



**ANNUAL REPORT**  
**2013/14**

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VALUE ADDED MATERIALS



**COVER PICTURE SHOWS THE HONEYCOMB-STRUCTURED FILMS DEVELOPED IN THE »INCOM« PROJECT**

***Honeycomb-structured films***

*These novel sustainable composite materials are an interesting alternative to conventional polymer composites in packaging, in automotive, or the aerospace industry. They offer economic and ecological advantages. Read more on page 70.*



**ANNUAL REPORT**

**2013/14**

**KEY TOPIC**

**»VALUE ADDED MATERIALS«**

# PREFACE

## **Dear friends and partners of Fraunhofer ISC, Ladies and Gentlemen,**

Fraunhofer ISC is a research and development partner for small, medium-sized and large companies when it comes to quality assurance and enhanced value added in research and production, but also in improving products. The Institute uses its entire expertise and experience to make sure that its partners and customers are always one step ahead of their competitors.

That is why the **key topic of value added materials** in the annual report 2013/2014 presents a very special part of the vast R&D range of Fraunhofer ISC. These topics were selected in order to inspire innovative ideas for challenging new projects to be realized together with you.

**Last year was under the banner of innovation for Fraunhofer ISC and its facilities.** After the grand opening of the new building Technikum III at Neunerplatz on May 8, 2013, attended by more than 500 guests from all realms of politics, science and economy, the architects and technical experts signed the building over to the principal – Fraunhofer-Gesellschaft – and the Fraunhofer ISC as user on September 24, after some finishing work. This day had been eagerly awaited. The Institute's headquarter at Neunerplatz now features state-of-the-art laboratories for materials analysis, for the development of biological materials and for the upscaling of coating and particle technologies. After setting up a »manufactory« for electrochemical cells, the Center for Applied Electrochemistry now covers the entire process chain for a successful development of electrochemical components. Placing the Technikum III into operation was a significant milestone for the sustainable expansion of all Business Units.

## **Spirit of success and advancement within the Project Group IWKS:**

In March, the groundbreaking ceremony was held for the new technology hall planned by the city of Alzenau; in April, the Fraunhofer Application Center for Resource Efficiency (a cooperation with the Aschaffenburg University of Applied Sciences with the goal of ensuring recyclability as early as in the preliminary development and design phase of products) commenced operations. By October, it was possible to move the first major pieces of equipment for materials recycling into the new hall, leased from the city of Alzenau. Another highlight in November was the start of the German Phosphorus Platform DPP under the auspices of the Bavarian Minister of the Environment, Marcel Huber. The state gave its go-ahead for the further expansion of the Project Group, so it can proceed together with and in Bavaria and Hesse.

## **The Fraunhofer Center for High-Temperature Materials and Design HTL in Bayreuth**

received support and impetus for further expansion on several accounts. The long-term research project ENERTHERM, with the objective of reducing energy consumption and improving sustainability in industrial heating processes, was granted a subsidy by the state of Bavaria. The commencement of the application center »Textile Fiber Ceramics« in cooperation with the Hof University in 2014 facilitates the integration of innovative textile processing technologies into composite ceramics production. Another reason to celebrate was the groundbreaking for and meanwhile the completion of the shell construction of the new building in Bayreuth with an available floor space of approx. 2,500 square meters. The currently high share in industrial sponsors is a confirmation of the successful establishment of the Center in Bayreuth as a partner for the ceramics and supplier industries.



In the past year, the parent institute completed its strategic planning process for the next five years and had the plans audited by a group of external experts in the course of a technology audit in July 2013. The feedback was very positive, both regarding the thematic orientation and expertise as well as the organizational changes, such as the implementation of a sales management in early 2014 with Dr. Victor Trapp in charge. So, Fraunhofer ISC is well prepared to face the challenges ahead.

The gap between past and present of the Institute for Silicate Research was bridged in October 2013 when the commemorative plaque affixed to what today is known as the Fritz Haber Institute of the Max Planck Society in Berlin Dahlem was unveiled. The FHI campus still features the original building in which the Kaiser Wilhelm Institute for Silicate Research was established in 1926. It was the early beginning of today's Institute in Würzburg.

Dr. Ruth Houbertz was honored in recognition of her entrepreneurial spirit and scientific competence. She had been the head of the Optics and Electronics competence unit for a long time before she now founded the start-up »Multiphoton GmbH« together with Dr. Markus Riestler (Maris Tech Con). Fraunhofer ISC wishes her lasting success in the set up of the new company. Multiphoton GmbH already received the European »COWIN Entrepreneurship Award for Outstanding Contribution to Innovation in ICT Hardware and Smart Systems« in 2014. We further congratulate Dr. Houbertz and members of her former ISC team Sönke Steenhusen and Timo Grunemann for the »Green Photonics Award« granted by the International Society for Optics and Photonics SPIE for their developments in two-photon-absorption.

Other ISC employees also received recognition from outside the Institute. For the project »Phosphor recovery from waste water matrices via magnetically separable composite particles«, the project team was awarded the »Future award Re-Water Braunschweig« within the framework of the 4<sup>th</sup> International Symposium Re-Water 2013. Dr. Karl Mandel laid the foundation for this project in his thesis at the Fraunhofer ISC with magnetically switchable, surface-functionalized composite particles. For her thesis »Barrier layers«, Ms. Susanne Koch received the »New Materials Award for Young Academics« of Bayern Innovativ GmbH within the framework of the EU project DIBBIOPACK.

I would like to take this opportunity to thank all employees of Fraunhofer ISC and its facilities, as well as of the Faculty of Chemical Technology of Materials Synthesis for making this success of the Institute possible with their experience, creativity, and expertise. I would also like to thank our partners in industry and research for the trust and confidence they place in us and for their constructive cooperation, and the Fraunhofer-Gesellschaft as well as our institutional supporters and partners for their support of our strategic decisions. Again, I would like to thank the Bavarian Ministry for Economics, Media, Energy and Technology and the Hessian Ministry for Science and Arts for their trust and generous support of our projects.

Würzburg, August 2014

Prof. Dr. Gerhard SEXTL

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





# ORGANIZATION

## Director

### Fraunhofer Institute for Silicate Research ISC

Prof. Dr. Gerhard Sextl

☎ +49 931 4100-101

gerhard.sextl@isc.fraunhofer.de



---

## ISC International

Dr. Michael Popall

☎ +49 931 4100-522

---

## Fraunhofer Attract Group »3DNanoCell«

Prof. Dr. Doris Heinrich | ☎ +49 931 31-81862

---

## Research and Development

Dr. Rolf Ostertag

☎ +49 931 4100-901

### COMPETENCY CLUSTER

#### Materials Chemistry

Dr. Thomas Hofmann | ☎ +49 931 4100-350

#### Application Technology

Dr. Gerhard Domann | ☎ +49 931 4100-551

#### Services

Dr. Jürgen Meinhardt | ☎ +49 931 4100-202

#### Center Smart Materials CeSMA

Dieter Sporn | ☎ +49 931 4100-400

#### Center for Applied Electrochemistry

Henning Lorrmann | ☎ +49 931 4100-519



---

**Sales**

Dr. Victor Trapp

☎ +49 931 4100-370

**Energy**

Dr. Victor Trapp | ☎ +49 931 4100-370

**Health**

Dr. Jörn Probst | ☎ +49 931 4100-300

**Environment**

Dr. Gerhard Schottner | ☎ +49 931 4100-627

**Materials Chemistry and Patents**

Dr. Karl-Heinz Haas | ☎ +49 931 4100-500

---

**Fraunhofer Project Group Materials Recycling and Resource Strategies IWKS | Alzenau and Hanau**

Prof. Dr. Rudolf Stauber

☎ + 49 6023 32039-801

---

**Fraunhofer Center for High Temperature Materials and Design HTL | Bayreuth**

Dr. Friedrich Raether

☎ +49 921 786931-60

---

**Marketing and Communications**

Marie-Luise Righi | ☎ +49 931 4100-150

---

**Administration**

Axel Kuhn | ☎ +49 931 4100-102

---

**Technical Services | Construction**

Michael Martin | ☎ +49 931 4100-111

# ADVISORY BOARD 2014

**DIPL.-ING. PETER. E. ALBRECHT**

Boston Scientific Technologie Zentrum GmbH,  
Munich

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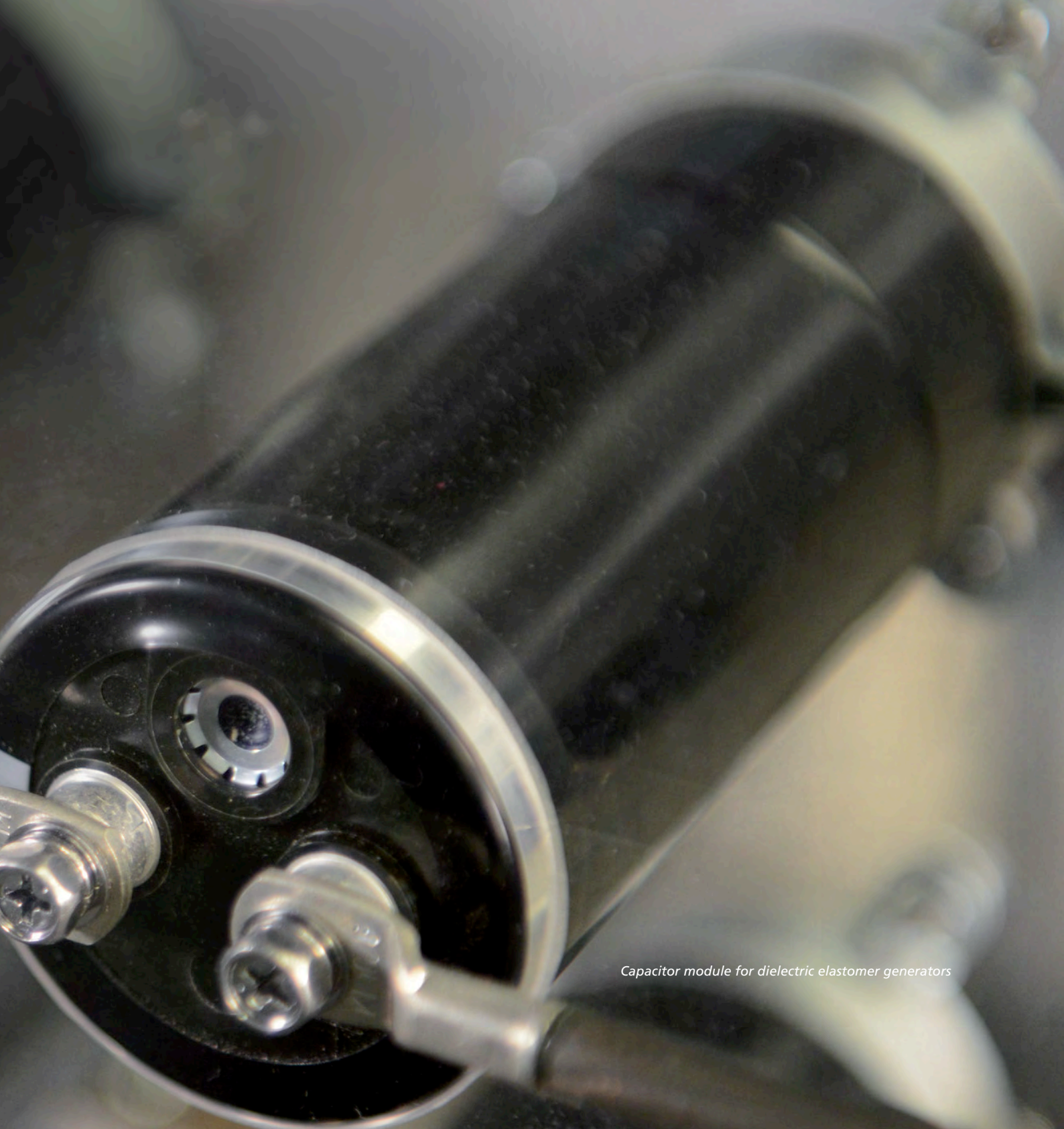
Max Planck Institute for Solid State Research,  
Stuttgart

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Wuppertal

**PROF. DR. STEFAN LEIBLE**

President, University of Bayreuth



*Capacitor module for dielectric elastomer generators*

# KEY FIGURES

## Facts and Figures

The development of the Fraunhofer ISC was marked by the successful support of the Center HTL in Bayreuth and the Project Group IWKS at the Alzenau and Hanau locations. The parent institute concentrated on further development towards customer orientation and marketing competence. Against the back-drop of this challenging situation, Fraunhofer ISC as a whole achieved a balanced result.

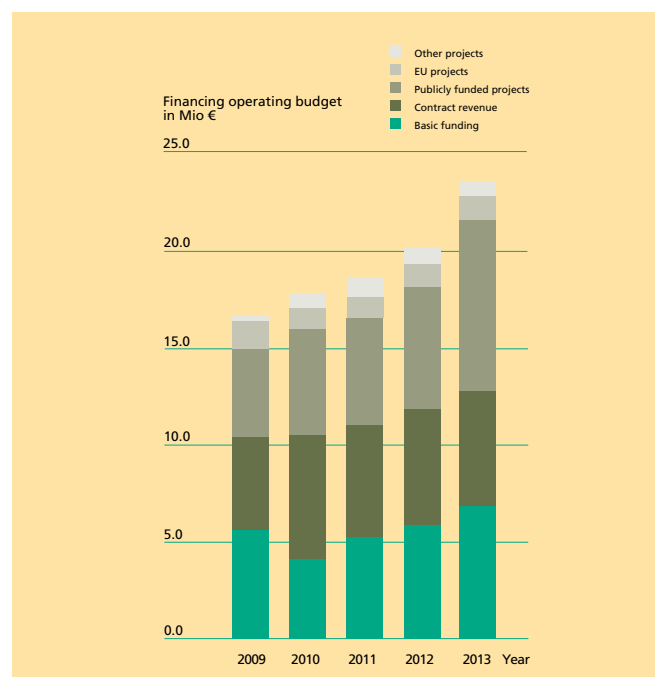
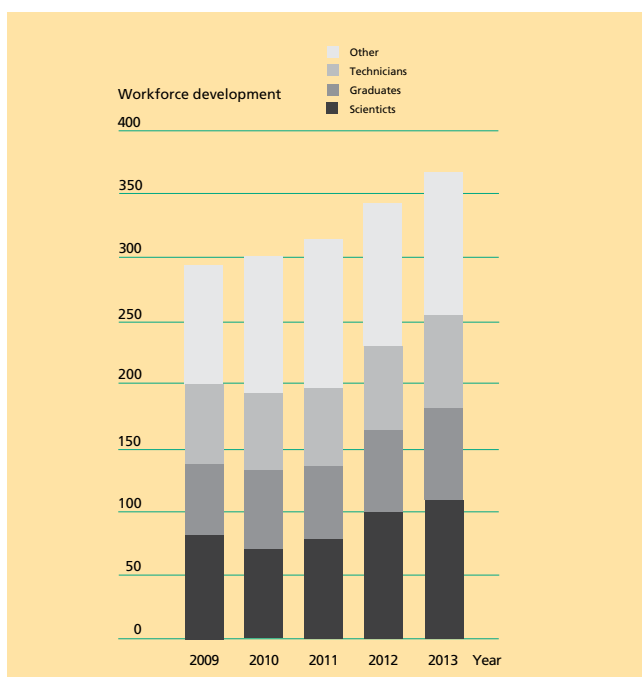
## Growth in the workforce

The growth in the parent institute including branches, as well as the successful expansion of the Center HTL and the Project Group IWKS, gave the Fraunhofer ISC reason for a growth in personnel by 25 employees. Approximately 61 % from altogether 368 employees are permanent staff, from which 61 % have permanent contracts. The percentage of perma-

nently employed scientists is 44 %. Despite a slight surplus in scientists, altogether, Fraunhofer ISC has a balanced personnel structure of scientists, graduates and technicians. Furthermore, the Fraunhofer ISC offered several students internships and the possibility to do their diploma theses and dissertations. With this, Fraunhofer ISC made an important contribution to material sciences tertiary education.

## Operating budget

In 2013, the operating budget increased by 17 % (3.4 million euros) to a total of 23.7 million euros. The development of personnel expenditure (14.5 million euros / + 14 %) as well as non-personnel expenditure (7.8 million euros / + 17 %) materially reflects the successful setup at the Bayreuth, Alzenau and Hanau sites. The internal cost allocation is 1.4 million euros. The Fraunhofer ISC is funded through 29 % (6.8 million euros) institutional funding of the Fraunhofer-Gesellschaft, the

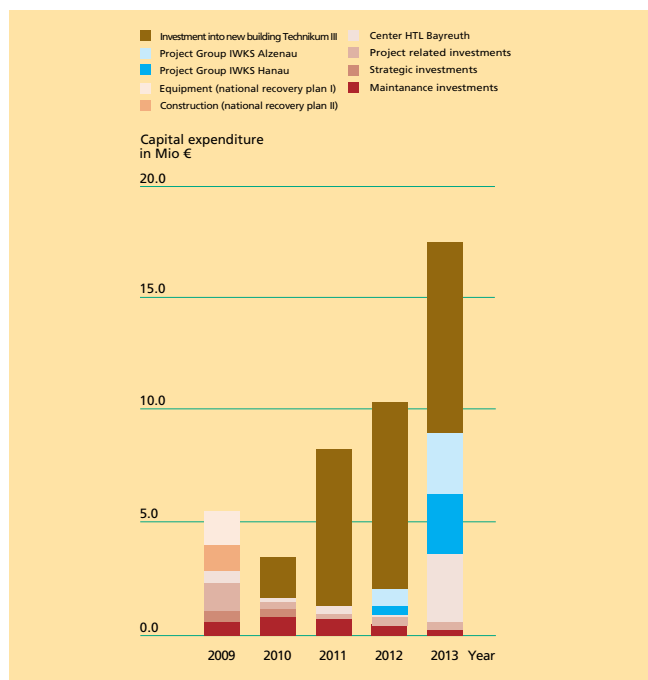
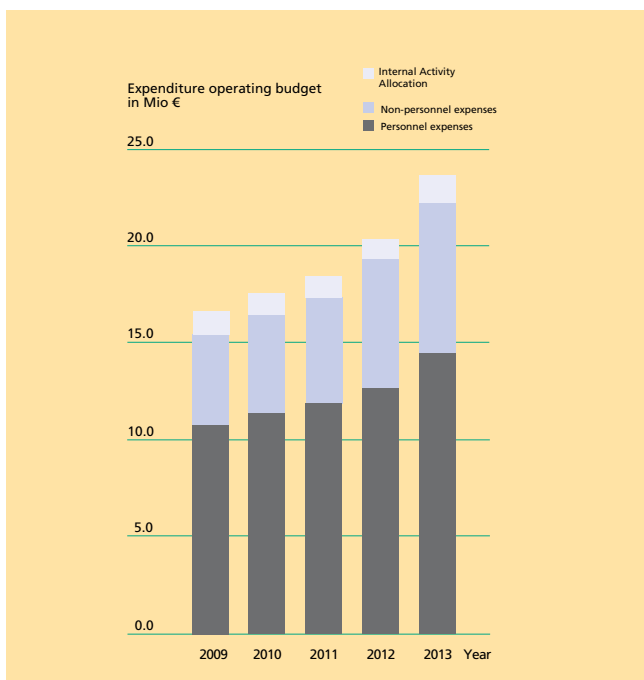


percentage of contract research is 71 % (16.7 million euros). The amount of public income is 8.7 million euros and of EU projects 1.3 million euros. Income from industry and economy is 6.0 million euros, other income is 0.7 million euros. The Fraunhofer ISC successfully ended the year 2013 with a balanced annual result, using 70 thousand euros from previous year's profits. In the financial year 2014, the ISC expects further growth due to the expansion of the Center HTL and Project Group IWKS. The parent institute aims at enhancing marketing activities in order to increase income from industry.

### Capital expenditure

In 2013, the Fraunhofer ISC invested more than 17 million euros. More than half (9.4 million euros) were invested in direct construction work. In addition to the new building in Würzburg, which has already been inaugurated, the construction of a new building started for the Center HTL

in Bayreuth. In addition to construction funds, 1.8 million euros were invested in equipment for the Würzburg and Bayreuth locations. A total volume of 5.4 million euros (50 % each for Hanau and Alzenau) was available for initial equipment for the Project Group IWKS. Some of the equipment is located in leased rooms and will remain there until the construction work is completed. Due to the federal, state and EU funding as well as funding from the states of Bavaria and Hesse (Hanau location) of all locations, we were not only able to prove ourselves in scientific competition with state-of-the-art technology, but also to expand our research to new fields. Another million was financed from projects in Bayreuth (0.2 million euros) and in Würzburg (0.4 million euros) and from basic funding (0.4 million euros) for new technologies, operational and office equipment and replacement investments.







*The new laboratory building at the Würzburg site –  
on the eve of the opening ceremony*



# REVIEW





# REVIEW

## INAUGURATION OF »TECHNIKUM III«

After some three years of construction, the new »Technikum III«, designed by the world-renowned architecture firm from London Zaha Hadid, was committed to its purpose as a laboratory and pilot plant building on May 8, 2013. About 550 guests from all realms of economy, politics and science came to celebrate the event, including a festive colloquium and opening ceremony. Among the guests were Martin Zeil, then Bavarian Minister of Economic Affairs, Georg Rosenthal, then Mayor of the City of Würzburg, and Barbara Stamm, President of the Bavarian Parliament. Also, Prof. Alfred Gossner from the Management Board of Fraunhofer-Gesellschaft and Patrik Schuhmacher, one of the two leading minds of the architecture firm in charge, Zaha Hadid Architects, London, attended the festivities.

In his address, Georg Rosenthal described the »Technikum III« as an urbanistic eye catcher. »The Fraunhofer ISC does not only provide us with excellent scientific work, giving the Institute worldwide recognition, but also with an exquisite shell.« Martin Zeil was impressed: »Together, we are opening up spaces for creative minds, scientists and members of Fraunhofer institutes, who will bring us the innovations we need. I wish you all the best of success in the new facilities.«

Scientific work, like the development of new materials for regenerative medicine or for new battery or other energy storage components, can be taken to the next level with the elaborate technical equipment which will be hosted by the building, spanning over 2500 square meters. Special laboratories with near-industry process standards were established especially for the efficient development of materials in the field of regenerative medicine and diagnostics. They are guided by the requirements of the so-called good manufacturing practice (GMP) – internationally standardized regulations for quality assurance in the manufacture of pharmaceuticals, medical devices, food and cosmetics.

Another novelty: shielded rooms with structures protecting highly sensitive measuring instruments against vibrations and electromagnetic radiation.

The complex architecture includes a rather uncommon façade made of curved glass. In some glass elements, a novel sensor technology for glass breakage was integrated – Fraunhofer ISC's own development, which is used in long-term tests this way. The goal is to implement an early warning system for modern glass façades, which also detects cracks in locations difficult to monitor or access, at an early stage before serious damage occurs.

Fraunhofer ISC also fulfills its own high standards when it comes to energy efficiency. Solar technology is used to heat and cold extraction. Photo-voltaic modules integrated in the façade supply electricity for two electric car charging points in front of the building. The indoor climate is supported by a structural temperature control and the motion-dependent light control is based on daylight sensors.

In September 2013, the TK III was officially handed over to the Fraunhofer-Gesellschaft after the last of the construction measures were completed. Jan Hübener, architect with Zaha Hadid Architect London, Tobias Micke, landscape architect with ST raum, Christian Horns and Rolf Weber representing the technical project management of the headquarters of the Fraunhofer-Gesellschaft, Karl-Heinz Albert, one of the managing directors of the engineering firm REA in Würzburg, Ingeborg Borst with the public construction authority in Würzburg, representing the construction supervision authority, and, representing Fraunhofer ISC, its director Prof. Dr. Gerhard Sextl and head of Technical Services Michael Martin all participated in the celebration. Since then, the laboratories have gradually been placed into operation, many employees moved in and the scientific work in the pilot plant building is now in progress. The construction was financed with federal and Bavarian state funds and the EU ERDF.









*International Award Winners:*

*SPIE Green Photonics Award for Ruth Houbertz and Sönke Steenhusen (to the right)*



### **Green Photonics Award 2013**

Dr. Ruth Houbertz and her team developed an efficient method of two-photon absorption for the production of waveguides. Ruth Houbertz, Sönke Steenhusen and Timo Gruneman received the international »Green Photonics Award« in the field of optimal communication for this technology at the SPIE PHOTONICS West conference in San Francisco in February 2013. The »Green Photonics Award 2013« was one of four awards selected from 55 contributions in energy-efficient and resource-efficient photonics.

### **New Technikum hall for Fraunhofer Project Group IWKS in Alzenau**

Within only six months, the new Technikum hall at the Alzenau location of the Fraunhofer Project Group IWKS was completed. The official ground breaking for this construction project had taken place at the beginning of March. As early as September 2013, the hall was completed. A few days later, first equipment was moved to the new building. The hall is destined to house equipment for the treatment of special secondary materials as well as for the technical upgrade of recycling technologies. In October already, the scientists were able to take up their work in the new facilities. 80 square meters are available for the chemical laboratories, and 40 square meters are reserved for sample preparation rooms. The city of Alzenau was the building contractor.

