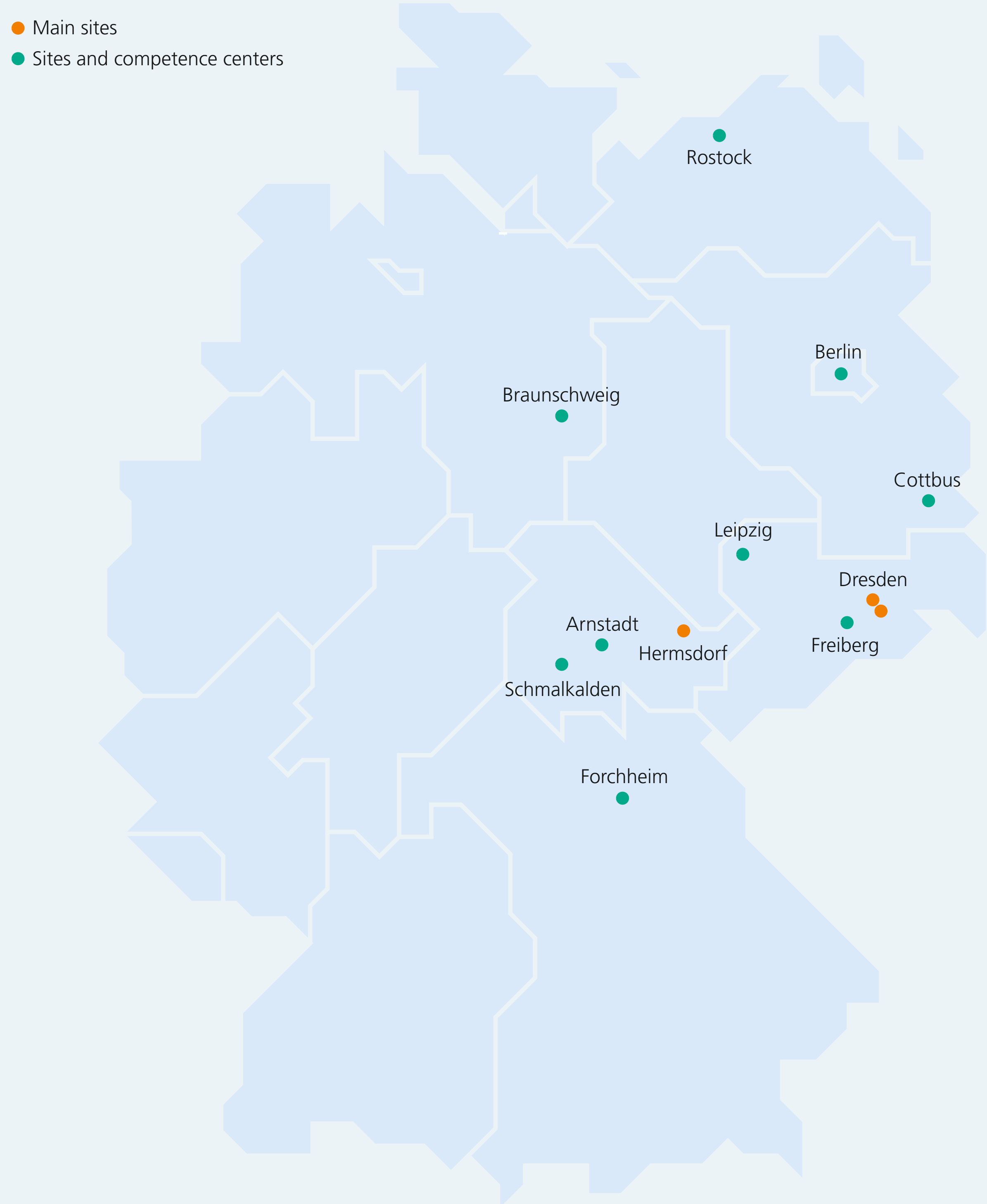
Fraunhofer IKTS

Fraunhofer Institute for Ceramic Technologies and Systems IKTS

Annual Report 2021/22

30 years Fraunhofer IKTS

Hello Future



Fraunhofer IKTS sites.

Cover

Laser-perforated transparent ceramics for sensor and optoelectronic applications.

Annual Report 2021/22

Fraunhofer Institute for Ceramic Technologies and Systems IKTS

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Foreword

30 years of IKTS.

Dear friends and partners of IKTS,

this time we look back not just on another successful year, but on our 30-year-long success story. Fraunhofer IKTS started out in 1992 with 84 employees and an operating budget of 8 million DM. IKTS was created from the renowned Central Institute for Solid State Physics and Materials Science ZFW of the Academy of Science in Dresden. Prof. Waldemar Hermel, founding director of IKTS, managed to assemble an outstanding team – a boon to our institute to this day. I was very fortunate to find the institute so well-positioned when I took over in 2004. At that point, the number of staff had already grown to 150 and the operating budget had reached approx. € 10 million.

This was followed in 2010 by the important milestone: the merger with the Hermsdorfer Institut für Technische Keramik e. V. (HITK). Successor to East Germany's most important manufacturing site for technical ceramics (Kombinat Keramische Werke Hermsdorf), HITK was founded in 1992 as an independent, business-friendly research institute by Dr. Bärbel Voigtsberger, who also assembled a great and highly successful team. The merger brought together two institutions that were basically meant for each other. The manufacturing Kombinat in Hermsdorf and the researchers from Dresden had been cooperating in an ideal partnership reaching back as far as the times of East Germany. IKTS then took another important step in 2014 by integrating the Dresden part of Fraunhofer Institute for Nondestructive Testing IFZP. The field of testing and monitoring technologies and associated digitization technologies across the complete product lifecycle offers enormous innovative potential in processes and products while striving to achieve sustainable economic development.

The integration measures mentioned here have done a lot to help Fraunhofer IKTS grow organically. They also meant that we were able to implement our strategy of covering the complete value chain of ceramic engineering, from the source material to the system and back (recycling). Thanks to this strategy, we can be a valuable partner for the manufacturers and users of technical ceramics.

In the recent reporting period, we continued to reach new heights, with a total budget of € 83,3 million and an operating budget of € 66 million. To our now more than 800 IKTS employees and to you as our partners: I cannot thank you enough. We were able to reach a total rate of return (third-party funds) of more than 87 %. Working with you, we were particularly successful in applying for and obtaining public funding. This also means that our direct industry income rate (rhoWi), as a percentage, has seen a moderate decline and stands at slightly below 30 %. We will be focusing more on increasing this rate in the future. We think it particularly noteworthy that we were able to invest a staggering € 18 million in our equipment. This benefited all IKTS departments, and therefore particularly you as our partners, since you can keep counting on top-level infrastructure when implementing projects with us. Please continue to use our infrastructure in the future. We look forward to talking with you to identify new ideas for projects.

You can find key highlights and developing trends from our business divisions in this report. In this context, I would personally like to point to the recent acquisition of the transparent ceramics manufacturing from CeramTec-Etec GmbH, well-known for their "PERLUCOR®" brand. Thanks to this step, we can unite our years of research knowledge with fresh manufacturing know-how, to develop higher performing and cost-optimized products. Furthermore, it helps us safeguard Germany's existing technological advantage as a location for business and investment. The production line is currently being set up in Hermsdorf, overseen by Dr. Sabine Begand. Hermsdorf is also the place where our Technical Center 4 went into operation. It is home, first and foremost, to our $Na/NiCl_2$ battery development work. Also, thanks to the strong support of the State of Thuringia (TMWWDG), we were able to acquire and develop our new site in Arnstadt. Under the management of Dr. Roland Weidl, a strong team of 30 employees got together in Arnstadt. The State of Thuringia contributed more than € 30 million over the past two years for the Arnstadt site alone, where we will continue to bolster our research and development resources on Li-ion batteries and hydrogen technologies, coordinated closely with our activities in Dresden. In Saxony, Dr. Mareike Partsch has led a successful effort to strongly expand operations in our Fraunhofer Technology Center High Performance Materials THM, operated in collaboration with Fraunhofer IISB and focusing specifically on battery recycling. We are glad that Prof. Martin Bertau of TU Bergakademie Freiberg (TUBAF) agreed to support these activities and work with IKTS long-term. We intend to deepen our very fruitful collaboration with TUBAF even more in the future. This will also help to keep strengthening the subject area of the circular economy, including recycling and water resources management, which is of growing importance for IKTS.

For a particularly successful example, look no further than to a project from our department led by Jörg Adler: In collaboration with ESK-SIC GmbH, his team developed a new SiC recycling process, which significantly diminishes the amount of energy required to manufacture SiC, thus reducing the associated CO_2 emissions by more than the factor 5. If this process were to be used globally, more CO_2 could be saved worldwide than is emitted by the whole of Germany's ceramics industry (more than 2.6 million metric tons CO_2 p.a.) – an example of economics and ecology working together optimally.

I hope you will enjoy perusing this report and find it a source of inspiration for new project ideas. We are always available for a conversation and the whole team of IKTS is looking forward to our cooperation.

Yours,

Alexander Michaelis
April 2022

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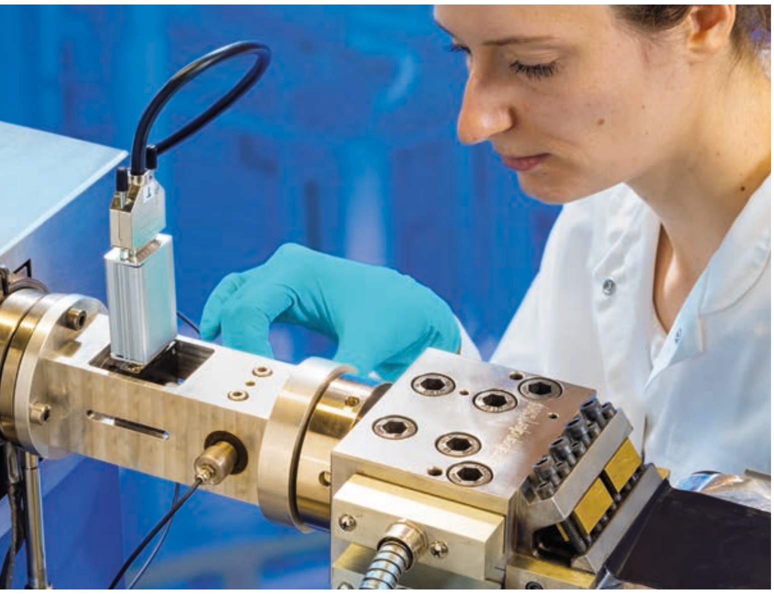
Fraunhofer IKTS in profile

Portrait

For more than 30 years, Fraunhofer IKTS has been demonstrating the potential of ceramic materials in 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 within the processes 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.

With state-of-the-art equipment on more than 40,000 m² of floor space, competent staff and result-oriented research management, we offer 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 the necessary manufacturing processes at the highest level. 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 inspection systems for the condition monitoring of manufacturing facilities and thus ensure optimal product qualities, low inspection 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 development.

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, reproducible and resource-friendly research outcomes. 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.

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

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 Filter Ceramics
- Nitride Ceramics and Fiber Composites

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. habil. Mathias Herrmann
- Thermal Analysis and Thermal Physics**
- Heat Treatment
- Ceramography and Phase Analysis
- Powder and Suspension Characterization**

Environmental and Process Engineering

Nanoporous Membranes
Dr. Hannes Richter
- Zeolite- and Carbon Membranes
- Polymer- and Mixed Matrix Membranes
- Membrane Prototypes
- Functional Carrier Systems and Layers

High-Temperature Separation and Catalysis
Dr. Ralf Kriegel
- 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
- Membrane Process Technology and Modeling
- Technical Electrolysis and Geothermal Energy
- Reaction Engineering Water

Chemical Engineering
PD Dr. habil. Matthias Jahn
- Modeling and Simulation
- Process Systems Engineering

Sites and Competence Centers of Fraunhofer IKTS

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

- Site Forchheim, Bavaria
- 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 research group, Rostock, Mecklenburg-Western Pomerania
- Biological Materials Analysis research group at Fraunhofer IZI, Lipsia, Saxony
- Cognitive Material Diagnostics project group, Cottbus, Brandenburg
- Fraunhofer Center for Smart Agriculture and Water Management AWAM, Porto, Portugal
- Site Berlin, Berlin
- Battery Innovation and Technology Center BITC, Arnstadt, Thuringia
- Industrial Hydrogen Technologies Thuringia WaTTh, Arnstadt, Thuringia
- Competence Center Tape Casting, Hermsdorf, Thuringia
- Pilot Center for Powder Synthesis and Extrusion, Hermsdorf, Thuringia
- Research and Development Center for Transparent Ceramics, Hermsdorf, 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 Director / Administrative Manager	Dr. Michael Zins
Deputy Institute Director / Marketing and Strategy	Prof. Dr. Michael Stelter
Deputy Institute Director / Site manager Hermsdorf	Prof. Dr. Ingolf Voigt
Deputy Institute Director / Site manager Dresden-Klotzsche	Dr. Christian Wunderlich

- Quality Assurance Laboratory** and Mechanics Laboratory
- Chemical and Structural Analysis
- Hardmetals and Cermets

Correlative Microscopy and Materials Data
Prof. Dr. Silke Christiansen
- Correlative Microscopy

Energy Systems

Materials and Components
Dr. Mihails Kusnezoff
- Joining Technology
- Materials for Printed Systems
- Ceramic Energy Converters
- High-Temperature Electrochemistry and Functionalized Surfaces

System Integration and Technology Transfer
Dr. Roland Weidl
- System Concepts
- Stationary Energy Storage Systems
- Thin-Film Technologies
- Industrial Data Concepts
- Smart Machine and Production Design
- Hydrogen Technologies

Energy Storage Systems and Electrochemistry
Dr. Mareike Partsch
- Electrochemistry
- Cell and Process Development
- Recycling and Green Battery

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

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

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

Fraunhofer IKTS in figures

Budget and income

With € 83.3 million, the total budget of Fraunhofer IKTS exceeds the previous year's level by € 7.7 million. At € 17.7 million, the volume of investments has increased once again, by € 4.5 million. Thanks to strong support from several federal states, we were able to invest € 7.6 million in Thuringia while expanding our infrastructure in Saxony and Bavaria for another € 10 million. We are happy to report that we were able to implement the majority of our strategic procurement processes despite the Covid-19 pandemic. More equipment will be taken into operation in 2022.

All in all € 58.9 million of external income was raised. On account of the difficult situation faced by industry partners due to the Coronavirus pandemic, industry income has shrunk again by € 2.2 million, standing at € 18.5 million. We are pleased that approx. 45 % of jobs still come from small and medium-sized companies. Our industry partners placed orders to the total amount of € 3.3 million in the states of Saxony and Thuringia. All in all however, the pandemic still leads to a significantly reduced project demand and to many launch dates being pushed back. Fortunately, the fields of activity and project groups managed to continue through strategic projects of the federal and regional governments and prepare the ground for an auspicious relaunch of the topics after the pandemic. The infrastructure was optimized in nearly all areas.

Jobs from outside Germany shrunk disproportionately by 20 %, to € 3.6 million. Strong partner countries, such as China and Austria, were particularly affected, with orders and assignments receding by up to 30 %. The volume is distributed among 35 countries. The industry income from Great Britain shrank by more than 85 %. It is important to differentiate between the effects of Brexit and those of the pandemic. In total, income from Europe rose from € 4.7 million to € 5.9 million. The increased EU project volumes played a major part in this development.

The disparate costing approaches applied by the various funding bodies constitute another challenge. These disparities lead to insecurity when determining billable costs and financial planning. In the medium term, the Fraunhofer-wide introduction of SAP's ERP system is expected to alleviate this issue. The new system was taken into operation on January 10, 2022. Customers and suppliers are asked to take part in this unique digitizing initiative of a research institution. As expected, the changeover of our systems constitutes a big challenge for Fraunhofer and its partners. IKTS is well-positioned to solve the existing challenges as soon as possible. Together with our partners, we will swiftly complete all tasks.

Human resources development

A total of approx. 800 staff members work at the various IKTS sites. The institute's family-friendly structure allows many young mothers and fathers to work part-time if they wish. Thanks to this structure, it has been possible to adapt staff capacity dynamically to suit the requirements of project tasks. Despite the pandemic, the employment coefficient rose by approx. 5 %. For increased comparability, the different groups are represented as full-time equivalents (FTE) in the figure. The number of scientists has increased by 35 positions and now stands at 291. Also, the number of technical assistants has increased to 315.

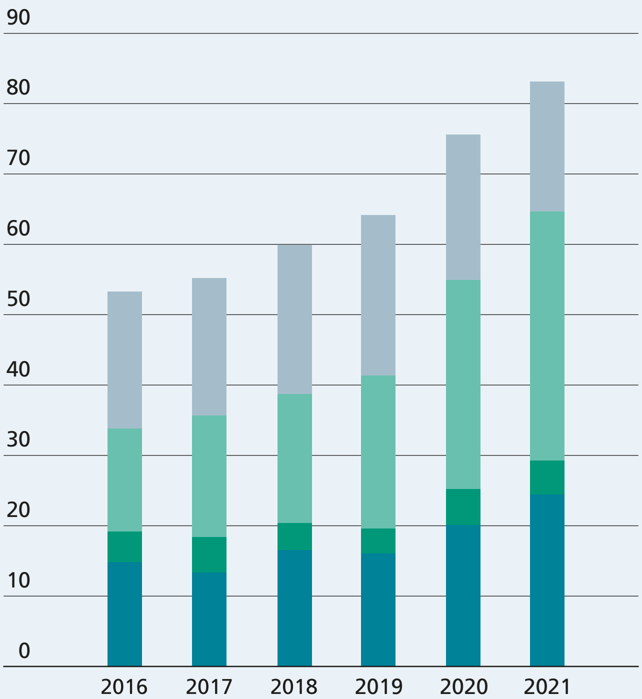
Doctoral theses continue to be written by employees in the context of PhD positions focused on a particular area (22), as well as in the context of project-related activities close to industry. In spite of working restrictions due to Covid-19 rules, the employment of students and trainees was roughly equal to that of 2020. It was possible to organize all IKTS lectures as planned.

Fraunhofer IKTS as an employer remains well positioned in the marketplace. However, finding and hiring staff in the scientific and administrative spheres will become one of the great challenges of the coming years.

Expanding the infrastructure

The infrastructure will be expanded in the context of long-term projects and with the strong support of the federal states of Saxony, Thuringia, Lower Saxony and Bavaria. The new sites are presented in detail in the annual report. Cooperation with other Fraunhofer institutes, universities and companies in various project centers remains a central plank in our strategy and will be strengthened further in future. The systemic approach will be pursued in all areas.

Revenue (in million euros) of Fraunhofer IKTS for the budget years 2016–2021

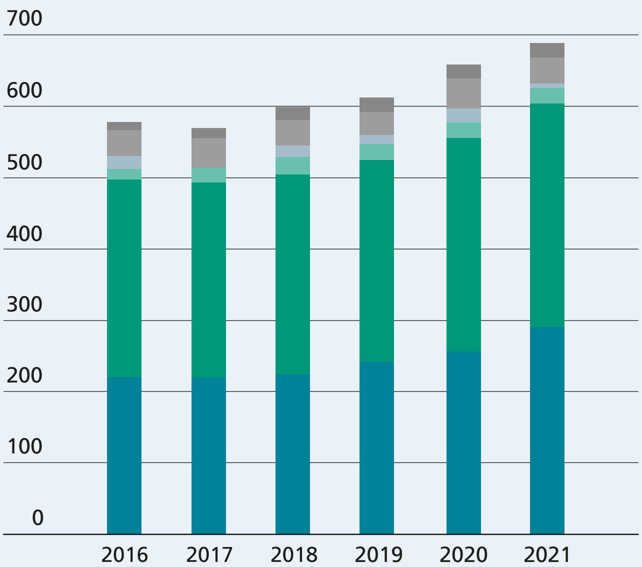


	2016	2017	2018	2019	2020	2021
Industrial revenue	19.6	19.6	21.2	22.9	20.7	18.5
Public-sector revenue	14.8	17.3	18.4	21.8	29.8	35.5
EU and other revenue	4.4	5.1	3.8	3.5	5.2	4.9
Institutional support	14.8	13.5	16.6	16.1	20.1	24.4
=	**53.6**	**55.5**	**60.0**	**64.3**	**75.8**	**83.3**

- Industrial revenue
- Public-sector revenue
- EU and other revenue
- Institutional support

Personnel developments at Fraunhofer IKTS

Number of employees 2016–2021, full-time equivalents, personnel structure on December 31 of each year



	2016	2017	2018	2019	2020	2021
Apprentices	11	14	18	20	19	20
Student workers, trainees, undergraduate students	36	40	36	32	42	36
Part-time and contract workers	19	1	16	13	19	6
PhD candidates	15	21	25	22	22	22
Employees with university degrees and technicians	276	273	280	284	299	313
Scientists	220	220	224	241	257	291
=	**577**	**569**	**599**	**612**	**658**	**688**

- Apprentices
- Student workers, trainees, undergraduate students
- Part-time and contract workers
- PhD candidates
- Employees with university degrees and technicians
- Scientists

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.

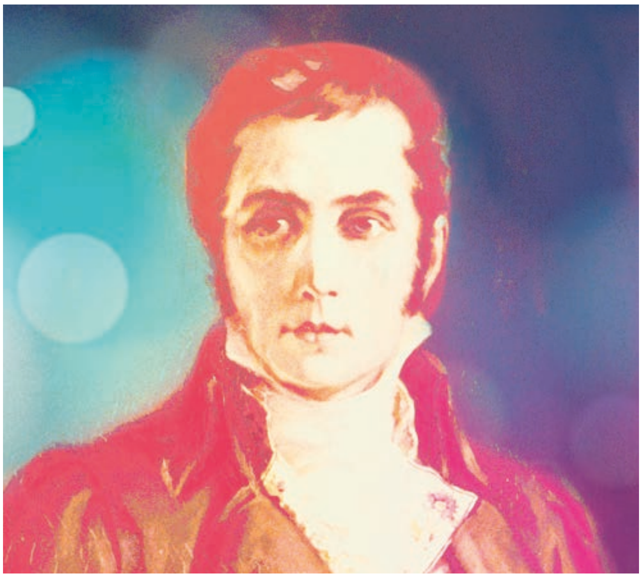
The Fraunhofer-Gesellschaft's interdisciplinary research teams turn original ideas into innovations together with contracting industry and public sector partners, coordinate and complete essential key research policy projects and strengthen the German and European economy with ethical value creation. 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.

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.



Joseph von Fraunhofer.

Retrospective

Due to the worldwide Coronavirus pandemic, the Fraunhofer IKTS presented its research and services to the general scientific public in 2021 mainly within the framework of digital trade fairs and event formats.

February 3, 2021
NDT4INDUSTRY – Online seminar series

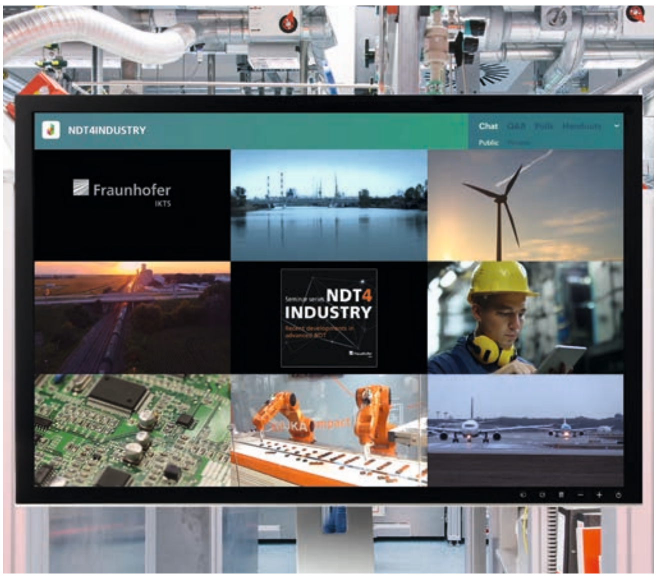
(Image on the left)

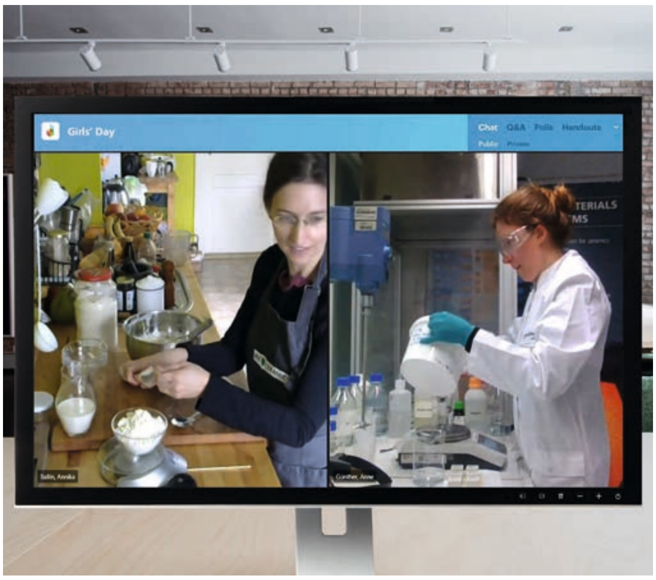
In the online seminar series NDT4INDUSTRY, Fraunhofer IKTS again presented new developments in the field of non-destructive testing (NDT) and their benefits for industry in 2021. To start off the year, Christoph Sander presented a 4-point bending system in February, which can be used to effectively characterize the influence of mechanical stresses on microelectronic components. In April, Dr. Frank Schubert dedicated his seminar to EFIT simulations, which are used for optimizing probes and ultrasonic equipment based on simulation. A special installment was in store for the audience in May: Together with the Institute for Lightweight Engineering and Polymer Technology (ILK) of TU Dresden, Dr. Jörg Opitz presented results of the joint project "robust evp 4.0". The focus was on hybrid metal composite structures, their development, production, non-destructive testing and necessary steps to introduce these technologies to industry. In September, Dr. Malgorzata Kopycinska-Müller and Ralf Schallert demonstrated possibilities of optical coherence tomography (OCT); a scanning method that inspects objects and processes in a non-contact, non-destructive and fast way. In November, Dr. Bernd Köhler presented unconventional ultrasonic methods developed for difficult inspection tasks. The successful format will be continued. Please find current topics and dates at www.ndt4industry.com.

April 22, 2021
Girls' Day

(Image on the right)

Our digital Girls' Day program taught the participating girls a lot about advanced ceramics and working in the lab. During a live feed from the lab and kitchen, around 20 female students learned about the similarities between baking and making ceramics. In the subsequent open talk with female lab technicians and IKTS scientists, the girls were able to ask their questions about everyday working life at a Fraunhofer institute.





April 23, 2021
Böttger Badge for Prof. Ingolf Voigt
(Image on the left)

As part of the virtual annual conference of the German Ceramic Society e. V. (DKG), Prof. Ingolf Voigt, deputy institute director and Hermsdorf site manager of Fraunhofer IKTS, was awarded the Böttger Badge. The Böttger Badge has been awarded by the DKG since 1929 for outstanding services to the interaction of industry, science and teaching. In his function as president of the DKG, institute director Prof. Alexander Michaelis congratulated the award winner: "The award is highly deserved. Prof. Voigt is an outstanding scientist who is known worldwide for his work on ceramic membrane technology and for the entire field of structural and functional ceramics."

May 4, 2021
Trade fairs and digital formats
(Image on the right)

Fraunhofer IKTS presented itself at numerous digital trade fairs in 2021: For example, Dr. Hannes Richter as well as Dr. Matthias Jahn and Gregor Herz presented the topics "High-performance separators: carbon membranes for H_2 and CO_2 separation from gas streams" and "High-temperature electrolysis – a key technology for the green chemical industry", respectively, in so-called "live pitches" at *ACHEMA Pulse*. At the digital *Sensor and Test* fair, IKTS showed its know-how in the fields of ultrasonic transducers, printed magnetoresistive sensors as well as ceramic pressure sensors for high-temperature applications.

Fraunhofer IKTS was also represented at on-site trade shows in 2021, including *Productronica*. Here, the focus was on photoimageable thick-film pastes for the 5G network, power electronics, additively manufactured components and ceramic solutions for sensors. Despite the ongoing pandemic, the trade fair industry, and IKTS, remain optimistic about the future. Trade fair organizers are clearly focused on physical events adhering to the highest levels of hygiene standards. For 2022, IKTS is planning to be present at *HMI*, *IFAT, Control, JEC World, FILTECH* and *Sensor and Test*.

May 7, 2021
ThWIC – Thuringian Water Innovation Cluster in the final round for cluster competition

With the Clusters4Future initiative, the German Federal Ministry of Education and Research (BMBF) provides targeted funding for regional clusters that use innovations from cutting-edge research to tackle challenges in important fields of the future. In May, the "Thuringian Water Innovation Cluster" (ThWIC) was among the 15 applications chosen out of 117 that can now enter a conception phase, with funding secured. Together with more than 20 partners, including the coordinating Friedrich Schiller University Jena, Fraunhofer IKTS will scientifically illuminate the topic of water in a multifaceted way within ThWIC, considering both the natural and social sciences perspectives. Up to seven finalists will then be selected in spring 2022, and their project ideas will be funded for up to nine years.

Visit at Fraunhofer THM Freiberg. F.l.t.r.: Prof. Klaus-Dieter Barbknecht (TUBAF), Dr. Jochen Friedrich (Fraunhofer IISB), Prof. Alexander Michaelis (Fraunhofer IKTS), Dr. Mareike Partsch (Fraunhofer IKTS/THM), Science Minister Sebastian Gemkow, Prof. Jens Gutzmer (HZDR), Prof. Johannes Heitmann (TUBAF/Fraunhofer THM) and Prof. Martin Bertau (TUBAF/Fraunhofer IKTS).

May 10, 2021
Honorary certificate of Hermsdorf for Prof. Voigt

On May 10, Prof. Ingolf Voigt was awarded the honorary certificate of the city of Hermsdorf. As site manager of IKTS Hermsdorf and board member of TRIDELTA CAMPUS HERMSDORF Prof. Voigt had served the welfare and reputation of the city of Hermsdorf in a special way, said Mayor Benny Hofmann.

