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FRAUNHOFER INSTITUTE FOR CERAMIC TECHNOLOGIES AND SYSTEMS IKTS

ANNUAL REPORT 2020 2021

ANNUAL REPORT 2020/2021

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FOREWORD

ANNUAL REPORT 2020/21

Dear friends and partners of IKTS,

what a strange year it has been! Many workflows had to be changed; mobile and digital work has become the norm. The Fraunhofer IKTS team has mastered these transformative steps very well. We were able to continue our work efficiently and to a high standard. Astonishingly, we managed not just to keep up our R&D efforts at the previous year's level, but to even increase them. Our budget has increased by a staggering 11.5 million euros and now totals approx. 76 million euros. Relative to our operating budget of 64 million euros, we have achieved an outstanding total rate of return of more than 86 %, meaning we were able to increase our external income significantly. Income from public funds has increased disproportionately, more than compensating for the shortfalls in our direct industry income. With our industry income rate of approx. 33 %, we remain fully within the target range set by Fraunhofer and have proven once again that we continue to accomplish our mission: research that is targeted towards transfer. Naturally, we will remain at your side as your trusted partner. In these tough times more than ever, research partnerships are particularly important and will always be paramount for us.

Based on our excellent economic result, we were able to invest more than 10 million euros in our technical equipment, of which all sites and business divisions have benefited. This time around, one focus of investment was on characterization technology. For instance, our new site in Forchheim received more than 3 million euros for correlative microscopy through an EU project we were able to secure (ERC grant). Also, we procured a new scanning electron microscope (Fib-SEM) for our Dresden site. This will enable us to further improve our workflows for sample testing and accelerate development efforts. Furthermore, we have expanded our shaping capabilities and created new floor space. A new technical center should be mentioned in this regard. It consolidates our activities with regard to additive manufacturing. In Hermsdorf, we have rented another building in direct vicinity of our institute, which we will use to expand our water technology research. We are very pleased that this location also houses our new Fraunhofer Attract group, focused on water technologies and headed by Dr. Patrick Bräutigam. The topic of water in all its aspects, from the circular economy to subsea technologies, has thus become an important focal point across all IKTS sites. Recycling is another key topic when it comes to the circular economy. We continue to develop this topic at our new research site, the Fraunhofer Technology Center High-Performance Materials THM in Freiberg. There, we focus specially on battery recycling under the umbrella concept "Research Fab Battery" by the Federal Ministry of Education and Research (BMBF), completing our developments in mobile (Li-ion and solid-state) as well as stationary ($Na/NiCl_2$) batteries.

We are grateful to the Saxon State Ministry for the Sciences, Culture and the Arts (SMWK) and the Free State of Saxony for their great support in this endeavor. With the recently opened Battery Innovation and Technology Center (BITC) in Arnstadt, the expansion of our production-adjacent battery activities is also going well. On more than 5300 square meters (approx. 57,000 square feet), new battery research opportunities are created here in close collaboration with partners from the industry. We thank the Free State of Thuringia – specifically the Thuringian Ministry for the Economy, Sciences and Digital Society (TMWWDG) – for its outstanding support. In addition to battery research, we also intend to expand our hydrogen technology competencies in the BITC. Based on our decades of experience in fuel cells and electrolysis systems, we want to build demonstration plants at the BITC for the production and use of green hydrogen, which will also be relevant for the ceramics industry. These activities are also meant to support a study on the subject of Co_2-neutral ceramic products, which we conduct together with the German Ceramic Society (DKG) and the Federal Association for the Ceramics Industry (BVKI). We intend to use that study to emphasize the funding needs of the ceramics industry vis-à-vis the federal ministries.

You can find more highlights and developing trends from our business divisions in our report. I hope you will enjoy perusing this edition and find it a source of inspiration for new project ideas. We are always available for discussions, so please do not hesitate to make use of our outstanding equipment. The whole IKTS team is looking forward to our collaboration.

Yours,

Alexander Michaelis

April 2021

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FRAUNHOFER IKTS IN PROFILE

PORTRAIT

The Fraunhofer Institute for Ceramic Technologies and Systems IKTS covers the field of advanced ceramics from basic preliminary research through to the entire range of applications. The institute boasts labs and technical centers with outstanding equipment and a total floor space of more than 30,000 square meters at its sites in Dresden (Saxony), Hermsdorf (Thuringia) and several other sites. Based on extensive scientific know-how on high-performance ceramic materials, the development work covers the complete value chain, through to prototype production and systems integration.

Furthermore, Fraunhofer IKTS has decades of experience in the non-destructive testing of components and systems. Using novel measuring technologies, approaches to automation and to interpreting complex data sets, we offer solutions for quality control and condition monitoring – from sensors to complete systems adapted specifically for the user.

Fraunhofer IKTS masters a triad of competencies – materials, technologies and systems – completed by comprehensive material diagnostics at the highest level, far beyond ceramic materials themselves. Chemists, materials scientists, engineers and software experts work together in cross-disciplinary teams at IKTS, supported in their work by experienced technicians.

The researchers showcase the potential of new technologies and components in various market-oriented divisions: Mechanical and automotive engineering, electronics and microsystems, energy, water, environmental and process engineering, bio- and medical technolgy, as well as non-destructive testing and monitoring. In the cross sectional fields of materials and processes, as well as materials and process analytics, we continuously refine technologies, both established and emerging, as accelerators for all other fields, while keeping an eye on the challenges faced by society as a whole with regard to new forms of mobility, innovative concepts for the circular economy and efficient digital production.

We offer the following unique competencies:

End-to-end production lines: from starting material to prototypes

For any class of ceramic materials, Fraunhofer IKTS has access to all the standard processes of raw materials preparation, shaping, heat treatment and finish processing. Regarding functional ceramics, our special core competence is in paste and tape technology. By combining different technology platforms in a targeted way, such as functional and structural ceramics, we are able to create multifunctional components and systems which make clever use of the different properties of ceramic materials. In particular with regard to complex production processes, such as ceramic manufacturing, our deep knowledge of materials and ceramic manufacturing processes in conjunction with the design and integration of complex test systems allows us to offer unique solutions for the decisive materials-related questions in product development, production and quality assurance.

Multiscale development

Fraunhofer IKTS has the proper infrastructure and experience to transfer developments from the lab scale to the technical scale. Cutting-edge, industry-grade equipment and machinery is available for all relevant technology lines, with the ability to realize, for the benefit of partners and clients, the prototypes and pilot-production series required for market entry, to develop industrial production lines and implement quality processes. This helps to minimize time-to-market and risks significantly.




Non-destructive testing: from concept to certified system

Fraunhofer IKTS offers custom-made solutions for non-destructive materials testing – from the first concept through to the certified test system. The focus is on the handling of noisy signals. We supply specially developed sensors which are adapted to suit geometries, materials and optical, acoustic or electromagnetic parameters. Client-specific test systems are equipped with modular and very powerful electronics and versatile software. We accompany the process up to the CE-certified system and take on the validation of the test process for developments from the fields of ultrasound, eddy-current and acoustic emission testing.

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 several national and international consortium partners, we provide support from the application phase, through 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, 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, e.g. the German Law on Medical Products, and undergo various regular audits from the industry.

Creator of networks

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

ORGANIZATIONAL CHART

Institute Director
Prof. Dr. habil. Alexander Michaelis

Materials

Nonoxide Ceramics
Dipl.-Krist. Jörg Adler
- Nitride Ceramics and Structural Ceramics with Electrical Function
- Carbide Ceramics and Filter Ceramics

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

Processes and Components
Dr. Hagen Klemm
- Powder Technology
- Shaping and Additive Manufacturing
- Component Development
- Finishing

Sintering and Characterization / Non-Destructive Testing
Dr. habil. Mathias Herrmann
- Thermal Analysis and Thermal Physics**
- Heat Treatment
- Ceramography and Phase Analysis
- Powder and Suspension Characterization**
- Quality Assurance Laboratory** and Mechanics Laboratory

Environmental and Process Engineering

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

High-Temperature Separation and Catalysis
Dr. Ralf Kriegel
- High-Temperature Membranes and Storages
- Catalysis and Materials Synthesis

Biomass Technologies and Membrane Process Engineering
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

* certified in accordance with DIN EN ISO 13485

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

Fraunhofer IKTS sites
- Headquarters Dresden-Gruna, Saxony
- Site Dresden-Klotzsche, Saxony
- Site Hermsdorf, Thuringia
- Site Forchheim, Bavaria
- Site Rostock, Mecklenburg-Western Pomerania
- Site Cottbus, Brandenburg
- Fraunhofer Project Center for Energy Storage and Systems ZESS, Braunschweig, Lower Saxony
- Battery Innovation and Technology Center BITC, Arnstadt, Thuringia
- Fraunhofer Technology Center High-Performance Materials THM, Freiberg, Saxony

Application centers
- Bioenergy, Pöhl, Saxony
- Bio-Nanotechnology Application Lab BNAL, Lipsia, Saxony
- Membrane Technology, Schmalkalden, Thuringia
- Tape Casting Center, Hermsdorf, Thuringia

Technische Universität Dresden
ifWW – Institute of Inorganic-Nonmetallic Materials
Prof. Dr. habil. Alexander Michaelis
IAVT – Institute of Electronic Packaging Laboratory
Prof. Dr. Henning Heuer
IFE – Institute of Solid State Electronics
Prof. Dr. habil. Thomas Härtling
DCN – Dresden Center for Nanoanalysis
Prof. Dr. habil. Ehrenfried Zschech

Deputy Institute Director / Head of Administration Dr. Michael Zins

Deputy Institute Director / Marketing and Strategy Prof. Dr. Michael Stelter

Deputy Institute Director Prof. Dr. Ingolf Voigt

Deputy Institute Director Dr. Christian Wunderlich

- Chemical and Structural Analysis
- Hardmetals and Cermets

Correlative Microscopy and Materials Data

Prof. Dr. Silke Christiansen

- Correlative Microscopy and Materials Data

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
- Validation
- Stationary Energy Storage Systems
- Thin-Film Technologies
- Sodium Battery Materials and Prototype Manufacturing
- Industrial Data Concepts
- Smart Machine and Production Design

Energy Storage Systems and Electrochemistry

Dr. Mareike Wolter

- Electrochemistry
- Cell Concepts
- Electrode Development
- Electrochemical Energy Storage Systems and Converters

Friedrich Schiller University Jena

Technical Environmental Chemistry

Prof. Dr. Michael Stelter

Ernst Abbe University of Applied Sciences

SciTec department – Materials Engineering

Prof. Dr. Ingolf Voigt

Freie Universität Berlin

Institute of Experimental Physics

Prof. Dr. Silke Christiansen

Electronics/Microsystems-/Biomed. 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

Prof. Dr. habil. Ehrenfried Zschech

- 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

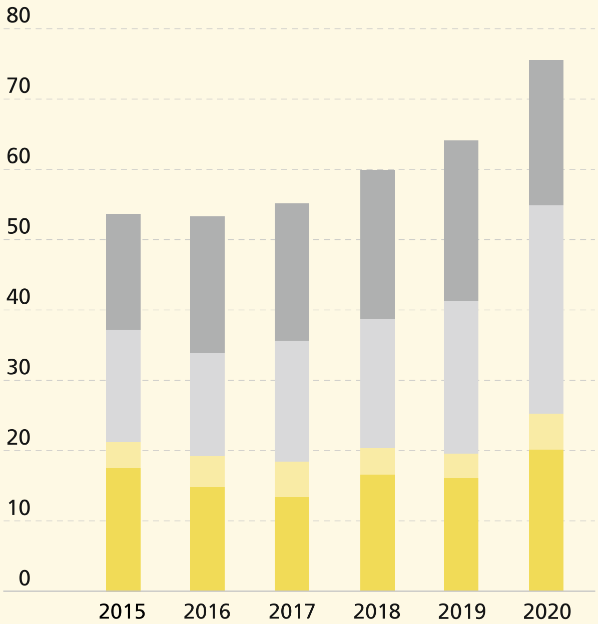
With 75.8 million euros, the total budget of Fraunhofer IKTS for 2020 exceeds the previous year's level by 11.5 million euros. At 13.2 million euros, the volume of investments has more than doubled. All in all 55.6 million euros of external income was raised. On account of the difficult situation faced by industry partners due to the Coronavirus pandemic, industry income has shrunk by 2.2 million euros, standing at 20.7 million euros for 2020. We are pleased that approx. 50 % of jobs still come from small and medium-sized companies. In the German Free States of Saxony and Thuringia, we were able to increase income by almost 300,000 euros to reach 3.9 million euros. All in all however, the pandemic still leads to a significantly reduced project demand and to many launch dates being pushed back. Jobs from outside Germany shrunk by 30 %, to 4.5 million euros. Strong partner countries, such as China and the US, were particularly affected, with orders and assignments receding by 40 %. As in the previous year, the volume is distributed among 30 different countries. Currently, approx. 8 % of the industry income from abroad comes from the United Kingdom. The trade restrictions which have been discussed so far will only have a limited impact. However, more remarkable effects will be felt from 2021 for scheduled EU projects.

A positive development is that the funding of projects by German federal states has increased in Thuringia (1.3 million euros) as well as in Saxony (4.6 million euros). In total, the various federal states support projects with a volume of 7.3 million euros. Income from EU projects was 2.5 million euros, meaning that their share in the overall volume has once again increased. The volume is expected to increase over the coming years owing to projects at the Forchheim site.

In particular thanks to long-term strategic decisions, IKTS has grown significantly and accepted a clear mission for growth, complicated to some degree by the consequences of the pandemic.

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

Revenue (in million euros) of Fraunhofer IKTS for the budget years 2015–2020

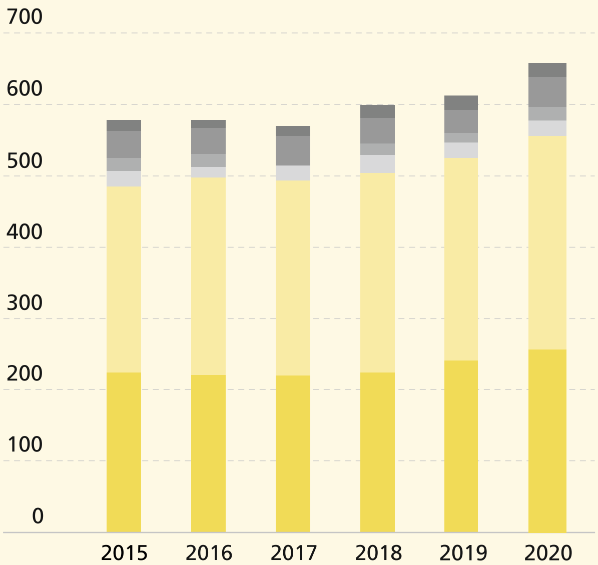


	2015	2016	2017	2018	2019	2020
	16.3	19.6	19.6	21.2	22.9	20.7
	16.4	14.8	17.3	18.4	21.8	29.8
	3.6	4.4	5.1	3.8	3.5	5.2
	17.8	14.8	13.5	16.6	16.1	20.1
=	**54.1**	**53.6**	**55.5**	**60.0**	**64.3**	**75.8**

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

Personnel developments at Fraunhofer IKTS

Number of employees 2015–2020, full-time equivalents, personnel structure on December 31 of each year



	2015	2016	2017	2018	2019	2020
	15	11	14	18	20	19
	38	36	40	36	32	42
	18	19	1	16	13	19
	21	15	21	25	22	22
	260	276	273	280	284	299
	223	220	220	224	241	257
=	**575**	**577**	**569**	**599**	**612**	**658**

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

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. IKTS is well-positioned to meet the existing requirements and contribute to designing the new tools.

Human resources development

A total of 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. For increased comparability, the different groups are represented as full-time equivalents (FTE) in the illustration. The number of scientists has increased by 16 positions and is now at 257. Also, the number of technical assistants has increased to 299. Doctoral theses continue to be written by employees in the context of PhD positions focused on a particular area, as well as in the context of project-related activities close to industry. Encouragingly, the number of students now corresponds to 44 FTE, up by more than 12 FTE, or more than 40 persons. All trainees were hired after completing their program.

Fraunhofer IKTS as an employer remains well positioned in the marketplace. Despite the pandemic, HR services were able to reach many students and future employees by participating in online formats.

Expanding the infrastructure

The infrastructure was expanded in the context of long-term projects and with the strong support of the federal states of Saxony, Thuringia and Lower Saxony. The new sites are presented in detail in the annual report.

The existing "head offices", however, also benefited from expansion efforts. For instance, the pilot center for powder synthesis and extrusion in Hermsdorf was completed in November 2020 and is expected to open in the Summer of 2021. Furthermore, the Hermsdorf site saw the construction of the lab for the optical characterization of powders and components and of an innovative powder synthesis plant with an overall volume of more than 1.3 million euros.

BOARD OF TRUSTEES

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

NEW FRAUNHOFER IKTS SITES

Rostock

Smart subsea technologies for the sustainable use of the oceans

The oceans are an important source of life and of the Earth's biodiversity. At the same time, they are used for recreational purposes, transport, as a source of raw materials and energy, as well as for waste disposal. The transition to an efficient and sustainable use of maritime resources has a very high priority and is the focal point of the United Nations Decade of Ocean Science for Sustainable Development (2021–2030). Therefore, the cross-disciplinary research group Smart Ocean Technologies (SOT), in which the Fraunhofer institutes IGD, IGP, IKTS and IOSB participate, is developing forward-looking subsea technologies in Rostock. This includes robust sensor systems and test methods for permanent condition monitoring of subsea structures, as well as wear- and corrosion-resistant ceramic key components ensuring the maintenance-free operation of subsea aggregates. Furthermore, we establish novel analysis methods which allow to characterize the complex aging processes of microplastics in the oceans.

1 For the purpose of testing our proposed solutions, we will have at our disposal an underwater test rig in the Baltic Sea (Digital Ocean Lab) in the near future. Testing in real conditions is an important contributor to successful development. The versatile underwater test rig close to the shore will be equipped for the most different application scenarios, such as offshore wind energy, aquaculture or unexploded ordnance removal. Its purpose is to serve research and industry alike by allowing to test, evaluate and optimize materials, modules and complete subsea systems under controlled conditions in a real environment.

Areas of research

- Condition monitoring of subsea structures
- Ceramic key components of subsea systems
- Analytics of microplastics

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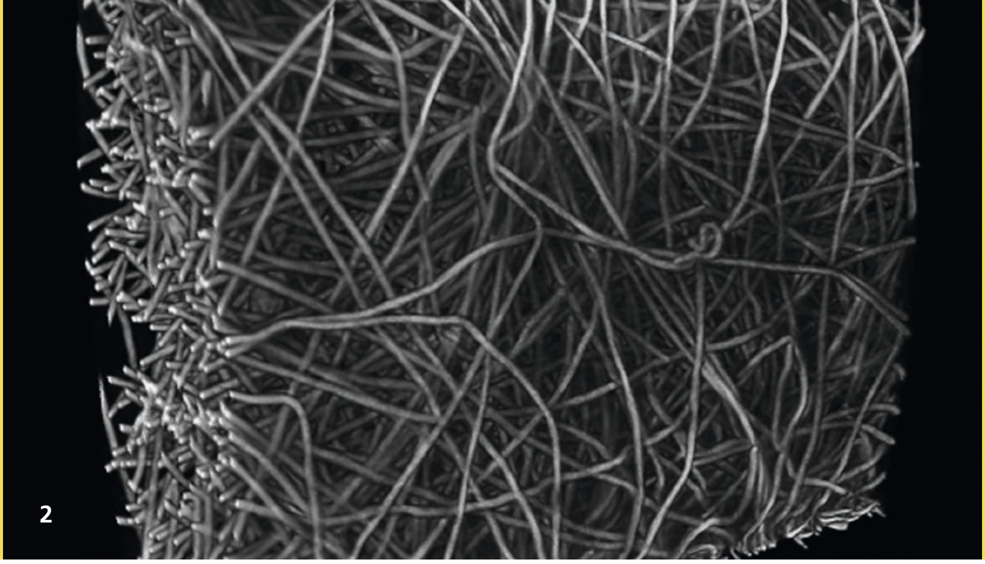


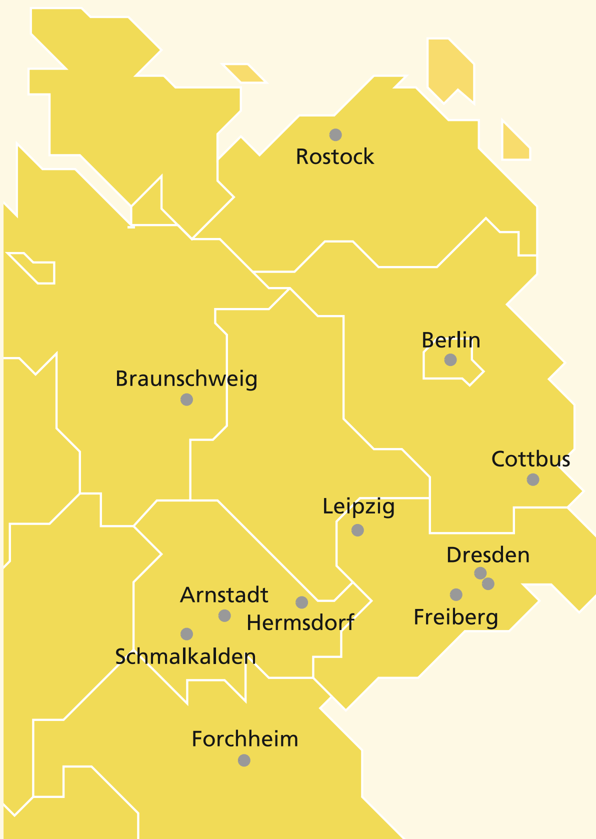
2

Forchheim **2**

Correlative microscopy for bio- and energy materials

More and more frequently, modern material developments, e.g. for medical or energy technology, use composite or nanostructured materials with novel and versatile properties. Their detailed characterization at our Forchheim site can be done with cutting-edge equipment, such as light, electron, ion or X-ray microscopy, as well as the associated spectroscopic measuring methods.

Fraunhofer IKTS sites



Fraunhofer IKTS uses sophisticated methods that allow to analyze material compositions and the associated physical and chemical properties under accurately adjusted environmental conditions. These are recorded correlatively, and examined and described on various dimensional scales. To be able to evaluate and interpret the material data and the complexity of their various combinations, we also develop intelligent and adaptive algorithms.

Areas of research

- Correlative microscopy and spectroscopy across all scales for composites from metallic, ceramic and polymer bio- and energy materials
  - Characterization of materials and components of batteries and fuel cells with different cell concepts and various degrees of technological maturity
  - Characterization of implant materials
- Characterization of complex material composites for material optimization or for the development of efficient, personalized therapies, e.g. bone architecture in the case of osteoporosis
- Examination of micro- and nanoplastic residues in water and water body samples, study of health effects, e.g. on human kidney and lung tissue
- Development of adaptive algorithms for the qualitative and quantitative evaluation of collected correlative data
- Use of machine learning methods to evaluate image data

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Arnstadt 1

Production research for energy storage solutions

Looking at the transformative processes taking place in the automotive and energy sectors, digital support for the production and quality assurance of battery cells and modules will play an ever greater role in the future. The comprehensive digitization of industrial production is one key to optimizing the complete production chain and thus increase the competitiveness of companies. At our site in Arnstadt – the Battery Innovation and Technology Center BITC – we use industry-adjacent pilot lines to test innovative data-driven approaches for process monitoring, control and quality assurance.

When it comes to manufacturing battery cells and battery modules, scaling – i.e. the production of components in the order of millions while maintaining a high standard of quality – comes as a big challenge. When the aim is to ensure the highest possible quality in battery production with minimal rejects, it is important to detect defects as early as possible in the manufacturing process. The BITC aims to use innovative non-destructive testing and measuring technology to monitor all relevant process parameters. AI-based concepts for intelligent aggregation, structuring, evaluation and storage are used for the data thus collected. This enables detecting defect patterns, optimizing production flows and establishing a holistic production data management approach. It also opens up new quality criteria and standards in battery production.

In addition to specific questions around battery development, we are also engaged with developing fundamental routines for the scalable production of complex energy storage and conversion solutions. Looking forward, we will transfer our experience from battery research to digitally supported production technologies for the hydrogen economy, e.g. for electrolyzers.

The BITC finds its greatest strength in its development-related cooperation with companies and research institutions in Thuringia, such as the Technical University Ilmenau, the universities in Jena and Gera-Eisenach, as well as CATL, one of the largest battery cell producers. This allows to concentrate the know-how directly at the site. This type of production research is enormously important for the expansion of new industrial capacities in Thuringia. Moreover, the BITC will be active in the training and further training of qualified employees from the region and promote Industry 4.0 concepts in battery production and other industrial areas.

Areas of research

- Industrial data concepts
- Test methods for battery production
- Workflow management
- Instrumentation and interlinking of process steps
- Quality control and evaluation of digitally supported production processes

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Freiberg 2

New approaches to battery cell recycling

High-performing lithium-ion batteries are a key component for the successful shift away from fossil fuels. Their economic sustainability and the continuous reduction of manufacturing costs are essential for expanding further the use of lithium-ion batteries for mobile or stationary energy storage in the future. At our Freiberg site, we develop efficient manufacturing processes, test methods and recycling concepts suitable for the industry.

To test new high-performing energy materials and cost-efficient manufacturing technologies for the mass market, we and our industrial clients have various technological facilities for mixing, slurry processing, tape coating, drying and compaction of electrode tapes available in dry-room conditions. Minimizing the number of rejects and scrap is another important contribution to reducing costs. For this purpose, we are working to develop non-destructive in-line test methods that are suitable for the industry and can detect defects or functional changes in the material composition or the cell structure early on. This allows to continuously improve the quality of the slurry and tape production.

However, over the coming years it will not just be lower production costs that will give a competitive edge. New concepts and technologies allowing to refeed recovered materials and raw materials into battery cell production will also play a decisive role. Fraunhofer IKTS is pursuing several initiatives in this regard. First, we aim to increase the yield and purity of economically strategic raw materials in the recycling of battery storage systems. This includes both hydrometallurgical and electrochemical processing methods, as well as the recovery of these products from digesting agents and process waters.

To automate material recycling and make recycling processes more efficient and precise, we use suitable monitoring systems and database solutions. Furthermore, we analyze under which conditions these recycled materials can be used for resynthesis and what their effect is on the electrochemical performance of the battery cells. With regard to the required material and substance quality – purity being the most important aspect – we also develop existing recycling processes further, with a view to resynthesis processes. Furthermore, we also develop guidelines for design geared toward the circular economy and for the recycling-friendly design of lithium-ion cells with liquid electrolyte, as well as for solid-state batteries. This allows to make battery systems more suitable for the circular economy and reduce the negative environmental effect of batteries.

Areas of research

- Transfer of efficient production methods for battery electrodes to the industrial scale
- Industrially suitable in-line test methods for electrode production
- Recirculation of battery components
- Material recycling of battery materials

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THE FRAUNHOFER-GESELLSCHAFT

The Fraunhofer-Gesellschaft is world's leading applied research organization. With its focus on developing key technologies that are vital for the future and enabling the commercial exploitation of this work by business and industry, Fraunhofer plays a central role in the innovation process. Based in Germany, Fraunhofer is an innovator and catalyst for groundbreaking developments and a model of scientific excellence. By generating inspirational ideas and spearheading sustainable scientific and technological solutions, Fraunhofer provides science and industry with a vital base and helps shape society now and in the future.

At the Fraunhofer-Gesellschaft, interdisciplinary research teams work together with partners from industry and government in order to transform novel ideas into innovative technologies, to coordinate and realize key research projects with a systematic relevance, and to strengthen the German and the European economy with a commitment to creating value that is based on human values. International collaboration with outstanding research partners and companies from around the world brings Fraunhofer into direct contact with the key regions that drive scientific progress and economic development.

Founded in 1949, the Fraunhofer-Gesellschaft currently operates 75 institutes and research institutions. The majority of our 29,000 staff are qualified scientists and engineers who work with an annual research budget of 2.8 billion euros. Of this sum, 2.4 billion euros are generated through contract research. Around two thirds of Fraunhofer's contract research revenue is derived from contracts with industry and publicly funded research projects. The remaining third comes from the German federal and state governments in the form of base funding.

This enables the institutes to work on solutions to problems that are likely to become crucial for industry and society within the not-too-distant future. Applied research also has a knock-on effect that is felt way beyond the direct benefits experienced by the customer: Our institutes boost industry's performance and efficiency, promote the acceptance of new technologies within society and help train the future generation of scientists and engineers that the economy so urgently requires.

Our highly motivated staff, working at the cutting edge of research, are the key factor in our success as a scientific organization. Fraunhofer offers researchers the opportunity for independent, creative and, at the same time, targeted work. We therefore provide our employees with the chance to develop the professional and personal skills that will enable them to take up positions of responsibility at Fraunhofer, at universities, in industry and within society. Students who work on projects at Fraunhofer Institutes have excellent career prospects in industry by virtue of the practical training they enjoy and the early experience they acquire of dealing with contract partners.