### **Workshop »Recycling of reusable materials«**

On March 14, 2013, the Fraunhofer Project Group IWKS, the cluster »New Materials«, the association Materials Valley e.V. and the Heraeus company in Hanau came together to organize a workshop on the recycling of reusable materials with

the goal of forming a communication platform and network on this topic. Guests from both industry and academia met to gather information on the status quo and the future development in recycling, resource efficiency and design for recycling and to discuss new trends. Among others, Dr. Carsten Gellermann, head of the Business Unit industrial slags, sludges and landfill of the Fraunhofer Project Group IWKS, Dr. Jan Schlapp with Heraeus Precious Metals GmbH & Co. KG in Hanau, Günter Kirchner with the German Association of the Aluminium Recycling Industry (VAR) in Düsseldorf and Detlef Cohrs with the Association of German Steel Recycling Industries and Disposal Companies (BDSV) in Düsseldorf provided valuable and interesting insights in this topic.

### **CeSMA Workshop »Smart Materials in Adaptronics«**

The 2013 workshop of the Center Smart Materials CeSMA on April 12 focused on the progress in the development, general fields of application and overall potential of smart materials in adaptronics. Experts from all realms of research and industry reported on adaptive solutions for smart systems and applications of piezoceramic materials.

Guest speakers included Thomas Heller representing the Mechatronics & Automation Cluster, Marcus Rauch representing the Cluster New Materials, Prof. Dr. Klaus Schilling with the Zentrum für Telematik (telematics center) in Würzburg, Dipl. Phys. Eberhard Henning with PI-Ceramic (wearing leather trousers) and Dr. Herbert Friedmann with Wölfel Beratende Ingenieure (consulting engineers) in Höchberg. The growing popularity of the series of workshops organized by the CeSMA reconfirms the steady interest of industry in smart materials.

# REVIEW

## **Notice of approval for the Fraunhofer Application Center for Resource Efficiency in Aschaffenburg**

On April 26, 2013, Martin Zeil, Bavarian Minister of Economic Affairs at the time, came to the premises of the Fraunhofer Project Group IWKS in Alzenau to personally hand over the notice of approval for the new Fraunhofer Application Center. It establishes the cooperation between the Fraunhofer ISC, the Fraunhofer Project Group IWKS and the University of Aschaffenburg. The Fraunhofer Application Center for Resource Efficiency focuses on three work categories: separation and screening technologies for electrical/electronic materials, laser technologies for resource-efficient assembly and process as well as product design for recycling of electronic modules, including life cycle assessment technologies.

## **HTL project »EnerTherm« receives 9.5 million euros**

On July 13, 2013, Martin Zeil, then Bavarian Minister of Economic Affairs, officially handed over the notice of approval for the project »EnerTHERM« to the Fraunhofer Center HTL in Bayreuth. Project goal is a drastic reduction in energy consumption and CO<sub>2</sub> emissions during the high temperature treatment of solid materials like ceramics or metal. In his address, Martin Zeil emphasized that with the Fraunhofer Center HTL, a competent team of researchers and cooperation partners is now available to the traditionally well-established ceramics industry in Upper and Middle Franconia and the Upper Palatinate. With this pioneering development, the HTL will become the leading contact point for industry when it comes to heat treatment processes. The mayor of the city of Bayreuth, Brigitte Merk-Erbe, the president of the International Chamber of Commerce Bayreuth, Heribert Trunk, the president of the University of Bayreuth, Prof. Dr. Stefan Leible and the chancellor of the university, Dr. Markus Zanner, as well as Dr. Lorenz Kaiser from the Fraunhofer-Gesellschaft attended the ceremony together with other guests from all realms of industry, research and politics.

## **Young people gather information on career opportunities with Fraunhofer ISC**

Together with another 98 companies and institutions, Fraunhofer ISC took part in the career information day in the s.Oliver Arena in Würzburg on June 15, 2013. The Fraunhofer ISC' HR department and selected employees informed the interested youths on career opportunities in research and development, especially as offered by the Fraunhofer ISC. The career information day specifically targets high school graduates who would like to get some information on training and apprenticeship positions or university studies. In addition to personal meetings with the exhibitors, the students were also offered a job application file check, interview practice and free photographs for applications.

## **Strategy audit**

In the course of continuous strategic planning, Fraunhofer ISC developed a new medium-term plan for the next five years in 2013. On July 8 and 9, 2013, the Institute underwent an evaluation by a group of experts made up of industry representatives and invited by the board of management of the Fraunhofer-Gesellschaft. The experts confirmed the excellency of the current structures in the research areas of the ISC and the organizational and scientific-technical courses of action contained in the strategy plan. They offered valuable advice for the implementation of the plans and further fine-tuning with both critical and positive feedback.

## **Wertheim »Glass Days«**

Fraunhofer ISC presented developments and services related to its core competency, glass, at the 5<sup>th</sup> »Wertheimer Glastage«, a glass convention organized by the Forschungsgemeinschaft für technisches Glas (FtG) (research association technical glass) on September 24 and 25, 2013 at the Bronnbach monastery.



Notice of approval: 9.5 million for the project »EnerTHERM«

Prof. Dr. Gerhard Sextl, Director of Fraunhofer ISC, gave a speech on the »Security in raw materials supply – resources – use instead of consumption«. Fraunhofer ISC presented product examples to visitors and guests, such as dental glass ceramics, wellness glass and decorative glass and informed about its research work on glass coatings, glass ceramics and crystalizing glass solder, special glass, special glass manufacturing, glass process technology, production of pipes, rods, fibers and powders as well as methods of glass inspection and analysis.

### Visits by delegations

On July 22, 2013, representatives of the Korea University and of the Korean World-Class Materials Program (WPM), the vice president of the Korea Electronics and Telecommunication Institute KEIT and renowned Korean scientists and representatives of 8 major companies in Korea visited the Fraunhofer ISC. The discussions focused on topics related to materials development on a sol-gel basis for microelectronics and optics.

Two delegations from Hong Kong practically bumped into each other at the Fraunhofer ISC in fall of 2013. On October 8, a delegation with 15 members of the Hong Kong Science and Technology Park arrived in Würzburg and promoted a closer cooperation between German and Korean materials research. On October 28, eight members of the Hong Kong Productivity Council with their Director Agnes Mak and representatives of other R&D facilities visited the Fraunhofer ISC. On this occasion, a Memorandum of Understanding was signed by Fraunhofer-Gesellschaft and the Hong Kong Productivity Council.

The employees of the ISC perceived it as a special honor to welcome Prof. Hiro Ohno from Tokyo University of Agriculture and Technology, the worldwide expert in the field of ionic liquids, at the Institute for a lecture on January 24, 2013.

### Spin-Off: Multiphoton Optics GmbH

The Multiphoton Optics GmbH was established in September 2013 as a spin-off of the Fraunhofer ISC. The company offers a new process in information and communication technology: In order to be able to handle the growing influx of bits and bytes, computers need more and more processing power – but this also increases their energy consumption. Optical data transmission is deemed to be a key technology in order to transmit data a lot faster in future, but with only a fraction of the energy needed today. However, the production of optical waveguides hitherto comprises 20 process steps and so requires a lot of materials, time and energy – which makes it unsuitable for industrial production. The process developed by Multiphoton Optics, however, is considerably more efficient and resource-conserving. The process is based on a development made by managing director Dr. Ruth Houbertz. The new process renders about 70 percent of the process steps redundant and thus drastically reduces energy and materials cost. In March 2014, no more than half a year after the spin-off, the founders of the company, Dr. Ruth Houbertz and Dr. Markus Riester, received the COWIN Entrepreneurship Award for their outstanding contribution to innovation in ICT Hardware and Smart Systems. What's more, the award-winning process can be easily integrated into standard processes for electronics production. Optoelectronic components, that can be produced in mass production, could optimize many communication technology products and provide financially very attractive solutions.

### Start of the »PEDEIEc project«

With 12 electric bicycles given to Fraunhofer ISC's employees, the first known field test of battery life and performance commenced in October 2013. During the next two years, the specially equipped electric bicycles will be used for commuter traffic. The routes, battery load and the condition of the battery cell will be subjected to a thorough analysis. The goal



Start of the PEDEIEC Project



Founding ceremony of the German Phosphorous Platform in Berlin in the presence of Bavarian's State Minister for the Environment and Consumer Protection, Dr. Marcel Huber (5<sup>th</sup> from left)

of this research project supported by the Bavarian Ministry of Economic Affairs is to create a well-funded database to improve batteries for electromobility. The field test is a joint project of the Fraunhofer ISC, the bicycle manufacturer Winora Group based in Schweinfurt, the system supplier for rechargeable battery packs BMZ GmbH based in Karlstein, the Technologietransferzentrum Elektromobilität (TTZ-EMO) (technology transfer center electromobility) University of Applied Sciences Würzburg-Schweinfurt and the model city electromobility Bad Neustadt.

**Back to the roots – commemorative plaque on the original building of the Kaiser Wilhelm Institute for Silicate Research**

The Institute for Silicate Research looks back upon a long history as an institute for research and development that started at the beginning of 1926 in Berlin-Dahlem, on the campus of the then existing Kaiser Wilhelm Society, within the Kaiser-Wilhelm-Institute for fiber chemistry. During a festive colloquium on October 29, 2013, a bronze commemorative plaque was affixed to the building still standing today, now part of the Fritz Faber Institute of the Max Planck Society, referring to the beginnings of what today is known as the Fraunhofer Institute for Silicate Research. Guest of honor of the event was the Nobel prize laureate Prof. Gerhard Ertl.

**Joining the »Alliance Family and Work«**

The topic of compatibility of family and work is taking a quite important and growing role when choosing an employer or a work location. The Fraunhofer ISC also attaches great value to the compatibility of family and work. That is why the Institute joined the »Alliance Family and Work in the Würzburg Region« on November 28, 2013.

This way, the Institute enhances its commitment to create the best possible pre-conditions for a balanced relation between work and family requirements. In the course of the annual »hands-on days« of the Alliance, Anette Rebohle-Mandel, Head of the HR department, accepted the membership certificate. The Alliance founded in July 2006 offers to its members information and consultation on the topic »Family-conscious HR policy«, support and consultation on the establishment of family-friendly structures and shows best practice examples.

**Creation of the German Phosphorus Platform DPP**

Under the auspices of the Minister of the Environment, representing the Free State of Bavaria at the federal government in Berlin, the German Phosphorus Platform (DPP) was launched on November 15, 2013. The goal of the platform established under the same roof with the Fraunhofer Project Group IWKS in Alzenau is to achieve a more responsible use of the element phosphorus, which is a vital and at the same time critical element. Phosphorus can be found in the carrier molecule of the genetic information of all living things and plays a central role in the energy metabolism of biological cells. Prof. Stefan Gäth, head of the Business Unit Recycling and Reusable Materials Cycles of the Fraunhofer Project Group IWKS, also heads the DDP. The President of the European Sustainable Phosphorus Platform, Arnoud Passenier, personally took part in the founding ceremony of the new platform. The Bavarian State Minister for the Environment and Consumer Protection, Dr. Marcel Huber, described the new phosphorus platform to be a milestone in the protection of natural resources.





Young researchers at the first Fraunhofer ISC Talent School



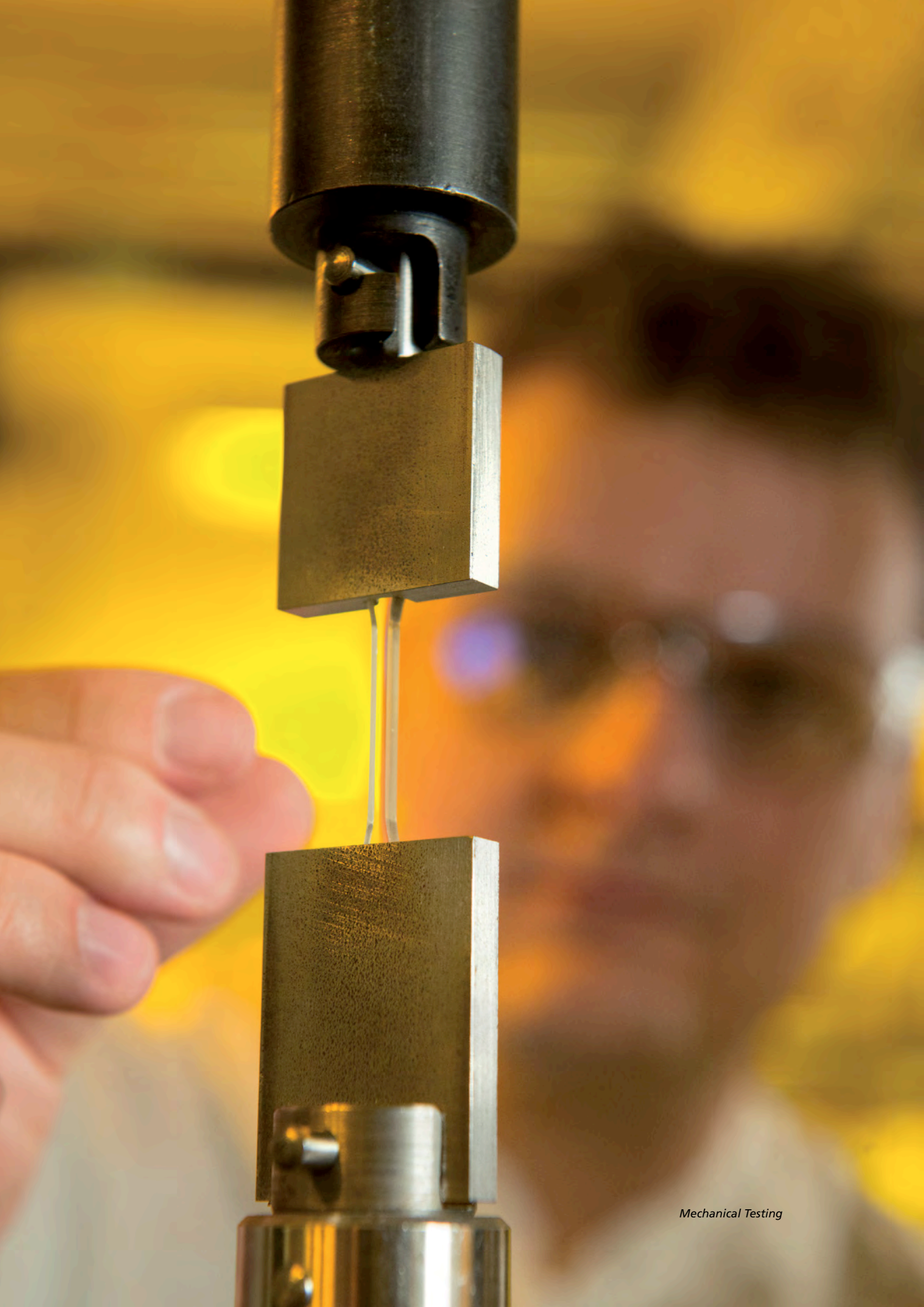
They came to figuratively lay the foundation of the new building for the Center HTL in Bayreuth: Dr. Friedrich Raether, Prof. Dr. Johannes Kister, Brigitte Merk-Erbe, Franz-Josef Pschierer, Dr. Lorenz Kaiser and Prof. Dr. Gerhard Sextl (from left)

### Promoting the next generation of scientists and engineers

The enthusiasm for physics and chemistry and a desire to experience and discover science at close range was what led 36 students to the Bronnbach monastery in November 2013. The young people aged 14 to 18 years used the long All Hallows weekend in order to research intriguing questions of our time together with scientists from the Fraunhofer ISC. Glow-in-the-dark radishes, gold and copper in mobile phones, a battery made of pencils – everything was possible at the first Fraunhofer ISC Talent School. And on Girls' Day in March 2014, 28 girls got a close-up look at how interesting science can be. They formed small groups in workshops and found out how a computer looks on the inside, made alginate capsules and looked at butterfly wings under the Institute's scanning electron microscope. In the course of the »Career Navigator«, an initiative organized by the Institute in February, around 30 interested students from near and far got information on training opportunities and co-op programs at the Fraunhofer ISC. The Career Navigator is an event within the framework of the Würzburger Wirtschaftstage (Würzburg economic forum).

### Laying of the first stone for the Center HTL Bayreuth

The first stone for the new building of the Fraunhofer Center for High-Temperature Materials and Design on the technology hill in Bayreuth's part of town Wolfsbach was laid on December 19, 2013. Under-secretary Franz Josef Pschierer came to present best wishes from the Bavarian Ministry of Economic Affairs and Media, Energy and Technology. »By expanding the Fraunhofer Center HTL, we offer long-term support to applied research in Upper Franconia. The Fraunhofer HTL is a valuable partner for innovative research and development projects for the companies in the region. Thus, the HTL helps secure and enhance the competitiveness of our industrial enterprises. Therefore, the Upper Franconian industry will continue to be the driver of growth and job creation in the future as it is today,« Pschierer said. Bayreuth's mayor Brigitte Merk-Erbe, Director of the Fraunhofer ISC Prof. Dr. Gerhard Sextl, and the Director of the Center HTL Dr. Friedrich Raether and the architect charged with the planning, Prof. Johannes Kister, all were present to celebrate together. The new building will be dedicated to the research into innovative processes to reduce energy consumption of high-temperature processes.



**PROFILE**

# PROFILE

## **MATERIALS FOR SUSTAINABLY MANUFACTURED PRODUCTS**

Research has a clear task: The global challenges of the 21<sup>st</sup> century, such as climate change, demographic development, widespread diseases, securing world food affairs or the supply of fossil raw materials and energy can only be mastered with novel solutions and technologies. The apparent paradigm shift in the development of new and the improvement of existing products, but also the responsible use of raw materials makes economic, ecologic and social aspects more and more important for consumers, manufacturers and developers. Manufacturers from all types of industrial branches, from energy suppliers over the chemical industry to the automotive, electric or food industry, are forced to react. That way, innovation clearly generates a tangible added value. Intelligent, highly efficient, resource-conserving material and technology solutions do pay off.

The Fraunhofer Institute for Silicate Research ISC is a reliable research partner for the industry. For many decades, it has addressed new materials and efficient processes for high added value and sustainability of products. Well-established materials, their manufacturing and processing procedures are enhanced in terms of reliability, functionality, cost efficiency and sustainability up to the production-gear design of process technologies. To Fraunhofer ISC, eco-friendliness and sustainability are criteria at least as important as recyclability or intelligent re-use, very much in accordance with the maxim »intelligent use of materials, low energy consumption«. More than 300 employees work closely with small or medium-sized companies and with large industry players to find innovative and sustainable solutions to these challenges.

## **Networked with industry and research around the world**

The Fraunhofer ISC attaches great importance to broad national and international networking. That also includes active participation in the dialog that exists between the scientific and industrial communities on a variety of platforms. Under the management of Dr. Michael Popall, the »ISC International« has significantly intensified the Institute's international contacts, in particular in Asia. Dr. Johanna Leibner supports the Institute's European activities from the Fraunhofer office in Brussels.

## **Highly modernized laboratories facilitate promising developments**

The new pilot-plant building TK III, that commenced operations in May 2013 at its main location in Würzburg, provides a near-industry research environment for the fields of battery development, continuous and large-scale coating technologies, and biomedical materials. Pilot plant, cleanroom facilities and GMP-oriented standards help not only to offer customers a single source for advanced development of materials and processes in these fields, but also to adapt existing production processes for the customized implementation. State-of-the-art laboratory facilities, standalone work spaces for new electron microscopy and preparation techniques make sure that Fraunhofer ISC's Center for Applied Analytics is perfectly equipped to solve even more demanding problems relevant to the areas of materials analysis, damage analysis and quality assurance.





*One of the new laboratories*

# PROFILE

## Three large superordinate research fields characterize the Fraunhofer ISC

The *Business Unit Environment* faces challenges emerging from the finite nature of material resources supply. Unconventional approaches for material and process solutions make the efficient use of resources possible (material efficiency) and reclaim reusable materials within a closed material loop (secondary materials). Since 2011, the Fraunhofer Project Group IWKS in Alzenau and Hanau has been a new partner for industrial players in this field. In close cooperation with companies, the Project Group IWKS develops recycling technologies, substitute materials, and strategies for securing supplies of raw materials. The research framework in this highly innovative field of development is expanded by the involvement of the Aschaffenburg University of Applied Sciences, namely by establishing the joint Fraunhofer Application Center for Resource Efficiency AWZ at the Aschaffenburg University of Applied Sciences.

Another contribution to environmental protection is the development and optimization of CO<sub>2</sub>-neutral building materials, biopolymers, mesoporous systems, catalytic active coatings and encapsulation technologies. The use of application-specific functional coatings helps preserve resources and adds value to the products of our cooperation partners.

The *Business Unit Health* focuses on regenerative medicine, dental materials and diagnostics. The materials developed within these areas can often be transferred to other areas, including applications involving high-tech medical devices, biophotonics and pharmaceutical packaging, as interdisciplinary technologies are employed which have the potential to be used in nearly every area of health research.

The Business Unit expanded its portfolio in materials development with the additional biomedical and GMP-oriented laboratories in the new pilot plant building. The research aims at making a contribution to affordable and personalized

medicine. The establishment of a Fraunhofer Attract Group to research 3D structures for use in tissue engineering, accompanied by close collaboration with other Fraunhofer Institutes and university centers, represents another cornerstone in this respect.

The basis for the *Business Unit Energy* is the Center for Applied Electrochemistry. Here, materials and components are researched for electrochemical energy storage in electro-mobility and also for stationary energy storage. In addition to efficient and safe energy storage opportunities, the focus is on sustainable procedures of energy conversion when using renewable sources and new, intelligent heat insulation systems.

The work of the Center Smart Materials CeSMA covers all Business Units. CeSMA develops customized »smart« materials and components based on the use of electronically and magnetically switchable material properties. Current research work refers to highly-elastic dielectric elastomer generators (DEGs) for low-emission energy conversion, elastomer sensors and highly sensitive piezoelectronic thin-film sensors for condition monitoring as well as to magnetorheological fluids and elastomers as controllable haptic components.

The Fraunhofer Center for High Temperature Materials and Design HTL based in Bayreuth is dedicated to improving the energy efficiency of high-temperature processes in industry with materials resistant to high temperatures and components and systems for high-temperature applications.

Ceramic composites, fibers and coatings are developed as materials resistant to high temperatures. The Center's expertise includes the chemical synthesis of the precursors, up-scaling to pilot scale production and computer-based material and component design. In fall 2013, the foundation of a large laboratory building, including office and laboratory space, was laid in Bayreuth. The expected completion date is in 2015.





**The Fraunhofer ISC conducts research at five locations:**

**Würzburg:** Head location

**Bronnbach:** Center of Device Development CeDeD  
International Convention Center for Cultural Heritage Preservation IZKK

**Bayreuth:** Fraunhofer Center for High Temperature Materials and Design HTL

**Alzenau and Hanau-Wolfgang:** Fraunhofer Project Group for Materials Recycling and Resource Strategies IWKS

**1**

*Fraunhofer Institute for  
Silicate Research ISC  
Neunerplatz 2  
97082 Würzburg, Germany*

**3**

*Fraunhofer Center for  
High Temperature Materials and Design HTL  
Gottlieb-Keim-Str. 60  
95448 Bayreuth, Germany*

**2**

*Fraunhofer Institute for  
Silicate Research ISC  
Außenstelle Bronnbach  
Bronnbach 28  
97877 Wertheim-Bronnbach, Germany*

**4**

*Fraunhofer Project Group for  
Materials Recycling and Resource Strategies IWKS  
Brentanostraße 2  
63755 Alzenau, Germany*

**5**

*Industriepark Hanau-Wolfgang  
63357 Hanau, Germany*



# MATERIAL BASE

## Inorganic sol-gel materials

Fraunhofer ISC has profound chemical expertise in realms of synthesis of inorganic non-metallic materials from liquid precursors as well as process know-how to design tailor-made materials for manifold applications, to develop manufacturing and processing technologies or to adapt material properties to already existing processes. Thus sol-gel processing offers numerous possibilities to control the physical and chemical properties of the later material in order to optimize its behavior during processing, structuring, tempering, and application. Inorganic sol-gel materials are materials base for the manufacture of particles, coating and fibers. Spinning technologies, printing and coating technologies are available for further manufacture of the inorganic sol.

Products already established on the market are, for instance nanoporous anti-reflective coatings for solar modules and wavelength sensitive increase of transmission for window glass and façade glazings («feel good» glass), sensitive layers for humidity sensors, photocatalytic coating as well as high refractive coating systems for color filters.

## ORMOCER®s

Besides the class of purely inorganic sol-gel materials, Fraunhofer ISC also develops inorganic-organic hybrid polymers – so-called ORMOCER®s. This class of materials is manufactured in correspondence with the process of chemical nanotechnology and functionalized to individual requirements. By selecting appropriate monomer or polymer initial components, it is possible to create materials and surfaces with multifunctional property profiles. 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 know-how for synthesis through sol-gel processing as well as functionalization and further manufacture of ORMOCER®s is continuously being developed and is base for many industrial applications.

## Technical specialty glass

The development and characterization of specialty glasses and glass ceramics has been one of Fraunhofer ISC's core competencies for a long time. Properties such as homogeneity, viscosity, thermal coefficient of expansion, bending strength and chemical resistance are painstakingly optimized to meet specific industrial requirements. Besides the know-how in glass chemistry and manufacture, latest in-situ measurement methods for characterization of glass-forming melts are used as well as an automated glass screening system which is the only one of its kind in Europe. It enables the high-throughput-screening of glass with defined mixture variations for faster development of new glass compositions.

Technical and optical specialty glasses with adapted property profiles find its application in, for instance, measuring techniques, microscopy, electronics, medical technology, car industry and construction industry.

## 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 Center Smart Materials has amassed extensive experience and considerable expertise in development and design of components such as dampers, actuators and sensors based on Magnetorheological and Electrorheological Fluids (MRFs and ERFs) and magnetically or electrically controllable elastomers (MREs and DEAs).

