Fraunhofer
IKTS

Fraunhofer Institute for Ceramic Technologies and Systems IKTS

Annual Report 2023/24

Fraunhofer IKTS sites.

Cover:
Demonstration plant for CO_2-free electricity generation with ammonia in high-temperature fuel cells (SOFC).

Annual Report 2023/24

Fraunhofer Institute for Ceramic Technologies and Systems IKTS

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Foreword

Dear friends and partners of IKTS,

We look back once again on a very successful year with continued healthy growth. Due to the still difficult introduction of SAP at Fraunhofer level, we do not have any final business figures at the time of the report, but we are expecting record levels: With a balanced operating result, our overall budget exceeded the €90 million mark. It is particularly gratifying that we were able to significantly increase our industry income to around 39 %, confirming our industrial relevance as prescribed by the Fraunhofer model. We were also once again able to invest more than €11 million in the continuous modernization of our equipment. This equipment and, above all, our excellent IKTS team of experts will be happy to assist you in joint projects. Our expertise covers the entire value chain of technical ceramics up to the upscaling range and non-destructive testing technologies for process monitoring.

Despite the challenging political environment, which has led to some lack of planning certainty (e.g. by unexpectedly reducing federal funding in the battery sector), we see a stable earnings situation for the current year as well, with continued growth in industry income. We will remain true to our forward strategy this year, investing in our future technologies like never before. Energy and environmental technology will once again be an important focus. In particular, we will further develop the production of green hydrogen and green synthesis gas. A pilot plant for the production of high-temperature electrolysis stacks is being set up at our site in Arnstadt as part of a major industrial project, which allows us to carry out further strategic projects for the development of electrolysis and fuel cell systems. We will also continue to develop our battery research consistently and, in addition to lithium-ion batteries, we will continue to focus on the topic of sodium batteries in particular.

We would also like to demonstrate our strong focus on sustainable energy technologies at our various sites. In Hermsdorf, we are committed to the development of the region, which is industrially shaped by numerous ceramic companies. With our support from the Thuringian Renewable Energies Network (ThEEN), a transformation concept for energy conversion has been developed in order to supply the companies with safe, affordable, emission-free energy in the long term. The planned implementation of the concept opens up opportunities for Fraunhofer IKTS to establish our new technologies for energy conversion and storage on a real-world laboratory scale. In Dresden, we are also working together with our Fraunhofer partner institutes at the Fraunhofer Institute Center Dresden (IZD) to develop an "energy campus concept".

Among the many diverse topics we deal with in the field of circular technologies and recycling, the topic of "water" plays a prominent role. A particularly good success in this area was achieved by Prof. Michael Stelter, who managed to secure a BMBF future cluster "ThWIC" (Thuringian Water Innovation Cluster) with a total amount of €45 million for 9 years.

I would also like to highlight the extension of our ceramic material characterization and component testing. We were able to expand our excellent equipment with the chemical analysis we have established at the Hermsdorf site. We are thus able to quantify the composition, doting, trace constituents and impurities of powders, suspensions and components through chemical digestion and optical emission spectroscopy. This plays a major role in the development of functional ceramics and in quality assurance in the production of ceramic components, among other things.

Furthermore, I would like to mention our two new spin-offs, of which we are proud and which underpin our orientation toward knowledge transfer: AMAREA Technology GmbH commercializes the multi-material jetting process (MMJ) developed by us in the field of 3D printing. Nicoustic AS is based on our ultrasonic technology and offers innovative solutions in the field of level determination of solids and liquids in pressure vessels, e.g. in the chemical industry.

Finally, I have some very sad news. On February 17, 2024, our founding director Prof. Waldemar Hermel passed away at the age of 86. Waldemar Hermel was extremely committed to the founding of IKTS in January 1992 and managed the institute very successfully until 2004. He set up IKTS excellently and put together an outstanding team from which we still benefit today. He and this team are responsible for initiating the IKTS success story. We as IKTS and I personally have a lot to thank him for. In addition to his scientific expertise, his human warmth and collegiality must be emphasized. He was an outstanding personality with excellent social skills. We will miss him very much.

Reception on the occasion of the 80th birthday of IKTS founding director Prof. Waldemar Hermel. In the picture f.l.t.r.: his wife Gisela Hermel, Dr. Michael Zins, Dr. Christian Schubert, Prof. Alexander Michaelis, Dr. Gert Leitner, Claus Richter and Dr. Udo Gerlach.

You can find more highlights and developing trends from our business divisions in this report.

On behalf of the entire IKTS team, I wish you a lot of fun perusing this report and some good ideas for projects. We are looking forward to our mutual cooperation.

Yours,

A. Michaelis

Alexander Michaelis
April 2024

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Fraunhofer IKTS in profile

Management of IKTS, f.l.t.r.:
Dr. Michael Zins, Dr. Christian Wunderlich, Dr. Roland Weidl, Prof. Alexander Michaelis, Prof. Michael Stelter and Prof. Ingolf Voigt.

Portrait

For more than 30 years, Fraunhofer IKTS has been developing ceramic materials for a steadily growing range of applications. Our development work is derived from the needs of the nine market-oriented business divisions – supplemented by strategic preliminary research at the highest scientific level.

It is our goal to develop complete system solutions and services, but also to solve specific challenges of our partners from industry and science. Our expertise in characterizing materials, components and systems along their life cycle provides us with a unique data pool to carry out new developments more efficiently and faster.

We offer state-of-the-art equipment on more than 40,000 m² of floor space, competent staff and result-oriented research management. This makes us a contact point for companies and research partners to tap the unique properties of ceramic materials for new and improved applications. Our special competences are:

Materials

We qualify ceramics, hardmetals and composites for specific application scenarios and master all necessary manufacturing processes. We open up new fields of application through the targeted combination of structural and functional material properties. We can transfer developments from laboratory to pilot-plant scale and realize the prototypes and pilot series required for market entry, establish industrial manufacturing processes and implement quality processes.

Process engineering

We are one of the world's leading research institutes in the field of complex ceramic-based systems for energy-efficient separation processes, chemical mass transfer and materials recovery. Our approaches are based on the sustainable use of resources and closed material cycles. With state-of-the-art laboratory machinery and pilot plants, we can model, validate and optimize relevant parameters for these processes. With our excellent infrastructure, we are able to realize projects of the most diverse scope and scale.

Data-driven analytics and monitoring

Increasing the market acceptance of new materials requires high-performance analytics and quality control – from raw material evaluation to use and recycling. For the development of new materials and products, the clarification of complex failure mechanisms or the assurance of qualitative standards, we make use of new sensor concepts, robot-assisted measurements and the potential of cloud-based data acquisition and AI-supported data evaluation. In addition, we offer solutions for the process and condition monitoring of manufacturing facilities and thus ensure optimal product qualities, low costs and reduced maintenance efforts.

System demonstration

For energy and process engineering systems, we are able to implement targeted system demonstrations based on market and customer requirements on one side and available technological options on the other. Material or technology issues are dealt with at the individual stages of the value chain, prototypes are evaluated on the basis of extensive validation and target/performance analysis of market readiness, as well as production and quality processes suitable for series production are developed. This qualifies us as a complete service provider for the entire process of technology development and the step-by-step transfer of knowledge into the customer's series production.

Project management

Fraunhofer IKTS has proven competences in the planning and execution of research projects of various scopes – from short-term support to supernational large-scale projects. In the field of contract research with small and medium-sized companies, we provide flexible and timely support with customized services or development processes. In complex large-scale projects with various national and international consortium partners, we provide support from the application phase, to project coordination, communication of project outcomes and the development of exploitation strategies.

Cross-site quality management

Quality, traceability, transparency and sustainability are some of the most important instruments for IKTS when it comes to providing partners and clients with valid and reproducible research outcomes in a resource-efficient way. Therefore, Fraunhofer IKTS has a unified management system in accordance with DIN EN ISO 9001, as well as an environmental management system in accordance with DIN EN ISO 14001. Beyond this, the institute and its various divisions are certified according to other guidelines, among them EN ISO 13485:2016, and undergo various regular audits from the industry.

Creator of networks

We have an active role in numerous regional, national and international alliances and networks. By building and actively working within various networks, IKTS is able to identify different complementary competences at an early stage, and promote and integrate them for future product development. Thus, we jointly find solutions for the benefit of our partners.

Organizational chart

Institute Management

Institute Director
Prof. Dr. habil. Alexander Michaelis

Materials

Nonoxide Ceramics
Dipl.-Krist. Jörg Adler
- Structural Ceramics with Electrical Function
- Carbid Ceramics and Cellular Ceramics
- Nitride Ceramics and Fiber Composites
- Protective Ceramics
- Filter Ceramics and Exhaust Gas Aftertreatment

Oxide Ceramics
Dr. Sabine Begand
- Pilot Manufacturing of High-Purity Ceramics
- Oxide and Polymerceramic Composites*
- Transparent Ceramics

Processes and Components
Dr. Tassilo Moritz
- Powder Technology
- Shaping
- Component Development and Manufacturing
- Additive and Hybrid Manufacturing

Materials and Process Characterization

Sintering and Characterization
Dr. Annegret Potthoff / Dr. Johannes Pötschke
- Thermal Analysis and Thermal Physics**
- Heat Treatment
- Ceramography and Phase Analysis
- Powder and Suspension Characterization**
- Quality Assurance Laboratory** and Mechanics Laboratory

Environmental and Process Engineering

Nanoporous Membranes
Dr. Hannes Richter
- Zeolite- and Carbon Membranes
- Polymer- and Mixed Matrix Membranes
- Membrane Prototypes

High-Temperature Separation and Catalysis
Dr. Jörg Richter
- High-Temperature Membranes and Storages
- Catalysis and Materials Synthesis

Circular Technologies and Water
Dr. Burkhardt Faßauer
- Biomass Conversion and Nutrient Recycling
- Systems Engineering for Water and Wastewater
- Electrochemistry
- Membrane Characterization and Modeling
- Technical Electrolysis and Geothermal Energy
- Reaction Engineering Water
- Applied Membrane Technology

Chemical Engineering
PD Dr. habil. Matthias Jahn / Prof. Dr. Martin Gräbner
- Modeling and Simulation
- Process Systems Engineering
- Circular Carbon Technologies
- Systems Integration
- Energy System Concepts

Sites and Competence Centers of Fraunhofer IKTS

- Headquarters Dresden-Gruna, Saxony
- Site Dresden-Klotzsche, Saxony
- Site Hermsdorf, Thuringia

- Site Forchheim, Bavaria
- Site Berlin, Berlin
- Fraunhofer Project Center for Energy Storage and Systems ZESS, Braunschweig, Lower Saxony
- Fraunhofer Technology Center High-Performance Materials THM, Freiberg, Saxony
- Fraunhofer Smart Ocean Technologies SOT research group, Rostock, Mecklenburg-Western Pomerania
- Biological Materials Analysis research group at Fraunhofer IZI, Leipzig, Saxony
- Circular Carbon Technologies KKT project group, Freiberg, Sachsen
- Cognitive Material Diagnostics project group, Cottbus, Brandenburg
- Fraunhofer Center for Smart Agriculture and Water Management AWAM, Porto, Portugal
- Battery Innovation and Technology Center BITC, Arnstadt, Thuringia
- Industrial Hydrogen Technologies Thuringia WaTTh, Arnstadt, Thuringia
- Application Center Water, Hermsdorf, Thuringia
- Application Center Membrane Technology, Schmalkalden, Thuringia

Technische Universität Dresden

ifWW – Institute for Inorganic-Nonmetallic Materials
Prof. Dr. habil. Alexander Michaelis
IAVT – Electronic Packaging Laboratory
Prof. Dr. Henning Heuer
IFE – Institute of Solid State Electronics
Prof. Dr. habil. Thomas Härtling

Deputy Institute Directors

Administrative Director — Dr. Michael Zins
Marketing and Strategy — Prof. Dr. Michael Stelter

Site manager Hermsdorf — Prof. Dr. Ingolf Voigt
Site manager Dresden-Klotzsche — Dr. Christian Wunderlich
Site manager Arnstadt — Dr. Roland Weidl

- Chemical and Structural Analysis
- Hardmetals and Cermets
- Thin-Film Technologies

Correlative Microscopy and Materials Data

Prof. Dr. Silke Christiansen

- Correlative Microscopy
- Correlative Spectroscopy

Energy Systems

Materials and Components

Dr. Mihails Kusnezoff

- Hydrogen Technologies
- Joining Technology
- Materials for Printed Systems
- Ceramic Energy Converters
- High-Temperature Electrochemistry and Functionalized Surfaces

Stationary Energy Storage Systems

Dr. Matthias Schulz

- Ceramic Electrolytes and Electrodes
- Cell Concepts and Prototypes

Energy Storage Systems and Electrochemistry

Dr. Mareike Partsch

- Cell Design and Testing
- Recycling and Green Battery
- Process Development and Process Control

Freie Universität Berlin
Institute for Experimental Physics
Prof. Dr. Silke Christiansen

Friedrich Schiller University Jena
Institute for Technical Environmental Chemistry
Prof. Dr. Michael Stelter

Ernst Abbe University of Applied Sciences Jena
SciTec – Materials Engineering
Prof. Dr. Ingolf Voigt

Technische Universität Bergakademie Freiberg
Chemical Technology
Prof. Dr. habil. Martin Bertau
Energy Process Engineering and Chemical Engineering
Prof. Dr. Martin Gräbner

Electronics/Microsystems- and Biomedical Engineering

Smart Materials and Systems

Dr. Holger Neubert

- Multifunctional Materials and Components
- Applied Material Mechanics and Solid-State Transducers

Hybrid Microsystems

Dr. Uwe Partsch

- Thick-Film Technology and Functional Printing
- Microsystems, LTCC and HTCC
- Functional Materials for Hybrid Microsystems
- Systems Integration and Electronic Packaging
- Ceramic Tapes

Testing of Electronics and Optical Methods

Dr. Mike Röllig

- Optical Test Methods and Nanosensors
- Speckle-Based Methods
- Reliability of Microsystems

Systems for Testing and Analysis

Prof. Dr. Henning Heuer

- Electronics for Testing Systems
- Software for Testing Systems
- Eddy-Current Methods
- Ultrasonic Sensors and Methods
- Machine Learning and Data Analysis
- Project Group Cognitive Material Diagnostics Cottbus

Microelectronic Materials and Nanoanalysis

Dr. Birgit Jost / Dr. André Clausner

- Nanoscale Materials and Analysis
- Nanomechanics and Reliability for Microelectronics

Condition Monitoring and Test Services

Dr. Lars Schubert

- Condition Monitoring Hardware and Software
- Methods for Monitoring Systems
- Model-based Data Evaluation
- NDT Lab**

Bio- and Nanotechnology

Dr. Jörg Opitz

- Biological Materials Analysis
- Characterization Technologies
- Biodegradation and Nanofunctionalization
- Biologized Materials and Structures

* certified in accordance with DIN EN ISO 13485
** accreditation in accordance with DIN EN ISO/IEC 17025

Fraunhofer IKTS in figures

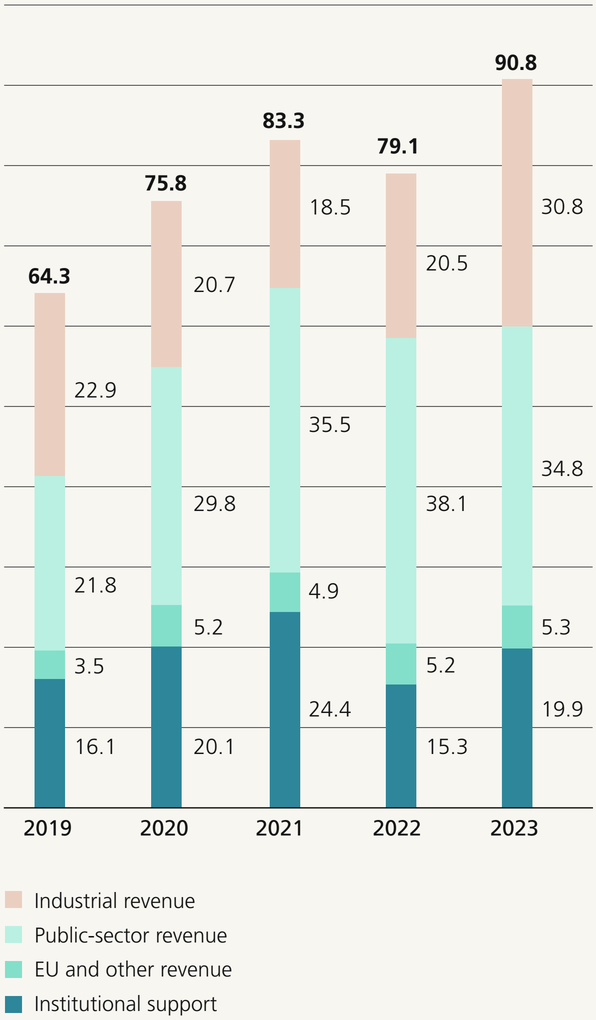
Budget and income

The institute looks back on a very successful year 2023. The focus of the project work is on energy and environmental technology as well as in the Water business division. The total budget has grown to a record €90.8 million. The budget consists of €11.7 million for investments and €79.1 million for operations. In view of the overhead structure, it was largely possible to compensate for the considerable increase in costs for energy, personnel and consumables. The changed cost structure was stabilized within the planned limits by the growth achieved.

The volume of industrial projects in 2023 rose by more than €10 million to a record level of €30.8 million. For the first time, the headquarters in Dresden with its sites achieved the top spot. €18.4 million corresponds to an economic factor of 41.9 % of the operating budget. The cost centers IKTS Hermsdorf and IKTS Dresden-Klotzsche also achieve very good values of 37.8 % and 31.3 % respectively. Focusing on strategic industry issues and investing in new infrastructure has led to the desired growth. The decline in public projects was thus compensated. In particular, the strategic investment resources of the German federal states have strongly supported this objective. A total of €16.7 million has been made available for projects and the respective site expansion. More than €3 million was invested in small-scale construction projects at the various sites.

At €34.8 million, public income was €3.3 million below the previous year's level. However, the volume is at a very good level, as are the EU revenues of €5.3 million. For many public projects, reduced funding rates are increasingly problematic, as basic funding cannot be used to compensate for gaps in funding. The starting position for the following year is very positive, as high project volumes are still available in the strategic topics. However, the current political situation suggests that it will be much harder to work on the strategic topics in 2025. Further growth in the industrial sectors is therefore being sought. The planning for the next few years includes high investments here.

Revenue (in million euros) of Fraunhofer IKTS for the budget years 2019–2023*



Human resources development

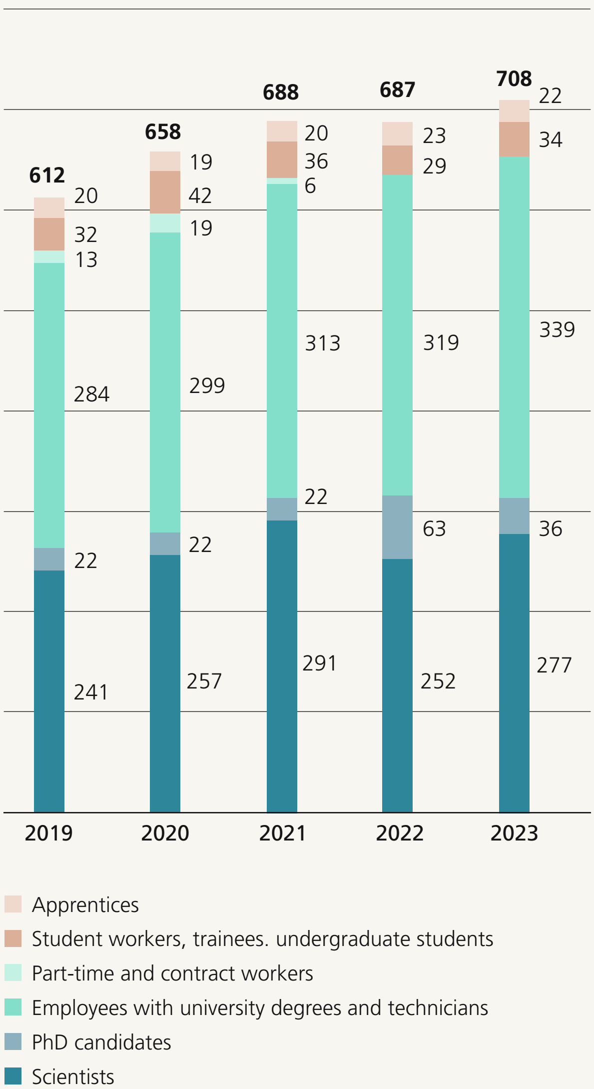
A total of 832 staff members work at the various IKTS sites. Despite the tense situation on the labor market, we were able to recruit employees in the scientific field and for administration. The relevance of research topics in connection with modern working conditions attracts people to work at Fraunhofer IKTS. The expansion of the sites in Freiberg (Fraunhofer THM, Carbon Cycle Technologies Research Group), Forchheim and Arnstadt also contributed significantly to our growth. Strategically, these locations will be further strengthened by new rented space in 2024. Work-life balance and work from home remain criteria that are becoming increasingly important. In all areas, employees choose part-time models. Our willingness to adapt contracts to suit individual needs is a decisive reason for starting at and staying with Fraunhofer IKTS.

*Revenue projection February 26, 2024

With more than 50 supervised doctoral theses, the institute makes an important contribution to the training of future managers. Agreements for the various phases of each doctoral thesis including specific goals and schedules make working on PhDs at Fraunhofer an attractive proposition. The research infrastructure at Fraunhofer IKTS also occupies a top position in international comparison. However, training in apprenticeships is also increasingly popular. With targeted funding, Fraunhofer IKTS is trying to train and retain its own young talent.

Fraunhofer IKTS as an employer remains well positioned in the marketplace. Nevertheless, the acquisition of employees in the scientific and increasingly also in the administrative area remains one of the major challenges. The introduction of SAP remains another major challenge. It continues to be an additional burden in all areas. Workflows need to be adjusted without allowing for short-term efficiency gains. Tasks need to be redistributed between administration and research groups.

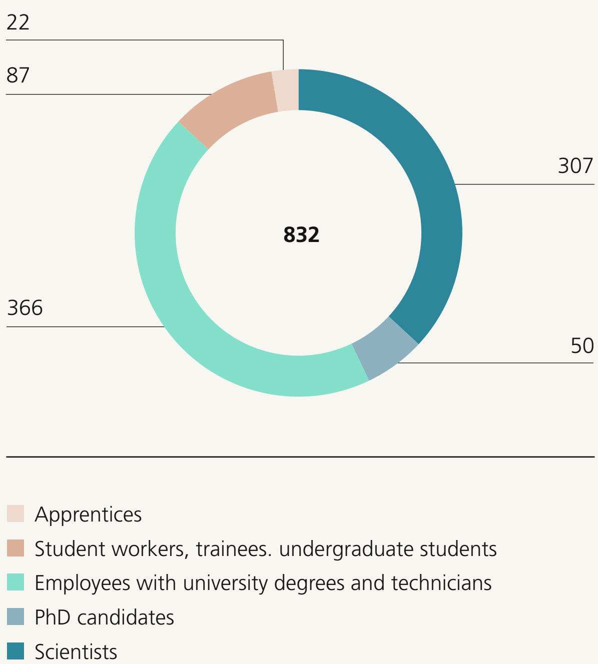
Personnel developments at Fraunhofer IKTS – Number of employees 2019–2023, full-time equivalents



Expanding the infrastructure

The research infrastructure has grown very rapidly in recent years. Energy efficiency and environmental compatibility are gaining increasing significance. Comprehensive analyzes have helped to significantly reduce energy consumption at the institute. The aim of the next few years will be to stabilize this development. Extensive measures were examined in 2023 as part of a pilot project. Financing must now be found for 2024 in order to implement these measures. The particular challenge is to ensure such measures in the buildings of the field offices and to connect the members of staff of all sites.

Number of employees of Fraunhofer IKTS in 2023, headcount



Board of trustees

The president of the Fraunhofer-Gesellschaft has appointed the following people to the board of trustees at Fraunhofer IKTS:

The Fraunhofer-Gesellschaft

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

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

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

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

Joseph von Fraunhofer.

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

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

Retrospective

In 2023, Fraunhofer IKTS presented its research and services at numerous trade fairs in Germany and abroad and as the organizer of several scientific congresses as well as at various events for the general public.

January 1, 2023
Carbon recycling at the Freiberg site

With the integration of the Freiberg research group Carbon Cycle Technologies KKT into Fraunhofer IKTS, the institute aims to leverage further synergies in electrolysis, hydrogen and power-to-X technologies and develop sustainable carbon sources for the circular economy. Carbon is a key raw material for countless products in our daily lives. At the new site in Freiberg, chemical recycling processes such as pyrolysis and gasification are being optimized and tested on an industrial scale. In future, these recycling processes are to be combined with high-temperature electrolysis and Fischer-Tropsch synthesis, both core technologies at Fraunhofer IKTS, in order to provide new raw material and energy resources for a green industry.

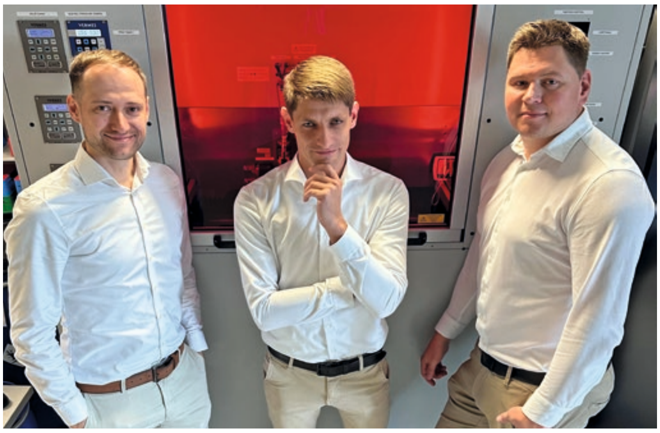
January 8, 2023
Research partnership for sustainable shipping and energy

Prof. Alexander Michaelis, Institute Director of Fraunhofer IKTS, has signed a memorandum of understanding with Korea Shipbuilding and Offshore Engineering (KSOE) Co, LTD and the European SOC producer ELCOGEN in Las Vegas. The partners have agreed to cooperate closely in the fields of hydrogen and fuel/electrolysis cells.

February 1, 2023
Spin-off AMAREA Technology GmbH founded

(Top image)

Multi-material 3D printing with high-performance materials makes it possible to print functionalized or functionally graded products within a single process while saving resources – individually, quickly and cost-effectively. The technology was developed at Fraunhofer IKTS and successfully demonstrated in



projects with industrial customers. In February 2023, the developers founded AMAREA Technology GmbH to commercialize the multi-material jetting technology and bring the 3D printers to series production.

March 15, 2023
Trade fairs: Where you could meet our employees in person

(Middle image)

A total of 43 appearances in Germany and abroad reflected the diversity of Fraunhofer IKTS and the areas of application of ceramic components, systems and non-destructive testing technologies. The overarching key topics were increasing efficiency, protecting resources and closing cycles.

The institute demonstrated solutions for water treatment at the **TausendWasser** trade fair in Berlin and at **HANNOVER MESSE**. By combining the latest UV diodes and cellular functional ceramics, highly diluted, dissolved chemical microparticles such as glyphosate, bisphenol A, drug and cosmetic residues can be eliminated from water in an energy-efficient manner, for instance in sewage treatment plants.

Together with Friedrich Schiller University Jena, the institute also focused on sodium-ion batteries in Hanover. With exhibits and presentations, the partners showcased the expertise established in Thuringia and Saxony for the commercialization of these sustainable batteries made from local, readily available raw materials along the "New Via Regia for Batteries". What these clusters of expertise currently need is strategic coordination and support. Looking ahead, industrial mass production of sodium-ion batteries could be achieved in Germany within five years.

At **FILTECH**, one of the world's largest trade fairs for filtration and separation technology, IKTS presented, among other things, carbon membranes that can separate CO_2 from industrial gases with concentrations of over 97 %. This CO_2 can be recycled, e.g. as a raw material for non-fossil fuels or chemicals. IKTS presented further solutions from materials to systems for the energy transition at the **European Hydrogen Week** in Brussels and at **ees Europe**.

Visitors to **CONTROL** and **JEC World**, among others, learned about innovative systems for condition monitoring and non-destructive testing. The highlight at **AeroNDT** in South Korea was EddyCus® MPECS flex. This device can be placed on aircraft and other structures and tests 2.5D-curved CFRP surfaces on site. This allows delamination from bird strike or other causes to be detected early on.

IKTS developments also enable precise diagnostics and individualized, gentle treatments in the medical field, for example in dental technology, small joint prosthetics or instrumental medicine, with IPUclean, FingerKIt and ClicKit-Well presented at **IDS**, **formnext** and **Compamed**.

March 17 | April 27, 2023
Schau rein! and Girls'Day – Profession: Chemical and physics laboratory technician

(Top image)

What does it mean to work in the laboratory of a research institution? On March 17 and April 27, Dresden school students spent a day immersed in everyday laboratory life at the IKTS site in Dresden-Gruna as part of the "Week of Open Companies Saxony" and the nationwide Girls' Day. They got to know the profession of chemistry and physics laboratory technician, tried their hand on some typical lab tasks and gained exciting insights into trainee programs at Fraunhofer IKTS from former trainees and our recruiting team.

March 27–30, 2023
Annual Meeting of the German Ceramic Society

In spring 2023, the ceramics community met for the annual conference of the German Ceramic Society at the Ernst Abbe University of Applied Sciences in Jena and in Hermsdorf. Over 300 participants took the opportunity for personal networking and attended the three-day lecture program. The high-tech companies at the Tridelta Campus Hermsdorf opened their doors as part of an industry excursion. The up-and-coming ceramists took part in an intensive contest for the best lecture, and in a panel discussion experts from politics, business and research discussed the opportunities and risks for the ceramics industry in the context of the energy transition.

March 29, 2023
Prof. Michaelis receives Rieke Ring of the DKG

(Bottom image)

Prof. Alexander Michaelis, Institute Director of Fraunhofer IKTS, was honored with the Rieke Ring of the German Ceramic Society for his many years of commitment to the DKG. The award ceremony took place during the DKG Annual Meeting in Jena.

April 17, 2023
Young researchers welcome
(Top image)

The IKTS working group “Condition Monitoring Systems” has a long tradition of inviting preschool children to the institute. In many small experiments, the youngsters learned how monitoring systems help to increase safety for people and the environment and to prolong the service life of systems.