RETROSPECTIVE

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Due to the worldwide COVID-19 pandemic, numerous trade fairs and events were cancelled in 2020. Fraunhofer IKTS presented itself to a broad scientific public in the context of virtual trade fairs, digital conferences and own virtual event formats.

January 22–23 / February 12 / May 13, 2020 **1**

Young researchers at Fraunhofer IKTS

The positions available to young scientists at the Dresden-Klotzsche site in 2020 were once again in great demand. At the preschool children's program traditionally held in January, children from Lisa Kindergarden and from Pirna Protestant Children's House playfully learned about methods used in condition monitoring. In February, students from Dresden Martin-Andersen-Nexö-Gymnasium spent a week doing projects at IKTS. They examined bone replacement structures using optical coherence tomography (OCT) under real conditions and then successfully presented their results to a larger audience. In February and May, the budding junior doctors once again inspired IKTS researchers with their curiosity and creativity in workshops on the topic of ultrasound and effortlessly earned their stamp of approval on their way to the Junior Doctor's hat.

January 24, 2020

Prof. Michael Stelter chairs joint committee on advanced ceramics of DKG and DGM

Since January 2020, Prof. Michael Stelter, Deputy Institute Director of Fraunhofer IKTS, has chaired the Joint Committee on Advanced Ceramics of the German Ceramic Society (DKG) and the German Society for Materials Science (DGM). The Advanced Ceramics Joint Committee is concerned with the manufacture, properties and applications of advanced ceramics as well as their scientific fundamentals. The promotion of cooperation and networking, the initiation of new R&D fields as well as education and training are other objectives.

February 18–19, 2020 **2**

Plastic-free gardening – Franziska Saft wins first prize in Fraunhofer "Netzwert" symposium ideas competition

In Germany, three billion plant pots made of plastic are used every year, mainly as disposables. Engineer Franziska Saft proves that gardening can work without having to resort to plastics.

The IKTS researcher received an award at the Fraunhofer Symposium "Netzwert" in the ideas competition "For sustainable value creation" for her development of completely biodegradable plant pots made of 100 % natural fibers. Together with her team, she developed a technology to purify fiber material from organic residues and make it available again for material production.

March 1, 2020

Major challenges for the trade show industry

The emergence of the Corona pandemic in March 2020 has led to major uncertainties for trade fair organizers, as well as exhibitors and service providers internationally. In order to protect employees while at the same time providing good opportunities for interested parties to get in touch with researchers, IKTS presented research and product highlights digitally in the form of selected replacement formats, in addition to numerous conference presentations: For example, Dr. Juliane Spohn presented, for the first time, ClicKit-Well, a revolutionary tool for the standardized and resource-efficient testing of biomaterials, at the analytica virtual trade fair. Together with the Fraunhofer High-Performance Center "Smart Production and Materials", Dr. Peter Neumeister presented cooperation opportunities and training courses for automation industry players at SPS Connect. At the Fraunhofer Solution Days, shaping expert Uwe Scheithauer provided insight into the additive manufacturing technology of Multi Material Jetting (MMJ), developed at IKTS. And the team from the Environmental and Process Engineering department was available for participants at the IFAT Partnering Event. In 2021, further online participation is scheduled for events such as Sensor+Test, ACHEMA Pulse and Hannover Messe. In the fall of 2021, visitors will probably once again have the opportunity to meet IKTS scientists live at Productronica or IDS, among others.

June 3, 2020 **1**

Saxon workshop for the development of a strong hydrogen economy

Saxony's State Minister for Sciences, Culture and the Arts, Sebastian Gemkow, and Saxony's State Minister for Regional Development, Thomas Schmidt, as well as other representatives of the Saxon State Ministries for Energy, Climate Protection, Environment and Agriculture, and for Economic Affairs, Labor and Transportation, met at IKTS for a workshop discussing hydrogen strategies and how to develop a hydrogen economy in the Free State. Saxony already has competences in all components of the hydrogen value chain and in all parts of the state. What is now needed is a concept of how to turn this into a new industry for Saxony. The declared aim is to establish a hydrogen competence center, which is to prepare for the production of green hydrogen by means of electrolysis for industrial production. This could sustainably reduce or even completely eliminate CO_2 emissions in industrial processes and thus lay the foundation for an emission-free industrial sector.

July 10, 2020 / October 7, 2020 **2**

Battery Innovation and Technology Center BITC in Arnstadt opening, with grant money presented for the first CATL project

With a grant of 13.5 million euros from the Free State of Thuringia, the Battery Innovation and Technology Center (BITC) started operations on July 10, 2020 in the Erfurter Kreuz industrial park. The opening, attended by Prof. Reimund Neugebauer, President of the Fraunhofer-Gesellschaft, Marco Wanderwitz, Federal Government Commissioner for the New Laender, Thuringia's Minister of Economics Wolfgang Tiefensee and other guests from the spheres of politics, business and

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media, marked an important step in the expansion and networking of activities in battery and energy storage technology in Thuringia.

Only few months later, in early October 2020, the initial project, "BattLife", was launched at the new IKTS site in Arnstadt. In collaboration with the Chinese battery manufacturer CATL, a digitized test center for batteries and battery components is being established at BITC. The aim is to analyze and extend the service life of batteries on an industrial scale. Minister Tiefensee personally presented the 5 million euros in funding to Dr. Roland Weidl, head of BITC, and Jason Chen, plant manager at CATT, the Thuringia branch of CATL.

September 16–17, 2020 **3**

AM ceramics meets ceramitec virtual conference

Around 500 international participants followed the first virtual "AM Ceramics & ceramitec conference" live on their screens. During the two-day event, experts from research and industry, invited by Lithoz GmbH, Fraunhofer IKTS and Messe München, presented advances they made in 3D printing, novel ceramic additive manufacturing technologies and innovations in the ceramic process chain. A virtual tour provided hands-on insights into the know-how and infrastructure of Fraunhofer IKTS – along four additive process chains from feedstock to component. The processes Binder Jetting, Fused Filament Fabrication, Multi Material Jetting and Vat Photopolymerization were also on display.

September 29, 2020

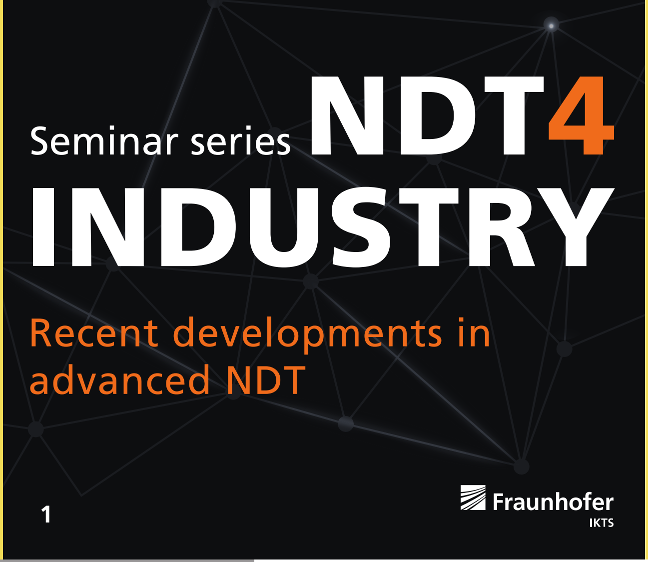
Media breakfast | Early Morning Science

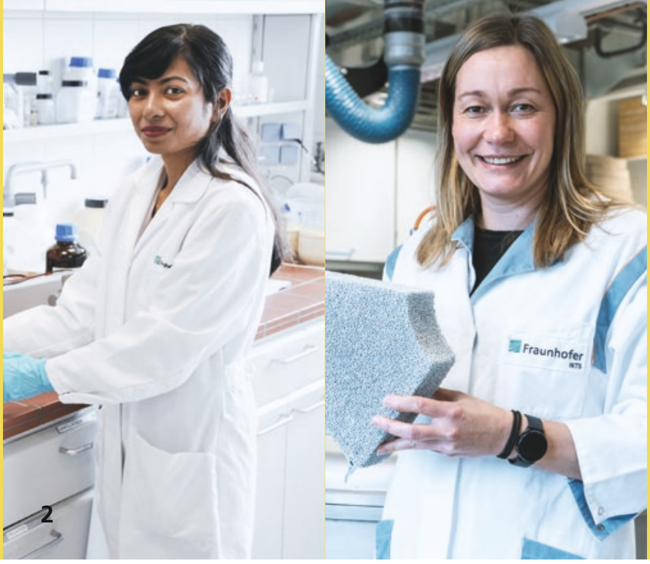
The four Dresden Fraunhofer Institutes at the Winterbergstrasse site frequently present current research highlights on site and via livestreams. Once again, numerous journalists from the regional, national and trade press accepted the invitation to the sixth Early Morning Science media breakfast. In their presentations, Fraunhofer researchers presented, among other things, novel radar sensors for headlights as well as interesting material developments for more powerful hydrogen cars and more efficient hydrogen production. The concept presentation by Dr. Matthias Jahn from IKTS for reducing carbon dioxide emissions by up to 95 % in the production of crude steel was met with particularly strong interest from the media.

October 10, 2020 **4**

20 years of DRESDEN-concept – science exhibition opens on the forecourt of the Dresden Kulturpalast

To make science tangible for the population and transfer results into society: With this goal in mind, the regional research network DRESDEN-concept (DDc) initiated an interactive exhibition for the whole family. Under the title "How will we live in the future? Research from Dresden finds answers.", the exhibition shows current cooperative projects of the DDc partners and addresses topics, such as climate change, a healthy life, the new materials of the future and artificial intelligence. As a long-standing DDc partner, IKTS contributes to several project examples and, above all, results. In the meantime, the exhibition can be visited in Dresden's city hall.





RETROSPECTIVE

October 14, 2020 **1**

NDT4INDUSTRY – new online seminar series showcases NDT developments

Inspired by the idea of networking industry and science even in times of a pandemic and transferring developments into applications to benefit the industry, IKTS has developed the NDT4INDUSTRY online seminar series. Since its kick-off event in October 2020, users from industry and other interested parties have been able to learn about testing solutions developed at the IKTS site in Dresden-Klotzsche. The topics, mainly from the field of non-destructive test methods, are presented in lectures and laboratory tours and then discussed with the participants. The NDT4INDUSTRY online seminar series takes place at regular intervals. Current dates and topics can be found at www.ndt4industry.com.

November 16–17, 2020

Honoring the best trainees of the Fraunhofer-Gesellschaft

At the annual ceremony for the best trainees of the Fraunhofer-Gesellschaft in 2020, IKTS was once again strongly represented. Three physics laboratory technicians were honored this year: Carsten Kruska and Christoph Lehmann (both from the Dresden-Klotzsche site) as well as Franz Müller (now at BITC in Arnstadt). In addition, Dr. Beatrice Bendjus and Dr. Norman Reger-Wagner were recognized for their outstanding work as instructors. Due to the Coronavirus pandemic, the award ceremony took place in a virtual format. Fraunhofer Executive Board member Prof. Alexander Kurz presented the awards to a total of 14 prize winners. It is gratifying to know that all three IKTS award winners will remain employed at IKTS after their training.

November 24, 2020

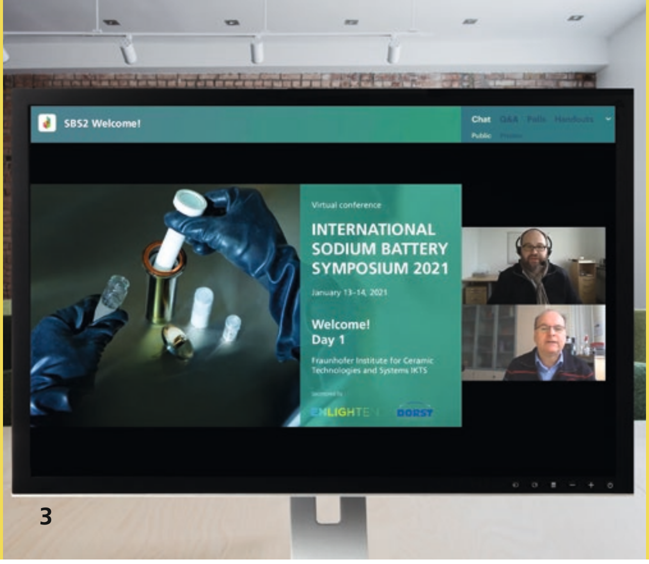
Communication award for mobile series #diensttalk

Every year, the Fraunhofer-Gesellschaft, together with a jury from industry and politics, honors the best examples of successful science communication. The 2nd place was awarded to Fanny Pohontsch, PR employee at IKTS, for the concept and implementation of the #diensttalk series. Since 2019, both scientific and technical staff as well as the group, department and institute management have been giving insights into their work, revealing in the process what drives them – including brief peeks into their private lives. The #diensttalk, consisting of a video clip and blog article, is designed for social media and has already led several interest groups to connect with IKTS directly.

December 10, 2020

Digital networking workshop "Thermoelectric applications in industry"

With the development of new products and components for thermoelectric applications, especially in the fields of sensor technology, process safety, temperature control and waste heat utilization, markets with high potential for the future have emerged – dynamic and attractive at the same time. In a networking workshop, researchers from Fraunhofer IKTS and other Saxon research institutes discussed promising project concepts with industry representatives. The aim was to highlight local competences and application potentials, to initiate cooperation and launch an active Saxon competence network for thermoelectrics.



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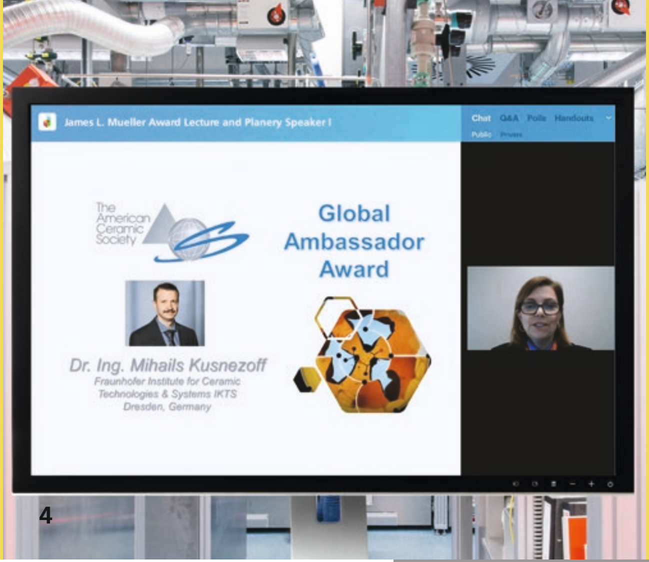

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January 1, 2021 **2**

Fraunhofer TALENTA funding for two IKTS scientists

"Fraunhofer TALENTA" is a funding and development program to attract and develop female scientists. Since 2013, TALENTA has offered female scientists at Fraunhofer the opportunity to strategically advance their careers through partial financing of their employment, tailored qualification and career-oriented networking. At the beginning of 2021, two female IKTS scientists were accepted into the program: Dr. Daniela Haase intends to use the TALENTA funding to pursue her goal of becoming a group manager in the field of cellular ceramics. Tashneem Ara Islam will receive support in the program during her PhD project in the group "Functional Materials for Hybrid Microsystems".

January 13–14, 2021 **3**

SBS2 | International Sodium Battery Symposium

Sodium batteries are a promising and cost-effective alternative to Li-ion cells. The exchange of ideas in this field is crucial for joint progress and public awareness. This year's second edition of the International Sodium Battery Symposium was held as a digital event for the first time. More than 100 international experts from eight nations discussed current research and development trends of sodium-based batteries, their market requirements and future prospects, as well as manufacturing issues. Digital laboratory tours also provided in-depth insights into the extensive equipment and capabilities of IKTS. In 2022, the experts will meet in Berlin.

February 8, 2021 **4**

ACerS Global Ambassador Award for Mihails Kusnezoff

The American Ceramic Society (ACerS) presented Dr. Mihails Kusnezoff, head of department "Materials and Components" at Fraunhofer IKTS with the ACerS Global Ambassador Award 2021 on February 8, 2021 during the virtual 45th International Conference and Expo on Advanced Ceramics and Composites (ICACC). Each year, this award honors individuals whose leadership and commitment have made a special contribution to ACerS and the global ceramics and glass community.

March 19, 2021

Prof. Alexander Michaelis is member of the Battery Research Advisory Board Germany

Fraunhofer IKTS institute director Prof. Alexander Michaelis has been confirmed as a member of the Battery Research Advisory Board Germany. The board with more than 40 high-ranking representatives from industrial companies and research institutions advises the German Federal Ministry of Education and Research (BMBF) on strategic research planning for electrochemical energy storage systems, independent of applications. The advisory board's tasks include recommendations on funding programs and topic clusters and the critical evaluation of study results.

CORONA RESEARCH AT FRAUNHOFER IKTS

ANNUAL REPORT 2020/21

Ceramic solutions to combat the Coronavirus pandemic

The challenges we are facing have shown that research and innovation are key to stemming the tide of the Coronavirus pandemic and its consequences. We are therefore working on several projects in which we use the outstanding range of properties provided by high-performance ceramics in the area of biomedical analytics and protection against infection.

MEMBsS

Decentralized supply of oxygen for ventilators

With the aim of increasing the number of available ventilators for severely impacted COVID-19 patients in times of peak demand, we are working to develop oxygen generators that allow to produce pure oxygen in a decentralized structure, to be set up in varying locations as needed in hospitals or provisional care facilities. The systems separate oxygen from ambient air. This oxygen is sterile and free from virucidal components. The separation process is based on mixed-conducting ceramic membranes which at high temperatures are permeable only for ultra-pure oxygen. The oxygen generator is constructed, tested and evaluated as the prototype of a serial device and will be able to serve approx. 15 patients (85 liters per minute).

CoClean-up

Highly efficient ambient air disinfection to contain the Coronavirus

Droplets and aerosols which contain the virus and are produced while breathing and talking are understood to be the main path of transmission for SARS-CoV-2. In a joint project, the Fraunhofer institutes IKTS and ITEM are developing a system that could be used to disinfect the air in enclosed spaces, such as hospitals, schools, restaurants or fitness studios. The system works based on the principle of electrochemical total oxidation, which completely destroys organic components, such as viruses. This also ensures that endotoxins or other products of the incomplete elimination of contaminants do not enter into indoor air, in particular when used in air conditioning or ventilation systems. Within the project, we are responsible for the overall system design and for developing ceramic diffusors and the electrochemical oxidation module.

#WeKnowHow
FRAUNHOFER VS. CORONA

Micro-PCR

Precisely adjustable thermal cyclers for quick detection of SARS-CoV-2

Laboratories testing for a Corona infection rely on PCR tests. To reduce testing times further in the future and be able to break up chains of infection sooner, IKTS is developing novel thermal cyclers. These help to heat and cool the sample material in a swift and precise way when reproducing and detecting the viral genetic code contained in the samples using the polymerase chain reaction. We combine several ceramic technologies for the new thermal cycler: Additive manufacturing processes are used to print the housing with integrated heating conductor structures, which are functionalized with ceramic heating pastes. This enables direct heat transfer and faster heating and cooling rates.

TO-G

Plasma disinfection of medical protective clothing

Plasma disinfection systems are used to disinfect protective clothing in the case of supply bottlenecks so it can be reused. However, the plasma electrodes used so far for this purpose are made of plastic and metal; they wear out quickly, limiting the use of this otherwise highly attractive method of disinfection. To solve this problem, we use electrically conductive ceramics for this functional core component, based on an innovative sintering technology for titanium oxides. These can, for one, reliably withstand the high electric voltage required for creating the plasma. Second, we can connect two functionally different electrode components in one single cost-efficient process step.

BioKomp

Quantitative biocompatibility testing for 3D-printed materials

3D-printed medical products make it possible to close supply gaps fast in a pandemic and create solutions for patient care (e.g. emergency ventilators, diagnostic consumable materials for acute cases). To be able to test 3D-printed plastic components in direct contact with cells/tissue, we are developing a novel biocompatibility test. The project aims to prove that it is possible, with our own developed in-vitro testing system "ClicKit-Well", to quantify cytoxicity in a direct cell test. This will enable medical professionals to evaluate risks and make a decision on the use of products made by additive manufacturing methods. The project team includes Leipzig University and Forschungs- und Transferzentrum Leipzig e. V. (FTZ). The partners cooperate with hospitals and the City of Leipzig.

COPERIMOplus

Personalized risk assessment models for heavy COVID-19 courses of illness

COVID-19 is causing significant problems for health systems, in particular with regard to the clinical treatment of severe courses of illness. A collaborative project aims to provide AI-based, individualized risk models which enable prognosticating such courses of illness. Fraunhofer IKTS contributes to the project with a platform for the statistical and quantitative evaluation of large, heterogeneous data sets. This includes using machine learning methods and enables synergetic support from other fields of application for data acquisition and risk models. Furthermore, we integrate other cross-sectional and pacemaker technologies in the data models, such as imaging analytics and automated data evaluation.

HIGHLIGHTS FROM OUR BUSINESS DIVISIONS

Materials and Processes

Energy

Water

Mechanical and Automotive Engineering

Environmental and Process Engineering

Materials and Process Analysis

Electronics and Microsystems

Bio- and Medical Technology

Non-Destructive Testing and Monitoring

Materials and Processes

page 28–32

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.

Mechanical and Automotive Engineering

page 33–35

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.

Electronics and Microsystems

page 36–39

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.

Energy
page 40–47

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

Water
page 54–58

Efficient use and purification of water is of the highest importance. Fraunhofer IKTS provides solutions for the treatment of waste wasters – 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.

Environmental and Process Engineering
page 48–50

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.

Materials and Process Analysis
page 59–62

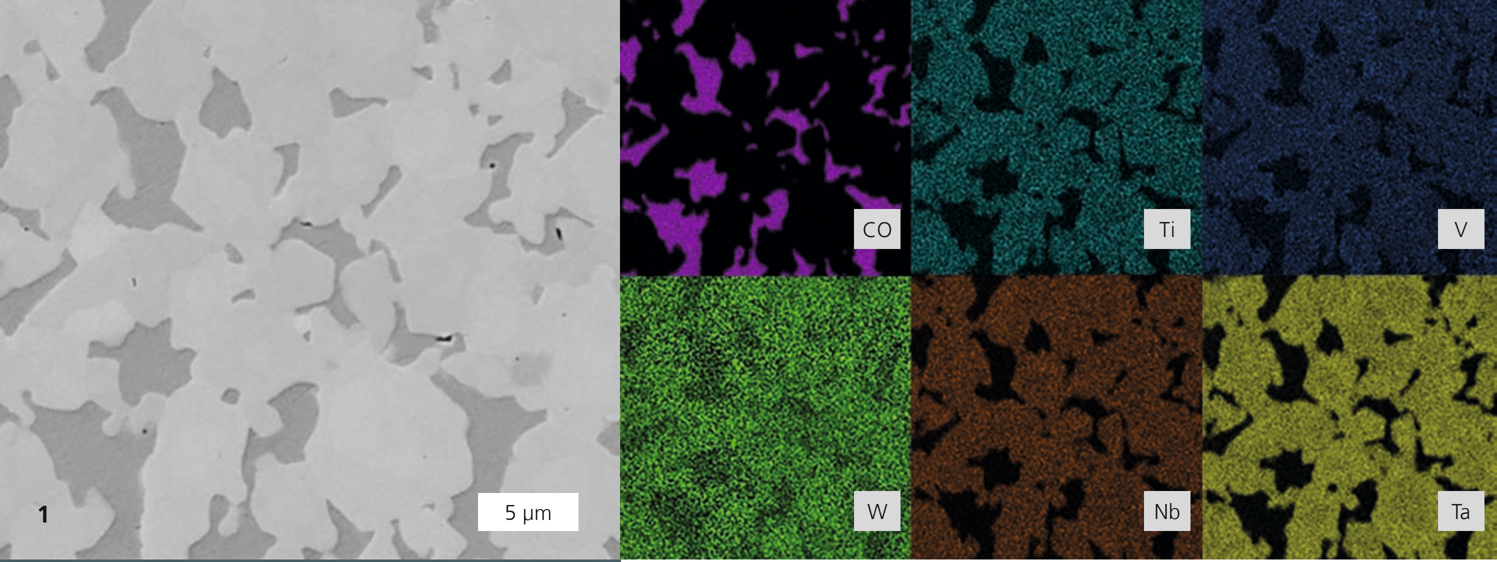
Fraunhofer IKTS offers a comprehensive portfolio in testing, characterization and analysis methods to control material features and production processes. As a service provider accredited and audited multiple times, IKTS supports the analysis of materials fundamentals, application-related questions and 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.

Bio- and Medical Technology
page 51–53

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.

Non-Destructive Testing and Monitoring
page 63–67

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.



NOVEL HARD PHASES FOR HARDMETALS, MMC AND THERMAL SPRAYING

Dr. Johannes Pötschke

For many different applications that require materials combining high hardness and high toughness, hard phase-based metal matrix composites (MMC) are used. Among these are hardmetals, which are used for drilling, cutting, and machining as well as for different shaping tools (e.g. pressing dies, extrusion tools). Other examples are thermally sprayed hardmetal coatings or wear parts produced by means of metal melt infiltration. In all these applications, only hard phase grains or particles consisting of one or two hard phase composing elements are currently used, such as tungsten in tungsten carbide, titanium in titanium carbide or titanium carbo-nitride and silicon in silicon carbide.

Multi-element hard phases

The new multi-element hard phases developed at Fraunhofer IKTS, so called high entropy hard phases (carbides, nitrides or carbo-nitrides), consist of several carbide forming metal atoms with equi-atomar composition. This makes it possible to use novel hard phase particles, some of them with higher hardness and adjusted thermal conductivity compared with single-element hard phases, for different applications.

High entropy hard phase composite materials

By mixing and subsequent sintering of the high entropy hard phase particles with ductile metal particles, such as cobalt, nickel or iron-based alloys, novel high entropy hard phase composites (patent pending) can be produced. Because of the high stability of the high entropy hard phases, the carbide forming elements do not fully dissolve within the metal matrix but remain to form a very hard hard phase skeleton. The chemical elements suitable for high entropy hard phase particles all come from the fourth to sixth subgroup of the periodic table of elements. They are, among others, Ti, Zr, Hf, V, Nb, Ta, Cr, Mo, and W. Based on their design, which requires at least four of these elements, plus carbon or nitrogen as carbide or nitride formers, a large variety of high entropy hard phases can be realized. By mixing with the mentioned ductile metal particles, a targeted design of adjusted mechanical as well as thermo-physical properties, such as hardness, fracture toughness, electrical and thermal conductivity, can be achieved. An advantage over conventional hard phases is that the phase design now allows the substitution of tungsten carbide, which is classified as a critical raw material (CRM) among hardmetals. Furthermore, it is expected that the use of high entropy hard phases will increase the service life of tools and reduce the consumption of resources as well as resource dependency. The levels of fracture toughness (up to 8.5 MPa*$m^{1/2}$) and hardness (up to 1450 HV10) reached presently are comparable with conventional tungsten carbide cobalt-based hardmetals or titanium carbonitride nickel-based cermets. With further developments and research work, these properties are expected to be strengthened even more. We plan to develop and validate these novel composite materials further by means of public co-funded projects.

1 *Microstructure and element distribution of metal atoms within a cobalt bonded (Ti,V,W,Nb,Ta)C high entropy hard phase hardmetal.*

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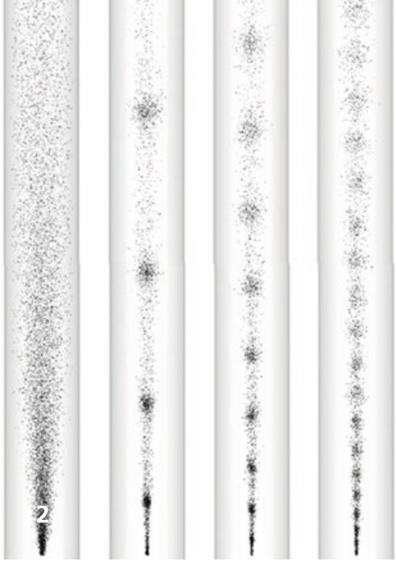

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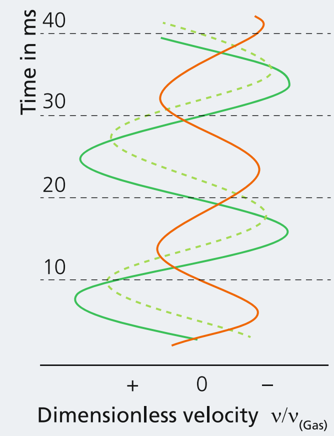

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SYNTHESIS REACTOR FOR OXIDE NANOPOWDERS

Dr. Sabine Begand, M. Sc. Kerstin Simon, M. Eng. Andreas Frickel

Achieving the high mechanical and optical properties of oxide high-performance ceramics requires specific powder properties. In addition to particle size (< 100 nm), a high degree of purity, a narrow particle size distribution and the particle shape play an important role. Fraunhofer IKTS has set up the world's first plant for the production of tailor-made, oxidic nanopowders on the kilogram scale based on a flameless concept with pulsating gas flow (ProAPP®, Glatt Ingenieurtechnik GmbH).