Speed and reversibility, two factors which enable these materials to change their viscosity or elasticity after creation of an electric or magnetic field, make them ideal for adaptive vibration damping and impact damping as well as for haptic control elements.

Furthermore, materials which are able to turn electrical signals in mechanical movements and/or vice versa movement in electrical signals which include piezo-ceramics, electro-active polymers (EAPs) and Carbon-Nanotube-Composites (CNTs) are processed. These are suitable for actuatoric and sensory components such as ultrasonic transducer for online monitoring and energy conversion (Energy Harvesting). In the realm of energy conversion, dielectrical elastomers will gain special importance. By means of dielectrical elastomer generators (DEGs), mechanical energy from water and wind is turned into electrical energy with aim of gaining additional areas of operation, for instance small rivers or weak-wind areas which are not suitable for conventional use of turbines. Depending on scope of application and requirements, profile suitable materials will be chosen and combined.

Besides energy harvesting, smart materials are very interesting for robotics. For this purpose there are developments and implementations of smart switches and sensors for collision detection, adaptive dampers and new actuators for grippers as well as for Human Machine Interfaces.

### **High temperature materials and process technique**

Ceramic fiber composites, CMCs, are used as a light, temperature-resistant and high-performance alternative to metals in extreme fields of application. The Fraunhofer Center HTL develops, together with partners from industry, manufacturing processes for temperature resistant non-oxidic and chlorine-free oxidic fibers from precursor synthesis to spinning on pilot scale. Besides the ceramic high-performance fibers, matrix materials for CMCs and components are being developed. Now, the focus lies on thermal-shock resistant lightweight structures which improve energy efficiency of heat treatment processes.

Manufacturing of high-performance ceramics, with or without fiber reinforcement, in high quality and with the lowest energy consumption possible requires optimal process parameters. With the aim of inherent safe and energy efficient manufacturing, the HTL Center examines and optimizes procedural steps such as design, debinding and sintering. The thermo-optical measurement method (TOM) developed by Fraunhofer ISC, is used for a contact-free in-situ examination of sensitive green bodies.

Thus the procedure of ceramics production can be precisely watched and predicted for any temperature cycle and under various atmospheric conditions. The combination of modeling and in-situ measuring enables optimization of ceramic materials' properties and process parameters for low energy consumption.

# CORE COMPETENCIES

## MAIN FOCUS

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

### Core skills include:

- Synthesis of materials from liquid precursors (nano-chemistry, sol-gel materials) and application-specific functionalization
- Analysis, characterization, and testing – in development and production or to investigate damage phenomena
- Process technology and process optimization in manufacture and production – adequate energy-efficient processing of materials
- Glass chemistry and technology – ranging from laboratory-scale melted material via automated high-throughput screening to plant development for the industrial production of specialized glass products
- Analysis of materials flows, development and assessment of materials cycles and recycling technologies, substitution of critical raw materials

## SPECIFIC FIELDS OF ACTIVITY

### Energy

Coatings (wind energy, PV, solar thermal applications), sensor systems (conditions monitoring, printed systems), small wind energy plants, energy harvesting, barrier films for organic photovoltaics, protective lacquers, material/components for batteries/supercaps, thermal energy storage, analysis/tests of/for batteries/components, post-mortem analysis, energy-efficient thermal treatment, thermal insulation,

efficiency enhancement of lighting systems and illuminants, functionalized window glasses (active and passive transmission control), energy-efficient thermal treatment, high temperature lightweight construction, high temperature materials, polymer ceramics

### Micro-electronics, packaging, semi-conductors

Electrical/optical AVT, printed/flexible electronics, functional materials for  $\mu$ -Smart systems, sensory systems (optical ORMOCER<sup>®</sup>s, ferro-electrical polymers), system-in-chip, system-in-package, protective lacquers, (functional) resists

### Optics and display, photonics, and biophotonics

Transparent conductive oxides, amorphous semiconductor oxides, LED, OLED, PV, lighting, opt. communication technology, silicon photonics, micro-optics, photonic structures, coupling and uncoupling layers (structures, scattering layers), waveguide and opt AVT, lab-on-a-chip, bio-functionalization

### Surface technology, corrosion, and packaging

Active and passive protective layers (scratch resistance, corrosion protection, anti-microbial, easy-to-clean, anti-static), anti-reflex, decoration, coating technology and hardening methods, characterization of layers, up-scaling, production of materials and methods, analysis of corrosion processes, protective layers, weathering and climatic tests, glass packaging (e.g. pharmaceutical), analysis (e.g. hydrolytic resistance), ultra barrier (e.g. O<sub>2</sub>, water vapour), barrier (fat, oil), films (e.g. carton, paper, plastics), metal, glass, encapsulation materials and methods

## **Construction – Dwelling – Consumer**

Mineral building materials – cement/concrete/gypsum, glass/architectural glass, construction chemistry, air-conditioning, insulation, heat storage, lighting, electro-chromics, analysis, cleaning, catalysis, sensor systems, climatic sensors

## **Automotive**

Actuators/sensors, sensors (printed systems), protective lacquers for electronic circuits, motion control/damping, controllable haptics, Smart Soft Materials (MRF, MRE, dielectric and conductive elastomers), electro-chromics

## **Dental/Medicine**

Multi-functional silanes/resins/hybrid polymers/composites, adhesive systems/adhesive systems, direct restoration/prophylaxis/regeneration, indirect restoration (inlay/onlay/crowns/denture teeth), glass ceramics (crowns/bridges), (bio-/active) functionalized, partially degradable templates/scaffolds in combination with 2D/3D structuring, peptide-based/combinatorial materials development

## **Regenerative Medicine**

Wound dressings, TE support structures/scaffolds, live-cell imaging, developmental environment for pilot manufacturing close to GMP conditions, packaging, actuators/sensors for prosthetics, orthotics, smart implants, and rehabilitation

## **Diagnostics**

Bio-functionalization and design of nano-particles

## **Glass**

Container glass, float glass (composition, shaping), glass solders, specialized glass, melting technology, production of glass melts (5 litre platinum crucible), glass ceramics, glass analysis (in the melt/wet-chemical)

## **Speciality Chemicals**

Production of small batches: Sub-contracted syntheses (up to 80 kg) and lacquer production up to 50 liters, multi-functional silanes/resins/hybrid polymers/composites

## **Mechanical Engineering**

Mechatronics and robotics, sensors (printed systems), actuators/sensors

## **Analysis and Measuring Technology**

Thermal analysis, microscopic analysis, surface analysis, chemical analysis, thermo-optical characterization < 200 °C, environmental monitoring, characterization/testing of layers, electro-chemical analysis, chemical/physical materials characterization/testing (analysis of properties), damage analysis, preparation, measuring technology HT processes

## **Efficiency of Materials**

Resource strategies, recycling concepts, recycling-adequate design, substitution of critical materials

# COMPETENCY CLUSTERS

## DEVELOPMENT OF COMPETENCE

The existing know-how is subject to steady further development and transferred to industrial application in the competency clusters Materials Chemistry, Application Technology and Services, the Center Smart Materials, and the Center for Applied Electrochemistry as well as the Fraunhofer Project Group for Materials Recycling and Resource Strategies IWKS and the Fraunhofer Center for High Temperature Materials and Design HTL.

### Competency Cluster Materials Chemistry

The focus of the cluster Materials Chemistry is on chemical (nano-) technology for the manufacture of inorganic or hybrid materials and the processing and forming thereof into layers, fibers, capsules or powders. The cluster Materials Chemistry streamlines the expertise from the specialized areas of sol-gel chemistry, coating technology and particle technology.

As a result, a wide range of synthetic methods is available for the development and optimization of materials and components of materials. Comprehensive solutions are worked out for specific applications in engineering, health, energy, construction and environment as well as the protection of cultural heritage.

#### Contact

Dr. Thomas Hofmann

☎ +49 931 4100-350

[thomas.hofmann@isc.fraunhofer.de](mailto:thomas.hofmann@isc.fraunhofer.de)



### Competency Cluster Application Technology

The cluster Application Technology comprises the areas of dental and micro-medicine, optics and electronics as well as glass and mineral materials. These areas of competence focus on the interaction between biological cells and materials, the interaction between light and/or electrical currents and materials and the corresponding process and manufacturing technology as needed to customize hybrid polymers, ceramics or speciality glasses for individual applications and to integrate them into the production processes.

The research area glass is certified to DIN EN ISO 9001:2008.

#### Contact

Gerhard Domann

☎ +49 931 4100-551

[gerhard.domann@isc.fraunhofer.de](mailto:gerhard.domann@isc.fraunhofer.de)





## Competency Cluster Services

This cluster of the Fraunhofer ISC makes the technical competence in the fields of analysis, testing, and characterization of materials available to the development and construction of scientific devices and to the training and knowledge transfer programs. The Center for Applied Analytics acts as the contact partner for internal and external clients in all questions related to the analysis of structures, properties or the correlation of the micro-structure and properties of materials. The Center offers a combination of the latest materials analysis equipment and application-related scientific counselling. Approaches to solutions are developed in close cooperation with the customer based on the interpretation of the analytical results.

The Center for Applied Analytics is accredited to DIN EN ISO/IEC 17025 and is a RAL or EUCEB testing laboratory for mineral wool.

The focus of the Center of Device Development CeDeD is on the development of special scientific devices used in both the characterization of new materials and the quality control of the production process. The CeDeD is certified to DIN EN ISO 9001:2008.

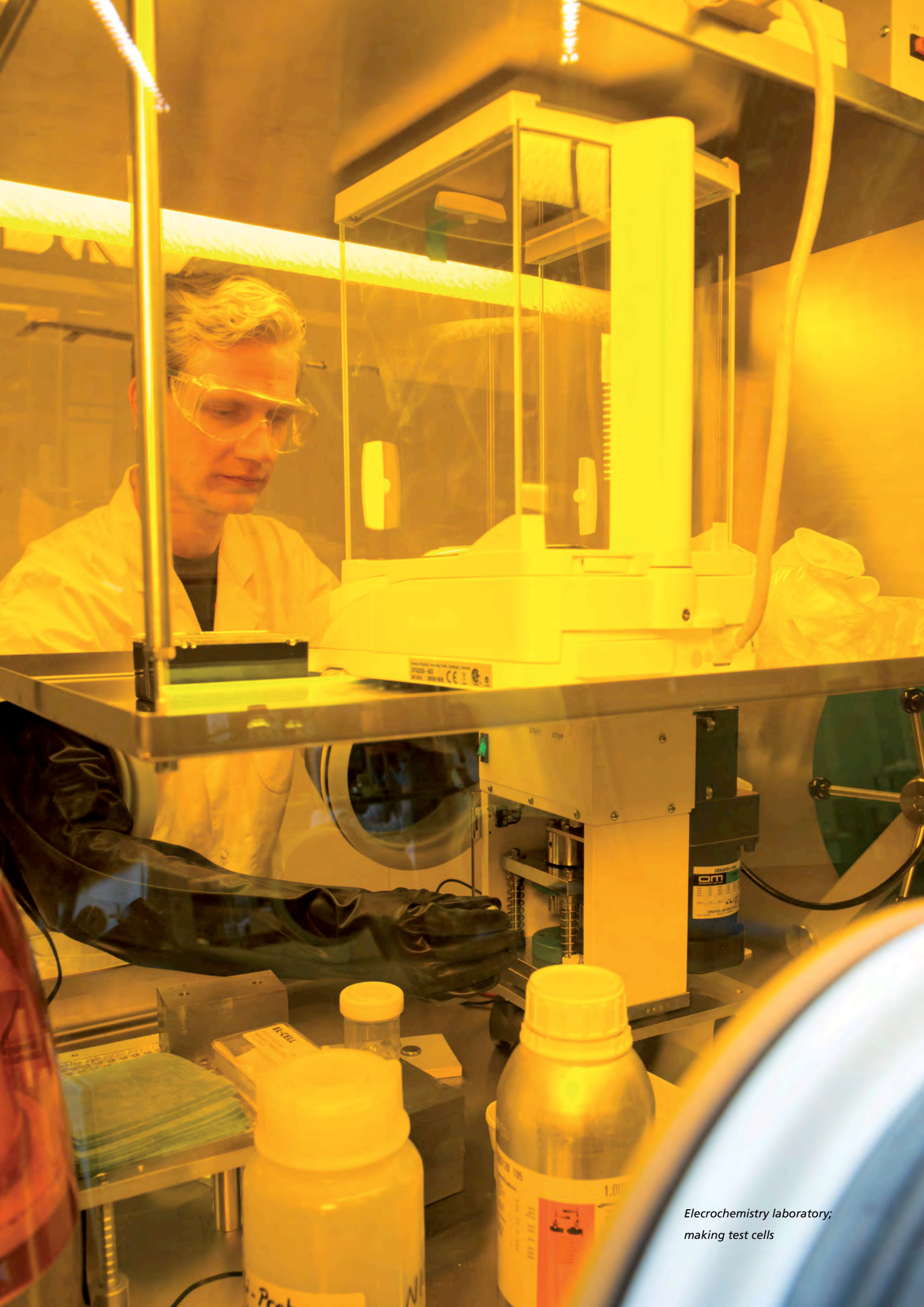
The International Convention Center for Cultural Heritage Preservation (Internationales Zentrum für Kulturgüterschutz und Konservierungsforschung, IZKK) is an educational institution and an important element of the sustainability strategy of the Fraunhofer society.

## Contact

Dr. Jürgen Meinhardt  
 ☎ +49 931 4100-202  
[juergen.meinhardt@isc.fraunhofer.de](mailto:juergen.meinhardt@isc.fraunhofer.de)







*Electrochemistry laboratory;  
making test cells*



# CENTER FOR APPLIED ELECTROCHEMISTRY

## A FOCUS ON BATTERY DEVELOPMENT

The Center for Applied Electrochemistry (Zentrum für Angewandte Elektrochemie, ZfAE) is the contact partner for all matters involving the development and optimization of materials and methods for efficient utilization of electrical energy for mobile and stationary applications.

The Center was founded in October 2011 as part of the »Bavarian Research and Development Center for Electro-Mobility (Bayerisches Forschungs- und Entwicklungszentrums Elektromobilität)« sponsored by the German state of Bavaria through its program »Advance in Bavaria (Aufbruch Bayern)« at sites in Würzburg and Garching. Both centers understand themselves to be links between basic research at the university level and industrial application.

The goal of the Center is to provide the foundations for the broad utilization of electro-mobility. In close co-operation with industry, it investigates and develops future-oriented electrode materials, electrolytes, and other cell components as well as the corresponding methods for production and processing up to the pilot plant scale. The most sophisticated test methods are available to the scientists for the investigation of all cell components and batteries.

### Key focus of development

- Development of materials and components for electrochemical energy storage
- Lithium ion batteries (LiB) – including modification of high-energy cathodes and anodes, solid state electrolytes
- Metal-air batteries – including catalyst development, interface design
- Lead-acid batteries – including additives for the electrode masses

- Double-layer capacitors – LiB supercapacitor
- Electro-chromic layers – materials and methods
- Recycling of batteries and electronic components
- Process development

### Component matching

Of special importance is the optimal matching of the individual cell components such as electrodes, electrolyte, and separator to each other. For this purpose, separators are being optimized and environment-friendly binder systems are being developed. Both in-house developments and commercial products, which can be modified according to need, are used in this context. Modern equipment and technologies provide the foundations for comprehensive analysis of the reaction processes ongoing in the cell components at in-situ and post-mortem conditions.

### Characterization of materials and tests

The Center for Applied Electrochemistry is equipped with the most sophisticated electrochemical measuring methods. This includes tests on up to 200 channels ranging from the femto to the kilo-ampere scale at controlled temperatures. Materials and cell components are tested supported by an analytical system that is accredited to DIN EN ISO/IEC 17025-2005.

### Contact

Henning Lormann  
☎ +49 931 4100-519  
[henning.lormann@isc.fraunhofer.de](mailto:henning.lormann@isc.fraunhofer.de)





*Components for novel pressure sensors*

# CENTER SMART MATERIALS CESMA

## SMART MATERIALS

Adaptive materials with properties that can be switched by means of electrical, magnetic or thermal fields are called »intelligent« or »smart«. Since these controllable materials offer a high added value, the Center Smart Materials CeSMa aims to make their potential available for industrial applications. They allow complicated technical systems to be simplified and new additional functions and properties to be integrated in them. For example, adaptive dampers and electrically switched couplings are conceivable. Integrated component and system monitoring or precise positioning systems, independent energy supply for sensors and intelligent control elements with haptic integrated functions are just some other examples of many.

The range of Smart Materials used at the Fraunhofer ISC is unique in its kind and allows complex issues to be solved through specific selection and combination of different material components. Exemplary application are, e.g., »Smart Materials« in components such as actuators, sensors, dampers, couplings, »Energy Harvesters« or in »Smart Windows« which can change color at the push of a button and allow the amount of incident light to be controlled.

### Materials – Functions – Components

»Smart Materials« comprise polycrystalline solids such as piezo-ceramic materials, liquids switchable by electrical or magnetic fields (ERF, MRF) as well as dielectric elastomers that can be used as actuators, sensors or generators (DEA, DES, and DEG) or which, filled with magnetisable particles, can reversibly change their rigidity and/or shape in a magnetic field (MRE). Another class of substances with useful switching properties are the metallo-polyelectrolytes (MEPE) which make a broad colour spectrum available for technical applications. They are used, for example, in »Smart Windows« and have

also been qualified for use in the fields of architecture and displays in projects which are conducted by the Center for Applied Electrochemistry.

The adaptive materials and components under development by CeSMa and being implemented in co-operation with industrial partners include:

- Dielectric elastomers for use as actuators (DEA), sensors (DES) and generators (DEG)
- High temperature-resistant magneto-rheological liquids (MRF) for dampers and couplings
- Magnetorheologic elastomers (MRE) for controllable damping and haptic actuators
- Piezoelectric high temperature ultrasonic transducers
- Piezoelectric integrated switches with proximity sensors
- Metallo-polyelectrolytes (MEPE) for switchable optical transparency and coloring

The researchers work on these development projects in co-operations with research groups from universities, advanced technical colleges and industry. This allows CeSMa to provide a broad, scientifically and technically sound range of materials and technologies for industrial users. Meanwhile, the annual »CeSMa Workshop«, which is supported by the Bavarian clusters »New Materials« and »Mechatronics and Automation«, has become an established event. A significant part of the necessary basic research is funded by the Bavarian State Ministry for the Economy and Media, Energy and Technology.

### Contact

Dieter Sporn  
☎ +49 931 4100-400  
[dieter.sporn@isc.fraunhofer.de](mailto:dieter.sporn@isc.fraunhofer.de)  
[www.cesma.de](http://www.cesma.de)





# ATTRACT GROUP

# 3DNanoCell

## SMART USE OF THE BODY'S SELF-HEALING FORCES

In regenerative medicine, the self-healing forces of the human body are used specifically to design the next generation of smart implants. An optimized combination of high-tech materials and cell tissue is designed appropriately to speed up and to provide a sustainable basis for the desired integration of the implant into its biological surroundings. Three-dimensional (3D) scaffolding structures are used as support material under in-vitro conditions for the production of tissue by the cells. For optimal colonization by the cells, it is desirable to combine a customizable 3D structure with a nano-scale surface structure and biochemical functionalization such that the cells are sufficiently cross-linked in space, while ensuring the supply of nutrients in all areas. In order to implement this rationale, the regulation of the cytoskeleton in living cells must be well understood such that these cell functions can be controlled and directed specifically. While the genome delivers the blueprint for all vital processes, the interaction of each cell with its surroundings determines the gene expression and thus the behaviour of the cell. Not only molecular concentration gradients, but also mechanical interactions with 3D scaffolds of the extracellular matrix have an impact on the range of functions of living cells.

## Development of standardized diagnostic assays

The Fraunhofer Attract Group »3DNanoCell« at Fraunhofer ISC directed by Prof. Dr. Doris Heinrich focuses on the development of standardized diagnostic assays for direction and control of cell functions (such as cell adhesion, migration, cell division, and apoptosis). Through systematic adaptation of nano-scale 3D structures, »Smart Implants« and 3D scaffolds are to be developed further for tissue engineering. Novel approaches to surface structuring, synthetic 3D scaffolds as tissue supports, nano-capsules for diagnostics and high resolution optical methods are combined to serve this purpose.

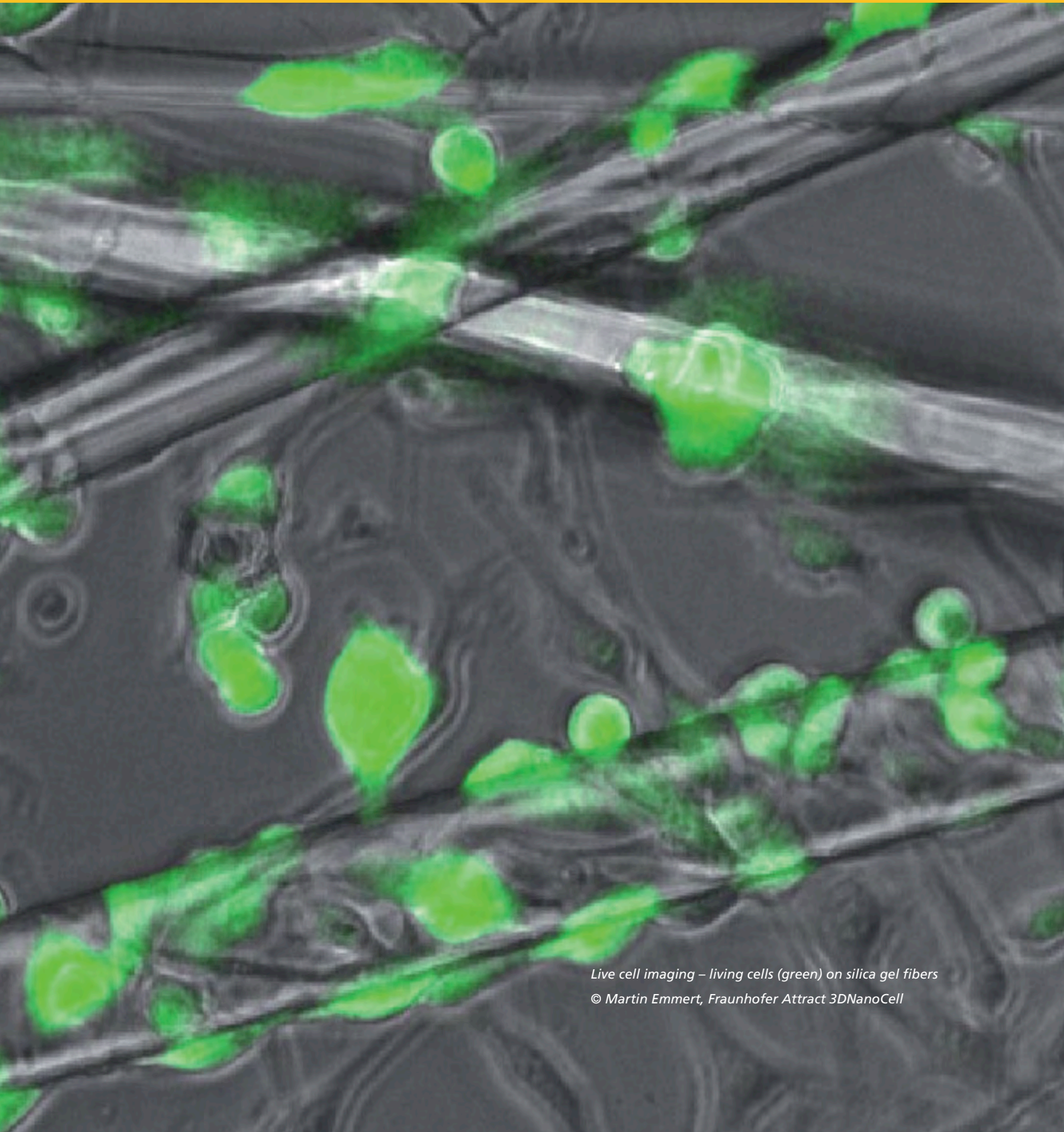
Evidently, a very productive field of research promising to produce highly interesting results for science, medicine and certainly also from an economic point of view is developing under the supervision of Prof. Dr. Doris Heinrich.

The Attract Program of the Fraunhofer-Gesellschaft supports young scientists who wish to further develop their ideas in Fraunhofer institutes for industrial applications. Prof. Dr. Heinrich is a professor of biophysics at Leiden Institute of Physics (LION) at Leiden University in the Netherlands.

## Contact

Prof. Dr. Doris Heinrich  
☎ +49 931 31-81862  
[doris.heinrich@isc.fraunhofer.de](mailto:doris.heinrich@isc.fraunhofer.de)





*Live cell imaging – living cells (green) on silica gel fibers*  
© Martin Emmert, Fraunhofer Attract 3DNanoCell

# ISC INTERNATIONAL

## ISC International

International markets play a crucial role for the Fraunhofer ISC in many economic sectors – for example in micro-electronics, opto-electronics, and consumer electronics – areas, in which most of the development and production are centered in East Asia. Consequently, the representative and coordinator of the Institute on an international level, Dr. Michael Popall, has focussed the networking of the Institute on Europe (supported by Dr. Johanna Leissner in Brussels) and Asia. Working closely with the regional offices and branches of the Fraunhofer Society, and in some cases even before these were founded, regional networks have been set up and successful long-standing co-operations with industrial partners have been established. A pool of research and development partners from industry and science, the positive experience made by the project partners and the regular presence on site are the foundations of this trust-based co-operation and enable the acquisition of projects that are important from a research-strategic point of view.

