das grüne Museum Wien,  
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Bellendorf, P.:

Naturwissenschaftliche Analysen und Methoden – unnötiger  
Luxus oder notwendige Maßnahmen?  
30. Mitteldeutsches Bau-Reko-Kolloquium »Kirchenkunst -  
sakrale Bauwerke und ihre Ausstattung«,  
Mühlhausen, 13.4.2011

Bellendorf, P., Rota, S.:

Der Einsatz von naturwissenschaftlichen Verfahren zur  
Sicherung von Archivgut.  
71. Südwestdeutscher Archivtag,  
Kloster Bronnbach, 21.5.2011

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Einsatz von 3D-Scannern in der Restaurierung.  
Werkstattgespräch FH Erfurt,  
Erfurt, 7.12.2011

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Characterisation of zeolites designed for improving indoor air  
quality.  
Deutsche Zeolith-Tagung,  
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Böse, H.:

Smart Materials und Anwendungen - Neue Möglichkeiten für  
die Mikrotechnik?,  
Institutskolloquium, IMM,  
Mainz, 24.1.2011

Böse, H.:

Electrorheological (ER) and magnetorheological (MR) fluids for  
suspension systems.  
IQPC Fahrwerkstagung,  
Düsseldorf, 15. – 16.3.2011

Böse, H.:

CeSMA - Neue Entwicklungen und Ergebnisse.  
CeSMA-Workshop Smart Materials für Automobile,  
Würzburg, 4.5.2011

Böse, H.:

Silicone elastomers with increased permittivity for dielectric  
elastomer actuators with enhanced performance.  
EuroEAP - International conference on Electromechanically  
Active Polymer (EAP) transducers and artificial muscles,  
Pisa (IT), 8. – 9.6.2011

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Novel Concepts of Magnetorheological Damping.  
5<sup>th</sup> ECCOMAS Thematic Conference on Smart Structures and  
Materials SMART 11,  
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Smart Materials zur gezielten Beeinflussung mechanischer  
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Vortragsreihe am Lehrstuhl für Technische Mechanik der  
Universität Erlangen,  
Erlangen, 12.7.2011



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Intelligente Materialien für adapttronische Anwendungen.  
Cluster-Treff bei pro-micron GmbH Kaufbeuren,  
Kaufbeuren, 16.5.2011
- Brunner, B.:  
Hochtemperatur-Ultraschallwandler zur kontinuierlichen  
Strukturüberwachung von Dampfleitungen.  
10. Dresdner Sensor Symposium,  
Dresden, 5. – 7.12.2011
- Dembski, S.:  
Multifunctional Nanoparticles for Biomedical Applications.  
Deutsch-Brasilianisches Medizin-Technik Forum,  
Sankt Augustin, 11.2.2011
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Biocompatible luminescent nanoparticles on the basis of  
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Neue Wege in der Krebsforschung.  
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Multifunctional Nanoparticles for an Integrated Microfluidic  
Diagnosis System.  
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Sol-Gel-Materialien: Hybridpolymere und anorganische  
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Multifunktionelle hybride Barrierematerialien.  
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nischer Baugruppen,  
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- Dörffel, M.-L.:  
Werkstoff Glas.  
Sitzung des Kuratoriums Kloster Steinfeld,  
Steinfeld, 10.12.2011
- Flegler, R.:  
Glasoberfläche/Glasgrenzfläche - Spezifische Analytik-  
Fragestellungen.  
Cluster-Treff Oberflächenanalytik von Glas,  
Bayreuth, 19.7.2011
- Gellermann, C.:  
Verkapselung auf Basis nanoskaliger Struktureinheiten.  
Chemische Nanotechnologien,  
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Polysilazane-based environmental barrier coating system.  
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Smolenice (SK), 9.5.2011
- Günthner, M.:  
Composite polymer derived ceramic coating system on steel.  
Euromat 2011,  
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Nanokeramische Funktionsschichten auf Precursorbasis als  
Korrosionsschutzsystem in Müllverbrennungsanlagen.  
KW21 Workshop,  
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Hybrid Materials 2011,  
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Anorganisch-organische Nanokomposite: Ex-situ- und In-situ-  
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gestaltung von Papier,  
München, 12. – 13.4.2011
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Oberflächenveredelung durch chemische Nanotechnologien:  
Etablierte Anwendungen und zukünftige Möglichkeiten.  
Clustermeeting Oberflächen, Nanoinitiative Bayern,  
Würzburg, 25.5.2011
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Value chain analysis for selected nanotech applications –  
is Nano really special?  
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Applied R&D at Fraunhofer: Examples for commercializing  
chemical nanotechnologies.  
NanoMaterials 2011,  
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Ormocere - Nanotechnologie in der Anwendung.  
Bürgerdialog »Alles Nano«  
Deutsches Museum, München, 20.7.2011
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Applied R&D at Fraunhofer: Commercializing nanotechnologies.  
1<sup>st</sup> German-Turkish Workshop Commercialization of Future  
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- Haas, K.-H.:  
Hybrid inorganic-organic polymers as precursors for micro-  
porous inorganic hollow fiber membranes.  
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Polymere Nanokomposite.  
IIR-Seminar,  
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- Helbig, U.:  
Verkapselung von Latentwärmespeichern für Bauanwendungen.  
PolymerTherm – hot & cold,  
Rudolstadt, 6. – 7.9.2011
- Houbertz, R.:  
Tailored hybrid materials for sub-100 nm two-photon litho-  
graphy and micro optical applications.  
Photonics West 2011,  
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Ultra-short Laser Pulses for 3D Patterning of Hybrid Materials - a Scalable Technology for Optical and Life Science Applications. MRS Spring Meeting 2011, San Francisco (USA), 25. – 29.4.2011