The synthesis method is based on spray pyrolysis, whereby the process gas is set into dynamic pressure oscillation by means of a pulsation unit. The frequency and amplitude can be adjusted from 0 to 400 Hz and 0 to 60 mbar, respectively. After a preheating period, the pulsating gas flows into a 4 m long tube made of Al_2O_3. It can be heated up to 1300 °C by electrically operated heaters. The starting material in the form of powders, a solution, suspension or emulsion is sprayed into the reaction chamber through a binary nozzle. The unique feature here is that the pulsation creates a turbulent flow which increases the heat and mass transfer by a factor of 2–5 compared with stationary heat supply [1]. This allows the thermal shock-like decomposition and the subsequent crystallization to take place in a very short time. In comparison with laminar flow, where the flow velocity increases towards the center of the cross section, the injected aerosols in turbulent flow experience a constant treatment intensity over the cross section, so that each particle experiences the same conditions. This makes powder properties less scattered. Depending on the product requirements, the process gas can be selected as inert, reducing or oxidizing. The process parameters can be adjusted in a controlled way, making it possible to specifically influence phase state, morphology, particle size and distribution. After the reaction zone, abrupt air-cooling ensures that no further reactions take place. The synthesis reactor is supplemented by a glass apparatus for the preparation of precursors.

This process can for example be used to produce ZrO_2/Al_2O_3 powders for joint replacements, which provide increased strength and reliability thanks to their fine microstructure. Polycrystalline Mg-Al-Spinel powders can be processed into lenses or disks and guarantee high transmission values combined with superior mechanical properties. This process also offers the possibility of synthesizing powders for YAG lasers, catalysts and core-shell particles.

[1] Kudra, T.; Mujumdar, A.S. Advanced Drying Technologies, 2nd ed.; CRC Press: Boca Raton, FL, USA, 2009.

EFRE EUROPA FÜR THÜRINGEN EUROPÄISCHER FONDS FÜR REGIONALE ENTWICKLUNG
EUROPÄISCHE UNION
Thüringer Aufbaubank

1 *ProAPP® reactor at IKTS.*
2 *Spray patterns at different frequencies (Teiwes A., doi:10.3390/pr8070815).*
3 *Velocity curve of particles in a pulsating gas flow.*

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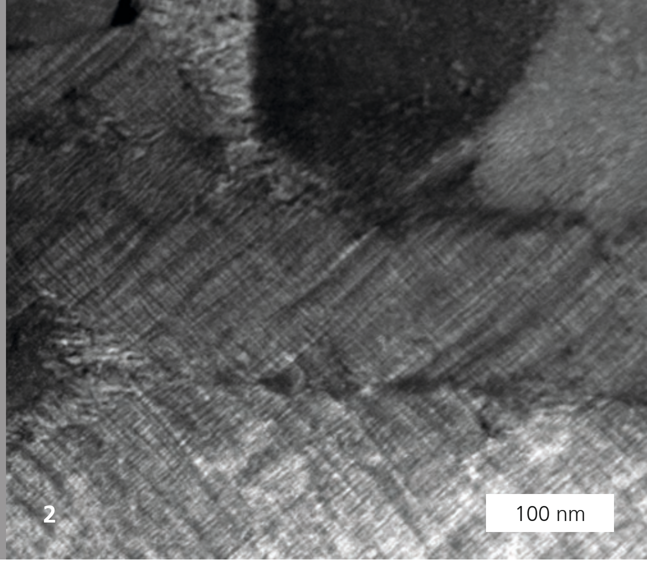

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WEAR-REDUCING ALUMINUM-RICH CVD-TiAlN LAYERS

Dr. Mandy Höhn, Dipl.-Phys. Mario Krug

Steadily increasing demands on cutting tools resulting from increasing requirements for high-speed and dry machining, as well as the machining of high-strength and difficult-to-machine materials, are the driving force behind the development of new and more efficient wear protection layers. Temperatures of over 1000 °C are reached at the cutting edge and especially on the rake face at high cutting speeds. Therefore, modern wear protection layers must offer a good resistance to oxidation as well as a chemical inertness to the workpiece material in addition to the required high hardness. Over the past few years, $Ti_{1-x}Al_xN$ with cubic structure has become an important standard layer for wear protection. Aluminum-rich $Ti_{1-x}Al_xN$ layers, which mainly contain the hard cubic phase, offer significantly better wear resistance than $Ti_{1-x}Al_xN$ layers with lower aluminum contents. $Ti_{1-x}Al_xN$ layers with a predominantly cubic structure and high aluminum contents of $x > 0.65$ are currently not achievable with conventional physical vapor deposition (PVD) processes, such as magnetron sputtering or the arc process. With thermal chemical vapor deposition (CVD), cubic $Ti_{1-x}Al_xN$ with $x > 0.65$ can be deposited on hardmetal substrates. However, it is not yet known why the cubic phase stabilizes in the CVD process with very high aluminum contents. That is why Fraunhofer IKTS is pursuing the goal of investigating the mechanisms of CVD deposition in more depth, with the aim of using the findings for further improvement of the layer structure. A horizontal vacuum hot-wall reactor with separate introduction of the reactive gases was used for the CVD process. The reactants $TiCl_4$, $AlCl_3$ and NH_3 as well as Ar, H_2 and N_2 were used as starting materials for the $Ti_{1-x}Al_xN$ layers. The deposition parameters of temperature (700 to 900 °C), pressure (5 to 60 mbar) as well as gas composition were varied. The formation of soft, wurzitic AlN in the deposited cubic $Ti_{1-x}Al_xN$ layers could be minimized through the specific adjustment of the NH_3/H_2 ratio. This resulted in an increase of the indentation hardness from 25 GPa to 32 GPa. The microstructure shows the formation of large Al-rich cubic $Ti_{1-x}Al_xN$ columnar crystallites, which grow along the <110>-direction. Under favorable deposition conditions, the formation of nanolamellar structures (so-called fishbone structure, Figure 2) within the aluminum-rich cubic $Ti_{1-x}Al_xN$ crystals can be adjusted in a targeted manner. These columnar crystallites are characterized by periodically arranged Al- and Ti-rich cubic $Ti_{1-x}Al_xN$ domains, which are observed by scanning TEM with EDS and EELS. The developed aluminum-rich cubic $Ti_{1-x}Al_xN$ CVD layers have excellent wear resistance, which results from their superior hardness, intrinsic residual compressive stress and good oxidation resistance.

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1 *CVD-TiAlN coated milling and drilling tool.*

2 *Fishbone-like microstructure of a $Ti_{0.19}Al_{0.81}N$ hard layer deposited by CVD (TEM image, Source: TU BA Freiberg).*

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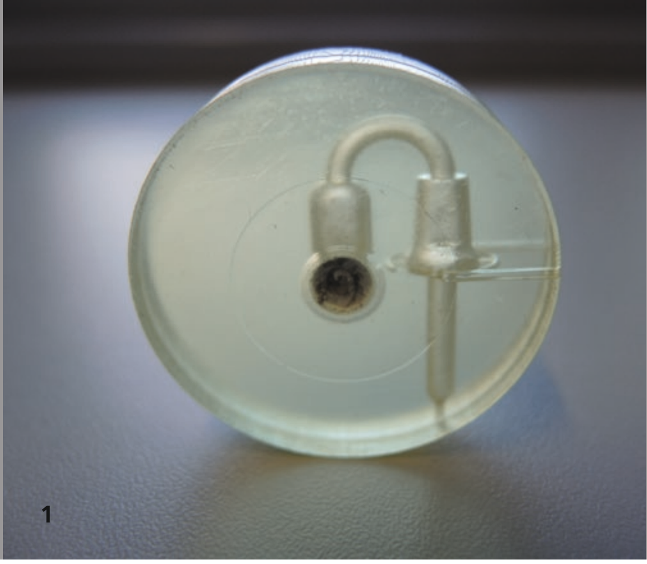

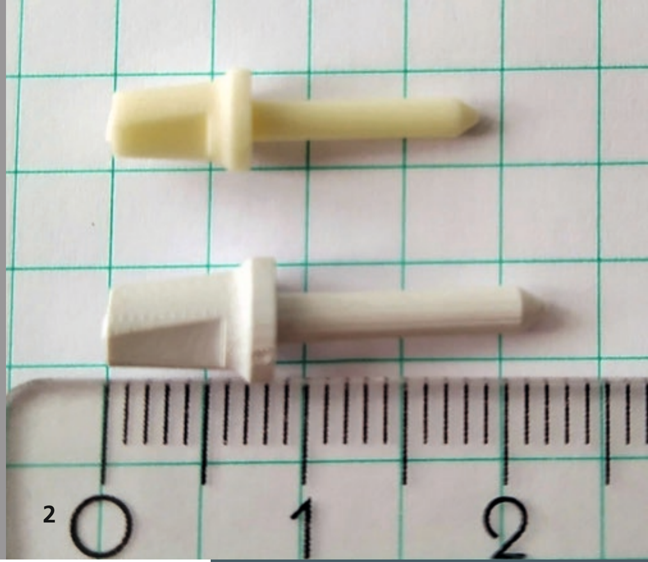

FREEFORM INJECTION MOLDING – CERAMIC INJECTION MOLDING WITH SINGLE-USE MOLDS

Dr. Axel Müller-Köhn, Dipl.-Ing. Eric Schwarzer, Dr. Tassilo Moritz

On the path from the first part design to a component ready for production, several iterations are often required where different aspects of the part design and the production process are tested. In the case of ceramic injection molding (CIM), this can be a time-consuming exercise, as tooling rework commonly requires several weeks. Therefore, many attempts have been made by parts producers to reduce the development steps, ranging from green part post-machining to additively manufactured (AM) parts to a method called 'soft tooling', which uses cast epoxy or AM polymer molds. Of these, only the latter approach allows prototyping with the same production process and material as used for the actual mass-produced component.

Freeform injection molding – Single-use molds

Freeform injection molding (FIM) uses a dissolvable UV-curing polymer for 3D-print molds. A lithography-based device (AFU5), made by AddiFab (Denmark), is used to print the molds. Such a dissolvable mold material removes all conventional mold design considerations regarding draft angles, ejector pins and split line. Furthermore, component design – comparable to additive manufacturing – is made possible since there are no restrictions with regard to undercuts, the way there are with conventional split tools. Neither is mold deterioration an issue, as the mold material is formulated to dissolve and is therefore single-use only. With each mold it is possible to produce different features and dimensions. This allows an exploration of prototypes at different stages of tool construction, such as material selection or different allowances for setting the desired sintering dimensions of the components. Therefore, such iterations on the final prototype can be carried out in less time and at reduced cost.

Single-use molds in ceramic injection molding

Commercial CIM feedstocks were successfully used to produce demonstration parts with the FIM process. FIM-inherent process steps such as injection into a polymer mold or demolding had no negative effect on the subsequent green part debinding and sintering steps. In comparison with conventionally produced CIM parts, the sintered parts showed very good performance and comparable shrinkage behavior.

Services offered

- Component and materials development for ceramic injection molding and prototype construction
- Design studies for new materials

1 *Printed insert for injection molding.*
2 *Demolded green and sintered part from FIM-process.*

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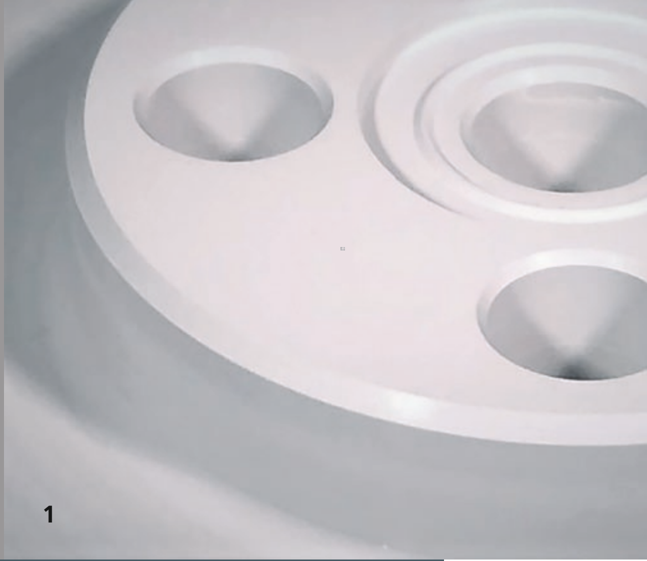

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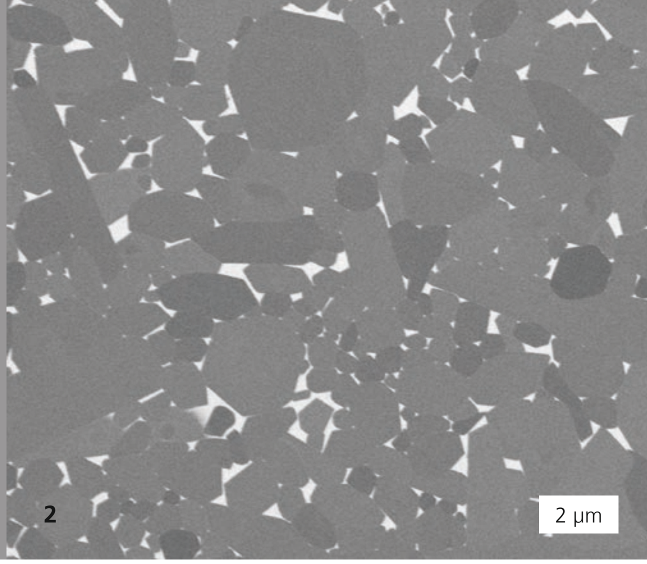

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SIALONS – A SPECIAL CERAMIC PRODUCED WITH LESS EFFORT

Dr. Eveline Zschippang, Fabian Loepthien, Dr. Anne-Katrin Wolfrum, Dr. Mathias Herrmann, Dr. Manfred Fries

Alpha and alpha/beta sialons are solid solutions of silicon nitride. Their advantage is their higher chemical resistance and hardness compared with silicon nitride (Si_3N_4), with the fracture toughness being almost equal. This not only makes them interesting for application as cutting tool material for the high-speed machining of high-temperature alloys (used in aviation, automotive, energy production and plant engineering), but also as a material for chemical, mechanical and plant engineering. Also, sialons are receiving more and more attention for applications in high-power LEDs because their luminance and color do not change significantly with the temperature thanks to their high temperature stability. However, sialon materials are far less established than silicon nitride, as their production costs have previously been significantly higher. To produce sialons, alumina nitride (AlN) powder is used, which is sensitive to hydrolysis. This makes aqueous processing difficult, so that solvent-based processing is usually required, which has special requirements for labs and staff. Fraunhofer IKTS has now developed a cost-effective aqueous processing route that minimizes the hydrolysis of AlN during the processing of sialon granulates. This allows the reproducible production of different sialon compositions, which can be used both for wear applications and for optically active materials. Since sintering and structure formation in sialon materials are different from Si_3N_4 materials, the process also allows the use of cost-effective silicon nitride powders without a significant difference in properties compared with the use of high-end powders. The manufacturing processes developed in the laboratory were successfully scaled up on a small scale (10 to 25 kg powder base). The developed granule with a specially adapted binder system shows a very good compaction behavior and enables compaction via uniaxial or cold isostatic pressing. The green parts could be machined very well by milling, turning and drilling. Different drillings, chamfers and grooves could be brought in without errors (Figure 1). The microstructure (Figure 2) of the densely sintered material is very homogeneous and leads to excellent properties: For example, an alpha/beta sialon (80:20) has a hardness (HV10) of 18.5 GP, a 4-point bending strength of > 750 MPa and a fracture toughness of 5 MPa $m^{1/2}$ (SEVNB). The material properties and chemical resistance can be further adapted by varying the alpha/beta sialon ratio and the oxidic grain boundary phase.

Services offered

- Optimization of the materials properties for optical or tribological applications
- Characterization and development of functional or ready to press powders

The IGF Project 20076 N 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 German Ministry of Economic Affairs and Energy (BMWi), based on a resolution of the German Bundestag.

Supported by: Federal Ministry for Economic Affairs and Energy

1 *Uniaxially pressed component after green machining.*
2 *FESEM image of the microstructure of the sintered sialon material.*

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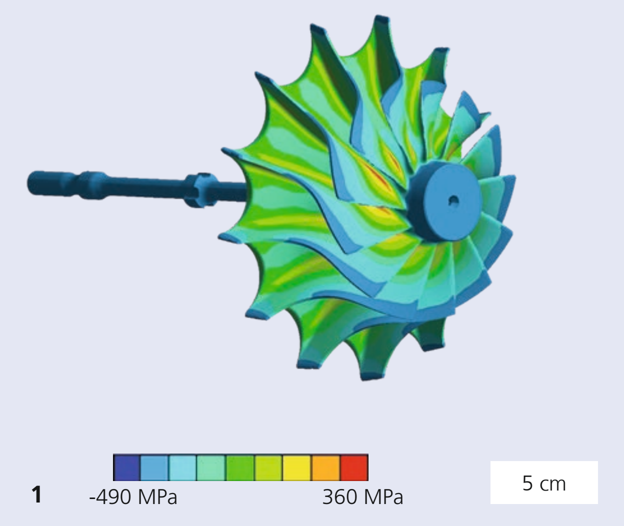

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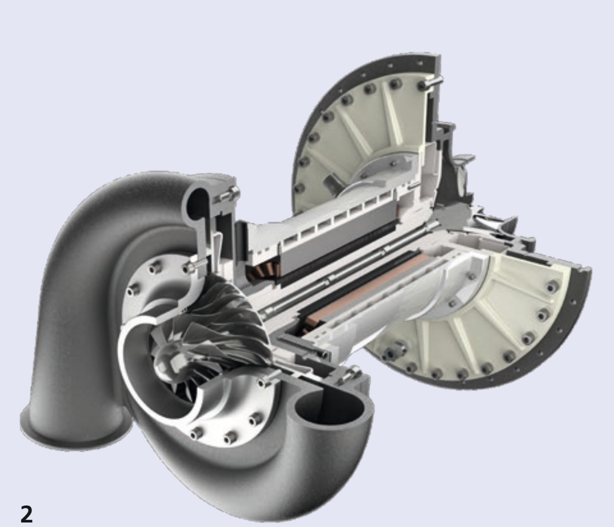

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TURBINE COMPONENTS MADE OF SILICON NITRIDE

Dr. Willy Kunz

Small gas turbines, called "micro gas turbines" (MGT), provide electrical energy in the power range up to about 200 kW. Their compact design enables flexible, decentralized use, for example for the energy supply of buildings and larger plants. With the emergence of e-mobility, further innovative fields of application with extremely high economic potential have developed. For example, MGTs used as range extenders in buses enable highly efficient passenger transport. Noise pollution is significantly lower than with piston engines – a significant increase in passenger comfort. Another advantage is fuel flexibility. Besides fossil fuel gases, renewable energy sources such as biogases and synthetic liquid fuels can also be used in the future. Further innovative concepts for energy supply are already part of current research, for example the symbiotic combination of high-temperature fuel cells and MGT.

Nothing turns without the right material

Besides the numerous advantages, there are still some challenges to be solved. The use of biogenic fuels leads to increased corrosion. Electrical efficiency needs to be increased and the usability of hydrogen or hydrogen-rich gases must be addressed. However, this is where current plant concepts, which rely on metallic components, reach their limits.

Advanced ceramics as a motor for the turbine

To increase the performance of turbine components, Fraunhofer IKTS is researching suitable high-performance ceramic materials. In the "BonoKeram" project (FKZ: 03EE5032A), funded by the German Federal Ministry for Economic Affairs and Energy, a rotor made of silicon nitride for a 60 kW_{el} micro gas turbine is currently being developed and its long-term stability tested. This is done in cooperation with the Fraunhofer Institutes IPK and SCAI as well as industrial partners.

Based on the experience of previous projects, the silicon nitride material is specifically adapted to the load situation in the turbine. The material must meet the following criteria: very high strength, oxidation and corrosion resistance, as well as sufficient creep resistance. The aim is to provide a durable material for turbine inlet temperatures of up to 1400 °C. In the future, this will lead to new generations of microturbines that can burn biogenic (corrosion) or hydrogen-rich fuels (extreme temperatures) with increased efficiency.

Services offered

- Material development and characterization
- Design and optimization, failure analysis

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1 *Simulation of stress distribution in a ceramic motor.*
2 *Center piece of a gas turbine.*

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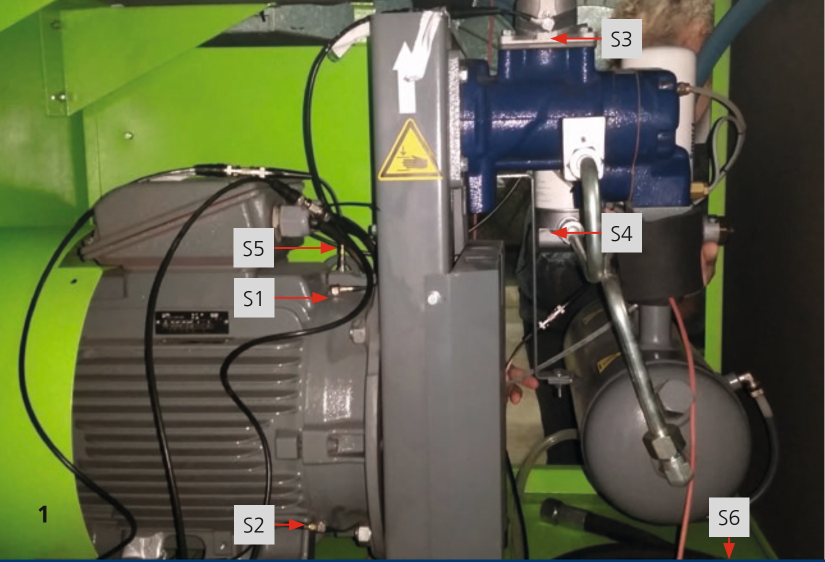

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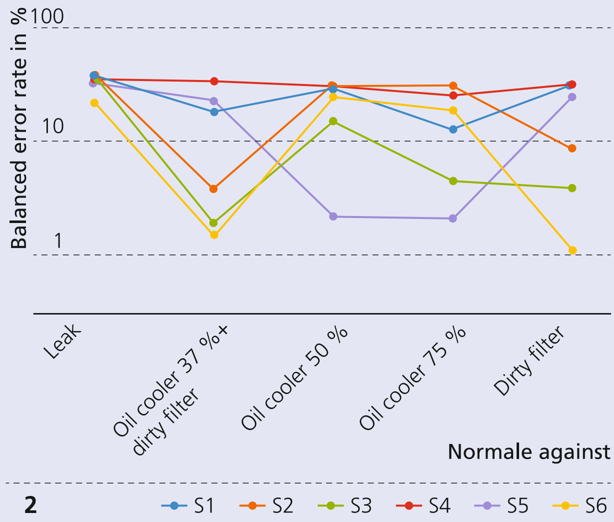

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CompWatch – AUTOMATED MONITORING OF COMPRESSORS

M. Sc. Maximilian Mühle, Dr. Constanze Tschöpe, Dr. Frank Duckhorn

Compressors are an important part of many industrial plants. Their stable operation is therefore required for many processes in the industial and transportation sectors as well as other areas of society. A failure has various consequences, e.g. downtime, repair times, service work and the resulting, often considerable, economic damage. So far, maintenance has mostly been carried out at fixed service intervals and process parameters have been checked on a random basis.

Goal: Event-oriented maintenance

As part of the CompWatch project, procedures are being developed which are intended to enable a transition from fixed to event-oriented maintenance intervals. To achieve this, it is necessary to recognize possible errors early on and thus to be able to predict failures. Hence, the project serves current global trends, such as Industry 4.0 and predictive maintenance.

Anomaly detection based on acoustic signals

Acoustic signals and vibration data contain signatures that allow conclusions to be drawn about the condition of the compressor and its trend. The data is evaluated using methods of artificial intelligence and machine learning. Oftentimes all errors must be known while designing the models in order to be able to recognize them later.

The special feature of our approach is that we predict and determine abnormal conditions (anomalies) without such prior knowledge. This would facilitate quick and easy integration into new environments and running systems.

The collaborating project partners each contribute their competencies: SONOTEC GmbH: modern sensor technology, Petko GmbH: expert knowledge about the operation and maintenance of compressors, as well as Fraunhofer IKTS: AI-based algorithms for error detection.

Different types of sensors for anomaly detection were used in the experiments. The sensor positions (Figure 1) were chosen in such a way that as many components as possible could be monitored. Figure 2 shows the detection rates (scaled logarithmically) for differentiating between an error and the normal state for each sensor. The lower the detection rate, the fewer false alarms occur and the better the detection of defects works. A leak in the compressed air system and contamination of the air filter can be found particularly well with the airborne sound sensor (S6). The cover of the oil cooler was best recognized with the sensor S5. The individual components are currently being integrated into a demonstrator and will then be evaluated on compressors.

This project is funded by the German Federal Ministry of Education and Research (BMBF, funding number 02K18K012) and implemented by the Project Management Agency Karlsruhe (PTKA).

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BETREUT VOM PTKA Projektträger Karlsruhe im Karlsruher Institut für Technologie

1 Position of sensors for acoustic anomaly detection at different compressor components.

2 The best error rates for each sensor and defect.

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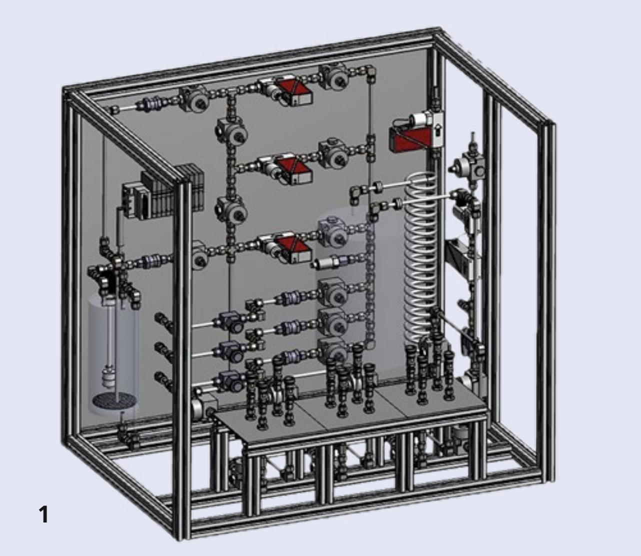

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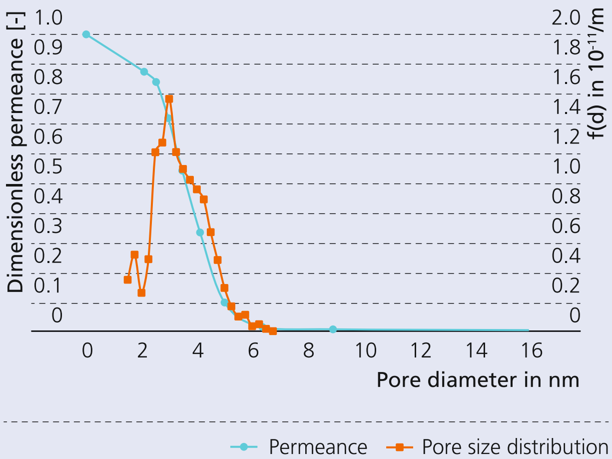
FULLY AUTOMATED PERMPOROMETRY PLANT FOR MEMBRANE CHARACTERIZATION

Dr. Marcus Weyd, M. Sc. Matthias Bernhardt

When developing and producing porous ceramic membranes, information on the pore size distribution and the absence of defects in the active separation layer is of great importance. Conventional analytical methods (mercury porosimetry, nitrogen sorption, SEM, determination of molecular weight cut-off, etc.) require the preparation of a special test sample or cause irreversible damage to the membrane. Permporometry, a relatively new measuring method, allows non-destructive analysis of defect pores and pore distributions in mesoporous membranes. Fraunhofer IKTS has for several years been successfully using a self-developed and mostly manually controlled permporometry plant for membrane characterization. This has now been supplemented by a fully automated version, which was also developed and built at IKTS. This system allows for a considerable increase in measuring capacities. Up to three membrane modules can be installed simultaneously. Three gases (standard nitrogen, argon and helium) can be used for the measurements and can also be changed automatically during the measurements. By using optimized pipe dimensions and a precise automatic pressure regulation system, it is possible to obtain much more precise measurement results in a shorter time. Different humidifying agents (e.g. water, ethanol, n-hexane) can be used. Dosing and temperature control are set automatically, ensuring high temperature stability and precise humidity adjustment. Thanks to the defined sequence control as well as the control and constancy of the operating points during the measurements, membrane characterization is faster and reproducible. Tubular membranes with meso- and microporous active separation layers of different geometries (internally and externally coated single- and multi-channel tubes, disks/plate membranes, etc.) can be analyzed.