June 7 | September 7, 2021
Visits at Fraunhofer THM
(Top image)

On June 7, Saxony's Science Minister Sebastian Gemkow visited the Fraunhofer Technology Center High-Performance Materials THM in Freiberg. In the course of a working session, the state minister learned about current research on battery recycling and innovative semiconductor materials for improved power electronics. In September, a delegation of European parliamentarians visited Fraunhofer THM and sought an exchange on the topic of batteries in the context of the new EU battery regulation as part of the European Green Deal. This visit was accompanied by local media highlighting the innovative work being done in Saxony.

July 6, 2021
abonocare® online conference

How to establish a sustainable and efficient nutrient recycling system based on organic residues, such as liquid manure, sewage sludge or organic waste? About 100 participants at the abonocare® online conference, from industry, science and politics, learned about novel recycling and closed-loop technologies from the abonocare® growth core. In addition to technologies for phosphorus and nitrogen recycling, legal framework conditions, operator models and application potentials of novel fertilizer products were also highlighted. In the abonocare® growth core, companies and research institutions are jointly developing technologies for the intelligent and sustainable nutrient recycling of organic residues. Their goal is an efficient circular economy in which waste is turned back into resources.

July 12, 2021
Kickoff for WaTTh in Arnstadt
(Bottom image)

The Battery Innovation and Technology Center BITC as part of Fraunhofer IKTS at Erfurter Kreuz will be expanded by a

"Hydrogen Application Center for Industrial Hydrogen Technologies Thuringia" (WaTTh). The State of Thuringia is supporting the project with € 6.9 million over three years. Thuringia is providing an additional € 3.4 million for the purchase of a building in which IKTS researchers can develop and test hydrogen technologies. Synergistic effects with the energy storage production technology 4.0 already being developed at BITC are to be exploited here. The main focus is on hydrogen production using large-scale stack technology and the industrial use of hydrogen.

August 2–6, 2021
Sensor Space Summer School

As the first event of the Tridelta Campus Sensor Space, the Sensor Space Summer School of Fraunhofer IKTS welcomed participants at the Hermsdorf Vocational School. The goal of the Summer School was to teach basic concepts of Industry 4.0 and to spark interest in STEM subjects (mathematics, computer science, natural sciences, technology). Students from grades 7 to 11 gained insights into programming, plant engineering and automation during the one-week vacation course. Microcontrollers, sensors and a programming interface for beginners were used.

August 18, 2021
2nd place at the SET4FUTURE Innovation Award

The "Sonic Rail Explorer (SRE)" is a mobile ultrasonic testing device for railroad tracks which was awarded 2nd place at the SET4FUTURE Innovation Award 2021 of the Saxon rail technology cluster Rail.S. The joint development of Vossloh Rail Services GmbH, Fraunhofer IKTS and WOLFRAM Designer und Ingenieure is used in the inspection of railroad rails and switches to detect defects and enables networked inspection data management.

August 27, 2021
Senodis is transfer project of the month of IHK Dresden

In the July/August issue of its business magazine ihk.wirtschaft, IHK Dresden presents Senodis Technologies GmbH as its transfer project of the month. Since 2014, research has been conducted at Fraunhofer IKTS on how metal components can be marked in such a way that the marking survives even intensive processing steps and the components can thus be recorded seamlessly along the process chain. The result of these efforts is Ceracode® marking, which has been marketed by the specially incorporated Senodis Technologies GmbH since 2019.

September 10, 2021
1st prize for CoMo shirt measuring vital functions

Under the motto "Design & Research vs. Pandemics", design students and Fraunhofer researchers worked together for a week at the Summer Camp of the Fraunhofer network "Science, Art and Design" in September 2021 to find innovative concepts for detecting pandemics at an early stage and overcoming them. On September 10, they presented their concepts to a jury of experts. The first prize of € 5000 was won by a team of four students, IKTS researcher Sascha Balakin and Fraunhofer ENAS researcher Julia Wecker. They designed and tailored a wrap-around shirt that contains sensors to measure ECG, lung function and temperature, as well as a camera to observe the surface of the skin. Energy-harvesting technologies, among others, generate the power for these functions. The Fraunhofer Summer Camp is held every year, centered around a different topic each time.

September 16, 2021
Inauguration of the PIZ at the Hermsdorf site

(Top image)

The "Pilot Center for Powder Synthesis and Extrusion PIZ" was ceremonially inaugurated after a two-year construction period and adds approx. 600 m² floor space to the Fraunhofer IKTS properties in Hermsdorf. The new building is home to the research topics of stationary energy storage and ceramic membranes for material separation. The construction was funded by the federal government and the Free State of Thuringia with € 6.4 million. Minister President Bodo Ramelow, economics minister Wolfgang Tiefensee and Fraunhofer board member Andreas Meuer came to Hermsdorf for the opening ceremony.

September 16, 2021
Honorary colloquium for Dr. Bärbel Voigtsberger
(Top image)

On the occasion of her 70th birthday, an honorary colloquium for former institute director Dr. Bärbel Voigtsberger took place on September 16, 2021 in the Hermsdorf town hall. The organizers secured Daniel Störzner (LCP Laser Cut Processing), Dr. Meinhard Schwefer (thyssenkrupp) and Michael Philipps (Endress+Hauser) as speakers. The subsequent get-together provided an opportunity for many conversations with former employees and companions.

September 23, 2021
NDT on Tour
(Right column image)

In order to make current developments in the field of non-destructive testing and condition monitoring accessible and tangible despite trade show cancellations, the concept of the NDT tour bus was developed at the Fraunhofer IKTS site in Dresden-Klotzsche. For this purpose, a van was equipped with measuring instruments and demonstrators and these were presented at the DGZfP training center in Berlin on September 23, 2021. The offer received much attention and shall be repeated at regular intervals. If you are interested in visiting our tour bus, please do not hesitate to contact us.

October 12, 2021
Early Morning Science with Fraunhofer: focus on water technologies

Water technologies are the key to a future-proof energy and food industry – that is the firm belief of Dr. Burkhardt Faßauer, department head of Circular Technologies and Water at Fraunhofer IKTS. At the seventh media breakfast "Early Morning Science with Fraunhofer" of the Fraunhofer Institute Center Dresden, Dr. Faßauer presented new water technologies and closed-loop concepts of IKTS, with which wastewater from municipalities, energy plants or mining can be treated more efficiently to obtain clean drinking water. At the same time, considerable value-added potential can be tapped by producing targeted fertilizers from residual materials, recovering metals and other raw materials, and producing hydrogen for electricity and heat.

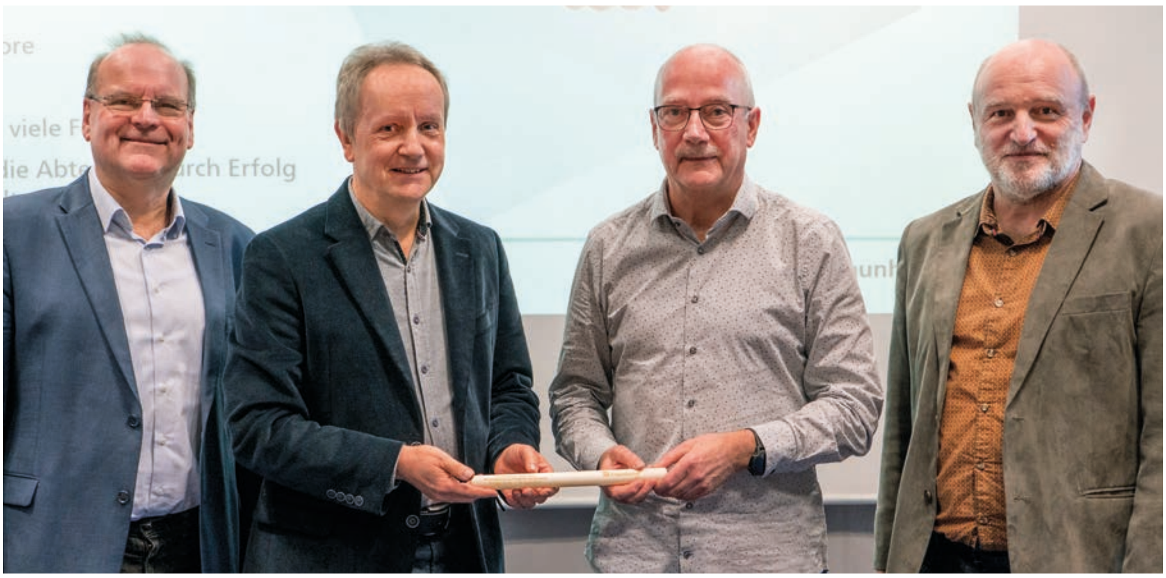
December 8, 2021
Silicon Science Award 2021 for Nadja Steinke
(Image on the right)

For her dissertation, "Plasmonic sensor for the on-site detection of diclofenac molecules", Dr. Nadja Steinke was awarded the Silicon Science Award 2021 at the 15th Dresden Sensor Symposium. Her work centers on the development of a plasmonic sensor system for the detection of drug residues, such as diclofenac, in wastewater. The goal is that in the future on-site analytics can monitor compliance with limit values directly in wastewater treatment plants and thus help to make wastewater treatment more efficient.

January 19, 2022
Honorary colloquium for Dr. Hagen Klemm
(Bottom image)

Since the founding of Fraunhofer IKTS in 1992, Dr. Hagen Klemm has worked at the institute as a scientist, group leader, department head and valued colleague. His topics at IKTS included ceramic matrix composites (CMC), environmental barrier coatings (EBC), silicon nitride/silicon carbide as well as high-temperature characterization. His retirement from active service was marked with an honorary colloquium. The IKTS team and companions from outside the institute paid tribute to the milestones of his research at Fraunhofer IKTS and reviewed the long-standing and unifying collaboration in projects.

F.l.t.r.: Prof. Alexander Michaelis, Dr. Tassilo Moritz, Dr. Hagen Klemm and Dr. Michael Zins.



Highlights from our business divisions

In focus
page 22–29

Industrial transformation, circular economy and sustainable energy supply 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.

Materials and Processes
page 30–33

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 34–38

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.

Environmental and Process Engineering
page 39–42

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.

Water
page 43–47

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, both to make process technology more efficient and reduce process costs.

Non-Destructive Testing and Monitoring
page 48–51

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.

Electronics and Microsystems
page 52–57

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.

Materials and Process Analysis
page 58–61

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.

Mechanical and Automotive Engineering
page 62–63

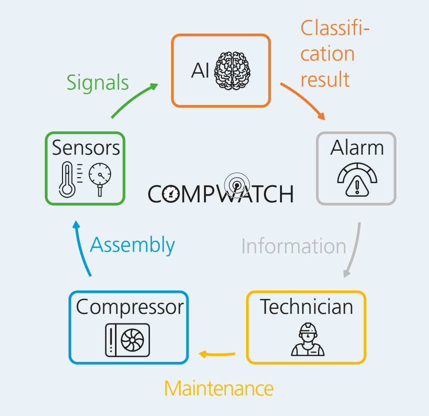
High performance ceramics are key components for plant engineering and construction as well as automotive engineering. Because of their outstanding properties, they often constitute the only viable solution. The business division traditionally provides wear parts and tools as well as components from high performance ceramics, cemented carbides and cermets 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 64–68

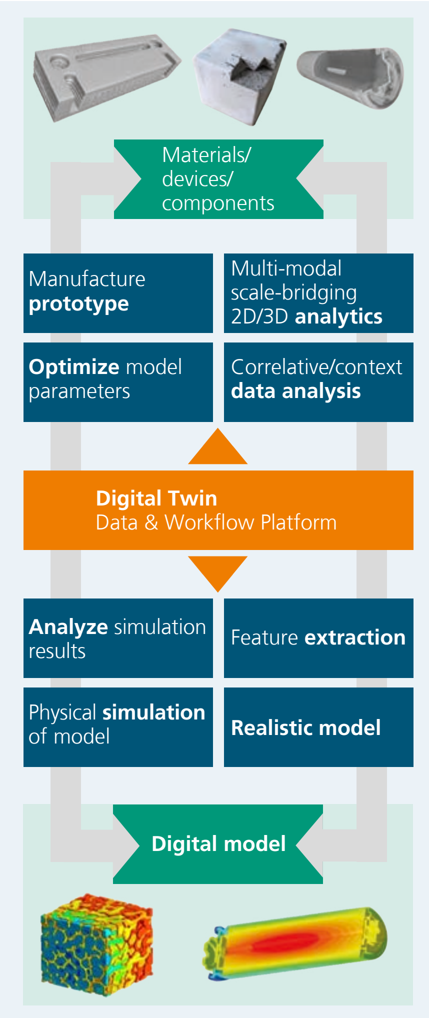
Fraunhofer IKTS makes use of the outstanding properties offered by ceramic materials with regard to the development of dental and endoprosthetic implants as well as surgical instruments. In our certified labs, we use the very best equipment to examine the interactions between biological and artificial 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.

Digital services in analytics and non-destructive testing at Fraunhofer IKTS

Prof. Silke Christiansen, Dr. Christian Wunderlich



Approach in AI-based condition monitoring of compressors.



Linking material and meta-data from analysis with modeling and simulation to establish a digital twin.

Challenge

Digital transformation will bring enormous changes to the scientific work of Fraunhofer IKTS. Not only will the latest methods of machine learning and pattern matching have to be integrated into existing analytics processes and procedures. Digital tools and bona fide business models need to be developed as well. At IKTS, research data are by nature very heterogeneous: Material, process and environmental data need to be collected and processed according to the FAIR (findable, accessible, interoperable, reusable) principle. Only data collected in this way, i.e. in a structured and systematic manner, can be evaluated, linked or used as the basis for generating synthetic data and models, allowing to reach new levels of value creation. At the same time, scientists cannot readily outsource the tasks of data analysis and AI projects, since this requires a common language and understanding between specialists and data scientists.

Implementation

Living up to these new challenges requires novel, cross-disciplinary teams consisting of materials scientists, natural scientists, engineers, IT specialists and data scientists. Such teams are currently being established by IKTS across several sites, e.g. in Cottbus (research group Cognitive Material Diagnostics, KogMatD), Forchheim and Arnstadt (Battery Innovation and Technology Center BITC). The fact that digital methods can work independently of site or location is a crucial advantage, allowing for agility and the efficient use of resources. For instance, computing resources and storage space can be made available from any of the institute's sites if suitable virtualization and cloud strategies exist to enable all IKTS business divisions and sites to use a combination of analytics and modeling, simulation, automation, as well as qualitative and statistic data evaluation.

Another factor is equally important: Material researchers and data experts at IKTS need to come to a shared understanding of digital value creation. They need to know and learn to comprehend technical terms, challenges and methods of the respective subdisciplines, be that materials science, engineering or data science. Moreover, digital methods also mean completely new ways of working for the IKTS research groups. This includes concepts, such as design thinking, rapid prototyping and agile teamwork.

Early AI elements are already part of the work routines of IKTS. Specially trained models are used to process large datasets from acoustic condition monitoring, while X-ray and microscopy data are improved and assessed with the help of image analysis algorithms. Sensor data from camera images and ultrasonic devices are merged. Automated literature analyses or the evaluation of past projects, the interlinking of data from simulations and experiments all lead to increased efficiency and improved quality. Even today, the equipment of IKTS makes use of highly specialized algorithms to optimize CAD files before they are processed.

The site of Forchheim is set to become a trailblazer for context microscopy and spectroscopy, in this context developing further, for IKTS as a whole, analytical measurement modalities, some of them absolutely unique, and preparing multimodal workflows – from data collection to statistical evaluation to visualization.

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Examples of business models

At the core of the digital offering of IKTS with regard to correlative microscopy are workflows that link individual databases with associated work steps. These workflows are run centrally on a high-performance computing infrastructure (HPC). On one side, the cluster interlinks the multitude of heterogeneous, multimodal and cross-scale data from individual microscopic processes. On the other side, Fraunhofer IKTS employees of all sites, but also external customers and project partners, gain access to this workflow engine. An intuitive user interface allows to store data in a structured way, work on quantitative data analyses or visualization, or merge data that were collected with multiple modes to create models, simulations or “digital twins”.

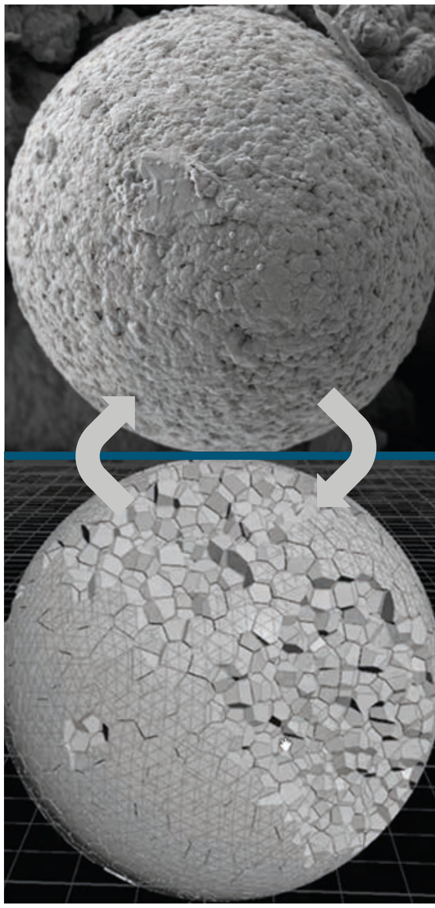
The workflow engine ensures that the data management adheres to FAIR principles and enables storing meta- and process data or sample IDs. The system also allows to integrate and feed external data processing tools, such as software for data compression, the segmentation of image data, or finite-element solvers.

For instance, microscopy data – numerous synthetic datasets based on photorealistic, three-dimensional renderings – have served as training data for machine learning (ML) algorithms to further develop battery materials. The figure on the right shows an electron microscopic image of a particle (of 20 µm diameter) from a nickel-cobalt-manganese alloy as used in cathode films.

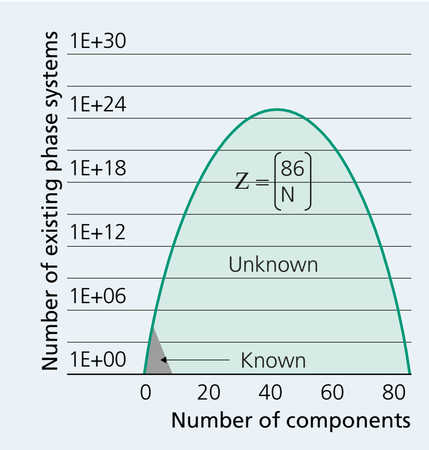
Data accrued or existing with industrial clients constitute another domain where IKTS intends to create value in the future. These often very diverse material, process, testing and environmental data are generated across the complete value chain. Collecting, interlinking and evaluating them is a challenge that IKTS meets with more than just technology. By having their representative as the “product owner” participate in the agile process, clients of IKTS can optimize the development’s direct usefulness even during the project period. This works well in various project formats, virtually as well as with physical presence. For IKTS, this is a big step toward setting up and introducing agile processes and mastering the fast and continuous delivery of features.

Industrial clients in particular will be ever more closely involved in the project work of IKTS in the future. The institute will ramp up its integration into the big national and international data science platforms, such as “Material Digital”, and make increasing use of the open-source methods of software development that are typically found in the industry.

This is another area in which Fraunhofer IKTS can point to early successful projects with digital condition data: As part of the CompWatch project, funded by the German Federal Ministry of Education and Research (BMBF), researchers have developed a process for event-based maintenance intervals for compressor units. The self-learning system is embedded with the customer and “learns” what an intact compressor unit typically sounds like. Any anomalies in this operating sound indicate a potential damage. It is only in such an event that the system triggers a preventive maintenance assignment. It does not necessarily need to be familiar with all possible noises that can occur in a damage event, but it constantly learns and optimizes itself. As a result, based on typical operating sounds and using the ML algorithms developed by IKTS plus simple microphone equipment, operating costs and downtimes can be reduced significantly. Additionally, thanks to the collective intelligence gathered from all compressor units, maintenance companies will be able to prepare damage reports much faster and more efficiently in the future.



Top: Scanning electron micrograph of a 20 µm particle of a nickel-cobalt-manganese alloy. Bottom: photorealistic, synthetically computer-modeled particle as part of a training dataset for machine learning algorithms.

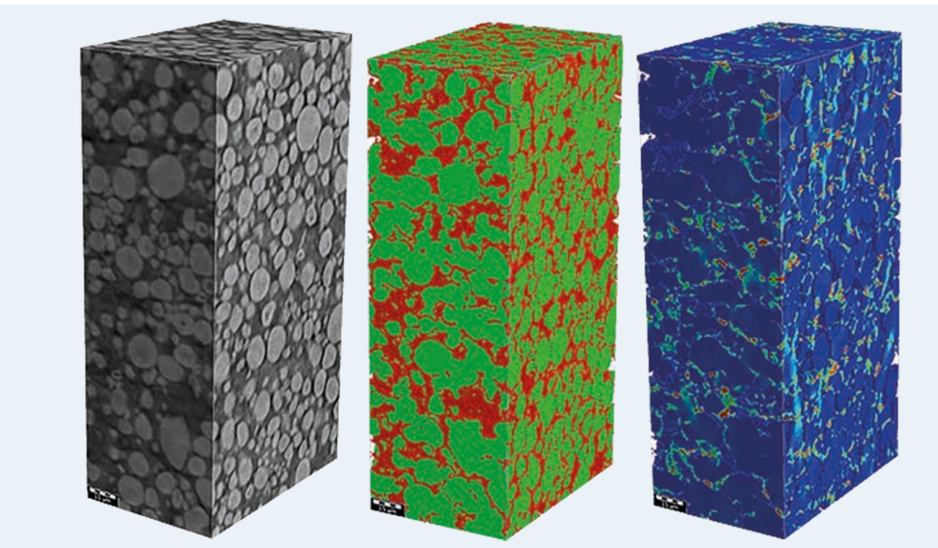


Constitution mountain, number of existing phase diagrams, each of which may have several compounds with fixed or varying composition. Only the part with gray background has been studied so far. [4]

Digital materials science at Fraunhofer IKTS

Dr. Mathias Herrmann, Dr. Wieland Beckert

Approaches to digitized materials science are set to become more and more comprehensive as advanced characterization techniques and new hardware and software for data retrieval, processing and analysis become available. This provides new instruments for developing and manufacturing materials and components based on a deep understanding of the relationships between structures and properties. Development and production processes can be performed much more effectively and reliably.



Example of a detailed microstructure analysis of a Li-ion battery electrode material: raw XRM data (left; 462 x 1367 x 702 voxels), derived synthetic voxel structure (middle), and strain field from mechanical analysis to derive the elastic tensor (right).

A mere look at the possibilities of material design based on stable chemical elements (top left figure) reveals the great potential afforded only when digitally supported materials development uses multiscale modeling to achieve the desired range of properties. Although the work has only just started [1–3], nearly 50 % of industrial companies put the optimization of production processes front and center of their digitization strategy, while 16 % say they focus on new materials [3].

The challenges lie in particular in the complexity of the processes, ranging from atomic sizes to microscopic and mesoscopic effects such as grain boundaries or displacements, to more macroscopic effects such as stress distributions due to temperature fields during manufacturing or machining. Adding to this, a major part of the relevant material properties depend not just on material composition and other, more accessible integral parameters, but also on rare and more extreme microstructural features, influenced by complex manufacturing conditions. Until now, such parameters have not been recorded in databases, so that in most cases only broad property intervals are available. With this kind of data basis, the possibilities of modeling and designing materials and components are very limited.

Providing production plants and whole manufacturing environments with novel instruments could open up completely new ways of developing and optimizing particularly complex processes, such as ceramic manufacturing.

If implemented successfully, this would amount to a revolution in the manufacture of ceramic components ("Digital services in analytics and non-destructive testing", p. 22). Fraunhofer IKTS drives these efforts on two levels at once – in the retrieval, collection, preparation and interpretation of the data, as well as in the development of new sensors and measuring concepts to record them. The synergistic effects from combining extensive know-how in ceramic materials and processes with non-destructive testing and monitoring skills bring significant and specific advantages.

As these remarks show, the tasks are intricate and come with challenges on various levels. Therefore, Fraunhofer IKTS is focusing on the

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structured retrieval of measured data and their improved preparation for downstream analyses, such as modeling, among other things. Furthermore, tools for evaluating data from production processes are being developed further to refine production monitoring and quality assurance. A broad range of statistical and AI-based methods are used for this purpose, adapted specifically for each process.

Before material properties can be modeled and production processes verified, it is necessary to gather material characteristics and statements on the microstructure in an effective way. The material and process characterization of IKTS supplies the appropriate infrastructure and know-how for these steps. These data need to be prepared purposefully ("AI-based quantitative microstructural analysis of ceramic materials", p. 60), with Fraunhofer IKTS placing particular emphasis on generating 3D structures with 3D-FIB and computer tomography and on the micromechanical characterization and determination of surface boundary properties ("Determining microscopically adhesive and cohesive material behavior", p. 58).

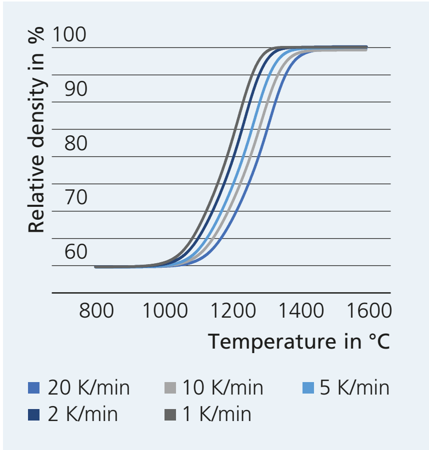
This is especially challenging when it comes to heterogeneous materials and material compounds, where the structural analyses of the correlation between structures and properties are correspondingly more complex. To meet this challenge, geometric voxel-based models for experimental or synthetic 3D structures are specifically generated and prepared for use in various program packages for numerical, mathematical and physical analysis. IKTS has comprehensive methods and software environments (GeoDict, COMSOL, ANSYS, Fluent, Open-Source FDM, FVM, FEM) at its disposal to analyze structural effects on the virtual images of materials and predict specific properties (bottom figure on the left). These are validated with real material data for special systems and offer numerous advantages in the form of quasi-virtual material analytics. What makes the work more efficient here is the ability to do away with creating and preparing samples and to facilitate access to material characteristics that are difficult to characterize experimentally. Moreover, it becomes possible to set defined and targeted material properties.

This process has already been applied successfully when describing the permeability of ceramic foams (Nusselt-Sherwood number, pressure loss coefficient), determining the effective resistances of conductive composites (pastes, Li-ion electrodes) or modeling the thermal conductivity in WC/Co materials ("Thermophysical properties of hardmetals as a function of microstructure", p. 59).

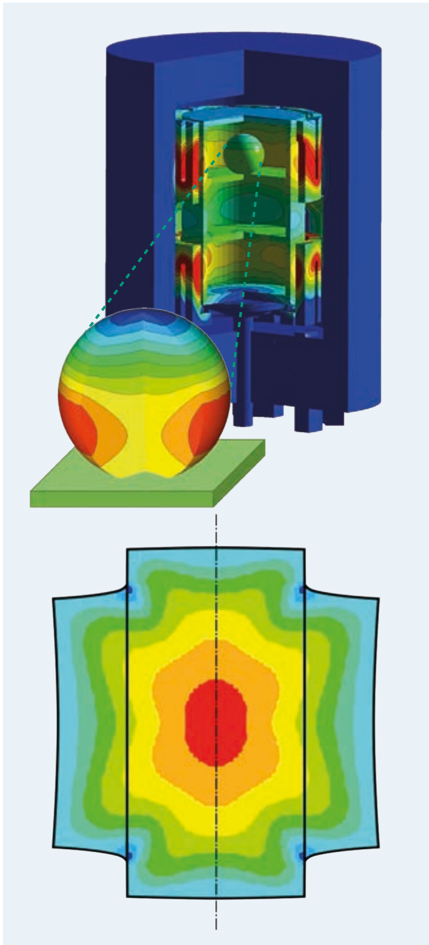
Fraunhofer IKTS also pursues a very similar approach with regard to simulating individual manufacturing processes. First, it involves developing methods to capture experimentally the required starting parameters. Second, these methods are also used for modeling, often in cooperation with our partners. The focus in this regard is on modeling the sintering behavior and temperature distribution in furnaces (bottom figure on the right). This allows to calculate deviations in shape and the resulting internal stresses. We are currently expanding these methods, so they can be used for components that are anisotropic or stem from additive manufacturing.

Literature

[1] Strategy paper (in German): Digitalisierung der keramischen Fertigung – Herausforderungen und Chancen (https://dgm.de/fileadmin/DGM/Netzwerk/Ausschuesse/GA-Hochleistungskeramik/2021-DKG-DGM-Strategiepapier-Digitalisierung.pdf).
[2] Report (in German): Digitale Strategien für mehr Materialeffizienz in der Industrie (https://www.iwkoeln.de/studien/adriana-neligan-digitale-strategien-fuer-mehr-materialeffizienz-in-der-industrie.html).
[3] J. Kimmig et. al.: Advanced Materials, 2021, 33, 2004940 DOI: 10.1002/adma.202004940.
[4] Following G. Petzow, cfi ceramic forum international, Berichte der DKG, 81 (2004, No. 4, E34).



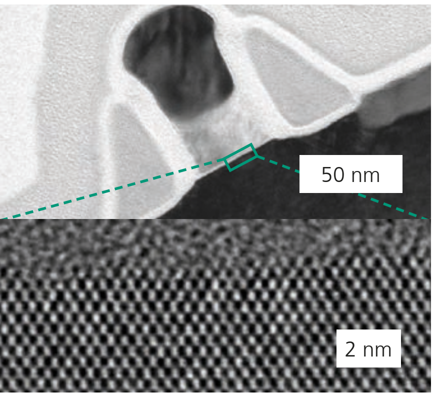
Dilatometric measurements as the basis for modeling sintering behavior.



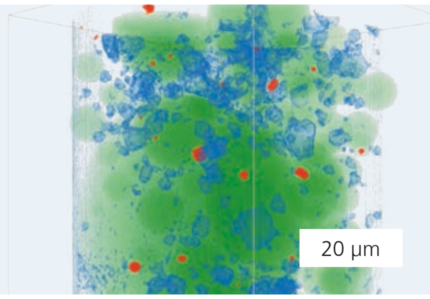
Modeling of the temperature distribution in the furnace and the shrinkage behavior.