Houbertz, R.:

Inorganic-organic hybrid materials for advanced packaging technology. INTERREG IV B Workshop (Atlantic Area Project, Uni Aveiro), Aveiro (PT), 24. – 25.11.2011

Kilo, M.:

On the use of a purely inorganic sealant for low-temperature sealing of ancient glass. 3. Glassac Conference, Bronnbach, 10. – 12.5.2011

Kilo, M.:

Fügen mit Glas – Spezialglasentwicklung und Glaseigenschaften. 29. DKD/DAkKS, Würzburg, 27.5.2011

Kilo, M.:

Neue Methoden zur Bestimmung der Viskosität von Glasmelzen in situ. 85. Glastechnische Tagung, Saarbrücken, 30.5. – 1.6.2011

Kilo, M.:

Herstellung und Wasseraufnahme von porösem Glaspulver. 110. Bunsentagung (Annual German Conference on Physical Chemistry), Berlin, 2. – 4.6.2011

Kilo, M.:

Optische Materialien am Fraunhofer ISC. DFG-Kolloquium FA-Glasforum/FA-I, Erlangen, 4. – 6.10.2011

Kleine, M., Heidrich, C., Bellendorf, P.:

Zur Problematik korrodierter Mattweißbeschichtungen an Glasfenstern bedeutender Künstler des 20. Jahrhundert. Stained Glass After 1920: Technology and Conservation. Forum for the Conservation of Stained-Glass Windows, Lissabon (PT), 26. – 28.9.2011

Konschak, A.:

Schnellsilizierung von C/C-Preformen via LSI-Verfahren. 18. Symposium Verbundwerkstoffe und Werkstoffverbunde, Chemnitz, 30.3. – 1.4.2011

Krauß, M.:

Farbige Innenmarkierung von Glas durch Laserbestrahlung. 2. Workshop Laserbearbeitung von Glaswerkstoffen, Erlangen, 12.4.2011

Krenkel, W.:

Rapid Siliconization of C/C-Preforms. 35<sup>th</sup> International Conference on Advanced Ceramics and Composites, Daytona Beach, FL (USA), 23. – 28.1.2011

Krenkel, W.:

Entwicklungstrends bei faserverstärkten Keramiken. Mitgliederversammlung des Carbon Composites e.V., SGL Group Forum, Meitingen, 11.3.2011

Krenkel, W.:

Keramische Verbundwerkstoffe – Herstellung, Einsatz und Perspektiven. ITCF-Kolloquium, Denkendorf, 17.5.2011

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Design and Manufacture of Ceramic Safety Components. 4 World Materials Research Institutes Forum (WMRIF-4), Shenyang (RC), 22. – 26.5.2011

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- Krenkel, W.:  
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- Krenkel, W.:  
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- Krenkel, W.:  
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- Langhof, N.:  
Der Einfluss von freiem Silizium auf den Verschleiß keramischer  
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mensionaler Gegenstände oder Oberflächen durch Laser-  
Bestrahlung, solche Gegenstände, deren Verwendung sowie  
Ausgangsmaterialien für das Verfahren  
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EP 009463217 Erteilungstag 2011/03/01

Offenlegungstag/Publication date  
Erteilungstag/Date of patent  
Datum/Date: YYYY/MM/DD

# WISSENSCHAFTLICHE KOOPERATIONEN

## mit Hochschulen with universities

Academy of Fine Arts, Faculty of Art Conservation, Krakau (PL)	Hochschule Osnabrück
AGH-University of Science and Technology, Krakau (PL)	Hochschule Potsdam, Studiengang Restaurierung, Studienrichtung Metallkonservierung
Albert-Ludwigs-Universität Freiburg	Hochschule Würzburg-Schweinfurt-Aschaffenburg, Fachbereich Informatik
Aristotle University of Thessaloniki (GR)	Institut National Polytechnique de Grenoble, Laboratoire SIMAP (Science et Ingénierie des Matériaux et Procédés), Saint Martin d'Herès (F)
Bauhaus-Universität Weimar, Fakultät Bauingenieurwesen, Professur Bauchemie	Institute Electronic Structure and Laser, Foundation for Research and Technology, Holography Lab – Laser Applications, Heraklion (GR)
Charité Campus Benjamin Franklin, Berlin	Johannes Kepler Universität Linz (A)
Czech Technical University, Prag (CZ) - Faculty of Mechanical Engineering	Julius-Maximilians-Universität Würzburg - Experimentelle Physik V – Nanooptics and Biophotonics Group - Lehrstuhl für Funktionswerkstoffe der Medizin und Zahnheilkunde - Lehrstuhl für Klassische Archäologie - Lehrstuhl für Materialsynthese - Lehrstuhl für Technische Physik
Ecole Nationale Supérieure de Céramique Industrielle, Limoges Cedex (F)	Karlsruhe Institute of Technology KIT -Institut für Werkstoffe der Elektrotechnik
Friedrich-Schiller-Universität Jena	Katholieke Universiteit Leuven (B)
Ghent University (B) - Department of Geology and Soil Science - IMEC Center for Microsystems Technology	Korea University, Sejong Campus
Glasgow Caledonian University (UK)	Leibniz Universität Hannover
Gotland University, Department of Building Conservation, A Baltic Sea Region Network on Indoor Climate in Churches, Visby (S)	London School of Economics & Political Science, Grantham Research Institute on Climate Change and Environment (UK)
Hochschule Anhalt, Medizinischer Gerätebau	
Hochschule Emden	