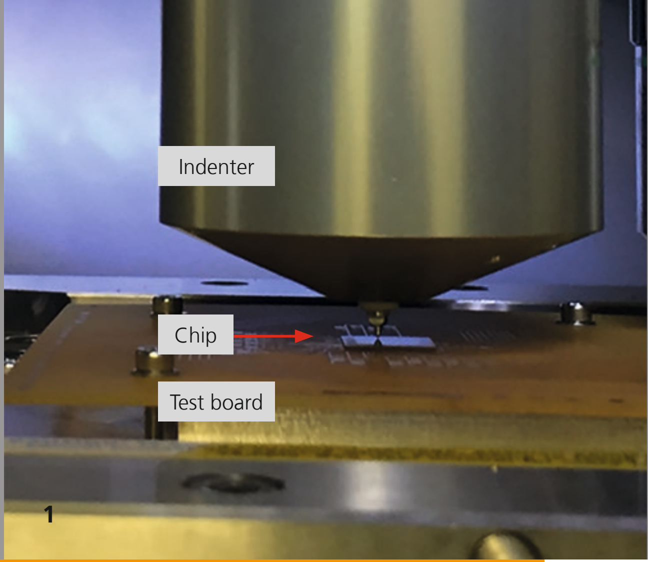
The plant is an important tool for membrane characterization during membrane development. However, the process also shows great potential for use in quality control during membrane production, e.g. for determining characteristic gas flows under defined test conditions.

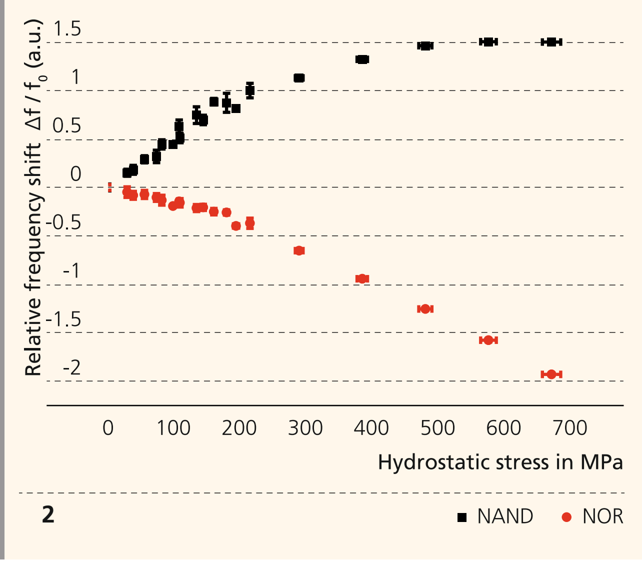
Permporometry data and calculated pore size distribution of an ultrafiltration membrane



1 *3D construction of a plant.*

2 *Permporometry system in the Fraunhofer IKTS lab.*





ELECTRONICS AND MICROSYSTEMS

STRESS EFFECTS IN MICROELECTRONIC DEVICES STUDIED WITH INDENTATION

M. Sc. Simon Schlipf, Dr. André Clausner, M. Sc. Simone Capecchi[1], Dipl.-Ing. Jens Paul[1],
Prof. Ehrenfried Zschech ([1]GLOBALFOUNDRIES Dresden)

Stress effects in transistors

In microelectronic technologies, local mechanical stress is used to enhance performance and efficiency. The phenomenon known as 'piezoresistive effect' leads to improved electrical performance. However, uncontrolled thermo-mechanical stress can affect the functionality and reliability of microelectronic devices in harsh environments, for instance in cars. An established technique to estimate the influence of stress on device performance under stress is four-point bending. But this method only allows the application of homogeneous global stress. In order to determine the local influence of stress effects with a high resolution, a novel technique for localized loading based on non-destructive indentation was developed and successfully implemented at Fraunhofer IKTS .

Non-destructive indentation on test chips

In this study, test chips with integrated stress-sensitive circuits (ring oscillators) are utilized and soldered on a board for electrical contacting. The approach allows to monitor the behavior of electrically active circuits and transistors under local mechanical load. To achieve this, the test chips are non-destructively loaded on the silicon side using an indenter with a spherical tip as depicted in Figure 1. Simultaneously, characteristic electrical signals (frequency f) of the circuits are monitored as mechanical loads continuously increase, as shown in Figure 2.

Mechanical simulations (FEM) of the full experiment are set up to compute the stresses in the transistor channels of the circuits, taking into account the experimentally applied loads, chip layouts and the selected contact geometry. The determined stress/strain is the physical root cause for the transistors' observed parametric variations.

Two different ring oscillator structures (NAND and NOR circuits) were studied and the results observed indicate different electrical responses to the experimental loads applied, which can be explained by their specific circuit layouts. Additionally, the accuracy and resolution of the experimental approach, the working range as well as the impact of technique-related parameters were studied and improved. Based on these results, directional stress effects in transistors were also studied using cylindrical tips. Combining the indentation studies with spherical and cylindrical tips made it possible to determine quantitatively the piezoresistive coefficients of the chip technology under review, which is an excellent result with a view to implementing the process in an industrial setting. With the help of the method developed, local effects of stressed silicon and uncontrolled stresses on the components can now be estimated.

Supported by:
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1 Experimental indentation setup with active devices under local load.

2 Ring oscillator frequency deviations as a function of local stress.

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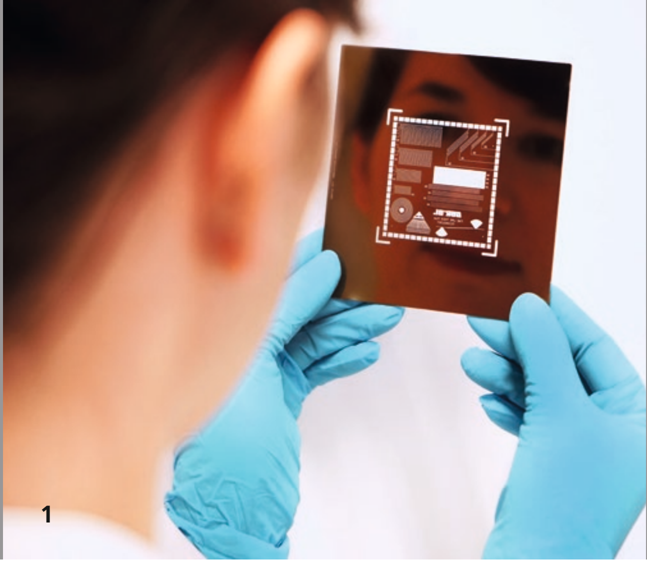

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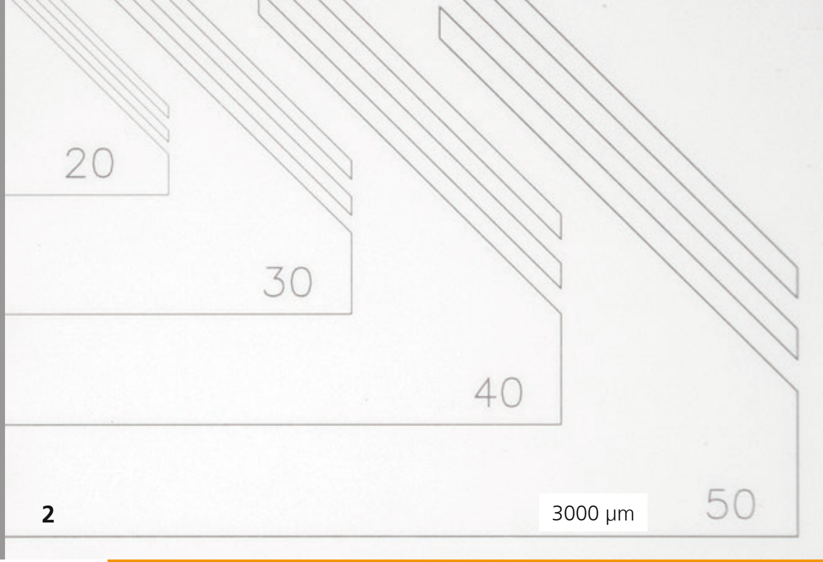

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PHOTOIMAGEABLE PASTES FOR HIGH-FREQUENCY APPLICATIONS

Dr. Kathrin Reinhardt, Dr. Stefan Körner, Dr. Uwe Partsch

Photoimageable thick-film pastes – the new path for high-speed internet?

The next generation of mobile internet and mobile communication is here: the Fifth Generation – 5G for short. For transmitting and receiving signals, this technology requires electronics and associated antennas with significantly finer structures than before. Initially, it will operate at 3.6 GHz and later at even higher frequencies. In terms of miniaturization, the thick-film technology currently used has reached its limits: A resolution of around 50 micrometers (µm) is the limit today – at least regarding industrial implementation. This means the individual electrical structures, such as conductors, are at least 50 µm wide. The 5G standard, however, requires circuitry as fine as 20 µm and smaller. One option to generate such structural dimensions industrially by means of thick-film technology is called PI technology (PI = photoimageable). Fraunhofer IKTS has developed a new generation of thick-film pastes which enable photolithographic structuring. With these new PI pastes, extremely high-resolution thick-film structures with a 20 µm sintered line width and 20 µm line spacing can be produced. As in the standard thick-film process, screen printing technology is used as the deposition process. PI technology adds only two simple steps to this process: In a first step, the printed and dried paste is exposed to UV light using a photo mask or a laser (laser direct imaging, LDI). The exposed paste structures are cured and the unexposed structures are removed in a second step. Immediately after the wet chemical development, the samples are sintered in a standard thick-film regime to produce the final properties of the functional layer.

The two additional steps require only between 5 and 20 seconds each and can be easily integrated into the production process line. It is also possible to work in a normal laboratory environment without the UV-protective measures necessary in other photolithographic processes.

Tailor-made thick-film pastes are required for the PI technology to work. At the present time of development, Fraunhofer IKTS has developed PI paste systems based on silver and gold, which can be used for both sintered aluminum oxide and non-sintered LTCC (low temperature co-fired ceramics). For silver, sheet resistivities of less than 3.5 mohms/sq can be achieved, for gold less than 6 mohms/sq. Current research includes adapting PI paste systems to a variety of ceramic systems, as well as developing other paste materials, such as platinum, silver/palladium, dielectric and resistor pastes. This offers a promising paste portfolio, with which components can be produced that achieve a significantly better RF performance than previously possible, at higher frequencies. The pastes can be used directly in mass and industrial processes with low investment costs and only slightly higher production times.

1 *Structured photo mask for the exposure of PI pastes.*

2 *Microscopic comparison of different structures from 20 to 50 micrometers.*

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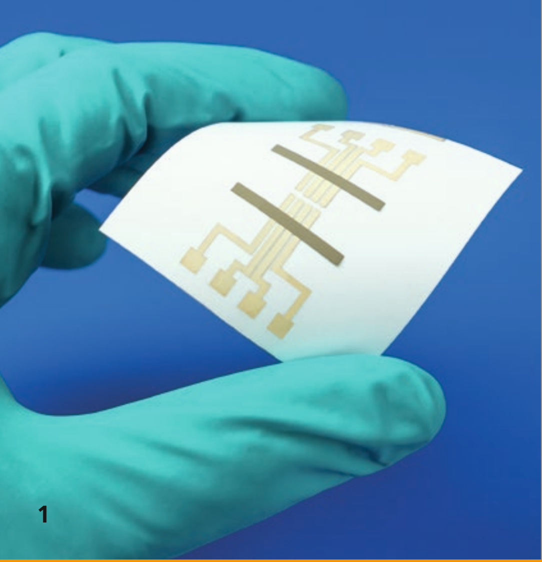

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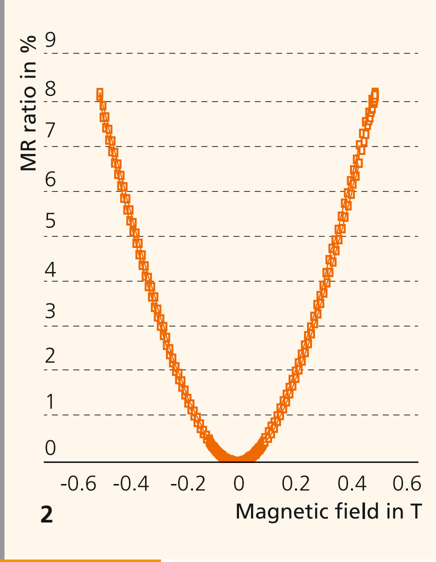

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3

PRINTED FLEXIBLE MAGNETIC FIELD SENSORS USING COST-EFFICIENT MATERIALS

C. Voigt, Dr. M. Vinnichenko, Dipl.-Ing. C. Baumgärtner, Dr. M. Fritsch, Dr. N. Trofimenko, Dr. S. Mosch, Dr. V. Sauchuk, Dr. M. Kusnezoff, M. Sc. E. S. Oliveros Mata[1], Dr. G. S. Canon Bermudez[1], Dr. Y. Zabila[1], Dr. D. Makarov[1] ([1]HZDR)

Magnetic field sensors are used to detect any kind of movement, they are key components of modern electronic compasses and contactless switches. Currently available commercial sensors are realized via thin-film vacuum-based technologies on rigid substrates and are therefore inflexible, bulky and relatively expensive to produce. Preparing magnetic field sensors through printing methods of industrial relevance, such as screen printing or inkjet printing, is a promising approach to make them mechanically flexible, reduce costs and facilitate their integration with various measurement systems.

The only printed magnetic field sensors currently available are based on the giant magnetoresistive (GMR) effect and are realized by brush painting. This preparation method is difficult to scale up because it requires physical vapor deposition (PVD) of GMR thin films on sacrificial layers as well as their consecutive delamination and milling to prepare a printable paste.

Therefore, Fraunhofer IKTS and Helmholtz-Zentrum Dresden-Rossendorf (HZDR) started to develop, in close cooperation, fully printed magnetic field sensors based on common and cost-effective materials with a high magnetoresistive (MR) effect. Starting with the powder with magnetoresistive properties, pastes were formulated and the sensor structures with contact pads were deposited on various substrates (polymer films, paper, etc.) using screen, inkjet and dispenser printing (Figure 1). The structures were sintered in air within milliseconds using micro-optically optimized diode laser arrays. This rapid sintering is of critical importance for preventing oxidation of the active material in air and to realize field sensors with MR ratios as high as 8 % at 500 mT (Figure 2).

The functionality of the sensor as a printed switch was subsequently demonstrated (Figure 3). In the demonstrator, the permanent magnet approaches the sensor. The resulting stronger magnetic field increases the electrical resistance of the sensor. An analog logic circuit converts the change in resistance into an on-off signal. The light source is thus switched on or off. This is the first known demonstration of a fully printed magnetic field sensor fabricated using easily scalable methods and commercially available materials.

Because these sensors can be manufactured in large quantities at low prices, they are of particular importance for non-contact switching applications. Thanks to their mechanical flexibility, they have the potential to replace conventional reed sensors in many areas, especially in human-machine interaction applications. Following technology demonstration at a laboratory scale, the researchers at IKTS and HZDR are now looking for industrial partners for further joint development, technology transfer and upscaling.

1 *Flexible printed magnetoresistive sensor with contacts.*

2 *MR ratio of the sensors.*

3 *Demonstration of the functional principle of the printed switch (Source: HZDR).*

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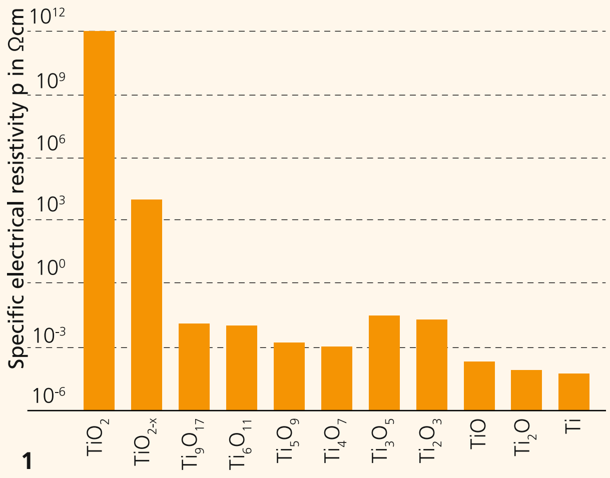

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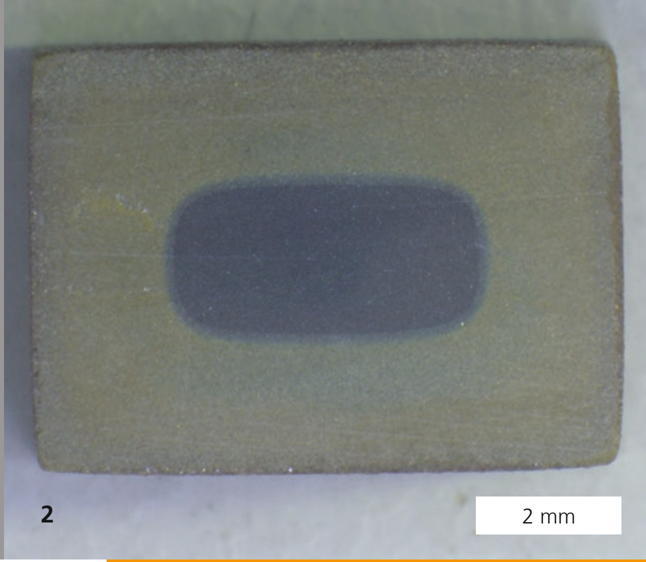

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TITANIUM OXIDES – ELECTRICAL ALL-ROUNDERS

Dr. Hans-Peter Martin

At Fraunhofer IKTS, titanium oxides are adapted to customer-specific user requirements, components are manufactured from them and extensively tested. Titanium oxides are characterized by extraordinary variability concerning their oxide compounds. Besides titanium dioxide (TiO_2), which is used for numerous products, such as wall paints, cosmetic products, paper or carriers of catalysts, there are multiple other oxide compositions of titanium. Their variable compositions range from Ti_2O to TiO_2. Even a tiny oxygen deficiency in TiO_2 can decrease the electrical resistance from 10^{12} Ωcm to a level between 10^5 and 10^3 Ωcm. The crystallographic phase change to e.g. Ti_4O_7 shifts the electrical resistance to 10^{-2}–10^{-3} Ωcm. Figure 1 illustrates the proportions across 15 orders of magnitude of electrical resistivity covered by various titanium oxide types. Furthermore, non-linear correlation of voltage and currency can be created through the doping of TiO_2. Electrical permittivity is particularly high, at a level between 60–800 depending on the applied frequency. Significant oxygen conductivity already sets in at 500 °C. Also of technical interest is the photocatalytic effect, which is particularly linked with the TiO_2 type anatase.

Electro-technical applications

This wide range of properties offers advantages in numerous technical applications: specific materials for electrodes, thermoelectric materials, varistor materials, active catalyst substances, electrical conductors, semi-conductors and insulators or even sensors for oxygen identification and analysis. These applications have a variety of different requirements regarding densification, mechanical strength or oxidation stability. Through the specific modification of the manufacturing parameters, titanium oxide ceramics can be produced as dense and high-strength material or made to be porous and gas-permeable. TiO_2 is completely oxidation-resistant and can be used up to 1500 °C under air. Suboxides are oxidation-resistant up to 400 °C. Furthermore, titanium oxides are chemically stable against almost all reactive substances.

The electrical parameters can be modified to suit almost all applications. Joined compounds of titanium dioxide and titanium suboxides can be produced which combine electrically insulating and electrically conductive parts within a monolithic component (Figure 2).

Services offered

- Adaption of titanium oxides to specific application requirements
- Manufacture of customer-specific titanium oxide components
- Implementation of material- and application-orientated investigations and tests

1 *Illustration of the multiple specific electrical resistivities of titanium oxides at room temperature.*

2 *Monolithic joint consisting of TiO_2 (shell) and Ti_4O_7 (core).*

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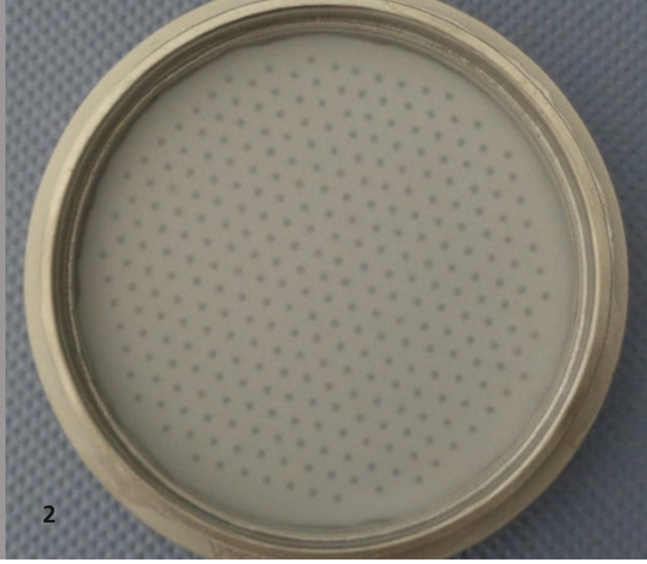
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ENERGY

PLANAR $Na/NiCl_2$ BATTERY CELLS – POWERFUL STATIONARY ENERGY STORAGE

M. Sc. Martin Hofacker, Dr. Matthias Schulz, Dipl.-Chem. Beate Capraro, Dipl.-Ing. (FH) Dirk Schappel, Dr. Roland Weidl

The expansion of renewable energies increases the need for efficient and safe energy storage devices for stationary applications. The batteries used must provide cycle stability and remain safe over a service life of 15 years. $Na/NiCl_2$ batteries meet these requirements: They are ecologically sustainable and are based on readily available raw materials, such as table salt, aluminum oxide and nickel. The raw metallic materials can be reused through simple recycling.

$Na/NiCl_2$ cells are commercially manufactured in tubular form and operated at approximately 300 °C. A sodium-ion-conductive solid electrolyte (sodium-β-alumina) separates the anode and cathode compartments. When charged, the anode fills with liquid sodium and the cathode with metals and salts.

To further exploit the performance potential of this cell technology, a planar $Na/NiCl_2$ cell was developed as part of the "planβeta" project. In contrast to the tubular cell, this cell type enables an increase of the cell diameter and thus storage capacity, without negatively affecting the performance. The cell design developed at Fraunhofer IKTS has been developed to enable the cells to be stacked inside one another (stack). Stack operation makes possible the space-saving installation of a large number of cells in a thermally well-insulated battery housing. This enables high energy densities in a small space.

Typically, the cathode in tubular $Na/NiCl_2$ cells is vacuum-infiltrated with a secondary electrolyte that turns liquid when heated. The planβeta cell makes this technologically demanding process obsolete because the cathode is pressed from a monolith at room temperature. In order to lower the influence of the solid electrolyte on the cell resistance, it is manufactured by tape casting. In contrast to uniaxial pressing, its wall thickness can thus be reduced considerably. For example, at IKTS, solid electrolytes that are 500 µm thick can be produced through tape casting (ionic conductivity at 300 °C up to 0.3 S/cm, ß" phase content ≥ 93.5 %). These can be flat, indented, or plate-shaped. The increased operating temperature and the volume changes in the anode and cathode compartments lead to pressure differences in the cell. Despite this, it was possible to produce defect-free cells with the help of a specially developed vacuum-welding process. FEM calculations resulted in a low-stress design of the metal-ceramic cell closure. 110 mm planar $Na/NiCl_2$ cells were developed and manufactured, which withstand the thermal loads of heating up and cooling down to 300 °C. With a discharge speed of 1 h^{-1}, depths of discharge of up to 80 % could be achieved.

We are grateful to the German Federal Ministry for Economic Affairs and Energy (BMWi) for funding the "planβeta" project (funding code: 03ET6110C).

Supported by: Federal Ministry for Economic Affairs and Energy

1 Planßeta $Na/NiCl_2$ cell.
2 Planßeta cell with sodium-ß-alumina foil incl. indentations.

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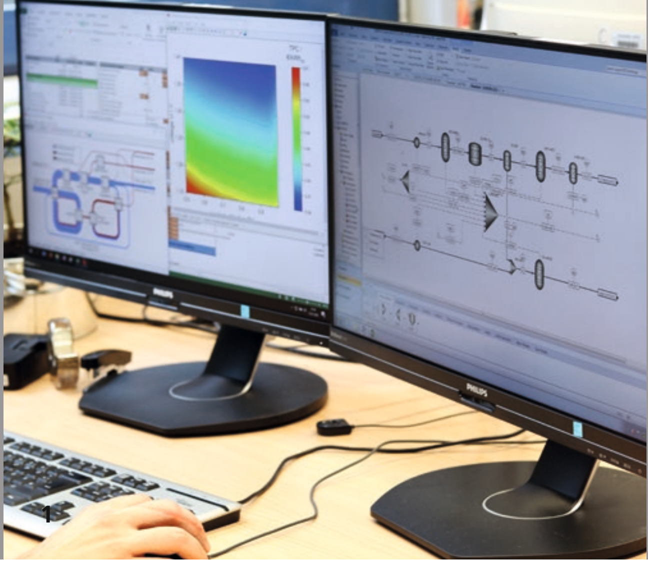

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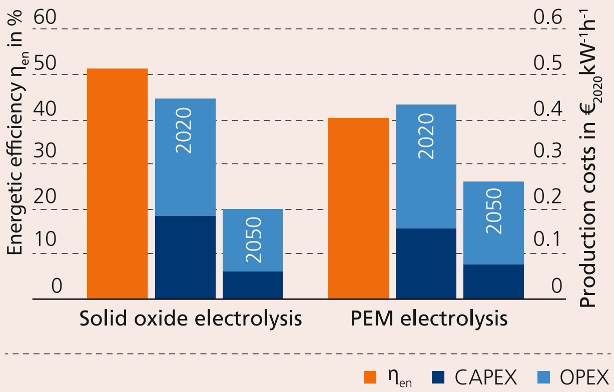

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ENERGETIC AND ECONOMIC EVALUATION OF POWER-TO-X PROCESSES

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

In connection with the necessary reduction of industrial CO_2 emissions, power-to-X processes are of crucial importance, as they allow the use of renewable energy for the production of various chemical products. This is achieved by coupling an electrolysis for hydrogen supply with a product synthesis step. In this way, synthetic fuels, e.g. for the aviation sector, as well as important basic chemical products can be produced. Carbon-based raw materials for the chemical industry, which can be further processed e.g. into plastic products and cosmetics, as well as compounds such as ammonia, which is decisive for the production of fertilizers, are also an option. Due to the conversion of the entire energy system and the associated increase in demand, renewable electricity will remain a limited resource in the foreseeable future. Consequently, the processes used need to be highly efficient. At the same time, costs for the transition to a renewable energy system should be minimized. Therefore, it is important to identify the most efficient and economic options among the various possible power-to-X processes prior to their technical implementation.

Fraunhofer IKTS employs various tools for energetic and economic evaluation to achieve this. A technical evaluation of different process routes is carried out with the help of process simulation and experimental data from demonstration plants. In addition to technical maturity and feasibility, special attention is paid to efficiency. Using an economic model developed at IKTS, the production cost of renewable products can be calculated for different processes and scenarios. One of the studies evaluated the production of synthetic crude oil from CO_2 and H_2O by coupling electrolysis and Fischer-Tropsch synthesis.

The established polymer electrolyte membrane (PEM) electrolysis was compared with the ceramic-based solid oxide electrolysis developed at Fraunhofer IKTS. The different levels of technological readiness of the two processes make this comparison particularly interesting; it allows to evaluate their potential based on the expected future development of the technologies. The results show that the process based on solid oxide electrolysis has a higher potential due to the ability to utilize waste heat generated by the synthesis step or provided externally, therefore yielding a higher energetic efficiency than the process based on PEM electrolysis. Since this process is not yet as technologically mature, current manufacturing costs do not reflect this advantage. However, when the production of solid oxide electrolyzers is established on an industrial scale in the future, significant economic advantages are to be expected for this application.

An advantage of the tools developed for the conducted analysis is that they can also be applied to evaluate other technical processes.