Microelectronic materials and nanoanalytics for improved performance and reliability

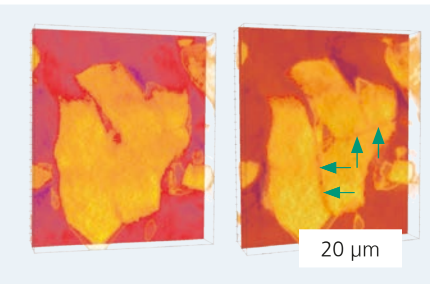
Dr. André Clausner, Dr. Birgit Jost, Dr. Zhonquan Liao, Dr. Jürgen Gluch, M. Sc. Kristina Kutukova, Dipl.-Ing. Christoph Sander



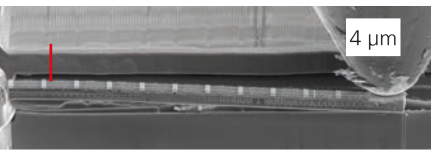
HR-TEM micrograph of a transistor structure with atomic resolution of the transistor.



X-ray tomographic 3D microscopy of a heterogeneous mold compound material.



Operando X-ray microscopy experiment on an active battery cell, left: cathode particles before cell cycling, right: crack formation after 37 cycles.



In-situ SEM nanomechanics cantilever experiment on a nanostructured microelectronics specimen.

New and complex materials systems are the key to innovation in micro-, nano- and optoelectronics as well as energy, environmental and medical technology. Most of the macroscopic properties of materials and structural systems stem from the microscopic world. The correct knowledge of relevant relationships between structures and properties can speed up the development of new products, improve the reliability of components in a targeted way and increase the efficiency of technological processes.

The Microelectronic Materials and Nanoanalytics department at Fraunhofer IKTS is deeply engaged in cutting-edge nanoanalytical methods as well as innovative, problem-specific experimental designs in microscopes to make microscopic effects observable and further exploit the measured data. One particular focal point is the combination of processes and the observation of time-resolved interactions.

Microelectronics is an important field of application. In close cooperation with industry, the department addresses questions on the chip level, reaching down in scale from micrometers to a few nanometers. The portfolio of methods includes:

- High-resolution analytical transmission electron microscopy (HR-TEM including EDX and EELS)
- High-resolution X-ray nanotomography (nXCT)
- Scanning electron microscopy/plasma-FIB (SEM/FIB) for flexible sample preparation as well as EDX/EBSD for chemical and crystallographic characterization
- Cutting-edge nanomechanical test systems (e.g. nanoindentation)

These methods can, for example, be used for the high-resolution imaging of transistor structures and their failure modes down to the atomic scale (top figure) or of heterogeneous materials in 3D with resolutions of several 10 nm (second figure). This facilitates a considerably deeper insight into the structure and behavior of microelectronic materials.

In addition to imaging methods, the department is working intensively to understand and optimize issues of reliability, such as electromigration, thermomechanical reliability and radar frequency behavior. Relevant equipment is at hand, for instance a radio frequency wafer prober and EM testing ovens.

Moreover, the integration of experiments inside microscopes, meaning the assembly of in-situ and operando tests, for instance for microelectronic or energy systems, is part of the department's core expertise. The assembly of an active battery cell in the nXCT is one example of an innovative realization of operando experiments in X-ray microscopy. The setup allows to investigate microscopic crack formation in cathode particles during cell cycling (third figure). Additionally, in-situ experiments in microscopes provide insightful information. For example, the system E-modulus of a nanostructured microelectronics sample can be determined in situ in a scanning electron microscope (bottom image).

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Research and development center for transparent ceramics

Prof. Ingolf Voigt, Dr. Sabine Begand

Expansion of development of transparent ceramics

By integrating the transparent ceramics division of the CeramTec-ETEC GmbH (PERLUCOR®), Fraunhofer IKTS will significantly expand its existing competences in the development of transparent ceramics. The new technical infrastructure enables the establishment of a research and development center for transparent ceramics at the IKTS site in Hermsdorf.

With the financial support of the Free State of Thuringia, a complete ceramic technology chain consisting of equipment for conditioning high- purity powders, shaping, heat treatment, laser processing and ultra-precision finishing will be installed in Hermsdorf, providing a link between laboratory scale and industrial production.

Ceramic technology in Hermsdorf will thus achieve a performance leap in terms of component size, degree of purity and innovative manufacturing.

The funding is an important foundation for future projects. It represents a real milestone in the development of Thuringia, especially the industrial region Hermsdorf, towards Europe's leading center for advanced ceramics.

Transparent ceramics are characterized by excellent material properties and are superior in comparison to glass, sapphire or gorilla glass in many applications:

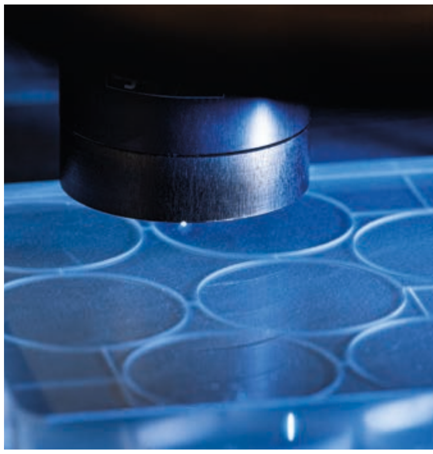
- Spectral transmission 0.2–6 µm
- Refractive index 1.72
- Hardness 13.8 GPa
- Bending strength 350 MPa
- Dielectric constant 8–9
- Melting point ~2000 °C

Unique characteristics and subsequent applications of transparent ceramics

- Extreme robustness, hardness and resistance to scratches for longer-lasting visibility and functionality of scanners and displays
- Protective windows in armored vehicles with reduced weight
- Efficient utilization under extreme conditions in industry for a more secure monitoring of processes: e.g., in production, in high-temperature areas, in furnace windows, inspection glasses and spin windows
- Long-lasting protection for optics and sensor systems in harsh environments, such as desert regions, subsea or space, e.g., optical lenses and optical camera elements for night-vision devices, lidar sensors or surveillance systems
- Biocompatibility and biostability of optics for medical devices, endoscopes and point-of-care diagnostics

The project is partially funded by the Free State of Thuringia with the funding code 2021 FGI 0002.

Thüringer Aufbaubank



Laser-perforated transparent ceramics for sensor and opto-electronic applications.

Electronic device with spinel cover.

Optical lense made of spinel ceramics.

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Industrial Hydrogen Technologies Thuringia WaTTh at the Arnstadt site

Dr. Roland Weidl, Dr. Karl Skadell, M. Eng. Justin Reichert

Location of the WaTTh hydrogen application center.

Awarding ceremony for subsidies, with Thuringia's Economics Minister, Wolfgang Tiefensee, and the site manager, Dr. Roland Weidl.

As a versatile energy carrier, hydrogen will play a key role in decarbonizing our world. In parallel with the worldwide expansion of hydrogen infrastructure, the economic scaling of hydrogen technologies is becoming more and more essential. In order to be able to cover the future nation-wide demand for green hydrogen and to make it directly available to industrial end users, electrolysis systems needs to be significantly further developed.

Fraunhofer IKTS operates the Hydrogen Application Center WaTTh at its Arnstadt site to achieve just that. The focus is not only on automated stack assembly and smart machine and production design but also on logistics and data acquisition, framed as industrial data concepts. The WaTTh's cooperation with the BITC, which is already located in Arnstadt and focuses on ceramics and battery production research (Industry 4.0), produces synergistic effects. In an effort to upscale electrolysis technology, the goal is to develop all subcomponents of hydrogen technology into the 10 to 100 kilowatt class. We are focusing on high-temperature electrolysis with solid oxide cells (SOE) as well as alkaline electrolysis (AEL).

Since producing highly scaled stacks is not feasible in a laboratory environment, WaTTh provides the corresponding production and quality testing procedures as well as test fields on a pilot-plant scale. IKTS thus contributes to the timely achievement of industrial maturity and large-scale stack production.

To expand the capabilities of WaTTh, a power-to-X plant with customized high-temperature electrolysis cells will also be installed. This plant will demonstrate how co-electrolysis from CO_2 and water produces sustainable, CO_2-neutral raw materials and fuels, in a fully automated process.

Another major contribution that hydrogen can make to decarbonizing industry lies in its use for generating heat in industrial furnaces. According to the current state of the art, these furnaces use natural gas, oil or electrical energy. In order to make hydrogen-fired furnaces more attractive as a field of activity for cooperation partners in regional industries, in particular the ceramics industry and industrial furnace construction, and to demonstrate and explore the resulting possibilities, the plan is to construct and operate a modular hydrogen-fired sintering furnace with corresponding furnace peripherals. As a demonstrator in modular design, different variants of H_2 heat generation will be tested, analyzed and verified, and established firing processes will be adapted for this type of heat generation.

In order to ensure sufficient space for the set-up and activities, an adjacent vacant lot (13,000 m²) has been acquired.

We thank the Thuringian Ministry of Economy, Science and Digital Society for its financial support.

Freistaat Thüringen
Ministerium für Wirtschaft, Wissenschaft und Digitale Gesellschaft

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Cognitive Material Diagnostics project group

Dr. Constanze Tschöpe

Test site for cognitive systems at BTU Cottbus-Senftenberg.

Data is becoming the key factor for new ways to create value in plants, products, and processes. With the help of artificial intelligence (AI) and machine learning (ML), even large amounts of data can be effectively analyzed and thus made usable.

The Cognitive Material Diagnostics project group (KogMat^D) develops and applies the latest approaches in AI and ML to a wide range of applications. Since 2019, it has been located directly at BTU Cottbus-Senftenberg and is funded by the State of Brandenburg and the Fraunhofer-Gesellschaft. A broad spectrum of applications can be tapped by working with numerous companies in the region, BTU chairs, national and international universities, and clinics. Applications range from the quality assessment of manufactured components and predictive maintenance of industrial equipment and wear components to processing spoken and written language and analyzing biological and medical data.

Since the start of the project, we have already succeeded in acquiring third-party funding of more than 1.2 million €. The establishment of research activities in Lusatia is intended to create new qualified and forward-looking jobs in the fields of cognitive materials, machine learning and artificial intelligence in this mining region.

In the joint project "Data-based services", for example, Fraunhofer IKTS is working with ABB AG, Lausitz Energie Bergbau AG and EWG Automation Cottbus to preserve the extensive knowledge of conveyor belt systems in open-cast mining. Artificial intelligence will be used to secure the expertise that will be applied in a targeted manner to restructure the companies affected by the undergoing structural change in the Lusatia region and make the expertise available to other companies. This ensures that these competencies will not be lost in the upcoming coal phase-out.

In a further joint project named "Digital twins for process optimization and predictive maintenance", the project partners are developing a system for planning and optimizing operating modes and maintenance measures in industrial plants and outside the power plant sector. The KogMat^D project group ist also making valuable use of its expertise in the areas of pattern recognition and data analysis in the joint project "Intelligent information processing". Here we are working on methods and algorithms for modeling continuous industrial processes, analyzing large data sets and making them usable for optimizing and increasing the efficiency of industrial processes.

Test set-up for the inspection of cracks in glass bottles.

In addition to R&D cooperation projects with companies and research institutions, KogMat^D offers feasibility studies, scientific consulting as well as data analysis and evaluation. Furthermore, the range of services includes the construction of hardware modules for portable, flexible data acquisition, the development of detection and training software for pattern recognition, among other things, as well as the combination of hardware and software for constructing customer-specific in-line- and offline-capable testing systems.

LAND BRANDENBURG

Fraunhofer

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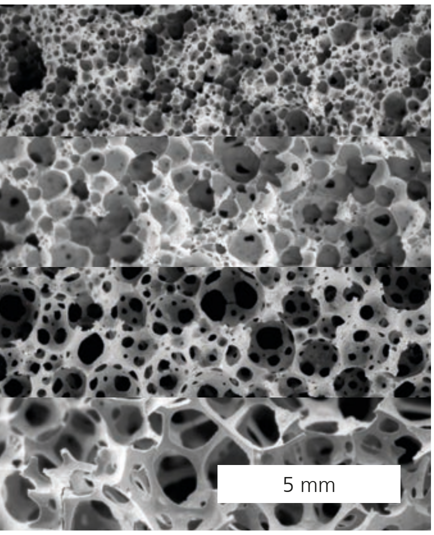
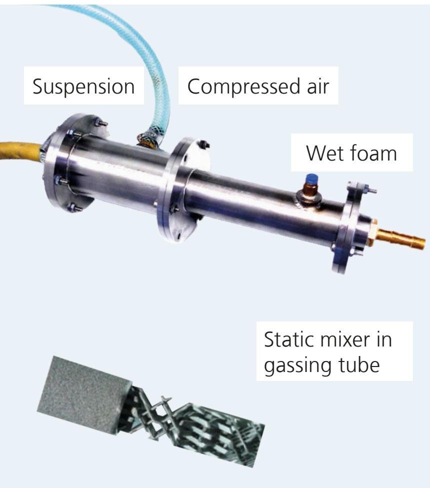
Direct foaming of ceramic slurries

Dr. Daniela Haase, Dipl.-Krist. Jörg Adler



Pore morphology of various direct-foamed ceramics.



Patented foam generator for the continuous production of direct foam.

Direct-foamed ceramic components made of various materials with different porosities.

Direct foaming enables the production of highly porous ceramics with closed or (partially) open porosity. The pores can be introduced directly into the structuring phase through various methods, for example by means of chemically acting blowing agent processes or by physically generating vapor pressure. A particularly efficient and ecological process is the introduction of air by gassing and/or mechanical stirring of the gas phase into a suspension using surfactants. The resulting wet foam is then filled into a mold, dried, demolded, and heat-treated.

Foam generator for the continuous production of direct foam

A foam generator was developed and patented at Fraunhofer IKTS. It enables the production of foamed ceramic slurries which is almost wear-free compared with conventional rotor-stator systems. Inside the unit, the slurry is pumped through a porous pipe while pressurized air is used to enable a stream of fine dispersed gas bubbles through the pipe into the slurry. Afterwards a static mixer blends slurry and air bubbles into a homogeneous foam. The porosity of this foam can be adjusted to values between 30 and 95 % by volume via the volume flow ratio of slurry and air. The pore size depends on the components used (pore size of the porous tube and diameter of the static mixer) and can be varied in the range between 100 µm and 2 mm. The new foam generator can produce 10 to 300 l of wet foam per hour. This makes the foaming device suitable for both laboratory operation and industrial production processes. Further upscaling to larger throughputs is possible.

An important aspect in the development of direct foams is stabilizing the gas bubbles in the wet foam. For this purpose, characterization methods were developed, and parameters were identified at Fraunhofer IKTS that allow targeted differentiation into stable and unstable foams. In particular, rheological parameters such as yield point, viscosity and storage and loss modulus have a significant influence on foam stability.

In addition to the rheological stabilization of the foam structure, current research focuses on methods for the accelerated consolidation of the wet foam state in order to shorten the drying process and thus make direct foam technology more efficient, especially for large-size components.

On the basis of this new technology, IKTS has already developed a variety of ceramic foams with adapted pore structures from a wide range of materials. These can be used, for example, for heat or sound insulation, in lightweight construction, as filter material or artificial bone replacement.

Services offered

- Development and characterization of cellular and highly porous ceramics
- Development and transfer of manufacturing technologies for components made of cellular ceramics
- Prototyping and prototype testing

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Zirconium carbide – high-temperature material for high technologies

Dipl.-Ing. Katrin Schönfeld, Dr. Hans-Peter Martin

At Fraunhofer IKTS a technically practicable and inexpensive method to produce high-quality zirconium carbide ceramic materials has been developed. Due to its very high melting point (3540 °C) and its very low vapor pressure (<10^{-6} mbar at 2000 °C), zirconium carbide (ZrC) is an outstanding high-temperature and high-vacuum material on par with the strategically critical tungsten, tantalum and molybdenum materials.

Material characteristics of ZrC components (> 98 % of the theoretical density)

Flexural strength / 20 °C	350 MPa
Flexural strength / 1400 °C	200 MPa
Flexural strength after annealing 1900 °C	350 MPa
Fracture toughness	4 MPa$\sqrt{m}$
Thermal conductivity / 20 °C	31 W(mK)$^{-1}$
Thermal conductivity / 2000 °C	38 W(mK)$^{-1}$
Spec. resistance / 20 °C	1-10^{-3} Ωcm
Spec. resistance / 2000 °C	2-10^{-3} Ωcm

Up to now, zirconium carbide has mainly been used in nuclear energy technology. Until now, compact ZrC components were not economically attractive for other applications. The IKTS development of pressureless sintering of ZrC opens new cost-effective processing options. Tungsten components provide an orientation on the potential uses of ZrC materials. Tungsten is a high-priced material which, due to its outstanding properties in high-temperature and high-vacuum technology, could not be replaced by any other material so far. It combines properties such as corrosion resistance, chemical stability, maximum thermal load capacity (> 2000 °C), temperature change resistance, good electrical conductivity and mechanical properties such as modulus of elasticity, strength, fracture toughness over a wide temperature field. Only the combination of these properties enables the reliable and long-lasting function of certain system components, such as heating elements in high vacuum furnaces. The developed zirconium carbide materials can be used advantageously as a substitute for refractory metal components. Because besides their material characteristics, they are lighter, more cost-effective and contain no critical raw materials. Their application as heating elements and evaporation boats up to extremely high temperatures under vacuum has already been successfully tested in laboratory conditions (FKZ: 003VP05870). But also in other fields, such as semiconductor technology, photovoltaics, OLED, and nanoelectronics, zirconium carbide can bring its unique features into play. At the same time, the use of ZrC in the production of components in mechanical and plant engineering results in a significant reduction of weight and energy compared to refractory metals.

Services offered

- Manufacture of heating conductors in customer-specific dimensions
- Manufacture of kiln furniture
- Manufacture of targets and vaporizer accessories

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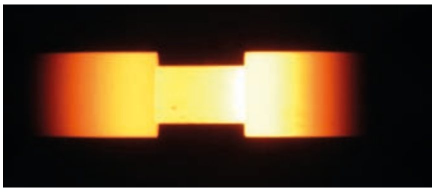
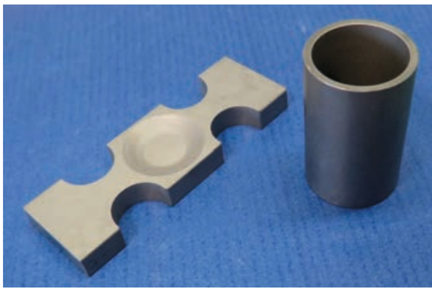
Gefördert durch:
Bundesministerium für Bildung und Forschung
aufgrund eines Beschlusses des Deutschen Bundestages

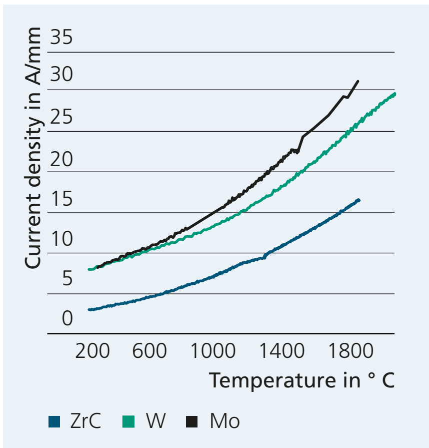
ZrC heating elements.



Glowing heating rod at 2000 °C between graphite electrodes.



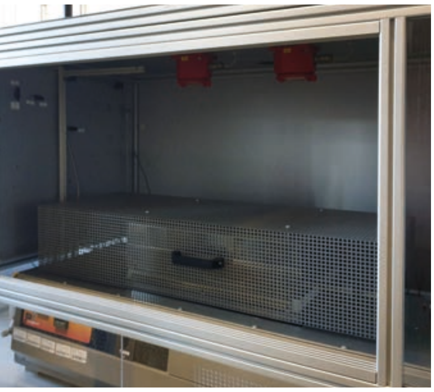
Evaporator and crucible material made of ZrC.



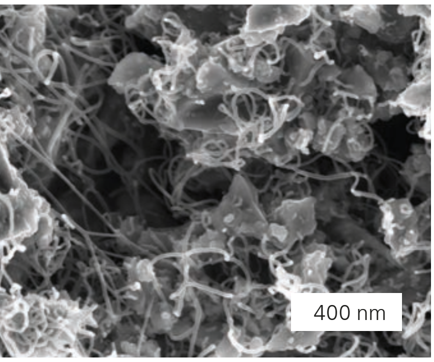
Current density of ZrC, tungsten and molybdenum.

Production of high-performance CNT-ceramic composites

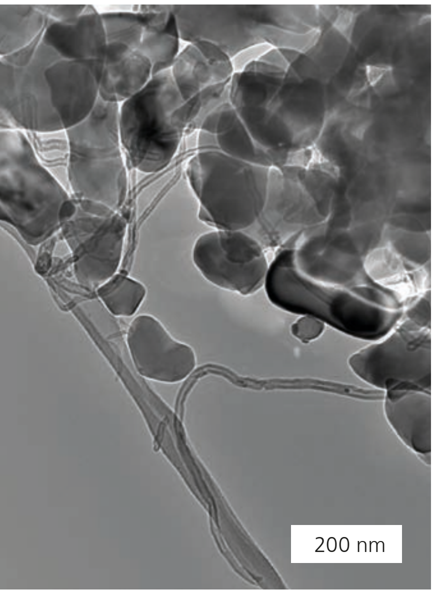
M. Sc. Marc Pezoldt, Dipl.-Chem. Martina Johannes, Dr. Daniel Schumacher, Dr. Adrian Simon



CVD reactor.



FESEM image of Si_3N_4 powder with grown CNTs.



TEM image of Al_2O_3-CNT powder.

Enhancing high-performance ceramics with CNTs

High-performance ceramics are very versatile thanks to their high wear resistance, compressive strength, hardness and corrosion resistance. Nevertheless, where good thermal and electric conductivity is required, their fields of application are limited.

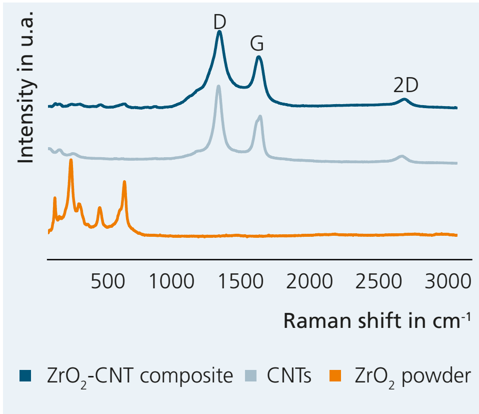
The combination of carbon nano tubes (CNTs) with ceramic powders, on the other hand, is exceptionally well suited for tackling this drawback of ceramic components. CNTs are characterized by extreme tensile strength (30–100 GPa), a high Young's modulus (1–1.2 TPa) and high thermal (2000–6000 W/mK) and electric conductivities (10^6–10^7 S/m).

CNT-ceramic composites

The state of the art for manufacturing CNT-ceramic composites involves mixing ceramic powders with CNTs, followed by sintering. During powder mixing, however, the CNTs are prone to agglomeration, shortening and even decomposition.

A Fraunhofer patented process allows covering oxidic and non-oxidic primary ceramic particles (Al_2O_3, ZrO_2 and Si_3N_4) with deagglomerated CNTs. Defined concentrations of catalyst particles are deposited on the ceramic particles by a wet-chemical route. Subsequently, a chemical-vapor deposition process leads to the growth of the CNTs, starting from the catalyst particles. This leads to a very homogeneous distribution of the CNTs in the final CNT-ceramic composite.

Such high-performance composites are ideal for use in ceramic heating elements, conductive thread guides and low-wear rolling bearings.



Quality control of the composites using non-destructive Raman spectroscopy.

Services offered

- Supply of ceramic powders functionalized with CNTs
- Shaping and sintering of ceramic powders functionalized with CNTs
- Comprehensive characterization of CNT-ceramic composites

We are grateful for the financial support (FKZ: 03XP0205E) of the German Federal Ministry of Education and Research (BMBF).

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Sealing ceramic fiber composites with laser technology

Dr. Willy Kunz, Dr. Mykola Vinnichenko, Dr. Viktar Sauchuk, Dr. Sindy Mosch

Oxide ceramic matrix composites (OCMC) are materials with excellent high-temperature stability up to approx. 1200 °C and damage-tolerant behavior. Furthermore, these materials are characterized by a high chemical resistance in many media and a low density. For this reason, the OCMC materials are well suited for demanding applications in combustion technology (gas turbines, engines, burners), in the heat treatment of steel (charging racks, baskets) and the chemical industry (reactors, heat exchangers, swirlers).

Pores as show stoppers for many applications

In order for the material to retain its damage-tolerant properties, it needs to be porous. This, however allows liquids and gases to enter or pass through the material. In addition, the pores make the material susceptible to wear.

Why not just coat it?

Common coating processes, such as plasma spraying, allow OCMC to be sealed. However, under mechanical stress or thermal shock, such coatings tend to crack or flake off. This severely limits the service life of the component.

Coating adhesion by laser radiation

To improve the durability of the coating, Fraunhofer IKTS is currently developing a new coating process: By means of laser radiation, a ceramic powder applied to the surface is melted, and the surface of the OCMC infiltrated.

The coating material does not just lie on the surface, it also bonds with the base material. This significantly improves the adhesion of the coating and seals the material.

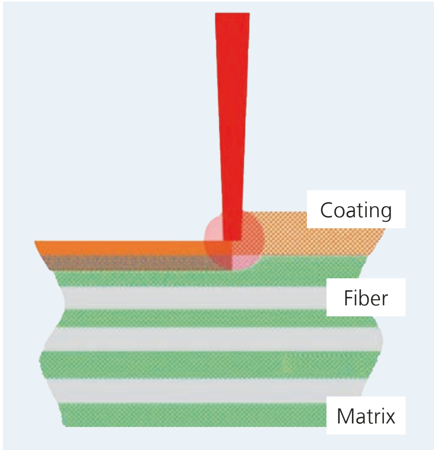
The new approach uses a special physical principle, which is used to heat up and melt the high-temperature-resistant coating materials locally without overheating the component.

A micro-optically optimized diode laser array that delivers a line-shaped focused beam (Focuslight/LIMO GmbH) serves as a cost-efficient laser source. It enables fast processing of larger areas and ensures higher energy efficiency compared with conventional lasers with a point-shaped focused beam.

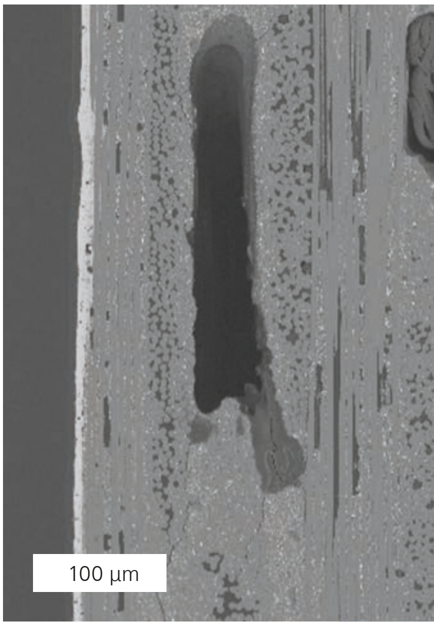
In parallel, IKTS is working on quantifying the component properties of such sealed OCMC (tightness, strength, etc.).

Services offered

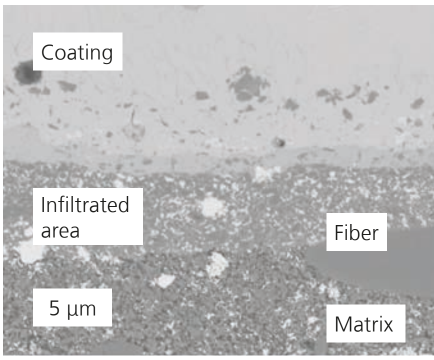
- Surface sealing: liquids and gases no longer penetrate the material. Pressure differences can exist without mass transport through the material.
- Adaptation of the coating system to the application: Corrosion or abrasion? The choice of the appropriate coating material is decisive.
- Measurement and evaluation of material properties: investigation of thermal and corrosive resistance as well as microstructure and mechanical properties.



Process schematic; laser heats only the applied coating material.

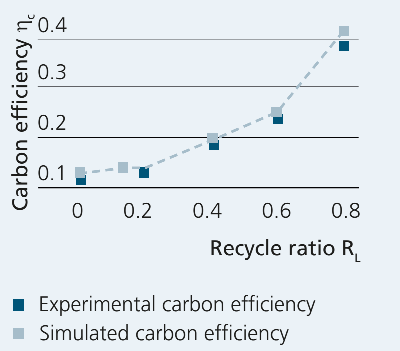


Homogeneous coating (light area on the left).



Microstructure after coating, OCMC infiltrated by coating material.

Lab-scale demonstration plant.



Influence of tail gas recirculation on carbon efficiency.

Liquid FT-product with visible aqueous and hydrocarbon phase.

Lab-scale demonstration of an integrated Co-electrolysis-based power-to-X process

Dipl.-Ing. Gregor Herz, Dipl.-Ing. Michael Gallwitz, Dr. Erik Reichelt, PD Dr. Matthias Jahn

When it comes to mitigating industrial CO_2 emissions, power-to-X processes are frequently discussed as a technological option for utilizing these emissions. In particular, high-temperature electrolysis (solid oxide electrolysis, SOE) is a promising technology. It efficiently converts CO_2 and water into syngas, and subsequently into valuable hydrocarbon products.

High-temperature electrolysis-based power-to-X plants can reach high process efficiencies, because the cathode is catalytically active for reforming short-chained by-products of the synthesis step (e.g. methane). This allows for the direct conversion of these low-value products back into syngas, leading to increased carbon efficiency,

$$\eta_C = \frac{\eta_{C,products}}{\eta_{CO_2,input}}$$

Moreover, it reduces the complexity of the entire process, since no additional reforming step has to be included.

In order to demonstrate the potential of internal reforming within an integrated process, a power-to-liquid lab-scale plant, consisting of high-temperature co-electrolysis coupled with Fischer-Tropsch synthesis, was implemented as part of the project "Colyssy" (FK 03ZZ0741A), funded by the German Federal Ministry of Education and Research (BMBF). The rated electric input into the electrolyzer was $P_{el,SOEL} = 1$ kW. For the fixed-bed Fischer-Tropsch reactor, an industrial cobalt catalyst was chosen for its performance and favorable product spectrum, yielding high-value long-chained hydrocarbons. The lab-scale plant was successfully operated for over 1200 hours. Over the course of the experiments, different operating conditions of the electrolyzer and the Fischer-Tropsch reactor were tested.