# SCIENTIFIC COOPERATIONS

Medizinische Hochschule Hannover, Klinik für Zahnärztliche Prothetik und Biomedizinische Werkstoffkunde

Nagoya University, National Institute of Advanced Industrial Science and Technology AIST, Nagoya (JP)

National Technical University of Athens (GR)

- School of Mechanical Eng., Lab. of Heterogeneous Mixtures & Combustion Systems
- School of Civil Engineering, Lab. for Earthquake Engineering

Otto-Friedrich-Universität Bamberg

- Institut für Archäologie, Denkmalkunde und Kunstgeschichte

Paris-Lodron-Universität Salzburg (A)

- Fachbereich Materialwissenschaften und Physik

Philipps-Universität Marburg

- Institut für Anorganische Chemie

Polytecnio di Torino (I)

Rheinisch Westfälische Technische Hochschule (RWTH) Aachen

- Institut für Elektrochemische Energiewandlung und Speichersystemtechnik
- Institut für Gesteinshüttenkunde
- Institut für Physikalische Chemie
- Institut für Werkstoffanwendungen
- Klinik für Plastische Chirurgie, Hand- und Verbrennungschirurgie

Risø Technical University of Denmark DTU

Risø National Laboratory for Sustainable Energy, Roskilde (DK)

Sächsisches Textilforschungsinstitut e.V. an der TU Chemnitz

Dandia Nationals Labs, CA (USA)

Tampere University of Technology, Tampere (FIN)

Technical University of Denmark, Department of Management Engineering, Kongens Lyngby (DK)

Technische Universität Bergakademie Freiberg, Institut für Automatisierungstechnik, Freiberg

Technische Universität Berlin

Technische Universität Braunschweig

Technische Universität Darmstadt

Technische Universität Dresden

- Institut für Festkörperelektronik

Technische Universität Graz (A)

- Institut für Chemische Technologie von Materialien

Technische Universität Kassel

Technische Universität München

- Studiengang für Restaurierung, Kunsttechnologie und Konservierungswissenschaft

Technische Universität Wien (A)

- Institut für Angewandte Synthesechemie
- Institut für Nachrichten- und Hochfrequenztechnik

Technische Universiteit Eindhoven (NL)

- Department Technology, Unit Building Physics and Systems
- Department of Applied Physics (Plasma and Materials Processing)

# WISSENSCHAFTLICHE KOOPERATIONEN

The Royal Danish Academy of Fine Arts, Kopenhagen (DK)  
- The School of Conservation

Tokyo Institute of Technology (JP)

Tokyo University of Agriculture and Technology, Ohno-Lab (JP)

Universidade do Minho, Braga (P)  
- Grupo de Revestimentos Functionais

Università di Genova (I)

Università Milano-Bicocca, Mailand (I)

Universität Alicante (E)

Universität Augsburg  
- Anwenderzentrum Material- und Umweltforschung

Universitat Autònoma de Barcelona (E)  
- Instituto de Ciencia de Materiales

Universität Bayreuth  
- Bayerisches Geoinstitut  
- Lehrstuhl keramische Werkstoffe  
- Lehrstuhl für Werkstoffverarbeitung

Universität Bremen

Universität Erlangen-Nürnberg  
- Institut für Werkstoffwissenschaften  
- Lehrstuhl Werkstoffe der Elektrotechnik

Universität Hannover  
- Institut für Anorganische Chemie

Universität Jena  
- Institut für Angewandte Physik

Universität Linz  
- Institute of Applied Physics

Universität Rostock  
- Institut für Biomedizinische Technik  
- Kompetenzzentrum für Biomaterialien  
- Medizinische Fakultät, Institut für Biomedizinische Technik  
- Poliklinik für Zahnärztliche Prothetik und Werkstoffkunde

Universität Stuttgart

Universität Ulm  
- Abt. Anorganische Chemie I

Universität zu Köln  
- Lehrstuhl für Anorganische Chemie

Universitätsklinikum Würzburg  
- Augenklinik und Poliklinik

Université de Haute-Alsace, Mulhouse-Colmar (F)  
- Département de Photochimie Générale CNRS-UMR 7525

Université de Picardie Jules Verne, Amiens (F)  
- Laboratoire de réactivité et Chimie des Solides LRCS

Université Montpellier (F)

Université Pierre et Marie Curie, Paris (F)

University College of Antwerp, Hogeschool Antwerpen (B)

University of Birmingham

University of Huddersfield (UK)

University of Leeds (UK)  
- Nanomanufacturing Institute

# SCIENTIFIC COOPERATIONS

University of Ljubljana (SLO)

- Faculty of Civil and Geodetic Engineering, Chair for Research in Materials and Structures

University of London, Birkbeck College (UK)