1 *Model-based process evaluation.*

2 *Comparison of two power-to-X processes based on solid oxide electrolysis and PEM electrolysis.*

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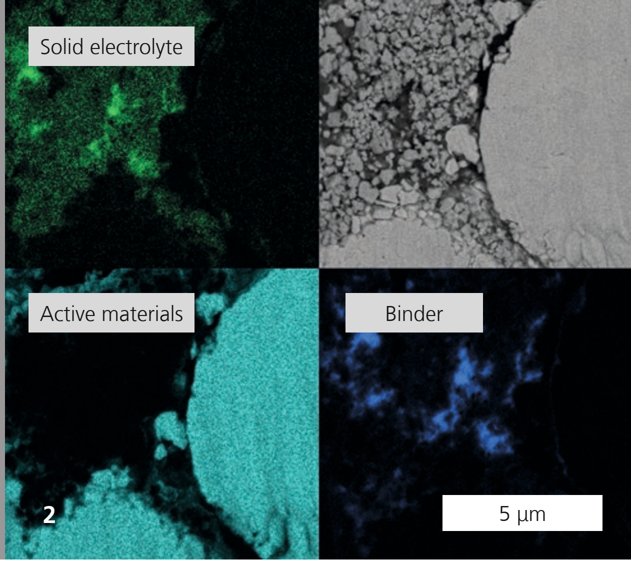

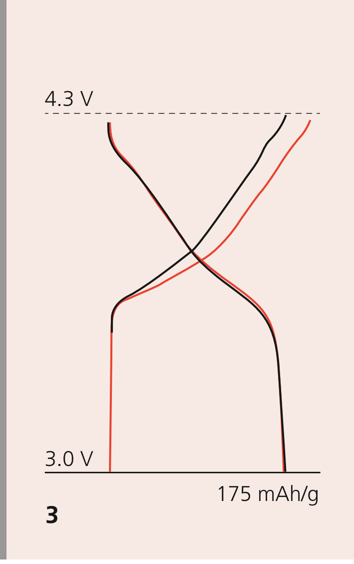

DEVELOPMENT OF PROCESSES FOR SULFIDE ELECTROLYTE-BASED SOLID-STATE BATTERIES

Dr. Henry Auer, M. Sc. Matthias Seidel, Dr. Christian Heubner, Dr. Kristian Nikolowski, Dr. Sebastian Reuber, Dr. Mareike Wolter

The development of advanced solid-state batteries and scalable manufacturing processes is essential for opening new fields of application, such as in electromobility. Inorganic systems, in which lithium-sulfur-phosphorus compounds are used as solid Li-ion conductors in the cathode and separator, are currently considered to be the most promising candidates. They combine favorable properties, such as a high ionic conductivity, good availability and processability. However, they still require some development work with regard to their sensitivity to air humidity, the scalability of manufacturing processes, as well as the electrochemical stability in interaction with high-energy cathode materials and Li-metal anodes.

Research and development concept

At Fraunhofer IKTS, solid-state batteries with sulfidic Li-ion conductors are being developed along the entire process chain, from material to battery system. First, active materials are electrochemically evaluated and optimized regarding their interaction with the solid electrolytes. To counteract the thermodynamic instability between active materials and the electrolyte, coating processes are being used to stabilize interfaces and improve the ion transport. A variety of technologies for component production are being examined based on the materials. The manufacturing of electrodes is carried out using various methods, such as doctor blades, slot-die coating, or extrusion. Finally, the components are assembled to produce solid-state batteries. The cell concepts implemented thus undergo constant further development.

Various glove box systems are available at IKTS in Dresden for fully inert component and cell production. The development of components and cells is accompanied by extensive electrochemical and morphological investigations. More than 200 channels are available for battery cycling in temperature-controlled chambers, including some that offer impedance spectroscopy.

At Fraunhofer IKTS in Braunschweig, this work will be scaled to the pilot scale. Drying rooms with an adapted dew point or micro-environments will be available for this purpose.

Conclusion and vision

Fraunhofer IKTS can draw on many years of experience with ceramic technologies to establish scalable processes for sulfidic solid electrolytes. The field of competencies encompasses the development of materials and components, such as electrodes and separators, as well as ultimately the design, development and testing of solid-state cells.

Niedersächsisches Ministerium für Wissenschaft und Kultur

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1 Free-standing electrolyte separator.

2 FESEM image of a sulfidic composite cathode.

3 Charge/discharge curve of a sulfidic solid-state cell.

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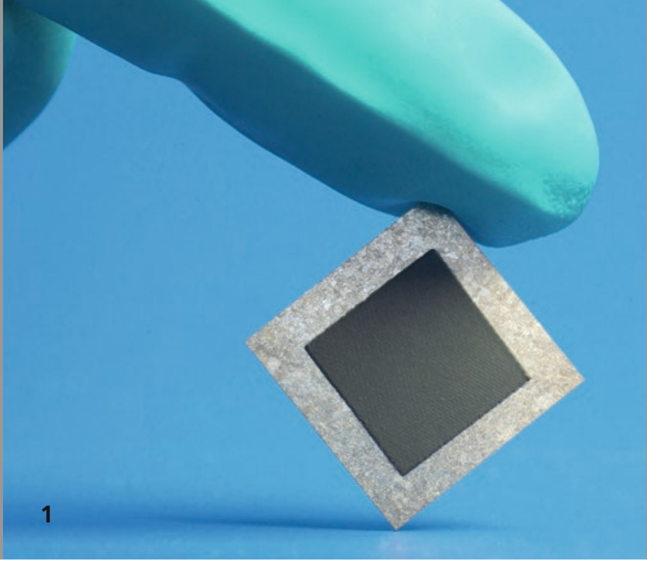

ELECTRON-EMITTING CERAMICS FOR SATELLITE PROPULSION

Dr. Katja Wätzig, Dr. Sindy Mosch, Dr. Axel Rost, Dr. Jochen Schilm

Electride materials are used as cathodes in electron-emitting assemblies, e.g. in the ion propulsion of satellites or in thermionic converters. Their special property is a low work function for electrons, which means that notable electron currents can be generated in an electric field. Due to their material-specific work function for electrons and Richardson's constant, established electride materials, such as LaB_6 and BaO:W, only emit electrons to a useful extent at temperatures above 1000 °C. Therefore, the aim of worldwide research is to develop electride materials that enable an application-relevant emission of electrons already at temperatures significantly below 1000 °C. The oxide ceramic material C12A7 ($12CaO \cdot 7Al_2O_3$) with its special, cage-like lattice structure exhibits defect states with a concentration of mobile electrons greater than 10^{21} electrons per cm^3. At Fraunhofer IKTS, this material can be synthesized in a scaled manner and finds application as a sintered body or printed layer. A work function of 2.37 eV and a Richardson constant of over 8 Acm^{-2} K^{-2} could be measured on sintered hollow cathodes made of pure C12A7. Because of these properties, the electride C12A7 is suitable for use as an electron emitter at temperatures below 1000 °C. This results in considerable advantages for the constructive and electrical integration, for example, in propulsion systems of satellites.

The growing number of communication and observation satellites in Earth orbit increases the probability of collisions and the risk of incalculable failures and their consequences.

In the E.T. PACK project, which is funded by the European Union, electrodynamic and propellant-free propulsion systems (deorbit kits) are being developed to enable the controlled removal of retired satellites from orbit. For this purpose, the electride C12A7 is contacted as a thick film on a metallic tape (Figure 1) and attached to the satellite as a coil. At the end of its service life, this tether is unwound, slowing down the satellite through the electrodynamic effect by absorbing electrons from the plasma in one segment and releasing them elsewhere through thermionic emissions. The resulting electric current, in conjunction with the earth's magnetic field and the satellite's direction of flight, causes a Lorentz force that constantly pulls the satellite towards the earth.

In the EU project iFACT, hollow cathodes made of C12A7 are being developed for novel, more effective ion propulsion systems for satellites based on iodine instead of xenon (Figure 2). The hollow cathodes are intended to ionize vaporized iodine and thus generate an ion current in an electric field that can be used for the position control of satellites. C12A7 promises improved stability against the iodine ions and should thus ensure a long service life.

1 *Powder-based C12A7 coating on a metallic carrier substrate.*
2 *Sintered hollow cathodes made of C12A7 before (white) and after activation (black).*

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PROCESS DEVELOPMENT FOR THE COMMERCIAL PRODUCTION OF SOC CELLS AND STACKS

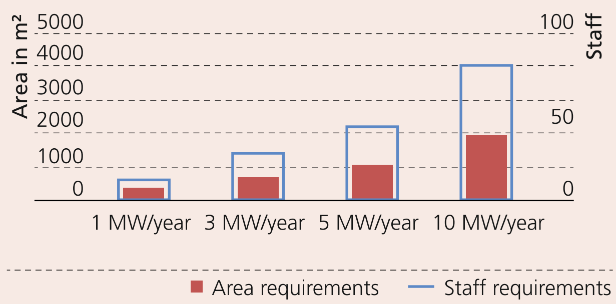
Dr. Stefan Megel, Dr. Nikolai Trofimenko, Dr. Mihails Kusnezoff

For more than 20 years, Fraunhofer IKTS has conducted intensive research on high-temperature fuel cells (SOFC) with electroyte-supported cells, with the focus in recent years placed increasingly on their use in high-temperature electrolyzers (SOEC). For this reason, IKTS has developed bidirectional SOC cells and stacks. They are key components for the conversion of excess power to synthetic gas, liquid fuels and their efficient conversion back to electric power. SOC stacks based on a chromium-based alloy of the MK35x design have now reached a sufficient level of technology to be transferred into commercial production. In collaboration with mPower GmbH, a pilot production scheme with a capacity of 1 MW/year and an extended capability of 10 MW/year was conceived based on the well-established prototype production at IKTS. For the steps of lab production that determine the production rate, such as coating, stack assembly and joining, specific automated solutions were developed. As a result, a process chain suitable for series production was designed and configured, which achieves a maximized output quota with minimal equipment and manpower requirements. Continuous screen printing and drying technology for cell production, including the non-destructive examination of the ceramic electrolyte, resulted in higher output rates. The semi-automated glass application machine (SANGAM) developed at IKTS reduces the cycle time for assembling single components by 70 % and enables an automated stacking procedure. The technical breakthrough came thanks to a change of technology at the glass sheet application. The glass is sintered and molten in the joining process and seals the fuel gas from the air and the surrounding atmosphere. As this process requires a lot of energy, heat treatment was reduced significantly and the reduction was experimentally validated. Adapted joining machines were designed which need 90 % less energy than state-of-the-art devices. The core components and improved processes thus developed enable the production of 1 MW/year (1000 stacks including cell production) on less than 500 m² production space.

Services offered

- Process optimization of screen printing and stack assembly
- Test of stack components under real conditions
- Stack and stack module development for SOFC/SOEC systems

Planned capacity for commercial MK35x SOC production



SAB Sächsische AufbauBank

mPower GmbH

1 *Automated screen printer for SOC cells.*

2 *Glass application and stacking machine for SOC stacks.*

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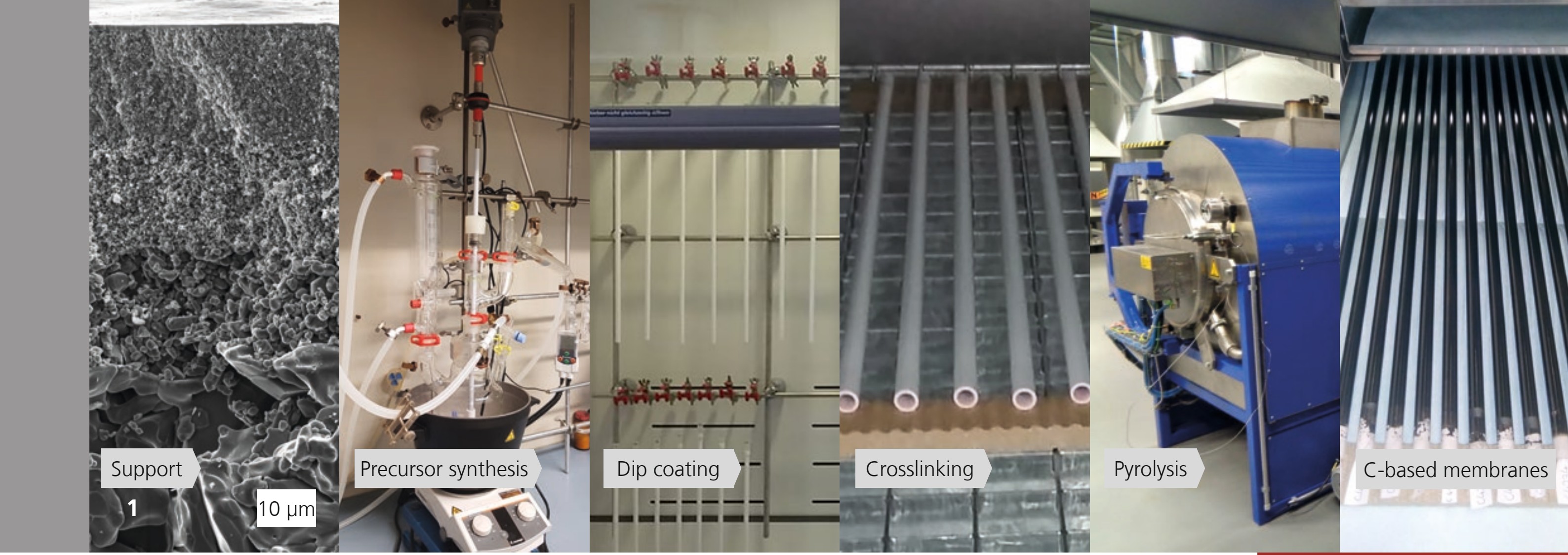
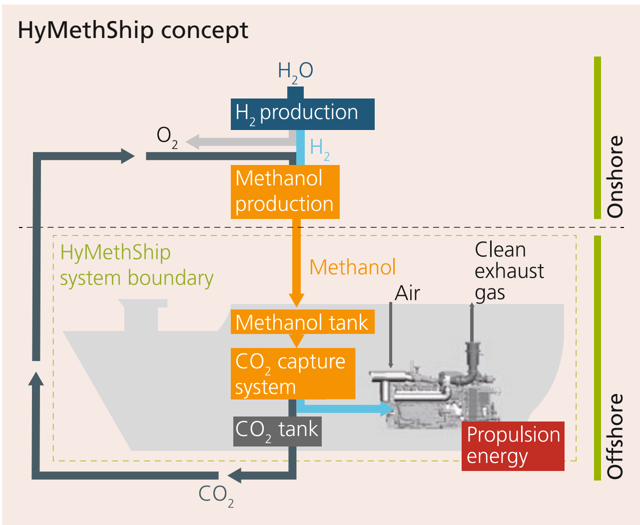


GREEN REVOLUTION ON THE HIGH SEA – EU PROJECT HyMethShip

Dr. Jörg Richter, Dr. Benjamin Jäger, Dr. Norman Reger-Wagner, Dr. Adrian Simon, Janine Hercher, Stephanie Kaiser

A visionary, safe and environmentally friendly concept for the propulsion of ships is the research subject of Fraunhofer IKTS scientists at the Hermsdorf site in collaboration with partners, such as the Meyer Werft shipyards, engine manufacturer INNIO, ship operator EXMAR as well as certifier Lloyd's Register, amongst others, within the Horizon 2020 EU project HyMethShip (GA-No. 768945), which is coordinated by LEC Graz. The aim of the project is to reduce shipping emissions by up to 97 % by using hydrogen for the engine. Said hydrogen is generated on board by reforming methanol. This concept is especially relevant in the context of ships, as seagoing vessels traditionally burn heavy oil, which causes sulfur compound emissions. Furthermore, diesel is used for routes along coastlines, resulting in emissions of nitrogen oxide and CO_2. This can be avoided by using the new propulsion concept. Sulfur compounds do not occur, nitrogen oxides are minimized, and the CO_2 produced is captured, stored on board and therefore not released into the atmosphere. The propulsion system works as follows: The ship is fueled with methanol onshore, which, in contrast to hydrogen, can be stored easily and poses no threat to the environment even in the case of a complete tank spill or drain. Methanol serves as a liquid hydrogen carrier. Aboard the ship it is converted with water by steam reforming. During this process, hydrogen is obtained via membrane separation and burned directly in the engine for ship propulsion. Significantly more hydrogen is generated than is stored in the methanol itself, because the water also provides additional hydrogen according to the reaction $CH_3OH + H_2O \rightarrow 3\ H_2 + CO_2$. Additionally, CO_2 is produced, which is stored aboard and drained on return. Onshore, it can then be used for methanol synthesis once again – thus completing a closed-loop propulsion system. The heat needed for this endothermic process comes from the engine, which further increases efficiency.
In HyMethShip, IKTS is tasked with the complete process and reactor design as well as the preparation of the membranes at a technical scale with a membrane area > 5 m². A demonstration unit with more than 1.6 megawatts hydrogen energy will be installed at the Technical University of Graz. Initial test runs are planned for the start of 2021 and trial operation will follow by mid-2021. Furthermore, the consortium will compile a study for a Scandinavian ferry based on the novel propulsion system with 20 megawatts of power. For comparison: an oil tanker has a power of 50 to 80 megawatts.



1 *Process for the production of carbon membranes.*

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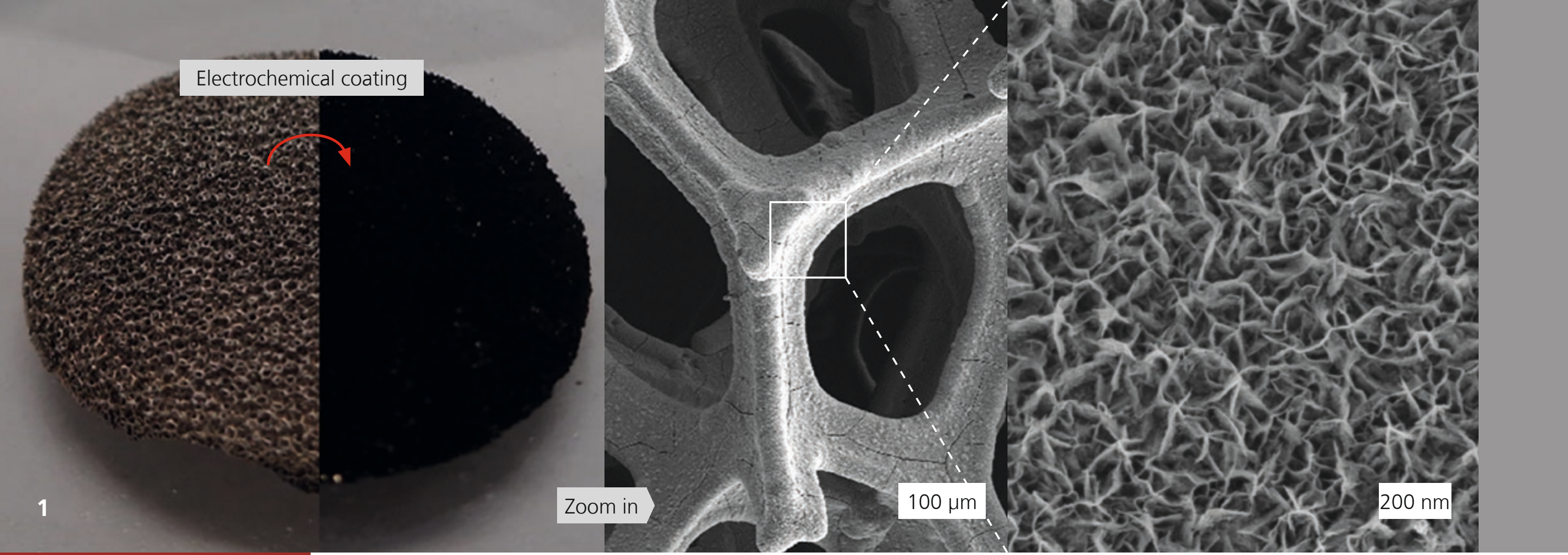


SUSTAINABLE GAS DIFFUSION ELECTRODE FOR ALKALINE ENERGY CONVERTERS

M.Sc. Artur Bekisch, Dr. Karl Skadell, Dr. Matthias Schulz, Dr. Roland Weidl, Prof. Michael Stelter

Oxygen gas diffusion electrodes (GDE) play a central role in alkaline energy converters, such as metal-air-batteries (Zn/O_2) and polymer-membrane-electrolyzers (AEM-EL). GDEs provide the chemical reactions of oxygen evolution (OER) or oxygen reduction (ORR) but OER is the bottleneck for energy-efficient battery and electrolyzer technologies. The state-of-the-art GDE consists of carbon, electrochemical catalysts and PTFE (hydrophobic binder), of which carbon is particularly susceptible to corrosion. This shortens the service life of the GDE and thus also the operating time of the battery or electrolyzer. To counteract this, a carbon-free and therefore corrosion-resistant GDE was developed, which is bifunctional, meaning it is capable of both reactions (OER and ORR). Through the electrochemical deposition of manganese oxide on nickel foam (Figure 1), a carbon-free GDE was produced. Samples were prepared, characterized and compared with a commercial GDE (GDEref) in electrochemical measurements.

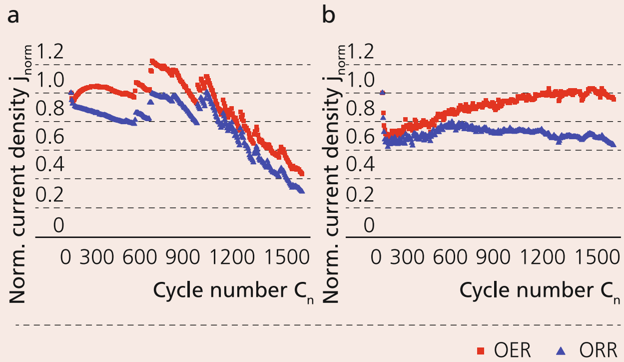
Oxygen evolution and oxygen reduction was measured for the commercial and the carbon-free GDE respectively, and the two were compared. A cycle represents a completed sequence of OER and ORR. The samples were run up to 1500 cycles and measurements for long-term stability (diagrams on the right) were performed. The results show a significant difference between the two types of GDE, with considerable advantages for the newly developed GDE.

The diagrams clearly show the carbon corrosion of GDEref (a). The performance reduction starts at approximately 900 cycles and continues steadily until it reaches around 60 % total loss. The carbon-free GDE however shows a mostly stable behavior for 1500 cycles. Following a drop of around 35 % in the first cycles, the capacity for OER (red) and ORR (blue) continually increases. Subsequently, ORR is maintained at the same level, while OER increases further until the last cycle.

The results presented here clearly demonstrate the potential of carbon- and precious-metal-free gas diffusion electrodes, which enable bifunctionality, higher current densities and voltages in alkaline metal-air batteries and polymer-membrane electrolyzers.

This work was funded by a scholarship from the Reiner Lemoine foundation.

Long-term stability measurement of GDEref (a) and carbon-free GDE (b).



1 *Nickel foam with manganese oxide coating in 100 µm and 200 nm visualization.*

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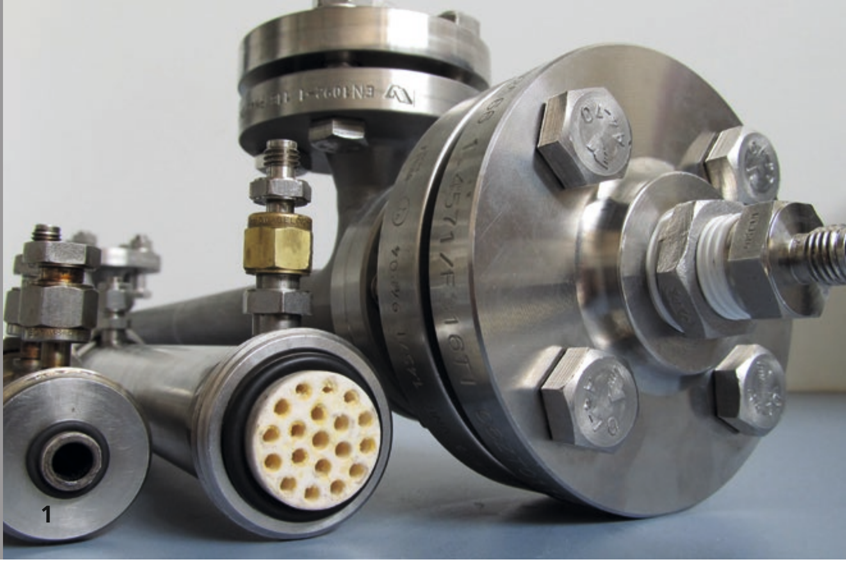

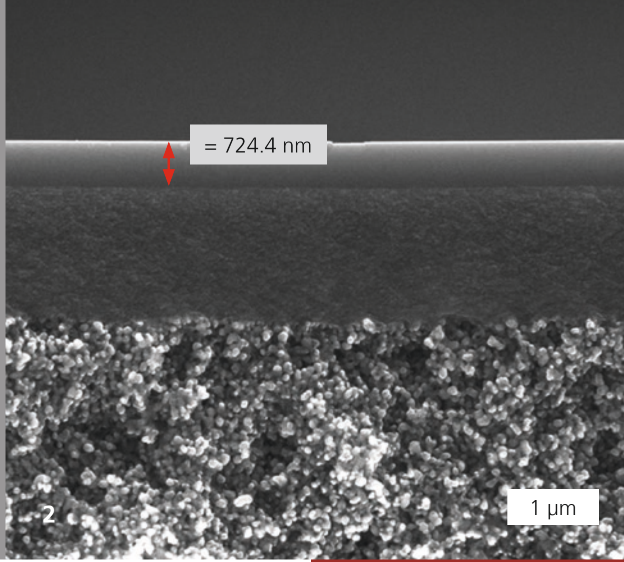

HYDROGEN SEPARATION FROM NATURAL GAS WITH CARBON MEMBRANES

Dr. Adrian Simon, Dipl.-Ing. (FH) Susanne Kämnitz, Dr. Norman Reger-Wagner, Dr. Hannes Richter

Carbon membranes as separation technology for H_2/natural gas mixtures

A main issue in achieving the switch from fossil fuels to renewable energies is the limited availability of renewable electricity due to its dependency on the weather. This challenge has led to numerous concepts aimed at converting power via power-to-gas technologies. Yet, none of the innovative technological approaches has so far passed the threshold of economic efficiency. One reason for this is the absence of a distribution grid. The project HYPOS (Hydrogen Power Storage & Solutions East Germany) aims to connect the chemical power grid, the natural gas grid and the electrical grids in East Germany to provide cost-efficient "green" hydrogen. It has been the general consensus that no separate infrastructure for the storage and distribution of hydrogen will be established in Germany for the foreseeable future. Therefore, one will need to make use of the existing natural gas grid for the production and storage of hydrogen. However, for certain applications such as the use as fuel, the concentration of hydrogen in the natural gas grid must not exceed a certain threshold. To still be able to use that infrastructure, separating both components (hydrogen and natural gas) before redelivery would be an option: shared storage, separate use. The separation of both components can be realized efficiently by using carbon-based membranes developed at Fraunhofer IKTS in collaboration with project partner DBI-GUT GmbH. The basis for the synthesis of carbon membranes is a suitable precursor. The precursor is applied on an asymmetric porous, ceramic substrate in single-channel geometry. In a next step, the precursor is converted to carbon species with defined properties during a thermal treatment process.

The layer thickness of carbon membranes is typically between 250 nm and 1 µm depending on the synthesis procedure and is characterized by an excellent separation behavior of H_2/CH_4, with ideal permselectivities of 300. The best membranes were able to concentrate 5 vol % hydrogen in the feed up to 80 vol % in the permeate. In a second separation step, more than 90 vol % hydrogen can be reached in the permeate. Additionally, it has been experimentally proven that the small amounts of water and hydrogen sulfide in the natural gas do not have any significant influence on the separation performance of the membrane. In the research project, carbon membranes were successfully scaled to industry-relevant 600 mm long 19-channel tube substrates.

We would like to thank the German Federal Ministry of Education and Research BMBF for their financial support (funding code: 03ZZ0706A).

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1 Carbon membrane on the inside of 19-channel tube substrates located in a membrane module of project partner DBI-GUT GmbH (Source: DBI-GUT GmbH).