A special focus was placed on the variation of the recycle ratio,

$$R_L = \frac{\dot{m}_{tail\ gas}}{\dot{m}_{tail\ gas} + \dot{m}_{off\text{-}gas}}$$

which represents the fraction of the Fischer-Tropsch product gas stream recycled into the electrolyzer. The aim of this variation was to demonstrate the potential increase in carbon efficiency η_C through by-product utilization via internal reforming, and to highlight the inherent advantages of high-temperature electrolysis.

The results of the tests have shown a significant increase in carbon efficiency as the recycle ratio increases, without the electrolyzer showing any sign of performance degradation. The data were correlated with a process model and a good agreement between experiment and simulation was found. Increasing the recycle ratio R_L further – above the value of 0.8 adjustable for the lab-scale plant – would be possible on a larger scale, and modeled data suggest a significant further increase in carbon efficiency η_C.

All knowledge derived from the lab plant and the process model will be used to upscale the technology. In this context, a container-based plant will be realized at a lime production facility utilizing CO_2 derived from exhaust gas. Additionally, possible means of heat integration will be investigated.

Gefördert durch:
Bundesministerium für Bildung und Forschung
aufgrund eines Beschlusses des Deutschen Bundestages

STROM ALS ROHSTOFF

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Degradation study on SOC stacks

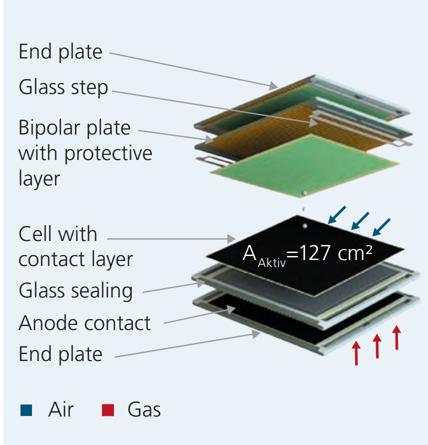
Dr. Stefan Megel, Dr. Nikolai Trofimenko, Dr. Mihails Kusnezoff

For years, Fraunhofer IKTS has been putting a lot of effort in developing solid oxide cells (SOCs). Recently, the focus has increasingly been on their use in high-temperature electrolyzers (SOEC). The SOC cells and stacks developed at IKTS, with interconnectors based on chromium and electrolyte-supported cells in MK35x design (top figure), can be operated reversibly, i.e. in electrolysis mode and in fuel cell mode. Thus, they are simultaneously the key components for converting excess electricity into synthetic fuels as well as for efficient conversion of these fuels back into electricity. In recent years, research activities have focused, above all, on lowering costs and degradation rates. While the technology for the manufacturing of SOC cells and stacks has already been successfully transferred to industrial parners, the manufacturing processes continue to evolve at IKTS with the aim of reducing production costs. Such savings will only materialize once production volumes increase. Accordingly, many SOFC and SOEC projects are working to expand the application spectrum of SOC systems in order to boost production numbers. Long-term stability is another important research goal for SOC stacks. Determining degradation rates is one of the main tasks of component development, achieved mainly by investigating cells, protection layers, glass sealings and metal-ceramic contacts. The current determined degradation rate of $\Delta P/P_0 < 0.7$ %/1000 h at a constant electric current of 35 A in SOFC mode (bottom figure) requires a high-precision measuring system. It is especially difficult to keep the measurement parameters on a constant basis over several thousand hours. This can only be achieved by excellent lab technology and continuous maintenance. The temperature measurements are highly influenced especially by thermocouples and gas flow control.

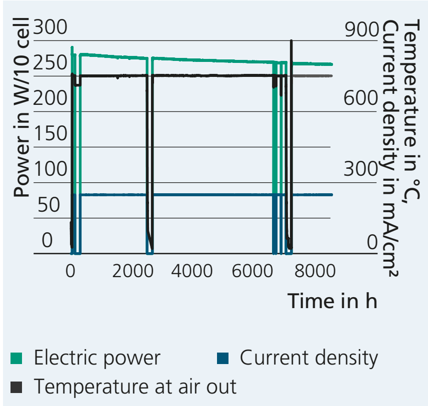
The standard deviation of the measuring devices leads to about 1 % uncertainty. It is possible to get sufficiently accurate performance figures through referencing and calibration. By doing this, the degradation can be determined reliably after 3000 h of testing, and it is possible to provide lifetime forecasts for more than 20,000 hours. With the test conditions being equal, stacks in degradation cause a rise of temperature through increased heat development. The effect of temperature on stack performance is determined through simulations and measurements, because it is not possible to compensate this heat development by modifying test conditions. Standard test protocols have to be established for the different fields of application for fuel cells and electrolysis operation. Simulating and measuring temperature distributions contributes to understanding the monitored phenomena as there is a wide difference between exothermal SOFC operation and thermo-neutral SOEC operation. The knowledge of how the power losses in a stack are divided is based on many stack analyses, validated models and numerous single measurements on stack components. This knowledge enables the focused development of components, which can be validated with standardized test protocols.

Services offered

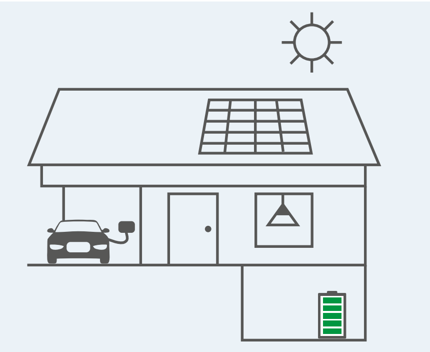
- Test of stack components under real conditions
- Stack and stack module development for SOFC/SOEC systems



Exploded view of an MK354 stack.

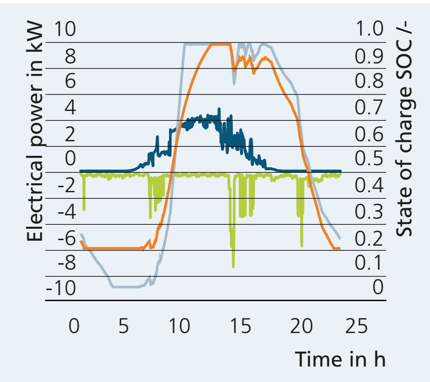


Degradation of a 10-cell MK354 stack.



Schematic diagram for a photovoltaic home storage system.

5 kWh $Na/NiCl_2$ battery module.

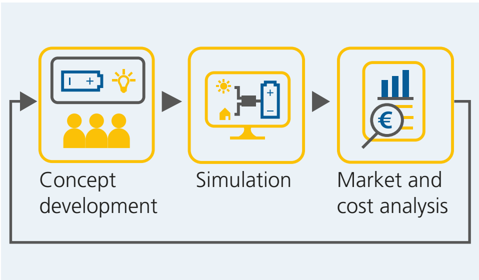


Daily simulation of PV power production (blue), consumption (green), and state-of-charge of a Li-ion battery (grey) compared with the $Na/NiCl_2$ battery (orange).

Simulation-based analysis and economic evaluation of energy systems

Dipl.-Ing. (FH) Daniela Herold, Dipl.-Ing. Laura Nousch, Dipl.-Phys. Maria Richter

In the development of innovative energy system concepts of the future, early predictions of system performance and economic viability are of crucial importance. At Fraunhofer IKTS, low-dimensional simulation models are used to investigate real application scenarios, which provide the all-important basis for any subsequent cost analysis.



Tool chain in the development process.

Simulation of energy systems

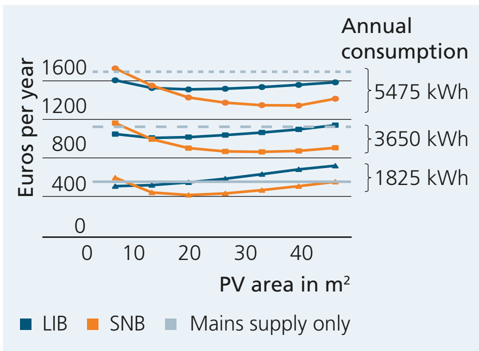
Energy systems for the storage and generation of electricity and heat in different levels of detail and contexts can be considered in daily and annual simulations (utilized software: Modelica and Matlab). Automated tool chains allow the variation of significant system parameters. The result matrix is used for dimensioning, energetic assessment, and the underlying concept development. In addition, economic evaluations can also be derived.

Market and cost analysis

Technology research is an indispensable tool for well-founded market and cost analyses. They form the basis for sustainable and long-term project decisions. Information on market potentials, target market structures, competitors, potential customers or even cooperation partners is included in the research. When it comes to cost analyses, the development team is able to consider different objectives. For example, the manufacturing costs of a battery prototype are identified during the development project in order to determine a cost estimate which includes the potential cost savings. This can be done for both small-scale and large-scale series production.

Example: Comparison of battery technologies in the household storage sector

Fraunhofer IKTS is developing the sodium nickel chloride high-temperature battery ($Na/NiCl_2$) as an alternative battery technology under the cerenergy® brand. With the help of annual simulations, its use as a photovoltaic (PV) home storage system is investigated compared with Li-ion batteries (LIB). The cost models show that the use of the $Na/NiCl_2$ battery in combination with a larger PV area results in lower annual costs than an LIB household storage system (figure below).



Comparison of annual costs for 5 kWh LIB and $Na/NiCl_2$ home storage.

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Optimizing the electrode properties of Lithium solid-state batteries

Dr. Henry Auer, M. Sc. Silian Yanev, Dr. Sören Höhn, Dipl.-Ing. Kerstin Sempf, Dr. Timo Paschen, Dr. Kristian Nikolowski, Prof. Silke Christiansen, Dr. Mareike Partsch

Fraunhofer IKTS is developing electrodes and cells for solid-state batteries with oxide, sulfide and polymer electrolytes. Imaging and electrochemical methods are combined to specifically improve the electrode properties. The newly established workflows enable targeted optimization of the electrode morphology. As a result, solid-state batteries can be developed in significantly shorter iteration cycles.

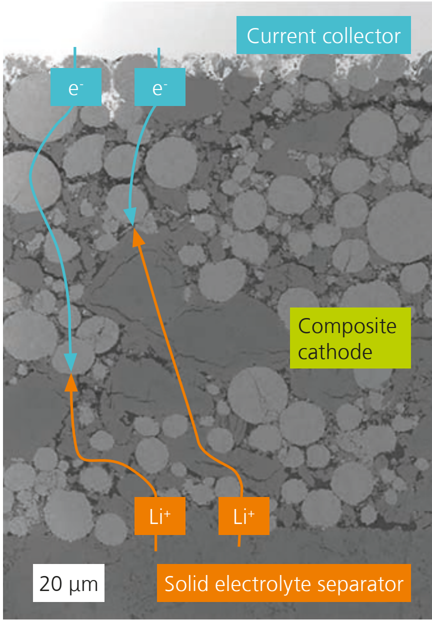
A cathode consisting of an active material (NCM811) and a highly conductive sulfidic electrolyte was optimized so that its function – high capacity at high rate-capability – is improved with the highest possible active material content. The electrodes of solid-state batteries have a more complex structure than those of conventional Li-ion batteries. Different classes of materials from the field of inorganic solid ion conductors – oxide ceramics, sulfides and halides – as well as polymers are used here. The solid electrolyte is an additional component introduced during the manufacturing process. Two interlocked conducting networks (top figure) are formed for electrons via the active material (blue arrows) and for ions via the sulfide solid electrolyte (orange arrows). Passive components, such as binders or residual porosity, interfere with this conduction.

For a detailed understanding and with a view to optimizing this complex morphology, electrochemical measurements were combined with direct imaging techniques (middle figure). Information on the electrochemical bonding of the active material particles and the effective ionic and electronic conductivities can be obtained from capacity, rate capability and impedance measurements. Scanning electron microscopy on electrodes complements this information with morphological data on homogeneity and conduction paths. Secondary ion mass spectroscopy (SIMS) in the helium ion microscope additionally visualizes the binding of individual active material particles by means of lithium analysis.

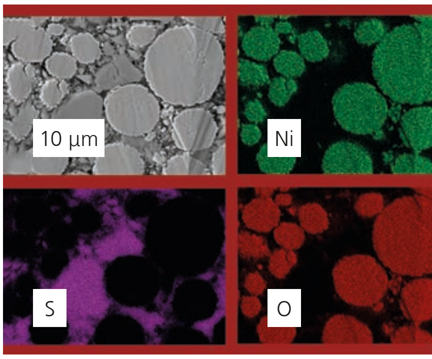
A major preparative challenge for the sulfide cathodes shown in the top figure was the high demands placed on the working atmosphere. For this reason, a workflow consisting of all analytical steps – preparation, sample transfer, and measurement – was established under an inert gas atmosphere. In this way, fresh electrodes or those recovered from solid-state batteries can be prepared and analyzed completely free of contamination in the absence of air. This combination has enabled electrodes with good electrochemical properties (bottom figure) to be developed in significantly shorter iteration cycles.

Services offered

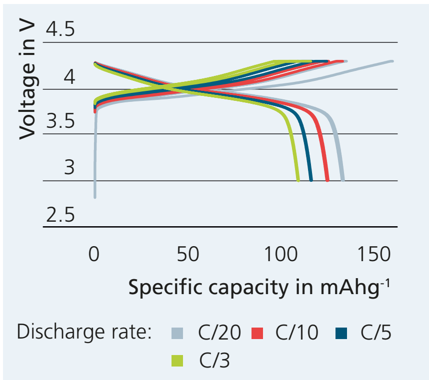
- Development and post-mortem analysis of solid-state batteries and components
- Electrochemical analysis: ionic and electronic conductivity, full-cell and half-cell tests
- Ion milling and inert transfer into field effect scanning electron microscope and helium ion microscope, lithium detection (SIMS)



FESEM image of the cut through a sulfide electrolyte-based solid-state cell; conductive path for electrons (blue) and Li-ions (orange).



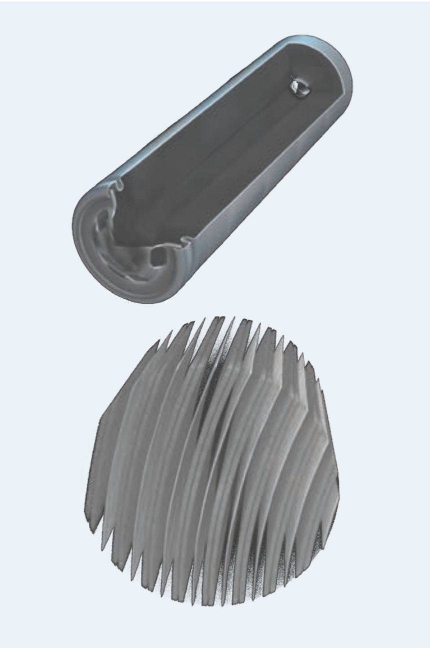
Cross section of the sulfidic composite cathode in FESEM and EDX element mapping.



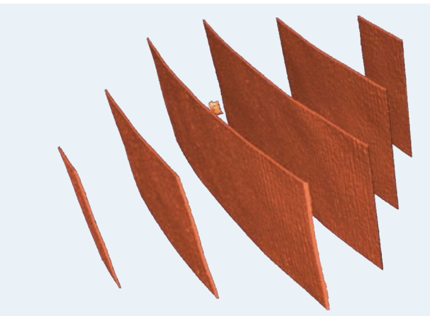
Rate capability test of a solid-state battery cell.

Digitized workflows for microstructure evaluation in the battery industry

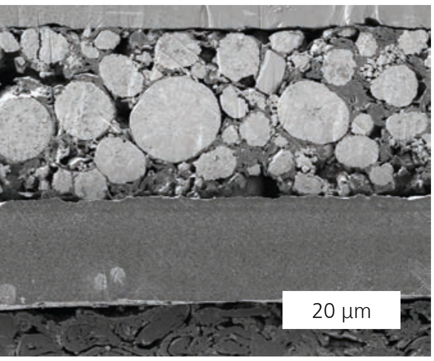
Dr. Timo Paschen, M. Sc. Sabrina Pechmann, M. Sc. Andre Borchers, Prof. Silke Christiansen



Overall image and cropped detail view of a 18650 Li-ion battery using X-ray tomography (XRM).



Segmentation of XRM data and identification of a defect on the current conductor.



SEM image of a Li-ion electrode stack after cryo-vacuum preparation.

Powerful and safe battery concepts will be essential for a sustainable energy and mobility revolution. The performance of current established technology of the Li-ion battery (LIB) and new concepts, such as all solid-state batteries (ASSB), therefore needs to be continuously improved. Important for this are parameters that can be obtained from multi-modal, cross-scale microscopy and spectroscopy, e.g. size distributions of particles in the cathode foil, porosities in the total volume, or interfacial properties of electrode and separator or electrolyte and active material. At its Forchheim site, Fraunhofer IKTS offers precisely this interaction from microscopy to spectroscopy, the correlation of data from different analytical methods from the macro to the nano scale. A fully comprehensive preparative workflow is available for the characterization of battery materials, which avoids oxidation and thermal artifacts while allowing cells and components to be opened and prepared under inert gas and, if necessary, cryogenically cooled during preparation and analysis.

Non-destructive detection of defects

The top figure shows reconstructed X-ray tomography images of a Li-ion battery as an overview and in detailed view. X-ray tomography microscopy (CT with voxel sizes of 500 nm upwards) is able to generate non-destructive three-dimensional images of the internal microstructure of the battery. This method allows to detect structural changes that would otherwise only be visible with invasive methods. A copper outgrowth on the copper current conductor (middle figure) is clearly visible after dedicated image segmentation. Such copper outgrowths occur while the battery is being used and lead to irreparable damage. Such defects can be delayed or avoided by optimizing the material and cell concepts, for which multi-modal analysis can be used.

Cryo-vacuum preparation and dedicated multi-modal, cross-scale, correlated characterization of material, components and integrated devices

At Fraunhofer IKTS in Forchheim, battery cells, components and starting materials of various types can be opened in an inert atmosphere and transferred to preparation tools or microscopes and spectrometers using an airtight sample shuttle. In order to achieve the highest surface quality, the samples are processed with a cryogenically cooled ion beam polish to prevent the alteration of materials due to heating (e.g. for polymer electrolytes). High-resolution images in the scanning electron microscope (e.g. bottom image), which can also be integrated tomographically from a large number of images to form a 3D volume, provide access to parameters such as particle size, distribution, pore volume, interfacial property, layer thickness and cell structures with a high degree of statistical certainty.

Digital workflow

The entirety of all data from the analytics can be quantitatively evaluated and correlated on an interactive data platform. The data can be used for training machine learning algorithms, e.g. to enable and speed up the automated segmentation of new image data. The resulting database can also be used to generate synthetic data or to set up realistic simulations.

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Nutrient recycling based on extraction with ceramic membrane contactors

M.Sc. Sarah Trepte, Dipl.-Ing. André Wufka, Dr. Marcus Weyd, Dr. Hannes Richter

Nutrients, such as nitrogen and phosphorus, are the keystones of high-yield agriculture. They are produced at high cost in the form of mineral fertilizers through chemical processes. At the same time, enormous quantities of nutrient-containing residues produced in animal husbandry remain unused or have to be disposed of, likewise at high cost. In terms of resource conservation and environmental protection, recycling and utilizing valuable nutrients from such residues represents a cost-effective and sustainable alternative to mineral fertilizers. Thanks to the development and combination of key technologies for nutrient recycling, nutrient cycles can be closed efficiently.

Membrane extraction is a promising technology for the recovery of ammoniacal nitrogen from aqueous agricultural residue streams. Temperature-stable, chemically resistant and abrasion-resistant materials are required for the process. For this application, Fraunhofer IKTS is developing and investigating robust ceramic membrane contactors based on single-channel tubes made of aluminum oxide which can meet the high requirements. A durable water-repellent (hydrophobic) membrane surface is one essential property required for the process. Such hydrophobic surface coating based on silanes has been successfully developed at IKTS. The coating prevents wetting of the ceramic membranes with the aqueous media and ensures a stable, gaseous phase boundary in the membrane pores.

By setting a partial pressure gradient, the gaseous ammonia present in the residual stream passes through the membrane pores and can be extracted from the stream. The key process parameters have already been extensively evaluated on a technical scale. The diffusion path through the membrane layers is a limiting factor in extraction. With ceramic capillary membranes, manufactured at IKTS (top picture), with reduced wall thicknesses (600 µm) compared to conventional, ceramic single-channel tubes (1.5 mm), the ammonia transfer could be increased by almost 90 % (bottom figure). Ammonia can be redissolved in a sulfuric acid solution after passing through the membrane, producing ammonium sulfate solution – a valuable approved fertilizer in liquid form.

One advantage of the process is that ammoniacal nitrogen can be selectively recovered and impurities as well as pollutants are retained by the membrane.

Other applications can also be realized with ceramic membrane contactors, such as the recovery of ammonium in industrial processes for the subsequent decentralized production of hydrogen.

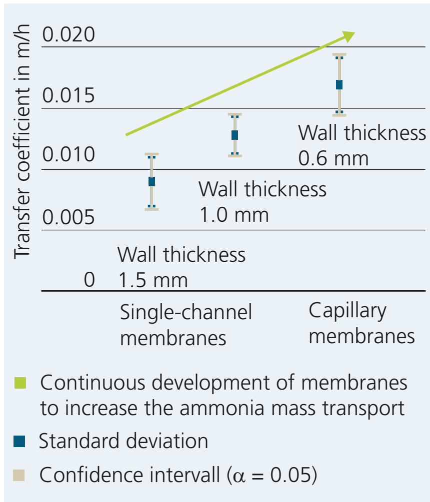
The scientific work is supported within the growth core abonocare® by the funding program "Innovative Regional Growth Cores" (German: Innovative regionale Wachstumskerne) of the German Federal Ministry of Education and Research (BMBF).

Gefördert durch: Bundesministerium für Bildung und Forschung aufgrund eines Beschlusses des Deutschen Bundestages

WACHSTUMSKERNE UNTERNEHMEN REGION Die BMBF-Innovationsinitiative Neue Länder

Ceramic capillary membranes with hydrophobic surface coating.

Technical test plant with membrane contactor for nutrient recycling.

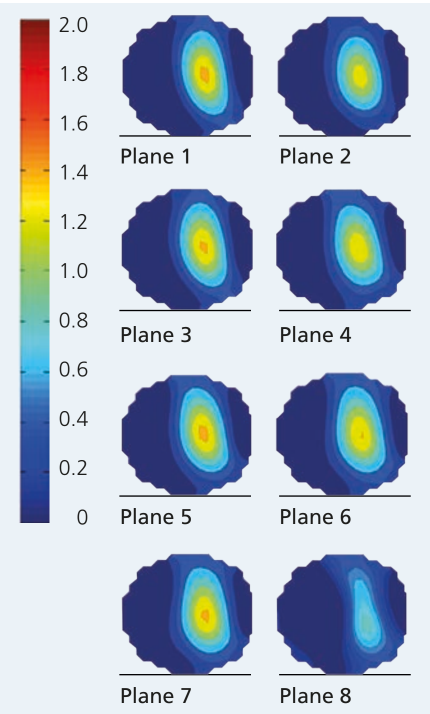


Determination of the membrane-specific transfer coefficient as a measure of ammonia mass transport.

Characterizing the gas distribution in bubble columns

Dipl.-Ing. Anne Deutschmann, Dipl.-Ing. André Wufka

ERT reactor for characterizing gas distribution in bubble column.



Comparison of volume concentrations in different planes.

Conditioned biogas, a medium for chemical energy storage, can be injected into the natural gas grid as synthetic natural gas (SNG).

The prerequisite for such injection is that the biogas, which contains methane (CH_4) and carbon dioxide (CO_2) in equal parts, is preprocessed to reach natural gas quality, with a methane content of at least 95 %. The conversion from biogas to methane can be achieved with biological methanation, in which microorganisms convert carbon dioxide and added hydrogen into methane.

Technically, this process is particularly efficient when performed in bubble column reactors, which do not require energy-intensive components, such as agitators, circulation or gas separation.

In the project "BioStore", Fraunhofer IKTS is collaborating with DBI – Gastechnologisches Institut gGmbH Freiberg on the development and optimization of efficient reactors adapted to biological methanation. DBI has evaluated various bubble column reactors for this purpose. IKTS examined the bubble distribution in the reactor using process tomography for variable boundary conditions. Pressure, temperature, and gas flow rate were varied, and different spargers (venting elements) were tested.

The bubble column test bench with the process tomography unit (ERT) is shown in the top image. ERT provides a view into the reactor and multi-phase processes can be quantified based on different electrical conductivities of the phases to be examined. The volume concentration determined through process tomography at a specific gas flow rate of 0.62 L/(L · h) and 2 bar is shown for the different planes in the bottom figure.

The images show that the gas bubble distribution is inhomogeneous over the cross-sectional area even in the first plane, which is the one nearest to the sparger. Due to the gas flow rate and the associated homogeneous bubble flow, this gradient can be measured over the entire height of the column. These inhomogeneities in the gas distribution have a negative effect on the formation of methane, since areas with low volume concentrations lead to substrate limitation. The aim is, therefore, to achieve a homogeneous gas distribution across the cross-section and column height. Overall, the investigations have shown that design and quality of the sparger have a significant impact on the bubble distribution forming in the reactor, and thus on the phase transition.

Services offered

- Optimization of industrial multi-phase flows with practical importance in various process engineering devices
- Determination of bubble size distribution and bubble rise velocity in bubble column reactors
- Investigation of flow conditions
- Determination of mass transfer coefficients and specific exchange surfaces

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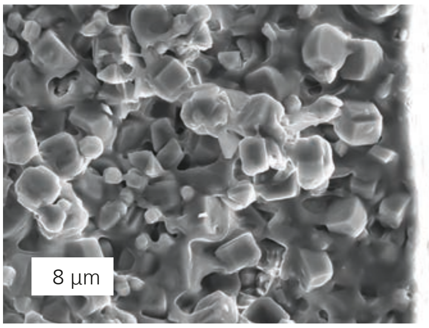
Mixed-matrix membrane for the extraction of a sustainable solvent from molasse

Dr. Marcus Weyd, Dr. Thomas Hoyer



SEM picture of an organophilic mixed-matrix membrane.

Green solvent from residues

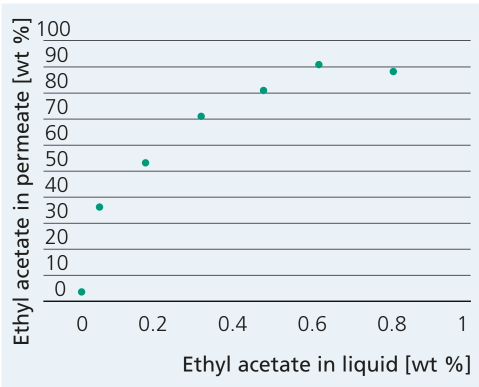
Milk processing in Germany currently produces 12.6 million tons of whey per year. After the proteins and the lactose have been separated, a mother liquor (sugar-containing molasses) remains, which is expensive to dispose of.

In a research project with TU Dresden (AiF 20311 BR), a process for the fermentative production and membrane-based separation of ethyl acetate from mother liquor is under development. Microbially produced ethyl acetate is a sustainably produced solvent that can be used, for example, to produce green adhesives. It is easily microbially degradable and therefore environmentally friendly to use.

Membrane process for solvent separation from process exhaust gas

TU Dresden is developing the process of fermentative production of ethyl acetate using the food-grade yeast Kluyveromyces marxianus. With its high volatility, the acetate is stripped from the bioreactor with the exhaust air. The aim is to separate the acetate from this gas flow by means of organophilic membranes. At IKTS, different development types of inorganic membranes and composite membranes are synthesized and tested to separate the ethyl acetate from the exhaust gas. Composite membranes made from zeolite silicalite-1 and silicone rubber show the best separation performance. With these membranes, highly concentrated ethyl acetate is obtained as permeate. Most of the water and inert gases remains in the exhaust gas. In the first attempts to couple the membrane module and the laboratory bioreactor, the ethyl acetate was separated almost completely (94 %) and with a high degree of purity (97.5 %).

The aim of a follow-up project is to develop the technology further. For this purpose, the salt tolerance of the yeasts is to be improved, the membrane area is to be scaled through the development of special membrane modules and the process combination is to be demonstrated on a pilot scale.



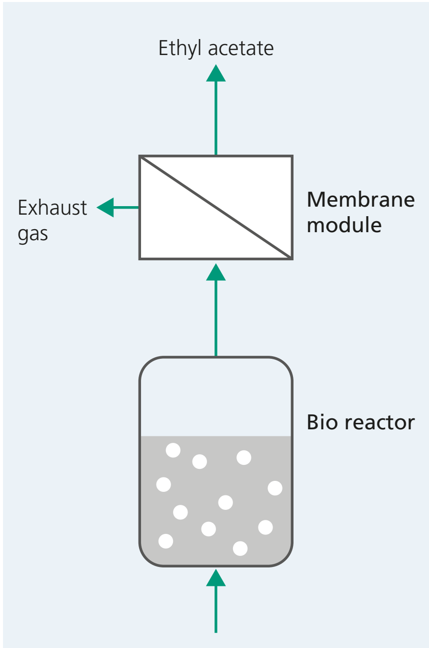
Ethyl acetate separation from stripping gases.

Furthermore, the organophilic membranes are tested for the separation of volatile components from other process and exhaust gases.

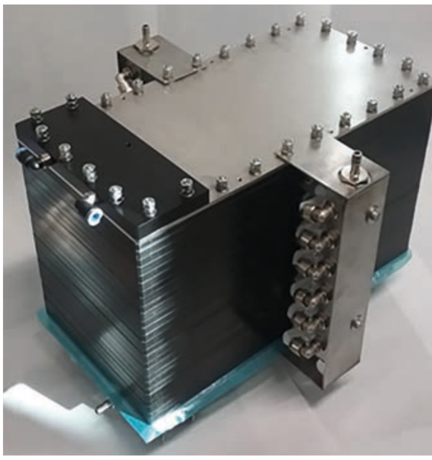
Services offered

- Customer- and project-specific membrane development and testing
- Delivery of membrane prototypes
- Process testing and development of laboratory and pilot plants

Gefördert durch: Bundesministerium für Wirtschaft und Klimaschutz aufgrund eines Beschlusses des Deutschen Bundestages



Process scheme for the separation of ethyl acetate from fermenter waste gas.