## Japan

As early as in 1999, even before the Fraunhofer Representative Office in Japan was founded, the Fraunhofer ISC established contacts in Japan and the first major projects were acquired from 2002. The Fraunhofer ISC thus played a pioneering role for other Fraunhofer institutes in Japan as well. Today, there are a number of bilateral co-operations with industry and research, for example a strategic research partnership with the Japanese Research Center of the National Institute of Advanced Industrial Science and Technology (AIST) in Nagoya. A successful research partnership with long-term prospects was also established with Nissan Chemical Industries and already resulted in the development of new ORMOCER®s featuring a high and specifically variable refractive index. A wide range of applications in optics and opto-electronics can be addressed through this cooperation.

## Korea

Contacts in Korea have also been established systematically over a long period of time. In cooperation with institutional partners such as the University of Korea and Yonsei University, the Korea Advanced Institute of Science and Technology (KAIST) and the Electronic and Telecommunication Research Institute (ETRI), student and post-graduate exchange programs have been established and joint projects are being undertaken. The presence in Korea associated with these activities generated trust and led to the involvement of Korean companies. This includes long-standing co-operations with the Korean display and electronics industry. The Fraunhofer ISC partakes in a partnership with the University of Korea as the sole German R&D partner working on two large long-term materials research projects which are sponsored in the scope of a global excellence initiative by two state institutions, KEIT (Korea Evaluation Institute of Industrial Technology) and KIAT (Korea Institute for Advancement of Technology), and a large Korean industrial syndicate. This was possible only because of the excellent standing of the Fraunhofer ISC in the area of materials research and development of hybrid polymers.

## China

The contacts to China started bilaterally with occasional Chinese partners from the solar energy industry. In co-operation with the regional office of the Fraunhofer Society and a specialized consultant, Hangzhou Ocean ImP & ExP Co., Ltd, coating materials and technologies of the Fraunhofer ISC are currently being marketed in China. These activities were boosted by the exchange with the Research Council and the Science and Technology Park Hong Kong. On the occasion of the visits of top-ranking delegations of both organisations at the Fraunhofer ISC in early and late October 2013, which were accompanied by the first industrial companies, a memorandum of understanding was signed. Due to its special legal status and its enormous economic power, Hong Kong is a very





Hongkong Science and Technology Park delegation visiting the Fraunhofer ISC



attractive business location that offers conditions in industrial sectors that are of interest for research partnerships and are basically no longer present in Europe or Germany. Moreover, Hong Kong is seen as the gateway to mainland China since the orientation towards the English language and the good networking of Hong Kong-based companies inside and outside China promise to lower the barriers of entry into the Chinese market.

Currently, contacts are also being established in the strongly developing countries Taiwan and India in order to set up networks in similar fashion. Likewise, some successful research co-operations have already been established in the Near East – in close consultation with the headquarters of the Fraunhofer Society.

## Europe

In the two most recent research framework programs of the EU, Dr. Popall was actively involved in setting-up the EMMI platform – the European Multifunctional Materials Institute ([www.emmi-materials.eu](http://www.emmi-materials.eu)). The Fraunhofer Society is very involved in the EMMI as the president of the Fraunhofer Society, Prof. Dr. Reimund Neugebauer, serves as the Chairman of the Governing Boards and Dr. Popall serves as the Chairman of the Industry Support Group (Advisory Panel) of EMMI. The pool of partners of the EMMI includes many institutions and companies of Europe-wide prominence from the area of sol-gel materials and ceramics development and application. Accordingly, it was feasible to initiate some fundamental and novel ideas about new materials and to advance them on a European level, such as the development of meta-materials for a new generation of micro-electronics/photonics in the scope of the METACHEM project (see below). A solid foundation provided by an organization networked throughout Europe makes it easier to manage invitations to tender of the European Institute of Innovation and Technology (EIT) on Knowledge

and Innovation Community (KIC), presently Raw Materials, in which the Fraunhofer Project Group IWKS is to assume an essential part.

## Composites research on a European level

The ISC has contributed as a key partner to a large number of European projects for many years. In recent years, the ISC developed along the value-added chain from a materials developer into a technology and process developer. The EMMI-initiated METACHEM project is just one of many examples.

The name of the project, METACHEM, stands for »Nano-chemistry and self-assembly routes to metamaterials for visible light«. The aim of METACHEM was and still is to develop novel meta-materials – i.e. materials with optical, electrical or magnetic properties that differ markedly from those of natural materials, like a negative refractive index. Properties of this kind can usually be attained through nano-scale structures of, e.g., noble metals, ferroelectric substances, etc. Hybrid polymers (ORMOCER®s) have been used at the Fraunhofer ISC to produce support structures for METACHEM by nano-imprint lithography and a special 3D structuring method called two-photon polymerisation. Another new approach advanced by the project partners was the targeted self-organization into 2D or 3D materials. Materials of this kind are used as aberration-free lenses, hyper-lenses permitting optical resolution below the wavelength of the light, and as optical waveguides. [www.metachem-fp7.eu/index.php/about-the-project](http://www.metachem-fp7.eu/index.php/about-the-project)

## Contact

Dr. Michael Popall  
 ☎ + 49 931 4100-522  
[michael.popall@isc.fraunhofer.de](mailto:michael.popall@isc.fraunhofer.de)



# FRAUNHOFER PROJECT GROUP IWKS

## **FOCUS ON RAW MATERIALS SUPPLY**

One of the major challenges facing humanity in the 21<sup>st</sup> century is the responsible and sustainable use of energy and raw materials. This challenge holds world-wide conflict potential. There is a need to develop efficient and resource-sparing (production) processes and methods for energy harvesting and storage and to implement these technical innovations. This task is addressed with a view to the future by the Fraunhofer Project Group for Materials Recycling and Resource Strategies IWKS.

Residing in Alzenau and Hanau, the Project Group IWKS was established in 2011 by the Fraunhofer Society under the umbrella of the Fraunhofer ISC. The activities of the three Business Divisions »Resource Strategies«, »Recycling and Reusable Material Cycles«, and »Substitution« are focussed on ensuring the availability of raw materials to the industry – in order to cement its leading position in the high-tech sector on the long-term. Working in close co-operation with industrial partners, the Project Group IWKS develops innovative separation, sorting, reprocessing, and substitution options. The research idea pursued at the Fraunhofer Application Center for Resource Efficiency (Anwendungszentrum für Ressourceneffizienz AWZ) addresses a much earlier point in the chain: As early as in the developmental phase, new product designs are optimized in terms of recyclability to ensure the recovery of valuable raw materials at the end of the product cycle.

The team of directors managing the Project Group IWKS as an organizational unit consists of the research directors Professor Dr. Armin Reller (University Augsburg), Professor Dr. Stefan Gäth (Justus-Liebig-University Gießen) and Professor Dr. Oliver Gutfleisch (Technical University Darmstadt), with Professor Dr. Rudolf Stauber as executive manager. The overall responsibility for the establishment and expansion of the Project Group is with the Fraunhofer ISC in Würzburg and its director Professor Dr. Gerhard Sextl. The number of staff has increased to

40 positions since 2011 as planned. A total of 22 new permanent positions are to be filled in 2014. At full strength in the future, the team is to consist of approx. 80 staff members.

## **Business Division Resource Strategies**

*Research Director: Prof. Dr. Armin Reller*

The Business Division Resource Strategies identifies quantitative and qualitative factors of primary and secondary resources for current and future technology developments. This includes the assessment of the availability as part of the overall process comprising the harvesting, utilization and re-use of raw materials.

The resources strategy concept defines criteria for estimating the potentials and risks involved in the use of raw materials, materials, processes, and technologies. The research focus is on:

- Resource conflicts, availability
- Geo-political dependencies
- Safety and design of global supply routes
- Economic potentials
- Socio-cultural factors, acceptance of new technologies
- Technical performance of functional materials
- Ecological impact and risk potential

## **Business Division Recycling and Reusable Material Cycles**

*Research Director: Prof. Dr. Stefan Gäth*

The Business Division Recycling and Reusable Material Cycles develops innovative concepts for materials flows, waste disposal, and resource management. Always with a view to the triangle of (reverse) logistics, technology, and socio-economics. As early as in the product development phase, a design that is adequate for later recycling (»Design

for Disassembly») is developed in close co-operation with the clients. For this purpose, a wide spectrum of materials and products is taken into consideration, such as, e.g., electrical components, illuminants, and packaging materials.

The investigations also extend to reusable materials/materials from:

- Slags, slurries, disposal sites
- Ashes
- Adsorbents
- Waste water
- Food waste

### Business Division Substitution

*Research Director: Prof. Dr. Oliver Gutfleisch*

The Business Division Substitution is mainly concerned with the adequate replacement of rare and expensive raw materials and elements in products, applications, and technologies. The activities are aimed at the development of innovative materials and at substitution on the level of components, processes, and technologies. One focus of the activities is on the development of permanent magnets containing drastically reduced amounts of rare earth elements at unchanged or even improved operating properties. Examples of applications include electrical motors and wind turbines.

The focus is on the optimization and development of:

- Magnetic materials
- Optical materials
- Optoelectronic components
- Lighting systems
- Refrigeration systems

### Contact

Executive Manager  
Prof. Dr. Rudolf Stauber  
☎ + 49 6023 32039-801  
[rudolf.stauber@isc.fraunhofer.de](mailto:rudolf.stauber@isc.fraunhofer.de)



### Team of Managing Research Directors

Prof. Dr. Stefan Gäth  
☎ + 49 6023 32039-801  
[stefan.gaeth@isc.fraunhofer.de](mailto:stefan.gaeth@isc.fraunhofer.de)



Prof. Dr. Oliver Gutfleisch  
☎ + 49 6023 32039-801  
[oliver.gutfleisch@isc.fraunhofer.de](mailto:oliver.gutfleisch@isc.fraunhofer.de)



Prof. Dr. Armin Reller  
☎ + 49 6023 32039-801  
[armin.reller@isc.fraunhofer.de](mailto:armin.reller@isc.fraunhofer.de)





# FRAUNHOFER PROJECT GROUP

## IWKS

### R&D AREAS BY BUSINESS UNITS

#### **Business Unit Electrics, Electronics**

*Head: Dr. Thorsten Hartfeil*

Electronic devices are complex technical products that contain numerous chemical elements at high concentration. The Business Unit Electrics and Electronics is concerned with various issues related to resources strategy, recycling of waste electrical and electronic equipment (WEEE), and the substitution of raw materials and other materials in the developmental phase of components. The focus of the activities is on:

- Analysis and assessment of resources and harmful substance potentials of WEEE.
- Logistics and collection concepts
- Development of innovative recycling technologies
- Alternative electro-technical materials
- Design for disassembly

#### **Background**

According to estimates of the foundation »Waste Electrical and Electronic Equipment Register«, some two million tonnes of electrical and electronic equipment reach the market in Germany each year. Put simply, this includes all equipment that needs or generates electrical currents and/or electromagnetic fields in order to run properly. Accordingly, the spectrum of WEEE is just as broad and ranges from a simple toaster to high quality tablet computers.

#### **Business Unit Slags, Sludges, Landfill**

*Head: Dr. Carsten Gellermann*

The Business Unit Slags, Sludges, Landfill is point of contact for the efficient and sustainable use of resources from waste materials, e.g. from the glass or grinding industry or from the incineration industry. In close cooperation with the customer, materials cycles are optimized, aiming at a waste-free and economic use. Special focus is on mineral and glass-like materials systems such as ashes, dust, slags, composite materials or sludges, as all these tend to contain an interesting cocktail of precious and critical ingredients which should be kept within the cycle. The portfolio is rounded off by the development of concepts for landfills or the reclamation of landfill sites.

#### **The task**

The Business Unit helps industry partners to implement new use and recycling concepts and to develop novel sustainable processes for a targeted shredding with a selective separation of valuable materials – from laboratory to pilot plant scale. The competence portfolio includes mechanical, physical, chemical as well as biological procedures which can be customized to meet very specific requirements.

#### **Novel recovery method for industrial sludges**

Following the hierarchy of waste products, the manufacturers and users of refuse are obliged to no longer dispose, but rather recover, a material as soon as a recovery method becomes available. The currently available methods guide the sludges mentioned above mostly towards disposal, whereas the novel distillation method ensures complete recovery.



Material specific recycling analyses



### Pilot plant of the Fraunhofer Project Group IWKS

The novel pilot plant of the Project Group IWKS in Alzenau features a system, in which emulsions or oils can be separated by distillation from the solids fraction, such as e.g. metals and silicon dust. The system affords virtually complete separation without having to subject the substances to any chemical modification. The method is implemented in a vacuum at a temperature of up to 400 °C. One of the advantages is that the metals content is not exposed to oxygen and does not oxidize in this process. Accordingly, there is no need for subsequent reduction before the material can be re-used. The plant is completely closed such that no harmful substances can escape. The pilot plant is operated using batches of up to 200 litres.

### Successful cycle for reusable materials

This method can be used to complete a material cycle, in which virtually all components of the mixture can be recovered and re-introduced into the economic cycle. The recovered oil is re-used and sold. The recovered metal chips are packed in so-called big bags and delivered directly to the metal-processing industry for use as a secondary raw material for blast furnaces and shaft furnaces.

### Feasibility precedes production

The Fraunhofer Project Group IWKS operates the pilot plant to study the reaction conditions for the separation of thus far unknown mixtures and to fine-tune the isolation of the components. This ensures that even unknown mixtures of polishing sludges can be analyzed. Then, an optimal separation procedure is worked out specifically and transferred to

the large-scale plant of Destimet in Bitterfeld-Wolfen, Germany. The operation is to be adjusted variably to suit the requirements of any client.

Overview of the benefits of the method:

- Separation by distillation of solid-liquid mixtures in a vacuum
- Complete recovery of the components
- No harmful exhaust gases produced during the process
- No chemical change to the separated and purified components due to a closed system and vacuum conditions
- Process flow can be adapted to process input

### Business Unit Biological Materials, Food

Head: Dr. Stefan Hanstein

The growing population of the world, expecting its prosperity to increase steadily, demands a reliable supply of food, energy, and raw materials. However, valuable resources are discarded in domestic and industrial refuse, sometimes without ever being used, rather than being recycled for further use. We won't be able to afford this luxury much longer.

The world's population is expected to grow to as many as 9 billion people by 2050. This urgently calls for the evaluation and securing of the supply of food. Considering that currently some 900 million people in the world suffer from hunger, the scarcity or squandering of food is an omnipresent issue. The consumer society in the countries with the highest income, including Germany, tends to exercise some inappropriate and wasteful handling of food.

# FRAUNHOFER PROJECT GROUP IWKS

Losses are evident during the entire production chain. The production consumes a lot of resources, such as, e.g., water, soil, and energy. And still, many products never even reach their intended use, since they are discarded before ever getting there. Considering that resources are becoming scarcer here as well, a sustainable way of operating needs to be attained especially in the food sector to make sure that the food supply for future generations is secured.

The core competence of the Business Unit is the optimization of (production) processes and products in the food industry. The Project Group IWKS analyses, evaluates, and optimizes the production processes of its clients with a view to the entire value-added chain by applying various management systems:

- Substance flow management
- Waste management
- Resource management
- Life cycle assessment

The assessment is based on ecological, economical, and sociological criteria. The resulting individual solutions for resource-efficient and sustainable production are implemented directly into the practice of the client. The Project Group IWKS has developed a concept for this purpose that optimizes the utilization of raw materials and resources in the food industry with a view to sustainability.

## **Certification system s:Lim – say: Less is more**

Taking into consideration that the food industry is a highly resource-consuming sector, the Project Group IWKS developed a graded certification system that provides for the efficient use of all relevant resources and aims for optimal utilization of the reusable materials. Periodical auditing ensures that the process flows stay up to date. Aiming for sustainable use of raw materials and products from production to disposal, three main approaches are used:

**1.** In materials flow management, the flows of materials in a company are assessed. The concept can be applied in all areas of the food industry and leads to an optimization of the production in terms of resource efficiency. Starting points for measures can be identified specifically in this analysis to ensure the sustainability of the production. The processes can be analyzed by this means, existing problems can be identified, and solutions can be developed.

**2.** The production process is associated with the production of waste. The analysis by means of quantitative and qualitative aspects can provide for a waste management system that is characterized by its efficient handling of raw materials and a customized concept for minimization of the waste products in the company and for sustainable disposal of the waste products. Considering the intensive use of raw materials and resources in production, the main aim must always be to minimize the amount of waste produced through a sustainable way of manufacturing.

An important focus is on delineating options of re-use of the (production) waste or ingredients of waste products taking into consideration the rapid progress that is being made in the development of an ecology-based economy, specifically in the area of bio-based materials.





Recycled product from the melt-spinning process



Working with the melt-spinning process

**3.** Industrial production is associated with emissions that have a negative impact on the environment. In the third building block of concepts, an eco-balance (life cycle assessment) is used to determine the emissions related to production in as far as they are relevant for the environment as well as the energy consumption in order to identify savings and optimization potentials. The requisite innovations in methods and technology are developed and implemented in close co-operation with the client.

The application of the certification system s:Lim enables the production to become cost- and resource-efficient. A special logo demonstrates the implementation of the system in the operations and affords the client benefits in marketing activities.

### **Business Unit Magnetic Materials**

*Head: Dr. Roland Gauß*

A main focus of the research and development activities of the Fraunhofer Project Group IWKS is the development of magnetic materials, e.g. for permanent magnets, magneto-caloric materials, magnetic shape memory alloys, and magnetorheological fluids. These materials provide the foundation for a large variety of existing technologies and some others on the verge of a breakthrough, such as e.g. new refrigeration technologies based on the principle of magnetic refrigeration (in close co-operation with the Business Unit Energy Systems). The Project Group can exploit an ideal situation: While the group of Prof. Gutfleisch is concerned with the basic research on magnetic materials at the TU Darmstadt, the Fraunhofer Project Group IWKS implements the projects that are nearing industrial application.

### **Research Focus Permanent Magnets**

As one of the technologically most advanced and economically most stable countries in the world and a main consumer of energy and raw materials, Germany also bears a large part of the responsibility for identifying new ways of harvesting, converting, transporting, and storing energy as efficiently and resource-sparingly as possible.

Permanent magnets play a central role in these processes, especially in electrical machinery. Along with the increasing acceptance of wind energy and E-mobility, the demand for permanent magnet machinery is also expected to increase. The permanent magnets boasting the largest market share (turnover) are based on Nd-Fe-B alloys. These magnets currently attain the highest energy densities. Depending on the specific application, they contain the light rare earth metal neodymium and fractions of heavy rare earth elements, mainly dysprosium and terbium. Since the crisis in the supply of rare earth elements in 2010/2011, rare earth elements and especially dysprosium are viewed as critical in the EU. More than 95 % of the rare earth elements are mined in China. The turnaround in energy policy and E-mobility are therefore inconceivable in the absence of a systematic and market-oriented development of permanent magnets containing no or significantly reduced amounts of rare earth elements. Nd-Fe-B magnets are also used in large quantities in the computer and electronic industry as well as in medicine.

The Fraunhofer Project Group IWKS pursues two main strategies in the development of permanent magnets: The long-term focus is on the development of new compositions for permanent magnets, while the short- and medium-term focus of the research is on drastically reducing the use of heavy rare earth elements while keeping the materials' properties the same or improving them.

# FRAUNHOFER PROJECT GROUP IWKS

## **Pilot plant of the Project Group IWKS**

In this context, the production line for the manufacture of magnet materials on a pilot scale funded by Fraunhofer perfectly supplements the academic research conducted at the TU Darmstadt. The production line basically comprises kilns for the manufacture of suitable starting alloys and facilities for powder metallurgy and reforming technology.

Along with the materials development, studies of life cycles of substances and of the recycling of magnetic materials are two more central areas of interest of the Business Unit. Methods for the recycling of Nd-Fe-B are being implemented e.g. in the scope of the EREAN project of the EU in co-operation with renowned European partners from research and industry (coordinated by KU Leuven). The Project Group IWKS focuses mainly on obtaining powders from scrap magnets for the production of new magnets. Hydrogen-based methods are developed specifically for this purpose. The major advantage of re-using powders made from scrap magnets is that it allows to forego laborious chemical and physical methods for recovering rare earth elements and the production of new starting alloys.

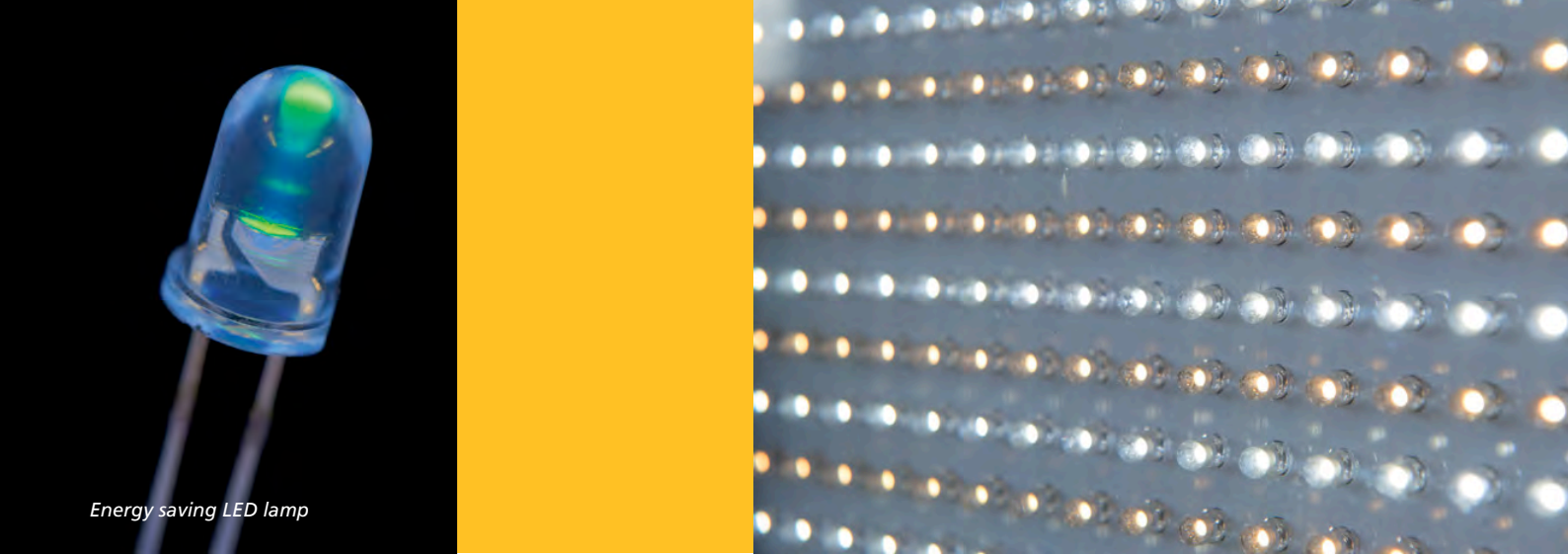
## **Business Unit Energy Systems**

*Head: Dr. Claudia Güth*

The rapid economic growth in developing countries will lead to an increased demand for energy in the future throughout the world. The Fraunhofer Project Group IWKS addresses this trend through research investigating the use of new materials and products that contribute to a reduction of energy consumption. The Project Group IWKS sets its focus on substitution of materials, processes, and systems with a view

to energy efficiency, lesser consumption of resources, and environmental compatibility. A central topic at this time is the energy-efficient generation of low temperatures. At present, approximately 14 % of all of the electrical power consumed in Germany is used for refrigeration technology each year. Experts consider the field of refrigeration and air-conditioning to be one of the fastest growing. Technical refrigeration is achieved almost exclusively through compressor-based systems which necessitate the use of coolants with a detrimental impact on the environment and the climate. Unlike conventional cooling systems, »Magneto-caloric cooling« is a technology that makes use of the magneto-caloric effect: Magneto-caloric materials heat up when exposed to a magnetic field and cool down as soon as the field is removed. This future-oriented technology promises to increase the energetic system efficiency by 30 % as compared to conventional gas compressors and therefore bears an enormous savings potential for electrical energy throughout the world. Moreover, a magneto-caloric system can be operated without a coolant and its hazardous effect on the environment and climate, and thus provides an energy-efficient, low-vibration and low-noise alternative to conventional cooling systems.

The Project Group IWKS aims to address the markets of cooling units, heat pumps, and air-conditioning units with a broad portfolio of new materials, technology concepts and electronically-controlled systems. The development of materials for e.g. permanent magnets and magneto-caloric materials provides the foundation for new technologies in innovative energy systems.



Energy saving LED lamp

## Business Unit Lighting

Head: Dr. Jörg Zimmermann

Illuminants, such as energy-saving lamps and LEDs, still contain various hazardous substances and rare elements that are notable. The recovery of mercury from fluorescent lamps and the separation of rare earth elements are insufficient at this time.

Currently, the elements that can be recovered from illuminants are hardly used as secondary raw materials. Moreover, the existing methods are very laborious and a burden on the environment. The recycling of LEDs is not made into an issue since there are no reasonable approaches to solutions at this time. There is a need for suitable methods for the recovery and re-use of critical raw materials to attain an ecologically and economically positive result. As an alternative to recovery, the Business Unit Lighting is concerned with the substitution of elements, materials, and systems. The incentive for substitution of critical raw materials is given by their market price as well as socio-political sustainability criteria.

The focus is not only on illuminants, but also on cathode ray screens, scintillators, luminophores, and other light-emitting components, in which critical elements are used. For many of these components, there is not even a collection system in effect at this time.