2 SEM image of a carbon membrane in cross section.

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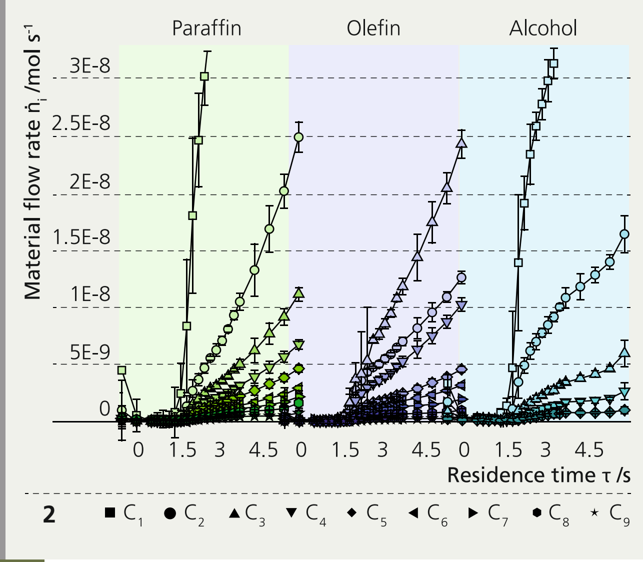

UNVEILING THE FISCHER-TROPSCH MECHANISM THROUGH SPATIALLY RESOLVED REACTION

M.Sc. Florian Wolke, Dr. Erik Reichelt, Dr. Matthias Jahn

The Fischer-Tropsch synthesis represents a central process stage of numerous power-to-X concepts for the sustainable production of high-quality chemical products from CO_2 and H_2O using renewable energy. Essential features in the product synthesis on iron-based catalysts, i.e. for the production of higher alcohols, are the presence of numerous catalytically active phases, a large reaction network and a product mixture of hydrocarbons of different substance groups and chain lengths. Due to this complexity, the underlying mechanism of the reaction is not yet sufficiently understood, hindering process optimization according to ecological and economic criteria. Utilization of in-situ measurement techniques provides promising new insights into previously inaccessible information.

With a novel reactor concept called ‘profile reactor’, it is now possible to look inside tubular reactors and follow directly the main, secondary and parallel reactions based on product distribution. A capillary, which is centrally located in the catalyst bed and can be moved relative to it, is used for sampling. The composition of the gas phase thus obtained is analyzed by gas chromatography. This yields spatially resolved reaction profiles, which allow conclusions to be drawn about the character of the chain growth, kinetic parameters such as the reaction rate, re-adsorption and on secondary reactions of by-products.

The variation of catalyst composition and operating conditions gives access to structure-activity relationships inside the catalyst. The analyses were able to show a strong correlation between the extent of ongoing secondary reactions and the operating conditions. In particular, oxygenates such as higher alcohols, which are promising products of the Fischer-Tropsch synthesis on iron catalysts, have a strong tendency, due to their chemical structure, to be converted into undesired secondary products in side reactions. Therefore, an understanding of the reaction mechanism is particularly relevant for optimizing the yield of higher alcohols. Specifically, it could be shown that by targeting the adjustment of temperature, pressure and catalyst loading, these unwanted reactions can be minimized. In combination with a tailored catalyst composition applying promoting elements like potassium, copper or molybdenum, it becomes possible to optimize selectivity towards higher alcohols.

The established methodology can also be used for the investigation of reaction mechanisms of other complex reactions.

1 *Profile reactor.*

2 *Profile of C_1-C_9 products for Fe catalyst at 473K/21bar.*

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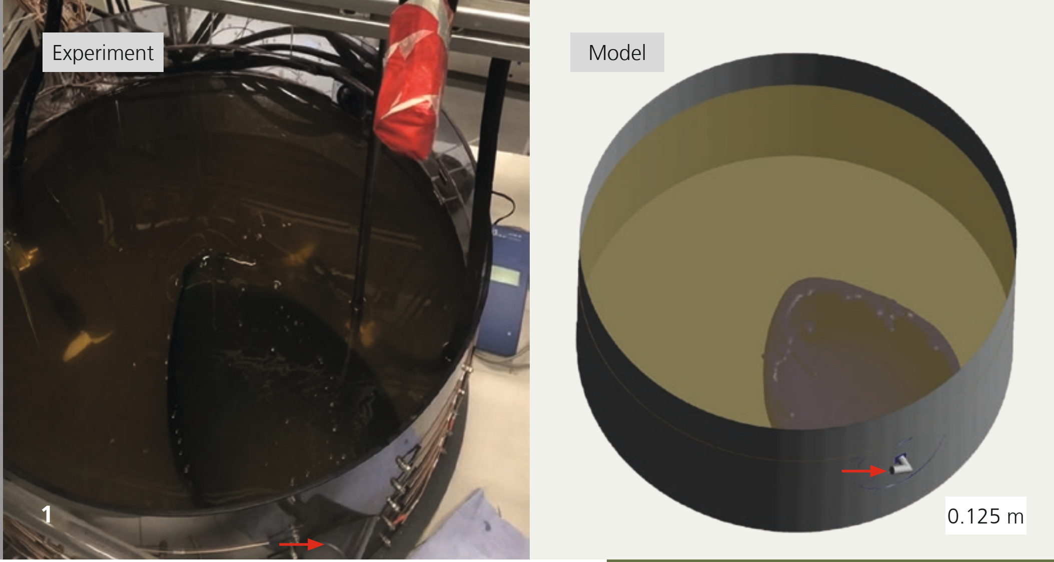
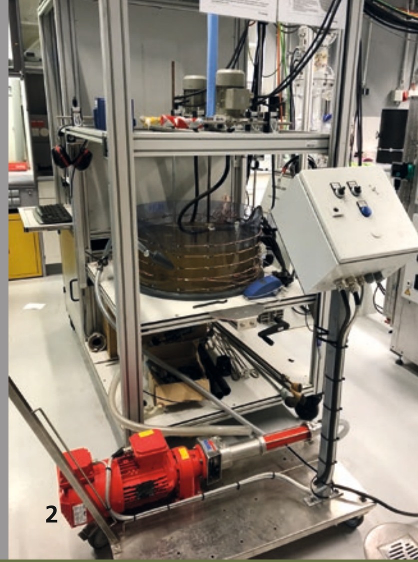


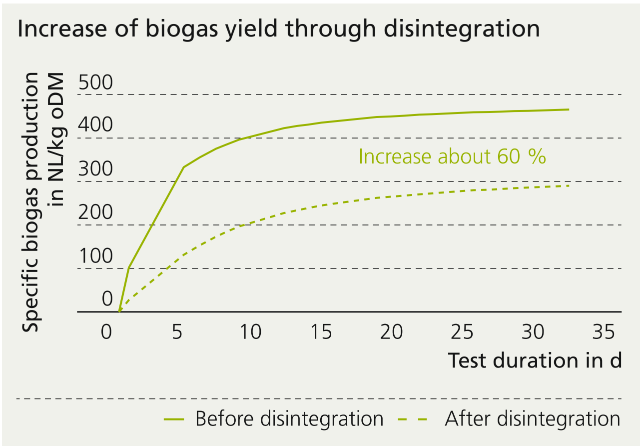


SMART PUMP SYSTEMS FOR MIXING OF BIOGAS REACTORS

Dipl.-Ing. Anne Deutschmann, Dipl.-Ing. (FH) Gregor Ganzer

Feeding of fresh substrate and adequate fermenter homogenization are still major challenges for the economic operation of biogas plants, especially when biogenic residues, such as straw and solid manure, are used. This is where the ongoing research project FlexPump comes in. Together with its partners, Vogelsang GmbH & Co. KG and A&U Service- und Vertriebs GmbH, Fraunhofer IKTS is developing a smart pump system for the hydraulic mixing of biogas reactors, testing it under practical conditions. The pump technology was designed to feed and mix the reactor. This is achieved by suspending the feed, for example straw and solid manure, with the fermenter contents and returning this mixture back into the biogas reactor with high hydraulic intensity. This means that an external circulation – as known in systems for sewage sludge digestion – is used for mixing. The prerequisite for this procedure is that the viscosity of the suspensions is adapted to the pump technology. For this reason, disintegration technology was taken into account. The project was able to demonstrate that disintegrated substrates have a significantly reduced viscosity. Batch fermentation tests have confirmed the improved disintegration effect and shown a significant increase in the biogas yield as seen in the graph on the right. The mixing system under development was first evaluated on the pilot-plant scale at IKTS. For this purpose, the large-scale process conditions were scaled down to pilot-plant scale, with a constant entry speed of the pumped medium into the reactor. By means of process-tomographic investigations with electrical resistance tomography (Figure 2), the fluid dynamics of the mixing process could be evaluated and optimized depending on the substrate properties. In addition, computational fluid dynamics (CFD) models are being used (Figure 1).

The results are verified and optimized under practical conditions in a large-scale biogas plant.



Services offered

- Scaling and characterization of flow and mixing processes
- Multiphase computational fluid dynamics (CFD) with non-Newtonian fluids

Supported by:
Federal Ministry for Economic Affairs and Energy

PtJ Projektträger Jülich Forschungszentrum Jülich

1 *Comparison of experiment and model with only pump operation.*

2 *Tomographic test bench.*

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LOW-EMISSION ETHANOL FIREPLACES

Dr. Uwe Petasch, Dipl.-Krist. Jörg Adler

Ethanol fireplaces are popular because they can generally be operated in private households without a chimney or other exhaust systems. They also require little space and are quite inexpensive. Since ethanol fireplaces currently do not have an integrated exhaust gas purification system, users are directly exposed to the pollutants emitted, such as benzene, formaldehyde, carbon monoxide and nitrogen oxides. This can potentially cause health problems. Within the project "Clean EtOH-fire" (development of an emission-minimized combustion system for [bio-]ethanol), a system for the pollutant-free and operationally safe combustion of ethanol was developed together with industrial partners. This system can be used not only in households or by the commercial sector (restaurants, hotels and events), but also as a supplementary CO_2-neutral chimney heating system in low-energy houses.

Fraunhofer IKTS has developed a catalyst concept for this purpose, based on its extensive know-how in the field of engine and industrial exhaust gas purification. On the one hand, this enables reducing pollutants at very low reaction temperatures and, on the other hand, optimal flow distribution of the reaction gases within the catalyst support. Furthermore, it does not require any additional auxiliary energy and has a long service life. The catalyst support is based on open cellular ceramic foams, which boast a much lower back pressure than catalyst beds. At the same time, the network-like structure allows for long residence times of the pollutants on the catalyst, which is a major advantage over catalyst honeycombs. Open-cell foam ceramics are produced by replication of reticulated polymer foams using the so-called Schwartzwalder process.

The catalysts are adapted to the special operating conditions of ethanol burners and the catalyst support in order to achieve high conversion rates under the given temperature and exhaust gas conditions. This includes the synthesis and functionalization of the catalyst materials as well as their processing to achieve suspensions with which homogeneous and crack-free layers can be realized on the catalyst support. As a result, hydrocarbon and CO emissions can be reduced simultaneously when the exhaust gas comes into contact with the catalyst.

Services offered

- Development of suitable catalyst supports made of cellular ceramics
- Synthesis of catalysts and process development for catalytic coating
- Laboratory tests on the application properties of coated substrates and evaluation of the catalytic behavior and long-term stability

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1 *Conventional ethanol fireplace without exhaust gas purification system (© pixabay | Antoine Belverge).*

2 *Catalyst support made of cordierite foam ceramics with catalytic coating.*

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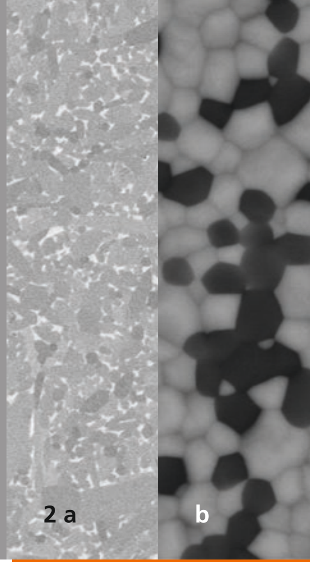
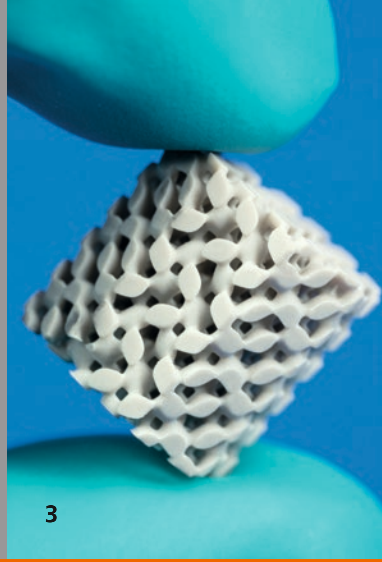




OSSEOINTEGRATIVE SURFACE DESIGN FOR CERAMIC FINGER JOINT IMPLANTS

Dr. Sabine Begand, Dr. Eveline Zschippang, Dr. Annegret Potthoff, Dipl.-Ing. Eric Schwarzer-Fischer, Dipl.-Chem. Martina Johannes

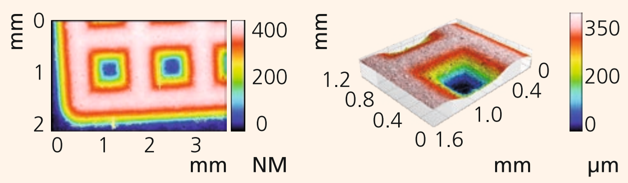
Patient-specific implants promise a high degree of fit accuracy and thus better functionality and durability. Individualization is also a great opportunity for those fields in which the possibilities of implant restoration and remobilization are still limited. For small joints, especially in the area of finger joints, therapy consists mainly of stiffening joints, which reduces mobility. In Germany alone, this affects 5 million people suffering from symptomatic arthrosis and 1.5 million people suffering from rheumatic diseases. In the Fraunhofer-internal project "Remobilization of Finger Joints by AI-based Reconstruction and Development of Patient-Specific Ceramic Implants – FingerKit", the Fraunhofer institutes IAPT, IKTS, ITEM, IWM and MEVIS are collaborating to enable, for the first time, a continuous, automatable process chain in the manufacture of patient-specific implants, from design to manufacture, to certification-compliant testing.

In this project, IKTS focuses on the material and surface design of ceramic implants. The long-term stability of custom-made finger joint implants is to be significantly increased compared with commercially available standard variants by customizing the mechanical strength, osseointegration (growth of bone cells onto the implant) and implant design. The slip casting process for the oxide ceramic materials 3Y-TZP and alumina-toughened zirconia (ATZ) enables direct shaping in a porous, structured mold. This requires the production of complex shaped casting molds with an integrated structure. The molding behavior was investigated during the casting process and material characteristics were determined. The goal is to manufacture finger joint prototypes with a macro-/microstructure of the outer surfaces in a single process step.

An exemplary macro-/microstructure is shown in Figure 1 by using white light interference microscopy.

In a parallel development track, silicon nitride (Si_3N_4) is used as bioceramic material. Implant production will be realized with the CerAM VPP process (Lithoz LCM technology), a 3D printing technology. This process can be used to create, for example, the so-called TPMS structures (triply periodic minimal surfaces, Figure 3), which have many advantages in terms of mechanical properties and osseointegration. Furthermore, the unique surface chemistry of Si_3N_4 is modified to further optimize interaction with the surrounding tissue. With this targeted topographic and chemical modification of the ceramic surface, osseointegration of implant materials is to be significantly improved.

Topography of an implant using white light interference microscopy

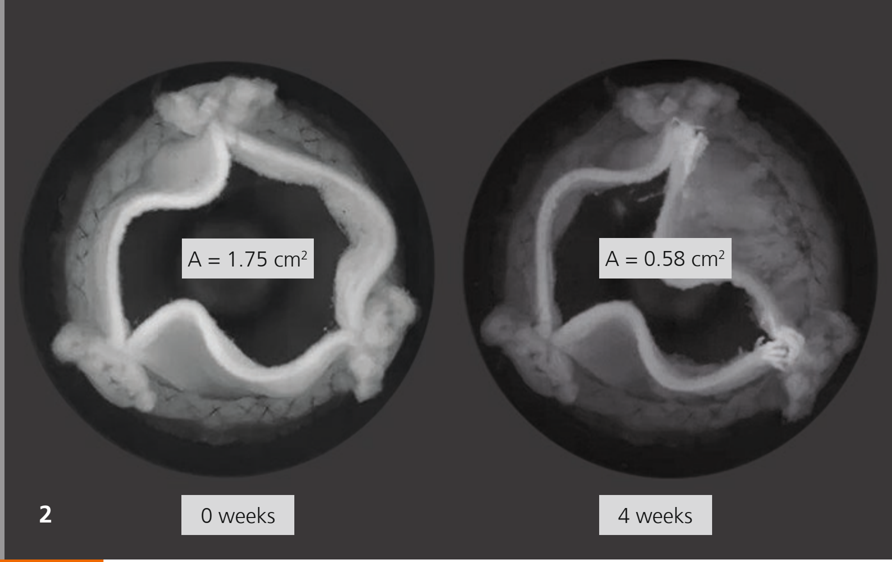


1 X-ray of a diseased hand (Source: istock: WILLSIE).

2 Microstructure of Si_3N_4 (a) and ATZ (b).

3 TPMS structure made of Si_3N_4.

1



2

CALCIFICATION OF HEART VALVES – IN-VITRO CHARACTERIZATION AND PREVENTION

Dr. Natalia Beshchasna, Agnieszka Maciejewska, Dr. Jörg Opitz

Aortic valve stenosis, the constriction of the outflow tract, is one of the most common heart valve diseases, followed by mitral valve regurgitation. Today 300,000 to 400,000 heart valve replacement surgeries are performed annually all over the world. In general, two types of heart valve bioprostheses are used: mechanical and biological. Biological valves offer a higher ten-year-survival rate, are silent and require no anticoagulation therapy. A disadvantage, however, is their limited service life (12 years on average), because calcification and material fatigue impair the functionality of the valve leaflets.

Chemical treatment against calcification

As part of a master's thesis at Fraunhofer IKTS, new chemical pretreatments were investigated to prevent the calcification of porcine bioprostheses for heart valves. For this purpose, pericardial tissue was selected as the base material and crosslinked with substance molecules for stabilization. Instead of the more traditional glutaraldehyde crosslinking, diepoxide was used to counteract calcification. Crosslinking was performed with and without the immobilization of biophosphonates.

Natural human heart valves operate in a complex interaction of anatomical-structural properties with environmental conditions. They are determined by the anatomical position of the valve and the pumping function of the heart. Calcification is characterized by the deposition of crystalline hydroxyapatite and is a long-term complication, the investigation of which requires a considerable amount of time and experimental effort in the lab. Two accelerated fluid-dynamic in-vitro calcification tests were used to analyze the samples. Calcification fluids with a modified electrolyte concentration (increased calcium and phosphate concentration compared with human blood plasma) as well as a high cyclic load served as accelerating factors. The pH value of the solution was buffered and corresponded to that of human blood plasma.

Great potential for biphosphonates

After 6 to 8 weeks of long-term testing, the calcified heart valves were examined using traditional methods, such as scanning electron microscopy (SEM), Raman spectroscopy and micro-computer tomography (µCT). The study showed a promising effect of bisphosphonates on the calcification of heart valve replacements. The anti-calcification treatment must, however, be confirmed in further in-vitro and in-vivo tests as well as in clinical trials.

The work was supported through a collaboration with the Institute for Applied Medical Technology, Rheinisch-Westfälische Technische Hochschule Aachen and the Meshalkin National Medical Research Center in Novosibirsk (Russia).

1 *Pericardial heart valve (leaflets – bovine periradium; stent coating – porcine pericardium).*
2 *Deterioration of heart valve function induced by calcification as result of in-vitro calcification test.*

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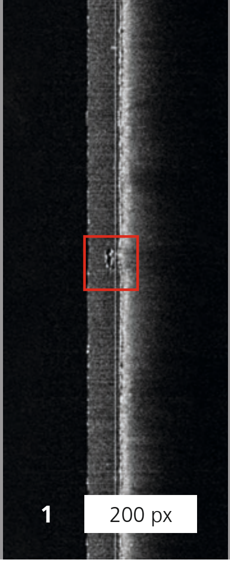

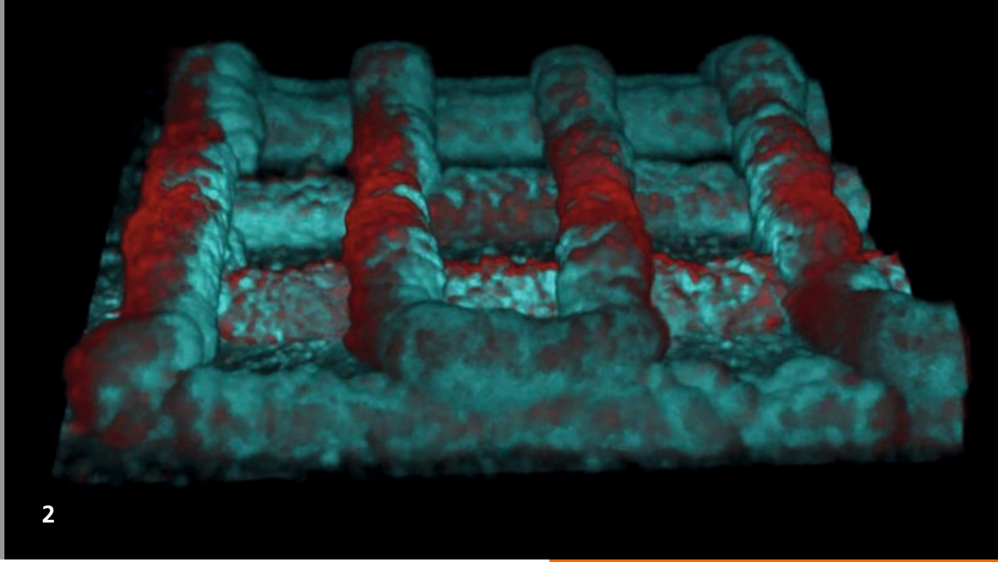

EVALUATION OF BIOLOGICAL 3D PRINTING PROCESSES USING OCT

Dipl.-Ing. Luise Schreiber, Dipl.-Ing. Vincenz Porstmann, Thomas Schmalfuß, Dipl.-Ing. Andreas Lehmann, Dr. Malgorzata Kopycinska-Müller, Dr. Jörg Opitz

Additive manufacturing (AM) is becoming increasingly important in all fields of industrial application. In medical technology, the artificial production of tissue, known as tissue engineering, is of particular relevance. The aim is to produce highly individualized structures, partly mixed with living cells, in small batches. To achieve this, suitable biomaterials must be developed, in addition to 3D printing technologies for biocompatible implants.

Monitoring the 3D printing of biomaterials

In biological 3D printing, called bioprinting, quality control is challenging due to the fragility of the tissues produced. Technologies for the monitoring of bioprinting processes must be fast, contact-free and radiation-free in order to be directly applicable in the manufacturing process. Optical coherence tomography (OCT) meets these criteria. The imaging measurement method based on white-light interferometry has been established in ophthalmology for many years but is also increasingly used for non-destructive material testing. OCT can be used to obtain topographic information for semi-transparent sample systems, as well as information about the internal structures of the object.

Integration of OCT in a 3D printer

In order to evaluate OCT for use in biological 3D printing, an OCT measurement module was successfully integrated into a bio 3D printer from RegenHU Ltd. Initial in-situ investigations were carried out during the strand deposition process. The effects of different process parameters (strand deposition height and atomization pressure) and materials (alginates and xerogels) on the deposited strand were examined. The cross-sectional area of the deposited ribbon allows conclusions to be drawn about the print quality.

In addition to quality control, the integration of an OCT module has further advantages: Since printed structures do not have to be removed from the 3D printer and prepared for further examination, changes and damages to or the destruction of the object can be ruled out. After printing, a full 3D image of the structure can be taken, enabling a digital comparison with the CAD model to verify manufacturing accuracy. Furthermore, the OCT module offers the possibility to dynamically record or monitor the drying behavior directly after the printing process. These studies on the printing process are part of the materials research of the biomaterials used.

The investigations presented here were carried out in cooperation with the Technical University of Dresden (Max Bergmann Center for Biomaterials Dresden).

1 *Reconstruction of a strand printed on a base; undesired inclusions in the strand material are marked.*

2 *Comparative tomograms of a printed grid-like structure before and after drying; differing areas are shown in red.*

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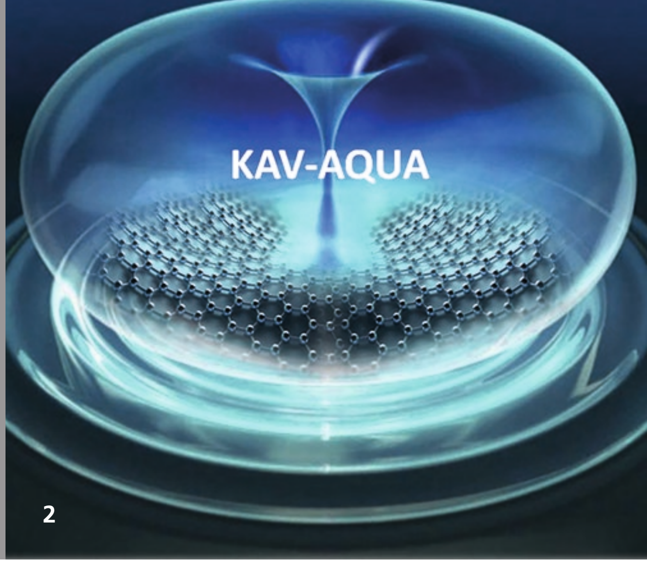


WATER PURIFICATION PROCESSES WITH SOUND AND PRESSURE – ATTRACT GROUP KAV-AQUA

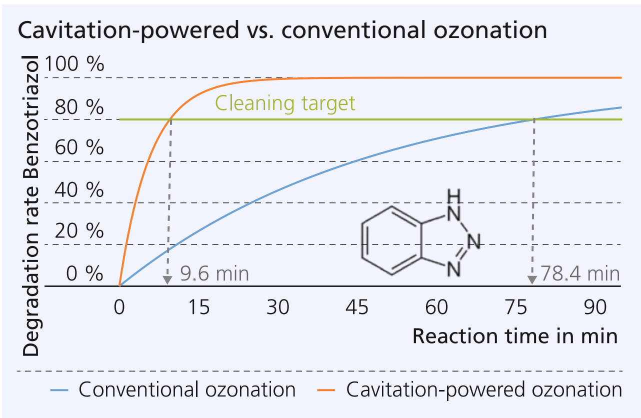
Dr. Patrick Bräutigam

With “Fraunhofer Attract” funding, outstanding external scientists can use the Fraunhofer infrastructure to further develop innovative ideas in an application-oriented way. Beginning in November 2020 at the IKTS site in Hermsdorf, the Attract Group KAV-AQUA, led by Dr. Patrick Bräutigam, will develop innovative cavitation-assisted processes, reactors and sensors for use in water management.

The focus is on the removal of micropollutants (e.g. residues of pharmaceuticals and industrial chemicals) and the continuous recording of total parameters to determine the water quality, which cannot be achieved with existing technologies. The aim is to develop significantly more effective and energy-efficient approaches to water treatment compared with the state of the art. This means that, at best, all organic micropollutants are removed using only half of the energy used by conventional methods.

In order to achieve this, the Attract Group couples processes of hydrodynamic, acoustic and sub-/stable cavitation and their combinations with advanced oxidation processes (AOP, e.g. ozonation) and sensor technology. This creates completely new reactors and processes that release synergetic effects through specific interactions and can also be modulated, i.e. they can be adapted to different levels of pollutants and volume flows in the process. Furthermore, predictive models are being developed using machine learning approaches. This solves a central problem of water technology: the prediction of the speed and completeness of removal even for unknown, unexamined micropollutants as well as the determination of appropriate design criteria for reactors.

For Fraunhofer IKTS, the Attract Group provides another way of tapping into the targeted development of future areas of application and innovative solutions in the field of water and environmental technology. In addition, the newly developed methods, reactors, processes and sensors allow long-term use in other areas of application or as services provided. These include, for example, the procedural use of cavitation-assisted processes in other industries (chemistry, pulp and paper, food, cosmetics), the use of reactor principles for other sensor applications and analytical methods for testing cavitation effects, e.g. in medicine. This ensures that the group continues to be embedded closely with Fraunhofer IKTS and will achieve successful results long into the future.