Flat membrane modules on an extended laboratory scale (1 m² membrane area).

Recultivation materials from sewage sludge composts and mycelium

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

Laboratory tests on plant toxicity.

Reference area in May 2021.

Test bed with completely closed canopy in May 2021.

Germany has tens of thousands of old landfills and dumps, as well as active landfills. An area of approx. 15,000 ha of inoperative municipal waste landfills must be provided with safe, ecologically valuable and landscape-compatible cover layers. Operators of landfills are therefore looking for potentially suitable materials available at the regional level and for corresponding processes for the production of approvable landfill substitute construction materials for recultivation layers.

With this in mind, Fraunhofer IKTS, together with Veolia Klärschlammverwertung Deutschland GmbH, the Institute of Waste Management and Circular Economy at TU Dresden, Silberland Sondermaschinen und Fördertechnik GmbH, and the Institut für Holztechnologie Dresden gGmbH, is developing functionalized recultivation materials for landfill or contaminated site cover systems in the joint project "Boden2". While matrix substrates, such as overburden material from strip mining or material from soil remediation plants, are available in large volumes, they usually have very poor soil mechanical properties and low biological activity and are in an unfavourable granulometric condition. These properties make covering such substrates with vegetation difficult. Therefore, the project relied on regionally produced residual materials, such as sewage sludge composts and extracted growing media from edible mushroom production in order to permanently improve soil properties. However, the recycling of these residues is restricted by law. For example, mushroom substrates may only be used after sterilization, and sewage sludge may only be spread in a very limited manner due to potential heavy metal contamination. These limitations become an added value with the preparation technology developed and the targeted mixing into the matrix substrate. Extensive work was carried out by the consortium partners to develop a process for conditioning a wide variety of source materials and incorporating them in optimal proportions. In the project, Fraunhofer IKTS dealt with the analytical evaluation of starting materials and end products, the development of formulations and the production of substrate mixtures. The materials were successfully validated in field tests at a landfill in Saxony. It was possible to establish ground-covering vegetation within one vegetation period without any maintenance or irrigation measures, despite the selected test area exhibiting the typical erosion-favourable characteristics of dumps and landfills (steep slope, exposure to strong wind). Furthermore, the test year of 2019 turned out to be particularly dry with rather high temperatures. In contrast to the surrounding, conventionally covered areas, the trial area also offered a closed canopy formed from mixed vegetation during the monitoring period in 2021. Also, the test site is increasingly colonized by insects and small mammals.

Services offered

- Laboratory tests on nutrient availability and toxicology of fertilizers and substrates
- Development of high-quality fertilizers and substrates from residues and recyclates
- Analysis of environmental impacts and energy balances (LCA)

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Test field for the development of industrial water treatment processes

Dipl.-Ing. André Wufka, Dipl.-Chem. Hans-Jürgen Friedrich

No living being can exist without clean water. The sustainable purification and treatment of wastewater and its return to the natural cycle are therefore highly important. The scarcity of our most important resource, water, due to global warming is also presenting the water industry with new challenges. To ensure that water remains available at industrial sites, treating and reusing wastewater, e.g. treatment plant effluent, is therefore increasingly coming into focus. In this context, the treatment of highly saline process water and the removal of endocrine disrupting trace substances (micropollutants) and thus the fight against the spread of antibiotic resistance and fertility disorders are particularly important topics within the German industrial water management. In order to test innovative water treatment technologies and forward-looking water utilization concepts in practice, Fraunhofer IKTS and Fraunhofer partner institutes have set up an experimental technology and innovation platform on the site of the Bitterfeld-Wolfen Joint Sewage Treatment Plant (GKW). The GKW is one of the largest and most modern wastewater treatment plants in central Germany, treating not just municipal wastewater but also the industrial wastewater from the Bitterfeld-Wolfen Chemical Park (top image).

Technology platform

The platform comprises several test containers as well as test facilities in the form of interconnected modules, flexible to use, for the development, testing and transfer of new technologies. These technologies refer to water desalination and the recovery of process chemicals and raw materials, as well as water stemming from complex industrial wastewater of the Bitterfeld-Wolfen Chemical Park.

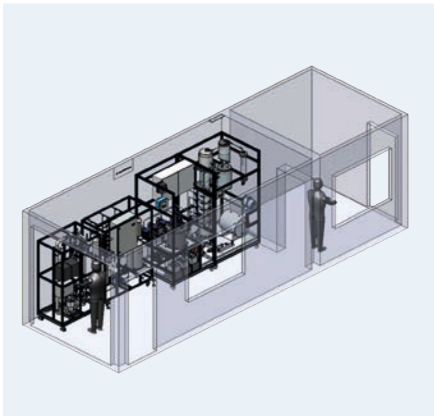
The pilot-scale test plants include filtration plants equipped with ceramic membranes, molecular and bipolar electrodialysis systems for electrochemical separation and recovery, electrolysis plants for the electrochemical total oxidation of water constituents that are particularly difficult to break down, and for sulphate separation and hydrogen generation using the RODOSAN® process. Special attention is paid to the technical replication of processes that are established on a large scale at the GKW, such as expanded granular sludge bed reactors for anaerobic wastewater treatment. This makes it possible to directly investigate the effects of new treatment concepts on the operation of the GKW and to draw important conclusions for a large-scale transfer of the technologies into practice.

With the technology platform, process optimizations and developments can now be transferred directly, and suitable technical solutions can be offered. Transfer potential exists at the specific site of the Bitterfeld-Wolfen Chemical Park itself, in the neighboring Bayer Industrial Park, in the entire Central German Chemical Triangle and beyond.

The authors acknowledge the financial support by the German Federal Ministry of Education and Research (BMBF) in the framework of the stimulus program.

Gefördert durch:
Bundesministerium für Bildung und Forschung
aufgrund eines Beschlusses des Deutschen Bundestages

Joint sewage treatment plant, in background: Bitterfeld-Wolfen Chemical Park (Source: GKW).

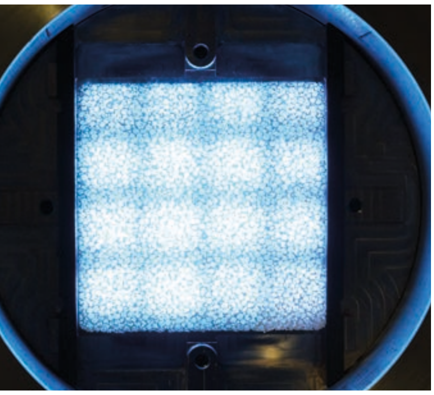


3D model of an experimental container equipped with water treatment systems.

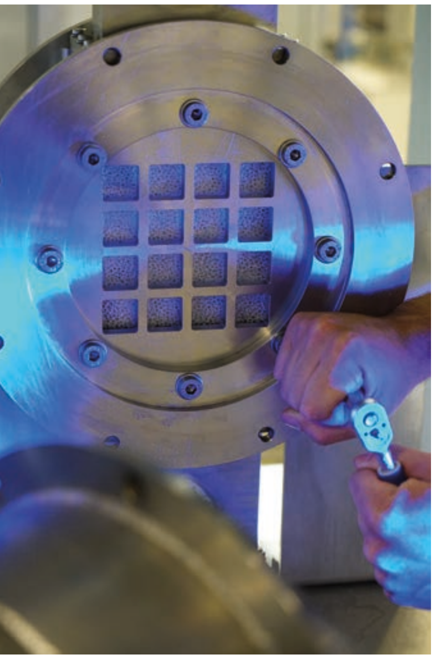
Container setup in December 2021.

Multifunctional test stand for the characterization of ceramic components in water treatment

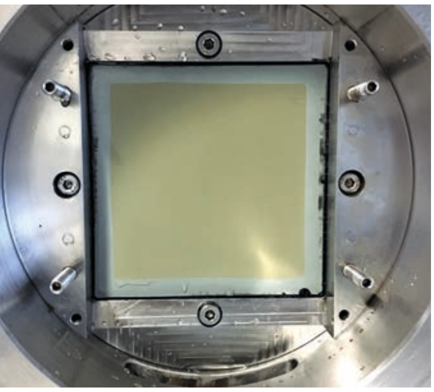
Dipl.-Ing. André Wufka



Cellular TiO_2-coated ceramic under UV-C radiation in the reaction chamber.



Assembly of the photocatalysis reaction chamber.



Top layer on SiC membrane after filtration of wastewater treatment plant effluent.

The concentration of anthropogenic trace pollutants in the water cycle is constantly increasing. These substances include human and veterinary pharmaceuticals (antibiotics, hormones, contrast media), which are discharged into the wastewater system and into surface waters via hospital wastewater, private households, and industrial processes. Against this background, innovative advanced oxidation processes (AOP) are playing an increasingly important role in the treatment of water to make it a safe and pollutant-free resource.

For this purpose, Fraunhofer IKTS develops complex AOP functional components based on functionalized cellular structures catalytically coated with titanium dioxide (TiO_2). For the systematic further development of these multifunctional components into systems ready for practical application, a special test stand was developed, manufactured and put into operation.

Functionality

The developed multifunctional test stand combines the processes of membrane filtration and photocatalysis in a unique way. The flat ceramic membranes used are produced through the multilayer ceramic tape casting of glass-bonded silicon carbide (SiC) and subsequent co-firing. Commercial ultra-fine-grained SiC powders with narrow particle size distributions and d_{50} values of 3 µm and 0.7 µm are used for the membrane layers. This results in pore distributions with d_{50} = 1.5–2 µm and d_{50} = 0.25–700 µm, respectively. The membrane structure is thus in the range of microfiltration. The filtration is operated in cross-flow mode, whereby the feed side of the flat membrane is continuously overflowed in parallel. By adjusting the cross-flow velocity, it is possible to control the particle-laden top layer that forms during filtration. At the same time, the differential pressure between the feed and permeate circuits, the so-called transmembrane pressure, can also be defined. The overpressure generated on the feed side produces a largely particle-free filtrate, which is then immediately subjected to an intense photocatalytic reaction. The catalytically generated, non-selectively reacting hydroxyl radicals are capable of achieving complete oxidation of persistent substances and converting complex water constituents into non-toxic and biologically recoverable substances. After treatment, the purified water is discharged quasi-continuously from the system via relief valves.

Outlook

In the future, the process engineering possibilities of the multifunctional test stand will be systematically expanded. In addition, the traditional low- and medium-pressure UV lamps are to be replaced by UV LEDs, which are currently under development. In the long term, this will enable a significant reduction in the energy required to reduce pollutants.

The project was funded by the European Union and the Free State of Saxony as part of the InfraPro program.

Europäische Union Europäischer Fonds für regionale Entwicklung Europäischer Sozialfonds

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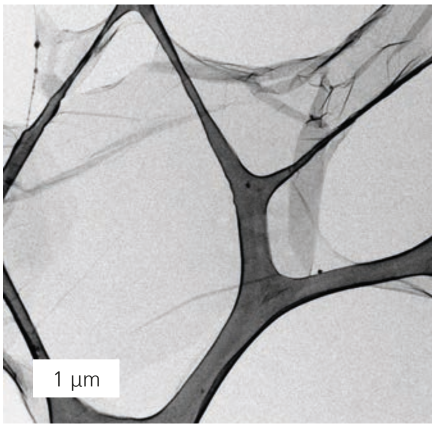
Graphene for micropollutant removal – Thuringian research group "SoWas"

M. Sc. Marc Pezoldt, Dr. Isabel Kinski, Dr. Marcus Weyd



TEM image of graphene oxide.

Micropollutants are immensely challenging for the global water management industry. These water-soluble organic substances are toxic for the aquatic environment, even in small quantities, and they are not removable by conventional three-stage sewage treatment technology.

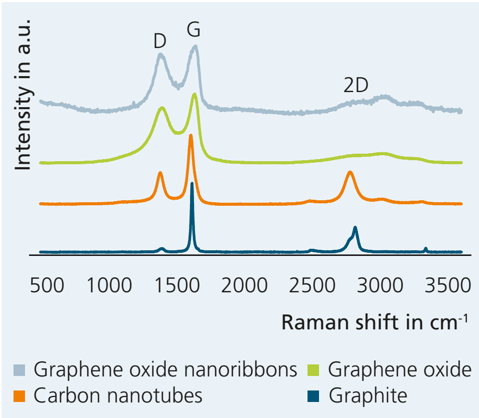
Synergy effects of hybrid process

As part of the research group "SoWas" and in collaboration with the Friedrich Schiller University Jena, Fraunhofer IKTS investigates how to completely remove micropollutants by combining adsorption and oxidation on nanoparticles. To achieve this, the oxidant can be introduced into the process by creating cavitation using ultrasound and/or through photocatalysis using TiO_2. The adsorption can be realized with carbon species such as graphene. Combining these methods creates a synergy effect, and the degradation rate of micropollutants can be greatly increased.

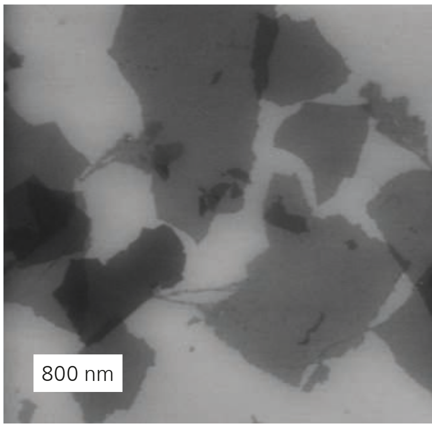
Graphene – an ideal adsorber

Graphene is a 2D material consisting of carbon atoms arranged in a honeycomb lattice. It is characterized by high electrical and thermal conductivity combined with high mechanical stability. Furthermore, graphene has a very high specific surface area, which makes it an extremely suitable adsorbent.

IKTS is able to synthesize graphene and graphene oxide through the exfoliation of inexpensive graphite and by unzipping carbon nanotubes (CNTs). Depending on the chosen starting material and its processing, it is possible to tune the mean graphene flake size within the nm to µm range. These flakes can be then directly bound to TiO_2, the photocatalyst. Furthermore, the adsorption properties of graphene can be adjusted depending on the micropollutants that need to be removed.



Raman spectroscopy for quality control of different adsorbents.

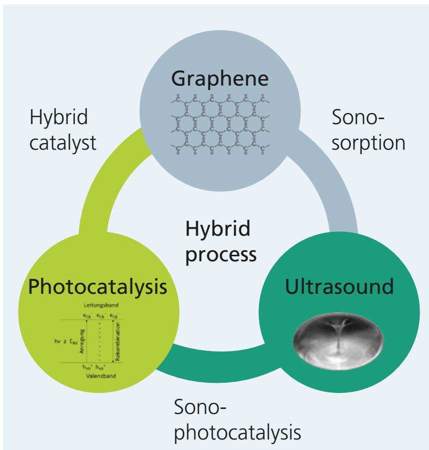


FESEM image of graphene oxide flakes.

Services offered

- Exfoliation of graphite and unzipping of CNTs for graphene fabrication
- Customer-specific functionalization
- Comprehensive characterization of graphene

We are grateful for the financial support provided within the framework of the Thuringian research group "SoWas" (funding code: 2019 FGR 0085) and would like to thank the industry advisory board.



Lines of development of the research group "SoWas".

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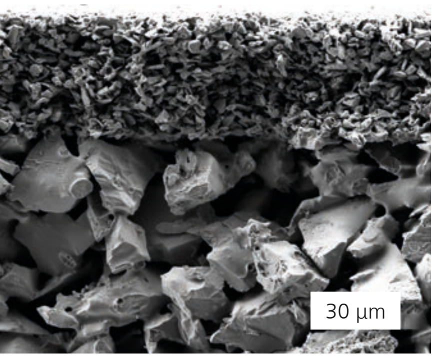
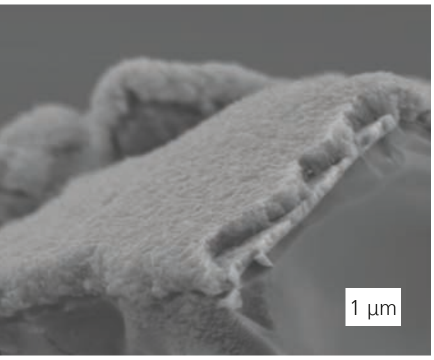
Highly active nanostructured TiO_2 filtration membranes for water disinfection and elimination of trace substances

Dr. Ulrike Langklotz, M.Sc. Sarah Trepte, Dipl.-Phys. Mario Krug

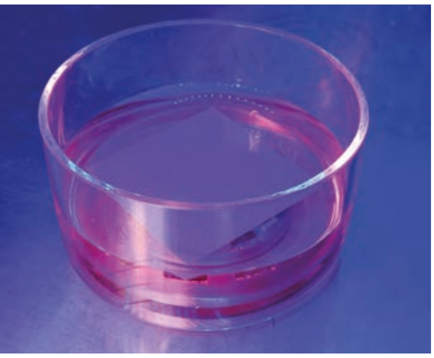


Ceramic microfiltration membrane.

Magnetron sputtering system.



Photocatalytic TiO_2 layer.



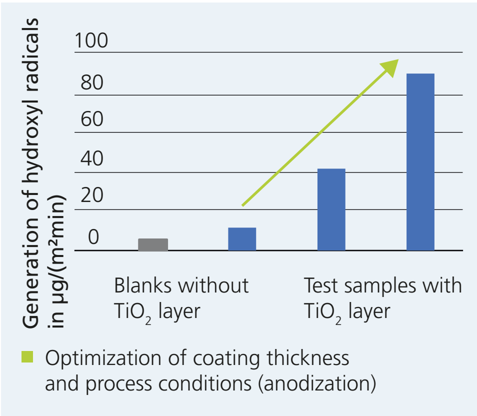
UV activation of photocatalytic membrane in rhodamine B.

Clean drinking water is one of the most precious commodities of our modern civilization, but ensuring its supply as the world's population is growing is a great challenge. The constant input of fertilizers, chemicals or medication residues into our waters and the associated presence of anthropogenic trace substances that are difficult to remove are damaging our available water resources more and more. Photocatalysis is a promising process for purifying water. It enables the complete degradation of organic contaminants without producing residual substances that need to be disposed of. However, solid particles cannot be removed.

A novel approach to comprehensive water purification developed by Fraunhofer IKTS consists in combining a ceramic filtration membrane with a photocatalytically active layer. A porous filtration membrane made of glass-bonded silicon carbide serves as the carrier structure. This is mechanically very stable and has excellent abrasion and corrosion resistance. Titanium dioxide (TiO_2), as photocatalyst, is applied in the form of a nanostructured layer on the surface of the ceramic membrane. This nanostructuring creates a large photocatalytically active surface area.

The ceramic membranes are photocatalytically coated in a two-step process. First, pure titanium is deposited on the ceramic surface by means of the technically very simple and easily scalable magnetron sputtering process. This allows the economically efficient creation of layers with thicknesses between a few nanometers and several micrometers, even on large-area substrates. Subsequently, the dense titanium layers are converted into TiO_2 layers with ordered nanoporosity by means of the technically established process of anodic oxidation, in which closed or porous oxide layers with adjustable morphologies (e.g. pore widths and lengths) are produced by selecting the anodization parameters in a targeted way.

The photocatalytic effectiveness of the nanostructured titanium dioxide layers produced in this way has already been successfully demonstrated in the laboratory. The short-wave UV light irradiation of the TiO_2 induces the formation of highly reactive hydroxyl radicals which break down contaminants oxidatively with high efficiency.



Photocatalytic effectiveness of nano-structured TiO_2 layers on porous ceramic filtration membranes.

The work for this topic was supported by the Deutsche Bundesstiftung Umwelt (DBU) and carried out in cooperation with the company scia Systems GmbH.

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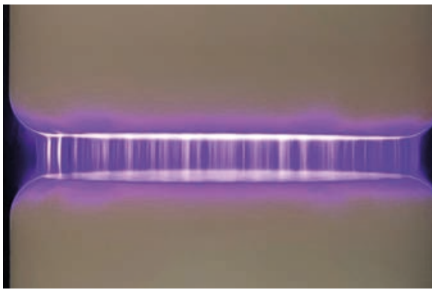
Ceramic electrodes and cold plasma – a combination for efficient wastewater treatment



Cold plasma (purple) (Source: Hochschule für Angewandte Wissenschaft und Kunst Göttingen).

Dr. Hans-Peter Martin, Dr. Axel Müller Köhn, Dipl.-Ing. Anne Mannschatz, Dipl.-Ing. Katrin Schönfeld

The purification of wastewater from industry and urban settlements requires new technologies and processes due to more stringent requirements with regard to water quality and the environment.

Cold atmospheric plasma technology may prove a solution for the challenging chemical and biological decontamination of water. Cold atmospheric plasma can be generated with simple technical equipment and in an energy-efficient way. However, the technical components needed for this relatively new technique have not yet completely matured. Some of them require intensive service and frequent replacement, particularly for long-term use. In order to apply plasma in commercial wastewater technology, it becomes particularly essential to adapt the materials and design of the plasma electrodes, which work under high electrical and chemically-corrosive stress.

Ceramic solutions for plasma electrodes

Plasma electrodes consist of two basic components – an electrical insulator and an electrical conductor. The insulator in particular determines the quality and characteristics of the plasma through its material properties. The plasma characteristics depend on the strength of the electrical field, the frequency and voltage. The electrical permittivity and the dielectric strength of the insulator make it possible to operate the electrode with extraordinary high electrical frequencies or high voltage levels. Extremely high electron temperatures can be reached within the plasma while the overall temperature of the gas is kept around 40 °C. Thanks to this phenomenom it becomes possible to use the high electron temperature to treat temperature sensitive materials against microorganisms or chemical substances.

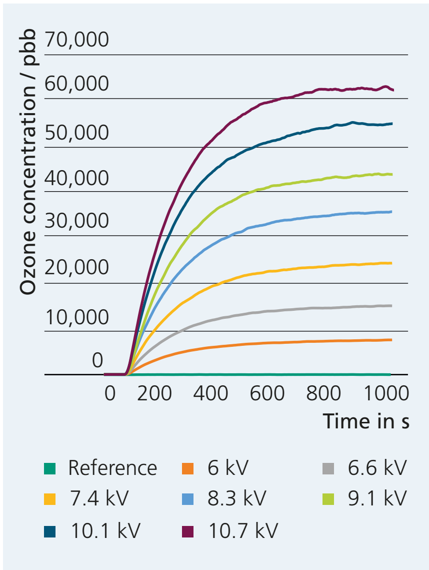
As a side effect, ozone (O_3) is generated. It efficiently neutralizes numerous harmful substances.

The use of plasmas for wastewater purification requires a redesign of electrodes, e.g. a combination with cellular or porous components. Alternatively, aerosol could be an option for supplying water into the plasma. So far, Fraunhofer IKTS has performed manufactural testing of titania-based ceramics as plasma electrodes. Their operational performance was successfully tested in cooperation with HAWK Göttingen (funding code: IGF 20546 BG). The results are promising. The generation of ozone, which can be considered an indicator of plasma efficiency, is superior to other ceramic and glassy insulator candidates. Ceramic insulators achieve much longer operating life compared with plastics. Consequently, service tasks on cold plasma devices can be reduced enormously in future.

Services offered

- Development of ceramic components for cold plasma systems
- Combination of plasma technology with wastewater technologies
- Electrical functional ceramic materials with high chemical and mechanical stability for wastewater technologies

Electrode design.

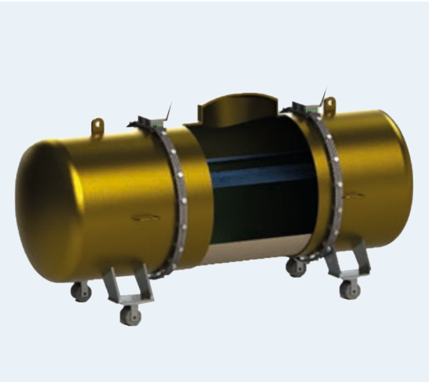


Development of ozone production by plasma over time.

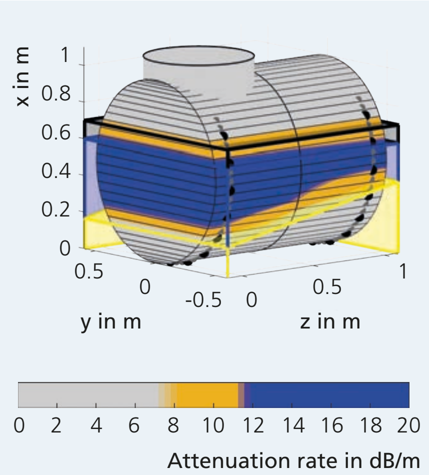
Gefördert durch:
Bundesministerium für Wirtschaft und Klimaschutz
aufgrund eines Beschlusses des Deutschen Bundestages

Precise online determination of vessel filling levels with guided waves

Dr. Bianca Weihnacht, M.Sc. Robert Neubeck, Dipl.-Ing. Tobias Gaul, M.Sc. Thomas Klesse, Dipl.-Ing. Uwe Lieske, Dipl.-Ing. Mareike Stephan, Dr. Lars Schubert



Schematic display of the measurement system as two rings around a horizontal vessel.



Graphic showing the attenuation tomographic measurements by guided waves. The color code on the outside wall refers to the measured attenuation rate, while the color code in the background refers to the real levels of oil (black), water (blue) and sand (yellow) in the vessel. The sand filling was achieved by applying a drainage textile with a tilting angle.

Knowing the precise filling levels in vessels is a common problem, particularly in the chemical industry. Such knowledge can be used to optimize processes and avoid system failures or accidents.

Continuous measurement during operation

The measurement of multi-phase filling levels often has to be performed during operation, while the vessels need to withstand high pressures and often also contain corrosive media. Furthermore, they may be subject to additional safety regulations, e.g. high-pressure tanks in the oil and gas industry, which gravitationally separate the different phases of the crude oil stream. Potential sediment build-up or rapid changes in the composition of the inflow may reduce the operating efficiency or cause undesirable and costly downtime. Reliable non-invasive online measurement could prevent this.

Most commercial level measurement techniques, such as floatings, pressure sensors, ultrasonic pulse-echo techniques, guided radar waves or capacitive measurements, are not capable of reliably measuring multi-phases and especially solid phases. Moreover, they cannot be used externally or on existing vessels without costly structural modifications. Active gamma ray methods are an exception. However, these require additional radiation protection precautions, which prevent people from entering the area. This results in high costs for the online measurement, especially on offshore platforms, which is why this method is hardly ever used for permanent monitoring in practice.

New approach for fill measurement

In contrast to the technologies described above, the solution developed at Fraunhofer IKTS is based on the use of guided elastic waves. Those are excited on the outer wall of a vessel by a scalable array of piezoelectric actuators and then measure the filling state. Along their path on the outer wall, the actively excited guided ultrasonic waves interact with the medium inside, depending on its viscoelastic properties and the excited wave mode and frequency range. Thus, a variety of measurement effects can be used and combined, the main effect is caused by an apparent attenuation through conversion to space waves and other surface waves. Finally, using a tomographic approach, a virtual image of the apparent attenuation on the outer wall can be calculated, corresponding to the contents of the vessel (attenuation tomography). The developed measurement system can be used on tanks and vessels of different geometries with and without insulation. In addition, it has an electromechanical self-testing routine, as well as the ability to detect changes in wall thickness due to corrosion and structural defects, by guided waves.

The work described here was carried out within a long-term cooperation with the company Equinor ASA.

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Mobile ultrasonic rail testing system

Prof. Henning Heuer, Dipl.-Inf. (FH) Stephan Heilmann, Dipl.-Ing. Ralf Schallert, Dipl.-Ing. (FH) Christian Richter, Zsolt Bor, Dipl.-Ing. Frank Macher, M.Sc. Christoph Prüfer, Dr. Frank Schubert, Dipl.-Inf. (FH) Oliver von Kopp

Structure of the SoniQ Rail Explorer for the mobile rail inspection with ultrasound (Source: Vossloh Rail Services).

The requirements for rail-bound route networks are constantly increasing. With the demand for the highest possible level of operational safety, both the scope and the frequency of inspections increase while the time windows available for this are becoming smaller and smaller.

With "Smart Maintenance", a condition-oriented action planning and rail processing, the maintenance process can be simplified and accelerated in a targeted manner.

Success factor digital condition recording

Condition data of rails and switches, such as operational irregularities in the rail interior, corrosion at the rail foot or defects in the volume, are often collected with different systems of non-destructive testing. With the SoniQ Rail Explorer (SRE), developed on behalf of Vossloh Rail Services GmbH at Fraunhofer IKTS, an ultrasonic rail inspection device is now available, which records different data with only one measuring system in only one test run. The combination of various test data, video or ultrasonic signals, supplemented by GPS signal offers the user more security in data analysis and interpretation. Modern data interfaces enable the uncomplicated integration into digitalized process chains.

On the basis of AI-supported algorithms, the SRE can support the inspector in the evaluation process via pre-classification. Each indicator evaluated by the inspector without contradiction increases the performance of the pattern recognition and improves over time both the condition-based maintenance and the measure evaluation using methods of machine learning. With the help of an asset management program, the informative value of the AI-supported forecasts on wear development or service life can be increased.

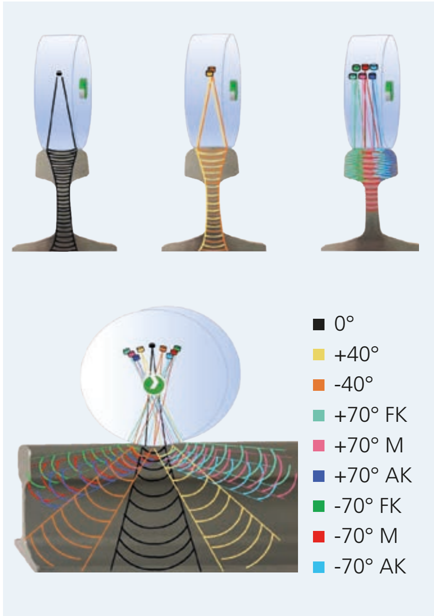
Matured design

With an inspection distance of up to one millimeter, the total of nine probes (0°, ± 40°, ± 70° in the middle, driving and outer edge) both identifiable near-surface irregularities and volume defects in the head, web and foot of the rail according to DIN EN 16729-1 in real time. The findings are visualized to the user synchronized as both A-scan and B-scan as soon as the recording limit is reached. In parallel, extensive raw data can be accessed in support.