The goals of this Business Unit are the optimization and development of innovative recycling methods for the rehabilitation of lighting systems and the development of new systems with a reduced content of critical elements. Increasingly scarce metals, e.g. rare earth elements, shall thus be recovered from lighting systems as secondary raw materials for recycling into the materials cycle. This reduces the storage of hazardous substances and promotes the independence from raw material deposits. Aiming for the development of economic and environment-friendly methods that can be used in concepts for new resource-sparing illuminants.



# GERMAN PHOSPHORUS PLATFORM DPP

## FOUNDING OF THE GERMAN PHOSPHORUS PLATFORM DPP

At its 80<sup>th</sup> meeting on 7 June 2013, the Conference of Ministers of the Environment responded to the critical current situation of phosphorus utilization and welcomed the initiative to found a German Phosphorus Platform (DPP) under the umbrella of the Fraunhofer Project Group for Materials Recycling and Resource Strategies IWKS. The DPP was founded in November 2013 and is directed by Prof. Dr. Stefan Gäth. The aim of the DPP is to establish a sustainable phosphorus management in Germany through a co-operation with the European Phosphorus Platform and international phosphorus networks.

A first essential element is going to be the establishment and management of an interactive information and monitoring database. This includes a new documentation database for more transparency in existing phosphorus flows and for quality assurance in the utilization of phosphorus. Aside from networking the players from the interested industries, public and private organizations as well as from research and development facilities, and bundling the existing knowledge and experience for a more efficient phosphorus use, the focus is especially on the development of innovative methods for recovery and the provision of secondary phosphorus resources as well as the exchange of information and co-ordination of projects and concepts related to the optimization of recycling procedures.

An industrial segment- and technology-transcending phosphorus forum will be established to strengthen the communication between the developers of technology, entrepreneurs, and the political players.

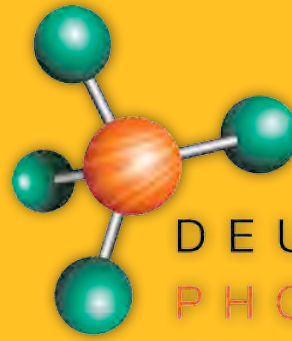
## Technical background

Phosphorus is a very special substance in nature. Phosphorus compounds are present in the molecules bearing the genetic information of all living beings, they play a central role in the energy metabolism of biological cells and also in a multitude of other biological processes. A sufficient supply of this element is therefore essential for the growth of plants as well. This underlines the significance of phosphorus compounds for the use of fertilizers in agricultural production. Moreover, major amounts of phosphorus are utilized in industrial applications, including the food and beverages industry, construction materials industry, detergent industry, semi-conductor and fluorescent lamp industry.

Phosphorus is used widely and in large quantities, which is associated with a major impact on the environment, such as over-fertilization and water pollution due to its use in agriculture. Aside from these problems, some other issues are moving to the fore, such as how the increasing demand in food production for the ever-increasing number of people in the world can be met in the long-term or the increasing demand in technical application fields.

## The availability of phosphorus is critical

The export-oriented production of phosphorus is limited to just a few countries and the reliability of its supply is therefore dependent on geopolitical conditions – but, in the medium term, not on the deposits which should last for another approx. 250 years. The issue of the reliability of the supply and the burden on the natural environment require politically supported strategies, which promote the efficient utilization



# DEUTSCHE PHOSPHOR PLATTFORM

of phosphorus and, specifically, the recovery of phosphorus through effective recycling and reprocessing methods, and are aimed at replacing phosphorus in industrial productions.

The utilization or use of phosphorus is associated with high dissipation rates and, in agriculture, also with strong pollution of soil and water as well as with negative repercussions for the biodiversity, feeds and, ultimately, our food.

## Contact

Head of the DPP  
Prof. Dr. Stefan Gäth  
☎ +49 6023 32039-801  
[stefan.gaeth@isc.fraunhofer.de](mailto:stefan.gaeth@isc.fraunhofer.de)



Head of the Competence Team  
Phosphorus  
Dr. Lars Zeggel  
☎ +49 6023 32039-833  
[lars.zeggel@isc.fraunhofer.de](mailto:lars.zeggel@isc.fraunhofer.de)



# FRAUNHOFER CENTER HTL

## ENERGY- AND RESOURCE-EFFICIENCY IN INDUSTRIAL CERAMICS MANUFACTURING

A large fraction of the primary energy consumed in Germany is used in energy intensive heat treatment processes in manufacturing, for instance in the manufacturing of ceramic materials. These processes are usually based on decades of experience. But through modern simulation methods, in-situ measuring procedures, and a detailed understanding of the ongoing structure-property relationships while the temperature treatment is progressing, significant improvements can be attained not only in the quality of the products, but also in terms of the expenditure of time and energy. Much can be saved in these areas.

The research and development activities of the Fraunhofer ISC associated Fraunhofer Center for High Temperature Materials and Design HTL residing in Bayreuth are aimed at improving the energy- and resource-efficiency in highly energy-consuming industries - through optimized materials as well as through optimized process technology in the heating and heat treatment procedures. This creates added value not only for the participating industrial partners, but for the national economy in general due to the reduced consumption of primary energy and lower CO<sub>2</sub> emissions.

### Conductive ceramics - innovative heating technology

One example of improved heating and kiln technology developed by the Fraunhofer HTL is a conductive ceramic material for use as a heating element. The goal of this development was to attain a high heat output very rapidly and efficiently, while maintaining a homogeneous heat distribution within the heating element. Accordingly, this was to be achieved foregoing the conventional combinations of heating coils

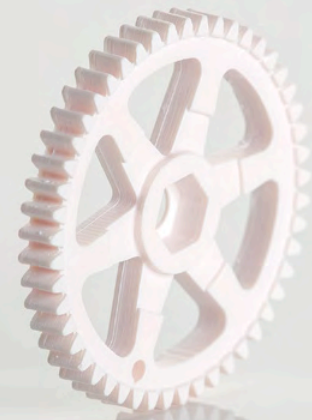
and insulating material. For this purpose, a porous support plate was infiltrated by a polymer coating developed at the Fraunhofer ISC and a special electrode concept was developed. The coating is a precursor stage of a high temperature-resistant ceramic material. The voltage supplying electrodes are connected in a form-fit to the high temperature-resistant surface and are designed to not produce any energy losses from hot spots during the heating process. The ceramic material features high conductivity and a homogeneous heating and cooling behavior.

The ceramic heating element is operated at a voltage of as little as 12 V and reaches a temperature of 200 °C within ten minutes. Even an operating temperature of 400 °C can be attained easily with this simple ceramic material. Fitting the ceramic material with an additional oxidation layer allows heating temperatures of up to 800 °C. The heat is emitted homogeneously across the entire plate. Due to the low voltage, it is not necessary to insulate the conductive ceramic material in many applications. However, where insulation is needed regardless – e.g., if higher voltages are applied – it can be added by means of a high temperature-resistant non-conductive coating. Since the mass of the heating plate is low, temperature changes can be controlled precisely and the response times are very short.

This provides a concept for kilns for temperature ranges of up to 400 °C or even 800 °C which are characterized by high efficiency, homogeneous emission of infra-red radiation, and exact temperature control. Since the ceramic material is also very resistant to chemicals, the concept is also very well-suited for pyrolytic processes, to name just one example.

The high conductivity and mechanical stability of the ceramic material is of interest in other application fields as well, for example in textile processing, where it can prevent electrostatic charging of the fibers or filaments during the process.





*High-precision 3D printing of ceramic components:  
sprocket, diameter 1.7 cm*

### Low-mass kiln furniture

Ceramic products are subjected to various heat treatment steps during their manufacturing, such as sintering and firing. For this purpose, they are placed on special racks in a well-defined arrangement and these racks are then introduced into the kilns. The racks are part of the so-called kiln furniture. They can take all kinds of shapes, from a small ring up to large shelves-like structures. Their essential role is to hold and possibly support the ceramic green compacts during the sintering process such that these do not change shape even at high temperatures and to make sure they are positioned securely and do not touch other green compacts. The kiln furniture material must not react with either the green compacts or the kiln atmosphere, which means it must be temperature-resistant and largely inert.

The kiln furniture accounts for up to two thirds of the mass placed into the kiln and must be heated and thermally-controlled during the heat treatment. Optimizing the kiln furniture can have a positive impact on energy consumption. The Fraunhofer Center HTL aims to reduce the mass of the kiln furniture through the use of fiber-reinforced highly stable specialized ceramics featuring an altered micro-structure. This allows the heat capacity to be reduced significantly. The fibre-reinforced ceramics and the porous ceramics manufactured at the Fraunhofer Center HTL show approximately 20 % higher strength than commercial kiln furniture materials and can be used at firing temperatures of up to 1,600 °C. This means that even in high temperature ranges, comparable or even better stability can be attained from significantly less material and the kiln furniture mass introduced into the kiln can be reduced accordingly.

### Generative ceramics manufacturing

The progress in 3D printing technology opens up interesting new opportunities in ceramics manufacturing. Especially complex ceramic components with finely structured details, which previously could not be manufactured at all or only with immense expenditure of materials, can now be produced by building up layer-by-layer in a resource-efficient manner. The main advantage of generative manufacturing of ceramic components at this time is in the area of small batch production of high-priced complex products featuring high surface quality or other component geometries that cannot be implemented by other routes. As such, this technology must be seen mainly as a supplement for conventional manufacturing methods at this time.

The advantages, i.e. freedom of design, manufacturing largely without post-processing – depending on the surface requirements of the finished component, are associated with the use of a large fraction of organic binding agents in the ceramic slurries used for printing, which is dictated by the technology. This comes with special challenges during the debinding and in the sintering process. The Fraunhofer Center HTL accumulated vast experience in recent years in the generative manufacturing of small batches, especially with a view to component design and layout and thermal post-processing of complex structures built-up by 3D printing. The ceramic slurries are further developed in a cooperation with a commercial vendor of ceramic 3D printing technology aiming to increase both the safety and the reliability of the process. For quality assurance, characterization and analytical methods, such as thermo-optical measuring methods or micro-computed tomography, are available at the Fraunhofer HTL and can also be used by external partners.

### Contact

Dr. Friedrich Raether  
☎ +49 921 786931-60  
[friedrich.raether@isc.fraunhofer.de](mailto:friedrich.raether@isc.fraunhofer.de)



# SMART TRANSLATION

## **TRANSLATIONAL CENTER WÜRZBURG »REGENERATIVE THERAPIES IN ONCOLOGY AND MUSCULOSKELETAL DISEASE«**

In view of the increasing life expectancy, improved awareness of health issues, and the increasing pressure of costs in the health sector, therapy that is personalized or individualized and the ensuing stratification of the patient groups are becoming more and more established.

Regenerative medicine and the development of innovative materials will have a key role in the increasingly more customized management of patients. And they are associated with a great potential of quantum leap innovations. The newly founded Fraunhofer Translational Center in Würzburg is focussed on current trends in healthcare.

Medical devices based on innovative materials and cell-based regenerative therapies are undoubtedly an essential building block of medical management in the future. They will heal diseases more effectively and relieve the burden on the health system creating a sustainable new market segment for the mainly medium-sized companies in this sector in Germany.

The development of innovative products necessitates close cooperation of medical doctors and scientists from the field of regenerative medicine and established medical technology companies. The following synergy interfaces are most promising in this context:

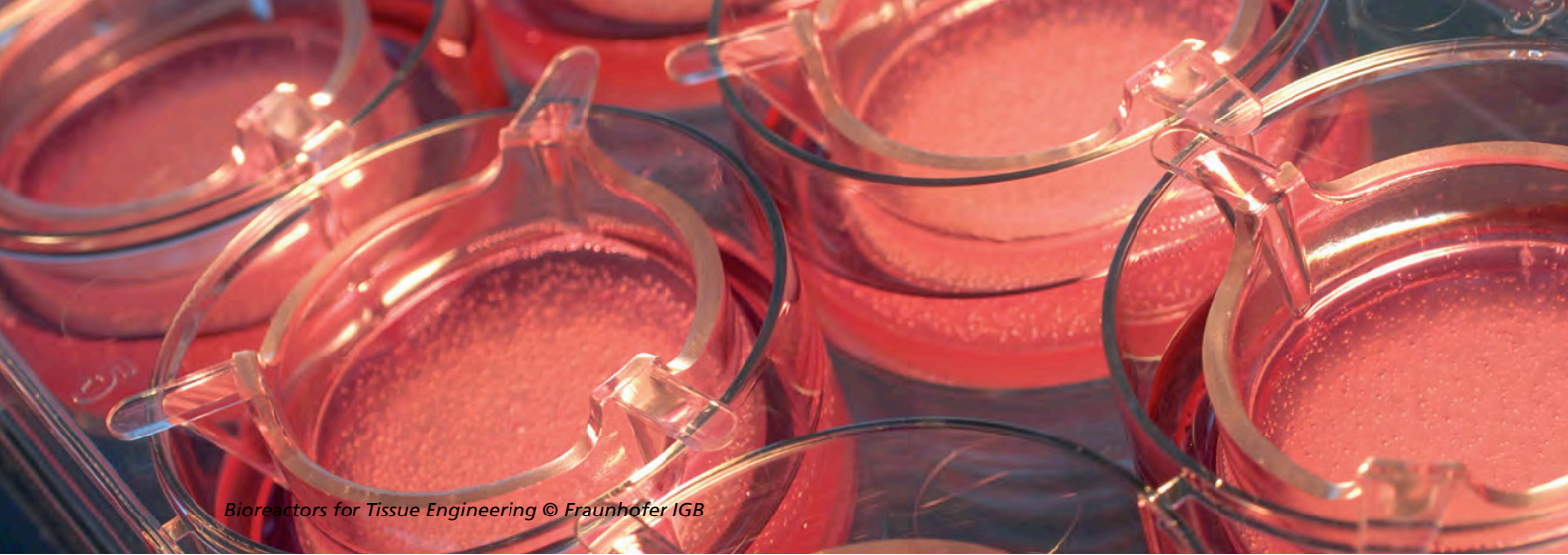
- Biomaterials for clinical use
- »Biologization« of medical devices
- Innovative application and implantation technologies
- Process technology for the production of cell-based implants
- Molecular and multi-modal imaging

The newly founded Fraunhofer Translational Center covers the entire value-added chain of regenerative therapies from product development up to the registration of medical devices, biologized medical devices and cell-based transplants. Aiming for a clear competitive advantage for the German medical devices industry.

### **Novel infrastructure for easy know-how transfer**

The medical technology sector is perfectly suited for an inter-disciplinary approach as it involves the increasingly more common application of a combination of new technologies from micro-system technology, biotechnology, and materials research. The combination of these technologies leads to a highly complex research and technology environment for the development of innovative medical devices. Robust infrastructures facilitating an effective inter-disciplinary cooperation of the participating fields, such as research, development, clinical testing and regulatory affairs, need to be established to this aim. The new center is designed to make a key contribution to furthering the sustained pioneering role of German medical technology companies in the face of global competition to build a future-oriented industry enjoying above-average growth rates. Moreover, this will strengthen the German health system and relieve it of existing burdens.

Scientists, biotechnologists, and medical doctors will work under the joint roof of the Fraunhofer Translational Center. This bundles the specific expertise in scientific methodology, registration-relevant animal models and materials, and the performance of (pre-) clinical studies to promote the transfer of new materials and/or cell-based regenerative therapies to medical applications.



Bioreactors for Tissue Engineering © Fraunhofer IGB

The Fraunhofer Translational Center thus introduces an infrastructure that is unique in Europe and allows standards for the registration of materials, biologized implants and cell-based therapeutics to be defined early in the experimental development or preclinical research.

As a result, programs for training and education of researchers, clinicians or the technical personnel of the regulatory agencies can be established specifically.

The Translational Center is based on five pillars. These reflect the main focus of the work done at the Center:

- Biomaterials: Regenerative materials and modified implant surfaces
- Implants: Biologized medical devices and cell-based implants
- Bio-reactors: Bio-reactors for tissue engineering
- Test systems: Tissue and tumour models for the development of diagnostic and therapeutic agents
- Theranostics: Particulate systems, molecular imaging, and cell tracking

An alternative method is already being investigated by the Fraunhofer ISC in a co-operation with the Fraunhofer IGB and the German Center for Cardiac Insufficiency (Deutsches Zentrum für Herzinsuffizienz, DZHI) of the University Clinic of Würzburg, and involves replacing dead tissue with vital tissue that was grown ex-vivo and then was transplanted into the body. This area of biomaterials also utilizes the silica gel fibrer fleece for chronic wound healing that was developed at the Fraunhofer ISC. In the »Particulate Systems and Molecular Imaging and Cell Tracking« field, the Fraunhofer ISC cooperates with the Fraunhofer IME and the Fraunhofer IIS in the scope of an inter-disciplinary project to develop an innovative automated leukaemia diagnostics method based on nanoparticles.

The research concept, infrastructure, and inter-disciplinary expertise of the Fraunhofer Translational Center in Bavaria are a unique combination throughout Europe. The Center is also integrated into an established and renowned medical faculty and university. The integration on the part of industry is product- and/or project-related. So, the center can offer a comprehensive R & D portfolio as well as a platform along with the required infrastructure to implement desired research goals. This enables not only a structured approach to the users (physicians and care-givers), but affords easier access to co-operations with Fraunhofer researchers and developers.

#### Contact

Dr. Jörn Probst  
☎ +49 931 41 00-300  
[joern.probst@isc.fraunhofer.de](mailto:joern.probst@isc.fraunhofer.de)



Prof. Dr. Heike Walles  
Würzburg Branch of the  
Fraunhofer IGB  
Translational Center  
University Hospital Würzburg  
Department of Tissue Engineering  
& Regenerative Medicine  
☎ +49 931 31-80183  
[heike.walles@uni-wuerzburg.de](mailto:heike.walles@uni-wuerzburg.de)  
[heike.walles@igb.fraunhofer.de](mailto:heike.walles@igb.fraunhofer.de)





# SUSTAINABILITY AT FRAUNHOFER ISC

## SUSTAINABILITY – RESPONSIBILITY IN RESEARCH AND DEVELOPMENT

Sustainability – it means to act responsibly beyond today and across national borders. Economic prosperity and social cohesion need to be made consistent with the protection of natural resources. The ecological and social consequences of the prosperity of a few industrialized nations must not be a burden to other countries or future generations.

Germany's goals in this regard are ambitious and will be pursued – not least – through raw materials strategies and materials efficiency technology. This has been called »sustainable development«. The Fraunhofer ISC is accepting the challenge of sustainability on two levels: As a research institution and as a Business Division.

### Sustainable development

One focus of the Fraunhofer ISC as a materials research institution is on the development of functional materials possessing unprecedented combinations of properties. Concurrently, the portfolio of materials is expanded towards renewable raw materials and fully recyclable components. Protection of the environment, resource-sparing aspects, recycling strategies, eco-design, environment-friendly disposal and user friendliness are taken into consideration from the very start of any development of new materials and components.

Funding of current research projects always considers the sustainability of the development. Two current projects, in which the Fraunhofer ISC is involved in a prominent role, may serve as examples:

The large European research project DIBBIOPACK commenced in 2012 and aimed to develop bio-based and bio-degradable films, containers, and packages. The project consortium includes five companies and six other institutes aside from

the Fraunhofer ISC. The research group of Dr. Sabine Amberg-Schwab is concerned with developing innovative bio-degradable functional coatings in order to optimize the mechanical and barrier properties of packaging materials. Anti-microbial properties are of interest as well. Moreover, smart technologies are to be integrated into the packaging to furnish the consumer with important additional information about the product, such as remaining shelf-life or the current quality status. In addition, production processes and manufacturing technologies are being optimized. The new multifunctional and »smart« packaging will be adapted to the latest ecological requirements along the entire materials and production chain.

Electro-mobility is another area, in which research and application go hand in hand at the Fraunhofer ISC: Since October 2013, employees of the Institute have been using electric bicycles for commuting as a service to science. This is part of the PEDEIEc research project, »Commuter eBike long-term test involving electrical and electrochemical studies (Pendler-eBike Dauertest mit elektrischen und elektrochemischen Untersuchungen«). The study of the e-bike as a commuter vehicle focusses on the optimization of the battery systems. For this purpose, tour profiles are recorded for a period of more than 12 months and are then analyzed for systematic investigation of the ageing of the battery packs and individual battery cells as well as the impact of the charge control.

### The Fraunhofer ISC in the Sustainability Network

Permanent successful economic operations are only possible if the environment and society are treated with care. That is why commitment to sustainability is an integral part of the mission statement of the Fraunhofer-Gesellschaft. Together with the political and business communities as well as with society, Fraunhofer-Gesellschaft would like to make its own contribution to secure sustainable development, which is indispensable.



*Sustainable use of resources  
for a livable future*

That is why Fraunhofer intends to better adapt research and the implementation of results to the general principle of sustainability, to analyze and optimize internal Fraunhofer processes with a view to sustainable development and to represent sustainability concepts both internally and externally.

The Fraunhofer Sustainability Network supports the current strategy process of the Fraunhofer-Gesellschaft. Fraunhofer ISC is one of 20 institute members of the network. This is to enhance the interconnectedness and cross-linking of research topics and stakeholders with a close relation to sustainability. This way, research efficiency can be enhanced and at the same time, the increasing complexity of research with a view to »sustainable developments« can be taken into account.

### **Resource consumption and waste production**

The responsible use of energy and available resources is a top priority for Fraunhofer ISC. In 2013, Fraunhofer ISC's power consumption totaled 3726 megawatt hours. Approx. 2040 megawatt hours were used for long-distance heating. Water consumption amounted to 9794 cubic meters. A total of 81 tons of waste was produced. The figures include all Fraunhofer ISC locations. Internal resource consumption and waste production are closely monitored in order to establish a basis for critical evaluation and improvement measures.

Another example for the implementation of the sustainability concept is the approach to print materials. Print shops that use climate-neutral production and use print colors on climate-neutral plant oil basis are given preference.

### **Family-friendly policies and junior staff development**

Fraunhofer ISC also invests in sustainability in its capacity as employer. The topic of compatibility of family and work often decides the choice of employer and domicile. Fraunhofer ISC is aware of the high priority the topic of family-friendly policies has among its employees and offers individual contracts, flexible working times, home and tele work. That way, the employees can adjust their work time to their individual needs and situations. By offering the possibility of bringing children to the office, the Institute facilitates their employee's re-entry in their job after parental leave. The share of ISC's female employees is 49 percent, among scientists 28 percent. By joining the »Alliance Family and Work in the Würzburg Region« in fall of 2013, the Institute emphasized its focus on the compatibility of family and career.

Junior staff development is an absolute must for a future-oriented employer, especially considering the future risk of shortage of skilled labor. With its »Fraunhofer Talent School«, Fraunhofer ISC afforded students interested in natural sciences the opportunity to get an insight in applied research. Here, the focus is both on the exchange of ideas and knowledge with other participants from all over Germany and scientists, and on practical work in a laboratory. The workshop is a chance for young people to get to know real, actual research outside the classroom and familiarize themselves with cutting-edge, 21<sup>st</sup> century natural science topics. The Fraunhofer Talent School 2013 was organized by Fraunhofer ISC, the International Convention Center for Cultural Heritage Preservation IZKK and the Initiative for young researchers ijf, and will be a constant in junior staff development. Another component is the membership in the newly founded Würzburg network »Wissen<sup>2</sup>« (knowledge<sup>2</sup>) which is to support students who are interested in conducting their own research projects within their curriculum and who require help from scientists.

### **Award »Sustainable construction« for Technikum III**

When it comes to the Institute's own construction projects, it still meets its high expectations regarding the development of innovative materials. In 2013, the Institute received the bronze pre-certification for the Technikum III building in Würzburg from the German Sustainable Building Council (DGNB). In the categories ozone layer depletion potential, sustainable resource utilization, exterior area quality or accessibility, the Technikum III received the highest possible result of 100 points. Not only does the Technikum III meet the highest possible technical and structural standards, it is also a showcase project on sustainability in technical laboratory buildings. Solar technologies generate heat or cold, photo-voltaic modules integrated in the façade supply electricity for two electric car charging points in front of the building. The indoor climate is supported by a structural temperature control and the motion-dependent light control is based on daylight sensors.