University of Manchester (UK)

University of Patras (GR)

- Department of Civil Engineering, Structural Materials Laboratory

University of Pisa (I)

- Department of Chemistry and Industrial Chemistry

University of Sheffield (UK)

University of Thessaloniki (GR)

University of Twente (NL)

- Department of Civil Engineering

University of Valencia (E)

University of Zagreb (CRO)

- Faculty of Civil Engineering

Warsaw University (PL)

- Laboratory of Electrochemical Power Sources

Westfälische Wilhelms-Universität Münster

- Institut für Anorganische und Analytische Chemie

Yonsei University Seoul (KO)

- Mechanical Engineering

## **mit anderen Forschungseinrichtungen with other research institutions**

Acree AB, Printed Electronics Group and Interconnect and Packaging Group, Norrköping (S)

Akademie der Wissenschaften der Tschechischen Republik, Prag (CZ)

- Institute of Radio Engineering and Electronics
- Institute of Chemical Process Fundamentals

Arbeitsgemeinschaft industrieller Forschungsvereinigungen »Otto von Guericke« e.V., Köln

Bundesanstalt für Materialforschung und -prüfung BAM, Berlin

Center for Documentation of Cultural & Natural Heritage, Giza (ET)

Center for Organic Chemistry, Pardubice (CZ)

Centro de Tecnologías Electroquímicas, San Sebastián (E)

Cercle des Partenaires du Patrimoine, Laboratoire de Recherche des Monuments Historiques, Champs sur Marne (F)

Commissariat à l'énergie atomique CEA, Laboratoire d'Électronique des Technologies de l'Information (Leti), Grenoble (F)

Deutsche Bundesstiftung Umwelt (DBU)

Deutsches Kunststoff-Institut, Darmstadt

Deutsches Zentrum für Luft- und Raumfahrt DLR, Stuttgart und Köln

- Institut für Technische Thermodynamik

# WISSENSCHAFTLICHE KOOPERATIONEN

Dombauamt Erfurt, Glaswerkstatt

Europäische Forschungsgesellschaft Dünne Schichten e.V.,  
Dresden

Europäisches Feuerfestzentrum ECREF, Höhr-Grenzhausen

Flemish Institute for Technological Research (VITO), Mol (B)

Forschungsallianz Kulturerbe (FALKE)

Forschungsgemeinschaft Feuerfest e.V., Bonn

Forschungsgemeinschaft Technik und Glas e.V., Wertheim

Forschungskuratorium Textil e. V., Berlin

Forschungszentrum Jülich  
- Ernst-Ruska-Centrum

Forschungszentrum Karlsruhe GmbH (FZK), Karlsruhe

Glasrestaurierungswerkstatt der Dombauhütte Köln

Gradbeni Institut ZRMK  
- Centre for Indoor Environment, Building Physics and Energy,  
Ljubljana (SLO)

Hüttentechnische Vereinigung der Deutschen Glasindustrie  
HVG, Offenbach

Institut de Chimie de la Matière Condensée de Bordeaux (F)

Institut de Recherche d'HydroQuébec (IREQ), Montreal (CAN)

Institut für Bioprozess- und Analysenmesstechnik e. V.,  
Heiligenstadt

Institut für Diagnostik und Konservierung an Denkmälern in  
Sachsen und Sachsen-Anhalt, Halle/Saale

Institut für Energie- und Umwelttechnik (IUTA), Duisburg

Institut für Fertigteiletechnik und Fertigbau Weimar e.V.

Institut für Klinische Hygiene und Qualitätssicherung e. V.  
(IKHQ), Köthen

Institut für Korrosionsschutz Dresden GmbH, Dresden

Institut für Luft- und Kältetechnik gGmbH, Dresden

Institut für Photonische Technologie e.V., Jena

Institut für Physikalische Hochtechnologie e.V., Jena

Institut polytechnique de Grenoble (INP), Grenoble (F)

Istituto di Scienze dell'atmosfera e del Clima, Consiglio  
Nazionale Delle Ricerche, Rom (I)

Joanneum Research Forschungsgesellschaft mbH, Graz (A)

Jožef Stefan Institute, Ljubljana (SLO)  
- Department of Surface Engineering and Optoelectronics

Laser Labor Göttingen

Max-Planck-Institut für Eisenforschung, Düsseldorf

Max-Planck-Institut für Meteorologie, Hamburg

Max-Planck-Institut für Plasmaphysik, Garching

Max-Planck-Institut für Polymerforschung, 5.nz



# SCIENTIFIC COOPERATIONS

MRB - Research Center for Magnetic Resonance Bavaria e.V.

National Institute of Chemistry, Ljubljana (SLO)

Norwegian Institute for Air Research, Kjeller (N)

Research Center on Nanoscience and Nanotechnology, CIN2:  
CSIC-ICN, Bellaterra-Barcelona (E)

SIMaP (Materials and Processes Science and Engineering  
Laboratory), Martin d Heres Cedex (F)

Staatliche Museen Preußischer Kulturbesitz, Berlin

Swiss Research Centre for Stained Glass and Glass Art,  
Romont (CH)

The Cathedral Studios, The Chapter of Canterbury Cathedral,  
Canterbury (UK)

VTT Technical Research Centre of Finland, Tampere (FIN)

Zentrum für Sonnenenergie- und Wasserstoffforschung, Ulm

Zentrum für Innovationskompetenz »Virtuelle Hoch-  
temperatur-Konservierungsprozesse –Virtuhcon«, an der  
TU Bergakademie Freiberg, Freiberg

## **Ehrungen und Preise Awards**

Amberg-Schwab, S.