With the amplitude-based volume view, the user can – in contrast to the classic aperture technique – subsequently edit the threshold value himself and thus obtain even more revealing information about the reflectors and their dynamics.

The ultrasonic inspection wheel is adapted to the rail profile to be inspected via the permanently rotating lateral guide rollers and reliably positioned above the rail middle. Thereby differentiates the guide system between forward and reverse operation and automatically aligns the stabilized slight inclination of the track rollers with a servo motor.

With its features, the SRE offers a wide range of possible uses that go far beyond simple ultrasonic testing.

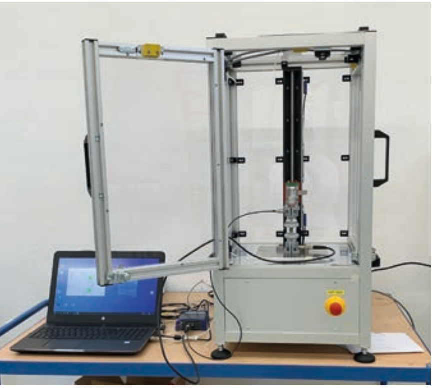


The nine probes of the ultrasonic inspection wheel simultaneously sound into the rail (Source: Vossloh Rail Services).

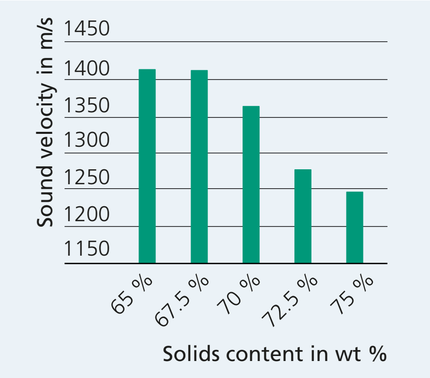
The SRE is ready for use on the track and offers a high test comfort due to its ergonomic design (Source: Vossloh Rail Services).

Vertical-axis ultrasonic measurement system for characterizing slurries

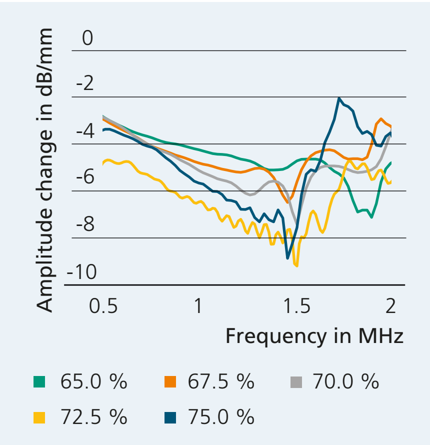
Dipl.-Ing. Susan Walter, M.Sc. Michael Reinhold, Dipl.-Ing. Frank Macher, Dr. Frank Schubert



Vertical-axis measurement system for the characterization of slurries.



Correlation between measured sound velocity and the solid content of a material system for slurries used in cathode production.



Frequency-dependent ultrasonic attenuation for slurries with different solid contents.

In addition to being used for the non-destructive testing of solids, ultrasonic methods are becoming increasingly popular for the material characterization of liquids and slurries as well. In particular, ultrasonic spectroscopy, i.e. the evaluation of frequency-dependent parameters, has proven a very suitable method for characterizing dispersive materials. Unlike optical spectroscopy, it is not limited to translucent materials, which means that opaque and highly filled slurries can also be characterized.

Precise measurements of material characteristics

Fraunhofer IKTS has developed a flexible measurement system for an industrial project in order to evaluate slurries with high solid contents. These are used, for instance, in the production of batteries and need to be evaluated in terms of their composition and mechanical properties.

The vertical-axis system shown in the top figure achieves precise measurements with different test volumes. The system operates in transmission and reflection modes. One ultrasonic probe is fixed to an arm on the vertical axis, which can be moved with a step width of 0.1 mm and a maximum possible accuracy of 0.01 mm. This probe emits an ultrasonic wave that travels through the sample and is received by a second probe. Alternatively, the backscattered echo from the sample can be detected by the transmitter. The system consisting of axis and motor provides a maximum torque of 0.62 Nm. Therefore, it is capable of characterizing even highly viscous materials. The housing complies with the necessary measures for industrial safety and can be fitted with an exhaust system when working with outgassing or hazardous materials. Customized flexible adapters were developed for fastening the probes. They can be produced quickly and inexpensively through 3D printing, thus allowing for the use of different types of probes. A specially developed software controls the axis. For ultrasonic measurements, the system can be combined with the Fraunhofer IKTS PCUS® pro devices or with other commercially available systems.

Characterization of slurries in battery production

This system can measure frequency-dependent sound velocities and attenuation coefficients. From this, it is possible to derive the (visco-) elastic properties of the material. When slurry is characterized, effects such as scattering occur, providing the measured signals with additional information on the material state, for example on microstructure, particle size and concentration. By comparing several measurements at different thicknesses, influencing variables can be minimized, helping to achieve high reproducibility and reliability. The characterization of battery slurries revealed further influencing factors, for example service life and the mechanical pre-treatment of the samples. In the future, the measuring system will also be used for other material systems, such as printing pastes.

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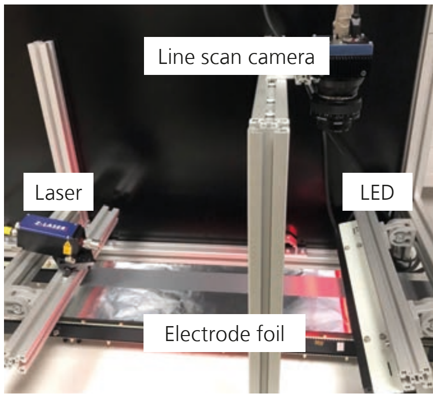
In-line testing of electrode tapes for Lithium-Ion batteries

Dr. Lili Chen, Dr. Ulana Cikalova, Tobias Stüwe, Dr. Beatrice Bendjus



Experimental setup of laser speckle photometry for defect detection on electrode tapes.

High-performance and cost-effective energy storage systems are key components for making the switch to renewable energy resources. The manufacturing costs of Li-ion batteries for mobile or stationary energy storage can be reduced further by minimizing production defects and resulting scrap rates. Detecting defects at an early stage of the manufacturing process and before further processing ensures the highest possible quality with minimal scrap, making battery production resource-efficient.

LSP for fast in-line defect detection and porosity determination

The method of time-resolved laser speckle photometry (LSP) was developed only recently and is suitable for observing optical defects. It allows to determine porosity and surface defects of various types and sizes. Compared with competing measurement methods, LSP is characterized by a simple, robust structure and low costs.

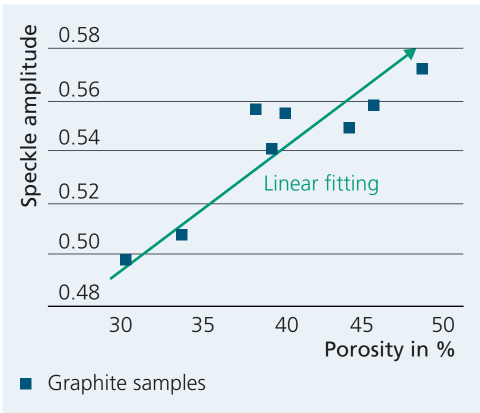
LSP uses a coherent light source, such as a laser, to illuminate the surface being inspected. Unique speckle patterns are generated which contain the morphological information of the surface. The patterns are recorded and processed further by a digital line-scan camera. With the help of image processing and machine learning methods, the defects in the electrode foil can be automatically recognized and classified.

Application in battery production

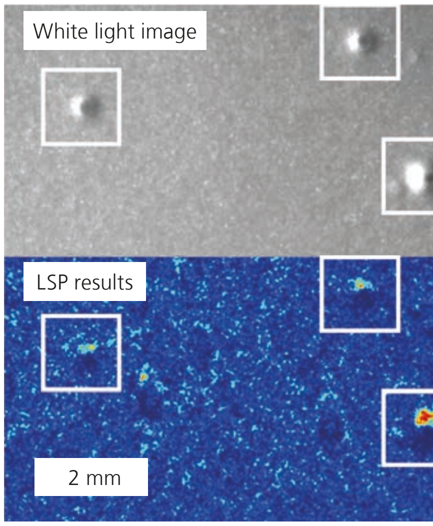
LSP is used in battery production for the inspection of electrode tapes in roll-to-roll processes. After being stimulated by a laser, the optically rough surface of the electrode tapes provides the patterns required for quality evaluation.

A first step consisted in characterizing samples in the form of LTO (lithium titanate) anodes with agglomerates. In addition, if the electrode material is excited by an external thermal source with a short thermal pulse, the porosity can also be determined by evaluating the change of the dynamic speckle patterns. The current experimental setup achieves a measuring speed of 4 m/min for a 16 cm wide electrode tape and agglomerates larger than 70 µm can be detected.

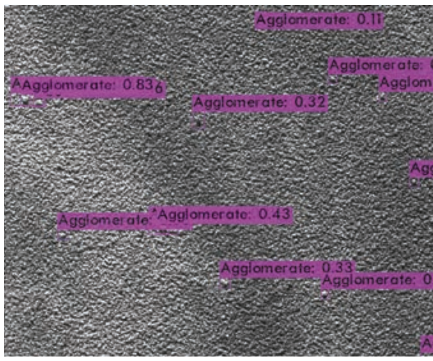
The LSP technology is currently being scaled to a production facility for battery electrodes. This includes drying, calendering and slitting processes.



Dependence of the speckle amplitude on the porosity of the electrode material.



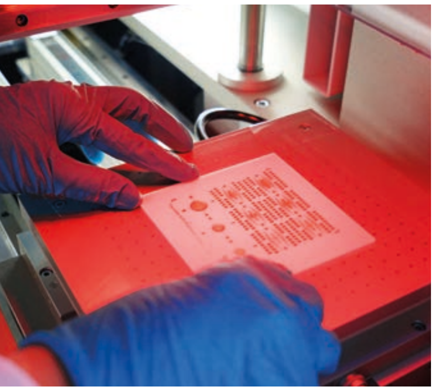
Results of defect detection. Top: white light image with defects. Bottom: LSP results after image processing.



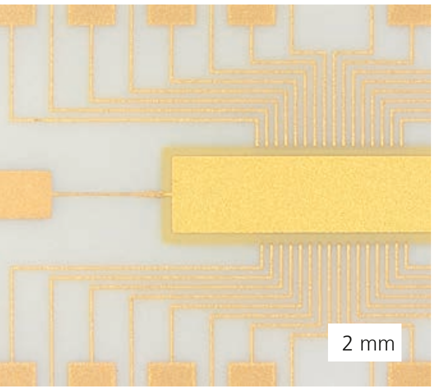
LSP results of defect detection with machine learning algorithms.

Printed ultrasonic transducers for medical imaging and non-destructive testing

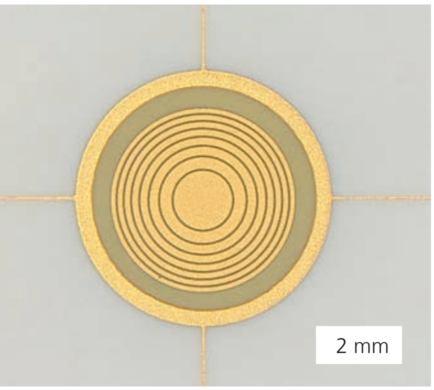
Dr. Sylvia Gebhardt, Dr. Peter Neumeister, Dr. Holger Neubert



Sample alignment in screen printer.



Printed 10 MHz linear array.



Printed 40 MHz annular array.

Ultrasonic transducers are widely used for medical imaging and non-destructive testing. Current research activities focus on improved image resolution, progressive miniaturization, and increased electronic density.

Phased arrays have become the preferred technology for diagnostic imaging. With these solutions, the active piezoelectric plate is divided into several elements, which can be activated and read out separately. This allows for electronic scanning, steering and focusing of the ultrasonic beam.

Conventional manufacturing technologies for ultrasonic probes are based on different dicing and mounting steps, which are complex and time-consuming. Additionally, adhesive layers as well as solder and bond pads can influence acoustic emissions.

Cost-effective manufacturing on a large scale

Fraunhofer IKTS has recently developed a novel manufacturing route for ultrasonic transducers based entirely on printing techniques. At the heart of the technology are piezoceramic thick films which are applied on planar or tubular substrates through screen-printing.

The design of the ultrasonic transducer is defined by the printing pattern, or more precisely the screen openings through which the thick film paste is applied. This happens very fast and with high reproducibility.

The performance of an ultrasonic transducer is influenced not only by the piezoceramic thick film itself, but also by the substrate material, the electrode design, and the acoustic matching layers. Materials have been developed for this porous substrate which directly serve as backing material for damping acoustic delay lines.

The array design is mainly defined by the printed electrodes, where lines with 70 µm width and 120 µm pitch are possible through screen printing, allowing for the cost-effective production of ultrasonic transducers with working frequencies of 10 MHz for linear arrays and 40 MHz for annular arrays. Moreover, it is possible to apply acoustic matching layers by pad printing to improve the transmission of ultrasonic waves into water or tissue.

The printed ultrasonic transducers are free from interfering adhesives and offer the advantage of three-dimensional packaging with printed electrical contacts on top or inside the substrate material (for instance by using ceramic multilayer substrates). This eliminates the need for voluminous solder or bond pads and improves the resonance behavior. The printed ultrasonic transducers are very compact and thus meet the requirements for miniaturization, price reduction and high functional density, making them ideal for applications in mobile devices, such as smartphones.

Acknowledgement

The work was supported by the German Ministry of Economic Affairs and Climate Action (BMWK) within the Industrial Collective Research project 20099BR of the German Ceramic Society DKG via AiF.

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Bundesministerium für Wirtschaft und Klimaschutz

Industrielle Gemeinschaftsforschung IGF

Forschungsnetzwerk Mittelstand AiF

aufgrund eines Beschlusses des Deutschen Bundestages

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Ultrasound for a faster and safer dental root canal treatment

Dipl.-Ing. Eric Haufe, Robert Kirchner, Dipl.-Ing. Fabian Ehle, Dr. Holger Neubert, Dr. Peter Neumeister, Dr. Sebastian Stark

Root canal treatment is certainly one of the most unpleasant dental treatments. Within the IPUCLEAN project, Fraunhofer IKTS, together with the Rostock University Medical Center and the companies Komet Dental, Werner Industrielle Elektronik, and Zahntechnik Leipzig, is developing an intelligent ultrasound system for root canal treatment, which reduces the duration of the treatment as well as any complications.

Simultaneous rotation and translation

In contrast to established systems, a translational motion in axial direction is superimposed on the rotational motion of the tooth file, while the root canal is purged at the same time. As a result, the cleaning step, which is currently still necessary to avoid failure of the tooth file, can be omitted. To generate the translational motion, a piezoceramic stack actuator is used, developed at IKTS specifically to satisfy these requirements. The suitability of a conventional lead-based as well as a lead-free piezomaterial is being investigated. With regard to transducer design, a particular challenge lies in the low operating voltage, which necessitates unusually thin individual layers of the actuator stack.

From laboratory prototype to function demonstrator

As a first step, a laboratory prototype was developed and tested. The oscillation behavior was investigated with a laser vibrometer. Based on these results, a function demonstrator was designed and built. In this context, the main challenge was to miniaturize the assembly as needed. This necessitated e.g. the custom development of a miniature slip ring based on a circuit board using tiny spring probe pins to contact the piezoceramic actuator and measure the penetration depth of the tooth file. The function demonstrators are currently being evaluated. In this context, it has already been found in fracture tests that tooth files with small diameters achieve a longer service life. For the future, further development of the control electronics is planned with regard to the optimal oscillation behavior of the tooth file depending on its penetration depth into the root canal. Additionally, further miniaturization is required before the system is market-ready.

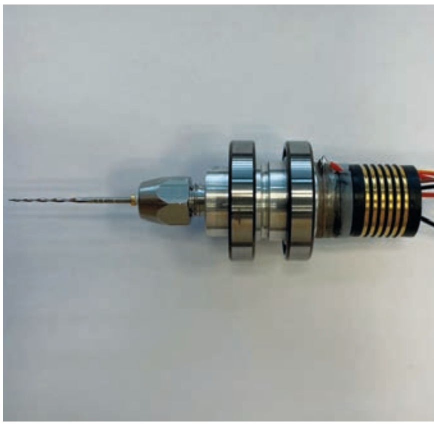
Transfer to other applications

Within the project, Fraunhofer IKTS has acquired competence for medical applications involving oscillating actuators. In particular, the know-how for the design of such actuators using lead-free piezo ceramics is groundbreaking and can be transferred to many other applications, such as ultrasonic cleaning and non-destructive testing.

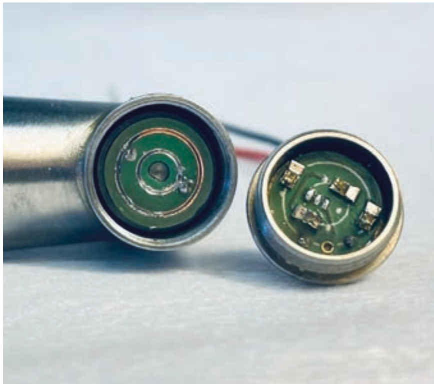
The project is funded by the German Federal Ministry of Education and Research (BMBF) as part of the Twenty20 – Partnership for Innovation program (funding code: 03ZZ1043E) and the smart^3 consortium and runs until May 31, 2022.

smart^3 materials solutions growth

Gefördert durch: Bundesministerium für Bildung und Forschung
aufgrund eines Beschlusses des Deutschen Bundestages

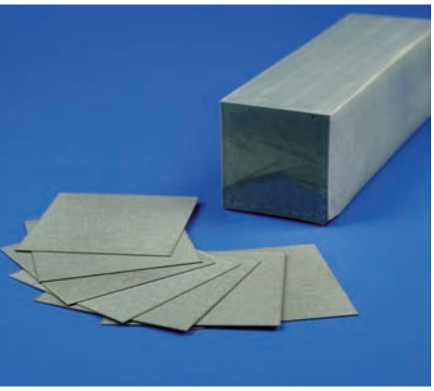


Laboratory prototype.

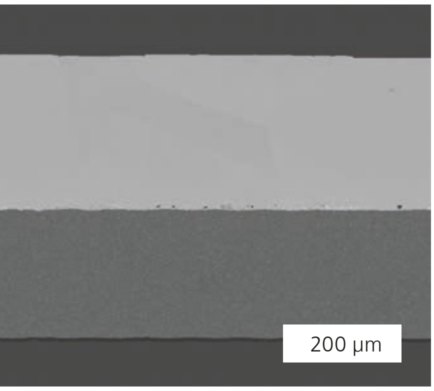


Miniature slip ring based on a circuit board.

Function demonstrator.



Si_3N_4 ceramic substrates produced by multi-wire sawing (2 x 2 inches).



Joining zone of an active metal-brazed Cu-Si_3N_4 composite.

Measurement test setup with AMB-DUT (device under test) and PRPD-pattern (phase-resolved partial discharge).

Cost-effective copper-silicon nitride composites as circuit boards for power electronics

Dr. Jochen Schilm, Dr. Axel Rost, Dr. Mathias Herrmann, Dipl.-Ing. Lea Schmidtner, Dr. Eveline Zschippang, Dr. Sindy Mosch, Dr. Nikolai Trofimenko, Dr. Lars Rebenklau, Dipl.-Ing. Henry Barth

Structured metal-ceramic substrates are an important component for power electronic components as circuit boards. Existing solutions such as directly bonded copper-aluminum oxide (DBC, direct bonded copper) or active metal-brazed copper-aluminum nitride substrates (AMB, active metal brazing) cannot meet the future requirements of electromobility and realize the full potential of new silicon carbide (SiC)-based semiconductor components. One solution might be composites with silicon nitride (Si_3N_4) ceramics with their superior mechanical properties. This enables metallized ceramic substrates to be used in power electronic assemblies with significantly improved stability against the active and passive thermal cycles.

In the joint project CuSiN, Fraunhofer IKTS and its partners are developing reliable and high-performance copper-silicon nitride (Cu-Si_3N_4) substrates using active metal brazing (AMB technology). Ceramic Si_3N_4 substrates with thicknesses < 320 µm made by means of multi-wire sawing of sintered Si_3N_4 blocks already show thermal conductivities > 90–100 W m^{-1} K^{-1} and strengths > 700 MPa (top image). The basis for this is particularly low-oxygen content Si_3N_4 powders in combination with aluminum-free additives. A project novelty is the possibility to sinter compact Si_3N_4 substrates with dimensions up to 5 x 7 inches to homogeneous and very low porous microstructures.

New filler metal brazing pastes suitable for automated screen printing are required for joining copper films to Si_3N_4 substrates by active brazing. In addition to good bond strengths (currently up to 25 N per mm copper width), the joining zones must be as pore-free as possible to ensure high reliability of the bonds (middle figure). This is achieved by paste formulations with homogeneously distributed, minimal proportions of active phases and active filler metal layers of less than 25 µm. Furthermore, a reliable removal of organic binder components from printed filler metal layers in planar Cu-Si_3N_4 assemblies is possible even in ultra-high vacuum below 380° C. The brazing process is optimized with regard to low-defect brazed filler metal zones, high bond strengths and minimized filler metal amounts.

In the field of characterization of active metal-brazed Cu-Si_3N_4 substrates, investigations of the partial discharge behavior require the development of new methodological approaches. Partial discharge measurement is a non-destructive characterization method for detecting defects in dielectrics. Customized measurement set-ups and analysis methods can record partial discharge processes with high temporal resolution and create an understanding of these effects by correlating them with material and substrates properties.

Based on the findings obtained within the framework of CuSiN, the field of offered services includes the development of Si_3N_4-ceramics, active filler metal pastes and active metal brazing processes as well as material specific and electrical characterization of copper-ceramic substrates.

Gefördert durch:

Bundesministerium für Wirtschaft und Klimaschutz

aufgrund eines Beschlusses des Deutschen Bundestages

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Highly dynamic ceramic matrix heaters for generating fast temperature fields

Dr. Lars Rebenklau, Dr. Uwe Scheithauer, Dr. Stefan Münch, Dr. Mike Röllig, Dipl.-Ing. Henry Barth, Dipl.-Ing. Eric Schwarzer-Fischer

A large number of technical manufacturing processes are based on the precise temperature control of process goods or chemical reagents. Because of their technical properties, ceramic materials and technologies are suitable for implementing selected heater applications in the geometrically mesoscale range of a few millimeters. One example is a highly dynamic and actively cooled matrix heater for generating fast temperature cycles. Such heaters consist of individual pixels that are combined to form a matrix. Supported by a simulation-based design of these components, well-known technologies such as thick-film technology are symbiotically combined with modern additive manufacturing techniques for ceramic materials at Fraunhofer IKTS.

FEM-supported design

The base bodies were designed with the finite-element method. The requirements of the specific temperature cycle profiles were used to identify optimal material combinations, the thermoelectric heater layout and the ideal set-up of the internal cooling channels. The aim is to avoid mechanical fractures by reducing the residual mechanical stresses in the material composite between the conductive pads and ceramic structure. For this purpose, variable heater layouts as well as cooling channels in differing shapes, quantities and positions were evaluated with respect to homogeneous temperature fields and the mechanical stresses in the interfaces. The stresses were simulated along the production chain and under operating loads.

Additive manufacturing of ceramic base bodies

Ceramic materials can only be machined at great expense due to their typical high hardness and low ductility. Additive manufacturing processes are "game changers", since complex geometries can be realized close to the final contour and functions, such as cooling channels, can be implemented even in small volumes. This results in larger geometric degrees of freedom and completely new fields of application, e.g. in medical engineering or for the Fourth Industrial Revolution. Fraunhofer IKTS uses various additive manufacturing processes for ceramics.

Functionalization

The optimized and additively manufactured ceramic components are functionalized using the well-known thick-film technologies. Electrical circuits, heating elements and sensors are printed in a structured manner and fired onto the ceramic basic structure.

Electrical contacting is achieved by means of advanced assembly and connection technology. Solutions up to temperatures of 350 °C have been successfully realized. High-temperature applications up to 600 °C are currently being tested. Temperature gradients of up to 70 K/s have been demonstrated successfully.
The project "DynaCool" is funded by the German Federal Ministry for Economic Affairs and Climate Action (BWMK) (funding code: 16KN054345).

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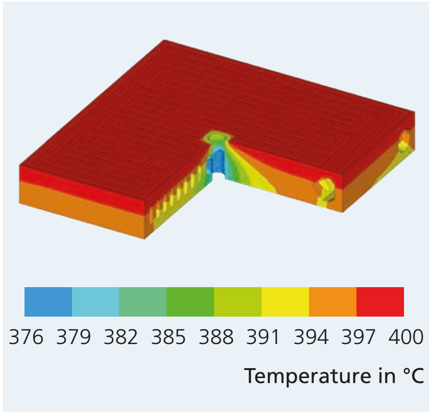
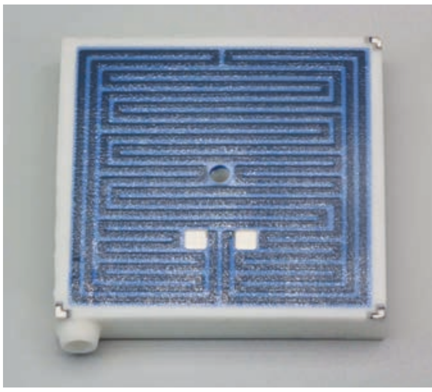
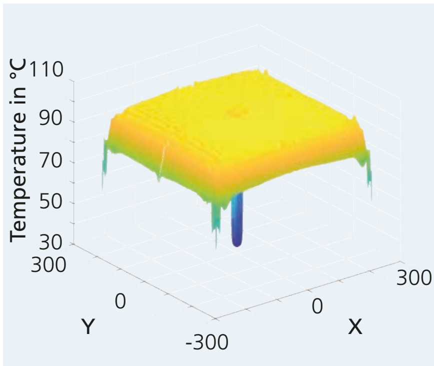


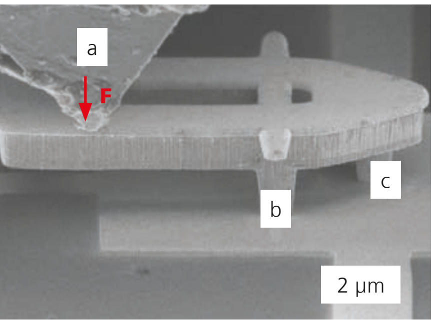
Design of the ceramic base body using finite-element modeling.



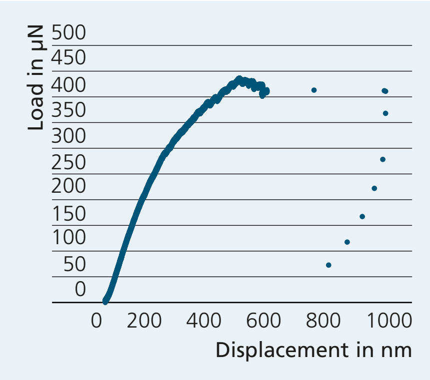
Additively manufactured ceramic base body with thick-film functionalization.



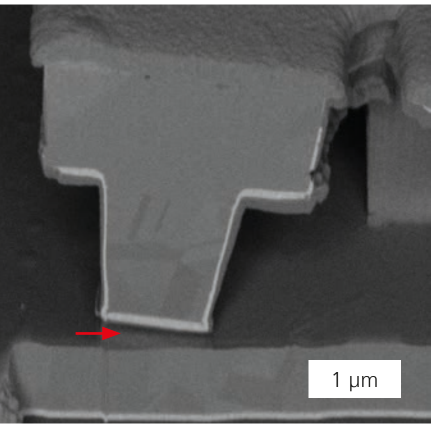
Temperature field over one single pixel.



SEM image of a test structure with the indenter tip (a) in contact.



Load-displacement curve of an experiment.



Cross-section of a tested copper via. The red arrow indicates the delaminated interface between diffusion barrier and copper.

Micromechanical in-situ experiments on copper interconnect structures

Dipl.-Ing. Wieland Heyn, Dipl.-Phys. Hanno Melzner[1], Dr. Klaus Goller[1], Dr. Sergey Ananiev[1], Dr. Johannes Zechner[1], Dr. André Clausner, Prof. Ehrenfried Zschech ([1] Infineon Technologies)

Adhesion testing for the reliability of microelectronic devices

Adhesion testing methods for very small wiring levels in microelectronic devices [back-end-of-line (BEoL) levels], are critical for the manufacturing and reliability testing of modern microelectronic structures. However, very few measurement techniques exist, and moreover, they do not allow the inclusion of product-identical size scaling or realistic structures in the study of interface properties. Therefore, an in-situ nanoindentation-based SEM approach was developed at Fraunhofer IKTS. It enables investigating product-like copper via structures that are just a few micrometers in size – and thus for the first time analyzing the interfaces of individual industrially manufactured vias.

Optimized micromechanical experiments

For the new approach, a nanoindentation system is installed inside the vacuum chamber of a scanning electron microscope (SEM). This makes it possible to accurately position the wedge-shaped indenter tip on the micron-sized test structures. The test structures are designed as cantilevers (top image). For the investigations, a load is applied to the cantilever at its freestanding side using the indenter tip (a); the force is then converted into a tensile force through a hinge via (b). This hinge via then engages, across the rear via (c), on the via underside of the interface under investigation. This causes the interface under the rear via to delaminate. In the recorded load-displacement data, the delamination event is indicated by a severe load drop (middle figure).

High variability of test structures

The test structures are prepared using the copper damascene process, which is widely applied in the industrial manufacturing of BEoL structures and generates test structures with a large variety of designs. This allows for other experimental designs, such as the testing of interfaces for different loading modes. Also, the process generates a high number of identical test structures to ensure that measured data are statistically well reproducible.

By slightly altering the manufacturing sequence, it is also possible to create different interfaces on the test via. Important interfaces with regard to the reliability of BEoL structures exist, for example, between copper, silicon nitride, diffusion barriers, and silicon oxide. The bottom image exemplifies the cross-section of a delaminated interface between copper and a diffusion barrier (indicated by a red arrow).