#### **Contact**

Sabrina Rota  
☎ +49 9342 9221-710  
[sabrina.rota@isc.fraunhofer.de](mailto:sabrina.rota@isc.fraunhofer.de)

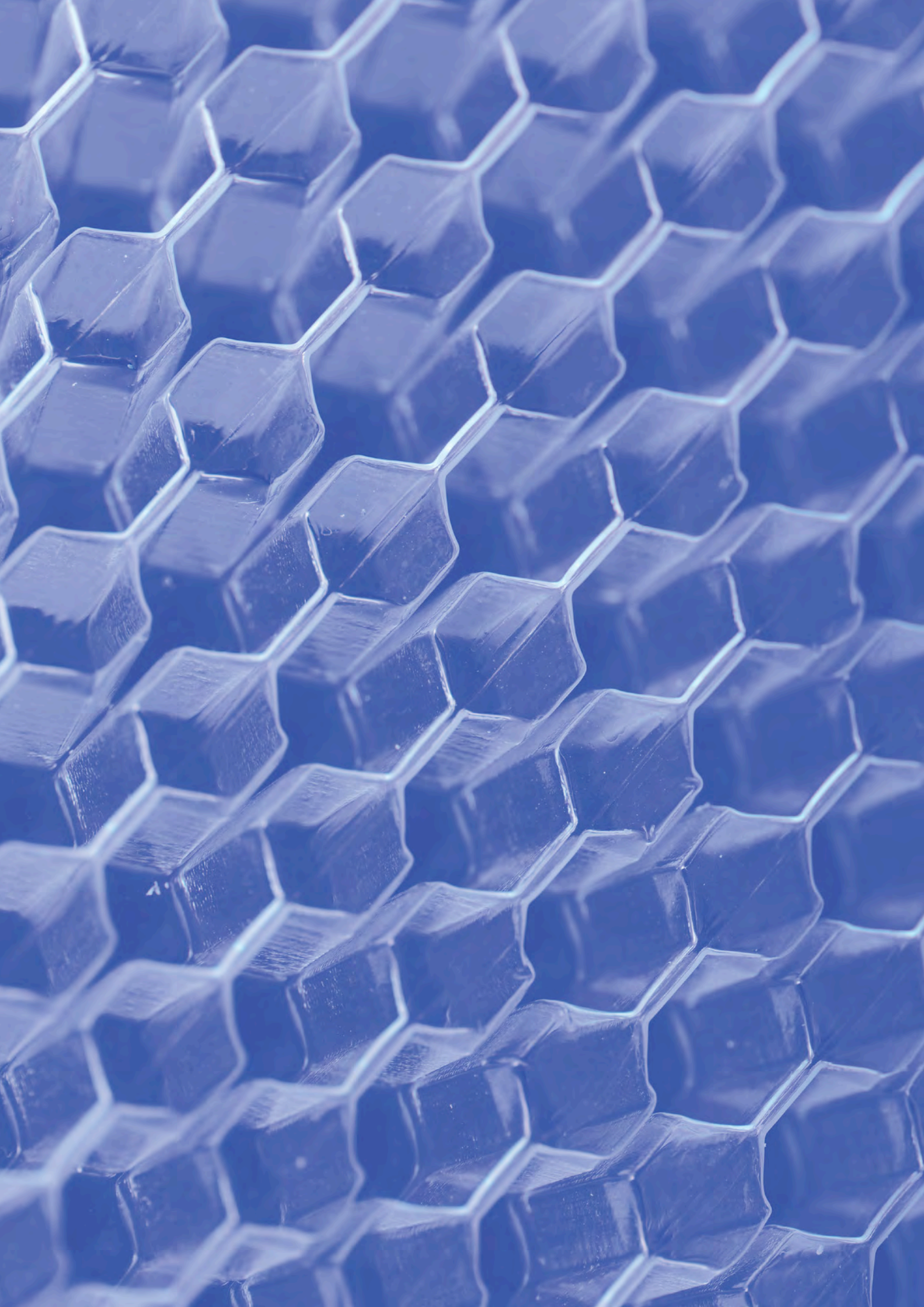






*Solar installation on the roof of TK III*









# **KEY TOPIC**

## **VALUE ADDED MATERIALS**



# RESEARCH PROJECT

# SMART SCAFFOLDS

## STIMULATORY ACTUATOR MEMBRANES FOR TISSUE ENGINEERING

Some 10,000 people in Germany suspected of a heart attack (also called myocardial infarction) are admitted to a hospital each day. The suspected diagnosis is confirmed in 800 of these cases and about 200 patients succumb to the disease each day. Myocardial infarction arises when a blood clot clogs a coronary vessel or a branch of a vessel such that only the amount of blood still transported is insufficient for supplying enough oxygen and nutrients to the heart. The insufficient supply causes the heart muscle to be damaged and the tissue to necrotise.

The most frequent symptoms, such as burning, pressing sensation in the front left chest, radiation into the left arm, massive trepidation, tightness or difficulty in breathing, manifest in only two thirds of the cases. Many afflicted people experience no more than generally being unwell, nausea, a pulling sensation in the back or they are asymptomatic altogether. As a result of this »silent« course of the disease, the infarction may be missed and the needed therapy may be initiated late or not at all. The damage to the heart muscle is irreversible, however, since the tissue is incapable of regeneration. Accordingly, the performance of the heart is reduced considerably after a myocardial infarction. The consequence: The patient suffers from a weak heart (or myocardial insufficiency).

### Growing heart muscle tissue outside the body

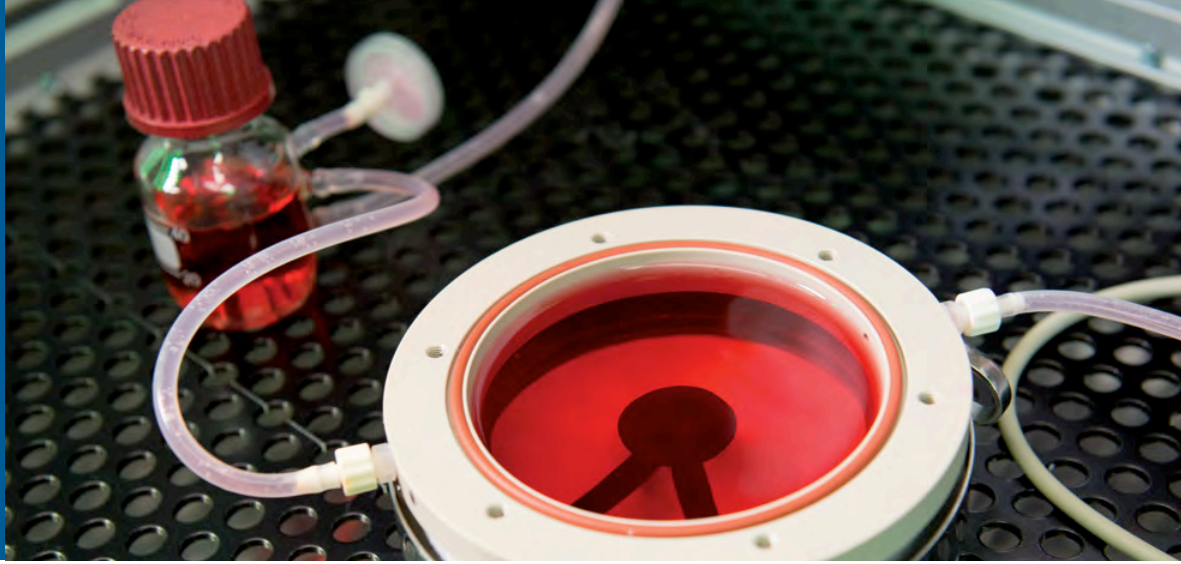
Some modern therapies are based on reactivating zones of dead muscle cells by injecting stem cells right into the damaged area. An alternative method is being investigated by the Fraunhofer ISC in a co-operation with the Fraunhofer IGB and the German Center for Cardiac Insufficiency (Deutsches Zentrum für Herzinsuffizienz, DZHI) of the University of Würzburg, and involves replacing dead tissue with vital tissue that was grown ex-vivo and then transplanted into the body. So-called

inherent cardiac progenitor cells (CDCs) are used to grow this vital tissue. For growth to be successful, the development of a cell support structure with an actuator function is at the focus of the research. Adhering cells are to be stimulated mechanically during the growth phase. The challenge is to develop such a scaffold that plays along during a simulated heart muscle motion. Heart muscle tissue is to be cultured from the CDCs on a biological scaffold outside the body. For this purpose, the biochemical ambient conditions need to be simulated in vitro. An alternative to the biological scaffold uses a synthetic silica gel fiber fleece that has been developed at the Fraunhofer ISC and is approved for chronic wound therapy. The fleece must be sufficiently flexible to transfer the actuator motion to the adhering cells. Another option might be a porous structure made of medical silicone.

### Smart material as a replacement muscle

The actuator motion stimulating the CDCs is provided by a new class of Smart Materials whose actuator effect can be controlled electrically. This involves placing the support structures bearing human CDCs on the surface of a dielectric elastomer actuator (DEA). Developed at the Center Smart Materials CeSMa of the Fraunhofer ISC, these DEAs have to mechanically stimulate the CDCs through a motion. The electrically controlled motion stretches and compresses the support structure. These finely tuned motions are meant to simulate the motion of the heart muscle and to thus stimulate cell growth. The dielectric elastomer actuator consists of a highly stretchable elastomer film made from bio-compatible silicone. Both sides of the film are coated with highly stretchable electrodes. Applying an electrical voltage to the electrodes compresses the thickness of the elastomer film, while its two-dimensional area size increases. Electrical triggering allows the scientists to determine the optimal stimulation for the CDCs. For example the actuator motion can be controlled to simulate a heart beat at different pulse rates.

*Dielectric elastomer actuator  
with electrode pattern for  
tissue engineering*



### Using complex materials smartly

A tissue grown outside the body is advantageous in that there is minimal burden on the patient. Since the CDCs originate from the patient's body, an immune reaction of the body after implantation is excluded. One challenge is to simulate the natural biological ambient conditions in a bio-reactor as closely as possible in order to be able to grow a vital and functional replacement tissue using CDCs on a support structure and a dielectric elastomer actuator. In this context, the designs of the electrodes and the time profile of the stimulation can be adapted as appropriate.

Smart Stimulation, a smart use of novel adaptive materials at the Fraunhofer ISC: The simulation of a biological process through an innovative artificial material. The cooperative research project of the Fraunhofer ISC and the Fraunhofer IGB focuses on a medical solution that improves the quality of life of patients afflicted by a weak heart, enables them to partake in a normal working day, and, last, but not least, reduces the costs.

### Contact

Dr. Holger Böse  
☎ +49 931 4100-203  
[holger.boese@isc.fraunhofer.de](mailto:holger.boese@isc.fraunhofer.de)



### Contact

Dr. Jörn Probst  
☎ +49 931 4100-300  
[joern.probst@isc.fraunhofer.de](mailto:joern.probst@isc.fraunhofer.de)



# RESEARCH PROJECT MULTINABEL

## SMART NANOPARTICLES – NEXT-GENERATION LEUKAEMIA DIAGNOSTICS

Leukaemia is a systemic disease. Systemic diseases have an impact on the entire body and manifest specifically in the nervous system, the muscles or the blood, as in leukaemia, to name but a few. This affects the bone marrow or the haematopoietic system, i.e. the system producing the blood. The normal process of blood cell production is disrupted by uncontrolled proliferation of leukocytes (white blood cells) and leukocyte precursors. In 2010, approximately 11,500 people in Germany had a new diagnosis of leukaemia. Six percent of these were children and adolescents below 15 years of age. The most common form of leukaemia in adults is called acute myeloid leukaemia (AML) and has an incidence rate of 4 cases per 100,000 people in Germany. Although children and neonates can be afflicted by this disease as well, the mean age at the time of diagnosis is 67 years. AML is a very heterogeneous disease and is fatal after a short period of time if left untreated. Accordingly, it is very important to have a safe, rapid, and reliable diagnostic and therapeutic procedure.

### Automated diagnostic procedure

Due to the complexity of this disease, it is very laborious to diagnose the disease at an early time and in the course of a therapy. The development of improved diagnostic methods can increase the healing rate and improve the quality of life of the afflicted patients significantly. The Fraunhofer ISC, Fraunhofer IME and Fraunhofer IIS are co-operating in an interdisciplinary project researching the development of an innovative automated diagnostic procedure. The project combines the expertise of the individual partners in the development of specific antibodies/biomarkers (IME), multifunctional fluorescent nanoparticles (ISC) and a hybrid transillumination and fluorescence imaging and processing

technique (IIS). The project aims to establish a method for automated identification of cells that are relevant for disease through the use of disease-specific biomarkers.

### New method reduces the number of steps in diagnostic work-up

The diagnostic methods used for leukaemia to date are very laborious and time-consuming. This includes preparing a smear from the bone marrow sample obtained and analyzing it by means of transmitted light microscopy. At the same time, samples for flow cytometric analysis are prepared and used in measurements. The results obtained from the two methods then need to be analyzed and interpreted by trained professionals.

The aim of this research project, which started in January 2013, is to recognise diseased cells through both their morphology and disease-specific surface markers. This information is crucial for the specialist in laboratory medicine to be able to initiate a suitable (individualized) therapy for each patient at an early point in time. The automation and concurrent combination of different methods for analysis of the preparations therefore assumes some of the tasks of an expert in leukaemia diagnostics. For this reason, a measuring system of this type might come in handy in many laboratories.

### Combining different diagnostic methods

Studies have shown that the AML-typical cells presumably arise from so-called leukaemic stem cells and differentiate through the expression of different surface molecules. Considering this background, immuno-phenotyping is becoming ever more important in the diagnostic work-up in haematology. The detection of such stem cell markers can

\* Source Robert-Koch-Institut



have a major impact on the prognosis and the selection of the adequate therapy. The Fraunhofer IME has been working for a number of years on developing new methods for selecting antibodies that are relevant for diseases (tumour diseases including leukaemia) right on primary patient material. These antibodies can be visualized by labeling them with fluorescent nanoparticles (NPs).

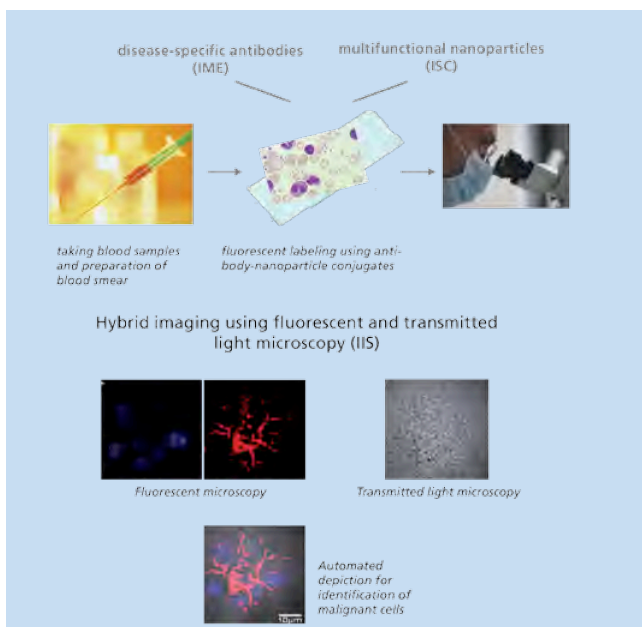
Multifunctional NPs are characterized by their high photostability and are matched to the wavelength used in fluorescence microscopy. The joint project aims to use AML as an example to demonstrate that a matched combination of antibodies, fluorescent NPs, and hybrid transmitted light/fluorescent image recording and processing for early detection of leukaemia in bone marrow biopsies is feasible and can be automated. The primary goal is to implement early detection and specification to differentiate different sub-types of AML. This goal is to be attained through the synergy of image-based analysis of morphological features of immature blood cells

in bone marrow specimens in conventional transmitted light microscopy and biomarker labeling with antibody-coupled fluorescent NPs in the corresponding fluorescence images. As a result, the number of working steps can be reduced, costs can be saved, and a reliable diagnosis can be assured.

### Use in different imaging methods

The competence team »Particle Technology and Interfaces« at the Fraunhofer ISC has been working for a number of years on developing multifunctional NP systems. These systems bind biomarkers, encapsulate active substances, and are accessible to different imaging methods under in-vitro and/or in-vivo conditions. They can be matched both to the biomarker and the sensors of the diagnostic system leading to sensitive biomarker analysis. The NP approach in in-vitro assays increases the sensitivity and the specificity of the method. Moreover, NP-based assays can be used for simultaneous determination of multiple parameters that are relevant for disease (multiplexing). Another advantage of NPs is their improved storage behaviour and the stability of the samples due to the NP-based fluorescence marker. The preparations can therefore be used in later studies as well.

The overriding project supports and strengthens the strategic orientation of the participating institutes in the area of health research and makes a contribution to the Fraunhofer mission »Affordable Health« and to the future-oriented Fraunhofer topic »Biofunctional Surfaces«.



### Contact

Dr. Sofia Dembski  
☎ +49 931 4100-516  
[sofia.dembski@isc.fraunhofer.de](mailto:sofia.dembski@isc.fraunhofer.de)



# JOINT RESEARCH PROJECT NANOSOLTEX

## FUNCTIONALIZATION OF TECHNICAL FABRICS WITH WATER-BASED NANO-SCALE COATING SOLS

Protective clothing must meet strict requirements and comply with certain standards, depending on the application area, in Germany and the EU. Personal protection and accident prevention are at the center of this close control. This means that the material used for protective clothing must be manufactured appropriately. Technical textiles are used in many work areas. They are designed to provide protection from mechanical impacts, from heat or flames, moisture or chemical substances as well as from micro-organisms and, in addition, have to possess an antistatic effect.

### Many features combined into one layer

Many versions of protective clothing can provide protection from one or more of these influences. But so far, even special refinement of textiles for protective clothing did not allow all desired protective properties to be combined in one product. In the scope of a cooperation project with the Saxonian Textile Research Institute (Sächsisches Textilforschungsinstitut e. V., STFI), T\_O\_P Oberflächen GmbH and other industrial partners, the research group of Dr. Sabine Amberg-Schwab at the Fraunhofer ISC successfully developed a new hybrid coating sol based on inorganic-organic hybrid polymers that can fill this void. The InnoSolTEX Protect coating systems are based on the substance class of ORMOCER<sup>®</sup>s, which have been developed at the Fraunhofer ISC. They are manufactured by means of chemical nano-technology and their profile of properties can be varied to suit specific applications. The coating sol made in this way is then functionalized on an aqueous basis such that multiple properties can be combined into the same coating. The coating can be hydrophobic, flame-resistant and washable and at the same time possess an antistatic surface, improved abrasion resistance, and an anti-microbial effect.

The novel coating system can be used either to combine these properties or to design customer-specific profiles of properties and functions. The modular system can be used to assemble coatings showing the following properties according to individual requirements:

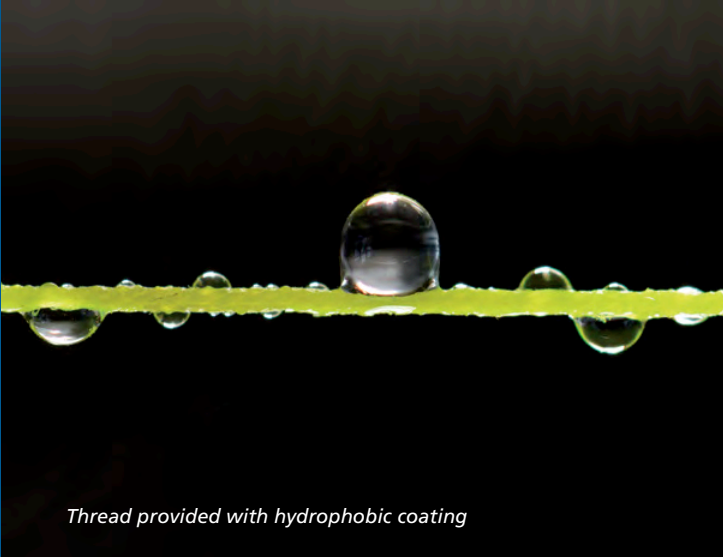
- abrasion-resistant
- antimicrobial
- antistatic
- hydrophobic
- washproof
- flame-resistant

### Manufactured in a single working step

The novel coating developed at the Fraunhofer ISC can be applied equally well to threads and finished fabrics or fleeces. Another benefit: Fabrics can be coated on existing production facilities and, even better, in a single working step. Different properties can be combined according to need in this step. The new nanosol lacquers can be processed easily like classical textile auxiliary agents and can be diluted with water. They can be stored at a temperature of 6 °C for a number of weeks without any change in the product being apparent.

Paralleling the development of materials at the Fraunhofer ISC, T\_O\_P Oberflächen GmbH researched the synthesis of the coating material and the up-scaling. Meanwhile, batch sizes of up to 30 kilograms can be produced and initial industrial tests have been completed. Further filament coating tests have shown that the coated filaments can easily be processed into two-dimensional structures. They are non-tacky and do not tear and can be un-reeled well even at high machine speeds.

Samples were functionalized with the novel coating material at the STFI e.V. and dried at different temperatures. The fabrics



Thread provided with hydrophobic coating



Color-neutral coating

can be washed at up to 60 °C using a delicates program. No stress whitening or pilling were observed. The samples can be washed with a mild detergent or disinfectant. Even after multiple washing cycles, the fabrics remain resistant and continue to show the antimicrobial activity.

The benefits of the novel hybrid coating add up. First of all: The manufacturing involves just one step, which means lower energy and production costs, and yields a product with better performance that is easy to process on conventional industrial plants. The cross-linking and drying times are similar to those of conventional textile auxiliary agents.

can be functionalized using the novel coating. Likewise, the flame-resistance of fabrics might add benefits in the areas of fire protection, for instance in the case of curtains or drapes in large rooms or public facilities. Another area of interest are passenger vehicle interiors – to name just a few examples.

### Contact

Dr. Sabine Amberg-Schwab

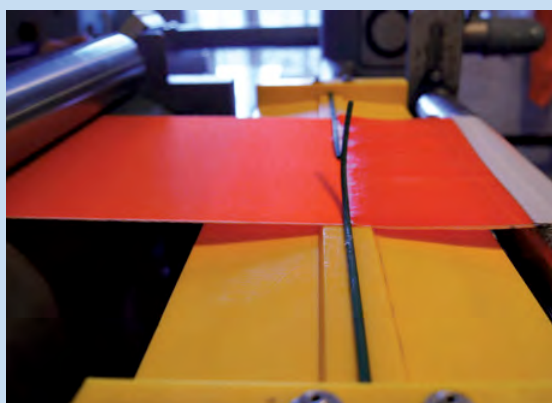
☎ +49 931 4100-620

[sabine.amberg-schwab@isc.fraunhofer.de](mailto:sabine.amberg-schwab@isc.fraunhofer.de)



### Versatile applications

Additional fields of application are conceivable for the new textile coatings. They afford new opportunities in air cleaning as well. Filter fleece substances for air-conditioning facilities in public buildings, hotels or even passenger cars



Equipment testing at German Project Partner TTR Ingenieurbüro für textile Verfahrenstechnik, featuring a vacuum extraction system from OptiVac AB, Sweden. (© STFI e.V.)



# JOINT RESEARCH PROJECT HARWIN

## THIN THERMAL INSULATION GLAZING INVOLVING TRANSPARENT COMPOSITE MATERIALS

As the turnaround in energy policy is in the making and worldwide efforts are being made to lower CO<sub>2</sub> emissions, saving primary energy promises to be another major factor. Aside from increasing the efficiency of energy production and energy-intensive production processes, the reduction of energy consumption in the construction industry also plays quite a role in this context.

This is where a research project seeking new materials solutions for thermal insulation glazing comes into play. In the EU-sponsored framework project HarWin (Harvesting Solar Energy with Multifunctional Glass-Polymer Windows), researchers from European universities, research institutions, and companies join forces to investigate the basic principles for new light-weight polymer-glass composite materials for energy-efficient windows. These materials are aimed to improve the energy efficiency of building glazing through additional functions. The project is coordinated by Prof. Dr. Monika Willert-Porada of the University of Bayreuth, Germany. Within this framework, the Fraunhofer ISC assumed the task to develop new methods for the integration of latent heat accumulators – also called phase change materials (PCM) – into a thermal insulation composite glass system.

### Phase transition balances temperatures

PCMs have interesting features, one of which is that they have a temperature-equalizing effect. If the room temperature rises beyond the respective melting temperature of the PCM, the material liquefies and removes heat from the room air while doing so. If the temperature in a room drops, the material recrystallizes and releases heat. Paraffin-based commercial systems are available already in the form of wall plasters or wall paints. These materials cannot be used in composite windows

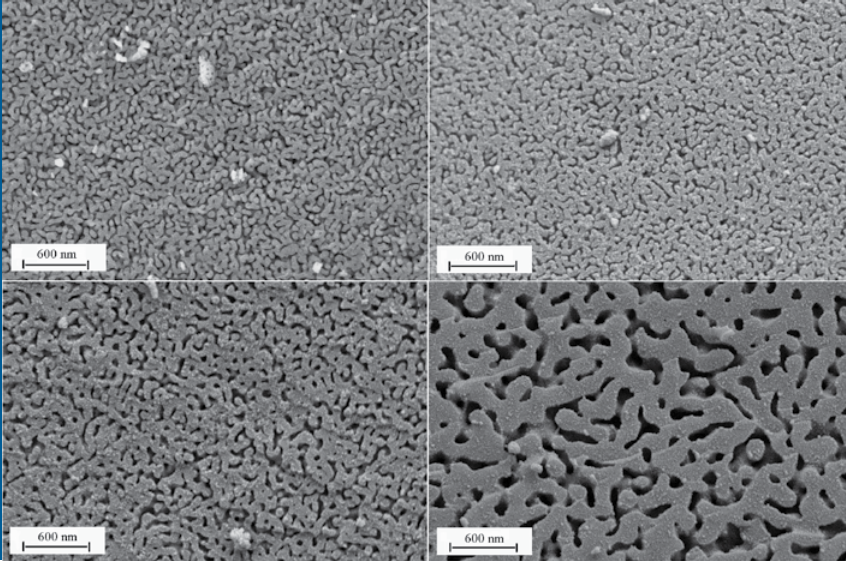
though, because they are not transparent. Inorganic PCMs are in a class by themselves. There are numerous different variants with adapted melting and crystallization temperatures. Unlike paraffin-based systems, inorganic PCMs can be translucent or even transparent if the conditions are right. However, there is no reliable method for encapsulating and incorporating them into a composite material at this time.

### New encapsulation method for inorganic PCMs

The glass researchers at the Fraunhofer ISC and the University of Bayreuth are jointly working on the development of a new method for encapsulating inorganic PCMs to make them usable in composite windows. For this purpose, the PCM is incorporated into small particles made of highly porous glasses using a special procedure. The Fraunhofer ISC contributed its extensive expertise with the production of porous Vycor® glasses from an earlier project. This FORGLAS project was sponsored by the Bavarian Research Foundation (Bayerische Forschungsstiftung). The composition of these glasses, a special temperature treatment leading to separation into different glass phases, and a subsequent treatment with acid, permit the production of defined pore sizes and pore volumes in the glasses.