As part of the Junior Doctor program, pupils in grades 3 to 5 experimented with eddy currents and examined various metals for defects that cannot be seen with the naked eye. They found small cracks or even the tiniest changes in the metal, which may later cause a component or device to break.

Under the motto “hands-on science”, primary school pupils took a look into various departments at Fraunhofer IKTS and experienced first hand how multifaceted the activities at a research institute are: from scientific work and supporting work in the laboratory and workshop to administrative tasks.

May 3, 2023
Nuclear technology and batteries are topics in online seminar series NDT4INDUSTRY

The NDT4INDUSTRY online seminar series presents the latest developments in non-destructive testing (NDT) for industry. In May, the focus was on how the latest ultrasound, eddy current, acoustic and X-ray technology can be used to monitor and test nuclear facilities during operation and what options IKTS offers to support the dismantling of nuclear facilities. The November seminar focused on batteries. Monitoring systems that ensure the fault-free production of battery electrodes were presented at the event. They can be integrated into the production line at various points so that processes such as mixing the electrode mass, coating, drying or calendering can be continuously monitored. The virtual laboratory tour at Fraunhofer THM in Freiberg showed a pilot line in which IKTS is testing new materials, manufacturing and monitoring technologies for battery electrode production.

June 3, 2023
Industrieerleben

At the “INDUSTRIEERLEBEN” event, visitors had the opportunity to get to know the companies at the Erfurter Kreuz industrial site. The Battery Innovation and Technology Center BITC also opened its laboratories and pilot plants to the interested public and offered insights into a state-of-the-art research facility. During guided tours of the institute, researchers explained how energy storage systems are tested in complex facilities and how this optimizes the production of batteries. There were also exclusive insights into current research projects in the field of hydrogen technologies.

Photo: Fraunhofer, Photographer: Andreas Rudolph

June 7, 2023
Ground-breaking ceremony for the new institute building of Fraunhofer ZESS
(Middle image)

The Fraunhofer Center for Energy Storage and Systems ZESS was launched back in 2019. In the presence of Lower Saxony’s Minister for Science and Culture, Falko Mohrs, and the Mayor of Braunschweig, Dr. Thorsten Kornblum, the ground-breaking ceremony for the new institute building at Braunschweig Research Airport took place on June 7, 2023. From 2025, researchers from the participating Fraunhofer institutes will have the necessary infrastructure in place to advance the development and implementation of innovative energy storage systems from prototype to industrialization.

June 20, 2023
abonocare® – sustainable nutrient recycling from organic residues

In the abonocare® growth core, companies and research institutions have jointly tested technologies for intelligent and sustainable nutrient recycling of organic waste in the spirit of the bioeconomy. Their goal: an economic circular economy in which biogenic waste is recycled into resources. To conclude the project, the partners presented their developments to the public and discussed the recycling and application potential of new types of fertilizer products, processing technologies and social framework conditions.

July 1, 2023
Science Night at TU Ilmenau

Thousands of visitors flocked to the Ilmenau Science Night on July 1 on the campus of the Technical University, where IKTS was also represented in the foyer of Fraunhofer IDMT. In an interactive presentation, visitors were able to find out about the topic of hydrogen and learn more about production research into energy storage systems.

July 4, 2023
Opening of the Hightech Incubator

With the "Hightech Incubator" program, start-ups at Tridelta Campus Hermsdorf can benefit from first-class support. Founders are advised by the Campus Business Angels, among others. Prof. Ingolf Voigt, Deputy Director of the institute and head of the Hermsdorf site, is also part of this mentoring team. The official launch of the program took place at Fraunhofer IKTS, where IKTS researchers are preparing the spin-off POXOS® aiming at the sale of oxygen generators with the support of the Hightech Incubator.

July 6, 2023
ThWIC kick-off

The first alliance meeting of the project partners in the ThWIC Thuringian Water Innovation Cluster took place in Jena with a two-day kick-off event. The main aim of the event was to network the sub-projects and partners in the cluster. The meeting was rounded off with an evening event in the Botanical Garden. The aim of the cluster is to provide impetus for solving global water problems and to use the advantages of Thuringia's small and medium-sized enterprises to open up cutting-edge research for social application more quickly.

August 31, 2023
Ceramics Meeting Point on three floors

The Ceramics Meeting Point at the IKTS site in Dresden-Gruna has been an integral part of Fraunhofer IKTS's public relations work for 20 years. It showcases the institute's range of topics and is therefore an important part of the program for guided tours, customer visits and conferences. In addition, more than 70 partners from industry and research present their range of services at this location as part of the cooperation with Ceramics Applications published by Göller Verlag. Following extensive renovation, the Ceramics Meeting Point was officially reopened on August 31 as part of an employee event.

September 4–5, 2023
International Sodium Battery Symposium SBS4

(Middle image)

Sodium batteries are a promising alternative to lithium cells. More than 120 international experts came to Dresden at the beginning of September to discuss established and innovative sodium-based battery concepts – from the fundamentals and active materials to cell concepts, systems, tests, markets and applications. Companies and researchers presented their latest developments at the accompanying industry and poster exhibition.

September 19, 2023
Media breakfast: Ceramic technologies for the bioeconomy

Vitamins from the rooftop? Prof. Michael Stelter, Deputy Director of Fraunhofer IKTS and holder of the Chair of Technical Environmental Chemistry at Friedrich Schiller University Jena, explained what technologies are needed in indoor farms and greenhouses for efficient and compact irrigation water and

nutrient recycling, heat and humidity management, lighting and sensor technology at the press breakfast of the Fraunhofer Institute Center Dresden on September 19. The necessary components and system know-how are readily available at IKTS. An interdisciplinary team is now working on integrating these into an automated and fully digitalized overall system.

September 25–27, 2023
Dresden Battery Days
(Top image)

Around 70 international experts in electrochemical energy storage got together for the 4th edition of the Dresden Battery Days to discuss the necessary "steps towards a sustainable and circular battery value chain". Circular processes, digitalization and recycling were the focus of the presentations and discussions at the two-day conference.

Photo: CATL

October 23, 2023
High-end test center for long-lasting batteries
(Bottom image)

Fraunhofer IKTS has been cooperating with the Chinese battery manufacturer Contemporary Amperex Technology GmbH (CATL) at the Arnstadt site since 2020. Together, the partners set up a test center in the "BattLife" project to create models for calculating the service life of batteries. Following the successful completion of the project, the continued cooperation in the follow-up project "BattForce" was celebrated at a ceremony. The joint high-end test center aims to further optimize battery production and extend the service life of batteries, particularly for the automotive sector.

December 1, 2023
Dutch delegation visits Fraunhofer IKTS

As part of a delegation visit, Dutch experts from the photovoltaic (PV) industry stopped by Fraunhofer IKTS for a German-Dutch network meeting on solar photovoltaics. The event was organized by the Dutch embassy with the support of the Dutch government and the Free State of Saxony to connect Saxon and Dutch companies, discuss the latest developments in the PV industry and exchange ideas.

December 7, 2023
Belgian-Saxon networking event on circular economy

Belgian and Saxon stakeholders from industry, research and business development discussed promising recycling technologies, expertise and framework conditions "on the path to a decarbonized and circular industry" at a networking event at Fraunhofer IKTS in Dresden. The focus was on networking the players and possible collaboration. The meeting was organized by the Wallonia Export & Investment Agency, hub.brussels, Energy Saxony e. V. and Fraunhofer IKTS – with the kind support of Wirtschaftsförderung Sachsen GmbH.

December 9, 2023

Best physics laboratory assistant in Saxony and award for dual training at IKTS

Anabell Zeller, who completed her training as a physics laboratory technician at Fraunhofer IKTS in Dresden-Klotzsche, was recognized by the Dresden Chamber of Industry and Commerce as the best in her field. Her outstanding degree also made her the best graduate in her field in the Free State of Saxony. In addition to the young skilled workers, companies training apprentices were also honored for their above-average dual vocational training. In this context, Fraunhofer IKTS at the Dresden-Klotzsche site was once again awarded the title of 'Excellent Training Company'.

January 17, 2024

Industry Day of the competence clusters "Recycling & Green Batteries" (greenBatt) and "Battery Usage Concepts" (BattNutzung)

Around 100 interested partners from industry and research accepted the invitation of the two competence clusters "greenBatt" and "BattNutzung" to Dresden and learned about the most important results and findings of the cluster projects. Over the past three years, scientific issues relating to the sustainable and lifecycle-oriented design of lithium-ion batteries as well as concepts for their subsequent use and recycling have been researched as part of the umbrella concept of battery research production.

January 24, 2024

Fraunhofer President Prof. Hanselka on dialog tour

(Bottom image)

On his dialog tour, a series of talks throughout Germany, the new Fraunhofer President Prof. Holger Hanselka visited the Fraunhofer Institute Center Dresden in mid-January. IKTS Institute Director Prof. Alexander Michaelis accompanied him on a laboratory tour of the institute. Dr. Stefan Rothe presented the electrolysis and fuel cell technologies developed at IKTS. Dr. Lars Schubert demonstrated pressure tank monitoring with ultrasound for safe hydrogen storage. Dr. Matthias Jahn and his team focused on power-to-X technologies and the direct reduction of steel with hydrogen. Daniela Herold presented the sodium solid-state battery for stationary energy storage.

February 20, 2024

Center for German-Korean research cooperation inaugurated

(Top image)

With a ceremony, the "Germany-Korea Technology Cooperation Center for Global Value Chains" was opened at Fraunhofer IKTS in Dresden-Klotzsche. Together with the Korea Evaluation Institute of Industrial Technology (KEIT), Fraunhofer IKTS will in future operate the center, which will act as a coordination point for R&D cooperation between Fraunhofer institutes, universities and companies from Germany and Korean research and industry partners. Together, technology needs and technology funding programs for joint projects in both countries are identified, project initiation is supported and technology transfer is prepared. Prof. Ingolf Voigt, Deputy Director of Fraunhofer IKTS, was appointed as IKTS representative to the Korea-Germany Future Technology R&D Planning Committee.

Highlights from our business divisions

In interview
page 22–27

Circular economy, sustainable energy supply and industrial transformation are current challenges for society as a whole. Fraunhofer IKTS works across disciplines and locations to develop needs-based and sustainable solutions. Through unique facilities and test fields, we quickly transfer research and development results into application – for the benefit of society, the economy and the environment.

In two interviews, we shed light on technological approaches to circular value creation and increasing resource efficiency in a post-fossil, sustainable economy.

Materials and Processes
page 28–33

This business division is a port of call for all questions concerning the development, production and qualification of high-performance ceramics for a wide range of applications. At its center is the long years of experience with all relevant ceramic materials and technologies for which functionally adequate solutions are developed based on the specific requirements. The business division works to solve issues along the complete process chain. It also functions as a central hub for all other business divisions.

Energy
page 34–40

For improved and groundbreaking new applications in the field of energy technology, IKTS tests components, modules and complete systems. These help to convert energy more efficiently, integrate regenerative energies and enable energy storage solutions to meet future needs. Ceramic solid-state ion conductors are a focal point of the work done within the business division. Applications include batteries and fuel cells, solar cells and thermal energy systems, even solutions for bioenergetic and chemical energy sources.

Water
page 41–44

Efficient use and purification of water is of the highest importance. Fraunhofer IKTS provides solutions for the treatment of wastewaters – from multifunctional components to compact overall systems. The combination of various methods, such as filtration, adsorption or sono-electrochemical oxidation, has significant advantages over traditional approaches. Furthermore, specific sensor systems are integrated to increase process efficiency, reduce process costs and enable balancing.

Environmental and Process Engineering
page 45–51

Work in this business division is focused on processes in the field of conventional energy and bioenergy, strategies and methods for water and air purification and for recovering valuable raw materials from residual waste. Many of these approaches aim for closed material cycles. Fraunhofer IKTS uses ceramic membranes, filters, adsorbents and catalysts to implement complex process engineering systems for energy-efficient separation processes, chemical conversion and the recovery of valuable materials.

Electronics and Microsystems
page 52–54

The business division gives manufacturers and users unique access to cost-efficient and reliable materials and manufacturing solutions for robust and high-performing electronic components. In addition to sensors and sensor systems, components for power electronics as well as smart multifunctional systems are another focal point. Using innovative test methods and systems, IKTS provides support throughout the complete value chain – from the material through to the integration of complex electronic systems.

Non-Destructive Testing and Monitoring
page 55–56

Quality, cost and time are key if products and services are to succeed in the marketplace. Non-destructive testing can contribute significantly to their continuous improvement. Fraunhofer IKTS combines its decades of experience in the testing and monitoring of components and plants with novel measuring technologies, automation concepts and approaches for the interpretation of complex volumes of data. The portfolio of our competencies thus far exceeds that of a typical NDT technology provider.

Mechanical and Automotive Engineering
page 57–60

High performance ceramics are key components for plant engineering and construction as well as automotive engineering. Because of their outstanding properties, they often constitute the only viable solution. The business division provides wear parts and tools as well as components from high performance ceramics, cemented carbides, cermets and hybridized composites with very specific load profiles. Testing systems for the monitoring of components and production plants based on optical, elastodynamic and magnetic effects are another focal point.

Bio- and Medical Technology
page 61–63

Fraunhofer IKTS makes use of the outstanding properties offered by ceramic materials with regard to the development of dental and endoprosthetic implants as well as surgical instruments. In our certified labs, we use the very best equipment to examine the interactions between biological and artificial materials, leading to improved developments in materials, analytics and diagnostics. To achieve this, we use some of the most unique optical, acoustic and bioelectric methods.

Materials and Process Analysis
page 64–67

Fraunhofer IKTS offers a comprehensive portfolio in testing, characterization and analysis methods to control material features and production processes. As a service provider accredited and audited multiple times, IKTS supports the analysis of materials fundamentals, application-related questions and developments in measuring technology. Characteristic values are not just determined but interpreted within the context of their specific application in order to reveal the potential for optimization.

Carbon in the cycle

Interview with Prof. Martin Gräbner, PD Dr. Matthias Jahn, Dr. Hannes Richter, Dr. Jörg Richter und Prof. Michael Stelter

Carbon (or simply: C) has a bad reputation. At the same time, carbon is everywhere. It is the atom of life and shapes our entire economy. Carbon is part of our DNA, the foods we eat, and the products we use every day. Carbon is part of the fuels that power our vehicles and factories or heat our homes, and the materials we use to build our cities. In industry, carbon is both a source of energy and a raw material – all of organic chemistry and the downstream added value, including the building materials and plastics industries, is based on carbon.

In nature, carbon flows continuously between the atmosphere, the oceans, the vegetation and the earth's crust. It was humankind that has knocked the cycle out of balance since the Industrial Revolution by using the fossil, finite sources of carbon oil, gas and coal. When fossil carbon is burned, it reacts with oxygen. This results in carbon dioxide (CO_2). In the last 150 years, these emissions from industrial exhaust gases or mobility on land, in the air and at sea have more than doubled the CO_2 concentration in the atmosphere – with severe effects on the climate.

The resulting goals, toward which the researchers at Fraunhofer IKTS are also contributing, are diverse: It is important to completely avoid further climate-damaging emissions in order to reduce the human impact on the climate. At the same time, the finite resources of our earth must be protected. In order to meet the demand for carbon for the products and fuels we use in our daily lives in a climate-neutral manner, we need alternative regenerative carbon sources – and process technology with which a sustainable carbon circular economy can be realized, which keeps reusing the carbon that is already in circulation (**CCU:** carbon capture and utilization).

Which sustainable sources of carbon exist?

M. Gräbner: I think that if we want to make carbon available beyond fossil resources as a basis for fuels or for the chemical industry, we have the following options: Firstly, CO_2 – the energetically worst form of carbon in terms of energy – can be extracted from the atmosphere via direct air capture only with great effort. It is better to use unavoidable industrial point sources. Secondly, biogenic carbon from biomass can be used even before it is oxidized. Thirdly, we can recover what we call anthropogenic carbon from plastics by chemically recycling waste streams.

M. Stelter: Carbon cycles are complex and must be thought through creatively. To ensure that the existing carbon can circulate, we at Fraunhofer IKTS rely on a wide range of technologies for future-oriented usage concepts.

Through electrification using renewable sources and the expanding hydrogen infrastructure, significant carbon emitters have already been converted energetically, e.g. parts of the steel industry. Where will CO_2 remain unavoidable in the long term and why? How can the carbon contained in it be used?

H. Richter: Overall, around 30 % of industrial CO_2 emissions in Germany are process-related, among them emissions from the lime and cement industries. Two-thirds of CO_2 emissions will be unavoidable here. These stem from limestone, itself a carbonate. While lime is a fossil carbon source too, it is indispensable as a raw material for cement production in the building materials industry.

M. Jahn: Therefore, we pursue the approach of separating unavoidable CO_2 emissions from exhaust gases right where they arise. The CO_2 can be used on site for synthesis or transported via a gas pipeline to refineries and chemical plants, where it can be recycled. Within the BMBF project Colyssy, for instance, we demonstrated a way to do this directly in the lime plant: First, ceramic filter plugs remove dust from the exhaust gas. The CO_2 can then be separated by ceramic membranes and converted into carbon monoxide in a high-temperature electrolysis reactor (SOEC) with 10 kW power at over 750 °C, while the same reactor generates hydrogen from water vapor. Carbon monoxide and hydrogen together produce syngas. The electrolysis reactor is operated with regenerative electricity. In a downstream Fischer-Tropsch reactor, also developed at IKTS, the syngas is converted into liquid hydrocarbons and waxes or synthetic crude oil, termed SynCrude. The CO_2 from all German lime and cement plants would cover one third of the naphtha demand in Germany and, as sustainable aviation fuel (SAF), half of the kerosene demand.

J. Richter: We are working on a BMBF-WIR project called **Grüner Kalk** (green lime) to investigate an alternative approach. A lime burning furnace is heated electrically instead of with natural gas, so that pure CO_2 is essentially produced inherently. Through a downstream methanation with regenerative hydrogen and subsequent methane pyrolysis, the carbon finally produced at the end of the process chain exists in its pure form. It does not enter the atmosphere as CO_2. The hydrogen produced from the methane during pyrolysis is returned to the methanation reaction. CO_2-intensive lime burning could actually become a CO_2 sink with this process.

H. Richter: The use of ceramic membranes as described above can generally be a game changer when used as a separation

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From left top to right bottom: Fanny Pohontsch in conversation with Prof. Michael Stelter, Dr. Jörg Richter, Prof. Martin Gräbner, PD Dr. Matthias Jahn and Dr. Hannes Richter.

technology for process gases. Currently, amine washing is used in industry as well as in some biogas plants on a large scale to separate CO_2 from gas streams. It raises many questions about the composition of the flue gas or the shelf life of the amine solution itself, and it basically requires a high level of additional energy. Polymer membranes are also in use, albeit on a smaller scale. Our focus is on ceramic membranes, which can withstand extreme temperatures compared with polymer membranes and are more stable against various ancillary components in the exhaust gas, such as nitrogen oxides or sulfur oxides, at a CO_2 separation rate of 98 %. This would allow the exhaust gas flow to be purified not only highly selectively, but also without the need for chemicals. For zero emission, the membranes could be coupled with a small-scale adsorption stage. Several studies have already shown:

"Membrane processes save 80 % energy compared with conventional separation processes."

J. Richter: This is advantageous, as many routes of use rely on electricity, which is ideally generated from renewable sources. Every bit of energy saved at this point immediately helps the entire system. Renewable energy must be sufficiently available to operate the envisaged systems and produce e.g. green hydrogen for the subsequent syntheses, in Germany or Europe and worldwide.

How can biomass be exploited as a sustainable carbon source?

M. Stelter: First and foremost: When it comes to biomass, our interest is focused mainly on agricultural, municipal and industrial organic waste and residues, such as plant residues or liquid manure. We must avoid competing with food producers for cultivable land. A biogas plant provides us with fermentatively produced biogas, composed of about 40 % biogenic CO_2 and 60 % methane. Up to now, the valuable CO_2 has escaped unused. The methane is often purified and fed into the natural gas grid if not used exclusively to produce for electricity and heat. Once feed-in tariffs have gradually expired over the coming years, this business model will no longer function. New ideas are then needed to continue to operate agricultural businesses economically. It is therefore worth considering the material use of the entire gas from the biogas plants. One approach here would be to produce fuel for utility vehicles, such as tractors. This could be achieved with a small, modular membrane system in which the available methane is purified directly.

H. Richter: This is also partly the subject of the EU project METHAREN. In this project, we want to demonstrate new cost-effective processes at biogas plants that increase the carbon conversion rate from biomass to methane to 80 %. That would mean, conversely, that CO_2 emissions at biogas plants would be halved. It would be a great lever for meeting the gas demand in Europe without relying on imports. In Turin, Italy, there is a pilot plant in which our ceramic membrane technology is also to be used. In another project, Innomem, we were able to show that our novel zeolite membranes provide excellent separation performance in this application.

M. Jahn: Since we are talking about supplying energy in a post-fossil age, research and development also go toward ensuring a weather-independent, decentralized, stable power supply by coupling the biogas plant with a high-temperature solid oxide fuel cell system (SOFC). Conventional combined heat and power (CHP) plants generally operate with gas engines that have an electrical efficiency of 40 %. A large part of the energy potential of biomass remains unused. At 60 %, SOFC systems are significantly more efficient. In addition to the provision of electricity, the use of heat must always be taken into account as well to achieve the highest possible overall utilization of energy. Since solid oxide cells can be operated both as fuel cells and as electrolytic cells, investment costs will fall sharply in the medium to short term thanks to growing electrolysis capacities. As an alternative to supplying electricity and heat via the fuel cell, biogas can also be reformed into syngas and, as in the previous example, converted into SynCrude in a decentralized manner, and then in a more centralized way into SAF and naphtha in refineries.

"The synthetic oil from biogenic waste provides us with a high-quality raw product from regional production."

This is advantageous for processing. The concept has already been evaluated in a biogas plant in Thallwitz near Leipzig.

At what plant size is this worthwhile?

M. Jahn: According to our calculations and techno-economic assessments, it can already be useful to use the technology on an average German biogas plant with 500 kW output. One important aspect: Where is the processing done, where does the use take place? The region around Leipzig with its large airport, agriculture and the chemical park in Leuna is an example region in which a new value chain can be established.

M. Gräbner: In contrast to the Fischer-Tropsch route mentioned above, we use methanol-based processes with TU Freiberg to generate renewable fuels. In the last quarter, we already produced 55,000 liters of green gasoline based on bio-methanol in a large-scale test facility. The product has been certified according to DIN EN 228 since Christmas, it is REACH-registered and can be used as E10 fuel. This is a huge milestone, reached in the joint project **DeCarTrans.**

M. Stelter: Does that mean that regional biomass could be used to produce fuels decentrally to supply a small region directly?

M. Gräbner: That would be the next scaling step. Our industrial partner CAC Engineering is working toward a target of 250,000 tons of gasoline a year. In an industrial plant, this would mean production costs of less than one euro per liter. However, we will also have to additionally import renewable energy from energy-favored countries in the form of hydrogen and its derivatives if we want to keep costs down, including methanol as a carbon carrier. The important thing will be that the methanol was synthesized from CO_2 from the air or biogenic sources, so that we achieve a closed cycle. Methanol is so versatile that we can, firstly, introduce it into the existing infrastructure as a fuel for energy use and, secondly, offer it as a raw material base for the chemical industry. This would only require minor process changes in those same plants in order to switch from methanol-to-gasoline, for example, to methanol-to-jet, like in our joint project **EwOPro**, or to methanol-to-chemicals. In this process we obtain chemical products, such as polypropylene, a plastic already produced today based on methanol, only with that methanol coming from coal. The import of regenerative methanol, on the other hand, can contribute to a sustainable carbon balance of the chemical industry.

M. Jahn: In Chile, in the BMBF project **Power-to-MEDME-FuE**, we are currently supporting, for instance, the construction of a pilot plant for methanol. As part of the project, dimethyl ether (DME) is produced in a subsequent process, which can be used as a direct substitute for diesel fuel, but also as a carrier medium for the transport of hydrogen. When DME is converted back into hydrogen, CO_2 is released. If this CO_2 is also directly separated there and returned to the exporting country, in this case Chile, the carbon cycle can be largely closed. Only a small amount of CO_2 must then be additionally separated from the air.

J. Richter: As a liquid hydrogen carrier, methanol is also of interest for shipping, which has so far been a huge emitter of fossil CO_2. Methanol reforming can be used to reform methanol with water into hydrogen and CO_2. If a membrane reactor is used as a reformer, hydrogen and CO_2 can be separated directly during this reaction. Hydrogen propels the ship, while CO_2 is stored in liquefied form on board in the now available methanol tanks. In this pure form, it can be used again for the production of methanol when on land. This creates a closed CO_2 cycle. In the EU project **HyMethShip**, we took over the process and reactor design and equipped these reactors with membranes and catalysts.

Let's stay with the anthropogenic, man-made carbon source – plastic. What processes are used here?

M. Gräbner: So far, more than half of all plastic-containing waste in Germany is incinerated. This amounts to more than three million tons per year – composite materials or mixed plastics that are currently not machinable, or only at great expense. The carbon contained therein escapes into the atmosphere as climate-damaging CO_2. By means of chemical recycling, such as pyrolysis and gasification, we keep the carbon almost completely within the cycle. Waste can thus be broken down into its smallest units. We are investigating this in the Fraunhofer lighthouse project **Waste4Future**. The recycling products that can be assembled precisely in the next step cannot be distinguished qualitatively from a new fossil product. Gasification even allows us to recover carbon from critical substances, such as those contaminated with chlorine. This includes polyvinyl chloride (PVC) from the 90s, which is mixed with lead, bromine and other substances. Today, the discarded materials – floor coverings, window frames, cable insulation – are partly transported through lime kilns in which the chlorine is absorbed as salt. Gasification allows to obtain both chlorine and hydrochloric acid and return these substances to chlorine production, as well as carbon in the form of carbon monoxide. In addition, there are no flue gases and filter dusts, in contrast with incineration. There is no need to landfill ashes as hazardous waste. We vitrify the substances into a glass-like material in which dangerous heavy metals or toxic mineral mixtures are safely integrated. It can then be ground granularly to serve as a sand substitute for the building materials industry. In principle, however, our facilities are flexible with regard to input materials. This means that biomass can not only be split up in the biogas plant, but also converted into valuable coke in pyrolysis.

That must surely require a lot of energy?

M. Gräbner: In order to be able to perform continuous industrial pyrolysis or gasification, the waste must be homogenized. However, metal parts, mineral elements and moisture can be separated even with simple process technology, which significantly reduces the further effort and energy consumption overall. In a gasification process, typically only about one fifth of the energy used is released as heat. As we look at the entire value chain, including all secondary streams, such as the slags, we also increase resource efficiency. Waste disposal costs are reduced, nothing is lost or ends up in a landfill. This approach is therefore much more energy-efficient than capturing CO_2 from the air after the valuable carbon carriers have been burned.

All these scenarios compete for the same carbon sources. Will these sources not dry up if we as a society use fewer plastic products and the limited biomass potential is exhausted?

M. Gräbner: That is why it is so important to keep carbon in circulation by making better use of the carbon-containing components in the waste and by reproducing high-quality raw materials for the industry.

"In a defossilized economy, carbon will be the determining element in providing the necessary quantities of regenerative fuels and sustainable chemical products."

Without CO_2 from the atmosphere, that will hardly be possible in the long term. The reason for this is the entire amount of waste that is currently being sent to German waste incineration plants would theoretically only suffice to supply the chemical industry with circulating carbon. For this reason, CO_2 must first be intercepted at any point source and approved as an energy and substance carrier – before it has been diluted in the atmosphere and needs to be separated at great expense.

M. Jahn: Yes, carbon will become a scarce commodity. The conversion of the plants requires regulatory incentives, such as the quota system for the addition of green kerosene, i.e. SAF. We offer our customers the opportunity to analyze the usage paths from an economic, ecological and social perspective. This allows determining the most sensible variant, which will pay off over the short or long term – economically and for the climate.

Cultivating plants in a controlled environment

Interview with Nico Domurath

People at Fraunhofer IKTS are driven by the aim to develop holistic economical and sustainable systems as well as services for practical applications. They work together across various disciplines to gain insight into the complex questions of our time, and drive innovation.

Agricultural expert Nico Domurath is one of them. His technical center in Dresden-Gruna is not hard to find. Just follow the violet light emitted from the panes of his lab door. It comes from compact, glazed test beds housing plants on several levels. The scent of basil lingers in the room. This indoor farm at the ceramics institute is a prime example of interdisciplinary cooperation.

Mr. Domurath, what is the research question you intend to solve as a horticulturist at an institute dedicated to technical ceramics?

My focus is on growing crops under controlled conditions, also known as **CEA, controlled environment agriculture**. This mainly includes greenhouse horticulture and vertical farming. The industry is currently experiencing an increasing dynamic growth. In view of the UN's sustainability goals, we aim for a bio-based economy that uses natural material cycles while protecting natural resources and meeting the needs of a growing world population. If it is eight billion people today, it will be more than ten billion people by 2050, which will have to be supplied with food and raw materials – 80 % of them in large cities. We consider CEA systems to be part of the technical infrastructure that underpins food production and the bioeconomy. They provide optimal growth conditions for plants or organisms, for example to ensure a healthy diet: In greenhouses or vertical farms, any climate in the world can be created indoors, regardless of the season and location. This promises year-round yields in consistent quality and quantity. For instance, tomatoes, lettuce and herbs, or protein-rich vegetables, no longer need to be harvested before they are ripe and then transported to our supermarkets for days across thousands of miles from the dry south or from overseas. This reduces emissions as well as the virtual water and land consumption. All this means that plant growing in a controlled environment is a major lever when it comes to the ecological footprint and the decentralized supply of demand for food and the bioeconomy. However, we know from analyses: A lot of development is needed for the CEA concept to become profitable. We aim to solve the urgent challenges with our robust ceramic and diagnostic components and technologies.

How can the efficiency of cultivation setups in a controlled environment be optimized? What is your approach?

> "We think that the state of the art in crop cultivation in controlled environments can be raised to a new level with an integrated, interdisciplinary systems approach."