Josef-von-Fraunhofer Preis 2011

für die Entwicklung von flexiblen transparenten Barrierefolien  
für Photovoltaik-Anwendungen

(zusammen mit Projektpartner Dr. Klaus Noller, Fraunhofer IVV)

# MITGLIEDSCHAFTEN

## Mitgliedschaften und Mitarbeit in Gremien Activities in associations and committees

Academy of Dental Materials (ADM)

Allianz Bayern Innovativ

- Cluster Chemie
- Cluster Mechatronik & Automation e.V.
- Cluster Medizintechnik
- Cluster Neue Werkstoffe
- Cluster Nanotechnologie

AMA Fachverband für Sensorik e.V.

AGEF Arbeitsgemeinschaft Electrochemischer  
Forschungsinstitutionen e.V.

American Ceramic Society (ACerS)  
- Fellow

Arbeitsgemeinschaft Wirtschaftsnahe  
Forschungseinrichtungen in Baden-Württemberg

AVN – Automation Valley Nordbayern  
Bayern Innovativ GmbH

bayern photonics e.V.  
Kompetenznetz optische Technologien

BMBF NanoExperts Working Group Russland-Deutschland

BioMedTec Franken e.V.

BioMST - Arbeitskreis Mikrosysteme für Biotechnologie und  
Lifesciences e.V.

Bundesanstalt für Materialforschung und -prüfung BAM  
- Arbeitsgruppe Glasig-kristalline Multifunktionswerkstoffe

Ceramic Composites im Carbon Composites e.V.

Cluster INNOB – Innovative Oberflächen

Cluster TEMASYS – Technologie und Management intelligenter  
Systeme

DECHEMA Gesellschaft für chemische Technik und Biotechnologie e.V.

- ConNeCat Kompetenznetzwerk Katalyse
- Fachsektion Nanotechnologie

Deutsche Forschungsgesellschaft für Oberflächenbehandlung  
e. V.

- Fachausschuss Oberflächenbehandlung von Stahl und  
Multisubstraten

Deutsche Gesellschaft für Materialkunde e.V. (DGM)  
- Arbeitskreis Verstärkung keramischer Werkstoffe  
- Fachausschuss Biomaterialien

Deutsche Glastechnische Gesellschaft (DGG)  
- Fachausschuss I

Deutsches Institut für Bautechnik (DIBt)  
- Expertenausschuss Abwassersysteme

Deutsches Institut für Normung (DIN)

- Normenausschuss für
- Volumenmessgeräte
  - UA Volumenmessgeräte mit Hubkolben
  - UA I/ FA I
  - NMP 261 (Chemische Analyse von oxidischen Materialien  
und Rohstoffen)

# ACTIVITIES IN ASSOCIATIONS AND COMMITTEES

Deutsche Keramische Gesellschaft (DKG)

- Arbeitsgruppe Keramografie
- Fachausschuss (FA1) Physikalische und chemische Grundlagen
- Arbeitsgruppe Thermoplastische Formgebung von Technischer Keramik

Deutscher Verband für Materialforschung und -prüfung e. V. (DVM)

- Arbeitsgruppe Zuverlässigkeit adaptiver Systeme

Editorial Board of »Dataset Papers in Optics«, Hindawi Publishing Corporation

Electrochemical Society ECS

EU Ad-hoc Advisory Group on Industrial Nanotechnologies for the NMP Program

Europa Nostra

European Multifunctional Materials Institute EMMI

Fachausschuss Biomaterialien der DGM

Firmenausbildungsverbund e.V.5.n-Tauber (Fabi)

Förderkreis Kloster Bronnbach

Forschungsgemeinschaft Technik und Glas e.V., Bronnbach (FTG)

- Technischer Ausschuss

Forum Elektromobilität

Forum für Medizin Technik und Pharma in Bayern e.V.

Forum Innovation und Technologie Heilbronn Franken

Fraunhofer-Demonstrationszentrum AdvanCer

- Mitglied des Projektleitungsrats

Fraunhofer Allianzen und Netzwerke:

- Adaptronik
- Batterien
- Bau
- Energie
- Hochleistungskeramik
- Nanotechnologie
- Numerische Simulation von Produkten und Prozessen
- Polymere Oberflächen (POLO)
- Optisch-funktionale Oberflächen
- Photokatalyse
- Qualitätsmanagement

Gemeinschaftsausschuss Hochleistungskeramik der Deutschen Keramischen Gesellschaft DKG und der Deutschen Gesellschaft für Materialkunde DGM

- Arbeitsgruppe Keramische Schichten
- Arbeitsgruppe Verstärkung keramischer Werkstoffe
- Arbeitsgruppe Polymerkeramik
- Arbeitsgruppe Ausgangspulver

Gesellschaft Deutscher Chemiker (GDCh)

- Arbeitsgruppe Chemie am Bau
- Fachgruppe Anstrichstoffe und Pigmente
- Fachgruppe Angewandte Elektrochemie

Gesellschaft Mess- und Automatisierungstechnik (GMA)

- Fachausschuss 4.16 Unkonventionelle Aktorik

GfKORR Gesellschaft für Korrosionsschutz e.V.