### Materials know-how for »invisible« helpers

The true challenge in the HarWin project are the conditions, in which the later composite window is to be used. The glass particles loaded with inorganic PCMs have to stay largely transparent. For this purpose, the compositions of the glasses are designed appropriately in a way to have their optical properties match those of the PCMs as best as possible. At the same time, the number of PCMs in the particles should be maximized. Pore sizes and pore volumes need to be optimized to render them suitable for accommodation of phase change materials.



*Porous Vycor® glass – acting as host for the phase change materials*

This means that the ISC researchers working with Dr. Johanna Kron and Ferdinand Somorowsky have to find the right balance of pore size, optical parameters, and pore volume. The leeway for the adjustment of the glass composition is limited further by constraints of the Vycor® glass materials. Moreover, it must be feasible to incorporate the glass particles later on into the polymer support layer, which is laminated between the composite window panes. The surfaces of the glass particles may need to be modified for this purpose. Further challenges are the longevity and the dynamics desired for heat management as well as the complete reversibility of the phase transition between solid and liquid.

of six industrial partners from Germany, Finland, Switzerland, Belgium, and the United Kingdom and researchers from the University of Bayreuth, the Technical University of Szczecin in Poland, and the Fraunhofer ISC.

#### Contact

Ferdinand Somorowsky  
 ☎ +49 931 4100-229  
[ferdinand.somorowsky@isc.fraunhofer.de](mailto:ferdinand.somorowsky@isc.fraunhofer.de)



#### Holistic approach to improving the feel-good factor

A lower mounting depth and lower weight as compared to the current state-of-the-art are to contribute to an efficient construction process. This requirement is met, in part, through the use of polymer materials which also increase the breaking strength. The EU project HarWin includes not only the development of the porous glass particles and the incorporation into the composite layer, but also the investigation of new frame materials made of fiber-reinforced composites, which afford better thermal insulation at lower weight. The glass panes are to be fitted with special anti-reflection coatings to allow more light to enter into interior spaces and the entire composite polymer-glass system shall make a significant contribution to the acoustic insulation. The temperature-equalizing effect of the PCM-combined composite glass windows and the improved lighting conditions in interior spaces as compared to conventional triple glazing should contribute to the feel-good effect in residential and office environments.

Other aspects of the project include the attainable potential of temperature management, efficient application fields for the new composite glass systems, and the economic benefits that can be reaped. The project consortium is a cooperation

The HarWin Project is financed by the European Community's Seventh Framework Programme under Grant Agreement 314653 ([www.harwin-fp7.eu](http://www.harwin-fp7.eu)) from 1 September 2012 to 31 August 2015





*Corrosion testing of coated plates*



# JOINT RESEARCH PROJECT ASKORR

## SELF-HEALING CORROSION PROTECTION – A KEY ISSUE IN THE AUTOMOTIVE INDUSTRY

The corrosion of metals causes economic losses on the order of magnitude of billions of euros every year. In industrial countries, current estimates are as high as approx. 6 percent of the gross national income if all secondary costs like reduced production output or production down-times are included. This adds up to 150 billion euros per year in Germany alone. Corrosion prevention is therefore a very important issue for a sustainable production.

The issue of chromium(VI)-free corrosion protection is held in high regard in industry and research, especially in the automotive industry. Until 2006, it was permissible to protect car body panels from corrosion by chromating with chromium(VI) compounds – a procedure which allows scratches in the protective layer to »self-heal« to a certain degree. An alternative to this procedure has been sought since the comprehensive ban of chromium(VI) in the EU End-of-Life Vehicle Directive of 2007. New developments investigate »smart« corrosion protection systems. In co-operation with project partners from the Fraunhofer Society and Max-Planck-Society, the Fraunhofer Institute for Silicate Research ISC has developed a »smart« environment-friendly solution for corrosion protection based on a sol-gel system with self-healing properties of a new kind.

This is of great import for the durability of the product in automobile manufacturing. The corrosion protection is applied by dip coating the entire body.

In the further production process, there is no way to check the hollow spaces, which are present in individual components before the coating, for the presence of fine cracks in the corrosion protection after coating – a self-healing layer would

be optimal to prevent micro-fissures of this type from causing further damage. Because it is difficult to detect fine fissures in hollow spaces. The customer gets to see only the surface.

### Active protection based on a sol-gel system

Substitutes for chromium(VI) need to perform very well in the new environment-friendly corrosion protection concepts. They have to provide adhesion substrates for later coating, survive forming steps and they have to close small defects in the multilayer composites automatically and rapidly and seal them before corrosion can cause more extensive damage. For a durable passive corrosion protection to be applied as an adhesion substrate that forms a stable protective layer even in subsequent forming processes, an environment-friendly solution on the basis of hybrid nano-composites that is ready for commercial use has already been developed at the Fraunhofer ISC. It offers a very good protective effect for a wide range of applications. But one thing has been missing so far: active protection from the self-healing of small defects.

This is the challenge a project team of basic and applied researchers directed by the Fraunhofer ISC is facing. The two Fraunhofer Institutes ISC and IAP and the Max-Planck Institutes for Polymer Research MPIP and for Iron Research MPIE are joining forces in the ASKORR project to develop an active corrosion protection based on a sol-gel system that involves the encapsulation of active substances. Combining protective layers and active substance containers is therefore a major step towards a damage-tolerant, self-healing corrosion protection.



Different protection coatings after salt spray testing

### Hybrid-polymeric nano-composites substituting for chromium(VI)

The newly developed procedure utilizes hybrid-polymeric nano-composites as substitutes for chromium(VI). Self-healing is designed as a two-component system. Adeptly combining specific zinc coating, hybrid nano-composite materials and new active substance containers produces active multilayer composites that can heal defects or corrosion phenomena in a site-selective manner. The active substance containers in the nano-composite layer and the zinc layer below it are activated by mechanical damage or by a change of pH. The active substance components present in the substrate of the paint are released within seconds and undergo a chemical reaction that produces a solid substance. This effectively provides for site-selective healing. The encapsulation is the basis for a specific mechanically or chemically triggered release of the active substances as soon as micro-fissures arise and at the same time protects the functional ingredients during the zinc coating and/or during the production of the hybrid-polymeric layer. The encapsulation also allows for long-term storage of the functional components.

The scientists successfully produced active substance containers of a particle diameter so small that the particles can be incorporated into the layers of nano-composite and zinc. The combination of more resistant inorganic-organic (hybrid) layers and encapsulated active substances both in the zinc coating and in the hybrid polymer layer is unique and suppresses corrosion specifically only when and where needed.

### Market maturity within two years

Currently, the self-healing capacity of coatings is at the basic research stage, close to the applied level. The application is expected to reach market maturity within one or two years. Fraunhofer ISC can manufacture the hybrid nano-composites in customized manner for specific applications.

The new protective layers provide multi-functionality at low resource consumption. The use of easy-to-clean layers or of corrosion protection on metal and glass or of barrier films for the protection of oxygen- or moisture-sensitive products increases the longevity and durability of the products considerably. This means added value of the products and preservation of value for the end-customer. More added value is created in terms of the environment through this environment-friendly and resource-saving production of coatings.

### Contact

Dr. Gerhard Schottner  
 ☎ +49 931 4100-627  
[gerhard.schottner@isc.fraunhofer.de](mailto:gerhard.schottner@isc.fraunhofer.de)







*Modularly designed dip coating facility with coated plate profiles*



# EU-FUNDED PROJECT INCOM

## SUSTAINABLE LIGHTWEIGHT MATERIALS

Dwindling crude oil reserves and international climate protection goals call for a change of thinking also in the plastic manufacturing and processing industry and demand the development of sustainable resource-saving materials. In the scope of the EU-funded INCOM project (Industrial Production Processes for Nanoreinforced Composite Structures), which commenced at the end of 2013, thirteen partners from seven countries join forces in the development of economical manufacturing processes for lightweight composite materials based on nano-cellulose. The project is coordinated by the VTT Technical Research Center of Finland. The new sustainable composite materials are to provide alternatives to conventional polymer composites that are interesting from both an economical and an environmental point of view for use in the packaging industry, automotive industry or aerospace industry. The research group of Dr. Klaus Rose at the Fraunhofer ISC is in charge of the development of high-strength coating materials in the scope of the INCOM project as these materials, reinforced by the incorporated nano-cellulose, are to impart greater mechanical strength on the composite material

### Nano-cellulose

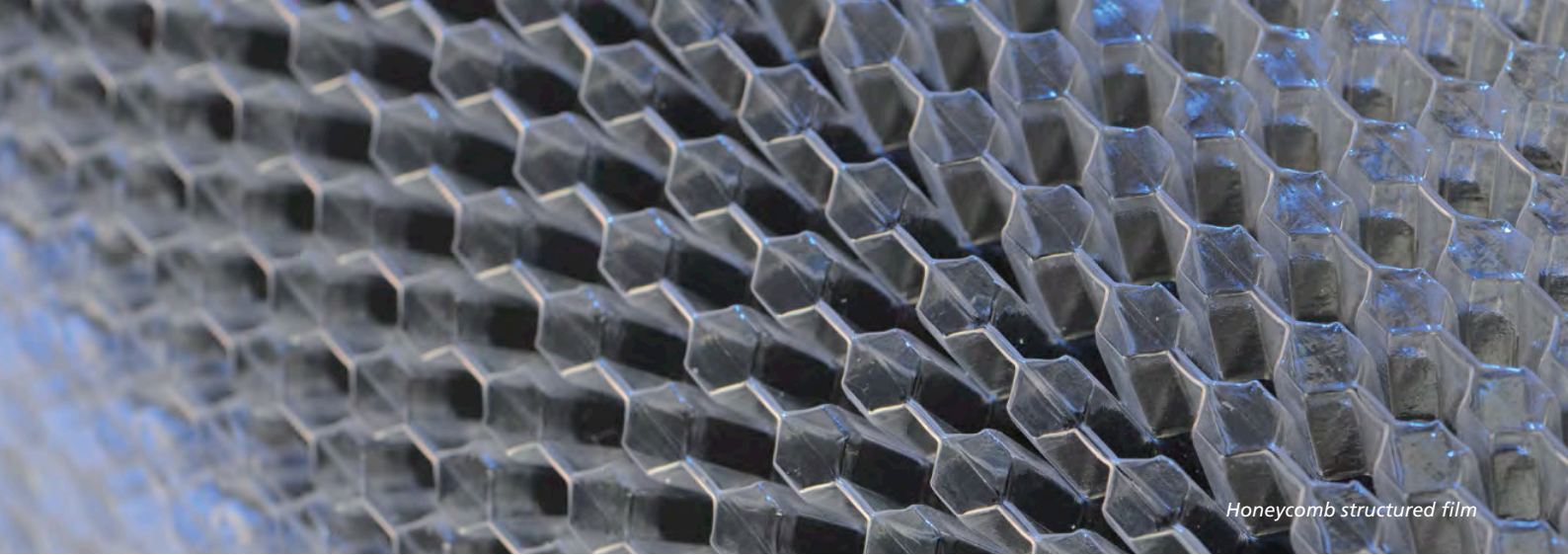
Synthesised from wood, this material features excellent tensile strength at a very low inherent weight. This renders nano-cellulose (NC) clearly superior to other reinforcing materials for plastics. This relatively new material, at least in its current form, is already being applied in various technical and pharmaceutical or cosmetic applications.

## Novel lightweight structures

The INCOM concept is based on lightweight sandwich structures. A reinforcing polymer core is inserted between two cover films. Either plastic foams or the so-called honeycomb-structured films, i.e rigid films pleated into three-dimensional honeycomb structures, are used for this core. The new aspect of the INCOM approach is to combine this structure with NC in order to attain higher rigidity than with conventional plastic lightweight structures. Accordingly, the honeycomb films are to be made even more rigid by the NC-reinforced coatings – similar to the way a chitin shell of an insect provides protection and stability through an external skeleton.

### Reinforcement by coating

The coating sols for this concept are developed at the Fraunhofer ISC. They are applied to the films prior to the structuring process and must meet a number of challenging requirements. For the processing to be economical, it must be possible to apply the coatings by the roll-to-roll method, the adhesion of these layers on the film substrates must be excellent, the layers must withstand the subsequent forming and/or pleating process during film structuring, and they must be able to take up large amounts of the reinforcing NC without losing the requisite processing properties.



Honeycomb structured film

### ORMOCER<sup>®</sup>s as »exoskeleton«

Inorganic-organic hybrid polymers (ORMOCER<sup>®</sup>s) were selected for this task due to their dual nature. The rigidity of ORMOCER<sup>®</sup>s is easy to adjust. They are compatible with most plastic substrates, they are temperature-resistant, and can be processed with a wide range of methods in rapid in-line production procedures – a key aspect in the manufacturing of pleated lightweight structures. The first steps in the INCOM project target the chemical adaptation of the ORMOCER<sup>®</sup>s to the films used for the structuring to allow coating and subsequent forming processes to proceed optimally and to provide for the requisite adhesion across the entire surface of the layers.

### Contact

Dr. Klaus Rose  
☎ +49 931 4100-626  
[klaus.rose@isc.fraunhofer.de](mailto:klaus.rose@isc.fraunhofer.de)



*The INCOM Project is financed by the European Community's Seventh Framework Program under Grant Agreement NMP2013-10-608746 from 1 September 2013 to 31 August 2017*



# CORE-SHELL MATERIALS

## GETTING MORE ENERGY OUT OF BATTERIES

Users of batteries mainly look at the amount of energy stored in a battery and its lifetime. In this respect, lithium ion technology is ahead of the field of its competitors and it allows for mains-independent operation of equipment that had to be directly connected to a mains outlet in the past.

### Increasing the energy density

New applications and environmental regulations demand that the energy density and performance of today's lithium ion batteries is increased. A battery consists of a number of electrochemical cells, and the energy density of each cell is defined as the product of charge density and electrical voltage. One way to increase the density is to increase the charge density of a cell. However, researchers and developers attempting to do so are reaching a limit that is very difficult to shift with the technology available today.

A second way of increasing the energy density, while keeping the charge density the same, is to increase the cell voltage. Commercially available lithium ion cells have a rated voltage of 3.7 V – that is three times more than what nickel-metal hydride or nickel-cadmium battery cells supply. If the cell voltage could be increased even further by using appropriate battery components, the energy density would be even higher. This would lead to a concomitant increase in battery performance.

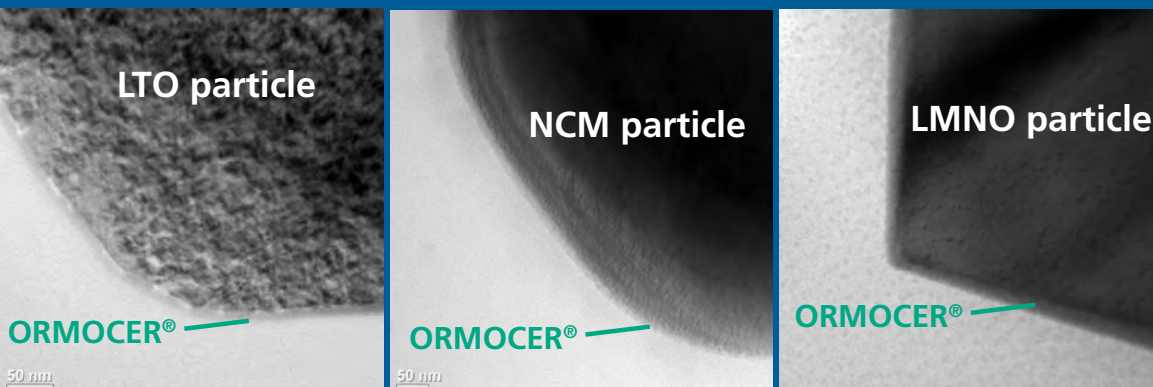
### Higher cell voltage

Researchers and developers of the Center for Applied Electrochemistry ZfAE headed by Henning Lorrmann work at the Fraunhofer ISC on developing battery components that allow for a higher cell voltage. One important aspect are the charge-storing active materials of the battery electrodes, which are responsible for the potential difference and therefore for the voltage of a battery cell. So-called high voltage spinels that attain a cell voltage of more than 4.6 V are already available and other combinations of materials can increase the cell voltage even further. The theoretical limit, i.e. a maximal potential difference of nearly 6 V, is given by the electrochemical series. In practical applications, it is crucial to perfectly match the electrochemical properties of the active materials for the battery electrodes – anode and cathode – to the other cell components in order to implement the levels possible on theory in a high performance and reliable battery.

### Protecting the electrolyte

One of the core issues in the development of lithium batteries at this time is to protect the electrolyte which works in conjunction with a thin membrane between the electrodes to ensure that the battery is charged and discharged orderly and that the electrodes are prevented from short-circuiting. Standard electrolytes used in commercial batteries do not withstand higher battery voltages as corrosion at the interface between the electrolyte and the electrode starts at voltages exceeding 4.3 V.





Core-Shell Particle

To still be able to work with the known standard electrolytes, which are time-proven, tested and inexpensive, the researchers at the ZfAE developed a procedure that protects the electrolyte from the high cell voltage. The charge-storing active material for the electrodes is provided with a functional coating that does not impair the transport of lithium ions, but conducts electrons poorly at the same time. As a result, the electrolyte is exposed to a lower voltage at the electrode surface without a detrimental effect on the cell voltage and the ion transport within the cell. This may seem paradoxical, but it really works. But the materials and the protective coating need to be matched perfectly to each other – a true challenge for materials and process technology.

#### Core-shell particles – electrochemical functional layers on a nanometer scale

The active material for storing lithium ions in battery cells usually consists of special metal oxides. These metal oxides are processed in the form of a powder that contains micrometer-sized particles such that the diffusion pathways are short in order to design the transport of ions into the electrolyte as efficiently as possible. Aiming to introduce a protective coating on the electrode and active materials without jeopardising the battery's properties, the ZfAE team coated the individual particles of the active material with a very thin functional layer.

The core-shell particles obtained in this way can be processed and compacted into electrodes easily. The layer material permits the charge transport without any measurable loss as compared to non-coated active material, but still shields the electrolyte from the high electrical potential at the electrode. As a result, even voltages of more than 4.6 V can be used with standard electrolytes.

At the newly established electrochemical process laboratory of the Fraunhofer ISC in Würzburg, lithium ion cells are manufactured in the form of so-called pouch bag cells using the new procedures and then subjected to ageing and performance tests under realistic performance profiles at the testing laboratory. The long-term stability and performance of the core-shell active materials is being tested and compared to non-coated active materials tested at the same conditions. A concluding post-mortem analysis permits the accurate identification of the ageing processes and highlights starting points for further improvements. Some initial results already indicate that the core-shell particles have a clearly longer service life as compared to non-coated materials.

The materials developed at the Fraunhofer ISC are incorporated into large-scale cell demonstrators and tested in a near-production level pilot facility in the scope of a Fraunhofer-funded support project in collaboration with the Fraunhofer ISIT.

#### Contact

Henning Lorrmann  
 ☎ +49 931 4100-519  
[henning.lorrmann@isc.fraunhofer.de](mailto:henning.lorrmann@isc.fraunhofer.de)



# FUNCTIONAL COATINGS ANTI-DUST

## Anti-soiling surfaces

In solar energy applications, it is immediately apparent to the naked eye: Layers of dust on the surface of solar panels – for photovoltaics and solar thermal energy alike – are more than just an optical nuisance as they impair the function of the panels, which is to transmit sunlight through the glass covers into the solar modules for energy conversion. The Competence Team Sol-Gel Materials and Products directed by Walther Glaubitt has a long history of research investigating the functionalization of surfaces for solar energy use. They successfully modified nano-porous functional layers, originally developed to impart an anti-reflective effect on solar panels, such that they now have an anti-soiling effect as well.

## More light behind glass façades

The transmission of light unimpeded by dust and dirt is important in other places as well, namely windows and large façade glazing. While precipitation removes most of the dirt from the outside of glass façades in our moderate latitudes, dust tends to build up in climatic regions where there is little rain as in dry or arid climates and effectively generates a significant barrier that impedes incident light from reaching the interior of the rooms behind these façades.

To address this issue, a project commenced in 2013 in collaboration with King Abdulaziz City for Science and Technology (KACST) aiming to develop an optimal anti-soiling and highly transmissive functional layer for arid climates. The project focuses on understanding the various soiling phenomena and adhesion mechanisms of dirt particles on surfaces as well as the (further) development of coatings imparting an optimal anti-soiling effect at different ambient conditions.

## Field test in the desert

Test benches for coated glasses have been set-up and run in six different locations in Saudi Arabia since the summer of 2013. These facilities are located in different climatic zones including the capital, Riad, which is known for its very arid climate and metropolitan conditions in terms of air pollution and air-borne fine particles, as well as in two locations on the Persian Gulf in the vicinity of an oil refinery, which also has a very specific pollution profile. Other locations in salty air near the Red Sea and in very arid climatic conditions in the interior of the country complete the broad spectrum of test sites.

## Key issue: Measuring methods – Equipment newly developed for extreme conditions

Firstly, the measuring methods were defined in preliminary experiments at the test benches. Due to the extreme amounts of incident light, it was impossible to accurately measure the soiling-caused opacity of the test panes on site using conventional measuring equipment. For this reason, special attachments were developed in the scope of the project, which are easy to handle and yield reliable measuring results. Since spring 2014, a standardized measuring procedure is established at the regional test benches to test the change of transmission on a total of 30 square meters of glass surface of three glasses bearing three different coatings. Uncoated glasses are used as the reference sample in these tests.



*Test-stands for panels with anti-dust coating*

### **Correlation of the properties of layers and soiling mechanisms**

Another component of this work is the analysis of the particles that remain just loosely attached on the different test layers as well as the analysis of the »smear layers« arising over time on which particles adhere firmly. The project team aims to use the results of this field test, which is scheduled to be completed by the end of 2014, to elucidate the special adhesion mechanisms of dirt and dust particles on the test layers in the different climates.

The test glasses comprise three different types of layers of strongly different surface characteristics and micro-structure. Based on a correlation of the results of the field test and the different properties of the layers, the characteristics required of an optimally dust- and dirt-repelling layer can be defined for each different climatic target.

### **Requirements for efficient development of layers**

Aside from the anti-soiling properties defined by means of the field test, other aspects such as weathering resistance, mechanical strength – in particular with respect to the abrasive effect of sand and dust – and the optical properties also need to be taken into consideration in the design of the new location-adapted architectural glass coatings. The combination of these requirements makes the further development of anti-soiling coatings for extreme climatic conditions a true challenge.

The field test and the data from the accompanying investigations provide the basis for systematic adaptation of the properties of the layers. Based on the excellent expertise in the synthesis of inorganic materials available at the Fraunhofer ISC and the long-standing experience with the established and anti-reflective coatings applied to large outdoor surfaces, the test coatings used in the scope of the project can be developed further efficiently for the use on architectural glazing. But anti-dust layers are of interest for other fields of application as well, such as, e.g., in power engineering and consumer goods.

### **Contact**

Walther Glaubitt  
☎ +49 931 4100-406  
[walther.glaubitt@isc.fraunhofer.de](mailto:walther.glaubitt@isc.fraunhofer.de)





# DIELECTRIC ELASTOMER GENERATORS DEGREEN

## TREND-SETTING TECHNOLOGIES FOR UTILIZATION OF WIND AND WATER ENERGY

The German Federal Ministry for the Environment, Protection of Nature and Reactor Safety (Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, BMUB) is banking on renewable energies as the main pillar of power supply in the future. According to the BMUB, at least 35 percent of the electrical power in Germany is to be contributed by renewable energies by the year 2020. In Bavaria, as much as 50 percent of the electrical energy consumed is to be covered by renewable energies within the next 10 years. This is twice as much as today. Innovative solutions and developments are needed to reach these goals.