At Fraunhofer IKTS, we have decades of know-how in energy and environmental technology, photonics, sensor technology and test technology. We want to apply all of this to CEA infrastructures and to the needs of plants, which require heat, light, water and nutrients. The vertical cultivation cabinets are our test benches. This is where we combine our technology portfolio for this specific application. We take a holistic view of the interactions and balance between water use, nutrient production and energy. We link processes such as water cycles with heat management, aiming to achieve closed cycles. Today, controlled cultivation is technically still so complex that great leaps in efficiency are possible. Depending on the application scenario, systems of different scale and complexity are useful.

Which components and technologies do you develop and combine? How do you make them interact successfully?

We specifically test and develop whether our calculations also work in practice over the long term. We want to get to a point where we recover even the water the plant transpires. We use our membrane technology for media processing – e.g. water is treated through ceramic nanofilters and AOP, advanced oxidation processes. At the same time, sensors determine which nutrients the water still contains and which ones must be resupplied, in our case as a hydroponic solution. With the optimizations we have planned, a yield of 80 to 100 g lettuce per liter of water is realistic. That is twice as much as in previous vertical farms. Depending on the geographical latitude, lettuce cultivated on an open field is expected to yield 5 to 20 g per liter.

We rely on intelligent materials, such as flowable molded bodies made of innovative zeolite ceramics. The zeolites provide both latent heat and water storage: When the zeolites absorb

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heat, they release stored water through evaporation. When they absorb moisture at a later point, they release heat. If the airflow in the test beds is tightly controlled, the zeolites could be used to store excess heat during the day and release it at night when needed. This could replace energy- and maintenance-intensive, external compression chillers or fossil heating systems.

“One of the strengths of the institute is to be able to solve technical challenges directly through functionalities in the material.”

We are going one step further and would like to integrate the entire controllable lighting technology into an energy management system integrated with the heat and humidity complex. Because where there is light, there is heat as well. By controlling plant exposure with pulse width modulation and synchronizing photon uptake and electron delivery, the energy requirement for light exposure could be reduced by 30 to 50 %.

Various inhouse biochemical and physical sensors could be used to determine whether the plants are doing well and how productive they are. They monitor the nutrient content, environmental parameters and plant pathogens. Integrated optical methods, such as laser speckle photometry, can be used to assess root growth or maturity. We want to orchestrate these diverse IKTS technologies as a modular, scalable system, fully digitized, for automated and even autonomous operation. In the end, it should be possible to build CEA systems so small and compact that they can be installed virtually anywhere, even in direct proximity to consumers. Agricultural production could then take place in locations that were previously unavailable for this purpose.

But surely each scenario – future indoor farms in, say, metropolitan areas or industrial parks – requires a varied ”configuration” ?

The concept is well suited for linking with commercial, industrial or urban infrastructures. Our goal is to integrate these systems into the respective environment in the best possible way. That is why we are using the modular approach. That may sound like an immense use of technology but we validate this from application to application using cost-effectiveness analyses and life cycle assessments. For instance, we look at the material and media flows and/or location interfaces that occur in the environment: What are the lighting conditions? Can renewable energy sources be combined and what do we do when there is no wind and the sky is overcast? Can I collect waste heat from server farms or hand over my own surplus to a manufacturing plant in the vicinity? Can I even use their emitted CO_2 directly, and how should it be reconcentrated and purified if necessary?

What about the nutrients supplied, such as phosphor and nitrogen – where do they come from and what are the development needs at this point?

The question of how nutrients can be recovered from organic residual material streams has been in our sights at IKTS for some time. We rely on biomass, such as sewage sludge from municipal sewage treatment plants or digestate from biogas plants. Ceramic membranes are used to separate the nutrients. At this point I should mention the abonocare® growth core, where we also test, in our vertical farming test beds, how well recyclates from biomass are absorbed by the plants. This is because the raw recyclates are often not yet to their liking at this stage. Phosphor tends to form alliances with other substances. The roots have difficulty absorbing it. Therefore, these phosphates must be specifically conditioned. The same applies to nitrogen: In organic fertilizers, this nutrient must first be dissolved from complex compounds. In nature, this happens automatically in the soil, a microbiological process. For a nutrient solution system as implemented at our institute, specific niches must be created for this purpose. In this regard, ceramic growth bodies make for great substrates.

What steps have you planned next?

Our long-term goal is a “toolbox” that enables users to connect them to any kind of indoor farm. These can come in the form of vertical cultivation cabinets like the ones we use, or greenhouses in different sizes and shapes, each optimally designed for the possible interfaces discussed here or elsewhere. For controlled cultivation, we want to pave the way for economic and ecological decentralized self-sufficiency – for secure and healthy nutrition and as a pillar of the bioeconomy.

Porous ceramics for optical moisture sensors

Dr. Stefanie Hildebrandt, Dr. Daniela Haase, Dipl.-Krist. Jörg Adler, Dipl.-Ing. (FH) Jörn Augustin, Dipl.-Ing. (FH) Georg Lautenschläger, Dr. Stefan Helbig

In the construction industry, many materials such as screed are installed and processed when moist. Excess water that is not required for the setting process needs to be released into the ambient air as quickly as possible. Simple and precise monitoring of moisture levels is required to avoid covering the screed prematurely and prevent potential structural damage. Additionally, the use of energy and other resources in production can be reduced if waiting times in construction operations are minimized.

Measuring principle: detection of the moisture-dependent light transmission through a ceramic pore structure

At Fraunhofer IKTS, humidity sensors based on porous ceramics are being developed that utilize the improved light conduction of water-filled pores. The light conduction decreases during drying and is insensitive to the salt content in the water.

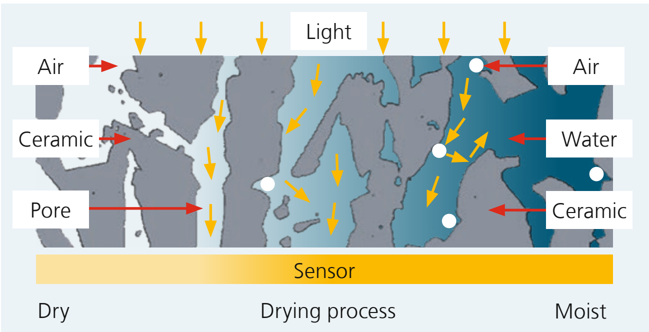

Figure 1: Schematic drawing of optical moisture measurement by light conduction (light diffraction, scattering and reflection) in porous ceramics in dry and wet conditions.

Customized pore ceramics

Moisture measurement requires that the moisture in the building material (e.g. calcium sulphate screed) and in the porous ceramic are similar. The porous sensor ceramics must therefore be matched to the screeds in terms of pore size and porosity. For this purpose, the building materials are analyzed with regard to these properties and, additionally, their moisture storage function is determined. The ceramic raw materials, suitable molding and sintering steps are coordinated to meet the requirements of the building material.

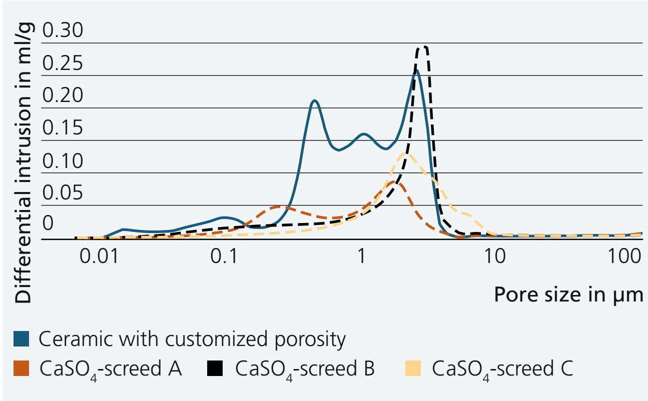

Figure 2: Customized porous ceramic in the moisture sensor, adapted to the actual pore sizes of the screed (for example calcium sulphate screeds A, B, C).

The sensors were tested on a laboratory scale and in application-relevant screed surfaces in calcium sulphate screeds. For screed floors whose pore structure was well matched with the pore ceramic, the moisture monitoring performed very well in accuracy until the screed was ready for covering.

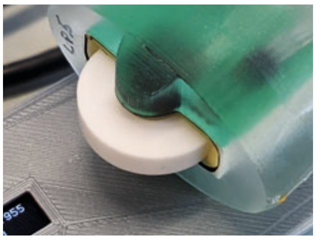

Figure 3: Prototype of light-optical moisture sensor for measurement in $CaSO_4$ screeds (sensor and pore ceramic).

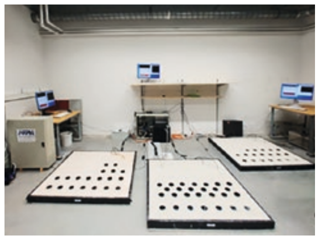

Figure 4: Test setup: screed surfaces with installed sensors and measured value recording. (Source: MFPA Weimar)

Services and cooperation offered

- Characterization of the microstructure and porosity of building materials, soils, inorganic materials
- Production of ceramics that are micro- and macro-structurally adapted to the material to be analyzed
- Investigation of the drying process and monitoring via light-optical measurement on ceramic discs

The work was carried out in cooperation with the MFPA Weimar and the BV Gips e.V. as part of the AIF/IGF project 20936 BR.

Forschungsnetzwerk Mittelstand
Industrielle Gemeinschaftsforschung
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Durable ceramic heat exchanger honeycombs for exhaust air purification

Dr. Uwe Petasch, Dipl.-Ing. (FH) Stephanie Schlotza, M.Sc. Lasse Fabian Köhl, Dipl.-Krist. Jörg Adler

Regenerative thermal oxidation (RTO) is an exhaust gas purification process used in industrial plants to reduce hydrocarbon emissions. In this process, the exhaust gases are heated to high temperatures in oxidation reactors to convert volatile organic compounds (VOCs) with oxygen. Ceramic honeycombs are commonly used as heat exchangers (regenerators) for regenerative heat recovery. The honeycombs are arranged in regenerator beds, which are preheated in a first step by the purified hot gas flow from the oxidation reactor. After reversing the flow direction, the absorbed heat energy is transferred to the cold, unpurified exhaust gas. At flue gas temperatures of 800 to 900 °C and sufficient VOC concentrations, the RTO system can operate in autothermal mode with self-sustaining combustion of the organic compounds in the flue gas.

Because of its high thermal and chemical resistance, alumina porcelain is often used as a material for ceramic heat exchangers. Even though the honeycombs have a good mechanical strength, high temperature differences and frequent temperature changes in the heat exchanger bed can lead to degradation. Analyses at Fraunhofer IKTS of aged honeycombs have shown that cracks on the inner surface increase the porosity of the honeycomb material. As a result, an increased amount of decomposition products can be deposited on the surface. Subsequently, the heat transfer efficiency decreases significantly and hydrocarbon emission thresholds cannot be met.

As part of project "LangRTO", funded by the German Federal Ministry for Economic Affairs and Climate Action (BMWK), which focused on the development of more durable exhaust air purification systems, research was performed at IKTS on materials and processes to stabilize the surfaces of ceramic honeycombs. The aim was to reduce the degeneration and subsequent loss of performance in the RTO process. To achieve this, Fraunhofer IKTS, together with project partner Relox Anlagen GmbH, worked on improving the RTO process to be able to permanently comply with future emission thresholds determined through continuous measurement.

To seal and stabilize the surface of the ceramic material, protective layers of glazing materials and coating processes for the post-treatment of commercially available ceramic honeycombs were developed in the project. The most homogeneous coatings with good adhesion to the substrate and layer thicknesses in the range of 35 to 70 µm were achieved with glazes whose firing temperature is below the softening point of the ceramic substrates. The resulting protective layers reduced the surface porosity of the material and minimized the formation of cracks at the honeycomb surface. Additionally, thanks to their softening behavior, the glazes also have the potential to heal cracks in the coated surfaces at higher temperatures. In real tests of coated honeycombs in the RTO process, no adsorption of hydrocarbons and decomposition products from the exhaust gas was detected that would significantly impair heat exchanger performance.

Services and cooperation offered

- Development of ceramic heat storage materials with application-oriented properties
- Development of processes for material modification and surface coating
- Characterization of honeycomb substrates and heat storage materials regarding chemical, mechanical and thermal properties

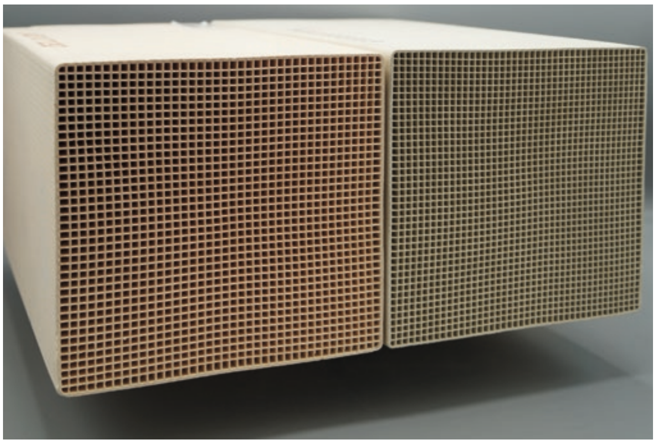

Figure 1: Alumina porcelain heat exchangers with glaze coating before (right) and after (left) use in the RTO process.

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Superlubrication for ceramic bearings on silicon nitride-silicon carbide basis

Dr. Eveline Zschippang, Dr. Mathias Herrmann, Dr. Tobias Aman*, Dr. Andreas Kailer*
(*Fraunhofer IWM)

Approximately 20 % of the energy in technical processes and systems is lost due to friction. Therefore, minimizing friction is an essential part of increasing energy efficiency. In order to significantly reduce friction losses, researchers from the Fraunhofer institutes IKTS, IWM, IWS and IPA are working on transferring superlubrication from laboratory scale to machine elements in the Fraunhofer internal program PREPARE (project "SupraSlide"). Ceramics made of silicon nitride (Si_3N_4) and silicon carbide (SiC) are corrosion-resistant, wear-resistant and have a high thermal load capacity – an ideal material for plain bearings. Researchers at Fraunhofer IKTS have developed Si_3N_4 and Si_3N_4-SiC ceramics and modified their surfaces by lapping and polishing. Within the scope of the project, different microstructures and material compositions were realized and their tribological properties were tested at Fraunhofer IWM in Freiburg. There, superlubrication was demonstrated in a model test using water-based lubricants. The test also showed that even a lapped surface is sufficiently smooth to achieve superlubrication – a major advantage for industrial implementation. Composite materials made of Si_3N_4 with SiC particle reinforcement were particularly promising. Figure 1 shows the surface of the Si_3N_4 material with SiC reinforcement following the tribological test (ball on three plates), on which the smoothing is clearly visible. The individual phases were detected and the topology assessed by using different detectors. There is no selective wear of the phases SiC, Si_3N_4 or the grain boundary phase under the test conditions. At Fraunhofer IKTS, test specimen were manufactured from the developed Si_3N_4 and Si_3N_4-SiC materials in order to test them under practical test conditions on the sliding pad tribometer. Using water-based lubricants, superlubrication was achieved for the Si_3N_4-based materials. The pairing of Si_3N_4 (sliding pad) and SSiC (ring) showed superlubrication in large areas with coefficients of friction below 0.01 (Figure 2). These promising results indicate: wear-resistant ceramics have the potential to create a new generation of plain bearings, which enable significant energy savings, lower wear and therefore a longer service life.

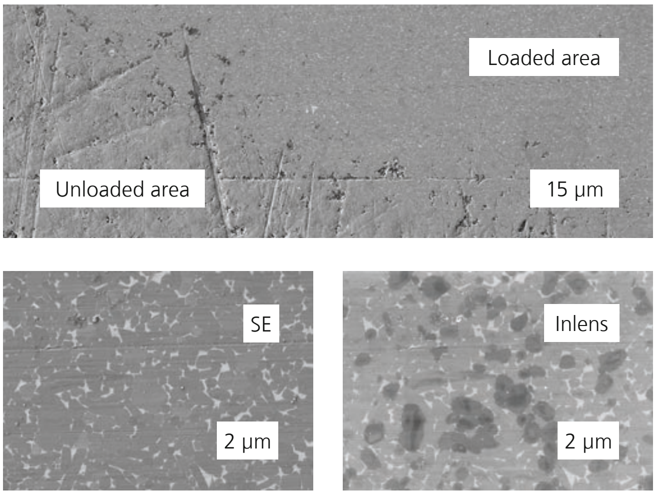
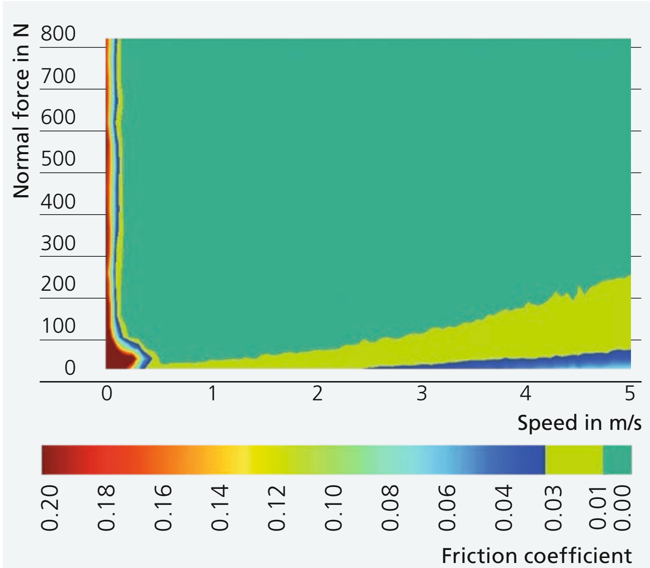


Figure 1: SEM image of the Si_3N_4 material with SiC reinforcement after test (top) low magnification, (bottom) image of the stressed surface using SE (left) and inlens detection (right).



Superlubrication = 75.0 %, Ultralubrication = 17.5 %, Remainder = 7.5 %

Figure 2: Demonstrated superlubrication (75 %) for the pairing Si_3N_4-SiC (sliding pad) / SSiC (ring).

Services and cooperation offered

- Development of ceramics for use as bearing materials
- Characterization and failure analysis of materials and components

Fraunhofer IWM

Funded as part of the internal programs of the Fraunhofer-Gesellschaft, funding number PREPARE 840066

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Cobalt-free hardmetal-diamond composites

Dr. Johannes Pötschke, M. Sc. Mathias von Spalden

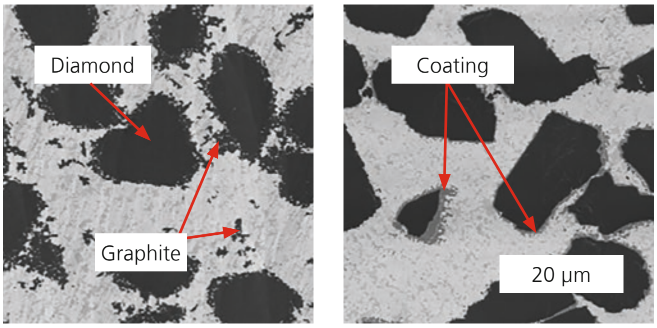

Figure 1: Comparison of DECC. Left: cobalt binder and diamond, right: adapted binder and diamond coated.

Hardmetals were developed one hundred years ago. Since then, the material has been established in many branches of industrial production and has become as relevant as steel and concrete. Hardmetals owe this to their unique combination of the hard ceramic phase tungsten carbide (WC) and tough, metallic cobalt (Co) as matrix material. By varying the WC grain size and share of Co binder the properties can be tailored to specific applications across a wide range. To ensure the supply of hardmetals to the European industry, the availability of tungsten and cobalt is strategically important. This is why both materials have been rated as "critical raw materials" (CRM) by the European Union in terms of supply risk and economic significance. This is made worse by the high demand for cobalt for use in Li-ion batteries. A large part of the required raw materials stems from countries outside the EU with unstable, repressive political systems and the associated inhumane and environmentally damaging working conditions, making the raw material supply volatile. Beside increased exploitation and processing of raw materials in EU countries and higher recycling rates, substitution is a third key factor. One way to reduce the need for raw materials is to increase the lifetime of hardmetal parts. In the context of the ongoing shift away from fossil fuels, difficult-to-machine high-strength materials are needed for the generation of sustainable energy and for lightweight design, testing the limits of hardmetals. Within the M-ERA.NET project "NovCom", co-financed by the Saxon State Ministry of Science, Culture and Tourism (SMWK, FKZ: 100406144), cobalt-free diamond-enhanced cemented carbides (DECC) are being developed at Fraunhofer IKTS, which will allow the EU to take further steps towards raw materials independence. Due to the extreme hardness and high thermal conductivity of diamond, the novel composite's properties will exceed those of conventional hardmetals. Very high pressures have to be applied to stabilize the diamond structure at the temperatures necessary to consolidate hardmetals and prevent its disintegration into graphite. However, cost-effective production is not achievable with these technologies. The biggest challenge to overcome in the development of DECC is therefore to inhibit the conversion of diamond into graphite. This can be achieved by lowering sintering temperature and reducing time through the field assisted sintering technique (FAST), developed at Fraunhofer IKTS. In combination with a newly developed binder alloy and coated diamond grains, graphitization was efficiently suppressed. Utilization of commercially available starting materials and established powder metallurgical procedures ensures smooth integration into existing industrial processes. Currently, together with GeniCore Sp. z o.o., a developer of sintering units, and the tool manufacturer HTM High Technology Machines Sp. z o.o., Fraunhofer IKTS is working on the implementation and validation of cutting tools. Near-net-shape sintered parts and functional gradation deliver additional potential for further development.

Figure 2: Tool with graphite felt cover during the FAST process.

STAATSMINISTERIUM FÜR WISSENSCHAFT KULTUR UND TOURISMUS | Freistaat SACHSEN
GeniCore Genius of the Core
HTM High Technology Machines

Selective laser sintering for the production of complex SiSiC ceramics

Dr. Steffen Kunze, Dipl.-Ing. Christian Berger,
Dr. Alexander Füssel, Dipl.-Krist. Jörg Adler

Selective laser sintering (LS) or laser powder bed fusion (PBF) is an established standard process in the field of plastics and metal printing. In laser sintering, materials are selectively sintered by a laser in a powder bed. At Fraunhofer IKTS the process which originated in plastics printing has now been adapted to produce silicon-infiltrated silicon carbide ceramics (SiSiC). Until recently, there has not been a way to use laser sintering to produce silicon carbide ceramics (SiC), as SiC is not fusible and forms passivating oxide layers at high temperatures. To address this issue, Fraunhofer IKTS, together with project partner ESK-SiC GmbH, developed fine-grained SiC powders, which have rounded particles and are well-processable. They have a high flowability due to their roundness and are ideally suited for powder bed-based manufacturing processes. The SiC powders were then coated with a special novolak. This resin can be melted thermoplastically and can also be converted into a duromer.

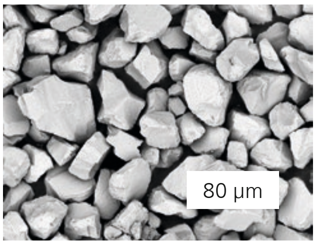

Figure 1: SEM image of a rounded SiC powder.

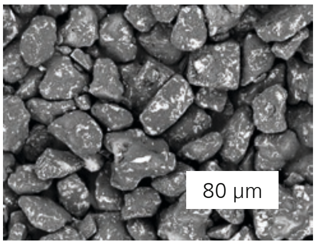

Figure 2: SiC powder with novolak-coating (dark areas).

SiC powders prepared in this way can be processed using inexpensive systems designed for polymer printing with diode lasers (less than 5 W power). The temperatures occuring during the process merely soften the plastic and thus bond the individual coated SiC grains together, without oxidizing the SiC surface. To produce the densest possible green bodies, parameters were developed for laser sintering. The energy density and assembly temperature used during laser sintering are the main process-related influencing factors for increasing the green density. It was possible to produce polymer-bonded SiC green bodies with a density of 1.3 g/cm³, which have sufficient stability for the subsequent processing steps.

After additive shaping, components produced in this way can be converted into silicon carbide by carrying out conventional pyrolysis and siliconization.

First applications in gas burners

Laser sintering is particularly suitable for manufacturing delicate components with tight tolerances. Using this process, early open-cell SiSiC components were produced at Fraunhofer IKTS for application tests at Promeos GmbH. These components (Figure 4) homogenize the thermal radiation pattern in gas burners and increase the emission of infrared radiation, which enhances the efficiency of drying processes. In terms of oxidation stability, there were no differences to conventional SiSiC components. Thanks to the high Weibull strength of up to 266 MPa achieved with a Weibull modulus of 21, the process is also suitable for addressing structural ceramic applications in the future.

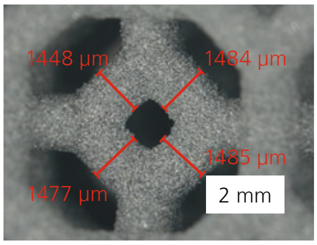

Figure 3: Detail of the printing image (green).

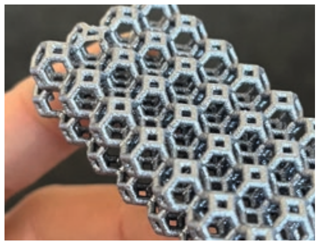

Figure 4: SiSiC burner geometry.

Services and cooperation offered

- Development of additive manufacturing processes for ceramic materials
- Customized powder preparation and coating
- Design optimization and production of complex additively manufactured components

We would like to thank the BMBF for its financial support in the joint project AMSIC (03XP0270D).

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Efficient multi-wire sawing process for high-performance oxide ceramic substrates

M.Eng. Andreas Frickel, M.Sc. Lea Schmidtner, Dr. Oliver Anspach (PV Crystalox), Dr. Sabine Begand

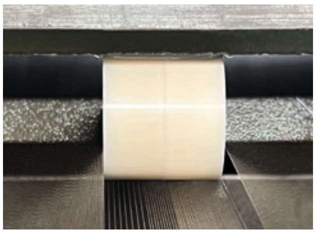

Figure 2: Saw interior during multi-wire sawing of sintered Al_2O_3 blanks.

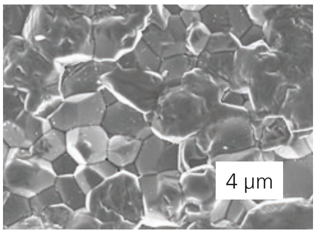

Figure 3: Topography of slurry-wire-sawed Al_2O_3 discs. Trans- and intercrystalline fracture behavior.

Multi-wire sawing is a common cutting process used in silicon wafer production, which produces hundreds to several thousands of wafers from a blank in a single sawing run. A distinction is made between diamond wire sawing, where abrasive grains are bound in the wire, and slurry wire sawing, where an abrasive grain suspension is applied to a wire field. The workpiece is pressed against this moving wire field, causing material to be removed simultanously in multiple sawing channels.

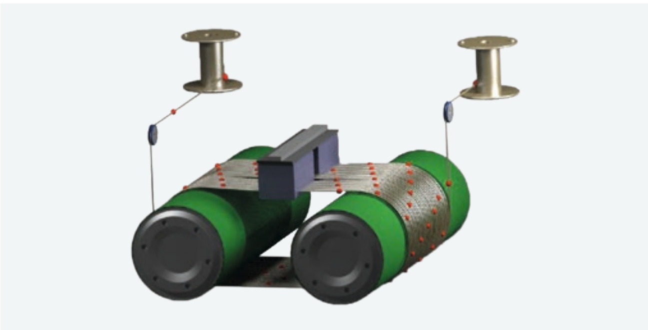

Figure 1: Design of a multi-wire saw.

As part of the project "SliCer", fine-grained high-performance ceramics were processed using the slurry wire sawing method. Together with PV Crystalox, Fraunhofer IKTS is investigating the sawing behavior of Al_2O_3, $MgAl_2O_4$ and ZrO_2 ceramics in order to produce particularly thin discs and rings for electronics, optics and measurement technology with high precision and efficiency. Previous work [1] has produced initial results concerning the correlation between sawing parameters and the resulting component properties. Based on this work, geometry and residual stresses were additionally characterized extensively in the "SliCer" project. Furthermore, the project partners looked at various measures intended to improve geometrical accuracy: they varied the slurry temperature and wire speed, used different fixation materials and adapted feed rates across the component cross-section. Using laser scanning images, the geometry of several adjacent slices was fully recorded and correlated with the sawing process parameters (Figure 4). Across all tests, the greatest challenge was encountered around the sawing-in and sawing-out area when trying to obtain components of equal thickness and flatness. The intrinsic hardness and the structural condition (grain size, proportion of pores) of the processed material have a significant influence on the material removal mechanisms. The deflection of the wire field serves as a measure of sawing resistance and sawing capability.

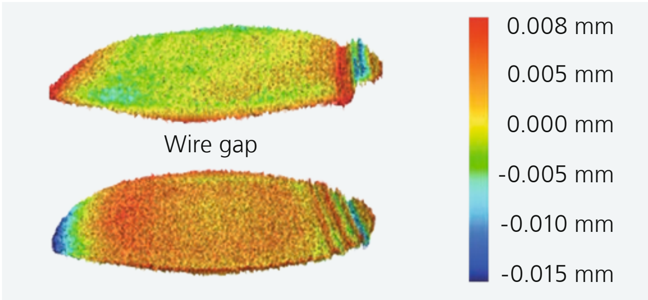

Figure 4: Microscopic height profile from laser scanning: short-term instabilities have a strong effect on the surface structure.

Fine-grained Al_2O_3 ceramics experience a wire field deflection of 4 to 8 mm in the center of the component at a feed rate in the range of 10 µm/min. $MgAl_2O_4$, on the other hand, hardly shows any deflection even at double the feed rate. The project results show that, when compared with the conventional manufacturing route, slurry wire sawing of high-performance ceramics could provide savings in terms of machinery, personnel and material, and it has the potential to produce disks in large quantities with a thickness of less than 100 µm.

Literature

[1] Schmidtner; L., Multi-Wire Sawing of translucent Alumina Ceramics, 2020.

Supported by: Federal Ministry for Economic Affairs and Climate Action on the basis of a decision by the German Bundestag

pv crystalox solar

Study on decentralized energy supply for agriculture and rural areas

Dipl.-Ing. (FH) Nico Domurath,
Dipl.-Ing. Björn Schwarz, Dr. Laura Nousch

In a study commissioned by the Saxon State Office for Environment, Agriculture and Geology (LfULG), the Fraunhofer Institutes IKTS and IVI investigated the conditions and possibilities for expanding and improving the decentralized generation, conversion, storage and distribution of renewable energies and energy sources in rural areas. Farms played a central role in this study, as they generally offer great potential regarding important resources such as biomass, roof surfaces and open spaces for photovoltaic and wind power plants and access points to electricity and, in some cases, gas grids. The study was carried out in close cooperation with an expert advisory board from industry and science.