1 Attract Group KAV-AQUA, led by Dr. Patrick Bräutigam.

2 Cavitation bubble with microjet.

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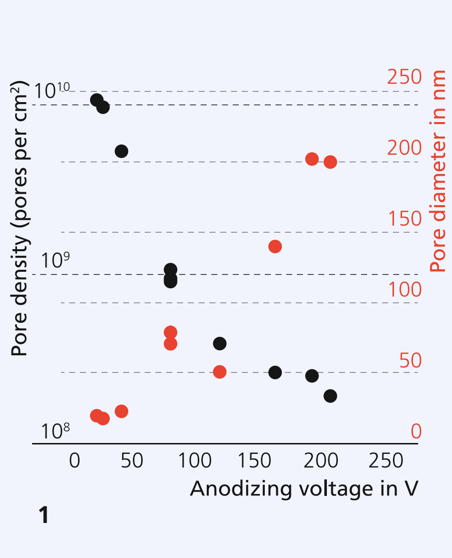
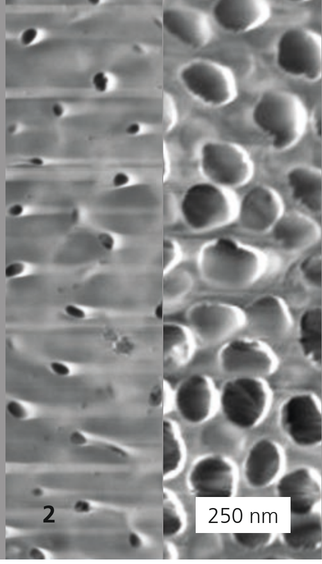
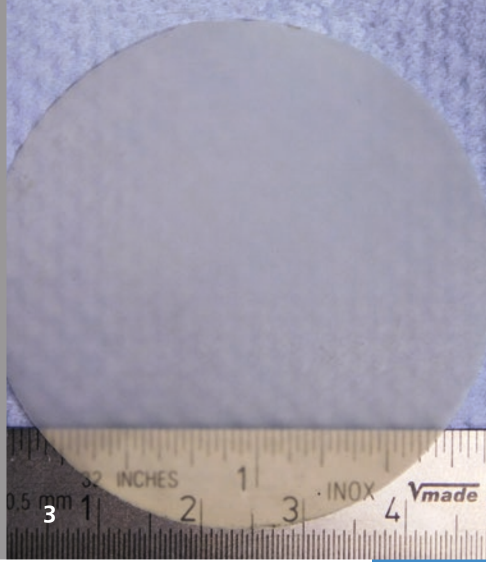






ELECTROCHEMICAL FABRICATION OF NANOPOROUS ALUMINUM OXIDE MEMBRANES

M. Sc. Karsten Voigt, Dr. Christoph Lämmel, Dr. Christian Heubner, Dr. Michael Schneider

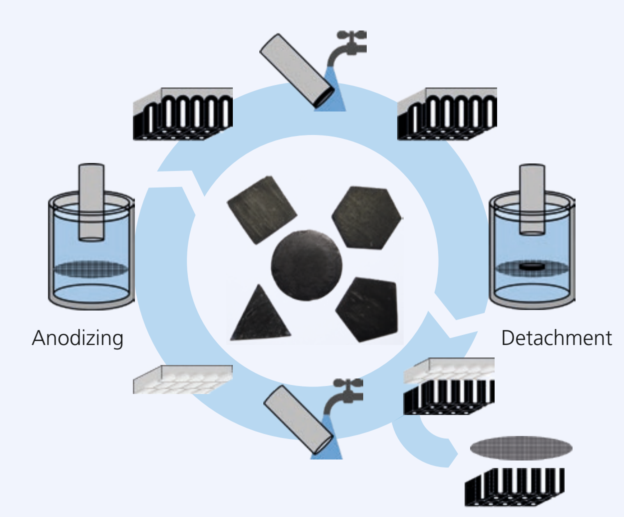
In recent times, the pollution of oceans with microplastics has been coming into public awareness. Microplastics find their way into wastewater and soil due to the abrasion of fibers while washing clothes or the use of cosmetics and cleaning products. The cost-efficient removal of microplastics during wastewater treatment requires suitable filter materials.

Cost-efficient and scalable processes are being developed at Fraunhofer IKTS using electrochemical technologies to produce tailor-made aluminum oxide membranes. Beside the application in sensor technologies, catalysis, energy storage and medicine, nanoporous aluminum oxide can be used as a membrane to separate microplastics from fluids.

Via anodizing, an aluminum substrate is electrochemically oxidized and forms a nanoporous oxide layer. Subsequently, the oxide layer thus formed is separated from the substrate by using a cathodic voltage pulse, which is applied only for a few seconds. The remaining aluminum substrate can be directly reused, which allows a quasi-continuous production process (right-hand graph). The pore size (10 to 400 nm), the number of pores (10^2 to 10^3 pores/cm^2) and the thickness of the membranes (0.1 to 600 µm) (Figures 1 and 2) can be modified through specific variation of the anodizing parameters. Targeted current-voltage modulation makes it possibly to vary the pore design, from straight aligned pores right up to periodic 3D structures. The range of available parameter combinations allows to adapt the membranes to the specific requirements of the elimination of microplastics. The entire fabrication process of the membranes does not require any toxic or environmentally hazardous chemicals.

The membrane thus obtained can be additionally modified to suit the desired application. For example, wider pore sizes can be achieved through chemical etching and mechanical stability can be improved by means of heat treatment. With the aid of suitable aluminum substrates, the fabrication can be realized in near-net shape, which reduces subsequent finishing steps.

Schematic diagram of a semi-continuous process route



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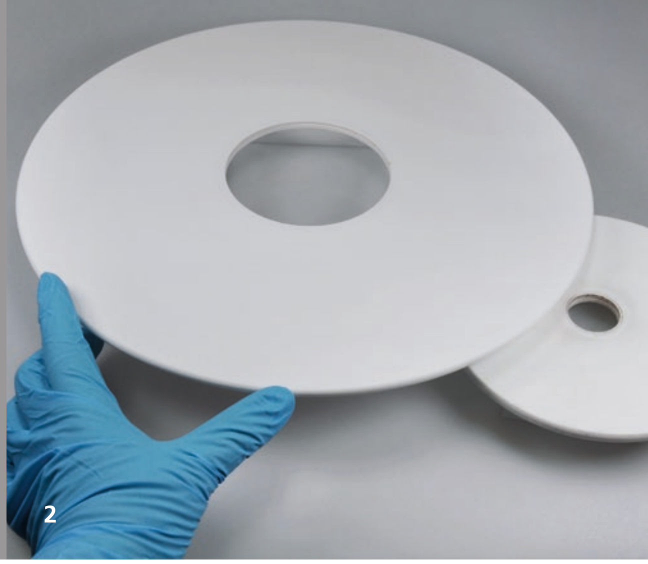
1 Pore size and pore distribution depending on the anodizing voltage.

2 Electron microscopic image of the pore design.

3 Membrane with 5 cm diameter.



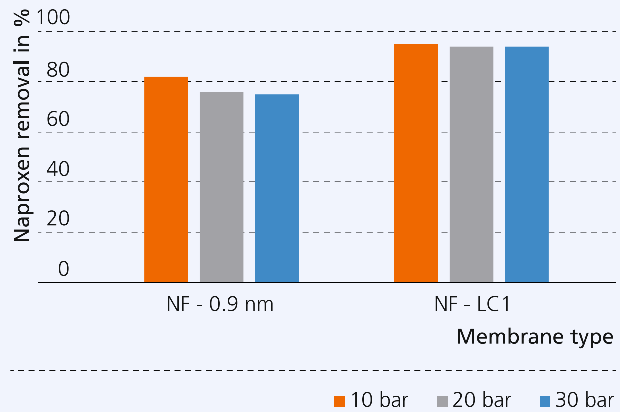
WATER

MICROPOLLUTANT REMOVAL BY CERAMIC MEMBRANES – PROJECT PharMem

Dr. Marcus Weyd, Dipl.-Ing. Christian Pflieger, Dipl.-Chem. Petra Puhlfürß

The reduction of micropollutants in water bodies is an important objective of water management and component of environmental policy. The joint project "Development of a process for the elimination of pharmaceuticals and other organic trace substances from wastewater using a combined system consisting of functionalized ceramic nanofiltration membranes and extended oxidation – PharMem" addresses the goal of developing a new treatment process for the separation of pharmaceuticals from polluted wastewater. The partners in this Thuringian project are E.S.C.H. GmbH, Rauschert Kloster Veilsdorf GmbH, Friedrich-Schiller-University Jena and Fraunhofer IKTS. The process consists of a nanofiltration step leading to extensive water purification and the downstream degradation of the remaining trace substances in the permeate by an oxidative process. The basis for the membrane separation step are ceramic nanofiltration membranes with a cut-off in the range of 200 g/mol (NF–LC1) or 450 D (NF–0.9 nm), which is unique worldwide. This means that molecules with equal or higher molecular weight are retained by the membrane under ideal conditions. Many pharmaceutical substances have a molecular weight between 200 g/mol and 500 g/mol and can therefore be retained by a nanofiltration membrane. In the PharMem collaborative project, membrane synthesis is transferred to multi-channel tubes with increased specific membrane area and to rotating disk filters. Nanofiltration membrane layers on rotating disk filters are a world first. Membrane systems with rotating disk filters are very energy-efficient because the energy required to rotate the disk filters is lower than the pump energy required to operate cross-flow filtration systems. The membrane separation and the downstream oxidation process are combined in a filtration system, tested and evaluated under real conditions. A retention of up to 95 % for the analgesic naproxen (diagram) and the beta-blocker Propranolol has already been achieved by the nanofiltration step. The combined process can thus achieve almost complete elimination of trace substances.

Naproxen removal of ceramic nanofiltration membranes at different pressure levels



The authors gratefully acknowledge the financial support of the Free State of Thuringia for the project PharMem (grant number 2018 VF 0014).

1 *Pilot filtration plant at IKTS.*

2 *Nanofiltration membranes as rotating disk filters.*

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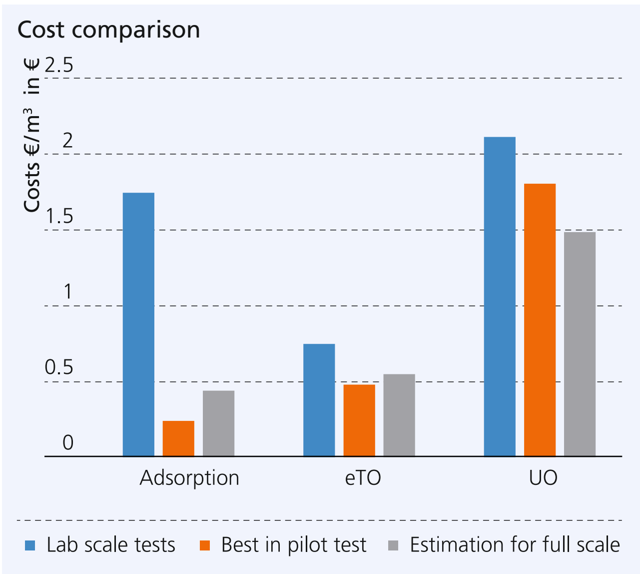
COMPARISON OF METHODS FOR HERBICIDE REMOVAL FROM DRINKING WATER IN PILOT SCALE

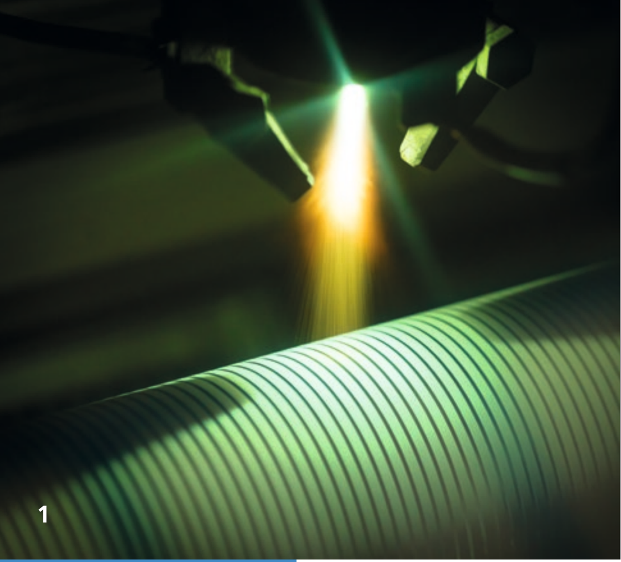
Dipl.-Chem. Hans-Jürgen Friedrich

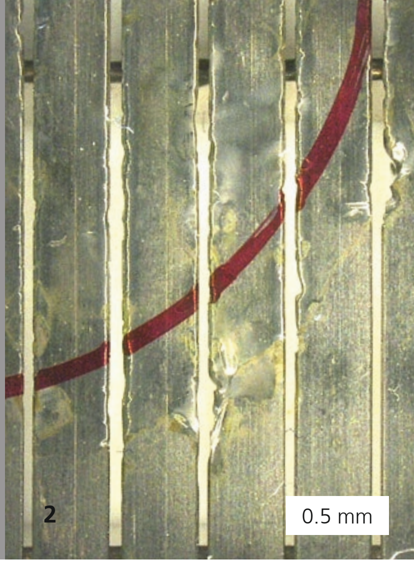
Pesticide and pharmaceutical residues in groundwater can impair the drinking water supply significantly and possibly lead to supply shortages. Sandy soils in particular are barely able to retain such substances. On behalf of mea Energieagentur Mecklenburg-Vorpommern GmbH, the separation of the herbicide bentazone from well water was investigated by researchers at Fraunhofer IKTS and tested at pilot scale. This pollutant was found in concentrations of approx. 400 ng/l in the deep wells of a water supplier, rendering it unfit for consumption. Preliminary tests showed that the processes of electrochemical total oxidation (eTO), reverse osmosis (RO) and adsorption on activated carbon are best suited for herbicide removal. The eTO is the only process that offers the possibility to remove organic pollutants directly without pretreatment of the water, by oxidizing them to CO_2. Reverse osmosis, in comparison, requires extensive preconditioning of the water, which leads to a high consumption of chemicals for de-ironing and softening as well as to large quantities of secondary waste. Adsorption on activated carbon is a simple, widely used technology. However, it is largely non-specific and carries the risk of germination and discharge of highly loaded particles from the bulk material. Subsequently, a modular pilot plant in container design was erected in the water plant and operated for more than 1000 hours (Figure 1 and 2). The throughputs were 30–60 l/h each. With all three processes, it was possible to reduce pollutant concentrations to the required target value of <100 ng/l in continuous operation. Accordingly, in this case, adsorption on activated carbon is the least expensive process, with costs of 0.24–0.45 €/m³ but this comes with the aforementioned limitations. Additionally, many trace substances are also poorly adsorbed on activated carbon. Bentazone can be destroyed by eTO at only slightly higher costs. The pollutant can also be removed by reverse osmosis but at significantly higher costs of >1.50 €/m³. In addition, the RO does not produce drinking water. In summary, the analysis shows that eTO processes certainly have the potential for wider use, as they are by no means associated with high costs per se.



1 *System for electrochemical total oxidation.*

2 *Module for reverse osmosis.*





THERMALLY COATED EROSION PROTECTION LAYERS FOR WIRE-WRAPPED SAND SCREENS

Dipl.-Ing. (FH) Bernd Gronde, Dipl.-Chem. Gundula Fischer

In oil, gas and geothermal wells, wire-wrapped sand screens prevent the input of mobilized formation particles into boreholes. The screen openings must have an exactly defined size in order to control the ingress of sand. If the filter fails, there may be permanent entry of solids or a decrease in production due to significant pressure drops in the area near the borehole. During operation, installation and workover measures, erosion, corrosion, deformation and blockages can lead to failure of the filter. Particularly in the initial phase, severe corrosion and hot spots arise, which can destroy the filter. Against this background, Fraunhofer IKTS was involved in a ZIM cooperation project for the coating of wire-wrapped screens with ceramic or carbon-enriched protective layers in order to optimize the flow conditions and increase the service life of the filters. While maintaining the defined gap width of the filter, ceramic and hardmetal layer systems were developed for wire-wrapped screens, making them more resistant to erosion and corrosion on the outside. Wire-wrapped screens have a diameter of approximately 40 to 200 mm and consist of segments with 4 to 6 m in length. In addition to high wear resistance, the requirements placed on the coatings are high chemical resistance to organic acids and a pH value of 4 to 8. The working temperature range is between -30 and +160 °C. The loads vary depending on the place of use and the raw material. Particularly challenging were the very precise gap dimensions and the special shape of the profile wire of the filter. The gap widths are in the range from 100 to 500 µm ± 25 µm and must also be guaranteed with the coating layer.

Several steps were necessary for the complex coating of wire-wrapped screens. First, the outside of the filter was pretreated in a defined way to achieve high mechanical adhesion of the layer. Next, a so-called adhesive layer was applied by thermal spraying. Only then could the erosion-resistant functional layer be applied, also by thermal spraying. In the project, 23 coatings based on oxide-ceramic, nitridic and carbidic materials were sprayed, examined and compared regarding torsional and adhesive strength as well as corrosion and erosion. To increase corrosion resistance, a sealer developed at IKTS was ultimately applied. The wetting properties of the coating can be influenced by selecting a particular sealer.

The wire-wrapped screens were developed and manufactured by our industrial partner, con-slot SCREENS GmbH. Our project partner TU Bergakademie Freiberg tested the samples in a specially developed test facility under conditions close to commercial application with regard to corrosion, erosion and chemical resistance. After successful completion of these investigations, early prototypes have been used in field tests in a gas well since September 2020.

1 Coating of a wire-wrapped screen by thermal spraying.

2 Uncoated section after erosion test.

3 Coated section after erosion test, same test time as Figure 2.

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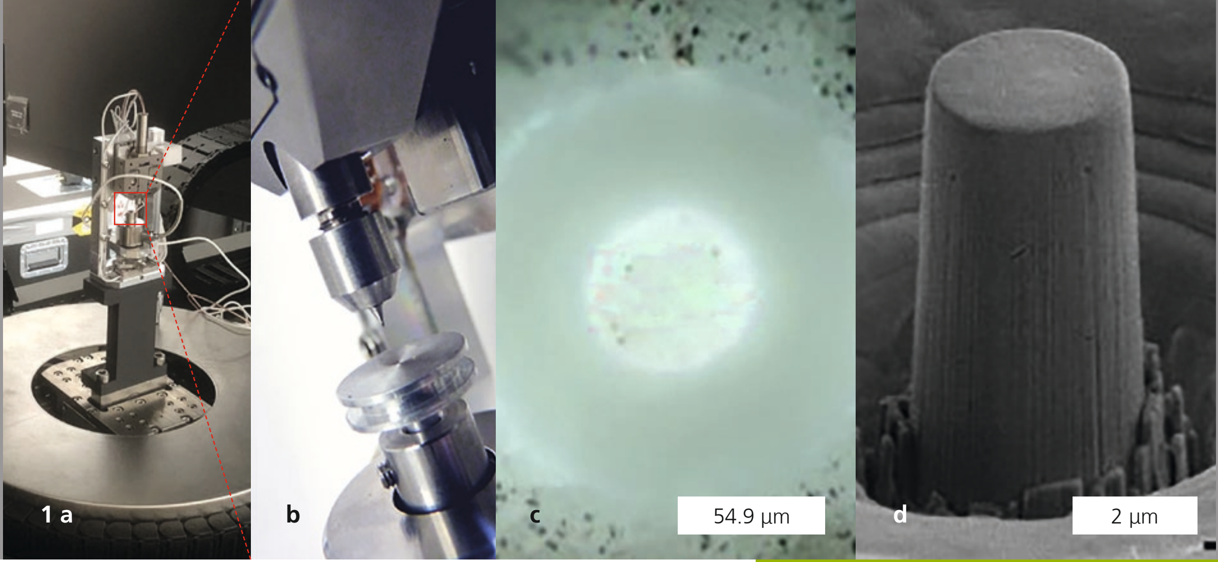

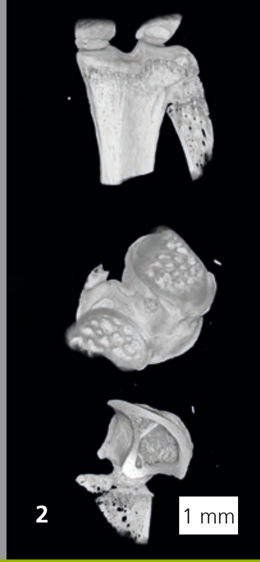

STUDIES ON OSTEOPOROSIS PREVENTION: ERC SYNERGY GRANT 4D+ nanoSCOPE

Prof. Silke Christiansen, Dipl.-Biol. Lasse Kling, Dr. George Sarau, Dr. Johannes Ast

The “4D+ nanoSCOPE” project aims to revolutionize our knowledge of osteoporosis. The six-year joint project funded by the European Union in the module “Excellent Science – ERC-Synergy” brings together three different skill sets: Prof. Georg Schett, Head of Department of Medicine 3 at Universitätsklinikum Erlangen, provides the medical expertise and the sample material. Prof. Andreas Maier, Chair of Pattern Recognition at Friedrich-Alexander-Universität Erlangen-Nürnberg, contributes machine-learning methods to enable an automated and statistically validated interpretation of measurement data. Prof. Silke Christiansen from the Fraunhofer IKTS site Forchheim provides a comprehensive sample analysis consisting of scale-bridging microscopy and spectroscopy to create an unprecedented analytical context. The time-dependent monitoring of bone remodeling dynamics in relation to load and drug therapy represents the fourth dimension, which can only be achieved by in-vivo investigation of bone remodeling (in a mouse model). This requires XRM tomography with the highest resolution and fast image acquisition, which involves new hardware and software developments at the XRM. These are carried out in close cooperation with the company Carl Zeiss. Bone, as a complex and dynamically changing material, has various structural elements such as the compact outer bone wall and a less dense framework architecture in the bone interior. Both structures are interspersed with pore and canal networks that are responsible for bone remodeling and restoration, but at the same time influence the mechanical properties. Biomechanical test procedures on the corresponding length scales (nano to mesoscale) offer the possibility to precisely analyze the mechanical properties, such as tensile and compressive strength, fatigue behavior and fracture toughness, in the different stages of development of osteoporosis and to link them to the bone microstructure. Together with important further analyses, such as Micro-Raman spectrometry, laser scanning microscopy and light sheet fluorescence microscopy, the results are embedded in a correlative-analytical context. This allows the results from the individual procedures to be put together to form a large overall picture, like pieces of a puzzle. Machine-learning methods allow computer-aided detection of recurring patterns in image data. These can be correlated with other diagnostic findings and enable an automated image evaluation with high throughput.

Services offered

- Context microscopy and spectroscopy workflows
- Development of application-specific context analytics

1 a–d *In-situ mechanical setup inside the XRM to investigate bone microstructure.*
2 *3D-tomographic images of a mouse knee section.*

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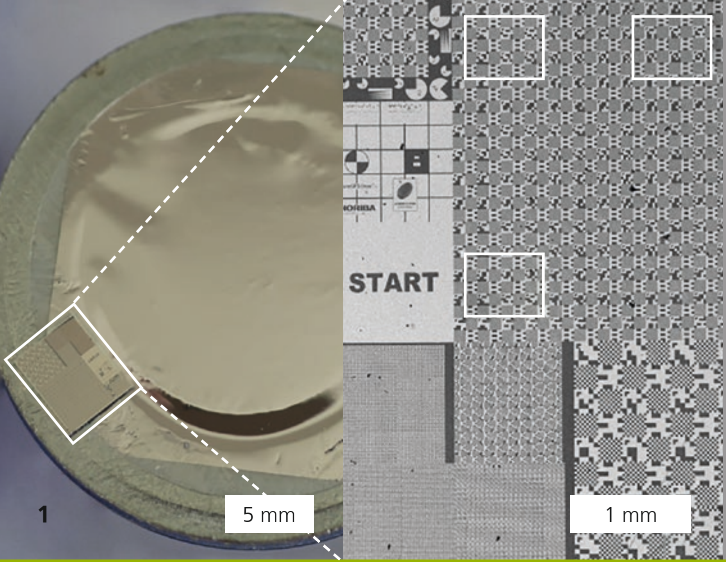

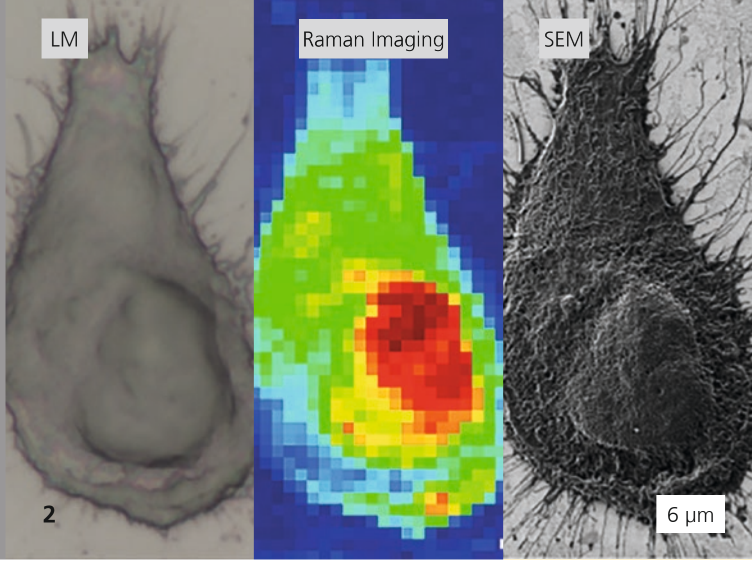

nanoGPS^R – AN ENABLING TECHNOLOGY FOR CORRELATIVE NANOANALYTICS

Prof. Silke Christiansen, Dr. George Sarau, Dipl.-Biol. Lasse Kling, Dr. Johannes Ast,
Dr. Annegret Potthoff, Dr. Mathias Herrmann

Nano-Global Positioning System (nanoGPS) for correlative imaging and analytical data acquisition

Although exposure to micro- and nanoplastic particles (MNPs) found in food and air is ubiquitous, the potential effects on human health, especially on internal organs, are largely unknown. Accurate risk assessment requires knowledge of the concentration and agglomeration of MNPs in the environment and in physiological media, as well as detection of MNPs using analytical techniques. For the first task, Fraunhofer IKTS has many years of experience and measurement methods; for the second, the newly developed relocalization technology nanoGPS^R (Horiba Scientific) is suitable. It is based on a hardware/software combination and facilitates the use of a correlative microscopy and spectroscopy workflow for the investigation of physical and chemical properties on one and the same object in the nano range. The nanoGPS^R tag serves as a position transducer that is firmly attached to the sample under investigation and is moved back and forth with it between different analysis devices (Figure 1). It contains lithographic patterns that are imaged at different resolutions. Software identifies these patterns for a given magnification, allowing the determination of sample coordinates in the different instruments.

The use of nanoGPS^R technology to combine analytical and imaging modalities leads to a comprehensive understanding of the processes in cells (here: podocytes, which act as filter barriers in the kidney) and tissues in relation to plastic exposure. Human kidney cells (Figure 2) were selected to demonstrate the accumulation of MNPs over the lifetime and deterioration of cell health. Micro-Raman spectroscopy is used to characterize the different types of plastics. Cell damage from MNP exposure is inferred from imaging using light and electron microscopy. By overlapping these data, it is possible to avoid overestimation of particle size and underestimation of particle number for clusters and individual MNPs and to obtain Raman measurement signals of MNPs. After incubation of podocytes with four different MNP types, cell viability assays, which determine the proportion of living cells, showed that the decrease in cell viability starts at different concentrations for different polymer types.

Services offered

- nanoGPS^R-enabled correlative microscopies/spectroscopies
- Development of application-specific context analytics
- Characterization of MNPs in physiological media
- Weathering of MNPs under marine conditions

1 *The nanoGPS^R technology enables correlative workflows in different instruments.*

2 *Correlative imaging of the same control podocyte.*

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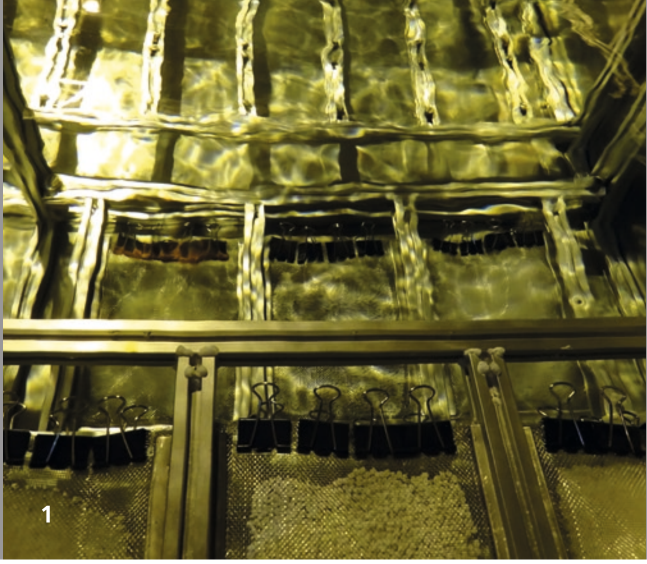

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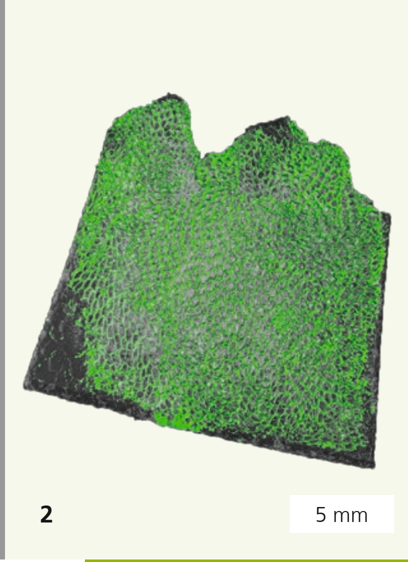

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MATERIAL WEATHERING UNDER REAL CONDITIONS IN THE MARINE ENVIRONMENT

Dr. Annegret Potthoff, Dipl.-Ing. Johanna Sonnenberg

Ceramic components

Antifouling coatings that reduce the growth of marine organisms on offshore wind turbines, anti-corrosive coatings for ship hulls, transparent ceramics for sensors in the sea – the advantages of ceramic components come to the fore under the harsh conditions of marine environments. The development of such materials must be accompanied by tests not only of their functionality but also of their durability under the conditions of use. Appropriate test setups in the laboratory, such as the salt spray test, are available for this purpose but they always represent only part of the real exposure. In real environments, the conditions are much more complex: Materials dissolved in water cause a chemical interaction while abrasive particles, such as sand, cause mechanical erosion. Finally, organisms present in marine environments can accumulate and cause biofouling.