### New ways to harvesting regenerative energies

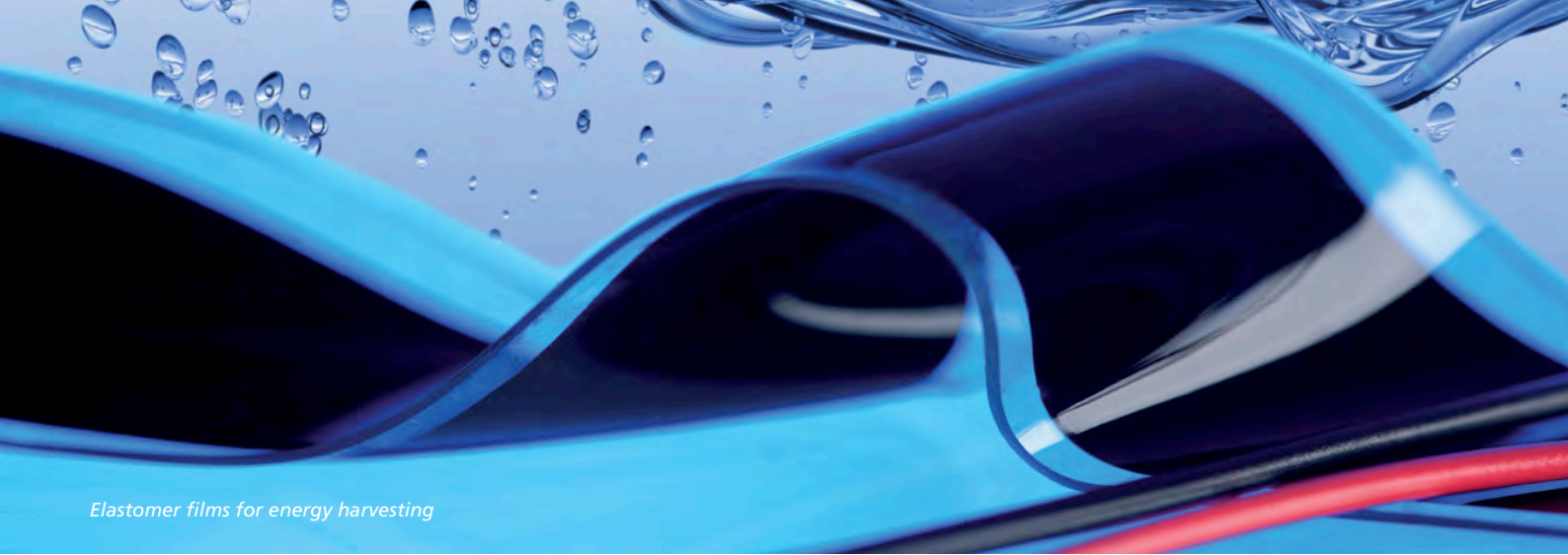
Harvesting the energy of wind and water necessitates the use of corresponding wheels, turbines, weirs, etc., whose optical, noise and biological impact are a subject of public criticism to an ever increasing degree. The Center Smart Materials CeSMA of the Fraunhofer ISC uses dielectric elastomer generators (DEG) in the development of novel technologies for effective energy conversion with a low impact on the environment. DEGs work without the bothersome effects accompanying conventional technologies. These specialized elastic films convert the energy of mechanical motions directly into electrical energy. The surface of these dielectric elastomer films is coated with highly stretchable electrodes to form a multilayer structure that works like a capacitor.

This novel elastomer material is stretchable by up to 100 percent and can directly convert the mechanical energy of wind flows near the ground, of up-currents or of water flows in rivulets to produce electrical energy. When the film is stretched mechanically by a flow of wind or water, its electrical capacitance changes. This can be used by means of an electronic circuit to charge an intermediate storage unit. The goal of the project are modular DEGs with an electrical output power of up to 1 kW.

### Decentralized energy supply in rural regions

This technology will allow new energy supply concepts to be developed that enable an effective, environmentally compatible and decentralized energy supply in rural regions. These are the places, in which decentralized energy supply concepts are of interest, since they make large power lines to distant regions dispensable. Elastomer materials are therefore the key to a new generator system technology for energy conversion. One potential application is a charging station for electrical vehicles far away from power line networks.

One of the major challenges facing the DEGREEN project is to develop a composite material that withstands the extreme burdens to which elastomer and electrodes are exposed due to its high alternating mechanical strain and still delivers high field strengths. The service life of this material must be at least 100 million cycles which corresponds to approximately five years in real life. Another challenge is the development of a design suited for adaptation to the rapidly changing conditions of use, e.g. low or high water levels.



Elastomer films for energy harvesting

### Production saves rare earth elements and costs

The dielectric elastomer generators are particularly well-suited to be integrated into flexible or mobile structures. And they work with absolutely no noise. The control sensor system can be integrated intrinsically into the DEG films which further reduces the technical effort involved.

Other advantages of the DEGs include the inexpensive production of large units and the savings of resources, e.g. rare earth elements, which are used in conventional electrical generators. Due to the use of natural rubber, the utilization of the units is both environment-friendly and sustainable.

### Contact

Dr. Bernhard Brunner  
☎ +49 931 4100-416  
[bernhard.brunner@isc.fraunhofer.de](mailto:bernhard.brunner@isc.fraunhofer.de)



*A field test began in the summer of 2013. A conventional small power station was set up in a branch of the river Tauber close to the Bronnbach Branch Office of the Fraunhofer ISC.*



Funded by the Free State of Bavaria

# DES – DIELECTRIC ELASTOMERS

# FLEXIBLE PRESSURE SENSORS

## FLEXIBLE PRESSURE SENSORS MADE OF DIELECTRIC ELASTOMERS

Airbags can save lives, for instance when a car approaches a sudden traffic jam too fast and a collision occurs. But if a passenger is »out of position« – or oop for short – just at the time of the impact, for example bent forward or has the seat reclined in order to sleep, the open airbag can cause severe injury to the sternum or neck. Seats fitted with smart sensors, which register the positioning of the person sitting in them, can help avoid this type of injury. Smart sensors can also be incorporated into mattress pads to aid in decubitus prophylaxis (pressure sore prevention). According to estimates of the Robert-Koch-Institute, each year approximately 400,000 people in Germany are afflicted by decubital ulcers. The Institute for Innovation in Public Health and Applied Healthcare Research (Institut für Innovation im Gesundheitswesen und angewandte Pflegeforschung, IGAP) presumes this figure to be even higher, i.e. 1.2 million cases of decubital ulcers. According to a publication of the Robert-Koch-Institute, the central goal from the point of view of medicine, healthcare, ethics, and healthcare costs must be to strictly prevent pressure sores by means of successful prophylactic measures implemented co-operatively. These requirements can be met by means of Dielectric Elastomer Sensors (DES).

### Versatile design and adaptation options

DES are a relatively new class of mechanical sensors for the measurement of expansions, forces, and pressures. They offer a wide variety of options for detection of expansions and forces under tensile stress through the application of a capacitive measuring principle. They consist of a highly stretchable elastomer film that is coated on both sides by electrodes which are stretchable as well. This produces a capacitor whose capacitance is measured by the sensor.

The advantages of this new class of sensors include their high flexibility and ability to be integrated into structures, their simple design and low production costs. Due to the high degree of variability of the materials and the range of design principles, numerous different sensor types can be implemented. Consequently, these sensors can be matched perfectly to the application on hand. They can not only detect whether or not a seat in a car is occupied and determine the weight bearing down on the seat, but they can also measure the pressure experienced by a bed-ridden patient as a measure of pressure sore prophylaxis. DES can perform load analyses in shoes or register the presence of people on floors to prevent hazards.

### High flexible new sensor mats

Basically, DES are fairly insensitive in the measurement of pressure loads due to the low level of deformation. But the researchers of the Center Smart Materials CeSMA succeeded to develop DES into novel sensor mats that respond extremely sensitive to pressure loads. The components of sensor mats with contoured surfaces are made from silicone elastomers. The major advantage of silicone is that it can be processed well not only via liquid precursor stages. The hardness of the elastomer can also be adjusted over a wide range through variation of the chemical cross-linking of the polymer. As a result, the mechanical properties of the new sensor mat can be matched perfectly to the application on hand.

The underlying sensor principle can also be implemented in various versions, since a broad range of parameters - from the design of the contours and the arrangement of the electrodes to the materials parameters such as the hardness of the profiles or elastomer film – can be adjusted to suit the specific application.





*Profiling for high sensitivity of measurement*

Just one example: sensor mats having a wave shape and consisting of two elastomer profiles can be produced. The profiles of this version are pre-shaped appropriately and are arranged with respect to each other such that they penetrate into each other alternately when the sensor mat is being compressed, and they can strongly stretch the elastomer film situated between them. Since both the profiles and the film consist of elastomer, the entire sensor mat is characterized by high flexibility. This allows the mat to adapt its contour to a pliable substrate. Alternatively, sensor mats, in which the electrode layers are shifted from the elastomer film to the profiles, can be implemented as well. For this purpose, the surfaces of the profiles are covered by conductive layers between which the capacitance is measured. Compressing the sensor mats moves the two electrode layers on the profiles closer to each other and the capacitance increases accordingly. The profile shape as well as the arrangement of the electrodes have a crucial impact on the characteristics of the sensor mat. The profile shape determines the way, in which the inside elastomer film is stretched when the mat is being compressed. A fin profile has been developed in addition to the wave-shaped profile. The advantages of this shape include that the mat with fin profiles is significantly thinner than sensor mats with wave-shaped profiles.

### **Variety of applications based on the broad application potential**

The new sensor mats increase the pressure sensitivity of the DES as a function of the shape of the profile, the design or the arrangement of the electrode layers. This results in broad application opportunities in a wide variety of areas, in particular on soft substrates. Just one example: the classification of seat occupancy in the automotive industry, in which the pressure distribution on the seat can be measured in a location-resolved manner such that the airbag can be controlled appropriately in case of a collision.

Based on their versatile application potential, sensor mats are associated with an added value that has not truly been tapped to date and from which many application fields will benefit. And, best of all: Elastomers are inexpensive raw materials. Conductive particles, such as carbon black, can be used for the electrode layers, which means these are inexpensive as well. And these materials are easy to process using simple mass procedures. As a result, sensor mats can be produced inexpensively in a mass process for large markets.

### **Contact**

Dr. Holger Böse  
☎ +49 931 4100-203  
[holger.boese@isc.fraunhofer.de](mailto:holger.boese@isc.fraunhofer.de)







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# MORE EFFICIENT USE OF LIGHT WOMBAT AND LIST

## LESS IS MORE – HOW SCATTERED LIGHT INCREASES THE EFFICIENCY

Usually something to avoid at all cost in optics: the scattering of light. This is defined as the diffuse reflection and transmission on rough surfaces and/or scattering centers inside a material. Incident light is thus distributed into various directions. This process usually leads to undesirable losses in light transmission and imaging errors, but can also be used to advantage in order to couple and uncouple light better. The research team around Prof. Peer Löbmann works at the Fraunhofer ISC in the scope of two BMBF-sponsored (Federal Ministry of Education and Research) projects on the development of novel sol-gel-based scattering layers for new applications in thin layer photo-voltaics and OLED technology.

### More light from organic light-emitting diodes (OLED)

They can be produced inexpensively as large-surfaced illuminants and consume very little electrical power: Organic light-emitting diodes, or OLEDs for short. But up to now their luminance is lower than that of conventional inorganic light-emitting diodes. And there is another grave aspect: On average, only approximately 20 percent of the light generated in an OLED can actually be utilized for illumination as the remainder gets lost due to internal scattering. In the scope of the WOMBAT research project (»White OLEDs from optimized materials, components, triggering and sub-processes«, **Weiße OLEDs durch optimierte Materialien, Bauteile, Ansteuerungen und Teilprozesse**), the Fraunhofer ISC, Philips Technology GmbH, Novaled AG, and Nanoptics Innovation GmbH are working cooperatively on concepts aiming to remedy this disadvantage. The goal of the project is to improve the uncoupling of light from the OLEDs to increase the useful yield of light.

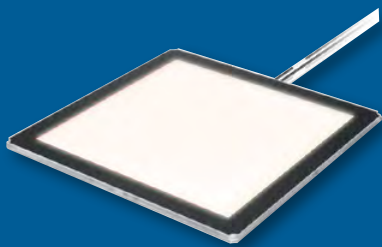
### Improved uncoupling by scattering layers

OLEDs consist of a front electrode and a rear electrode – transparent-conductive layers on the inside of the cover glasses – and the emitter and hole-conducting layers as well as possible additional functional layers between the electrodes. The internal scattering losses arise mainly due to reflection of the light generated in the OLED at the interface between the transparent-conductive electrode and the protective cover glass. If this interface could be »disarmed« by a scattering layer situated in between, then the light from the OLED could be uncoupled and utilized markedly more efficiently.

### Sol-gel chemistry for the control of layer properties

Usually, the transparent-conductive electrode is applied right to the glass and has to be absolutely planar in order to prevent topography-related voltage peaks and the associated danger of electric breakdown between front and rear electrodes. A scattering layer situated between glass and electrode has to adhere very well to both materials, meet its optical function of scattering the light, and, on top of all, be absolutely planar. This eliminates conventional methods for generating desired light scattering as they are based on rough or porous surfaces. The researchers of the Fraunhofer ISC successfully reconciled what appear to be contradictions. They integrated scattering center into a smooth sol-gel-based coating. The method affords excellent control over the scattering effect. Likewise, the interaction with the substrate and the transparent-conductive layer – an indium-tin oxide layer (ITO) – can be controlled very well using sol-gel chemistry. Following the basic proof of feasibility, further optimisation steps are now ongoing in the project aiming to refine the materials and methods for the complex application.





LED design variety  
(© Philips Lumiblade)



### Increasing the efficiency of photo-voltaics – thin-layer cells

While improving the efficiency of OLEDs required the extraction of as much light as possible from the solid, the production of electrical power from light calls for coupling as much light as possible into the components and using it efficiently. In thin-layer photo-voltaics, the light must be introduced into a series of transparent-conductive layers and absorber layers, in which it is converted to electrical power. For instance the reflection at the interface between the surface of the thin-layer cell and air is a limiting factor. Anti-reflective layers developed at the Fraunhofer ISC can be used to improve the yield markedly. But there is another option for improving the yield of electrical power.

#### Light on detour

The efficiency of the absorber materials used in the thin-layer cell – and therefore the path length of the light in the absorber – plays a role in the conversion of light into electrical power. A scattering intermediate layer can increase this path length since a larger fraction of the light passes obliquely through the absorber layers. Thus far, these scattering layers included in the design of the thin-layer cells are produced by etching the transparent-conductive layer – a zinc oxide layer – over the absorber layers, which roughens it. The light is then scattered at the rough surface. Thin-layer solar cells subjected to this work-up attain an efficiency of approximately 12 percent as compared to 7 to 9 percent by cells without scattering layer. The drawbacks include the more laborious production procedure – since the vacuum processes during production have to be interrupted for the etching of the conductive layer – and the high consumption of materials – part of the conductive layer dissolves during the etching process.

### Production made easier

The research approach of the Fraunhofer ISC in the scope of the BMBF-funded LIST project is to apply a sol-gel-based scattering layer on the inside of the glass cover of the thin-layer cell. The further build-up of the cell can then occur in an uninterrupted vacuum process with no need for etching the transparent-conductive layer of the cell. Moreover, the consumption of conductive layer materials can be limited to its function of conducting the electrical current. This project joining nine partners from industry and research aims to provide an inexpensive, resource-efficient, more easily manufactured alternative to the conventional etched scattering layers. The core of the project was the development of the coating materials, and the process technology was also in the focus of the project partners in order to attain a high performance and efficient system.

Using perfectly matched materials and simple coating technologies from the Fraunhofer ISC, it is now feasible to apply homogeneous and smooth layers which yet show the scattering effect. Expedient combination of high and low refraction components in the coating renders the rough surface topology of the scattering layer smoother without impairing the desired scattering and without generating losses due to reflection. The desired high transmission of light is preserved.

#### Contact

Prof. Dr. Peer Löbmann  
☎ +49 931 4100-404  
[peer.loebmann@isc.fraunhofer.de](mailto:peer.loebmann@isc.fraunhofer.de)





# CONDUCTIVITY MEASUREMENT BY SEM

## DETERMINING A MATERIAL'S PROPERTIES ON THE MICROMETER SCALE

Not only with electronic components, but also with batteries or even structural ceramics that are post-processed by means of an electroding process, it is essential to know the electrical properties, the chemical composition, and the micro-structure in order to be able to develop, optimize or perform a damage analysis on them as needed. This information is also essential for random sample-based quality monitoring.

Many answers to questions arising in this context can be found in the micro-structure of the materials that are employed, which means on the micrometer or even nanometer scale. Electron microscopy frequently is the investigation method of choice as it allows not only the local topography, but also the composition of the material to be determined for detailed characterization of the material. This method serves as the foundation for damage analysis and further research and development.

At the Center for Applied Analytics of the Fraunhofer ISC, which is accredited to DIN EN ISO/IEC 17025, scanning electron microscopy is applied in combination with energy-dispersive X-ray spectroscopy (SEM-EDX), a method for local chemical analysis under in-situ conditions. Scanning electron microscopy has been an established and reliable method for years and is used both in damage analysis and in studies accompanying developments.

The purchase of a ZEISS Auriga 60 workstation by the Fraunhofer ISC provided the opportunity to implement a micro-laboratory in the SEM. Since the sample chamber of this scanning electron microscope is large, not only the imaging detectors, a focused ion beam unit, a plasma cleaner, and the EDX detector, but also further modules can be incorporated that allow physical properties of the samples to be studied.

In a first expansion stage, an electrical measuring unit consisting of four micro-manipulators was procured in co-operation with the Center for Applied Electrochemistry, which also resides at the Fraunhofer ISC. The measuring station allows the electrical properties to be determined on a micrometer scale. For example microstructural constituents, layered systems or regions of complex components, such as printed conductors, can be subjected to measurements. The electrodes attached to the micro-manipulators can be positioned at a distance of just 2 – 5  $\mu\text{m}$  in a four-point measuring geometry in such manner that the conductivity and the actual specific resistance of the tested object can be determined. Even currents in the pA range can be reliably detected. Aside from these measurements at direct current conditions, the samples can also be subjected to alternating voltages, which allows the impedance to be determined.





Micromanipulators for measurements in  
the smallest of spaces in the SEM

### Application examples

#### ■ Use in the development of SiSiC ceramics

The four-point measurement on the micrometer scale was used to determine the specific resistance values of the silicon matrix and of the silicon carbide grains.

#### ■ Post-mortem investigation of battery electrodes

The focus is on investigating the mechanism underlying the failure of the battery electrodes. Initial preliminary experiments in co-operation with the Center of Applied Electrochemistry have already been completed.

### Investigation of artefact-free cross-sections

The measurements can be applied not only to surfaces, but to cross-sections as well. This is of great interest for the development of layered systems designed to possess certain electrical properties. These investigations require not only adequate measuring equipment to be present, but also call for perfect sample preparation. Therefore, the Center for Applied Analytics has been applying ion polishing techniques for years as these produce virtually artefact-free cross-sections for a clear view onto the micro-structure and perfect aiming for the regions to be studied.

### Contact

Dr. Alexander Reinholdt

☎ +49 931 4100-260

[alexander.reinholdt@isc.fraunhofer.de](mailto:alexander.reinholdt@isc.fraunhofer.de)



# FRAUNHOFER-GESELLSCHAFT

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

At present, the Fraunhofer-Gesellschaft maintains 67 institutes and research units. The majority of the more than 23,000 staff are qualified scientists and engineers, who work with an annual research budget of 2 billion euros. Of this sum, more than 1.7 billion euros 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.

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

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

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







# PROJECT INFORMATION

## **EnerTHERM – Energieeffiziente Thermoprozesse**

Funded by the Bavarian State Ministry for Economic Affairs, Media, Energy and Technology.

Duration: 1 February 2013 to 31 January 2018

## **PEDEIEc – NES-PEDEIEc-Pendler-E-Bike**

Funded by the Bavarian State Ministry for Economic Affairs, Media, Energy and Technology

Grant No. MOD-1209-0008

Duration: 1 January 2013 to 29 February 2016

## **Fraunhofer-Attract-Project**

3DNanoCell – Zellbasierte Assays auf 3D-bottom-up-nanostrukturierten Oberflächen für regenerative Implantate und Trägerstrukturen

Duration: 1 January 2013 to 31 December 2018

## **METACHEM – Nanochemistry and self-assembly routes to metamaterials for visible light**

EU funded research project within the 7<sup>th</sup> framework program

Grant No. NMP-2008-2.2-2

9 partners from 7 EU member states

Duration: 1 June 2009 to 30 May 2011

[www.metachem-fp7.eu/php/about-the-project](http://www.metachem-fp7.eu/php/about-the-project)

## **EREAN – European Rare Earth (Magnet) Recycling Network**

Marie Curie Initial Trainee Network

EU funded research project within the 7<sup>th</sup> framework program

Coordination: Katholieke Universiteit Leuven (B)

Partners: Chalmers University of Technology, Göteborg, Solay, Umicore, Technische Universiteit Delft, The University of Birmingham, Öko-Institut e.V., University of Helsinki

Duration: 1 September 2013 to 31 August 2017

<http://erean.eu/index.php>

## **Smart Scaffolds**

A Fraunhofer funded research project

Duration: 1 July 2012 to 30 June 2015

## **MultiNaBeL – Früherkennung und multimodaler Nachweis von Systemerkrankungen am Beispiel der Leukämie**

A Fraunhofer funded research project

Duration: 1 January 2013 to 31 December 2015

## **NanoSolTex – Funktionalisierung von Technischen Textilien mit wasserbasierten nanoskaligen Beschichtungssolen**

BMBF-funded research project

Grant No. 03X0121C

Project partners: Sächsisches Textilforschungsinstitut e.V., T\_O\_P Oberflächen GmbH; ROWO Coating GmbH, Schneider Textilveredlung GmbH, ALTERFIL Nähfaden GmbH

Duration: 1 February 2012 to 31 January 2014

### **HarWin – Harvesting solar energy with multifunctional glass-polymer windows**

EU-funded research project within the 7<sup>th</sup> framework program  
Grant No. NMP3-SL-2012-314653

Partners: Universität Bayreuth, Inglas Produktions GmbH, Eckart Pigments KY, Glassx AG, Centrosolar Glas GmbH & Co. KG, Isomatex SA, Integrated Environmental Solutions Ltd., JRC – Joint Research Center – European Commission, Zachodniopomorski Uniwersytet Technologiczny w Szczecinie, Bayerische Forschungsallianz Gemeinnützige GmbH  
Duration: 1 September 2012 to 31 August 2015

### **ASKORR – Aktive Schichten für den Korrosionsschutz**

A joint research project of Fraunhofer-Gesellschaft and Max-Planck-Gesellschaft

Partners: Fraunhofer-Institut für Angewandte Polymerforschung, Max-Planck-Institut für Polymerforschung, Max-Planck-Institut für Eisenforschung  
Duration: 1 June 2010 to 30 June 2013  
[www.askorr.com](http://www.askorr.com)

### **INCOM – Industrial production processes for nanoreinforced composite structures**

EU-funded research project within the 7<sup>th</sup> framework program  
Grant No. NMP2013-10-608746

Coordinator: VTT Technical Research Center of Finland – Biomaterials and Processing,  
Project partners: Danmarks Tekniske Universitet (DK), Diehl Aircabin GmbH, Sura Chemicals GmbH, Millidyne Oy (FIN), VMA-Getzmann GmbH Verfahrenstechnik, AXON Automotive Limited (UK), 2B SRL (I), Bergius Trading AB (SE); CSI Composite Solutions and Innovations Oy (FIN), Lulea Tekniska Universitet (SE), ECONCORE N.V. (B)  
Duration: 1 September 2013 to 31 August 2017  
<http://www.incomproject.eu>

### **DEGREEN – Dielektrische Elastomer-Generatoren für regenerative Energien**

Funded by the Bavarian State Ministry for Economic Affairs, Media, Energy and Technology

Grant No. VIII/3f-3629/71/4  
Duration: 1 June 2012 to 31 May 2017

### **WOMBAT – Weiße OLEDs durch optimierte Materialien, Bauteile, Ansteuerungen und Teilprozesse**

BMBF-funded research project

Grant No. 13N11633  
Partners: Philips Technology GmbH, Novaled AG und Nanoptics Innovation GmbH  
Duration: 1 October 2012 to 30 September 2014

**LIST** – Großflächiger Lichteinfang in der Silizium-basierten Dünnschichtsolarzellen-Technologie, TP: Nasschemische Erzeugung von Funktionsschichten für Si-basierte Dünnschichtsolarzellen.

BMU-funded research project

Grant No. 0325299D  
Project partners: Forschungszentrum Jülich GmbH, Institut für Energie und Klimaforschung, Fraunhofer-Institut für Schicht- und Oberflächentechnik IST, Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, InnoLight - Innovative Laser und Systemtechnik GmbH, Rheinisch-Westfälische Technische Hochschule Aachen, Euroglas GmbH, Laserzentrum Hannover, Sentech Instruments GmbH, Schüco, Universität Erlangen, Leybold Optics GmbH

Duration: 1 June 2011 to 31 May 2014

# EDITORIAL NOTES

## Editors

Marie-Luise Righi  
Pelin Aytac  
Martina Hofmann  
Katrin Selsam-Geißler  
Prof. Dr. Gerhard Sextl

## Illustrations and diagrams

Winfried Müller  
Katrin Selsam-Geißler

## Layout and production

Katrin Selsam-Geißler  
Frank-Wolf Zürn, Profil G.b.R., Reichenberg, Germany

## Translation

Intellitext SprachenService, Würzburg, Germany

## Photographs

Object photos: Knud Dobberke and  
Klaus Nüßlein p. 55, Fraunhofer IGB p. 57, Fraunhofer ISC  
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Fraunhofer Institute for Silicate Research ISC  
Neunerplatz 2  
97082 Würzburg, Germany  
☎ +49 931 4100 0  
marie-luise.righi@isc.fraunhofer.de  
[www.isc.fraunhofer.de](http://www.isc.fraunhofer.de)

## Adresses of other ISC locations

Fraunhofer ISC – Bronnbach Branch  
Bronnbach 28  
97877 Wertheim-Bronnbach, Germany  
☎ +49 9342 9221-702

Fraunhofer Center for High-Temperature Materials  
and Design HTL  
Gottlieb-Keim-Str. 60  
95448 Bayreuth, Germany  
☎ +49 921 786931-20  
htl.info@isc.fraunhofer.de  
[www.htl.fraunhofer.de](http://www.htl.fraunhofer.de)

Fraunhofer Project Group Materials Recycling  
and Resource Strategies IWKS  
Brentanostraße 2, 63755 Alzenau, Germany  
and Industrial Park Hanau-Wolfgang, 63457 Hanau, Germany  
☎ +49 6023 32039-801  
iwks.info@isc.fraunhofer.de  
[www.iwks.fraunhofer.de](http://www.iwks.fraunhofer.de)