Initially, available technologies for the generation, conversion, storage and processing of renewable energy were researched and the operational requirements for their use were recorded. Based on this data, the study identified eight process approaches as potential key technologies. From a broad spectrum of farms of different structures and sizes, eight were selected using a selection matrix. The identified key technologies were then simulated on these farms. The annual energy flows and energy sources available internally within the agricultural businesses and externally in rural areas were evaluated and visualized in an energy flow diagram, both for the current state (without key technology) and for the target state (with key technology). This was used to calculate the resulting CO_2 emissions and production costs for the individual technologies and forms of energy. Three particularly promising technology paths were chosen from this detailed analysis for further evaluation at selected trial farms.

These technology paths are:

1 Hydrogen production as a system service

This technology concept is based on the expansion of photovoltaics on areas with marginal yield. The energy generated should either feed electricity directly into the grid or produce hydrogen from photovoltaics at times when there is an abundance of electricity from renewable energies. The projected capacity of the system on an area that will continue to be used

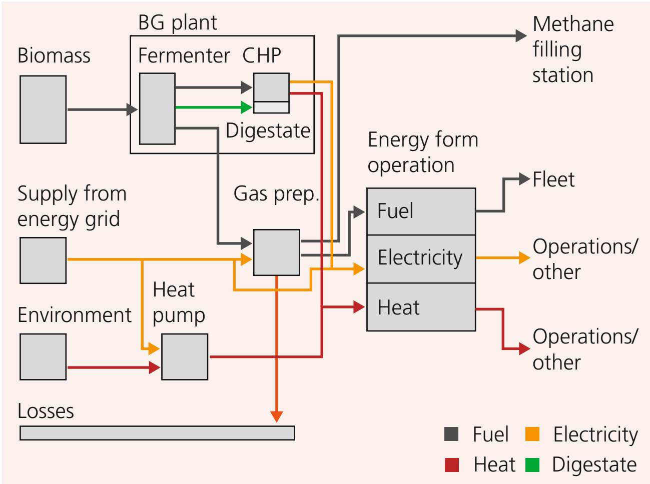

Figure 1: Exemplary energy flow diagram for the key technology of methane production and further use.

for agricultural purposes, as well as the flexibility of this business model being based on supply and demand in the overall grid, creates value and may make this approach the model to be emulated.

2 Methane injection into the high-pressure gas grid

The continuous feed-in of purified methane offers existing biogas plants the opportunity of reaching both local and supra-regional consumers via the natural gas grid, thus effectively replacing natural gas.

3 Electricity storage and management with battery storage systems

The introduction of a stationary battery storage system based on environmentally friendly $Na/NiCl_2$ technology was realized theoretically by dynamically simulating electricity demand and renewable energy generation.

Conclusion

The selected technology paths offer solutions for a resilient, grid-oriented and increasingly defossilized economy by using the latest technologies, adapting to agricultural production processes and reflecting infrastructural conditions. The full study is available on the LfULG document server.

LANDESAMT FÜR UMWELT, LANDWIRTSCHAFT UND GEOLOGIE | Freistaat SACHSEN

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Ammonia for efficient, CO_2-free power generation

Dr. Laura Nousch, Dipl.-Ing. (FH) Daniela Herold, Dipl.-Ing. Mathias Hartmann

Fraunhofer IKTS is developing systems for the efficient supply of electricity and heat based on solid oxide fuel cells (SOFC). Today, these devices for natural gas are mature and available on the market.

Carbon-free fuels, such as ammonia, are being considered to further reduce CO_2 emissions during conversion to electricity and heat. For the energetic use of alternative fuels, SOFC systems must be adapted to these new fuels, which also present different boundary conditions compared with conventional systems. Particular attention must be paid to the fuel gas preparation (cracking), systems integration and thermal management in the systems.

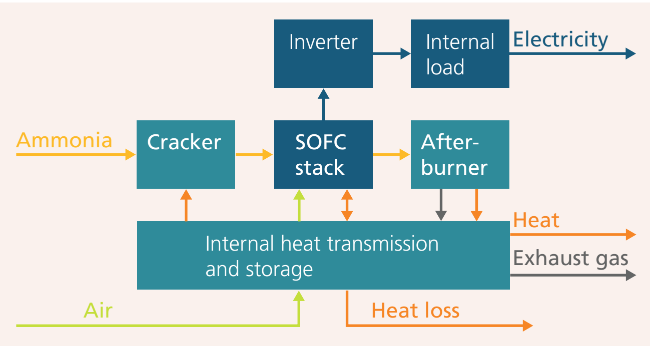

Figure 1: Schematic diagram of an ammonia SOFC system.

Demonstration plant with IKTS stack technology

The first near-system ammonia SOFC demonstration plant in the 1 kW_{el} power class was set up at Fraunhofer IKTS and has been operating successfully since August 2023. The test series looks at the behavior of the cracker, the heat management and the interaction with the SOFC stack. Gas analyses provide information about the degree of conversion of the ammonia under different cracker conditions and its influence on the overall process.

The demonstrator was able to demonstrate the basic suitability of SOFC systems for the use of ammonia as fuel. The performance of the SOFC system in ammonia operation is comparable to operation with hydrogen. The SOFC stack developed at Fraunhofer IKTS offers many degrees of freedom for efficient operation with ammonia thanks to its high operating temperatures and robust design. Even more efficient systems can be realized in the future through partial stack-internal cracking.

Figure 2: NH_3-SOFC demonstration plant.

System optimization

The demonstration plant and the accompanying analyses have laid the foundation for the development of an integrated, optimized SOFC system based on ammonia. In the next step, the team will work on a greater thermal integration of the components and on balancing heat sources and sinks in the system in order to further increase the electrical efficiencies at system level. Customer-specific ammonia system developments in a wide performance range for different applications are therefore possible.

Figure 3: Demonstration plant with SOFC stack and afterburner (TOX).

Dynamics of alkaline water electrolysis

Dr. Karl Skadell, M.Sc. Jakob Scholl,
Dr. Mihails Kusnezoff

Due to the expansion of fluctuating renewable energies and an increasing number of "prosumers" (both producers and consumers), the energy grid's more traditional, stationary mode of operation has reached its limits. The need for dynamic electrochemical processes for energy storage is growing. Consequently, water electrolysis, a promising green energy storage solution, has to be sufficiently dynamic – a real challenge for industry. In this context, various processes occupying different (continuous and non-continuous) time scales need to be looked at:

- Electrochemical transients in milliseconds
- Load changes of the electrolyzer in seconds
- Cold and warm starts in minutes to hours
- Degradation behavior measured in days to years

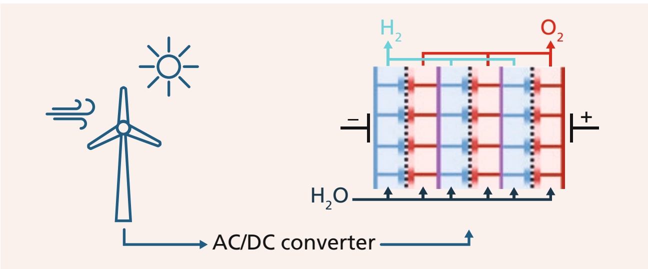

Figure 1: The dynamics of renewable energies set the framework for the operation of electrolysis systems.

In industry and science, the prevalent assumption is that only PEM (proton exchange membrane) water electrolysis is suitable for volatile energy generation because of its more dynamic response. By contrast, alkaline electrolysis is often not considered in the design of electrolyzer plants, despite the fact that other indicators (e.g. gas purity, load change time) should give that technology an edge. Scientific investigations carried out by the WaTTh Hydrogen Application Center at the Arnstadt site of Fraunhofer IKTS have shown that alkaline water electrolysis can indeed keep up with the transients of volatile renewable energies. Using this knowledge, researchers are working on the development of an optimized stack for a dynamic mode of operation.

The research team developed an electrochemical test cell with an active area of 100 cm² and an automated test stand for alkaline water electrolysis for scientific analysis. The test protocol shown in Figure 3 illustrates the cell's resistance and voltage degradation.

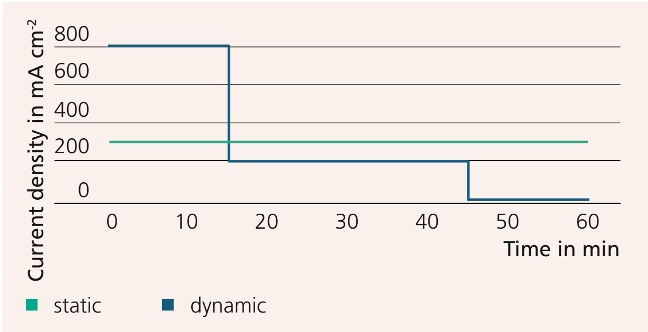

Figure 2: A dynamic and a static test protocol with the same charge transfer.

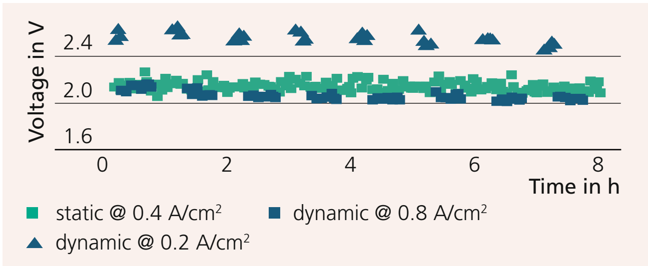

Figure 3: Voltage response to current densities for dynamic and static experiments.

The catalyst-free system showed strong efficiency losses of more than 0.4 A/cm². Within eight cycles, no degradation was observed. However, investigations using impedance spectroscopy show that the resistance for the electron transfer reaction decreased. The resulting roughening of the surface indicates a larger number of reactive centers. These developed during dynamic processing, even though the number of electrons transferred was the same as for the static reference protocol. This indicates harsh conditions at the elec-trode surface, which can lead to delamination or other degradation phenomena.
In future, the influence of other operating conditions, such as temperature, volumetric flow rate of electrolyte or bipolar plate geometry, towards dynamics in alkaline electrolysis will also be investigated. Another focus will be on the purity of the gases produced in the dynamic process. The ultimate goal is to develop a 100 kW stack design that is optimized for a dynamic mode of operation.

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Solid electrolyte substrates for sodium batteries

Dipl.-Ing. Rafael Anton, M. Sc. Ansgar Lowack, Dr. Dörte Wagner, Dr. Jochen Schilm, Dr. Kristian Nikolowski, Dr. Mihails Kusnezoff, Dr. Mareike Partsch

Sodium(Na)-based battery concepts are seen as cost-effective alternatives to lithium batteries thanks to their abundantly available and environmentally friendly raw material. Among them, the sodium solid-state battery is one promising technology. In comparison to conventional batteries, the electrodes are separated by a solid, ceramic ion-conductor and not by a liquid electrolyte-soaked separator. Because of its dense microstructures and redox stability, metallic sodium can be used safely as an anode. This enables higher theoretical energy densities than in commercial Li- or Na-ion accumulators. Known from stationary energy storage solutions at 300 °C in sodium-sulfur and ZEBRA batteries, the oxide ceramics beta-alumina and NASICON are considered prominent candidates for suitable Na-solid electrolytes. Fraunhofer IKTS has now developed novel glass-ceramic solid electrolytes, known as sodium rare earth silicates (Na*R*SiO), which can be processed via the powder route. At 1050 to 1120 °C, they have a lower sintering temperature than beta-alumina (> 1600 °C) and NASICON (> 1230 °C). The research focus is on the realization of thin sintered Na*R*SiO substrates for use in sodium batteries.

At Fraunhofer IKTS, the availability of glass melts and various mills makes it possible to produce the powder on a kilogram scale. Na*R*SiO materials with the conductive phase $Na_5RSi_4O_{12}$ (R= Yb, Y, Gd, Sm) have been synthesized, whereby the various rare earth elements have different effects on ionic conductivities (Table).

Ionic conductivities of Na*R*SiO substrates at 30 °C

σ, mS cm^{-1}	NaYbSiO	NaYSiO	NaGdSiO	NaSmSiO
Pellet (1500 µm)	0.3	0.2	2.1	1.5
Tape (350 µm)	0.2	1.5	1.7	2.1

The Na*R*SiO samples thus exhibit comparably high conductivities to the already established beta-alumina and NASICON. Cyclization of a full cell with a sintered NaGdSiO tape as separator shows high-capacity retention over 100 cycles.

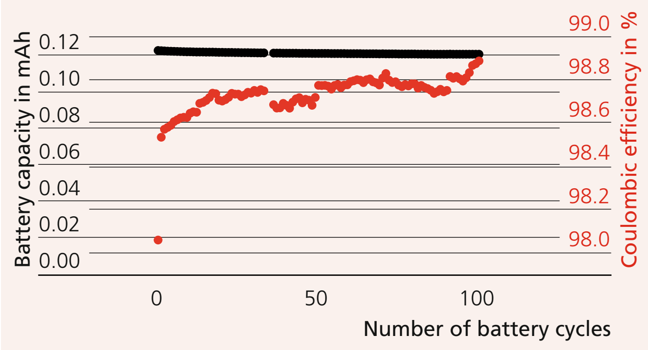

Figure 1: Cyclization of a full cell with NaGdSiO solid electrolyte at 30 °C.

The fabrication of thin substrates was achieved with tape-casting technology, which made it possible to produce a tape with a thickness of approx. 200 µm and a length of several meters. The tape was separated into smaller sheets in order to press two tape sheets together to bolster mechanical stability. For the measurements, discs with 20 mm diameter were punched out and sintered. Despite the difficulties in sintering thin ceramic substrates, which can result in warping or cracking, it was possible to successfully produce flat and dense substrates with good surface quality and ionic conductivity (Table).

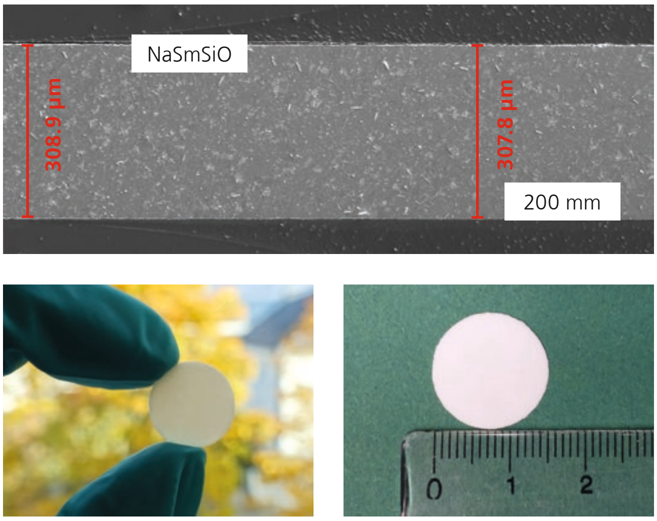

Figure 2: Cross-section in the scanning electron microscope and NaSmSiO substrates.

Fraunhofer IKTS develops novel Na-battery concepts and supports companies in materials development and in the production of thin ion-conducting substrates using tape-casting or thick-film technology.

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Composite electrodes and layered oxides: utilizing the potential of sodium batteries

Dr. Cornelius Dirksen, Dr. Matthias Schulz,
M.Sc. Micha Philip Fertig, Prof. Dr. Michael Stelter

Research on Na-ion batteries has gained considerable momentum in recent years and is increasingly establishing itself in the research landscape alongside traditional Li-ion cell concepts. Na-ion batteries promise several advantages over Li-based systems, such as raw materials that are more readily available and less expensive. In addition, many manufacturing methods of Li-ion technology are transferable to Na-ion technology.

Composite electrolytes based on Na-β"-alumina

With their excellent Na-ion conductivity, solid oxide electrodes made of Na-β"-alumina have for decades represented the state of the art in high-temperature sodium batteries, mainly Na/ $NiCl_2$ and NAS®. But due to its fracture behavior, it has not been possible so far to use the material in Li-ion cell production techniques. Fraunhofer IKTS, in cooperation with Fraunhofer IAP, has developed a composite electrolyte which combines the high ionic conductivity and chemical resistance of Na-β"-alumina with the flexibility and processability of polymer electrolytes. The advantages of two worlds are thus combined to make Na-β"-alumina usable for all-solid-state cells. The prototype of such a composite electrolyte is shown in the following figures. The ionic conductivities of the developed prototyped are in the range of 10^{-4} S cm^{-1}, looking promising already.

Figure 1: Polymer-Na-β"-alumina composite electrolyte (source: Fraunhofer IAP).

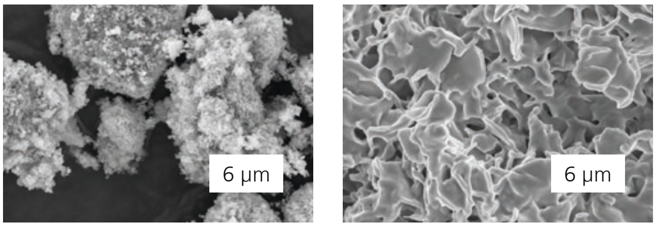

Figure 2: SEM image of Na-β"-alumina (left) and a PEO-Na-β"-alumina composite electrolyte (right).

Layered oxides as a sustainable active material

In addition to the electrolyte, new cathode formulations are also being developed for use with solid-state electrolytes. The layer oxide $Na_xMn_yO_2$ is used as active material. Compared with other material classes, layered oxides offer advantages such as the avoidance of critical raw materials, high work potentials or processability in air. The cycle stability of the layered oxides was increased to around 100 cycles – through doping and innovative synthesis processes in a pulsation reactor in cooperation with the company IBUTec. At the same time, the otherwise common addition of nickel or cobalt oxides was deliberately avoided.

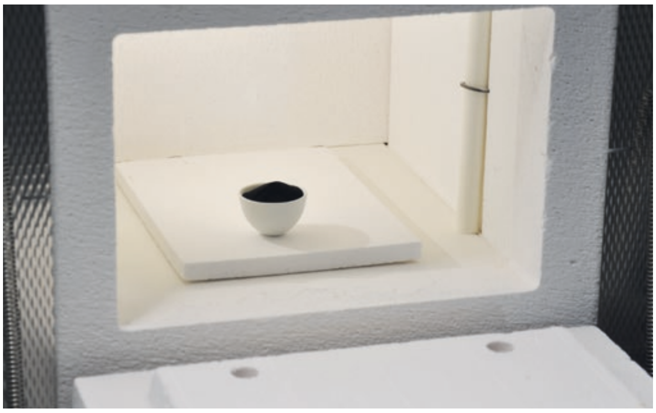

Figure 3: Active material after calcination in a furnace.

The work presented on electrolytes and active material and cathode material has in recent years laid the foundation for developing near-product all-solid-state Na-ion batteries at Fraunhofer IKTS. This goal will be pursued further and may be reached in the next two years.

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BATTERIE 2020

Securing critical raw materials for e-mobility. The METALLICO project

Dr. Sandra Pavón, Prof. Martin Bertau, Dr. Burkardt Faßauer, Dr. Mareike Partsch

Securing the raw material base for tomorrow's solutions

To drive the defossilization of the transport sector, it is important to secure the availability of the required raw materials. Almost all of these resources are classified as critical. The battery industry has been experiencing a growing demand for raw materials for years and it is vulnerable to supply risks, even though viable value chains have been established and waste recovery and recycling play a central role.

Moreover, electromobility has given a further boost to battery technology, a key strategic sector for the European Union (EU). The majority of electric vehicles use Li-ion batteries, which contain metals such as nickel, cobalt, copper, manganese and, of course, lithium. Globally, these battery metals come mainly from Australia, Chile, China, the Democratic Republic of Congo and South Africa. In light of this, the METALLICO project (ID grant agreement: 101091682), with a budget of almost 12 million euros, will develop a strategy for the EU on how to ensure security of supply on the basis of domestic raw materials. Half of the consortium of 20 partners from nine European countries is made up of companies, which is crucial for the technical implementation of the processes. The project brings together representatives from the entire value chain (including mining and production) to test new processes to produce battery materials using raw materials from primary and secondary sources. The development of modern, cost-effective processes with domestic raw materials not only secures Europe's supply. As a novelty, METALLICO pursues a zero waste approach. Five new processes aim to reduce product waste in the production of battery materials and ensure the complete recycling of unavoidable residues. The processes will be evaluated in terms of their sustainability. The aim of the project is to demonstrate in four different case studies that the critical metals lithium, cobalt, copper, manganese and nickel can be produced and recovered sustainably. To achieve this, the five METALLICO processes will be scaled up from laboratory scale to an industrially relevant scope at different industrial sites. The residues recycled into new products in the case studies will be evaluated and validated in the battery, cement, paint and ceramics industries. This is an important step towards establishing a circular economy because the products must meet the requirements of the markets and be able to be returned to the value chain.

The focus of Fraunhofer IKTS in the project is on the pilot-plant validation of the process for lithium extraction and geopolymer production. The cooperation with the Institute of Technical Chemistry at the TU Bergakademie Freiberg enables the selective extraction of lithium with the patented COOL process. The starting materials are lithium ores, such as spodumene. An initial heat treatment is followed by leaching with supercritical CO_2 and subsequent electrodialysis and crystallization, which enables the selective extraction of lithium carbonate in battery quality. The lithium-free residue produced in the filtration stage is used to make geopolymers, i.e., CO_2-free binders that can replace cement. Cement production is responsible for 8 % of CO_2 emissions worldwide. The project will evaluate the use of these siliceous residues as construction materials. This is the key step towards establishing a circular economy based on the zero waste principle. The process is being scaled up to TRL 7 and tested in Spain with the participation of *G.E.O.S. Ingenieurgesellschaft mbH, IDENER* and *CETAQUA water technology center.*

Figure 1: Autoclave system at Fraunhofer Technology Center High Performance Materials THM.

Funded by the European Union

METALLICO

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Multimodal analysis and automated evaluation of cathode quality

M.Sc. Rajkumar Kolan, M.Sc. Dennis Possart, M.Sc. Andre Borchers, Dr. Gihoon Cha, Dr. Berik Uzakbaiuly, Dr. Sabrina Pechmann, Prof. Silke Christiansen

In its pursuit of accelerated battery development, Fraunhofer IKTS is following an automated approach to assessing cathode quality with the help of machine learning (ML). This should provide a close feedback loop between component development, cell design, characterization and data analysis. The ML model is trained to identify and classify the different material components of a cathode: NCM (nickel cobalt manganese, active material), conductive additives, pores, and binder. This process helps to optimize the components faster and more systematically, enhancing the overall performance of the batteries.

To create a robust dataset for ML-training, 60 images with varying resolutions are extracted from FIB-SEM tomography. This is achieved by sequential slicing with a focused ion beam and imaging with the scanning electron microscope. The volumetric data is generated based on these images. A U-Net-based segmentation model is applied to differentiate the defined classes within the cathode SEM image.

Before it can identify components accurately, a segmentation network requires training data. However, manually annotating high-resolution images is very labor-intensive. To address this, we employ incremental learning. At first, a basic model undergoes training on an initial dataset and is then used to make predictions on unprocessed images. These predictions are then manually reviewed and corrected to create ground truth annotations. This process is repeated to expand the dataset gradually. In this case 60 SEM images are annotated in total with varying resolution and divided into subsets: 45 for training, 15 for validation, and five for testing. During training, the images are split into patches (256 x 256 pixels), shuffled, and used as a batch size of 16. Training continues for 50 epochs, and the Dice score – the statistical measure of similarity between results of the algorithm and the reference data – is calculated for each model. The model with the highest Dice score during validation is chosen for testing. Figure 1 shows a model evaluation based on test images and unseen data to assess the model.

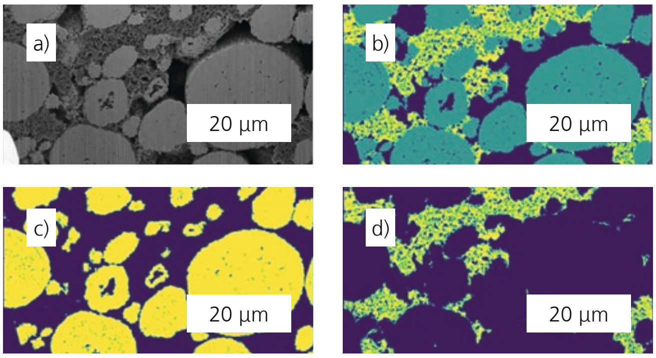

Figure 1: Model predictions on unseen data, a) unseen data, b) model predictions, c) active material, d) binder.

The performance of the automated cathode evaluation model on the test dataset has yielded promising and satisfactory results as shown in Table 1.

Class-specific Dice scores and mean Dice score

Test image	Dice pores	Dice particles	Dice binder	Mean Dice
NMC_1	0.84	0.98	0.82	0.88
NMC_2	0.96	0.97	0.85	0.93
NMC_3	0.96	0.97	0.88	0.94
NMC_4	0.91	0.92	0.82	0.88
NMC_5	0.94	0.95	0.50	0.80

After obtaining predictions on test data, class-specific masks are analyzed to count instances and measure sizes. This helps generate statistical data such as size distributions and class ratios. For example, it can reveal whether NCM particles have fragmented during manufacturing (Figure 2).

The integration of machine learning into cathode characterization and optimization offers an efficient automated solution for optimizing energy storage systems. This approach has the potential to revolutionize the battery industry by providing researchers and industry professionals with a valuable tool for a faster and more cost-effective development of energy storage solutions.

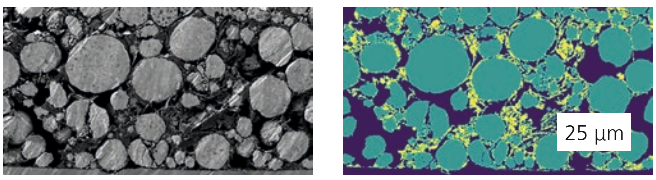

Figure 2: Example of model prediction on the test dataset with NCM particle size distribution after connected-component analysis: (left) raw test image; (right) multi-class prediction masks: green (NCM particle), yellow (binder), dark violet (pores).

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Removing PFAS with ceramic adsorbers and ultrasound

Dr. Patrick Bräutigam, M.Sc. Maximilian Dommke, Dr. Thomas Kutschin

PFAS (per- and polyfluoroalkyl substances) are a class of synthetic compounds which are used in various industries and applications. They have water- and oil-repellent properties and a high chemical and thermal stability. This resistance to thermal, chemical and biological reactions and their high mobility in the environment have led to the accumulation of various PFAS in humans, animals and the environment, which is why PFAS are also known as "eternal chemicals".

The compounds perfluorooctane sulfonic acid (PFOS) and perfluorooctanoic acid (PFOA) were among the first PFAS to be widely used and subsequently regulated by legislators. In light of new guidelines and threshold values for PFOA and PFOS, new PFAS have been introduced. One such substitute is GenX (hexafluoropropylene oxide dimer acid, HFPO-DA), which is now used in place of PFOA to produce fluoropolymers, such as Teflon, and is often found in water bodies near suspected PFAS sources.

In a joint study with the Technical University of Munich, Fraunhofer IKTS has investigated the degradation of the chemical GenX for the first time using high-frequency ultrasound and compared it with the degradation of PFOA and PFOS. Initial results indicate that with further optimization of the process, ultrasonic technology could be used as a robust, easy-to-use and additive-free method for treating highly contaminated PFAS streams.

Further research is focused on the enrichment of these compounds. To this end, IKTS researchers develop adsorbers based on porous ceramic materials that can be customized for specific pollutants (individual substances and groups of substances). In the future, these adsorbers should be able to desorb pollutants and be switchable, i.e., it should be possible to alternate between adsorption and desorption via external initiators. This means that the adsorbers do not have to be removed from the process but can be operated alternately in the long term.

The removal of PFAS using ultrasound and switchable ceramic adsorbers is a promising approach for dealing with these persistent, anthropogenic and often health-damaging chemicals. At Fraunhofer IKTS, the processes will be further developed in collaboration with Friedrich Schiller University Jena and industrial stakeholders.

Figure 1: Ceramic adsorbers for the removal of micropollutants (source: Jens Meyer, Friedrich Schiller University Jena).

Literature

Nebojša Ilić et al. (2023): Ultrasonic degradation of GenX (HFPO-DA) – Performance comparison to PFOA and PFOS at high frequencies, 10.1016/j.cej.2023.144630.

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Efficient production of modular silicon carbide membrane stacks

Dipl.-Ing. Michael Stahn, Dipl.-Umweltwiss. Christian Pflieger, Dipl.-Ing. Heike Heymer

Submerged membrane modules enable a particularly energy-efficient mode of operation, as no pumps are required to produce flow over the membrane surface. This membrane technology uses negative pressure on the permeate side to ensure flow and is particularly interesting for water treatment. However, the driving force is limited, so membranes with the highest specific permeate fluxes have to be used. Ceramic membranes made of silicon carbide (SiC) are suitable for this purpose, because they reach permeate fluxes of up to 10,000 l/(m^2 x h x bar), but they have to be optimized for submerged applications. The aim of the joint project "SiCaM" (FKZ: 2019 FE 9064) was to effectively produce flat SiC membranes and to contact and integrate them into membrane stacks with a high packing density. Two support geometries were considered: multi-channel plates and waved membrane elements. Each membrane support was provided with a membrane layer on the outside.

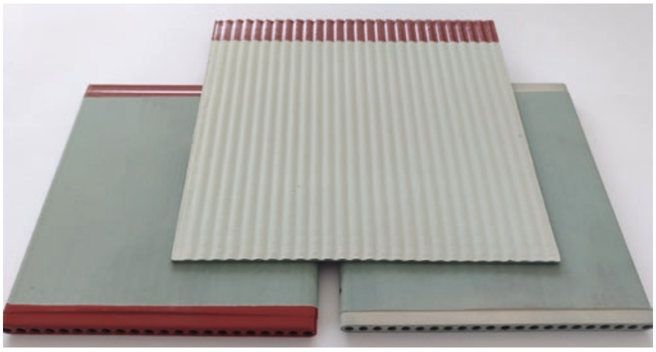

Figure 1: Multi-channel plate and waved membrane element.