The interfacial delamination made quantitatively accessible by this method forms the basis for FEM simulations which support reliability testing and help improve the design of interconnect structures in microelectronics.

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Testing machine for CT units

Dr. Peter Krüger, Dipl.-Ing. Claudius Birkefeld

Composite materials get their properties from the combination of their components. Different failure variants occur in loading scenarios. Temporal stages of failure (e.g. fiber or matrix fractures in fiber composites) can often be visualized using computer tomography (CT).

For highly structured materials, such as foams, it is the morphological changes under load that are of interest. This is especially true for the design of biocompatible materials that can serve as bone substitutes. The porous structure of the substitute materials as well as the bonding to the bone are of particular interest for investigation.

Principle behind the machine integrated into the CT

A test setup that applies different loads to the test specimen must fulfill conflicting requirements when integrated into a CT unit. On the one hand, the tensile testing machine must be strong and rigid in order to absorb the forces that occur. On the other hand, any auxiliary equipment placed in the X-ray beam must be light and as little X-ray-absorbent as possible. In addition, the specimen must be accessible from all sides during a tomographic examination. If these requirements are not observed, visible artifacts will appear in the tomography, possibly obscuring the features and effects of interest. Ultimately, the entire setup must not be too heavy for manipulation during the CT scan.

Considering the above requirements, an inspection device for 4D CT-testing was designed, which is divided into two design sections. The upper section comprises the actual tensile tester, consisting of guide rails, displacement bolts, force and position measuring devices and the control electronics. The lower section is the specimen chamber where the actual testing takes place. The upper and lower sections are connected by a tube made of carbon fiber-reinforced plastic (CFRP). The material offers good X-ray transparency and outstanding mechanical resistance.

The specimen is mounted externally on a specimen holder to make the assembly more stable. The specimen including specimen holder is mounted in the apparatus well above the X-ray beam. The sliding mechanism is then used to move the assembled group into the measuring position, where the lower counterholder is positioned, into which the measurement assembly is tightened by a vice similar to the upper one.

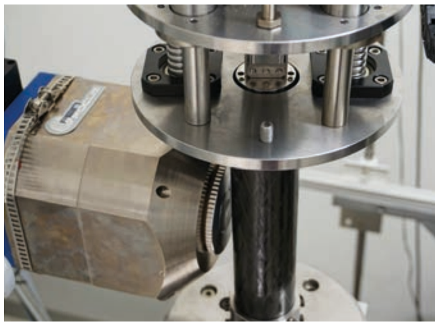
The following measuring modes are also possible as series tests:

- Tensile test
- Compression test
- Bending test
- Shear test

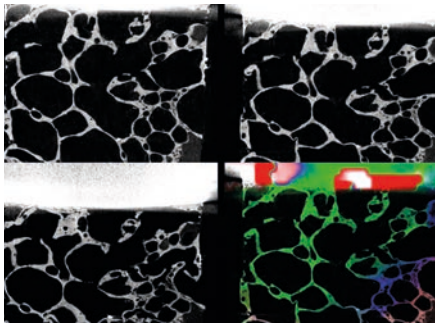
The design force for the tensile and compression tests is 10 kN. The overload capacity is 4 fold for tensile tests and 30 fold for compression tests.

The loading machine is equipped with a controller for local and remote operation.

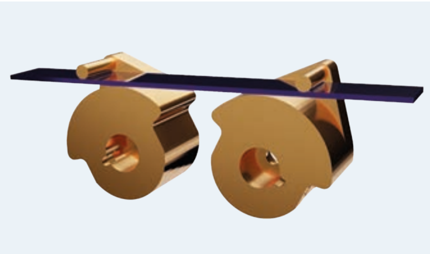
General view of the testing machine for loading in CT units.



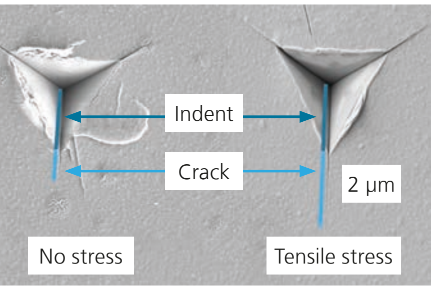
The specimen assembly is pushed into the CFRP tube from above.



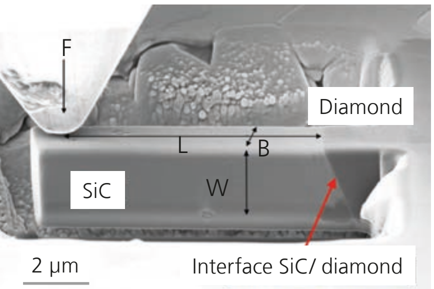
Compression test of an aluminum foam: Different stages, color-coded displacement vectors.



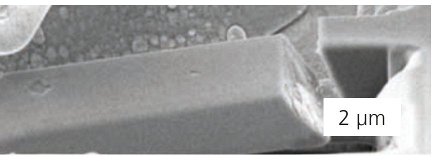
Patented in-situ four-point bending tool.



Nanoindentation experiments at non-strained (left) and tensile-strained silicon dioxide thin films (right) leading to big differences in the ratios between indentation corner length (IL) to crack length (CL).



Focused-ion-beam-prepared micro bending cantilever for testing the SiC to diamond interface in the microstructure of a SiC-bonded diamond material [1].



In-situ micro-bending test in the scanning electron microscope showing adhesive interface failure between SiC and diamond [1].

Determining microscopically adhesive and cohesive material behavior

Dr. André Clausner, Prof. Silke Christiansen, Dr. Mathias Herrmann, Dr. Peyman Yousefi, Dipl.-Ing. Christoph Sander

The macroscopic behavior of heterogeneous materials and components is mainly determined by micromechanical properties. This is especially true for microscopically structured systems, such as for instance thin-film systems. Therefore, characterization on the microscopic level is essential, besides macroscopic characterization, to understand the behavior of materials and systems. Only this understanding enables the target-oriented future development of structural and functional ceramics, microelectronics, as well as micromechanical systems.

When it comes to micromechanical characterization, Fraunhofer IKTS has vast amounts of experience and equipment, e.g. in measuring local elastic properties, mechanical stress at room and elevated temperatures, stress-strain curves, local adhesion of interfaces and grain boundaries of structural and functional materials, as well as in determining the cohesive behavior of thin films.

Microscopically cohesive failure of silicon dioxide thin films

Thin films made of silicon dioxide (SiO_2) serve as insulating layers in microelectronics and must be highly stable against cohesive fracture propagation, which requires quantitative determination of cohesive properties of the thin-film material. However, thin-film systems are not suitable for macroscopic characterization methods, due to their dimensions. Therefore, nanoindentation (NI)-induced fracture propagation is used. To separate the measured cohesive material parameters from the superimposed residual stresses of the films, the NI fracture experiments must be conducted at several different stress states of the film. This is done with the in-situ four-point-bending system (top image), developed and patented at Fraunhofer IKTS. With application of this system, the stress in the SiO_2 film can be adjusted to different levels, at which NI fracture tests can be readily conducted. The different stress levels lead to considerable differences in fracture propagation (second figure). With this information, a fracture toughness can be derived that is free from the effects of residual stresses.

Stability of diamond – silicon carbide interfaces

The firm inclusion of diamond particles in silicon carbide (SiC)-embedded diamond materials is essential for the immensely high wear resistance and hardness of these materials. The stability at the interfaces between diamond particles and SiC matrix can be investigated through microcantilever beam tests in the vacuum chamber of a scanning electron microscope and subsequent inspection of the fracture surface. The microcantilevers can be prepared with such precision, using a focused ion beam (FIB), that the interface of interest is located at the fixed end of the cantilever beam (third figure). Thereby, the cantilever is stressed with a high-resolution indenter, acquiring load-displacement curves (bottom figure). With this method, it was possible, for the first time, to confirm the firm embedment of the diamond particles via the epitaxial growth of the SiC matrix during fabrication. [1]

Literature

[1] Ast et. al (2021), doi: 10.1016/j.oceram.2021.100176).

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Thermophysical properties of hardmetals as a function of microstructure

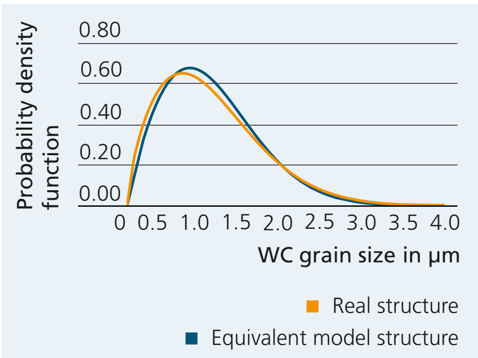
Dipl.-Phys. Jakob Schöne, Dipl.-Ing. Anne Vornberger

Tungsten carbide-cobalt hardmetals (WC-Co) have high hardness and good fracture toughness and are therefore widely used as cutting tool materials. The requirements for such tools increase with higher cutting speeds or the increasing share of hard-to-cut materials. In addition to mechanical properties, other properties, such as the thermal conductivity of the tool material, are of particular importance because high temperatures occur locally during the cutting process.

Although the fundamental relationships between microstructure and hardmetal composition are known for technically relevant properties, such as thermal conductivity, from empirical investigations of WC-Co hardmetals, making model-based predictions in order to tailor properties specifically remains highly desirable. A particular challenge consists in the strong influence of intra- and interparticle interface properties. These cannot be described satisfactorily by conventional state-of-the-art models. Modern methods of structurally detailed numerical modeling are an efficient alternative, in which a voxel-based, synthetically produced 3D geometrical model of the microstructure is used as the basis for analyzing the correlations between microstructure and properties and predict properties or specifically design the microstructure.

Fraunhofer IKTS has developed a workflow for such an analysis platform by connecting commercial, open-source and internally developed modeling tools (GeoDict, ANSYS, CCBuilder, FiPy, Mathematica) and tested and validated it by applying it to the example of thermal conductivity of WC-Co composites. Particular attention was paid to the specific shape of the interface description, which avoids the misrepresentation of the bulk volume fractions that often occurs when using voxel models. Extensive experimental data from qualitative microstructure analysis and thermal conductivity measurements was used for comparison to demonstrate that a very good agreement between models and experiments could be achieved with the new methodology. The accuracy of the results obtained exceeded the previous empirical model description significantly.

The prototypical application of this method can serve as a functional template for a microstructure-model-based property design for this material type. The general workflow developed for voxel-based synthetic microstructure analysis is also suitable for other material groups (composites, cellular materials) and properties (electrical, material transport, mechanical).



Comparison of real and synthetic virtual structure.

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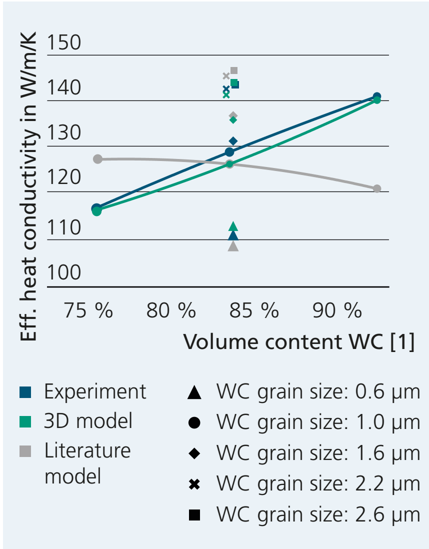
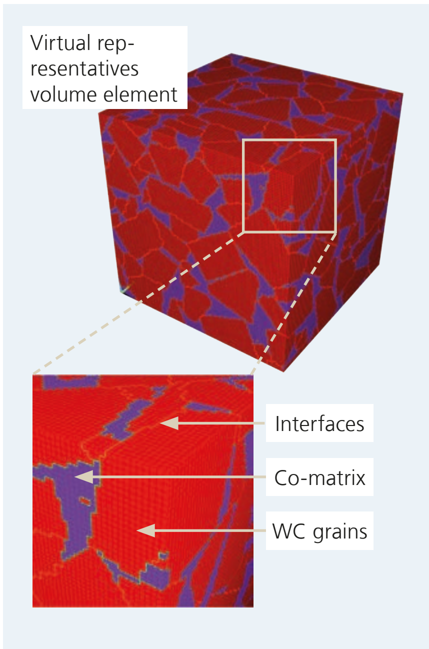
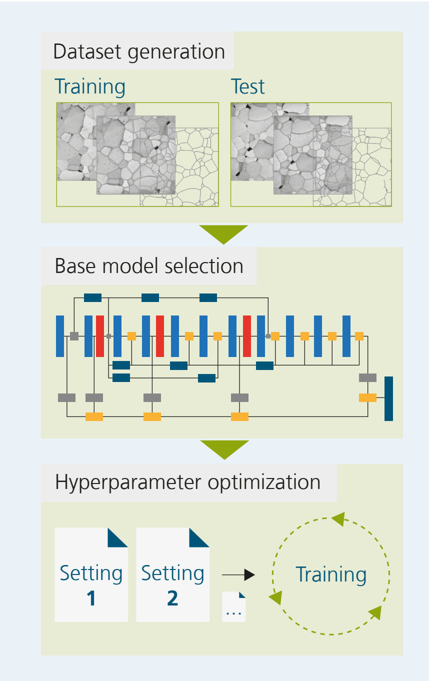
Real structure.



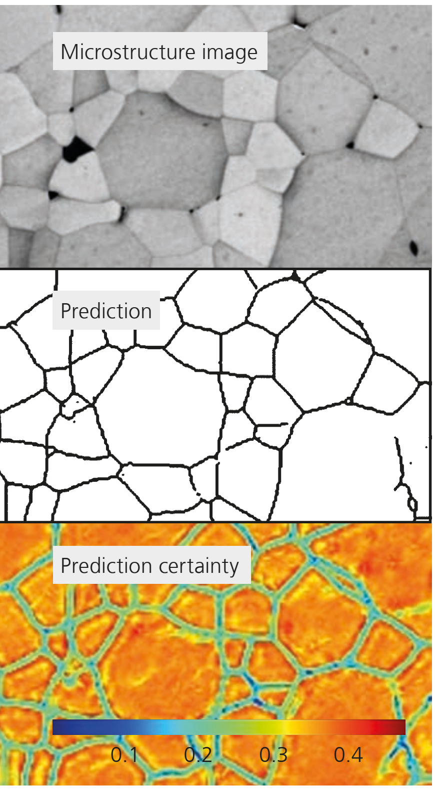
Results of comparison of 3D model, state of the art literature model and experimental data.



Voxel-based RVE geometry with interfaces.



Flowchart for the development of AI-based models for grain boundary detection.



Model evaluation using the example of an Al_2O_3 microstructure by means of model prediction and prediction reliability.

AI-based quantitative microstructural analysis of ceramic materials

Dipl.-Ing. Jan Klein, Dr. Björn Matthey, Dr. Sören Höhn, Dr. Mathias Herrmann

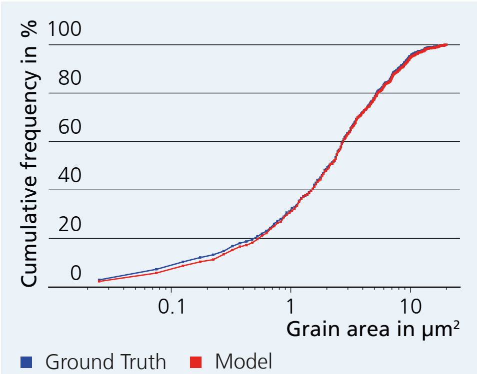
The quality and properties of ceramic materials strongly depend on their microstructure. In quantitative microstructural analysis, the grain boundaries must be identified correctly to form the basis for further steps. These boundary data are indispensable for reproducible results in both planimetric and line cutting methods. Traditional image processing methods used for this purpose, such as segmentation based on simple threshold values or other separation methods, reach their limits depending on the optical appearance of the microstructure. Therefore, grain boundaries are often detected manually in practice, leading to high costs, time expenditure and subjective results.

In recent years, modern AI-based image processing methods have proven their worth in diverse use cases with complex visual problems. They are becoming more and more popular in the field of material science.

Fraunhofer IKTS has developed a deep learning approach based on convolutional neural networks (CNN) for the detection of grain boundaries. This approach is based on a data set consisting of microstructural images of the material to be analyzed and the corresponding manually marked grain boundaries (ground truth). A special architecture from the field of edge segmentation was chosen for the CNN. The CNN was trained with specific, specially developed loss functions. Extensive automated hyperparameter tuning helped to find optimal hyperparameters, i.e. parameters that influence the training process and thus the final performance of the CNN.

The model performance is evaluated both visually and statistically. For the visual evaluation, model predictions are compared with the ground truths. In addition, visualizations of the predictive security provide information on which areas of the structure are challenging for the model.

During the statistical evaluation, both ground truth and model predictions are analyzed and compared planimetrically. The following diagram shows results using aluminum oxide (Al_2O_3) as an example. The training of the underlying model is based on microstructural images with only about 1300 grains.



	Ground Truth	Model
A50	2.14 µm²	2.14 µm²
A10	0.14 µm²	0.19 (+0.05) µm²
A90	8.01 µm²	8.33 (+0.32) µm²

Statistical model evaluation.

Services offered

- Reproducible microstructural analysis incl. adapted ceramographic microstructural preparation and FE-SEM images
- Development of AI models for the microstructural analysis of different material systems
- Training and analysis of customer data and materials for evaluation of the models

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Metal-matrix composites with diatoms as fillers

Dr. Jürgen Gluch, Dr. Birgit Jost

Diatomaceous earth is a biogenic siliceous sedimentary rock and consists mainly of fossil diatom shells (frustules). It can be extracted on a large scale and used as a natural component of composite materials.

If the cylindrical frustules, which are up to 100 micrometres in size, can be embedded homogeneously in a metal matrix, it is possible to set specific mechanical properties for this composite material.

Microstructural analysis for ideally designed composite materials

The design of such composites requires detailed knowledge of the geometry and mechanical properties of the diatoms used. Various imaging methods (correlative microscopy), allow to obtain a comprehensive 3D analysis of the composite.

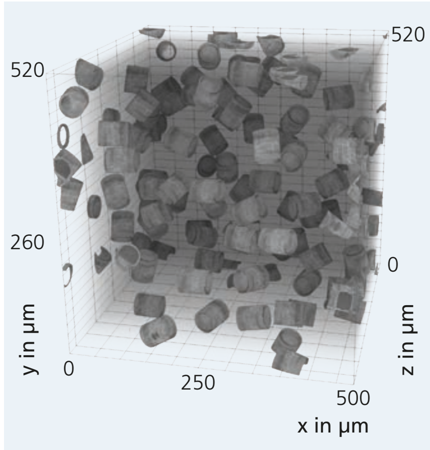
X-ray nano-tomography enables high-resolution, three-dimensional imaging of individual diatoms. The combination with in-situ loading tests allows to determine the forces that cause individual frustules. This data is the starting point for material simulations accompanying the project. On the one hand, the stress distribution in and around the pore formed by the frustule can be simulated. On the other hand, large FE models can be created directly from tomography data. The mechanical properties can be estimated through the software-supported generation of models with different filler contents. The results are used to produce and investigate test specimens in a targeted manner.

Pretreatment of frustules

To ensure that the diatoms in the metal-matrix composite form pores enclosed by frustules as uniformly as possible, the diatomaceous earth must be cleaned. For this purpose, wet sieving is advantageous over dry sieving, because it removes more fragments and foreign bodies.

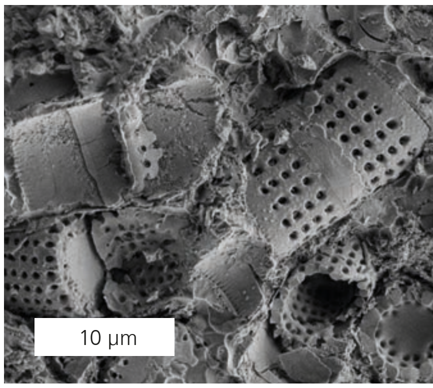
The diatoms prepared in this way are then mixed with aluminum powder and processed into a solid composite material by Spark Plasma Sintering (SPS). In addition to powder metallurgical production, a melt metallurgical process is also being tested. In this process, the diatoms are mixed with the metal matrix in a liquid state.

The results were obtained in the German-Polish Cornet project MECODIA in cooperation with the University of Białystok.



Simulated MMC data set based on nanoXCT data of a single frustule (fossile cell case).

Set of two stacked frustules, imaged in-situ during the vertical compression test.



SEM image of the fracture surface of an MMC with Al-matrix and 30 vol % diatomaceous earth.

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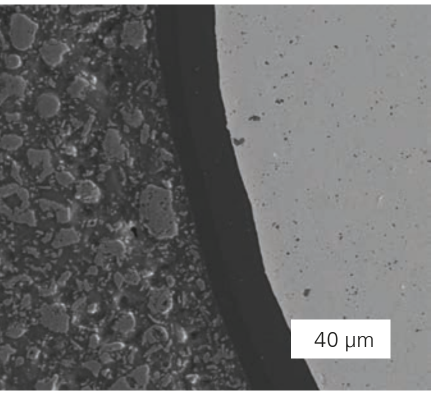
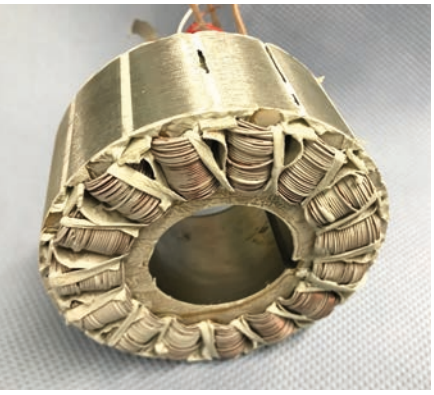
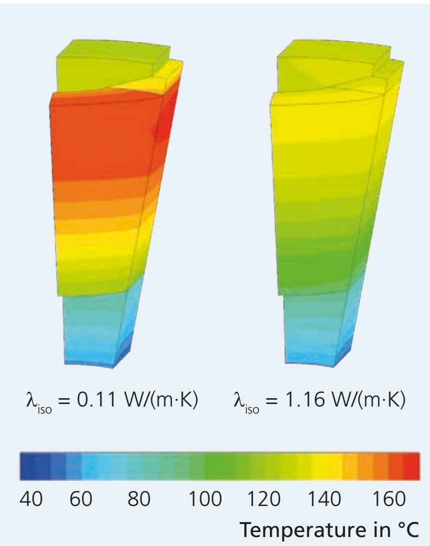


Microstructure of a compound of enameled copper wire and polymer-ceramic impregnation material filled with AlN.



Stator of a synchronous machine in outer rotor construction with polymer-ceramic isolation.



Simulation of stator heating with variation of the thermal conductivity of the impregnation material.

Polymer ceramics for the insulation of windings in highly stressed electrical machines

Dipl.-Chem. Ralph Schubert, M.Sc. Sören Miersch*, Prof. Thomas Schuhmann*
(*Hochschule für Technik und Wirtschaft Dresden)

The electromagnetic utilization and resource efficiency of electrical machines can be enhanced by increasing the current loading. This approach finds its limits in the maximum permissible temperature of the winding insulation materials and the reduced transportation of heat due to the low thermal conductivity of the synthetic isolating materials and multiple air gaps between winding, main insulation, and laminated core.

A sponsored R&D project has managed to develop polymer-ceramic composite systems with increased thermal stability and thermal conductivity for winding impregnation in electrical machines. The composites consist of a polysiloxane matrix and ceramic fillers, such as aluminum oxide, aluminum nitride and boron nitride. Surface modification of the filler particles made it possible to achieve filling degrees up to 40 vol-%. The composites have a sufficient fluidity of the paste-like initial systems, for a fast and complete winding impregnation. The polymer-ceramic impregnation systems exhibit a thermal conductivity that is improved four to six times compared with conventional impregnation systems, such as polyester imides.

Investigations on electrical machines with polymer-ceramic insulation in standard operational regimes have shown that the electrical insulation afforded by the impregnation is sufficient. Microscopical investigations of impregnated winding samples have revealed a pore-free and homogeneous microstructure of the polymer-ceramic composites and an even particle distribution in the polymer matrix. The impregnation agent wets the wire surface without any gaps (top figure). These properties of the microstructure are important preconditions for efficient heat dissipation.

For the impregnation, wound laminated cores are treated in an immersion bath filled with the paste-like initial system of the polymer-ceramic composite before being thermally cured. This technology is comparable to conventional technologies of impregnation with commonly used resins. Slightly modified polymer-ceramic impregnation materials were shown to also be suitable for the surface insulation of laminated steel cores of electrical machines. This makes it possible to do without conventional insulation foils with low thermal conductivity.

Analyses of the operating parameters of electrical machines with polymer-ceramic winding insulation (middle figure) show that the overtemperature of the winding, which describes the difference between winding and ambient temperature, is reduced by 50 to 60 % thanks to improved heat dissipation. These results confirm computational simulations based on measured parameters of the developed composite materials (bottom figure). As a result, the power density of the electrical sample machines could be enhanced by up to 44 %.

Acknowledgement

The IGF project 20387 BR was kindly supported by funding from the German Federal Ministry for Economic Affairs and Climate Action (BMWK) through the working group of industrial research associations (AiF).

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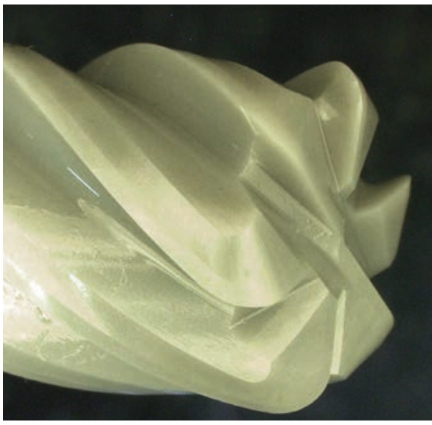
An innovative milling tool made of cost-efficient sialon in a test run

Dr. Eveline Zschippang, Dr. Mathias Herrmann



Sialon end mill (Source: GFE Schmalkalden e. V., Sommertools).

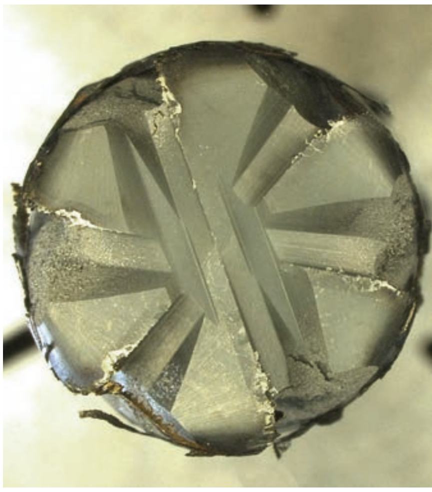
Nickel-based alloys are used in numerous industries, such as automotive, aerospace, chemical plant engineering and power generation, thanks to their resistance to corrosion and oxidation at high temperatures. However, their outstanding properties also make efficient machining more difficult. High temperatures occur while machining these alloys, leading to a need for innovative tooling solutions. Tools made of ceramics are very promising. In particular, sialons exhibit high hardness even at high temperatures and thus enable high cutting speeds when milling nickel-based alloys.

In the IGF project 20076 BR, Fraunhofer IKTS has developed an α/β-sialon prepared via an aqueous processing route and based on cost-effective powders (IKTS annual report 2020/21). The α/β sialon cutting material (80:20) has a hardness (HV10) of 18.5 GP, a 4-point bending strength of σ_0 = 785 MPa, a weibull modulus of m = 19 and a fracture toughness of 5.2 MPa $m^{1/2}$ (SEVNB).

IKTS has produced end mill blanks from this cost-effective sialon material. For this purpose, the company Sommertools developed a cutting geometry for the sialon cutters adapted to the machining of nickel-based alloys (top image).

Initial milling tests were carried out on Inconel 718 using the new sialon milling cutters under parameters close to those of application. The environmentally friendly dry machining processed used a cutting speed v_c of 470 m/mm, a depth of cut a_p = 5 mm and a width of cut a_e = 0.2 mm. The middle image shows the sialon end mill after realizing a tool life travel of 5.4 m in 1.7 minutes.

Despite typical wear phenomena, such as built-up edge formation (bottom image), sialon end mills enable a very long tool life travel during rough milling. Even chipping on the cutting edges, which is caused by the detachment of adhering Inconel chips during the milling process, can be tolerated when rough milling with sialon cutters. Therefore, significantly higher metal removal rates can be achieved compared with carbide tools.



Tool wear for sialon end mill after dry machining of Inconel 718 (Source: GFE Schmalkalden e. V., Sommertools).

The new sialon end mills performed very well in the first test run. The cost-efficient sialon material developed at Fraunhofer IKTS in combination with a perfect ceramic cutting edge design enables even higher efficiency in the machining of nickel-based alloys.

Services offered

- Development of ceramic cutting tool materials
- Failure analysis of ceramic cutting tools

The IGF project 20076 BR of the German Ceramic Society (Deutsche Keramische Gesellschaft / DKG) is supported via AiF within the program for promoting the Industrial Collective Research (IGF) of the Federal Ministry of Economic Affairs and Climate Action (BMWK)..

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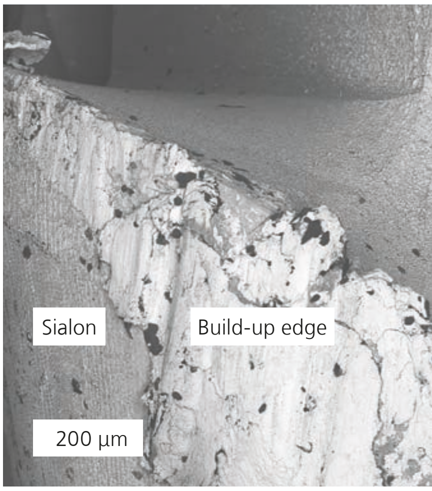

Scanning electron microscope image of a cutting edge.

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Hybrid bone test samples.

Hybrid and degradable bioceramics for jawbone replacement

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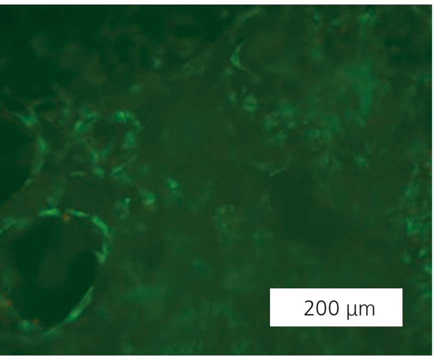


Live-dead-staining; green = living primary human osteoblasts (Source: Universitätsmedizin Rostock).