- Arbeitskreis Korrosionsschutz in der Elektronik und Mikrosystemtechnik

ICOM International Council of Museums

- Committee for Conservation

# MITGLIEDSCHAFTEN

ICOMOS International

Institute for Environmental Simulation (GUS)

International Advisory Board of Journal of Sol-Gel-Science and Technology

International Conference on Coatings on Glass and Plastics (ICCG)

- Programm-Ausschuss

ISGS International Sol-Gel-Society

Journal of Nano Research (TTP Switzerland, ed.)

- Editorial Board

LEADER-Aktionsgruppe Neckar-Odenwald-Tauber

Materials Research Society

- Program Committee Optical Interconnects

Materials Valley e.V. – Kompetenznetzwerk für Materialforschung und Werkstofftechnik

mst-Netzwerk Rhein5.n

- Kompetenznetzwerk Mikrosystemtechnik

Nano and Hybrid Coatings Conference

- Konferenzpräsidium

NanoMat – Netzwerk Nanomaterialien

Nanonetz Bayern e.V.

Photonics West

- Programme Committee Optoelectronic Interconnects and Component Integration

Quadriga – Associated Network on Organic and Large Area Electronics

Technologie-Roadmap LIB 2030

VDMA

- OEA-Plattform (Arbeitsgemeinschaft Organic Electronics Association)

Verein Deutscher Ingenieure (VDI/DIN)

- Kommission Reinhaltung der Luft

Wirtschaftsförderung Heilbronn, Industrie und Handelskammer (IHK)

Würzburger Forschungsverbund Funktionswerkstoffe

# **ACTIVITIES IN ASSOCIATIONS AND COMMITTEES**

# VERANSTALTUNGEN DES FRAUNHOFER ISC

## **Gastreferenten des ISC-Seminars in Würzburg Guest speakers at the Fraunhofer ISC**

20.1.2011

Assist. Prof. Woo Soo Kim

Mechanronic Systems Engineering, School of Engineering  
Science, Simon Fraser University, Vancouver, Kanada  
Nano manufacturing for flexible electronics.

28.7.2011

Dr. Matz Haaks

Universität Bonn und Aero-Laser GmbH Garmisch-Partenkirchen  
Materialforschung mit Positronen: Die Bonner Positronen-  
Mikrosonde.

26.9.2011

Dr. Doris Heinrich

Fakultät für Physik – Biophysics of Cell Dynamics Group at  
the Chair of Soft Condensed Matter and Biophysics,  
Ludwig-Maximilians-Universität München  
From Spatio-Temporal Control of Cell Functions to  
Nano-Medical Applications.

17.10. 2011

Dr. Jens Helbig

Kompetenzzentrum Analytik, Nano- und Materialtechnik  
(KAM), Georg-Simon-Ohm-Hochschule  
Neue Möglichkeiten für die Materialentwicklung in Nordbayern.

2.11.2011

Prof. I-Wie Chen

Department of Materials Science and Engineering, University  
of Pennsylvania, Philadelphia, PA, USA  
Electric Field Induced Microstructure Instability: Ionmigration,  
Electrosintering and Grain Growth.

9.12.2011

Dipl.-Chem A. Dreyer

Universität Bielefeld, Fakultät für Chemie/Anorganische  
Chemie und Strukturchemie, Fakultät für Physik, Centrum für  
Biotechnologie – CeBiTec/Institut für Biophysik und Nano-  
wissenschaften, Fakultät für Physik/AG Dünne Schichten &  
Physik der Nanostrukturen  
Koaleszenz- und Kristallisationsprozesse nanoskopische Metall-  
tropfen zur Kontrolle der Partikelmorphologie am Beispiel von  
Zinn und Cobalt.

## **Gastreferenten »Bronnbacher Gespräche 2011« Guest speakers at the Bronnbach branch**

16.2.2011

Paczkowski, J.

Glasfenster im Erzgebirge

13.4.2011

Lehmann, K.

Die Kunst des Porzellans



# EVENTS AT THE FRAUNHOFER ISC

## Veranstaltungen am Fraunhofer ISC

### Conferences and events at the Fraunhofer ISC

Führung im Rahmen der Würzburger Wirtschaftstage  
»Smart Materials in Aktion«  
Würzburg, 23.2.2011

Feierliche Einweihung des Testzentrums in der Remise  
Bronnbach  
Bronnbach, 16.3.2011

CeSMa-Workshop: Smart Materials für Automobile  
Würzburg, 4.5.2011

Kloster Bronnbach mit allen Sinnen genießen:  
Tag der offenen Tür in der Außenstelle Bronnbach  
Bronnbach, 3.4.2011

3<sup>rd</sup> GLASSAC Conference – Glass Science in Art and  
Conservation  
Bronnbach, 10.-12.5.2011

Feierliche Schlüsselübergabe zu den Räumlichkeiten des IWKS  
Alzenau, 23.5.2011

Clustermeeting »Oberflächen« Nanoinitiative Bayern.  
Würzburg, 25.5.2011

Kinder-Mikroskopiekurs »Lilliputs Welt – eine kleine Reise in  
die Mikroskopie«.  
Bronnbach, 28.5.2011