A comparison of the two support geometries shows advantages and disadvantages of both forms: while the extruded multi-channel plates have better scalability and higher component strength, the waved membrane elements laminated from cast films can be produced using less material and enable a higher packing density. The project partners then focused on the more robust multi-channel plates and the interchangeability of individual plates. This in turn places demands on the contact areas in terms of dimensional and shape accuracy. Machining turned out to be the best solution in terms of detachable and reusable contacting with connectors on the end faces.

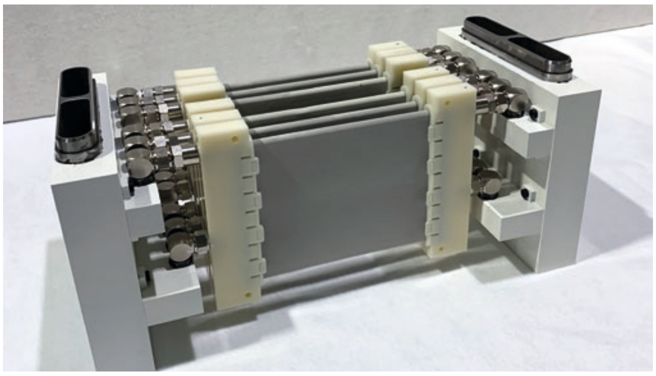

Figure 2: Membrane stack demonstrator with multi-channel plates.

As part of the project, it was possible to transfer the coating technology to multi-channel plates that are up to 50 cm long. Accompanying simulations of the flow behavior helped to adapt the design to minimize pressure losses on the permeate side.

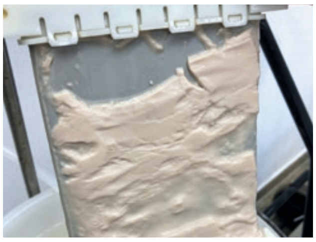

Figure 3: Multi-channel plate after filtration tests with yeast.

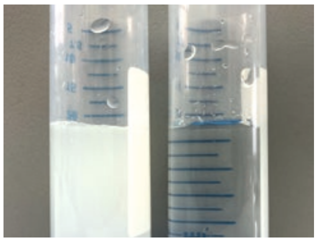

Figure 4: Feed and permeate of yeast filtration.

The membranes were tested with specially prepared waters. Filtration tests with a typical model wastewater (yeast suspension, 10.5 g/l, Figures 3/4) resulted in an easy-to-remove top layer and complete retention of the yeast cells. The filtration of defined dextran solutions and analysis of retention by gel permeation chromatography (GPC, 0.3 g/l, MW approx. 500,000 Da, Alfa-Aesar, dissolved in RO (desalinated) water) showed a separation performance comparable to that of industrially available tubular membranes in cross-flow operation mode. Submerged membrane modules with multi-channel plates based on SiC are therefore a promising alternative for separation processes with high energy efficiency.

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Potentials of energy- and nutrient-rich process water for a circular economy

Dipl.-Ing. Björn Schwarz, Dipl.-Ing. Marc Lincke

In many industrial plants, process water is generated in considerable quantities and with a very wide variety of components. Particularly in food processing but also increasingly in new branches of the bioeconomy, process water streams are contaminated with organic components which can be harmful to the environment. At the same time, these waters hold an untapped potential for energy generation and water reuse. As part of several research and industrial projects, scientists at Fraunhofer IKTS have developed and tested specific process combinations for the treatment and energy harvesting of these waters.

Anaerobic wastewater treatment with biogas production is an important process stage in this regard. Biomass retention, for example in the expanded granular sludge bed reactor (EGSB), is advantageous. High concentrations of salts and nutrients often make material conversion more difficult by inhibiting the microorganisms involved. At the same time, some of these nutrients are valuable substances and should be recovered in the interests of a circular economy.

Figure 1: EGSB test facility at Fraunhofer IKTS.

The IKTS working group "Biomass Conversion and Nutrient Recycling" conducts laboratory and small-scale tests to optimize the biogas production process in a specially developed EGSB test reactor. The test facility is equipped with advanced process monitoring and control, a special reactor design and automatic dosing of auxiliary agents, thus enabling a systematic process development. Parameters achieved so far: conductivity up to 27 mS/cm, sludge load up to 0.4 kg CSB/(kg oTR*d), hydraulic retention time of four days.

In addition to the biological stage, the upstream and downstream treatment stages are also considered and optimized. Here, for example, physical-chemical processes, such as ceramic-based membrane filtration, chemical (precipitation, extraction), thermal (stripping, evaporation) and oxidative processes (photocatalysis, electrolysis), are used to reduce nutrients and contaminants. Individual or multiple components are separated from the liquid phase using practically relevant precipitation and flocculation processes as well as dewatering units.

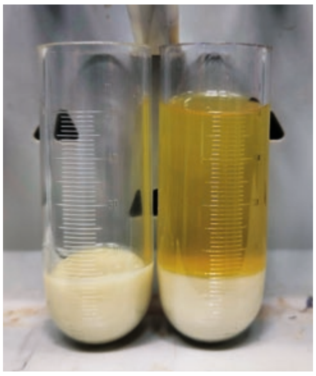

Figure 2: Separation of calcium phosphate from process water, centrifugation.

Figure 3: Separation of calcium phosphate from process water, chamber filter press with solids plate.

In addition, both the input and the output flows are analyzed. In parallel to conventional analysis to assess process stability, the concentration of dissolved contaminants and nutrients is also determined. This is the basis for an optimized strategy of nutrient recovery or salt removal. In this way, process waters are depleted in a targeted manner, which causes fewer issues in the fermentation stage or downstream processes (e.g. inhibition of biology or uncontrolled precipitation). Additionally, valuable substances (e.g. phosphorus or nitrogen fertilizer) are extracted, which can be returned to the economic cycle as plant fertilizer, for example. The effect of such products on plants is also being investigated at Fraunhofer IKTS.

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Underground testing facility for arsenic and fluoride removal from mine water

Dr. Hans-Jürgen Friedrich

Saxony has for centuries been one of the most important ore mining regions in Europe. Global technological trends as well as geopolitical factors have caused a renewed interest in locally sourced raw materials. However, mining now also has a major acceptance problem. Even before the mostly visible impacts on landscapes, the effects on the water balance are what will affect the costs of aftercare for a long time. They are thus also known as the "perpetual burden" of mining. As, Ni, Cd, Zn, Mn, Fe, but also F, SO_4 and occasionally U, Cl and organic substances are pollutants frequently found in mine water.

In the WIR! - recomine joint project TERZINN, we have, together with partners from science and industry, set ourselves the goal of demonstrating at the model site of the Ehrenfriedersdorf tin ore mine that it is possible to control such effects at reasonable cost by means of a "toolbox" of state-of-the-art mine water treatment processes. More than one ton of arsenic, approx. 50 tons of fluoride and other pollutants are emitted from the mine every year. More than 4 % of the arsenic load of the Elbe river can be attributed to this mine. However, with an annual discharge volume of around three million m^3 per year, the mine water itself also represents a regionally significant water resource that is increasingly coming into focus in view of supply shortages.

The joint project aims to develop both "low cost" processes for arsenic removal, as well as processes for further purification of the water. The team at Fraunhofer IKTS is focusing on the latter and primarily uses electrochemical membrane processes for this purpose. These can be used to remove not only arsenic but also, in contrast to the other processes, further pollutants such as fluoride, manganese, sulphate and others that prevent the mine water from being used for higher-grade purposes, such as drinking water. Another focus is on further treatment as feed water for hydrogen production using electrolysis. This requires large quantities of very pure water, which must not contain any arsenic or fluoride.

Our investigations to date have shown that electrochemical processes are very suitable for the separation of arsenic and other pollutants under conventional laboratory conditions (Figure 1).

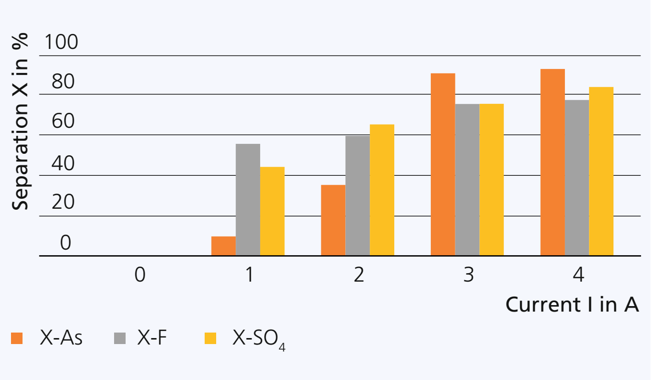

Figure 1: Electrochemical removal of pollutants from the mine water.

However, there are considerable differences between laboratory testing and practical application. For example, the mine water has a consistent temperature of only 7 °C and it is necessary to adapt the processes accordingly. For this reason, an underground technical center was set up in the Tiefe Sauberger Stollen tunnel at 100 metres depth and put into operation in July 2023 (Figure 2). Initial experience shows that the energy requirement for the same cleaning performance is around 20 percent higher than in the laboratory and that the maintenance cycles are somewhat shorter.

With the underground technical center, IKTS now has another unique research infrastructure. A follow-up pilot project has already been approved.

Figure 2: Underground testing facility.

recomine rethinking resources

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Recycling of polycarbonates through pyrolysis

Dr. Philipp Rathsack, Dr. Jörg Kleeberg,
Prof. Martin Gräbner

In the "PC2Chem" project, Fraunhofer IKTS is working with pro-ject partner Covestro AG to develop a process for the chemical recycling of polycarbonates (PC). For this purpose, a pyrolysis process is being optimized at the Freiberg site in the Circular Carbon Technologies group. The liquid pyrolysis products are purified by Covestro in order to reuse them for new syntheses.

Mechanical recycling is not always possible

Not all plastics can be recycled mechanically. These plastics include polycarbonate (PC), a technical thermoplastic. It is used in numerous applications with special mechanical or optical requirements, e.g., for casings for electronic devices, in various components of motor vehicles or as transparent panes. If PC is mechanically recycled from waste streams, it loses the required properties due to thermal stress during repeated extrusion. This significantly reduces material quality and usability. In accordance with the waste hierarchy, alternative processes are therefore being explored to preserve as far as possible the chemical structures synthesized at the expense of energy and resources.

Pyrolysis, the thermal decomposition in the absence of oxygen, breaks the chemical bonds in polymers. In the case of condensation polymers, which include polycarbonate, the bonds cleave preferentially at functional groups. This leads to mixtures of the original monomers or structurally closely related molecules. With suitable process control, sufficiently simple mixtures with high yields of these valuable molecules are produced. This approach contrasts with oilification, in which plastics are pyrolytically broken down into mixtures of hydrocarbons. For the new synthesis of condensation polymers such as PC, however, the functional groups would then have to be re-introduced in several synthesis steps. The route via the monomers is therefore more efficient for this type of polymer and the recycling cycle is smaller in accordance with the requirements of the waste hierarchy. This means that energy and valuable material resources can be saved.

Upscaling of the pyrolysis process

The "PC2Chem" project is investigating the pyrolysis of PC blends with acrylonitrile butadiene styrene (ABS), as this represents a large PC waste fraction. The pyrolysis process now makes it possible to produce the monomers phenol and bisphenol-A from PC and styrene from ABS from this material. These chemical compounds are valuable starting materials for polymer production or other products in the chemical industry.

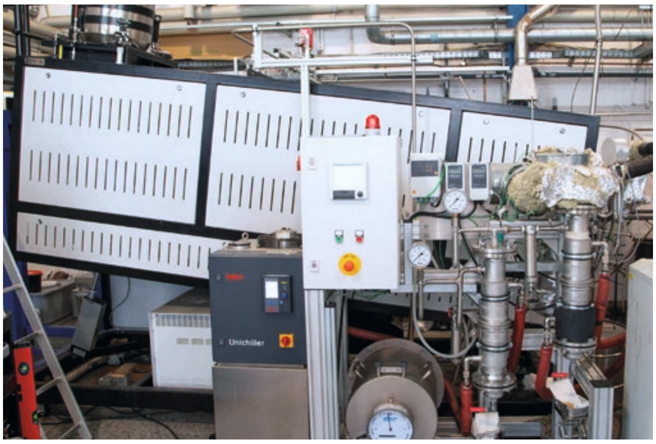

Figure 1: Pyrolysis rotary kiln on a pilot-plant scale with a specially designed and built condensation system in the foreground.

The objective of Fraunhofer IKTS is the detailed investigation of the pyrolysis of various polycarbonates on a technical scale. For this purpose, experimental investigations are carried out in a laboratory pyrolysis plant and in a continuously operating pyrolysis rotary kiln to determine the process parameters for a maximum yield of valuable products. The experiments in the pyrolysis rotary kiln are carried out on a scale of several kilograms per hour. To obtain the liquid products, a condensation system was designed and set up as part of the project. Pyrolysis oils were successfully produced in several test runs. The project partner Covestro uses them for the development of the downstream process.

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AI-based flame diagnostics for partial oxidation processes

M.Sc. Mohsen Gharib, Prof. Martin Gräbner, Prof. Andreas Richter

Optical flame diagnostics offers great potential for the control and optimization of (partial) oxidation processes, for example in the chemical industry, metallurgy and the glass industry. However, the large data rates resulting from the high image resolutions and frame rates of modern high-speed camera systems currently prevent any direct evaluation of the data, so that such high-resolution images cannot yet be used for real-time flame monitoring or process optimization. This is why Fraunhofer IKTS has started developing AI-based models to analyze flames in real time. This enables the development of new concepts for online process control and optimization, and improved safety concepts.

The experimental reference data for these models results from measurement campaigns using the multi-feed test facility operated at the TU Bergakademie Freiberg. An optical probe enables in-situ flame measurements. The optical tools were developed by measuring the flames of various gaseous, liquid and solid feed materials with a high-speed camera working at a frame rate of 1000 Hz.

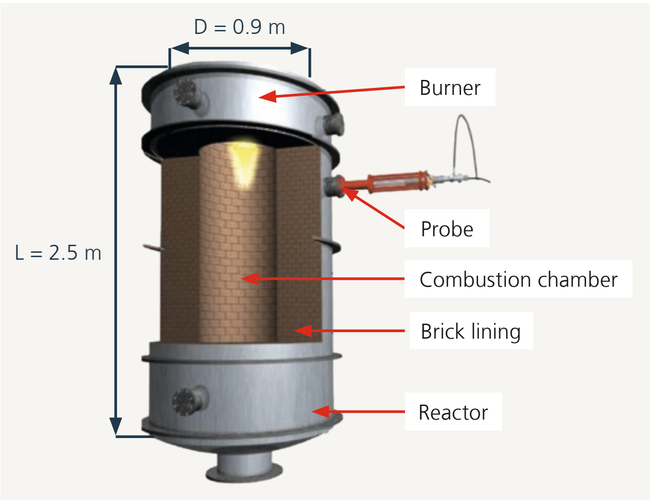

Figure 1: Multi-feed test rig with optical probe system (red).

Because the analysis of this data in real time is not possible with conventional image analysis tools due to the high data rates, the team developed an AI-based analysis tool. This is based on a neural network which was preconditioned using training data before being used to analyze online the image data from the flame measurement. The tool is able to estimate various flame characteristics such as length, width, center and ignition point of the flame with remarkable speed (5000 images processed in just two seconds).

The extracted characteristics play an essential role in controlling and optimizing the process. The implementation of a flame ignition point detector, for example, which was specially developed for analyzing flame stability, enables improved process control and safety. The model defines a threshold value that distinguishes between a stable and an unstable flame.

The real-time flame monitoring system provides a fast and precise method for monitoring flames in various high-temperature processes and is to be integrated into various industrial processes in the future, in addition to its use in technical test facilities.

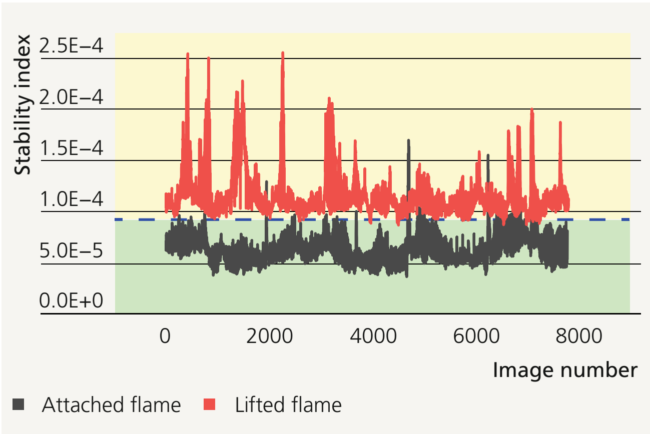

Figure 2: Real-time flame monitoring, displayed using the stability index. Top: unstable diesel flame, bottom: stable solid fuel flame. The blue line marks the stability criteria determined by the AI model.

This project is co-financed by tax funds on the basis of the budget approved by the Saxon state parliament.

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Degradation behavior of iron-based Fischer-Tropsch catalysts

M.Sc. Sascha Tim Bredow, Dr. Erik Reichelt,
PD Dr. Matthias Jahn

The transformation of the chemical industry towards climate neutrality poses challenges for all stakeholders. Last year, this chemical industry was responsible for around 935 Mt CO_2 equivalents in direct emissions (approx. 2.5 %) due to the predominant use of fossil raw materials. Part of the transformation of the sector is the establishment of a circular economy in which CO_2 is no longer seen as a waste product but as a valuable raw material. For this reason, the Fischer-Tropsch synthesis (FTS), which has been known for almost 100 years, is currently experiencing a renaissance. This reaction from hydrogen and carbon monoxide can be used to produce a considerable variety of valuable hydrocarbons, known as synthesis gas. This synthesis gas can be produced from electric energy, CO_2 and water in processes summarized under the term "Power-to-X" on the basis of electrolytic processes. Fischer-Tropsch synthesis thus opens up a path for the sustainable production of chemical products previously produced using fossil fuels.

Figure 1: Test plant for the performance of degradation tests.

At Fraunhofer IKTS, iron-based FT-catalysts are a focal point of research. This is because, unlike cobalt-based catalysts, they can produce not only kerosenes and olefins, but also high-quality oxygenated hydrocarbons, mainly alcohols. In addition, iron is cheaper, and unlike cobalt it can be extracted under less critical conditions. The actual active phase of iron-based catalysts is a complex mixture of various iron carbides and oxides, so that influencing and describing the product spectrum is very complex, especially as changes in the phase composition can also occur under reaction conditions.

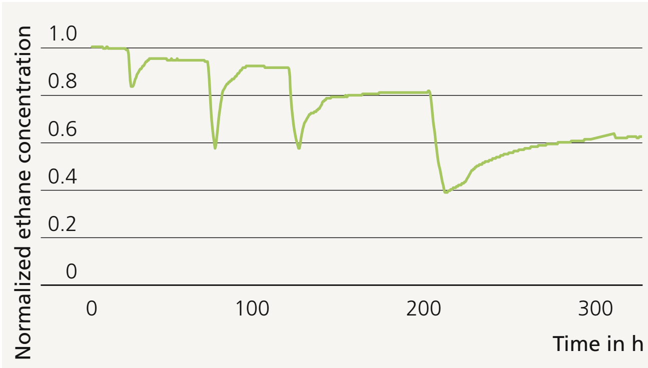

Figure 2: Illustration of the decrease in catalyst performance during an accelerated aging test based on the concentration of the product ethane.

Using selective synthesis strategies, specific active iron carbides were produced at Fraunhofer IKTS and investigated with regard to their catalytic activity and long-term behavior (> 1000 h). As part of the "SOC degradation 2.0" project, catalyst properties were identified which are advantageous for the Fischer-Tropsch synthesis of higher alcohols and greatly increase catalyst stability and service life. In addition to long-term tests, experiments were also carried out to accelerate the catalysts' aging process.

The results provide a better understanding of the relationships between catalyst composition, degradation and performance. On this basis, more resistant catalysts are now to be developed which enable longer service lives with optimized performance in terms of product composition.

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Water-saving production of soda using electrochemical membrane processes

Dipl.-Chem. Hans-Jürgen Friedrich

Soda and sodium bicarbonate are among the indispensable inorganic basic chemicals. They are used in many areas of daily life (detergents, food) as well as in numerous industrial sectors (e.g. glass and paper production). In Germany, more than 1.2 million tons of these chemicals were recently produced annually; the figure worldwide is around 35 million tons. It is produced either on the basis of naturally occurring trona (USA) or using the Solvay process on the basis of the raw materials brine, coke and limestone (I).

(I) $2\ NaCl + CaCO_3 \rightarrow Na_2CO_3 + CaCl_2$

Ammonia is also required in the Solvay process as a carrier for chloride (Cl) and hydrogen carbonate (HCO_3). Table 1 shows the raw material requirements and emissions.

Emissions in the Solvay process (according to German Environment Agency/VCI/ CSD)

Material	Emissions kg/t	Emissions t/a
CO_2	800	1,200,000
Cl	564	677,000
NH_3	1.5	1200
Waste brine (m^3)	9.4	12,500,000

At least as important as the high CO_2 emissions in this context are the large quantities of high-salinity NaCl/$CaCl_2$ waste brines that are produced and discharged to the next river. These lead to salinization of the receiving waters, with numerous other negative consequences such as fish mortality at low water levels and increased temperatures.

An alternative process for the production of soda is therefore being developed and tested as part of the BMWK-funded joint project "GreenSoda" (funding code 03EE5121A) with the participation of Stassfurt-based CIECH Soda Deutschland GmbH (CSD) and others. The effort centers around an electrochemical process route with bipolar electrodialysis. Figure 1 shows a laboratory test rig as a four-circuit system. The electrochemical process route enables the splitting of salt solutions into the corresponding acids and bases – in the case of NaCl brines, the splitting into HCl and NaOH according to (II). NaOH is subsequently carbonized with CO_2 (III).

(II) $2\ NaCl + 2\ H_2O \rightarrow 2\ NaOH + 2\ HCl$

(III) $2\ NaOH + CO_2 \rightarrow Na_2CO_3 + H_2O$

The CO_2 is obtained from combustion gases but also from fermentation processes (biogas production). At present, it is possible to produce an approx. 20 % soda solution based on raw brine from Stassfurt under laboratory conditions.

Figure 1: Bipolar electrodialysis stack for splitting of NaCl.

Neither limestone nor ammonia is required for this production route. This also means that $CaCl_2$ waste brines are no longer produced. Now, the process even represents a CO_2 sink. Fraunhofer IKTS has applied for a patent for this process together with CIECH Soda Deutschland.

The next step will be testing on a pilot-plant scale using purified CO_2 from combustion processes and investigations on adapted thermal treatment processes. The latter are taken over by another network partner.

Supported by: Federal Ministry for Economic Affairs and Climate Action on the basis of a decision by the German Bundestag

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Spin-off POXOS® launches membrane systems for oxygen to market

Dr. Ralf Kriegel, Dr. Robert Hoffmann,
B.Eng. Robert Diener, M.A. Friedbert Maul

The Fraunhofer IKTS spin-off POXOS® (Pure Oxygen On Site) is set to develop, build and distribute membrane plants for the customized production of pure oxygen (> 99.8 vol% O_2). The technology is based on MIEC membranes (Mixed Ionic Electronic Conductor). Their permeability for O_2 is based on the combined conductivity for oxide ions and electronic charge carriers at high temperatures. The production of oxygen directly on site with the end user is competitive especially where O_2 demand is continuous and throughputs are in the low or medium range. Currently, this is provided by PSA (Pressure Swing Adsorption) plants. These only attain a purity of around 95 vol% O_2 within the product gas, with an energy demand of > 0.9 kWh/m³. LOx (Liquid Oxygen; > 0.81 kWh/m³ (STP) O_2) comes with a similar energy demand. It is produced by cryogenic air separation units (ASU), which typically provide a high gas purity. However, ASU are only efficient and competitive at very high gas throughputs (e.g. steel plants). Therefore, many customers are supplied with LOx or compressed gas cylinders. This is particularly expensive if the O_2 demand is not that high.

This is where the future Fraunhofer IKTS spin-off comes in: POXOS® generators only need around 25 % of the electric energy required for a PSA plant or contained in LOx. While high-temperature heat is required for the separation process, gaseous fuels are much cheaper per kWh than electricity and in many cases cheap lean gases are available for heating at the consumer site, e. g. sewage gas, landfill gas, biogas, blast furnace gas or mine gas. Since energy costs dominate the operational expenditures of POXOS® generators, much lower running costs compared with PSA and LOx are possible. If operating costs and depreciation of the investment are normalized to the amount of O_2 produced, very low O_2 prices can be achieved. CO_2 emissions of POXOS® generators are also up to 60 % below those of PSA and ASU. This is because of their low electricity demand and the low CO_2 emissions per kWh of gaseous fuels compared with the specific CO_2 emissions of electricity produced in Germany.

Market entry in wastewater ozonization

The elimination of micropollutants (e.g. drugs, pharmaceuticals, pesticides) from wastewater requires an upgrade of sewage plants with a fourth purification step. Part of this stage involves ozonization, where ozone (O_3) is used for the oxidative cracking and removal of micropollutants. The corresponding costs for the O_2 demand can be decreased by up to 80 % using POXOS® generators.

This is, among other factors, because the off-gas generated during water treatment, which has a high O_2 content, can be reused on the feed side of the POXOS® generator. Depending on the cost of O_2, the price of electricity and heat, and the type of heating (electricity or combustion of sewage gas), the return on investment for POXOS® generators is reached after approximately three years.

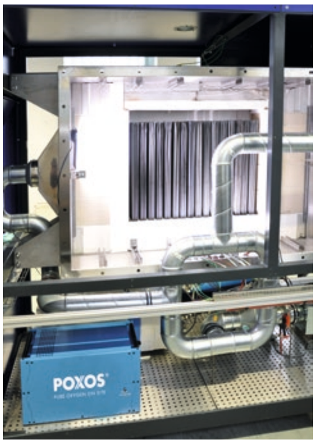

Figure 1: The prototype during assembly.

Figure 2: membO$_2$ plant being moved at IKTS in Hermsdorf.

Trial period at sewage plant

Since September 2023, a prototype running with electricity has been in operation at the municipal sewage treatment plant Bitterfeld-Wolfen (GKW BiWo) for a trial period. At first, the inside of the test container overheated locally, which was solved by discharging hot air. Since then, the generator has been working well. Frequent on and off switching does not affect the operation, no drop in the O_2 production rate was detected. The test demonstrates the reliability of POXOS® generators and is an important milestone on the way to market launch.

AI-controlled biogas production

Dr. Stefan Dietrich, Dr. Frank Duckhorn,
Dipl.-Ing. Anne Deutschmann

To facilitate efficient biogas production based on a fluctuating energy demand, a dynamically controlled substrate feed is vital. To achieve this, the future biogas production is forecast based on different process parameters and the feeding of the biogas plant is adjusted accordingly. The forecast is based not only on qualitative and quantitative substrate data, but also on the fluid dynamic properties within the fermenter. Until today, the process parameters for controlling agitation have only been selected based on the amount of biogas produced. However, due to changing loading rates, adjusting both the running time and the mixing intensity of the stirrers used for fermenter agitation is also required.

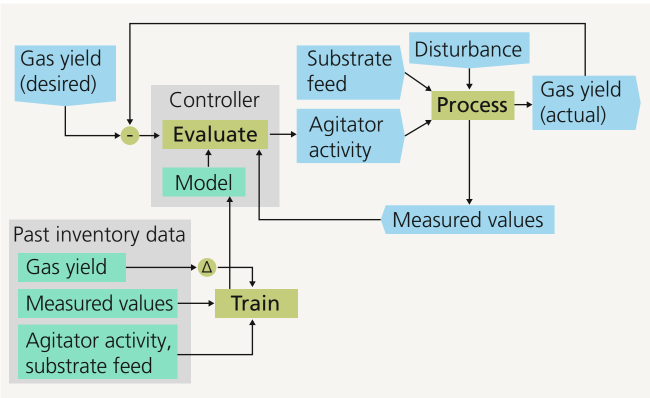

Figure 1: Process model and training concept for the AI controller.

Development of an AI controller

As part of the BMEL/FNR joint project "Sens-O-Mix", an AI-based controller has been developed and tested which enables automated stirring operation adapted to flexible feeding regimes (Figure 1). Since concepts such as reinforcement learning are difficult to implement due to long response times, an approach based on neural networks was chosen. It relies on theoretical process models, which are generated using stock data from the research biogas plant at the University of Hohenheim. These models incorporate feeding and sensor data as well as the previously recorded agitator performance and biogas yield. The basic version of the AI controller addressed only the control of the mixing process. Based on the specification of the future target biogas yield, the AI controller determines the future target agitator output. The input data for the AI controller includes the results of the material, rheological and granulometric substrate characterization as well as data from the agitator control. The feature set of the controller is currently being enhanced to include control of the entire flexible biogas production process. In addition to these basic parameters, models of predictive feeding and the fluid dynamic properties developing in the fermenter are also being implemented.

Training, validation and practical operation of the AI controller

Training and validation of the AI controller ensure reliable prediction of the stirring parameters depending on substrate quality and quantity as well as the desired gas yield. As a first step, models were trained based on neural networks that use real past data and the predicted future gas yield. Based on this input data, the future average agitator power and the activity over a period of 18 hours are derived. Both recurrent (RNN) and convolutional neural networks (CNN) were used, with the CNN providing more reliable forecasts.

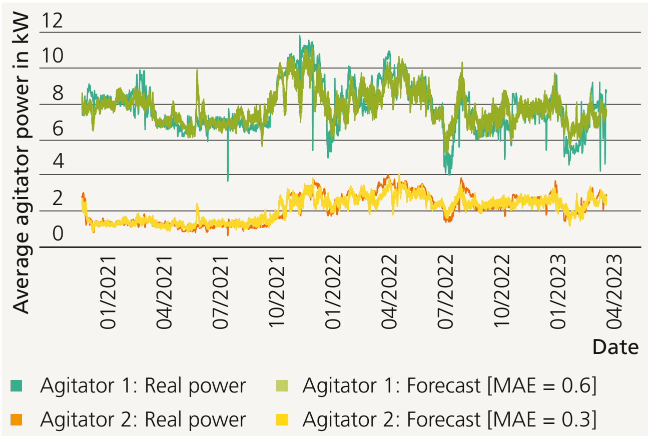

Figure 2: Results for agitator performance prediction.

After successful initial tests, the controller was used and validated from August to December 2023 in regular operation at the University of Hohenheim's research biogas plant. In the future, the newly developed AI controller is to be implemented and optimized in other biogas plants, with the focus on minimizing the energy required for stirring and avoiding floating layers.

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FNR Fachagentur Nachwachsende Rohstoffe e.V.