Bone defects in the craniofacial region are often associated with esthetic and functional impairments. Until now, autologous bone grafts, e.g. from the fibula or the pelvic bone, have been used for reconstruction. However, these offer only an inadequate reproduction of the complex anatomy of the facial skull.

New approach for bone regeneration

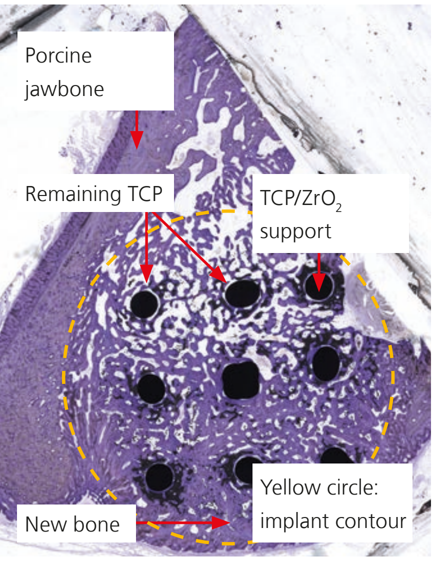
The "Hybrid-Bone" project (04/2020–03/2023, funding code 03VP07633) aims to develop personalizable and precisely fitting, mechanically stable bone substitute materials. The combination with growth factors in the degradable part of a hybrid scaffold also stimulates programmable bone regeneration. The hybrid bone consists of additively manufactured, load-bearing support structures filled and sorrounded with porous foam. The foam serves as a biodegradable lead structure for cell ingrowth.

Promising material combinations

The bioceramic materials used are degradable tricalcium phosphate (TCP) and bioinert zirconia. The CerAM VPP (Ceramic Additive Manufacturing Vat Photopolymerization) process was selected for additive manufacturing and fabrication of the pressure-loadable support structures from a TCP-ZrO_2 composite material. Specifically constructed holes were provided for subsequent screw fixation in the bone (top image, implant size 20 x 12 mm; H x ø). The ceramic foam was prepared from TCP via the so-called Freeze-Foaming process. Such a TCP Freeze Foam has open and interconnected pores. This allows it to be degraded by the body and at the same time cause new bone formation at the same location.

Good biocompatibility has been demonstrated on the hybrid test scaffolds based on in-vitro analysis: the middle image shows living primary human osteoblasts in the hybrid bone. Gene expression data of the primary osteoblasts, cultured on different materials, show when compared to the reference (Bio-Oss® Spongiosa Blocks, Geistlich Pharma AG) that the osteogenic markers Runx2 and COL1A1 are expressed equivalent to the reference.

Results of the first in-vivo test showed that the artificial porous scaffold was degraded within only three months, and autologous bone was newly formed at the same location (bottom figure).



Degradation of the artifical implant and new bone formation in the defect site (Source: University Hospital Schleswig-Holstein).

With these outstanding biocompatible properties, the bone substitutes will be developed further to take into account the natural distribution of loading forces in the respective bone while paying more attention to biomechanics. Chewing and muscular forces play a major role in the constant formation and degradation of bone tissue. Currently, larger hybrid bones (approx. 50 x 50 x 20 mm³) adapted to porcine jaw bones are being prepared and will subsequently be evaluated in vitro and in vivo.

The goal at the end of the project is to produce a personalized human jawbone for potential use in patients.

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Thin-walled ceramic abutments with high strength and precision

Dipl.-Chem. Martina Johannes, Markus Beyreuther, Dr. Sabine Begand

Dental implantology is a growing market. The industry network Aegis Communications has forecast annual growth rates of 7.5 to 9.3 %. As patients become increasingly aware of health and esthetics and more dentists start to offer them, implants are becoming more popular and readily available.

In a joint project with implant manufacturer Moje Keramik-Implantate GmbH & Co KG. and the engineering company ILMCAD – Ingenieurbüro Ilmenau GmbH, Fraunhofer IKTS researchers are attempting to develop a technology for manufacturing thin-walled abutments (the connecting part between dental implant and prosthetic restoration) made of yttria-stabilized zirconia (TZ3Y). This ceramic material has many advantages: It is biocompatible, allows only minimal plaque build-up, has a low thermal conductivity and is esthetically pleasing due to the good soft tissue attachment. In addition, no health hazards from allergic reactions have to be expected.

The project partner Moje Keramik-Implantate specified the design of the implants. The aim was to achieve a dimensional accuracy of 12 µm. Two molding processes were used: slip casting and injection molding. Previously, the project partner used to manufacture abutments through milling from uniaxial, pressed blanks. This resulted in high reject rates and material waste. Parts close to the final shape were produced by slip casting and subsequently post-processed at the project partner's site. Several injection molding compounds from different manufacturers were tested. Further investigations were carried out with the preferred compound and an injection mold was built for the thin-walled abutments, taking shrinkage into account. Process parameters, such as mold temperature, injection speed and injection pressure, were optimized. The green density of the parts produced by slip casting was 60 % of the theoretical density.

The abutments were densely sintered at 1350 °C. Imaging analysis of the microstructures showed a mean grain size of 210 nm. The injection-molded parts were sintered at 1450 °C. The grain size was 340 nm in the microstructure of the ceramic. The difference in grain size impacts the hydrothermal aging of the TZ3Y ceramic, which took place at 134 °C, 2 bar and 50 h and was investigated using X-ray phase analysis. No phase transformations take place in the yttria-stabilized zirconia produced with slip casting. In the injection-molded parts, the undesirable monoclinic phase is formed to a small extent. The four-point bending strength (EN 843-1) for the slip-cast ceramic was 1070 MPa with a Weibull m of 19, and for injection molding 1059 MPa with a Weibull m of 9.

Both molding processes were able to achieve the required dimensional accuracy of 12 µm. The injection molding process has the advantage that it does not require any post-processing, so that as a result of the project, the injection molding technology was introduced at Moje Keramik-Implantate, with advisory support from Fraunhofer IKTS.

We would like to thank the German Federal Ministry for Economic Affairs and Climate Action (BMWK) for funding the project within the framework of the "Central Innovation Program for SMEs".

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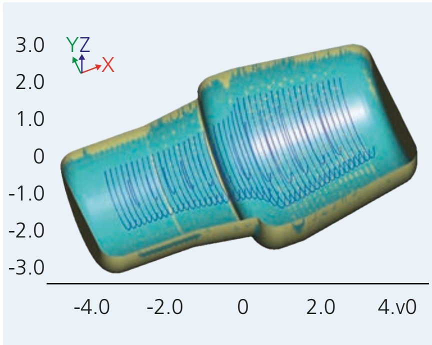
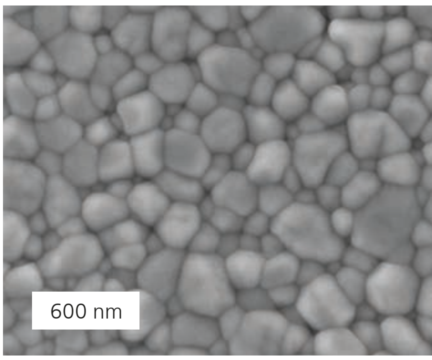
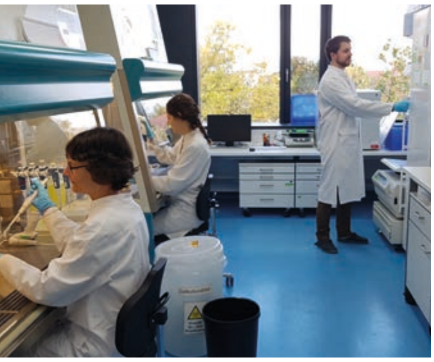
Thin-walled injection-molded abutments.



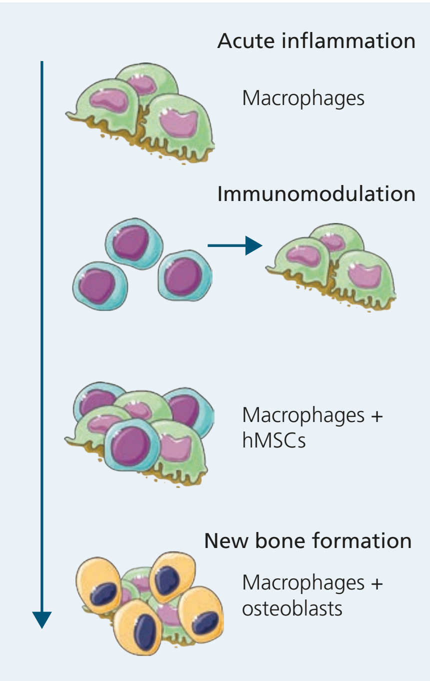
Milling path simulation for near-net-shape abutment using slip casting.



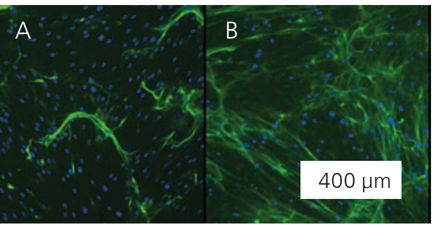
FESEM image of microstructure TZ3Y (slip casting).



The group Biological Materials Analysis develops standardized, preclinical test models.



Macrophages and hMSCs interact from acute inflammation until new bone is formed.



Staining of the generated extracellular matrix (green) via hMSCs without (A) and with inflammatory influence (B). Measuring bar 100 µm.

New bone formation after acute inflammation – assessment in vitro

M.Sc. Constantin Ißleib, Dr. Susanne Kurz, Dr. Juliane Spohn

Whether in bone fractures or the surgical placement of an implant as bone replacement: before the new bone forms, the surrounding tissue is damaged. The immune system responds with acute inflammation at the wound site around the bone.

In the preclinical evaluation of the efficacy of novel implant materials for bone replacement, tests are currently limited to new bone formation. However, it is now known that the preceding acute inflammation has a decisive impact on new bone formation.

Novel osteoimmunology model for preclinical in-vitro testing

The group Biological Materials Analysis at Fraunhofer IKTS has established an in-vitro model that depicts new bone formation under inflammatory conditions. The basis for the combined model consists of two human cell types: macrophages as the protagonists of acute inflammation, and mesenchymal stem cells (hMSCs), which undergo the fundamental process of new bone formation – osteogenic differentiation.

In the model, macrophages are first polarized to a proinflammatory subtype, which creates an inflammatory environment. The process is distinguished by the secretion of proinflammatory cytokines which, among other symptoms, leads to redness, swelling and fever in the patient. hMSCs are added to the inflammatory milieu and are subsequently osteogenically differentiated (middle figure). Subsequently, the performance of the osteogenic differentiation is validated and examined based on the production of an extracellular matrix as well as the deposition of calcium (bottom figure). During the investigation of test materials (active substances or [bio]materials), the polarization of macrophages already provides important insights into the immunomodulatory properties of the test item. Thus, the increase or decrease of inflammation is analyzed as a first step (middle figure, acute inflammation). In addition, the resolution of the inflammation via the immunomodulatory active hMSCs is also characterized (middle figure, immunomodulation). In a second step, the formation of new bone substance is assessed based on the performance of the osteogenic differentiation of the hMSCs under inflammatory conditions (middle figure, new bone formation). The process can be adapted depending on the questions asked about the test item (materials/active substances).

Analysis portfolio

- Secretion (ELISA, Multiplex)
- Gene expression
- Enzyme activity
- Biochemical assays (e.g., protein-, calcium determination)
- Immunofluorescence staining

Services offered

- Translation of test models onto test items (materials/active substances)
- Assessment of immunomodulatory properties of test materials/-substances
- Assessment of the new bone formation under inflammatory conditions
- Translation of test models for industry, as well as norms and standards

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Decentralized monitoring of lung ventilation with Pneumo.Vest

Dipl.-Ing. Ralf Schallert, Dipl.-Ing. Conner Phillips, Dipl.-Ing. (FH) Hendrik Funke

In Germany, 385,000 patients are hospitalized each year with respiratory problems or lung diseases – more than 60 % of patients require ventilation for longer than 24 hours.

The methods currently in use in intensive care units for monitoring lung function at bedside provide only global information. However, to select the correct ventilation parameters, physicians need a continuous flow of information about the regional distribution of ventilation. Until now, such differentiated lung ventilation data has only been available in the form of snapshots produced with imaging methods, such as thorax CT.

Location-independent patient monitoring

As part of the Fraunhofer anti-Corona project M3Infekt, a system for monitoring Covid-19 patients outside of intensive care units is currently in development. The competencies of nine Fraunhofer institutes as well as clinical partners have been combined to develop a textile vest prototype with integrated acoustic sensors.

These sensors help to assess the ventilation situation of the lungs – initially at 20 evaluation points on the back. Additionally, a "breath-by-breath" analysis of simultaneously recorded acoustic signal data enables continuous monitoring and assessment in real time. This can be used during therapeutic interventions, such as ventilation therapy or for condition assessment in the emergency room.

The project involved developing the individual sensor and miniaturizing it, designing the amplifier circuitry and developing a corresponding circuit board for power supply and for combining the 20 sensors.

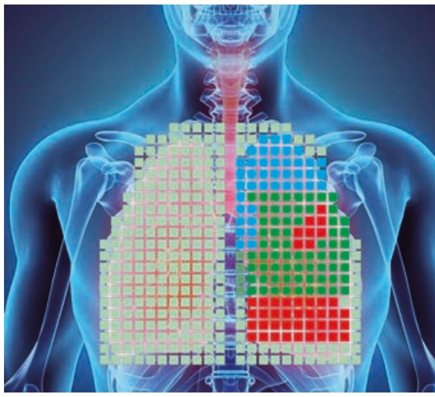
These components were integrated into a prototypical textile vest.

The vest was then tested by medical personnel and future users in intensive care at the Magdeburg Clinic. The experiences of these measurements did confirm the benefits of such a medical application.

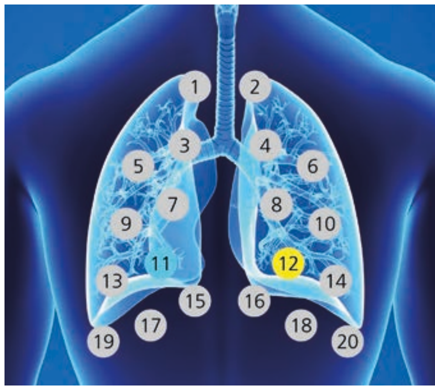
Into the age of digital care medicine

"Clinical grade wearables" (CGW), when combined with medical communication solutions, enable continuous data collection and analysis. Location-independent patient monitoring has significant advantages: in the future, it can be used in regular hospital wards, institutions of long- and short-term care, as well as at home. One important advantage for clinics is that it will make patient monitoring more decentralized, which can help maintain elective surgery schedules even during times of high infection rates and peaks in demand.

The system supports transforming medical care into "4P medicine" (preventive, participatory, personalized, predictive), with decentralized health monitoring.



View of Pneumo.Vest for the differentiated monitoring of lung ventilation.

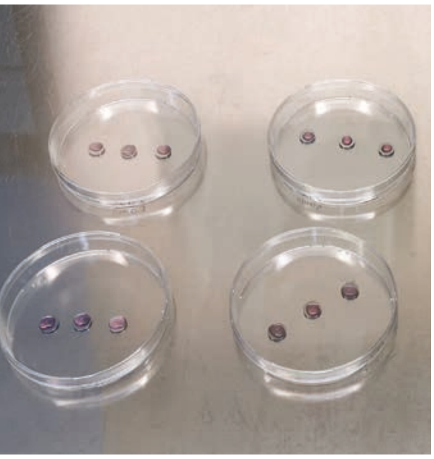


Sensor placement on the back (posterior) of the vest.

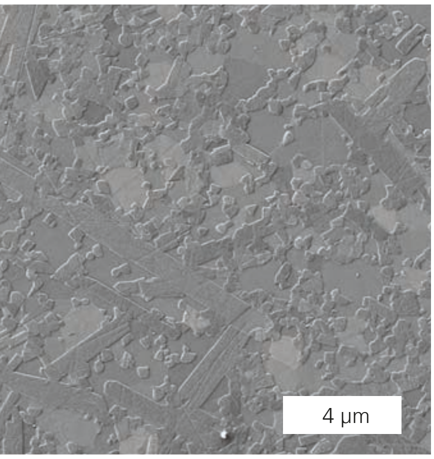
Prototypical textile vest with sensors.

Tungsten-based composite materials for antiviral and diagnostic applications

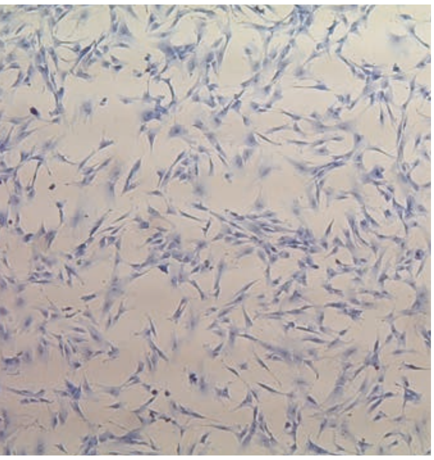
Dr. Johannes Pötschke, Dr. Holger Lausch, Dr. Claire Fabian (Fraunhofer IZI)



Set-up of convection trials.



Microstructure of an antiviral tungsten carbide-based composite.



Viral transduced cells 48 hours after transduction.

Tungsten-based composite materials have repeatedly been reported to have viricidal effects. Yet precise information on the specific binding state remains elusive. At Fraunhofer IKTS, this has motivated the production and evaluation of material properties of composites based on pure tungsten, tungsten carbide and tungsten dicarbide as well as composites mixed with stainless steel, copper and cobalt. The investigations of viricidal and bactericidal effects and of DNA-binding properties were conducted at Fraunhofer IZI. Additionally, the influence of the materials on the proliferation, morphology and metabolism of human cells was also examined. It was possible to show a reduction in viral vectors and E. coli bacteria, as well as a reduction of DNA, in three tungsten-containing materials. The investigations were enabled by applying a newly developed convection infection model, which allowed all microbial pathogens to come into contact with the active surface. The model has proven advantageous for such material tests and will be tested on further material systems in the future.

The metal-bound, as well as pure tungsten or tungsten carbide, composites that are most promising in terms of pathogen reduction have a high hardness of up to 2200 HV10, making them interesting for wear-resistant surfaces.

Side effects as opportunities for diagnostic and filtration applications

If the viricidal/bactericidal properties of tungsten-containing materials are combined with lipid membrane-dissolving ethanol or 2-propanol, these two limited viricidal methods are expected to complement each other optimally. Further tests are required to confirm this.

One tungsten-containing composite showed a surprising complete lack of reduction of DNA on its surface and is therefore recommended as a non-reactive vessel material for biological sample material in diagnostics.

Services offered

- Development of adapted tungsten-containing compositions for the production of bulk material as well as powder for laser deposition welding or thermal coating
- Characterization of tungsten and tungsten carbide-based composite materials in regard to their mechanical (Fraunhofer IKTS) as well as their viricidal and bactericidal properties (Fraunhofer IZI)

This work was supported by the Fraunhofer Internal Programs under Grant No. Anti-Corona 840249.

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Cooperation in Groups, Alliances and Networks

Scientists at Fraunhofer IKTS are active in numerous thematically oriented networks, alliances and groups. Therefore, our customers benefit from having a coordinated range of joint services available to them.

Membership in Fraunhofer Groups, Alliances and Networks

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.

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Carbon Composites e. V. (CCeV)

Ceramics Meeting Point

CiS Forschungsinstitut für Mikrosensorik GmbH

CO_2 Value Europe AiSBL

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COMPOSITES UNITED e. V.

Cool Silicon e. V.

DECHEMA – Society for Chemical Engineering and Biotechnology

DeepSea Mining Alliance e. V.

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

DIN Standards Committee Optics and Precision Mechanics (NAFuO)

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

Dresden Fraunhofer Cluster Nanoanalysis

DRESDEN-concept e. V.

Dresdner Gesprächskreis der Wirtschaft und der Wissenschaft e. V.

ECPE European Cluster for Power Electronics

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European Powder Metallurgy Association (EPMA)

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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

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Materials Research Network Dresden (MFD)

medways e. V.

Meeting of Refractory Experts Freiberg (MORE)

microTEC Südwest

Nachhaltigkeitsabkommen Thüringen

NAFEMS UK

Organic Electronics Saxony

Ostthüringer Ausbildungsverbund e. V. Jena

ProcessNet – an initiative of DECHEMA and VDI-GVC

QBN Quantum Business Network

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)

TITK Materials research institute for polymer functional and engineering materials

Traegerverein Institut für Holztechnologie Dresden e. V.

TRIDELTA CAMPUS HERMSDORF e. V.

VDMA Medical technology

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

Verein für Regional- und Technikgeschichte e. V. Hermsdorf

Growth core smood® – smart neighborhood

Wind Energy Network Rostock

Fraunhofer Group for Materials and Components – MATERIALS

MATERIALS – the Fraunhofer Group for Materials and Components – pools the expertise of the Fraunhofer Institutes working in the area of materials science and engineering. The Group uses its expertise, from the fundamentals of materials science to materials engineering system solutions, to create innovations for its customers´ and partners´ markets. The basis for this the Groups cross-scale materials expertise along industrial value chains.

Materials science and engineering at Fraunhofer covers the entire value chain, from developing new and improving or application-specificly adapting of existing materials to manufacturing technology on a quasi-industrial scale, in addition to characterizing properties and assessing service behavior. This also applies to the components and products made from these materials and their system behavior in relevant applications.

Equal importance is attached to experimental studies in laboratories, technical centers and pilot plants and to methods of numerical simulation and modeling; they are used across scales, from molecule and component, to complex system and process simulation.

Where materials are concerned, the Fraunhofer MATERIALS group covers the full spectrum of metals, inorganic non-metals, polymers, and materials made from renewable resources, as well as semiconductor materials. Over the last few years, hybrid materials have gained significantly in importance.

The scientists working in the Group's institutes deploy their knowledge and expertise on behalf of their customers specifically in the fields of mobility, healthcare, mechanical engineering and plant construction, building construction and living, microsystems technology, safety and energy and environment. As part of strong national and international networks they contribute towards material-related innovations and innovative processes in a wide range of working fields.

The Group considers digitization of materials along their entire value chain as a key requirement for the lasting success of Industry 4.0 as well as for the realization of resource-efficient materials and processes. With its initiative Materials Data Space© (MDS) the Group supports and pushes this development.

Special attention is also given to the development of customized materials for additive manufacturing, from expanding the range of materials that can be used to developing multi-material systems. Thus the Group is making a significant contribution to maximizing and economically exploiting this promising manufacturing technology.

Another key topic within the Group is hybrid lightweight construction. Climate change, scarcity of resources and a simultaneously increasing need for mobility call for a rethink in product development. Resource efficiency with weight and function-optimized design of components is becoming a central target parameter in the development process. Fraunhofer MATERIALS sees lightweight construction as a holistic challenge and focuses on sustainable, recyclable materials, intelligent hybrid structure design and consistent material and component evaluations.

The importance of renewable energies is rapidly gaining momentum as the energy transition continues. A large number of materials, from copper, steel and concrete to rare earths will be used to generate, store, transport and convert energy, to a significantly greater extent compared with traditional energy supply systems. The Group is addressing this set of questions, particularly with a view to resource availability and the creation of closed resource cycles for these systems and components.

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Ceramics Meeting Point – Ceramic Applications

The Treffpunkt Keramik (Ceramics Meeting Point) is an integral part of our institute's public relations activities. During the Covid-19 pandemic, the area was used mainly as a break room. The goals for 2022 have been newly defined to once again introduce external guests and the next generation of scientists to technical ceramics. Here, we benefit from the growing number of exhibitors. A total of 50 component manufacturers, 14 raw material suppliers and 7 equipment manufacturers are exhibiting at "Treffpunkt Keramik". Göller Verlag's "Ceramic Applications" has established itself as a marketing and information platform for end users and manufacturers. The members were also particularly involved at the Ceramitec Conference 2021 in Munich.

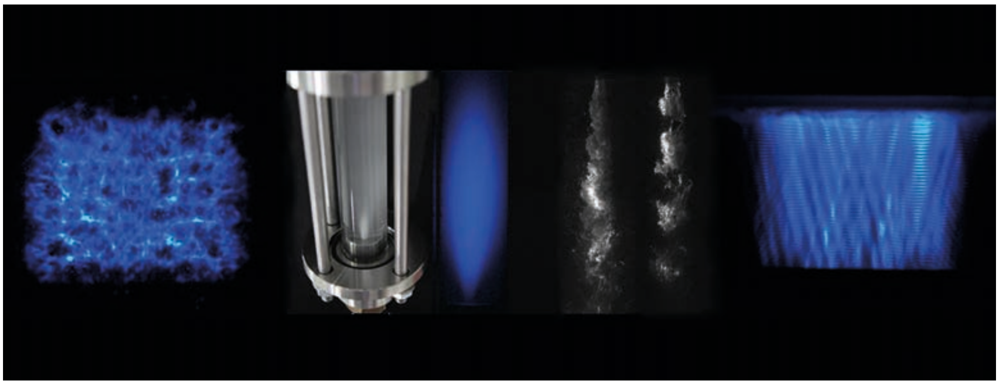
The exhibition makes it possible to include the complete manufacturing chain, from powder to component, in every visitor's tour in a very effective way. In addition to learning about the research infrastructure, visitors can thus also gain insights into the market with the portfolios of partner companies presenting real components weighing from a few milligrams to more than 100 kilograms.

The guests gain insights into the focal points of current research, from transparent ceramics to projects on corrosion protection in deep-sea applications. Exhibits you can touch help to build trust in the economic feasibility of new ideas and make it easier to initiate forward-looking projects in the future.

In-person seminars organized by Fraunhofer IKTS, the German Ceramic Society (DKG), and the German Materials Society (DGM) will once again take place in 2022. Special exhibits will be shown at the user forum of Ceramitec 2022, making this trade fair a ceramics meeting point for end users, manufacturers, suppliers, and research institutions.

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 2021 on the website

www.ikts.fraunhofer.de/en/dates2021

- Granted patents
- Patent applications

- Books and periodical contributions
- Presentations and posters

- Teaching activities
- Participations in bodies/technical committees

- Dissertations
- Theses

Events and trade fairs in 2022

Due to the pandemic situation, the scheduled dates may be postponed. You can find current dates on our websites.

Conferences and events

NDT4INDUSTRY – In vitro testing of cardiovascular implants for better quality
January 19, 2022, Online seminar

NDT4INDUSTRY – Inline inspection of multiaxial carbon-fiber plys
March 16, 2022, Online seminar

Girl's Day (DE)
April 28, 2022, Online event

NDT4INDUSTRY – Component marking for extreme process conditions – ceramic phosphors in metal processing
June 1, 2022, Online seminar

Vision Ceramics (DE)
June 7–8, 2022, Dresden, Winterbergstrasse

Nacht der Wissenschaft und Wirtschaft Freiberg (DE)
June 18, 2022, Freiberg, Helmholtz Institute Freiberg

Dresden Science Night (LNdWDD) (DE)
July 8, 2022, Dresden, Winterbergstrasse

Open day at the Hermsdorf site (DE)
September 10, 2022, Hermsdorf

ISPA International Symposium on Piezocomposite Applications
September 14–16, 2022, Dresden, Winterbergstrasse

NDT4INDUSTRY – X-ray and thermography
September 21, 2022, Online seminar

Early Morning Science with Fraunhofer (DE)
September 21, 2022, Dresden, Winterbergstrasse

Industry Day Transparent Ceramics (DE)
October 5–6, 2022, Hermsdorf

AM ceramics conference
October 12–13, 2022, Dresden, Winterbergstrasse

Industry Day Ocean Technology (DE)
November 8–9, 2022, Rostock, Fraunhofer SOT

NDT4INDUSTRY – Acoustic diagnosis – suits for a surprisingly large number of applications
November 23, 2022, Online seminar

Symposium Applied Electrochemistry in Materials Research (DE)
November 24–25, 2022, Dresden, Winterbergstrasse

Training seminars and workshops

DKG training seminar: Tape casting and the slot die process (DE)
November 9–10, 2022, Hermsdorf, Seminar and practical course

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

Trade fairs

FILTECH
March 8–10, 2022, Cologne

ZfP im Eisenbahnwesen
March 15–17, 2022, Erfurt

JEC
May 3–5, 2022, Paris
Joint booth Saxony Economic Development Corporation WFS

Control
May 3–6, 2022, Stuttgart
Joint booth Fraunhofer Vision Alliance

PCIM Europe
May 10–12, 2022, Nuremberg

Sensor und Test
May 10–12, 2022, Nuremberg

Rapidtech
May 16–18, 2022, Erfurt
Joint booth Fraunhofer Competence Field Additive Manufacturing

DGZfP Annual Meeting
May 23–25, 2022, Kassel

Hannover Messe
May 30 – June 2, 2022, Hannover
Joint booth Ceramic Applications

IFAT
May 30 – June 3, 2022, Munich
IKTS booth, Joint booth Fraunhofer SysWasser Alliance

Australian Hydrogen Conference 2022
May 31 – June 1, 2022, Adelaide
Joint booth Research in Germany (RiG)

Bonding
June 13–15, 2022, Dresden
Fraunhofer joint booth

Erfurter Energiespeichertage
June 14–15, 2022, Erfurt

Ceramitec
June 21–24, 2022, Munich
Joint booth Ceramic Applications

ACHEMA
August 22–26, 2022, Frankfurt

DWA-Innovationsforum
September 6, 2022, Weimar

Energy Storage Europe
September 20–22, 2022, Dusseldorf

Innotrans
September 20–23, 2022, Berlin
Joint booth Saxony Economic Development Corporation WFS

WorldPM 2022
October 9–13, 2022, Lyon

FAD-Konferenz
November 3–4, 2022, Dresden

Formnext
November 15–18, 2022, Frankfurt
Fraunhofer joint booth

Electronica
November 15–18, 2022, Munich

Hagener Symposium
November 24–25, 2022, Hagen

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

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 4th 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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30 years
Fraunhofer IKTS

Hello
Future

www.ikts.fraunhofer.de/en/30_years_ikts