Feierlicher Empfang anlässlich der Verleihung des  
Fraunhofer-Preises 2011 an Frau Dr. Amberg-Schwab  
Würzburg, 21.6.2011

Tag der Offenen Tür im Fraunhofer ISC  
Würzburg, 4.9.2011

Auftaktveranstaltung für den Start der neuen  
Fraunhofer-Projekgruppe IWKS  
Alzenau, 5.9.2011

Führung im Rahmen der DGG Fachausschusssitzung V  
Glasgeschichte und Glasgestaltung  
Bronnbach, 23.9.2011

Gesundheitstag im Fraunhofer ISC  
Würzburg, 30.9.2011

Gründungsfeier Zentrum für Angewandte Elektrochemie ZfAE  
Würzburg, 7.10.2011

Führung für Deutsche Stiftung Denkmalschutz  
durch die Außenstelle Bronnbach  
Bronnbach, 13.10.2011

Kulturtouristische Netzwerke: Chancen für Regionalentwick-  
lung und weibliches Unternehmertum

Eine Veranstaltung im Rahmen der FrauenWirtschaftsTage  
2011

Bronnbach, 14.10.2011

# MESSEN UND AUSSTELLUNGEN

## Messen und Ausstellungen 2011

### Fairs and exhibitions

Bau2011

München, 17. - 22.1.2011

Photonics West 2011

San Francisco, CA (USA), 25. – 27.1.2011

NanoTec 2011

Tokyo (JP), 16. – 18.2.2011

Symposium Material Innovativ

Fürth, 24.2.2011

Hannover Messe

Hannover, 4. – 8.4.2011

Sensor + Test 2011

Nürnberg, 7. – 9.6.2011

MS Gesundheit Wissenschaft im Dialog

Ausstellung zum »Wissenschaftsjahr 2011 – Forschung für unsere Gesundheit«

19.5. – 29.9.2011

Mechatronics

Karlsruhe, 25. – 26.5.2011

Jahreskongress Zulieferer Innovativ BAIKA 2011

Ingolstadt, 6.7.2011

Adaptronik Kongress

Darmstadt, 7. – 8.9.2011

Composites Europe 2011

Stuttgart, 27. – 29.9.2011

Productronica 2011

München, 15. – 18.11.2011

# FAIRS AND EXHIBITIONS

## Messen 2012

### Fairs and exhibitions 2012

Photonics West

San Francisco, CA (USA), 21. – 26.1. 2012

NanoTech 2012

Tokyo (JP), 15. – 17.2. 2012

Würzburger Wirtschaftstage

Würzburg, 27.2. - 3.3. 2012

Energy Storage

Düsseldorf, 13. – 14.3. 2012

Material Innovativ

Rosenheim, 14.3. 2012

Entwicklerforum Akkutechnologien

Aschaffenburg, 18. – 19.4. 2012

Hannover Messe

Hannover, 23. – 27.4. 2012

MS Wissenschaft im Dialog

Ausstellung zum »Wissenschaftsjahr 2012 – Zukunftsprojekt  
ERDE«

30. Mai – 15. Oktober 2012

IFAT ENTSORGA 2012

München, 7. – 11.5. 2012

Ceramitec 2012

München, 22. – 25.5. 2012

Sensor + Test 2012

Nürnberg, 22. – 24.5. 2012

Wirtschaftsmesse Rothenburg o.d.T.

Rothenburg o.d.T., 15. – 17.6.2012

Industrial Technologies

Aarhus (DK), 19. – 21.6.2012

Verband Deutscher Glasbläser, Fortbildungsseminar

TU Berlin, 14. – 15.9. 2012

Glasstec

Düsseldorf, 23. – 26.10. 2012

denkmal

Leipzig, 22. – 24.11. 2012

# LEHRTÄTIGKEIT

**Julius-Maximilians-Universität Würzburg**  
**Lehrstuhl für Chemische Technologie der Material-**  
**synthese**  
**Lehrstuhlinhaber: Prof. Dr. Gerhard Sextl**

## **Vorlesungen Sommersemester 2011**

Sextl, G., Löbmann, P., Staab, T.  
Materialwissenschaften II (Die großen Werkstoffgruppen)

Helbig, U.  
Von der Biomineralisation zur biologisch-inspirierten Material-  
synthese

Helbig, U., Löbmann, P.  
Chemische und biologisch-inspirierte Nanotechnologie für die  
Materialsynthese

Löbmann, P.  
Sol-Gel-Chemie I: Grundlagen

Raether, F.  
Praktikum zur Technologie sensorischer und aktorischer  
Materialien inklusive Smart Fluids

Staab, T.  
Eigenschaften moderner Werkstoffe: Experimente und  
Simulation

## **Vorlesungen Wintersemester 2011/2012**

Sextl, G., Staab, T.  
Materialwissenschaften I (Struktur, Eigenschaft und Anwen-  
dungen von anorganischen Werkstoffen)

Löbmann, P.  
Sol-Gel-Chemie 2: Schichten und Beschichtungstechnik

## **Übungen und Praktika**

Sextl, G., Löbmann, P., Hilbig, A.  
Übungen zur Vorlesung »Materialwissenschaften II«  
SS 2011

Sextl, G., Kurth, D., Schwarz, G., Staab, T.  
Materialwissenschaftliches Kolloquium  
SS 2011 und WS 2011/2012