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Standardized evaluation of the effect of nutrient recyclates on plant growth

Dipl.-Ing. (FH) Nico Domurath, Dipl.-Ing. Marc Lincke

The scarcity of resources and agricultural land as well as the growing world population are global challenges that require new, sustainable ways to create value. For instance, regional nutrient recyclates could potentially replace conventional phosphorus and nitrogen fertilizers. In the context of plant production, this would call for nutrient availability testing and toxicity analyses of the recyclates obtained from residual materials, such as sewage sludge ash or manure. The interaction between substrate, added nutrients and plants as well as potential anthropogenic contamination can be described in standardized plant growth tests. The established practical methods for such tests are either pot trials in greenhouses or field trials, both of which are time-consuming (up to several growth periods). Due to volatile growth conditions, such as light intensity, soil conditions or weather influences, the results are often difficult to differentiate, and any statistical evaluation of different trials is necessarily limited.

To enable the rapid and reproducible evaluation of primary products, recyclates and fertilizer products, standardized test beds were developed and set up within the two projects "Drei-SATS" and "NutriTest" to carry out reproducible plant trials independently of the seasons. Additionally, the project team established standardized investigation methods, which allow for both in-project screening and reproducible results during product definition and quality monitoring – independent of vegetation periods, weather effects and site conditions. The test beds allow for a defined control and regulation of the influential growth parameters of light intensity, photoperiod, temperature, wind speed and humidity. Influencing factors of plant growth can thus be related to the effects of the fertilizers or recyclates and be statistically evaluated.

Figures 1-4: Test beds for recyclates (top left: maize compatibility test; bottom left: nutrient availability of phosphorus recyclates; top right: salt compatibility test; bottom right: liquid nutrient recyclate compatibility test).

During the growth period, the plants are supplied with the material to be tested in various dosing levels. Any missing nutrients are supplied as needed through appropriate solutions. Test cycles may last from 12 to 22 weeks. The buffering effect usually caused by soils and the microbiome within them can be reduced as far as possible by using inert or nutrient-poor special substrates.

At the end of the trial, in addition to the suitability test, the fertilizer effect of the nutrient recyclates when compared with conventional mineral fertilizers is also specified as a mineral fertilizer equivalent value for the nutrients nitrogen and phosphorus.

Services and cooperation offered

- Standardized evaluation and advice on the use of recyclates and fertilizer products
- Development of processes for the extraction of nutrient recyclates from organic residues
- Evaluation of organic residues with regard to material and energy recovery

Supported by: Federal Ministry of Education and Research

RePhoR REGIONALES PHOSPHOR-RECYCLING

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Sustainable electronics: evaluation of the degradation of mold material for power electronics

Dr. Michael Schneider, Dipl.-Ing. (FH) Uta Gierth, Dr. Paul Gierth, Dr. Lars Rebenklau

Reliability by protection of electronics

Sustainability is achieved through the reliable longevity of products. In power electronics this is achieved by protecting vulnerable components using isolating encapsulation materials. There are strict requirements for these materials, which depend on extrinsic (environmental conditions) and intrinsic (operating parameters) factors. Power electronics are used especially in electromobility, industrial electronics, and power engineering.

Under harsh conditions (e.g. offshore) the reliability of the active components requires high-quality encapsulating materials, which are also readily available, cost-effective and easy to process. Because they are safety-relevant for high electric currents, these materials must be stable in the long term. Currently, a composite of highly filled epoxy polymer (EMC), which encapsulates power electronics via thermal transfer molding, is most promising.

Detailed knowledge of their degradation mechanisms and kinetics is critical for the reliability and lifetime of power electronic devices.

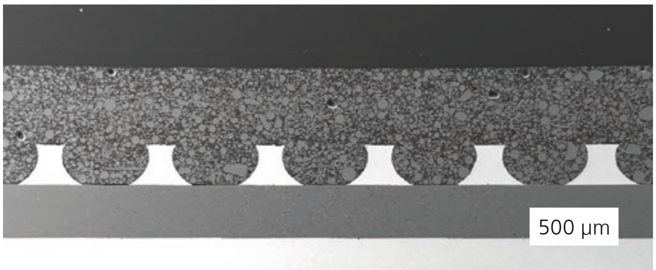

Figure 1: Cross-section of a single-side molded copper substrate.

A novel approach to the characterization of materials

In the past, optical and mechanical methods were frequently used as test methods for the investigation of encapsulations. However, highly filled epoxy mold compounds are optically non-transparent and mechanical tests are destructive.

Impedance spectroscopy is an alternative non-destructive test method. The use of so-called electrical equivalent circuits makes it possible to interpret the measured spectra as a temporary degradation condition. The degradation kinetics can be determined from the time-dependent repetition of the measurements (monitoring) and, with certain limitations, lifetime predictions become possible.

The high specific resistance of the encapsulation and the miniaturized structures available for measurement require precise current signal detection in the pico-ampere range. To realize this, the joint project "TTM-Process Reliability" develops high-impedance measuring devices and setups with sufficient shielding while defining industrially transferable parameters.

Image 2 shows exemplarily impedance spectra of EMC-encapsulated copper substrates before (0 h) and after one hour (1 h) of exposure under multiple stressors consisting of temperature, pressure, and humidity. The frequency-dependent changes in the impedance spectra impressively reflect the degradation process of the loaded encapsulation material and illustrate that impedance spectroscopy is very well-suited for the non-destructive evaluation of encapsulation materials.

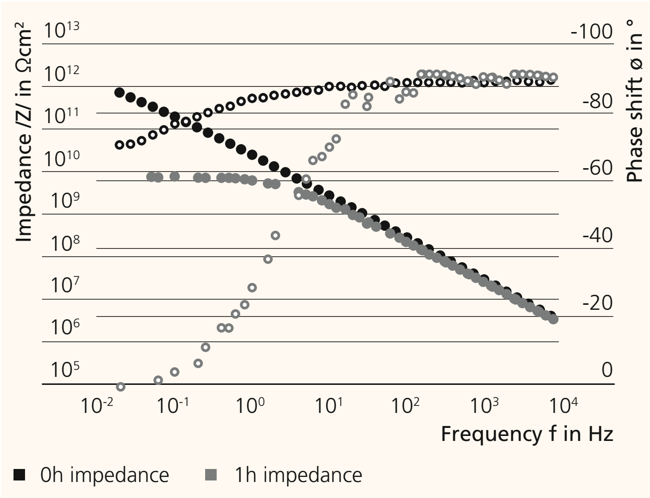

Figure 2: Impedance spectroscopy before and after environmental test.

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Geometrically highly complex ceramic sensor systems (sensor triad)

Dr. Lars Rebenklau, Dr. Uwe Scheithauer,
Dr. Paul Gierth, Dipl.-Ing. Eric Schwarzer-Fischer

Sensors in harsh environmental conditions

The central tasks in sensor technology are the monitoring of status variables, the conversion of sensor signals and their processing as well as communication with higher-level systems. Hardware is adapted to the measurement task required for this. This usually consists of a sensor element, substrate carrier and housing. Harsh environmental conditions with high thermal, chemical and/or mechanical stress are a challenge in nearly all industrial areas. Highly integrated sensor systems with metal or polymer components in these environments quickly reach their limits and complicate real-time-based data acquisition. Functionalized 3D ceramic components, by contrast, meet these requirements for robustness, miniaturization and reliability. Through purposefully selected materials and the combination of additive manufacturing with thick-film technology, these components combine advantages such as chemical and thermal stability, high hardness, low density and specific biological properties with highly complex geometries.

Additive manufacturing of ceramic components

Additive manufacturing processes make it possible to produce geometrically complex and functionalized structures that are difficult or impossible to produce with conventional manufacturing methods. These processes are a game changer especially for hard and difficult-to-machine ceramic materials. Tool-free shaping allows the processing even of individualized single pieces or small series as well as fast iteration cycles in development processes. In addition, only the material that is actually required is used.

Functionalization using thick-film technology

The ceramic components are functionalized with thick-film technology, which is based on the use of pasty materials printed onto the surface of substrates in a structured printing process. Conductor materials, insulators and functional pastes, which are subsequently sintered, are available for functionalization.

Afterwards, additional electronic components or sensors can be assembled or packaged, usually being installed on conductor lines. When it comes to connecting the entire component electrically, typical processes known from electronic packaging are used for assembly:

- Soldering with soft solders
- Wire bonding with aluminum, gold or copper wires
- Sinter assembly of power semiconductors based on nano-silver pastes
- Wire welding for high-temperature applications

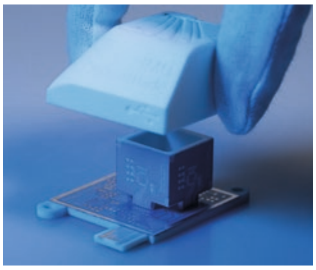

Figure 1: Overall setup and ceramic single components of the sensor triad.

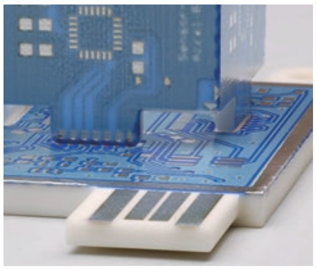

Figure 2: Detailed view of the functionalized single component.

Sensor triad

Within the Fraunhofer-internal project "Sensor triad", Fraunhofer IKTS, together with Fraunhofer ENAS in Chemnitz, develops highly robust sensor systems which enable determining the position and location in three dimensions. Until recently, the high-precision MEMS sensors from ENAS were installed on polymer PCBs to produce one-dimensional sensor systems, which were then coupled together. Within the novel, patented sensor system, the sensors and components are installed directly on the ceramic substrate, which is functionalized with conductor paths and features orthogonally aligned areas produced through additive manufacturing. Doing without polymer substrates means that the space required and the measurement uncertainty due to thermal stress can be significantly reduced.

The symbiotic combination of the two modern ceramic technologies of "additive manufacturing" and "functionalization of ceramic components using thick-film technology" in a two-step process enables highly complex substrate, sensor and housing variants that were previously unattainable. These in turn offer an approach for optimized measurement procedures in harsh environmental conditions.

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ProPlug – integrated interfaces for functionalized lightweight structures

Dr. Robert Schwerz, Dr. Mike Röllig

Lightweight structures increasingly include additional functions such as light sources, sensors or heating elements. However, practical experience to date has shown that the electrical feeds required for integrating functions do not work reliably in the long term. More specifically, the secured electrical and mechanical connection with the lightweight component and the cable guides within the component function poorly. Acceptable functional lightweight structures beyond the laboratory scale, however, require robust, durable and sustainable connections.

The path to a successful connector system

The solution developed at Fraunhofer IKTS is based on an interdisciplinary research approach. It starts with the assembly and connection technology of the integrated function to the supply lines, continues with the routing of these supply lines in the component with low residual stress and ends with the connection between the functional molded component and the outside world – the connector system, which is particularly critical. The new component-integrated plug-socket-system connects electrical supply lines in a robust and safe manner, in accordance with the socket specification in living quarters. It replaces previous connections, which were mostly realized via loose cables and without practical plug connections.

From a multitude of practical applications for functional integration, a tank for agricultural media was chosen as an example for the "ProPlug" project, funded by the German Federal Ministry of Education and Research (BMBF). The tank is made of carbon fiber and needs to be heated to protect it from frost. This specific application requires the functional integration of surface heating, sensory elements to regulate the heating current and a permanently robust and reliable plug connection for the electrical-mechanical connections with the power source and control system.

Low- and high-current-carrying conductors are required for the heating function. They were designed using simulation evaluations based on the finite element method for estimating the even heating through the structure, the necessary electrical power and structural soundness.

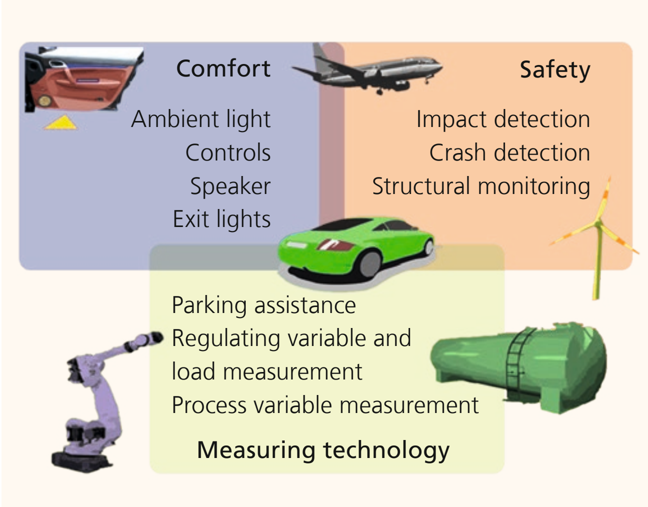

Figure 1: Potential application scenarios for fiber composites with integrated functionality.

The connections between the heating wire and the connector area are designed in such a way that they can withstand the subsequent process of component production in vacuum resin transfer molding (RTM). The resin is injected into a mold at 2 bar, so the structure needed to be fixated to guarantee the desired position. Special external mounts for the socket were developed for this purpose. For the first time, a solution for safe and long-term reliable contacting of the functional components in fiber-reinforced plastic composite lightweight structures has been created.

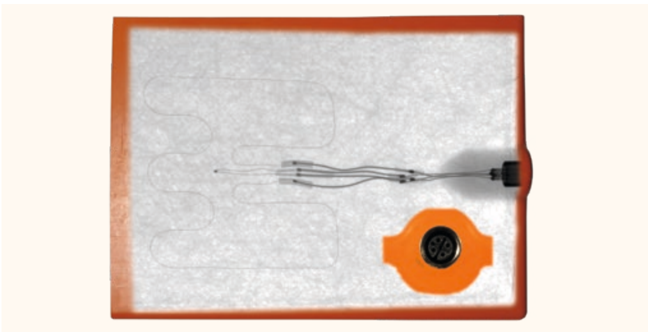

Figure 2: X-ray of the technology sample for functional integration including heating circuit, supply lines and ProPlug connector system.

The results are very promising and the technology steps are currently being transferred to the target demonstrator of the tank container.

Supported by:
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Reject-free forming with optical inline monitoring

Dr. Lili Chen, Dr. Ulana Cikalova, Dr. Beatrice Bendjus, Dipl.-Ing. Matthias Riemer (Fraunhofer IWU)

A significant proportion of the rejects in sheet metal forming occur due to batch-dependent fluctuations in material properties. This could be reduced with a time-consuming, manual setup of the processes or a cost-intensive integration of sensors and actuators into the forming tools. Despite these measures, reject rates of up to 15 % remain, resulting in costs of about 300,000 euros per tool.

The "OptiForm" project aims to reduce the material-related waste to 0 %, thus making a significant contribution to achieving the global sustainability goals around production and consumption.

Adjustment of material parameters before forming

The novel approach focuses on the fluctuating material parameters. These are to be specifically adjusted in the roll straightening process upstream of the forming process. This adjustment is based on an in-process recording of the material properties by means of Laser Speckle Photometry (LSP) and model-based control of the roll straightening process (Figure 1). The cost-intensive integration of sensors and actuators in the forming tools can thus be avoided.

For the detection and targeted adjustment of the material condition in the roll leveling process, LSP is being further developed and implemented as a prototype in a roll leveler available at Fraunhofer IWU. The LSP method is used for the optical determination of plastic deformation by analyzing speckle patterns. This provides information on the component condition, such as roughness and elongation.

Demonstrator shows suitability

In first trials, LSP was calibrated on thin metal sheets. The evaluation of the elongation using the speckle pattern in a tensile test showed a good agreement with the values determined experimentally using an extensometer (Figure 2). This is a prerequisite for the next step, in which LSP will be integrated into the forming process at strip speeds of up to 5 m/min.

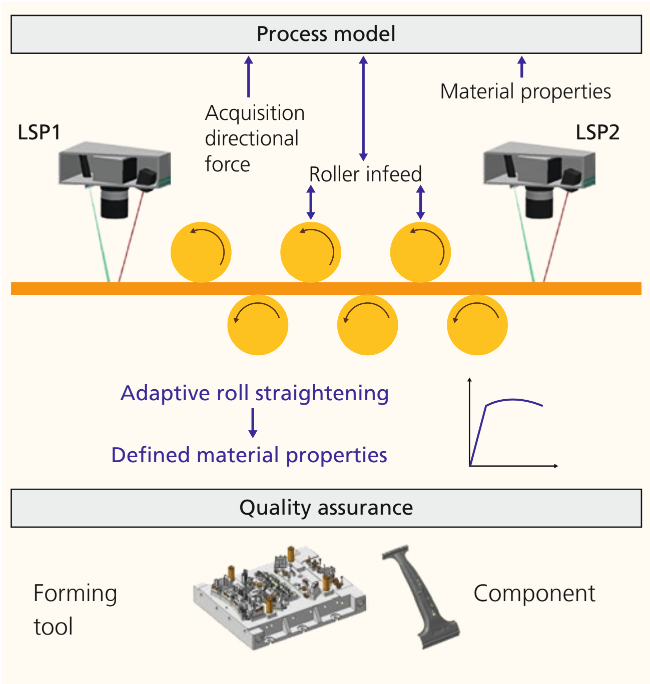

Figure 1: OptiForm – concept for the reduction of rejects.

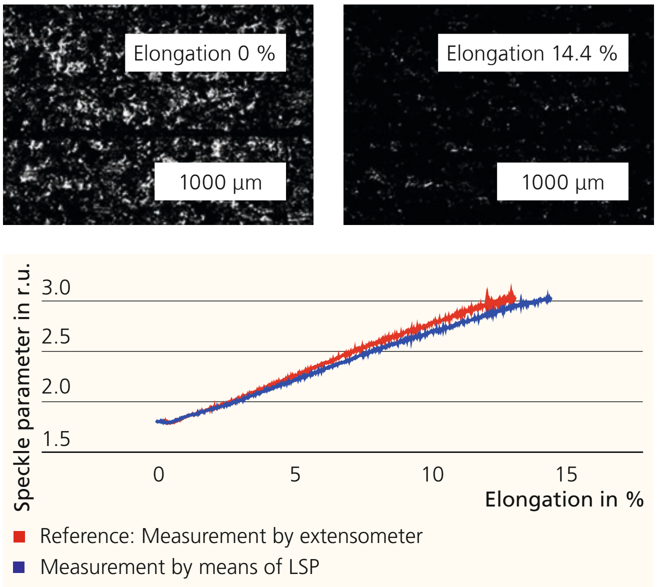

Figure 2: Calibration in the tensile test.

The authors acknowledge the support of the Fraunhofer-Gesellschaft for the "OptiForm" project within the framework of the program "Schnelle Mittelstandsorientierte Eigenforschung SME 2022" ("Fast SME-oriented in-house research SME 2022").

Integrated monitoring for durable lightweight vehicle modules

Dr. Kilian Tschöke, Enes Savli, Dr. Lars Schubert

Closed-loop vehicle components

Vehicles currently produce up to 20 % of CO_2 emissions during their manufacturing process. This is due to the linear, industrial fabrication processes (raw material supply – production – use – disposal). The energy demand results primarily from a short vehicle service life of about 15 years. The basic prerequisite for reducing the energy demand is to retain the value of the raw materials and components used for as long as possible, e.g. through reusable parts.

Durable components made from carbon fiber-reinforced compounds

Durable materials, such as carbon fiber-reinforced plastics, are highly resilient and therefore very well suited for multiple reuse. This is achievable with a circular value chain, in which individual components are tested after the first life cycle and, if necessary, reworked.

In a first step toward realizing this, Fraunhofer IKTS, together with INVENT GmbH, has developed an exemplary innovative fiber composite leaf spring with a novel connection and sensor concept. A sensor network integrated into the material compound (Figure 1, middle) continuously collects data. In this way, the condition of the spring can be holistically described both during operation and at the end of life.

Integrated sensor network

The data collected with the sensor network is evaluated with a corresponding diagnostics system which was developed at Fraunhofer IKTS. The measuring method itself is an established procedure in Structural Health Monitoring (SHM) based on the active Acousto-Ultrasonic method, whereby elastic waves in the range of ultrasound are introduced into the component, and also detected, by piezoelectric transducers. A comparison of the measurement data with a previously recorded reference condition makes it possible to identify the sensor paths on which a change occurred. If the signal deviations are visualized, a graphical interpretation of the measurement signals can be obtained (Figure 1, bottom).

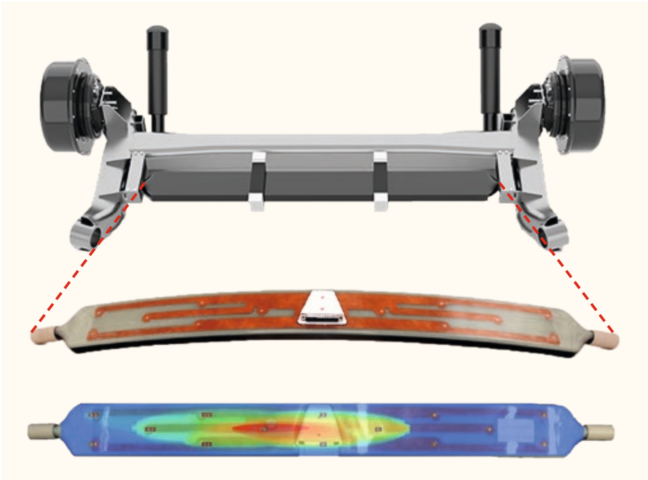

Figure 1: Leaf spring made of fiber composite material with integrated, innovative sensor network.
Top: Schematic representation of the installation state (source: EDAG Engineering Group AG).
Middle: Image of a leaf spring with integrated sensor network.
Bottom: Visualization of damage detection on a leaf spring in a laboratory test.

Using this structural monitoring, the component integrity of the spring can be evaluated during its entire service life. An undamaged leaf spring can be used safely and sustainably, even beyond its intended lifetime.

The cycle-oriented concept can be transferred to other automotive components and can trigger further developments in the automotive and aviation sectors. The ultimate goal is a circular-ready e-vehicle platform, which will in future reduce development costs and risks.

Supported by: Federal Ministry of Education and Research on the basis of a decision by the German Bundestag

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Diamond-SiC composites for highly exposed bearings and seals

Dr. Björn Matthey, Dr. Steffen Kunze,
Dr. Mathias Herrmann

Materials used in pumps are exposed to demanding industrial conditions. The media to be pumped are often corrosive and can also contain abrasive particles. This requires materials that can withstand high mechanical loads and meet these tribological-chemical system requirements.

Fraunhofer IKTS develops diamond-silicon carbide composites for this type of application. Thanks to the high hardness of the diamond phase and the excellent chemical resistance of diamond and silicon carbide, these materials are ideally suited for use under harsh conditions, e.g., in pump bearings and seals. The composite material is used in particular where maintenance is extremely complex and very long service lives are required, as is the case in the subsea sector and the chemical industry.

Figure 1: Gasket with polished diamond-SiC surface.

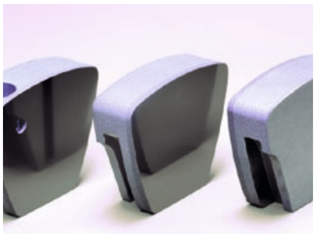

Figure 2: Plain bearing pads with diamond-SiC surface.

Material concepts

Diamond-SiC composites are very expensive to machine due to their excellent wear resistance. One focus of research at Fraunhofer IKTS is therefore the development of component concepts that allow to produce complex components from diamond-SiC at low costs. One way of doing this is to use a grading process to produce the diamond composite only in the highly stressed functional surfaces of conventional SiC components. This can be achieved by double pressing. In this process, a diamond granulate is pressed onto a pre-compacted SiSiC granulate. It is also possible to coat the surfaces of already siliconized or sintered carbide ceramics using slurry technology. The diamond zones produced in this way can be easily processed before liquid phase siliconizing. After the firing process, the diamond-SiC composite formed has a hardness of up to 48 GPa (HK2). The carbide base materials, on the other hand, can be machined after the firing process using established methods. In this way, the component dimensions required for the function can be implemented with high precision.

Diamond contents of approx. 50 % by volume can be applied to the functional surfaces using the press or slurry process. The low silicon content of below 5 % by volume guarantees high corrosion resistance even in alkaline media and under hydrothermal conditions. Tribological tests show that the SiC-bonded diamond materials exhibit wear behavior similar to that of extremely hard polycrystalline diamonds (PCD). In the project "SubSeaSlide", funded by the German Federal Ministry of Education and Research (BMBF), bearings and seals with the diamond-SiC composite were supplied to the companies EagleBurgmann Germany GmbH & Co. KG, Miba Industrial Bearings GmbH and Sulzer AG. The industrial tests and applications show promising results and prove the high potential of this material class.

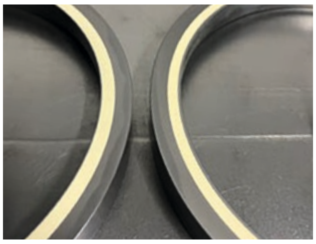

Figure 3: Plain bearing with diamond inlay in green condition.

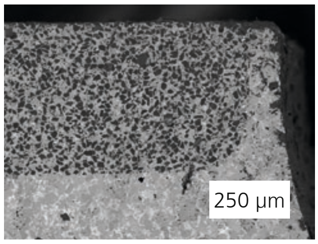

Figure 4: FESEM image of the diamond-SiC inlays.

Services and cooperation offered

- Development of functionally optimized diamond composites
- Application-oriented testing of thermal, chemical and tribological material characteristics
- Process development up to pilot component production level

The project partners thank the BMBF for its financial support in the joint project "SubSeaSlide" (FKZ: 03SX508F).

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Ceramic Tesla valve

Dr. Uwe Scheithauer, Dipl.-Ing. Eric Schwarzer-Fischer, Dipl.-Ing. Lion Sano

Valves are essential for almost all processes in which fluids are supplied or discharged in a defined manner. The Tesla valve is a special type of valve. This passive, fluidic valve was patented by Nikola Tesla in 1916. In contrast to traditional valves, the Tesla valve is a type of non-return valve without moving mechanical parts.

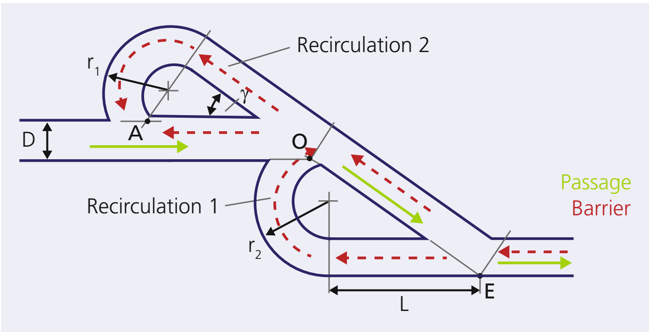

Figure 1: Schematic setup of a Tesla valve.

Ceramic Tesla valves

Ceramic materials possess outstanding thermal, chemical and mechanical properties and are therefore highly interesting for combustion processes, among other applications. During the combustion of gases (e.g. natural gas or hydrogen) for heat generation or within a combustion chamber for space propulsion, a flashback of the combustion into the supply system and the storage tank of the fluids must be avoided at all costs. In this context, valve designs without moving parts are highly attractive, especially for space applications, where high mechanical loads occur during the launch phase.

Diodicity

The key parameter of a Tesla valve is diodicity. It describes the ratio between the pressure losses of the flow in the opposite direction and the flow direction and is dependent on the volume flow. With the Tesla valve, the aim is to achieve the highest possible diodicity by using geometrically complex channels to achieve a low pressure loss in the flow direction and a high pressure loss in the opposite direction. The latter is achieved, for example, by channeling and recirculating the fluids against the actual flow.

CerAMfacturing = Additive manufacturing of ceramics

Additive manufacturing (AM) processes open up completely new opportunities in the geometric design of components, especially for very hard and therefore difficult-to-machine ceramic materials. AM is able to leverage the third dimension for the design of Tesla valves. As a result, diodicity is significantly increased. Current work at Fraunhofer IKTS focuses on component design and flow simulation in order to further improve the diodicity and manufacturability of ceramic Tesla valves.

Very good surface properties

Flow resistance is influenced, among other things, by the friction of the fluid on the wall and is therefore significantly dependent on surface roughness. Components made of Al_2O_3 using CerAM VPP (vat photopolymerization, a subtype of stereolithography) have Ra values below 2 µm even on double-curved surfaces and are therefore better than metallic AM components (Ra > 20 µm) by approx. one order of magnitude. This is achieved through finer ceramic powders (< 1 µm) and the diffusion processes during the subsequent sintering of the components.

Figure 2: Front view of a Tesla valve with inlet for countercurrent in the foreground.

Service and cooperation offered

- Design and simulation of geometrically highly complex components for a wide range of applications
- Selection of suitable ceramic, hardmetal or glass materials according to the application scenario
- Selection of suitable additive or conventional manufacturing processes according to the requirements of the component design
- Manufacturing of individual components through to prototype series production

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Cost-effective production of silicon nitride components with injection molding

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Dr. Rolf Wagner (Rauschert Heinersdorf-Pressig GmbH), Dr. Jürgen Hennicke (FCT Systeme GmbH)

The process chain for manufacturing ceramic components involves numerous individual steps, each of which has a considerable influence on the performance of the products and incurs specific production costs. Developing an economical production route requires the identification of potential cost drivers and a certain willingness to compromise on achievable target values. Using the example of a turbine wheel (Figure 1), this article presents some ideas for more efficient, economical process steps for complex, large-volume silicon nitride components.

Even as early as during the selection and preparation of raw materials, it is possible to impact specific costs. When preparing raw materials in the form of mixed milling for comminution and mixing using sinter additives and subsequent binder-free granulation, ball milling processes with subsequent aqueous spray granulation are used. Optimizing raw material selection and milling conditions (batch size, milling balls, filling) can help reduce costs considerably through shorter milling processes and savings in energy consumed as well as operating resources.

Figure 1: Sintered silicon nitride turbine wheel.

Feedstocks containing an organic binder are required to produce components via injection molding. One advantage of wax-containing binder systems is the possibility of multi-stage debinding. Paraffin, for example, can be dissolved very well in an isopropanol bath. Residual organics are then burnt out thermally. This multi-stage debinding allows converting higher wall thicknesses, such as those found in a turbine wheel. Furthermore, these feedstock formulations are suited for long flow paths and combinations of thin and thick areas.

Ceramic injection molding therefore allows the manufacturing of near-net-shaped components with a high degree of material efficiency compared with green machining.

Properties of sintered rotors

	1750 °C, 20 bar	1860 °C, 50 bar
Debinding	Combined, N_2	Combined, N_2
Sintered density	3.24 g/cm³	3.25 g/cm³
Ra value	0.99 µm	2.16 µm
3-point bending strength	910 MPa	950 MPa
Weibull modulus	11	13

In addition to air debinding processes, Fraunhofer IKTS is working on more efficient combined firing processes, which in the case of silicon nitride are carried out under nitrogen. Using the turbine wheel geometry, the team was able to demonstrate that large differences in wall thickness can be realized in a combined debinding of extraction and thermal decomposition. Typically, silicon nitride materials are sintered at above 1800 °C and at a very high superimposed gas pressure of 50 bar in a nitrogen atmosphere to enable complete densification. Even at lower process pressures of 20 bar and temperatures of 1750 °C, the sintered components showed good material qualities. In the future this will allow for larger or more economical furnaces for series production.

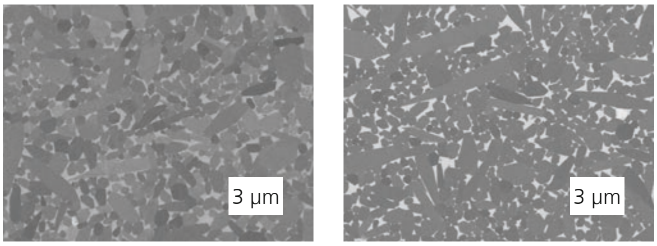

Figure 2: Microstructure of sintered turbine wheels at 1750 °C, 20 bar (left), 1860 °C, 50 bars (right).

Until now, the high costs of manufacturing silicon nitride components have been one of the obstacles preventing the wider use of the material. Thanks to favorable production costs, new fields of application can be addressed that were previously inaccessible due to the cost structure. Project "FlexHY" was funded by the Federal Ministry of Economy and Climate Action (BMWK), funding code: 19I21003G.

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CFRP containment shells in energy-efficient high-power pumps

Dipl.-Ing. Till Schulze, Prof. Henning Heuer, Dipl.-Ing. (FH) Christian Pilz, Dipl.-Ing. (FH) Matthias Pooch, M. Sc. Martin Schulze

Magnetic-coupled centrifugal pumps are used to transport aggressive and dangerous chemicals. A containment shell is located between the outer and inner lines of magnets and separates the engine from the pumped medium. During operation, eddy currents are induced into the containment shell structure through rotation. Since the high electrical conductivity of metallic pots results in efficiency losses of 10–15 %, these pots are more and more replaced by CFRP constructions. The reduced eddy-current induction due to lower conductivity is largely compensated by greater wall thicknesses, which are necessary to withstand the enormous pressure of up to 120 bar. The aim of the work at Fraunhofer IKTS was to dimension the containment shell in such a way that, first, the eddy-current losses can be minimized further and, second, the wall thickness can be reduced while still providing the required strength.

To electromagnetically simulate eddy currents in CFRP, the electrical conductivity of the fabric tapes was first determined on a test bench at TU Dresden. Important parameters of the components (coercivity and B-H curves) were taken from data sheets and entered into the simulation program Ansys Maxwell. This was followed by a simulation with a typical pump speed of 3600 rpm.

The layer structure of the material was then adjusted iteratively, and the resulting eddy-current losses were simulated. Together with the cooperation partner Connova, an optimized CFRP structure was developed, which enables an eddy-current reduction of around 95 %. Eddy-current measurements on a replacement model of the optimized and traditional structures confirm the result. Because of the skin effect, eddy currents propagate on the surface, e.g., when conductivity is high. This effect was more noticeable in the traditional structure than in the optimized material. As a result, the hidden layers were visible in the optimized scan (Figure 3).

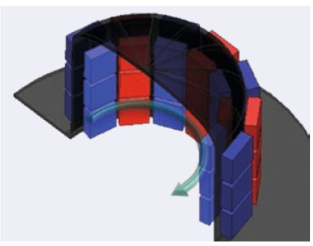

Figure 1: Containment shell with inner and outer magnets.

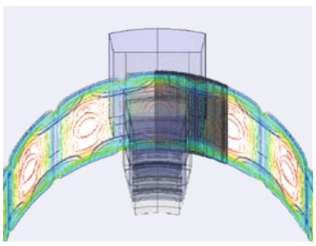

Figure 2: Eddy-current simulation in containment shell.

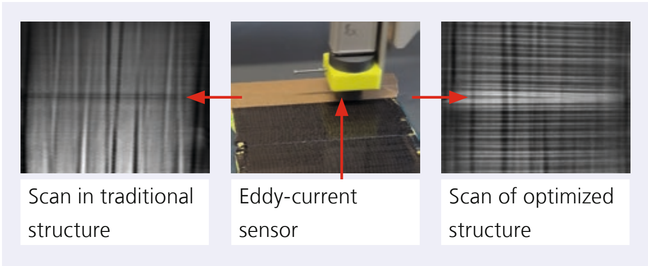

Figure 3: Eddy-current scans of traditional and optimized analogous model.

The simulations were validated by measurements on real containment shells. For this purpose, a test stand was set up which applies the load of the pump using an eddy-current brake, enables containment shells to be changed quickly and allows for typical operating speeds across several gear stages. Three containment shells were compared, consisting of pure CFRP, non-conductive GRP and the optimized structure. In each of the test specimens, flat coils were added at the same positions, in order to evaluate the eddy current losses. The sensor signals of the coils and the power consumption of the motor were evaluated during tests in defined speed ranges of the containment shells. The measurements confirmed the simulations qualitatively.

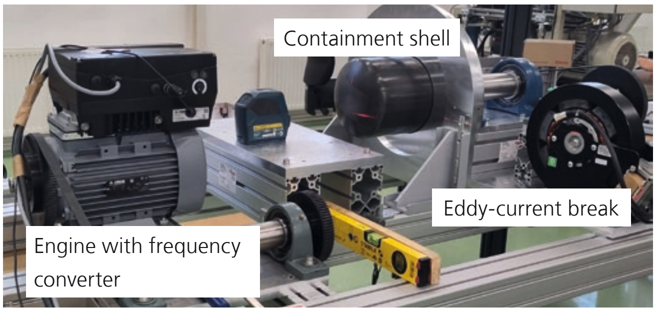

Figure 4: Construction of the test stand.

There are plans to qualify the containment shells for higher rotational speeds, e.g. for gaseous fluids pumped.

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Novel biogenic building and construction materials for CO_2 fixation

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Dr. Ulla König, B.Sc. Marleen Dietze,
Dipl.-Ing. Olena Reinhardt, Prof. Michael Gelinsky

Living (building) materials (LBM) are capable of absorbing carbon dioxide (CO_2) and converting it into carbonate or lime (calcium carbonate, $CaCO_3$). The required CO_2 can be absorbed from the atmosphere or extracted from industrial processes. Microorganisms contained in the LBM, such as cyanobacteria, use the CO_2 for calcium carbonate mineralization (MICP = microbially induced calcium carbonate precipitation).

To mineralize and solidify the lime into biogenic structures, access to sufficient light and moisture is a prerequisite for the microorganisms to carry out photosynthesis and thus MICP. The biogenic lime serves as a binder component between selected fillers and aggregates and thus forms the basis for sustainable building and construction materials. Depending on the implementation, they can be used on land and at sea. Space applications may also be possible in the future.

These versatile materials and material combinations offer a vast scope of application. They address the essential social issues of greenhouse neutrality in industry, sustainable and circular economy, energy, the environment, and our health.

Development of living building materials

Within the BMBF-funded project "BioCarboMin" (funding code 13XP5162A) and the Fraunhofer-internal project "BioCarboBeton", it has now been possible to produce such biogenically solidified structural bodies.

The IKTS invention of Freeze Foaming but also simple casting technologies or additive manufacturing (AM) have now been utilized for the first time to produce structures that allow the survival of the bacteria. The green coloring caused by chlorophyll proves that the microorganisms in the structure are alive (Figure 1).

The chosen materials and the design of the structures as well as the optimized mineralization parameters (exposure, temperature and humidity) enable the living bacteria to form calcium carbonate and even solidified components (Figures 2, 3).

Figure 1: "Living" freeze-foamed components.

Furthermore, it is also possible to produce a type of premix that can be used as a potential "biogenic mortar" after mixing it with a solvent, such as water.

Figure 2: Solidified biogenic "porestone".

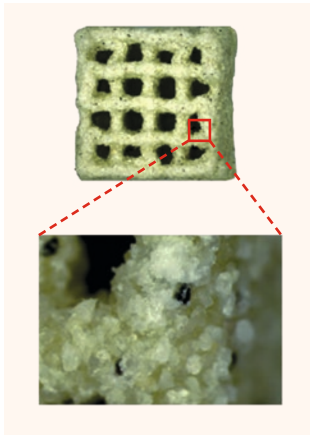

Figure 3: Solidified AM structure (Source: TU Dresden).

It is an aim for the near future to achieve a more targeted survival of microorganisms. Currently, the microorganisms creating the biogenic components die once the mineralization process is complete, turning to non-hazardous biomass.

With the developed approach, we aim to obtain an alternative to conventional cement and concrete mixtures, in which tons of CO_2 are typically produced from the burning of mined fossil lime. In contrast, based on the presented approach, the novel biogenic building and construction materials with sustainable CO_2 fixation contribute to reducing CO_2 emissions in production as well as in use.

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Fraunhofer FEP
Technische Universität Dresden

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AI-generated patient-specific finger joint implant

Dr. Daniel Schumacher, Dr. Sabine Begand,
Dipl.-Ing. Olaf Sandkuhl

Patient-specific joint implants promise a better fit and thus improved functionality and a longer service life than conventional implants. Especially for small joints, where the possibilities for remobilization are currently limited and stiffening is the standard therapy, individual implants offer better care options and an increase in the patient's quality of life.

As part of the project "FingerKit", the Fraunhofer institutes IKTS, MEVIS, IAPT, ITEM and IWM have developed an autonomous process chain from implant design to the production of patient-specific implants and standard-compliant testing.

Figure 1: Customized, ceramic middle finger base joint. (Photo: Jürgen Scheere)

Shape model, implant design and simulations

On the basis of clinical 2D X-ray data and 3D CT images, Fraunhofer MEVIS generated 3D shape models of the bone structure. Building on this, Fraunhofer IAPT was able to generate an AI-based patient-specific implant design. Fraunhofer IWM created a model predicting the design's reliability using parameterization and simulation.

Near-net shape slip casting for patient-specific finger joint implants

Ceramics have excellent mechanical properties in addition to high wear resistance and biocompatibility. They are considered to be more tolerable than metallic and plastic implants, which have a high occurrence of abrasion. In hip endoprosthetics, dispersion ceramics, such as alumina-reinforced zirconia (ATZ), have become particularly well established.

Figure 2: Finger joint implant made of ATZ ceramics with osseointegrative stem and polished articulation surface. (Photo: Jürgen Scheere)

At Fraunhofer IKTS, patient-specific finger joint implants made of the established oxide ceramic implant material ATZ were manufactured in a single step using slip casting. In contrast to conventional production by milling, the osseointegrative surface of the stem does not require any additional finishing. The process achieved a cross structure with a height of 200 µm, the surface of which has a roughness of Ra 12.5 µm, ensuring ideal cell adhesion.

Thanks to an easy-to-scale vibratory grinding and polishing procedure, the articulatory and contact surfaces were of high quality and very robust, and material abrasion was prevented. The implants' mechanical load capacity of up to 3500 N exceeds many times over the 500 N loads occurring in vivo in the implanted state.

The process chain from AI-based generation of the implant design to near-net shaping of ATZ shows great potential for extending the approach for patient-specific implants to other small joints.

Highlights of patient-specific finger joint implants made of ATZ ceramics

Design	Patient-specific, AI-generated from 2D X-ray data
Density	> 99.9 % theoretical density
Articulation area	Polished, Ra 0.08 µm
Osseointegrative shaft	Macro: grid structure height 200 µm, Micro: Ra 12.5 µm
Biocompatibility	Very good
Breaking strength (in accordance with ISO 14801)	3500 N

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AGEUM – analytical laboratory evaluates health risks of environmental pollution

Dr. George Sarau, Dr. Arslan Usman, Dr. Mustafa Kocademir, Dr. Hyoungwon Park, Dr. Sabrina Pechmann, Prof. Silke Christiansen

The analytical laboratory for health and environmental research (AGEUM) at the Forchheim site of Fraunhofer IKTS with its novel, cutting-edge microscopy and spectroscopy techniques offers strong characterization and data analysis capabilities to assess potential human health risks caused by environmental pollution. Environmental factors such as smog, micro- and nanoplastics, brake dust and tire particles (ultrafine dust) constitute highly heterogeneous particulate matter and their biological interactions with living organisms are very complex. This is why, when it comes to characterizing them, the laboratory uses a complementary, multimodal and cross-scale approach. X-ray fluorescence (XRF) microscopy provides high elemental sensitivity down to carbon, variable probe spot sizes (100 µm for statistically significant large area scans and ~15 µm for spatially detailed elemental distribution mapping), and an additional transmission X-ray detector to image internal structures. XRF identifies and quantifies elements present in environmental samples, usually powders and air filters (Figure 1).

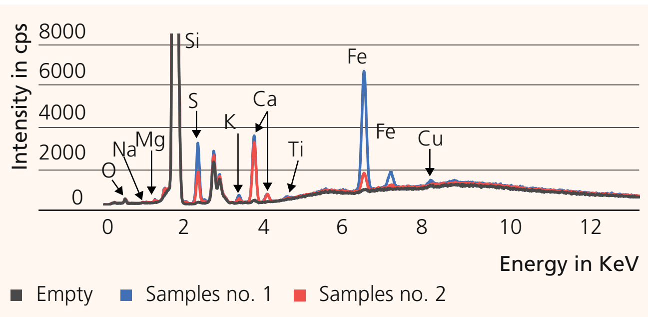

Figure 1: XRF of quartz filters exposed to urban (sample 1) and rural (sample 2) environmental pollution compared with an empty filter, indicating more iron (Fe) and sulfur (S) in the city due to increased human activity.

The integrated platform, incorporating coherent Raman scattering (CRS), second harmonic generation (SHG), fluorescence (FL), and fluorescence lifetime imaging microscopy (FLIM), offers high-throughput, high-resolution, and non-invasive detection of particles inside intricate biological matrices at the cell, organ tissue and small animal levels. CRS, including stimulated Raman scattering (SRS) and coherent anti-Stokes Raman scattering (CARS), chemically identifies different types of particles (plastic-, carbon- and metal oxide-based) and biological components (lipids, protein, collagen) without compromising the probe. This high sensitivity combined with machine learning algorithms can be employed to localize, count, and classify particles according to their size and shape despite intricate biological backgrounds (Figure 2). Moreover, CRS can be directly applied to samples from pathologists, ensuring human relevance by correlating the accumulation of particles inside organs and body fluids with existing patients' clinical data.

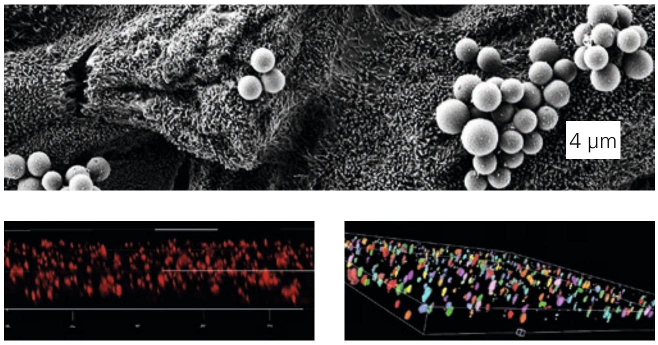

Figure 2: Top: SEM shows the presence of PS particles attached on top of the cells; bottom left: 3D distribution of polystyrene (PS) particles inside and on top of Calu-3 lung cells measured with SRS; bottom right: Machine learning reveals particle number, size, and shape.

Additionally, Fourier-transform infrared spectroscopy (FTIR) is able to measure vibrational modes of molecules associated with changes in dipole moment. FTIR thus provides high-throughput, high-sensitivity, label-free, and hyperspectral infrared imaging, enabling fast detection, characterization, and quantification of various environmental particles in complex biological entities. When combined, these three instruments will provide new insights into the biodistribution and penetration of particles across species, elucidating the potential impact of environmental pollution on human health.

Services and cooperation offered

- S2-bio-laboratory for sample preparation with cryo-workflow
- XRF for elemental analysis
- Integrated confocal microscope platform for label-free chemical imaging and molecular fingerprinting
- FTIR for hyperspectral chemical imaging
- Scanning electron microscope (SEM) with high-resolution in-operando nano-CT for 2D and 3D imaging

European Union
European Regional Development Fund
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BAYERN 2014–2020

Systematic failure analysis of ceramic components

Dr. Mathias Herrmann, Dr. Björn Matthey, Dr. Sören Höhn

Systematic failure analysis is used to understand the failure of systems (e.g. the collapse of the Aquadome in Berlin, train accidents in Eschede or Garmisch-Partenkirchen) and then make them safer. Applied to ceramic components it can help to detect weak points in production or design and make appropriate adjustments or establish quality assurance measures (including non-destructive testing). In addition, the analysis can also be used to optimize materials for the required demands or to select suitable materials.

Fraunhofer IKTS has many years of experience in analyzing the causes of failure of ceramic components. This expertise is based on materials know-how on the one hand and the sophisticated analytical capabilities on the other, which benefit both the development of materials and components and the prevention of downtimes in industry.

Particularly in the case of mechanical, thermomechanical, corrosive or even electrical stress, the fractographic examination of the fracture surfaces is an essential tool for determining or narrowing down the cause of failure. Figure 1 shows a raster-electronic image of the fracture surface of a SiC component with an internal channel that was used under chemical/thermal stresses. The analysis has shown that the primary cause of failure was not chemical corrosion, but defects caused by surface processing that reduced the strength level – a cause that could subsequently be avoided through optimized processing.

Sometimes it is necessary to clarify why increased failure rates occur in different material batches. In this case, in addition to the actual defect analysis, a systematic, statistically verified microstructure analysis is often necessary to determine the relative frequency of the identified defects and thus to be able to verify the differences in the batches. Relevant defects are often like the proverbial "needle in the haystack". To find them, large areas must be reliably analyzed.

To achieve this, distributions normalized on the measurement area are suitable approach, as these reflect the frequency of defects in the volume. An example can be seen in Figure 2. It shows the pore distribution in rolling elements from three different batches, with one batch exhibiting inadequate tribological behavior.

Only by analyzing an area of several square millimeters in size can a reliable distinction be made between the qualities.

Fraunhofer IKTS offers damage analysis of ceramic components and works with partners to develop prevention strategies through adaptations in technology, materials or design or by introducing quality assurance measures (e.g. non-destructive testing).

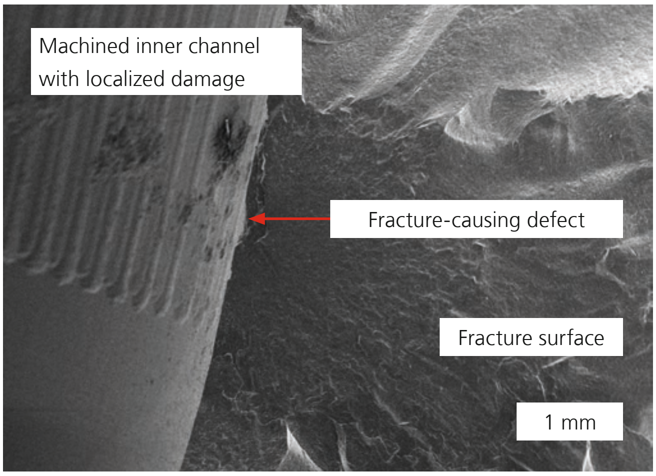

Figure 1: FEM micrograph of the fracture surface of a SiC component.

Figure 2: Area-based pore size distribution of three different batches of Si_3N_4 rolling elements.

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Fracture toughness of 3Y-TZP ceramics – measured with the CNB method

Prof. Bogna Stawarczyk (Ludwig-Maximilians-Universität München), Prof. Jürgen Geis-Gerstorfer (Universitätsklinikum Tübingen), Dr. Sabine Begand

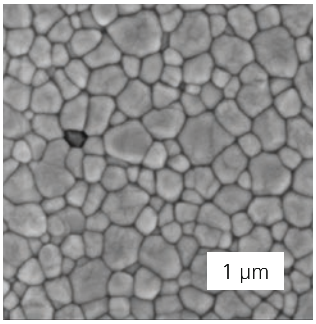

Figure 1: SEM image of a 3Y-TZP ceramic.

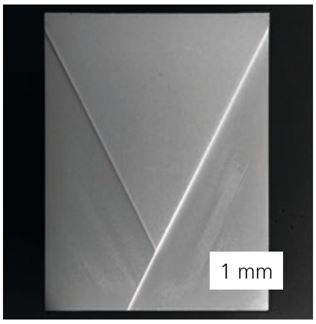

Figure 2: SEM image of a broken chevron notch.

Various standardized mechanical measurement methods are used to characterize the fracture toughness (K_{Ic}) of fine-grained zirconia polycrystals, e.g. the Single-Edged Precracked Beam (SEPB), Single Edge V-Notched Beam (SEVNB), Surface Crack in Flexure (SCF) and Chevron-Notch Beam (CNB) methods. Literature data show that the fracture toughness of 3Y-TZP (3 mol % Y_2O_3-doped tetragonal polycrystalline zirconia) has been measured in the range of 4.4 to 6.6 (13.6) MPa√m, with the differences in standard deviation and variance being too large [1].

So far, there has been no robust test method for determining the fracture toughness of the fine-grained dental ceramic 3Y-TZP. For this reason, Fraunhofer IKTS was one of ten test laboratories to take part in a round robin test to investigate the robustness of the CNB method and the effect of processing and test variations on the fracture toughness of a 3Y-TZP ceramic. In the CNB method, the test specimen is notched to produce the fracture to be analyzed as the load increases. The interlaboratory test was carried out in accordance with ISO 24370:2005 using standardized 3Y-TZP test specimens measuring 3 x 4 x 45 mm³. The participating laboratories established a standard operating procedure with narrow processing tolerances and the data was analyzed using one-way ANOVA followed by the Tukey HSD test. 95 % confidence intervals (CI) were calculated ($p < 0.05$). A previous round robin test, in which IKTS was also involved, had already considered further variations in the test conditions with regard to CNB notching, storage conditions and the test medium.

The fracture toughness of 3Y-TZP was measured as $K_{Ic} = 4.48 \pm 0.11$ MPa√m for the standard processing tolerance in all laboratories. The application of the standard operating procedure increased the number of valid tests and reduced the standard deviation. Preparation parameters such as notch offset and geometry had a significant influence on the results. The test medium used also influenced the K_{Ic} value. A reduced fracture toughness of 3.71 ± 0.52 MPa√m was measured under water.

The defined tolerances during preparation and testing and the close adherence to the procedure according to ISO 24370:2005 enable a highly precise evaluation of the fracture toughness of 3Y-TZP with low data fluctuations. The tests also show that a standardized notch shape with defined preload is important and that oil should be specified as the test medium in order to avoid any influence of foreign substances. The consistent results of the laboratories in the round robin test show that the CNB procedure is a reliable method for testing the fracture toughness of 3Y-TZP if the test parameters are adhered to. [2]

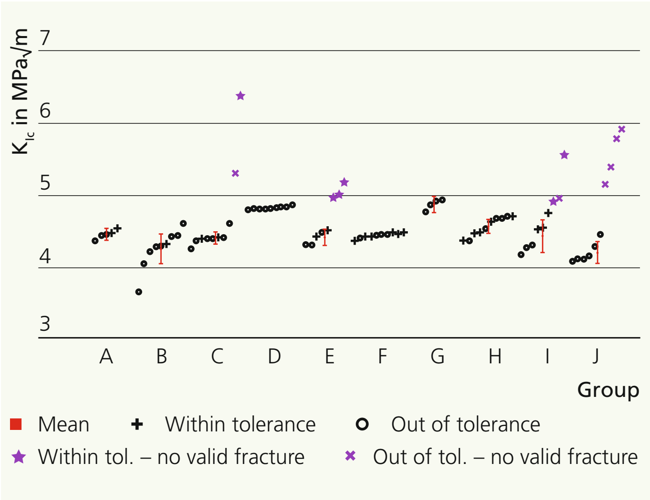

Figure 3: K_{Ic} in oil, individual values, mean value.

Literature

[1] R. Belli et al. (2018): Fracture toughness testing of biomedi-cal ceramic-based materials using beams, plates and discs, 10.1016/j.jeurceramsoc.2018.08.012.
[2] S. Begand et al. (2022): Fracture toughness of 3Y-TZP ce-ramic measured by the Chevron-Notch Beam method: A round-robin study, 10.1016/j.dental.2022.05.001.

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Simulating the thermal properties of diamond-SiC composites

Dr. Björn Matthey, Dipl.-Phys. Jakob Schöne,
Dr. Wieland Beckert, Dr. Mathias Herrmann

Diamond has the highest hardness and thermal conductivity of all materials. Materials with a high diamond content therefore have a high application potential for components for cooling power electronics, lasers or in process cooling. The silicon carbide-bonded diamond material developed at Fraunhofer IKTS combines excellent thermal properties with the possibility of manufacturing complex components. Since the microstructure of the material can be composed very variably, especially with regard to the grain size distribution of the diamond phase, the correlations between the maximum diamond grain sizes and thermal conductivity have so far been the best-known factor. However, many complex and costly process steps are required to optimize the material to achieve the optimum grain composition. New methods of virtual material design using targeted microstructure simulation can simplify this process.

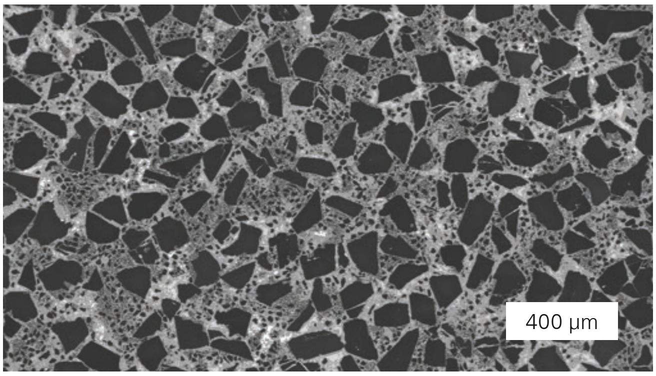

Figure 1: Microstructure of a highly thermally conductive diamond-SiC composite material.

Virtual material design

For the artificial generation of diamond-Si-SiC structures, a workflow has been developed that combines both commercial and open-source software. The synthetically generated basic geometric structure models can be flexibly exported to a variety of other modeling tools via dedicated import/export filters for further processing and physical analysis. The established workflow allows to generate synthetic structure models with realistic morphology and specific, variable volume fractions of diamond, Si and SiC. The predicted thermal conductivity shows good agreement with the measured structures [1].

Figure 2: Artificially generated 3D microstructure of a diamond-SiC composite as a basis for simulating thermal properties.

Based on this work using diamond-SiC as an example, further 3D structure modeling and analysis can be performed for a variety of other materials, such as hardmetals and other conventional ceramic materials. In addition to thermal behavior, other physical features, such as elastic and electrical properties, can also be simulated. In the future, the goal is to use simulation-based synthetic structure analysis methods to derive customized material structures according to predefined property specifications.

Services and cooperation offered

- Analysis of the microstructure of ceramic materials
- Generation of synthetic model microstructures with realistic morphology
- Measurement, simulation and correlation of a variety of physical properties

Literature

[1] Matthey, B., Kunze, S., Kaiser, A., & Herrmann, M. (2023). Thermal properties of SiC-bonded diamond materials produced by liquid silicon infiltration. *Open Ceramics, 100386*.

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High-resolution characterization of coated battery powders

Dr. Sören Höhn, Dipl.-Ing. Kerstin Gnauck, Dr. Mandy Höhn, M.Sc. Jean Philippe Beaupain

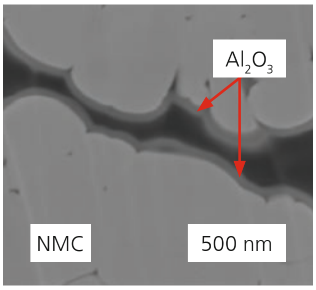


Figure 2: FE-SEM images of ALD-coated NMC particles.

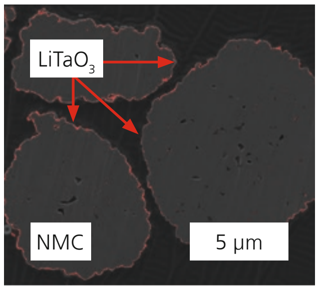


Figure 3: FE-SEM image with superimposed EDS tantalum signal of LiTaO$_3$-coated NMC particles using wet chemical spray drying.

The success of electromobility is highly dependent on the development and production of reliable and durable batteries. At Fraunhofer IKTS, materials and technologies are developed that meet the highest requirements for the energy and power densities of batteries. The coating of active materials using atomic layer deposition (ALD) and spray drying is a key step in increasing the longevity and energy density of batteries. Protective layers just a few nanometers thick, e.g. made of Al_2O_3 or $LiTaO_3$, improve the interface properties of the active materials by minimizing undesired decomposition reactions between the battery components. A workflow developed at Fraunhofer IKTS is used to prepare and characterize these thin layers, which guarantees inert conditions for the entire analysis process (Figure 1).

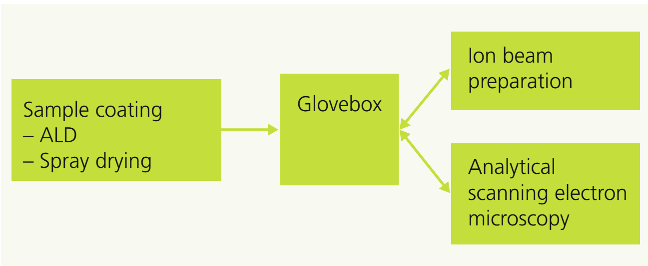


Figure 1: Workflow for sample preparation and characterization under inert conditions.

Using ion beam-based preparation methods established at Fraunhofer IKTS, large-scale structural areas are prepared as cross-sections, free of artifacts. In doing so, the in-situ sample cooling prevents the samples from heating up with liquid nitrogen.