Sextl, G., Staab, T.  
Übungen zu Vorlesung Materialwissenschaften I  
(Struktur, Eigenschaft und Anwendungen von anorganischen  
Werkstoffen)  
WS 2011/2012

## **Seminare**

Löbmann, P.  
Seminar zur Vorlesung Sol-Gel-Chemie I: Grundlagen  
SS 2011

Staab, T.  
Seminar Eigenschaften moderner Werkstoffe: Experimente  
und Simulation  
SS 2011

# TEACHING ACTIVITIES

**Universität Bayreuth**  
**Fakultät für Angewandte Naturwissenschaften**  
**Lehrstuhl Keramische Werkstoffe**  
**Lehrstuhlinhaber: Prof. Dr.-Ing. Walter Krenkel**

## **Vorlesungen Sommersemester 2011**

Krenkel, W:  
Hochtemperatur-Leichtbau

Hausherr, J.:  
Hochleistungskeramik (mit Glas und Glaskeramiken)  
Werkstoffmechanik und Werkstoffeigenschaften

Langhof, N:  
Metallinfiltrierte Keramik

Motz, G:  
Keramikfaser-Technologie

## **Vorlesungen Wintersemester 2011/12**

Krenkel, W:  
Einführung in die Materialwissenschaft - Keramik Aufbau  
und Eigenschaften der Keramiken Verbundkeramiken  
Eigenschaften von Verbundwerkstoffen

Motz, G:  
Werkstofftechnologie und Halbzeuge

Hausherr, J:  
Keramik II

# ALLIANZEN UND NETZWERKE

## Das Institut in Netzwerken

Das Fraunhofer ISC ist aktives Mitglied in zahlreichen nationalen und internationalen Forschungsnetzwerken. Ziel der Kooperationen ist es, den interdisziplinären Wissensaustausch mit der Industrie und anderen universitären und außeruniversitären Forschungseinrichtungen zu fördern, die eigene Kompetenz einzubringen und neue Partner zu gewinnen.

Innerhalb der Fraunhofer-Gesellschaft führen Mitarbeiter des Fraunhofer ISC die Allianzen »Nanotechnologie« und »POLO – Polymere Oberflächen«. Auf Geschäftsbereichsebene bestehen zusätzlich eine Reihe weiterer enger Kooperationen mit Fraunhofer-Netzwerken zu den Themen »Adaptronik«, »Hochleistungskeramik«, »Numerische Simulation von Produkten und Prozessen«, »Optisch-funktionale Oberflächen« und »Photokatalyse« sowie mit zahlreichen Universitäten und Forschungsinstituten außerhalb der Fraunhofer-Gesellschaft.

Das Institut ist Mitglied beim »Wilhelm Conrad Röntgen Research Center for Complex Material Systems« (RCCM) an der Universität Würzburg, auf nationaler Ebene im Kompetenznetz für Materialien der Nanotechnologie (NanoMat) und im Kompetenznetzwerk für Materialforschung und Werkstofftechnik Materials Valley e.V. sowie auf europäischer Ebene im »European Multifunctional Materials Institute (EMMI).

Als Materialentwicklungsinstitut gehört das Fraunhofer ISC dem Fraunhofer-Verbund Werkstoffe, Bauteile an. Vorsitzender ist Prof. Dr.-Ing. Holger Hanselka, Leiter des Fraunhofer LBF. Weitere Mitglieder sind die Fraunhofer-Institute EMI, IAP, IBP, ICT, IFAM, IGB, IKTS, ISE, ISI, ITWM, IWM, IZFP und WKI. Das Institut ist außerdem vertreten in dem als Demonstrationszentrum angesiedelten Themenverbund »AdvanCer« (System development with high-performance Ceramics - Weitere Informationen unter [www.advancer.fraunhofer.de](http://www.advancer.fraunhofer.de)).

## Das Fraunhofer ISC in weiteren Allianzen und Netzwerken

### Fraunhofer-Allianz Polymere Oberflächen (POLO)

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### Fraunhofer-Allianz Nanotechnologie

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### Fraunhofer-Allianz Bau

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### Forschungsallianz-Kulturerbe

Ansprechpartner:  
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# ALLIANCES AND NETWORKS

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## **Fraunhofer-Netzwerk »Nachhaltigkeit«**

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## **Cluster der Allianz Bayern Innovativ:**

### **Cluster Chemie**

Sprecher: Prof. Dr. Wolfgang A. Herrmann und  
Prof. Dr. Utz-Hellmuth Felcht  
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felcht@cluster-chemie.de  
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### **Cluster Mechatronik & Automation**

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klaus.feldmann@cluster-ma.de  
www.cluster-ma.de

### **Cluster Medizintechnik**

Sprecher: Prof. Dr. med. Michael Nerlich  
Kontakt: michael.nerlich@medtech-pharma.de  
www.cluster-medizintechnik.de/

## **Cluster Nanotechnologie**

Sprecher: Prof. Dr. Alfred Forchel  
Kontakt: info@nanoinitiative-bayern.de  
www.nanoinitiative-bayern.de

## **Cluster Neue Werkstoffe**

Sprecher: Prof. Dr. Rudolf Stauber und  
Prof. Dr. Robert F. Singer  
cluster-neuewerkstoffe@bayern-innovativ.de  
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