The precisely cut battery powder particles are imaged and characterized in the field emission scanning electron microscope (FE-SEM). Figure 2 shows Lithium-Nickel-Manganese-Cobalt-Oxide (NMC) powder particles that were coated with an approximately 40 nm thin Al_2O_3 layer using the ALD process. In order to image and characterize ultrathin layers in FE-SEM with sharp edges and surface sensitivity, it is essential to work at low acceleration voltages. This means that the interaction volume of the primary electrons with the sample is so low that particles and coating can be analyzed reliably.

A windowless SDD detector is used for characterization using energy-dispersive X-ray analysis (EDS) in low-voltage microscopy. This is characterized by high signal intensities and high sensitivity. It enables, for example, the mapping of the homogeneous distribution of a few nanometer thin $LiTaO_3$ layer on NMC particles using EDS mapping (Figure 3).

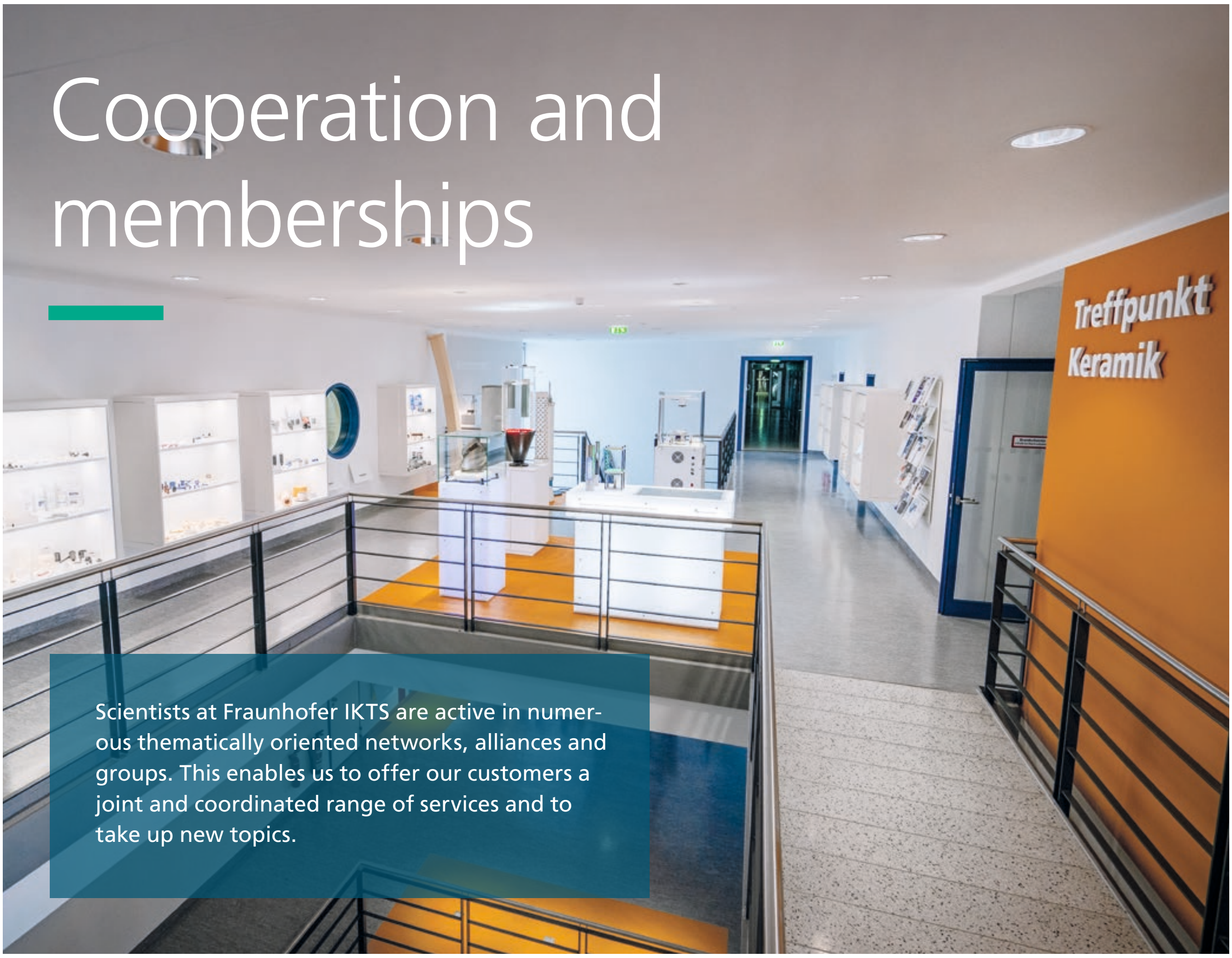
For further layer analyses (e.g. of layer adhesion, atomic structures), high-resolution transmission electron microscopy (HR-TEM) is available at Fraunhofer IKTS. By using highly specialized analytical methods, Fraunhofer IKTS is making a decisive contribution to solving the challenges of material development for longer-lasting and more powerful batteries.

Services and cooperation offered

- Powder coating using atomic layer deposition (ALD) and spray drying
- Artifact-free microstructure preparation of battery materials and water-sensitive samples under inert conditions
- High-resolution analytical scanning electron microscopy (FE-SEM) and transmission electron microscopy (HR-TEM)

This work was financially supported by the AiF (IGF project 22233 BR).

Cooperation and memberships



Scientists at Fraunhofer IKTS are active in numerous thematically oriented networks, alliances and groups. This enables us to offer our customers a joint and coordinated range of services and to take up new topics.

Memberships

AGENT-3D

AMA Association for Sensors and Measurement

American Ceramic Society (ACerS)

Arbeitsgemeinschaft industrieller Forschungseinrichtungen "Otto von Guericke" e. V. / German Federation of Industrial Research Associations

Association Competence Center for Aerospace and Space Technology Saxony/Thuringia (LRT)

Association for Manufacturing Technology and Development (GFE)

Association of Electrochemical Research Institutes (AGEF)

Association of German Engineers (VDI)

Association of Thermal Spraying (GTS)

Automotive Thuringia

BfR Commission for Risk Research and Risk Perception (RISKOM)

biosaxony e. V.

Carbon Composites e. V. (CCeV)

Ceramics Applications

Ceramics Meeting Point

CiS Forschungsinstitut für Mikrosensorik GmbH

CO_2 Value Europe AiSBL

Competence Center for Nano Evaluation nanoeva®

Competence Network on Optical Technologies (Optonet)

COMPOSITES UNITED e. V.

Cool Silicon e. V.

DECHEMA – Society for Chemical Engineering and Biotechnology

DeepSea Mining Alliance e. V.

Deutsche Glastechnische Gesellschaft e. V. (DGG)

Deutsche Industrie- und Handelskammer, Industrie- und Forschungsausschuss

Deutsche Keramische Gesellschaft e. V. (DKG) / German Ceramic Society

DIN/VDI Standards Committee Acoustics, Noise Control and Vibration Engineering

DIN Standards Committee Information Technology and selected IT Applications (NIA)

DIN Standards Committee Precision Mechanics and Optics

DKG Anwenderkreis Additive Keramische Fertigung

DRESDEN-concept e. V.

Dresden Fraunhofer Cluster Nanoanalysis

ECPE European Cluster for Power Electronics

EIT Health

Energy Saxony e. V.

European Powder Metallurgy Association (EPMA)

European Research Association for Sheet Metal Working (EFB)

European Society of Thin Films (EFDS)

Expert Group on Ceramic Injection Molding in the German Ceramic Society (DKG)

Expert Group on High-Temperature Sensing Technology in the German Society for Materials Science (DGM)

Fachverband Pulvermetallurgie

FarmTech Society (FTS) ASBL

Fördergemeinschaft für das Süddeutsche Kunststoff-Zentrum e. V.

Fördergesellschaft Erneuerbare Energien (FEE)

Fraunhofer Adaptronics Alliance

Fraunhofer Battery Alliance

Fraunhofer Big Data and Artificial Intelligence Alliance

Fraunhofer Chemistry Alliance

Fraunhofer Competence Field Additive Manufacturing

Fraunhofer Energy Alliance

Fraunhofer Group for Materials and Components – MATERIALS

Fraunhofer Nanotechnology Network FNT

Fraunhofer Simulation Network

Fraunhofer Research Field Lightweight Construction

Fraunhofer Water Systems Alliance (SysWasser)

German Association for Small and Medium-sized Businesses (BVMW)

German Association of University Professors and Lecturers (DHV)

German Biogas Association

German Chemical Society (GDCh)

German Electroplating and Surface Treatment Association (DGO)

German Energy Storage Association (BVES)

German Federation of Industrial Research Associations (AiF)

German Materials Society (DGM)

German Phosphor Plattform

German Physical Society

German Platform NanoBioMedizin

German Society for Crystallography (DGK)

German Society for Membrane Technology (DGMT)

German Society for Non-Destructive Testing (DGZfP)

German Thermoelectric Society (DTG)

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InDeKo Innovationszentrum Deutschland Korea

InfectoGnostics Research Campus Jena

Initiative Erfurter Kreuz e. V.

Innovation Institute for Nanotechnology and Correlative Microscopics – INAM e. V.

Innovationszentrum Bahntechnik Europa

Institut für Anwendungstechnik

Institut für Energie- und Umwelttechnik e. V. (IUTA)

Institut für Mikroelektronik- und Mechatronik-Systeme gGmbH

International Microelectronics and Packaging Society, IMAPS Deutschland

International SOS GmbH

International Zeolite Association

ISSS Geschäftsstelle IGD-R

JenaVersum network

Joint Committee High Performance Ceramics of the German Materials Society (DGM) and the German Ceramic Society (DKG)

KMM-VIN (European Virtual Institute on Knowledge-based Multifunctional Materials AiSBL)

Materials Research Network Dresden (MFD)

medways e. V.

Meeting of Refractory Experts Freiberg (MORE)

microTEC Südwest

Nachhaltigkeitsabkommen Thüringen

NAFEMS – International Association Engineering Modelling

Organic Electronics Saxony

Ostthüringer Ausbildungsverbund e. V. Jena

ProcessNet – an initiative of DECHEMA and VDI-GVC

QBN Quantum Business Network

Rail.S e. V.

Regionale Aktionsgruppe Saale Holzland e. V.

Research Association for Diesel Emission Control Technologies (FAD)

Research Association Mechatronic Integrated Devices 3-D MID

Research Association of the German Ceramic Society (FDKG)

Research Association on Welding and Allied Processes of the German Welding Society (DVS)

Silicon Saxony e. V.

smart³ e. V.

SmartTex Network

Society for Corrosion Protection (GfKORR)

Thüringer Erneuerbare Energien Netzwerk e. V. (ThEEN)

Thüringer Wasser-Innovationscluster

TITK Materials research institute for polymer functional and engineering materials

TRIDELTA CAMPUS HERMSDORF e. V.

TWI Innovation Network

VDMA Medical technology

Verband Deutscher Maschinen- und Anlagenbau e. V. (VDMA)

Verein für Regional- und Technikgeschichte e. V. Hermsdorf

Wind Energy Network Rostock

Fraunhofer Group for Materials and Components – MATERIALS

The Fraunhofer Group for Materials, Components – MATERIALS stands for cross-scale materials expertise along industrial value chains. It applies its expertise from materials science fundamentals to materials engineering system solutions to create innovations for the markets of its customers and partners.

The Fraunhofer MATERIALS Group bundles the competencies of materials science and materials engineering in the Fraunhofer-Gesellschaft. This applies in particular to the development of new and improved materials, the application-specific (re)design of existing materials, the appropriate manufacturing processes and process technologies up to quasi-industrial scale, the characterization of material and component properties up to the evaluation of the system behavior of materials and components in products.

Numerical modeling and simulation techniques are used as well as state-of-the-art experimental investigations in laboratories and pilot plants. Both are carried out across all scales from molecules and components to complex systems and process technology. In parallel, the methods and tools used are constantly being developed to the highest standards. In terms of materials, the Fraunhofer MATERIALS Group covers the entire range of metallic, inorganic-non-metallic and polymeric materials, and materials produced from renewable raw materials, as well as semiconductor materials, hybrid and composite materials.

The scientists in the collaborative institutes apply their know-how and expertise primarily in the business areas of mobility, health, mechanical and plant engineering, construction and housing, microsystems technology, safety and security, and energy and the environment. They are well networked at national, European and international level and make a significant contribution to innovation processes at these levels. At European level, for example, the Group is committed to strengthening Europe's technological sovereignty through excellent materials science and engineering as part of the Advanced Materials Initiative (AMI 2030).

In the view of the Fraunhofer MATERIALS Group, a key function lies in the digitization of materials research and materials technology throughout the entire value creation process, along the life cycle of materials. Digitization in this area is an essential prerequisite for the sustainable success of Industry 4.0, as well as for the realization of resource efficiency. Data generation and the development of digital material twins are therefore a particular focus of the Fraunhofer Group's projects.

Climate change, scarcity of resources and a simultaneous increase in demand for mobility, living space and comfort call for a general rethinking in product development. From the point of view of the Fraunhofer MATERIALS Group, hybrid lightweight system construction offers a high potential for solutions. The target parameter in the development process here is resource efficiency with a weight-optimized and at the same time function-optimized design of components. The Group sees lightweight construction as a holistic challenge and focuses on sustainable, recyclable materials, intelligent hybrid structure design and integrated material and component evaluations.

Renewable energies are gaining a dominant importance in the course of the energy transition. In order to generate, store, transport and convert them, a variety of materials will be used to a much greater extent than for classic energy supply systems, from copper, steel and concrete to rare earths. The Fraunhofer Group for Materials, Components – MATERIALS is working on this complex of issues in the context of sustainability, particularly with regard to resource efficiency, the development of new material flows and the creation of closed resource cycles.

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Ceramics Meeting Point

The Treffpunkt Keramik (Ceramics Meeting Point) in Dresden continues to be an integral part of our institute's public relations activities. In total, more than 70 partners use this platform to present their range of services with exhibits and information material to new users in industry and research. The cooperation with the "Ceramic Applications" of publishers Göller Verlag is an effective combination of science and communication practice.

Because of the successful acquisition of large-scale projects, the previous area of Treffpunkt Keramik is needed as logistics space. Following an elaborate redesign of the circulation areas, the exhibition is now presented over three floors in the center of the institute. Combined with modern presentation technology, it is a highlight at all tours of the institute, seminars and conferences, as well as at employee talks. In future, coffee breaks will evolve into impromptu further training and forays into market research. Raw material suppliers are to be found there as well as suppliers of machine technology. However, the focus will continue to be on component manufacturers and the research highlights of Fraunhofer IKTS.

Additively manufactured components in oxide and non-oxide ceramics are presented next to material composites. If requested, this can be followed by a visit to the corresponding laboratories. Systems from more than 10 manufacturers are tested for the latest applications, from the jewelry industry to fusion technology.

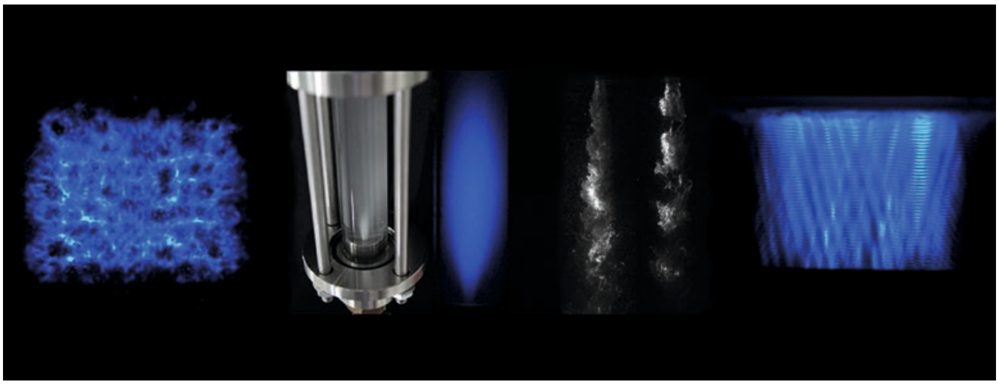
Gigantic structural ceramic components made of silicon carbide and weighing more than 50 kg can be viewed in addition to complex, modular, brazed structures made of aluminum oxide and more than two meters high. Of course, there are also energy or hydrogen technology exhibits. Even after 20 years of Treffpunkt Keramik in Dresden, the material continues to fascinate visitors.

In 2024, there will once again be seminars and training sessions of Fraunhofer IKTS, the German Ceramic Society (DKG) and the German Materials Society (DGM). In-house training at companies also remains an option.

A second "Ceramics Meeting Point" was inaugurated at the IKTS site in Hermsdorf in March 2024. Exhibits from the site's key research areas of oxide ceramics, functional ceramics, battery and membrane technology are on display in four showcases.

Ceramics Meeting Point at Fraunhofer IKTS in Dresden-Gruna.

Center for Energy and Environmental Chemistry Jena (CEEC)



Hydrodynamic and acoustic cavitation phenomena and visualization of cavitation fields in reactors (source: P. Bräutigam, CEEC).

The Center for Energy and Environmental Chemistry Jena (CEEC) is an interfaculty center operated jointly by Fraunhofer IKTS and Friedrich Schiller University (FSU) Jena. The CEEC bundles the activities of the two research institutions in the fields of energy conversion, energy storage, and technical environmental chemistry. Focus is mainly on electrochemical energy storage systems and the materials, especially ceramics and polymers, used for them, energy converters, such as solar cells, and innovative water and wastewater treatment methods. There are currently 13 professorships from FSU and 5 departments from IKTS represented at the CEEC, including the Fraunhofer ATTRACT group "CAV-AQUA" under the leadership of Dr. Patrick Bräutigam. In addition to the new institute building in Jena, which has been in operation since 2015, laboratories and pilot-scale facilities for battery manufacturing and membrane technology are part of the center at IKTS in Hermsdorf.

For IKTS, the CEEC represents a strategic cooperation platform with Friedrich Schiller University Jena, especially in the field of basic research. Numerous joint Master's and PhD theses are organized, joint events offered, research projects initiated, and large-scale equipment used via the center. The "Chemistry – Energy – Environment" Master's program, in which IKTS is particularly prominent with its research activities, is also supervised and overseen by the CEEC and is the only program of its kind offered in Germany.

One focus of the collaboration is the "Technical Environmental Chemistry" chair, which is held by Prof. Michael Stelter. The working group is dedicated to water treatment, water purification, and water analysis using novel methods, such as ultrasound and hydrodynamic cavitation, electrochemistry, and ceramic membrane technology.

In 2019, new equipment for high-performance analytics, penetrating extremely low concentration ranges and providing data on pollutant degradation processes in automated high throughput, could be procured especially in the research area of trace substances. This technology opens the path for digitalization and sensors even in water treatment.

Additional topics addressed at the CEEC and of particular relevance to IKTS include the following:

- Materials for electrochemical reactors and batteries
- Organic active materials and membranes
- Carbon nanomaterials
- Glasses and optically active materials for photovoltaics and photochemistry
- Physical characterization

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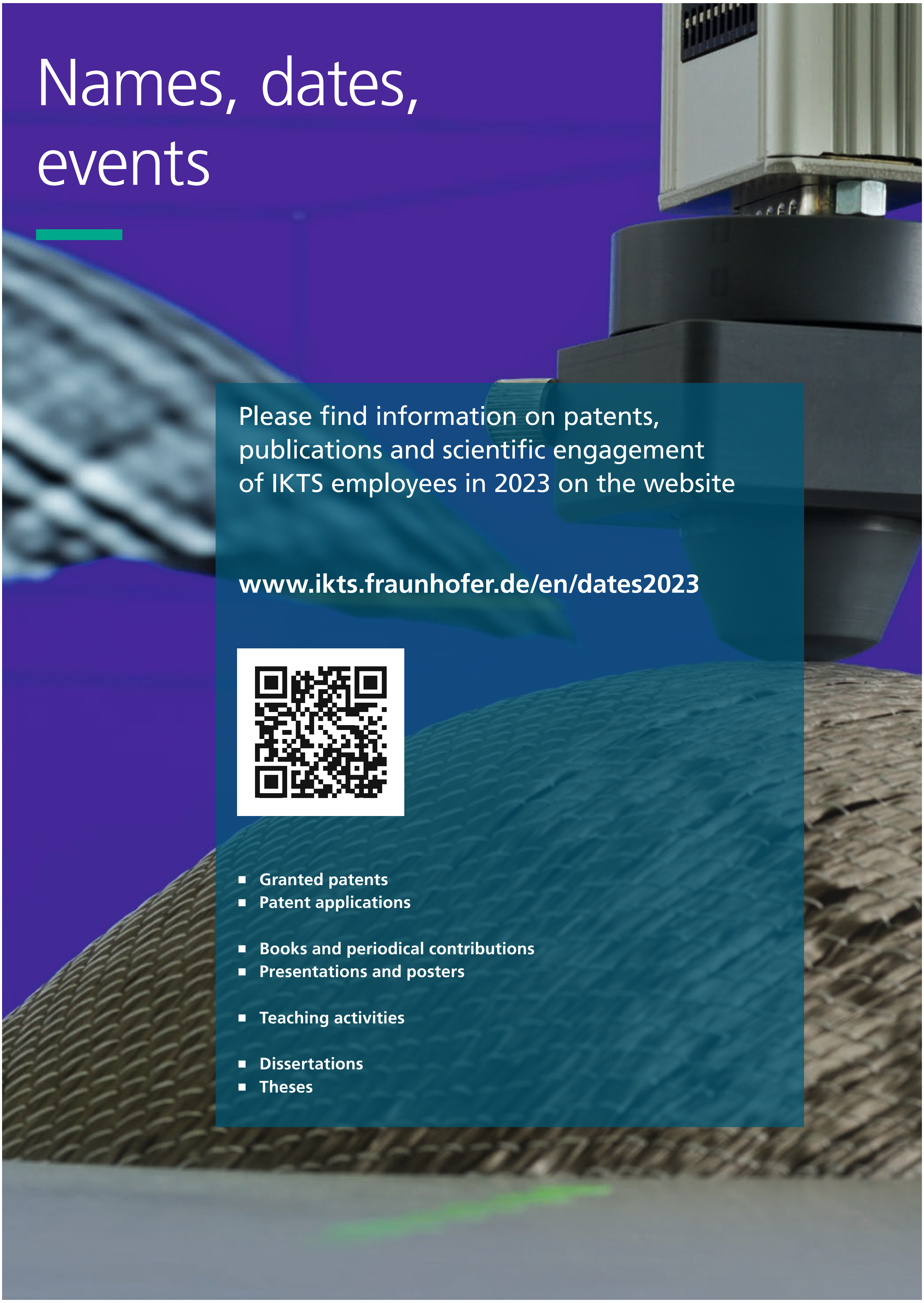
CEEC JENA
Center for Energy and Environmental Chemistry Jena



Names, dates, events

Please find information on patents, publications and scientific engagement of IKTS employees in 2023 on the website

www.ikts.fraunhofer.de/en/dates2023

- **Granted patents**
- **Patent applications**

- **Books and periodical contributions**
- **Presentations and posters**

- **Teaching activities**

- **Dissertations**
- **Theses**

Events and trade fairs

Please find further information at
www.ikts.fraunhofer.de/en/communication

Conferences and events

Junior doctor "Little detectives: searching for faults with ultrasound"
March 7 and April 18, 2024, Dresden-Klotzsche

LithAM workshop – Lithographic additive manufacturing in practice
March 12, 2024, Dresden-Gruna

SCHAU REIN! – Open Business Week Saxony
March 14, 2024, Dresden-Klotzsche

NDT4INDUSTRY: Unveiling characterization techniques for advancing biologized materials in development
April 17, 2024, Online

Girls' Day
April 25, 2024, Hermsdorf and Dresden-Gruna

Science and Business Night Freiberg
May 25, 2024, Freiberg

Dresden Science Night (#LNdWDD)
June 14, 2024, Dresden-Gruna

Open day at Hermsdorf site
September 7, 2024, Hermsdorf

Hard materials, hardmetals and refractories through the ages – Honorary colloquium for Prof. Gerhard Gille
September 17, 2024, Dresden-Gruna

NDT4INDUSTRY
October 2024, Online

ISPA International Symposium on Piezocomposite Applications
November 6–8, 2024, Dresden-Gruna

Symposium Corrosion in (power) electronics
November 28–29, 2024, Dresden-Gruna

Training seminars and workshops

DGM training seminar: Ceramic materials – properties and industrial applications (DE)
September 25–26, 2024, Dresden-Gruna

DKG training seminar: Tape casting and slot die processing
November 6–7, 2024, Hermsdorf

Trade fairs and exhibitions

KarriereStart
January 19–21, 2024, Dresden

SPIE.PhotonicsWest
January 27–February 1, 2024, San Francisco (USA)

ICACC
January 30–31, 2024, Daytona (USA)

IWA Outdoor Classics
February 29–March 3, 2024, Nuremberg

JEC
March 5–7, 2024, Paris (FRA)

LOPEC
March 6–7, 2024, Munich

Spin2030 Wissenschaftsfestival
March 8–9, 2024, Dresden

CIPS
March 12–14, 2024, Dusseldorf

ZfP im Eisenbahnwesen
March 12–14, 2024, Erfurt

Ceramitec
April 9–12, 2024, Munich

Hannover Messe
April 22–26, 2024, Hanover

Bonding-Firmenkontaktmesse
April 23–25, 2024, Dresden

DGZfP-Jahrestagung
May 6–8, 2024, Osnabrück

GPEC
May 6–8, 2024, Leipzig

IFAT
May 13–17, 2024, Munich

WCNDT
May 27–31, 2024, Incheon (KOR)

Woche der Umwelt
June 4–5, 2024, Berlin

ACHEMA
June 10–14, 2024, Frankfurt a.M.

EPHJ
June 11–14, 2024, Genf (CHE)

PCIM
June 11–13, 2024, Nuremberg

Rad+Schiene
September 18–20, 2024, Dresden

Innotrans
September 24–27, 2024, Berlin

EuroPM
September 29–October 2, 2024, Malmö (SWE)

Chillventa
October 8–10, 2024, Nuremberg

FAD-Konferenz
November 5–7, 2024, Dresden

Filtech
November 12–15, 2024, Cologne

Electronica
November 12–15, 2024, Munich

Hydrogen Week
November 18–22, 2024, Brussels (BEL)

Formnext
November 19–22, 2024, Frankfurt a.M.

Erfurter Energiespeichertage
November 24, 2024, Erfurt

Hagener Symposium
November 28–29, 2024, Hagen

How to reach us at Fraunhofer IKTS

Please find further information and direction sketches at www.ikts.fraunhofer.de/en/contact

How to reach us in Dresden-Gruna

By car

- Highway A4: at the three-way highway intersection "Dresden West" exit onto Highway A17 in direction "Prag" (Prague)
- Exit at "Dresden Prohlis/Nickern" (Exit 4)
- Continue 2 km along the secondary road in direction "Zentrum" (city center)
- At the end of the secondary road (Kaufmarkt store will be on the right side), go through traffic light and continue straight ahead along "Langer Weg" in direction "Prohlis" (IHK)
- After 1 km, turn left onto "Mügelner Straße"
- Turn right at the next traffic light onto "Moränenende"
- Continue under the train tracks and turn left at next traffic light onto "Breitscheidstraße"
- Continue 3 km along the "An der Rennbahn" to "Winterbergstraße"
- Fraunhofer IKTS is on the left side of the road
- Please sign in at the entrance gate

By public transport

- From Dresden main station take tram 9 (direction "Prohlis") to stop "Wasaplatz"
- Change to bus line 61 (direction "Weißig/Fernsehturm") or 85 (direction "Striesen") and exit at "Grunaer Weg"

By plane

- From Airport Dresden-Klotzsche take a taxi to Winterbergstraße 28 (distance is approximately 7 miles or 10 km)
- Or use suburban train S2 (underground train station) to stop "Haltepunkt Strehlen"
- Change to bus line 61 (direction "Weißig/Fernsehturm") or 85 (direction "Striesen") and exit at "Grunaer Weg"

How to reach us in Dresden-Klotzsche

By car

- Highway A4: exit "Dresden-Flughafen" in direction "Hoyerswerda" along "H.-Reichelt-Straße" to "Grenzstraße"
- "Maria-Reiche-Straße" is the first road to the right after "Dörnichtweg"
- From Dresden city: B97 in direction "Hoyerswerda"
- "Grenzstraße" branches off to the left 400 m after the tram rails change from the middle of the street to the right side
- "Maria-Reiche-Straße" branches off to the left after approx. 500 m

By public transport

- Take tram 7 from Dresden city to stop "Arkonastraße"
- Turn left and cross the residential area diagonally to "Grenzstraße"
- Follow this road for about 10 min to the left and you will reach "Maria-Reiche-Straße"
- Take suburban train S2 (direction "Airport") to "Dresden-Grenzstraße"
- Walk back about 400 m along "Genzstraße"
- "Maria-Reiche-Straße" branches off to the right

By plane

- From Dresden-Klotzsche airport, take bus 80 (direction "Bf. Klotzsche") to "Grenzstraße", then walk back to "Grenzstraße", turn right there. After approx. 150 m "Maria-Reiche-Straße" turns right
- Or take the suburban train one stop to "Dresden-Grenzstraße", and after about 400 m turn right into "Maria-Reiche-Straße"

How to reach us in Hermsdorf

By car

- Highway A9: exit "Bad Klosterlausnitz/Hermsdorf" (Exit 23) and follow the road to Hermsdorf, go straight ahead up to the roundabout
- Turn right to "Robert-Friese-Straße"
- The 4^{th} turning to the right after the roundabout is "Michael-Faraday-Straße"
- Fraunhofer IKTS is on the left side

- Highway A4: exit "Hermsdorf-Ost" (Exit 56a) and follow the road to Hermsdorf
- At "Regensburger Straße" turn left and go straight ahead up to the roundabout
- Turn off to right at the roundabout and follow "Am Globus"
- After about 1 km turn off left to "Michael-Faraday-Straße"
- Fraunhofer IKTS is on the left side

By public transport

- From Hermsdorf-Klosterlausnitz main station turn right and walk in the direction of the railway bridge
- Walk straight into "Keramikerstraße" (do not cross the bridge)
- Pass the porcelain factory and the Hermsdorf town house
- Turn right, pass the roundabout and walk straight into "Robert-Friese-Straße"
- After 600 m turn right into "Michael-Faraday-Straße"
- Find Fraunhofer IKTS after 20 m

Editorial notes

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