With the aim of being able to carry out tests under real conditions in the future, Fraunhofer IKTS is partnering with three other Fraunhofer institutes in the establishment of the "Smart Ocean Technologies" (SOT) research group in Rostock. The characterization of components of various geometries under real conditions can be realized from the laboratory to deployment in mesocosms which are permanently flowed through and monitored (Figure 1) or in an artificial reef in the Baltic Sea (Figure 3). The components and coatings are analyzed in detail regarding functionality and damage. Additionally, the leaching of substances is considered, thus creating the basis for an ecotoxicological risk assessment of the components.

From polymers to microplastic

While ceramic materials are deliberately introduced into the environment on an application-related basis, plastics enter the oceans unintentionally and can cause considerable damage there. Weathering processes and fragmentation lead to the formation of microplastics; additives can be leached out. The development of new polymers (including biodegradable ones) and the use of more effective additives require efficient testing for environmentally relevant side effects in the event of improper use before they are placed on the market.

The required analysis is adapted to the specific test and considers both the surface properties of the component/plastic (microscopy, chemical composition, functional groups, charge, etc.) and the properties of the surrounding water (ion concentrations, DOC, etc.). Being able to take this holistic view into account as early as in the development of new materials is an added value for the users resulting from the work in the SOT.

1 *Mesocosm with flexible interior.*
2 *CT image of biofilm on plastic.*
3 *View from the research platform of the artificial reef Nienhagen (Source: Thomas Mohr).*

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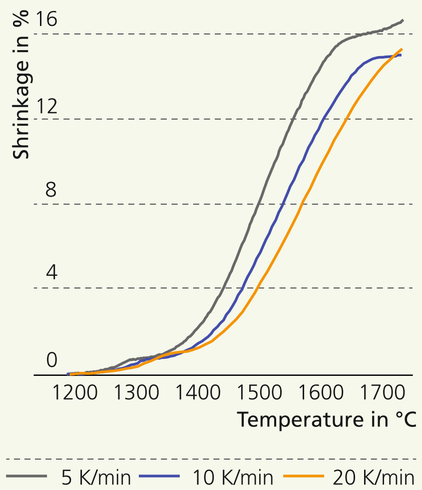

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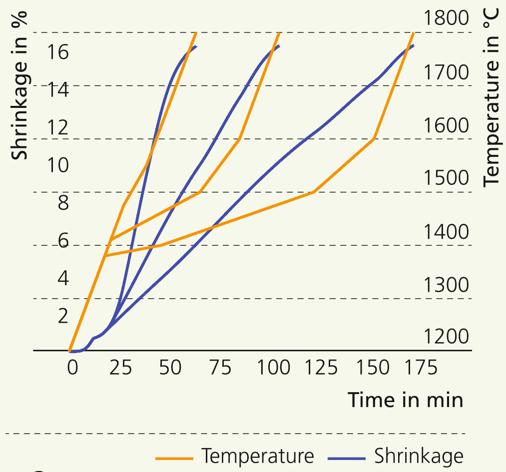

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OPTIMIZATION OF SINTERING PROCESSES

Dr. Tim Gestrich, Dr. Arno Kaiser, Dr. Eveline Zschippang, Dipl.-Ing. Jan Räthel, Dr. Mathias Hermann

To optimize sintering processes, Fraunhofer IKTS uses a variety of instrumented furnaces on a pilot-plant scale and thermoanalytical methods on a laboratory scale. Changes in the properties of the materials of interest are analyzed in relation to temperature, time, atmosphere and other process parameters (component size, furnace workload, among others) and the influence of these parameters on the product properties are determined. Particularly for the steps of debinding, outgassing and sintering, the results make it possible to control and optimize technical processes on a production scale.

When producing ceramics, precise knowledge of the shrinkage behavior during sintering and thus of the change in density is of particular interest. Thermodilatometric examinations on a pilot-plant and laboratory scale, for example, provide information on when sintering begins and ends, which helps to optimize the sintering processes for energy-efficient and cost-effective production. Other methods can be applied that describe the kinetics of sintering and allow to calculate the change in length for any temperature-time profile. This makes assessing temperature-time profiles possible without time-consuming laboratory-scale experiments or pilot-plant trials. This is demonstrated by characterizing, modeling and optimizing the sintering behavior of silicon nitride ready-to-press granules (Si_3N_4 RTP) provided by Industriekeramik Hochrhein GmbH based on the Si_3N_4 powder Silzot HQ of AlzChem Group AG. This involved determining the shrinkage behavior of debindered green bodies in the process dilatometer of a gas pressure sintering furnace at three different heating rates. The dilatometer was made of boron nitride (BN)-coated graphite. Figure 2 shows the results.

To calculate the minimum possible sintering time until closed porosity is achieved for various production scenarios (e.g. thin-walled or thick-walled products, dense or loose furnace workload), the shrinkage curves were evaluated using various methods (master sintering curves and formal thermokinetics). The modeling was used to design optimized sintering regimes. One approach consists in calculating simplified temperature-time profiles for a constant sintering speed (RCS: rate-controlled sintering). Such profiles (Figure 3) are characterized by time-saving process management. Additionally, cracks and similar defects become more rare because they often arise from high stresses caused by high sintering rates.

IKH

AlzChem

1 *Si_3N_4 grinding jar.*
2 *Shrinkage curves of Si_3N_4.*
3 *Calculated temperature-time profiles for three different nearly constant sintering speeds.*

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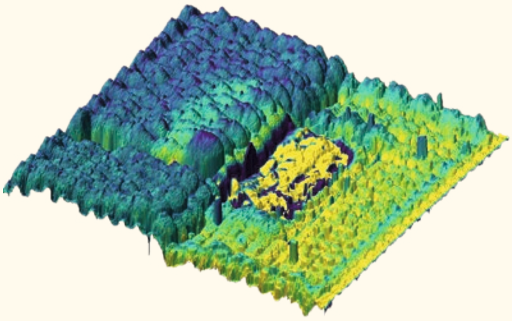

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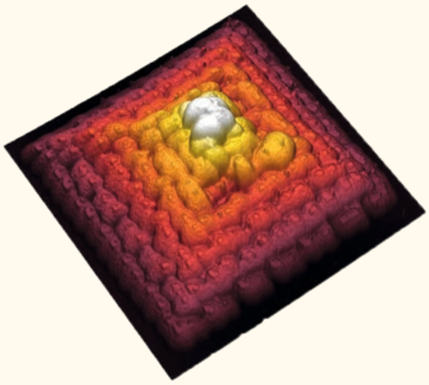

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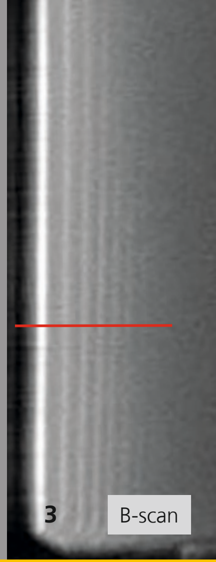


3

OCT FOR THE CHARACTERIZATION OF 3D-PRINTED CERAMIC OBJECTS

Dipl.-Ing. Luise Schreiber, M. Sc. Conner Phillips, Dipl.-Ing. Andreas Lehmann, Dr. Jörg Opitz, Dr. Malgorzata Kopycinska-Müller

Additive manufacturing (3D printing) of advanced ceramics offers the possibility to create highly specialized structures. Their very specific geometry and finely tuned mechanical, thermal, and electrical properties require the highest quality standards even during manufacture. This can be realized with in-line monitoring methods, such as optical coherence tomography (OCT).

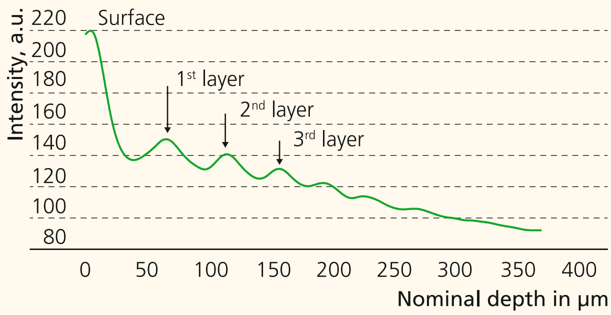
Non-destructive OCT uses a laser beam to illuminate a small area on the sample surface. While part of the beam is reflected from the surface, a portion of it can propagate into the sample, where the light is backscattered from inclusions, delamination, pores, and other defects. The local variations alter the path of the laser beam. The backscattered light interferes with a reference signal, allowing the extraction of information about the sample interior. This complex diffraction pattern is analyzed with the fast Fourier transform (FFT) method to yield variations in the light intensity as a function of the sample depth. This signal is called A-scan and it is repeatedly recorded in a line across the surface. As a result, a cross-section image (B-scan) of the sample is obtained. The acquisition of laterally spaced B-scans yields a tomogram containing volume-related information.

Detecting defects and material variations in the object

Figure 1 shows a combination of geometry and material variations extracted from a tomogram measured on a ZrO_2/support material probe. The dimensions of the structure can be extracted and compared with those parameterized for printing. Subsurface defects and material variations can be detected, and the information can be used to optimize the printing process. The topography of a printed pyramid is shown in Figure 2. Both structures were printed in a multi-material jetting process. The B-scan presented in Figure 3 shows several layers of a ZrO_2 probe printed via a lithography-based process. At the marked position, an A-scan was extracted, as shown in the diagram below. The positions of the peaks clearly identify the layer interfaces. This allows tracking of variations in layer thickness – a perfect indicator for the stability of the printing process.

These results were obtained within the Fraunhofer Innovation and Transfer Center "Smart Production and Materials" and were funded by the Free State of Saxony.

Evaluation of the layer thickness – A-scan



1 Topography and material variations in printed test structure.

2 Topographic reconstruction of a printed pyramid structure.

3 B-scan of a ZrO_2 probe.

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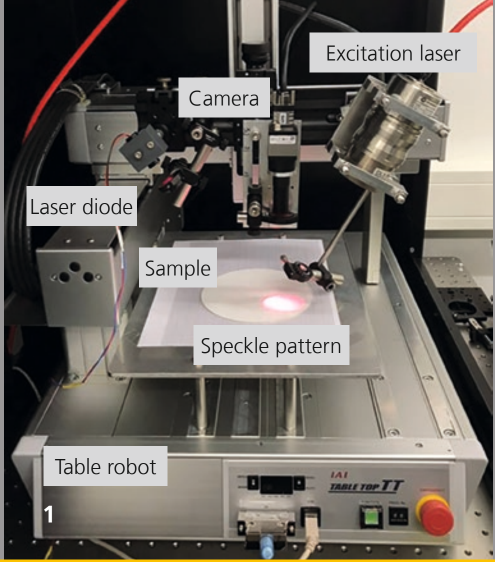
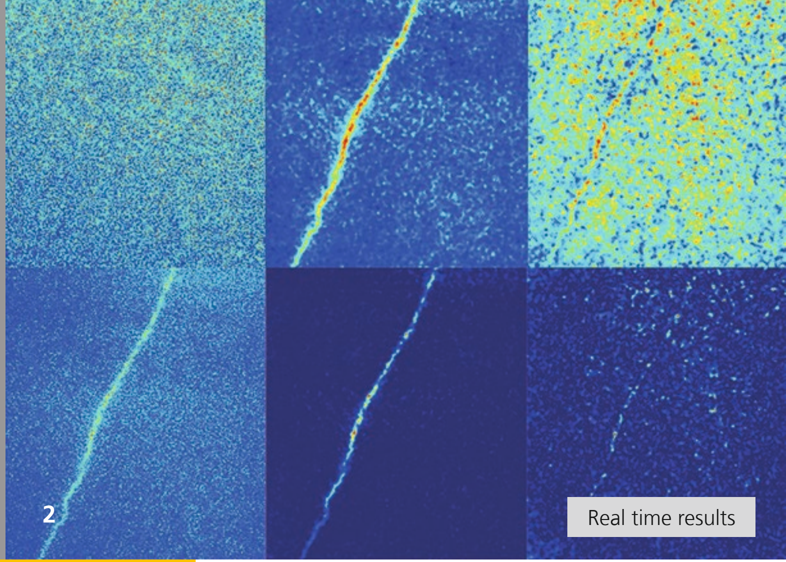




OPTICAL IN-LINE MONITORING OF HIGH-PERFORMANCE CERAMICS PRODUCTION

Dr. Beatrice Bendjus, Lili Chen, Dr. Ulana Cikalova, Dipl.-Chem. Gundula Fischer, Birgit Köhler

Characterization is essential for the quality control of high-performance ceramics. Despite optimized production technologies, defects still occur in the manufacture of ceramic materials due to the complexity of the processes. The detection and elimination of cracks, disruptions and inclusion defects is very time- and cost-intensive. In commonly used visual inspections, detection of defects is subjective and depends on the size. Established non-destructive test methods are usually costly because the samples need to be scanned individually on laboratory equipment. Usually, this equipment can be integrated into the production process only with difficulty, or not at all.

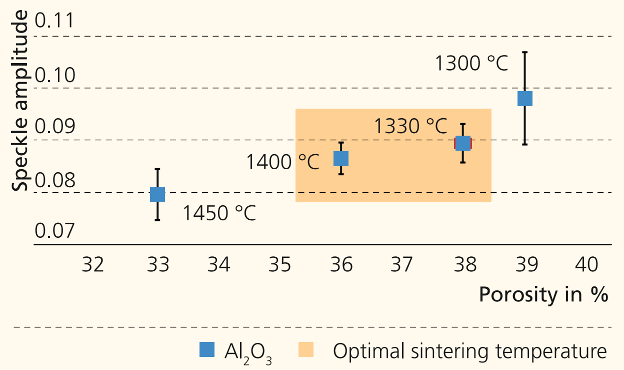
Quick, in-line-capable ceramic testing with LSP

Time-resolved laser speckle photometry (LSP) is a relatively young method, which can be used for optical defect control. It creates the possibility of determining in-line the porosity and surface defects of different types and sizes. It boasts a simple, robust design and low costs compared with competing measuring methods. The method is based on the evaluation of the temporal change of speckle patterns, for which an optically rough surface is illuminated with a laser beam. The reflection on the surface creates interference patterns, known as speckles. Short thermal excitation leads to changes of the speckle patterns, which are recorded by a camera.

Demonstrator shows compatibility for ceramics testing

Within the IGF project "OptiKer", a concept for quality monitoring of ceramic materials based on LSP was developed. In a first step, dense Al_2O_3 components (e.g. Na β'' aluminate), porous oxide, silicate and non-oxide ceramics were produced and characterized. At the same time, a robot-guided demonstrator was designed and built, which is able to detect porosity and defects as small as 70 µm in sintered and unsintered ceramics. By evaluating the change of the speckle amplitude, deviations in porosity in the sintered ceramics can also be characterized. The measurement and evaluation time for a flat sample with a diameter of 30 mm is four minutes, which can be significantly shortened through powerful computing technology.

Dependence of the speckle amplitude on the porosity of the ceramics



Supported by:
Federal Ministry for Economic Affairs and Energy

1 *LSP demonstrator for defect and porosity detection.*

2 *User interface of the demonstrator.*

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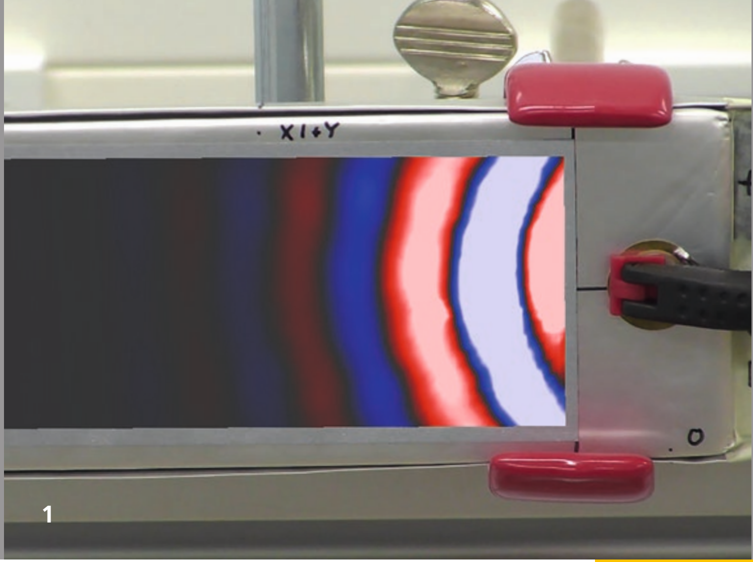

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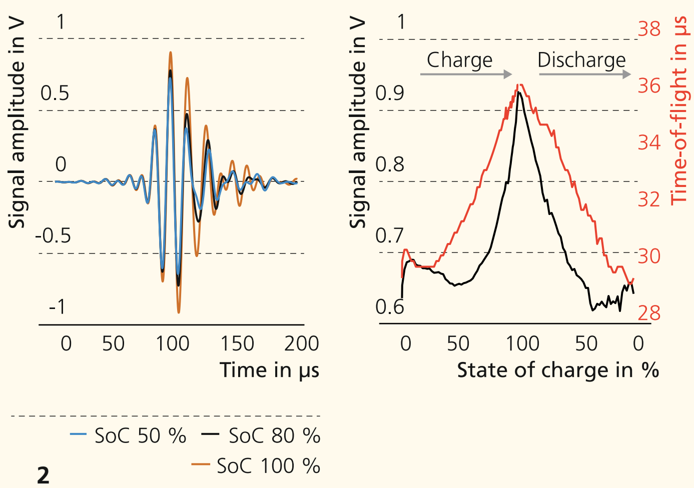

2

CHARGE-STATE MONITORING OF LITHIUM-ION BATTERIES WITH GUIDED WAVES

Dipl.-Ing. Tobias Gaul, Dr. Kilian Tschöke, M. Eng. Konrad Chwelatiuk, Dr. Lars Schubert

The use of Li-ion batteries is widespread nowadays. Their highly available power and energy density make them interesting not only for applications in consumer electronics but also in the rapidly growing field of electromobility. In use, the availability of this power across the entire service life is key. The complex physical and chemical structure of the materials used leads to unwanted degradation within the battery. This is caused by various processes, such as the loss of freely migrating Li ions, and electrode aging. Over time and over several charging cycles, this will decrease capacity and power, and therefore reduce efficiency. The battery's lifetime will be significantly shortened.

Innovative solutions for battery monitoring

Currently, the entire battery system is monitored by the integrated Battery Management System (BMS). It can monitor and control the batteries at the module level using measurands, such as temperature, voltage and current. Monitoring of batteries down to the cell level is only done in high-performance applications using electrochemical impedance spectroscopy (EIS). For this, EIS requires accessible electrical contact points, which is difficult to implement in closed, ready-to-use battery systems.

By using guided ultrasonic waves, Fraunhofer IKTS facilitates the monitoring of batteries at the cell level, which is not based on the measurement of electrical parameters of the battery itself. Piezoelectric transducers excite and receive guided waves on the surface of a battery cell. These waves are influenced by the change of the elastic modules and density of the electrodes while the battery is being charged/discharged, and they can be measured. The complex propagation behavior of the waves was investigated with a laser vibrometer (Figure 1). It could be shown that the properties of the waves (amplitude, phase) are directly related to the state of charge (SoC) of the battery (Figure 2). This allows measuring the state of charge independent of the electrical parameters and does not require access to electrical contacts.

Beyond the state of charge

When it comes to planning the replacement of batteries, the remaining service life is as important as the current state of charge. A loss of capacity directly affects the measured signal parameters of the waves. This makes the degradation of the battery measurable and predictable. With this procedure, battery systems of the future can be replaced at the optimal time and continued operation in second-use applications becomes possible depending on the actual battery condition.

1 *Wave propagation measured with a laser vibrometer on the surface of a battery.*

2 *Trend of signal parameters over a charge/discharge cycle of a Li-ion battery.*

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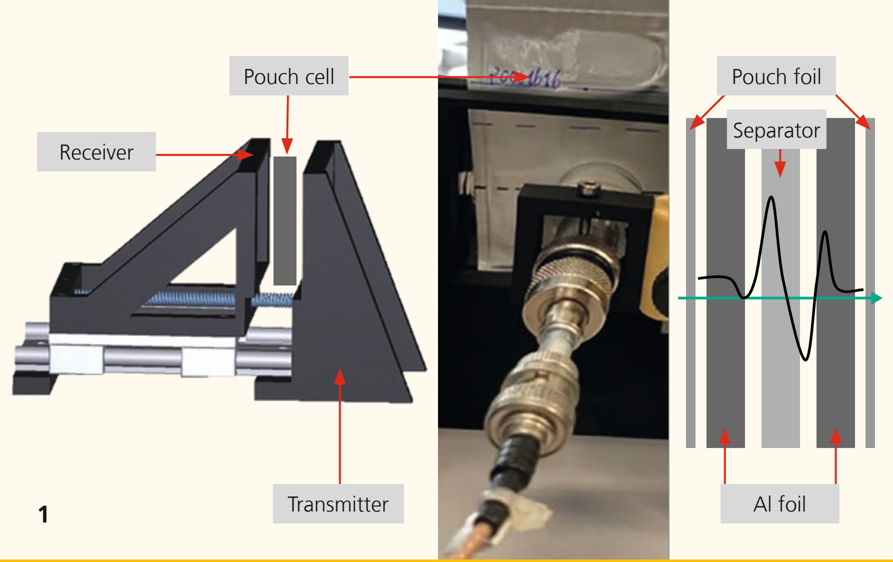

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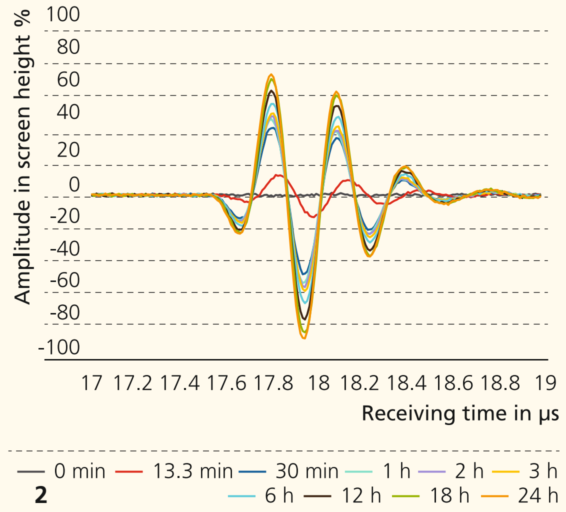


2

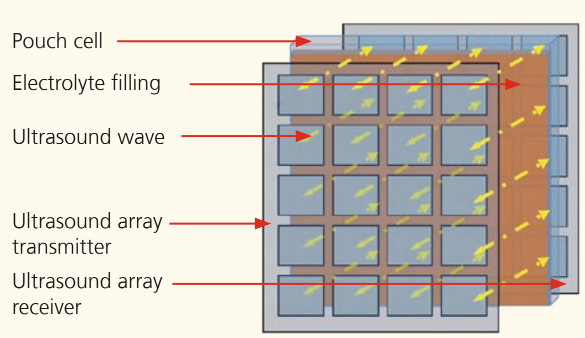
OPTIMIZING THE FILLING OF LITHIUM-ION BATTERY CELLS WITH IN-LINE METHODS

Dipl.-Ing. Mingzhe Han, Dr. Sebastian Reuber, Dr. Thomas Herzog, Prof. Dr. Henning Heuer

Electrolyte filling is a quality-relevant process step in the production of Li-ion battery cells (LIB), which has a direct influence on the performance and lifetime of the cell. Since there is currently no applicable in-line measurement method in the industry, empirical studies are conducted on cells. Most commonly, destructive methods, which involve the disassembly of the cell, are used. In order to reduce the production costs, there is a need for a non-destructive method with which the filling and wetting process can be visualized in situ during the production of the cell. The ultrasonic system developed at Fraunhofer IKTS (Figure 1) is used to monitor the wetting process of Li-ion batteries. The probes were fixed to both the front and back side of the cell. The measurement is carried out through the transmission of ultrasound through the cell while it is being filled with electrolyte. A visible change in the received signals (Figure 2) relating to the filling and wetting can be observed. The preparation path and the energy of the sound waves are strongly influenced by the wetting of the cell, whereby the pore volume of cell components is soaked in the electrolyte. This can be demonstrated by increasing the amplitude of the signal received from the measurement. A wet cell attenuates the sound wave less than a dry cell. More details about the filling process are obtained from the signal curve of the ultrasonic receiver. The change in the received signal can be divided into two parts: At first, there is a rapid increase in the signal amplitude – this corresponds to the macroscopic wetting of the cell. The subsequent slower signal change is attributed to the microscopic wetting. The different filling behavior of an LIB can thus be determined non-destructively by means of ultrasound detection.

With the integration of sensor arrays, this in-line method will be developed further into a measuring system. This would make it possible to resolve the wetting process spatially and ensure the complete wetting of the battery electrodes and the separator, thus shortening the safety margin for the filling time currently used throughout the industry.

Concept adaptive sensor array for wetting testing



ProZell Cell-Fill

SPONSORED BY THE Federal Ministry of Education and Research

1 Ultrasonic system for monitoring the filling process.

2 Signals received from ultrasonic measurement during the filling process.

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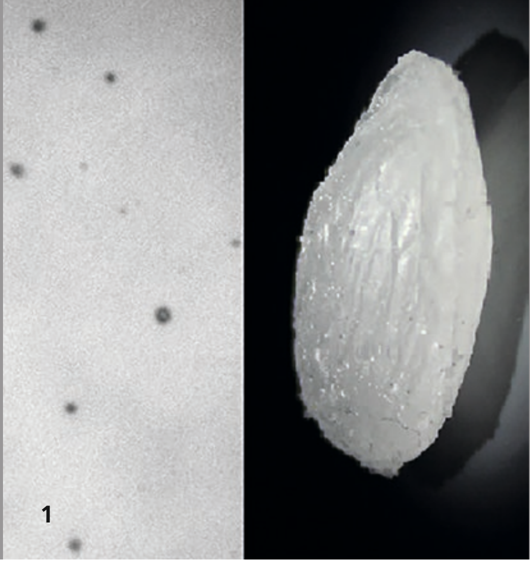

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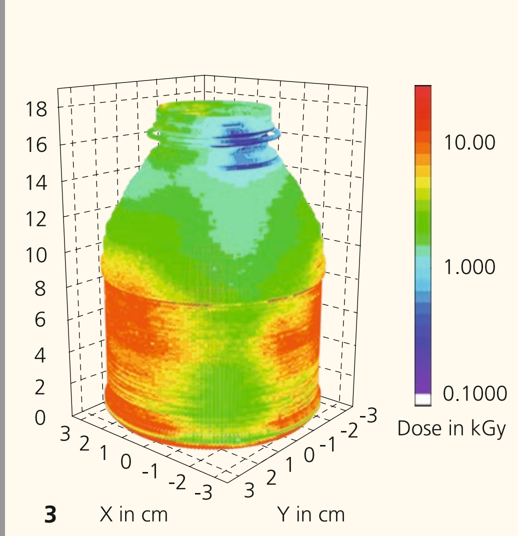

3

MULTIDIMENSIONAL DOSIMETRY FOR PROCESS CONTROL IN ELECTRON BEAM IRRADIATION

Dr. Christiane Schuster, Dr. Julia Katzmann

Electron beam irradiation is an important health- and security-related technology, which is required in many fields, such as surface sterilization, vaccine production or the definition of material properties in radiation processing. Dosimetry ensures the assessment of the ionizing radiation dose absorbed, quality assurance and process control. Dosimeters come in the form of tailored polymer stripes or pellets as carriers of a radiation-sensitive material, which are analyzed in laboratory devices. But state-of-the-art dosimetry systems cannot determine doses on complex product surfaces (3D), in points (1D) or as depth dose profiles (2D) inside a product. Nor are they suitable for in-line process control.

Dosimetry in 1D, 2D and 3D

To eliminate these drawbacks, Fraunhofer IKTS, together with international partners, developed a multidimensionally applicable dosimetry system based on a radiation-sensitive ceramic phosphor in the Eurostars project "READ". Upon excitation with a near-infrared light pulse, the material shows luminescence, the decay time of which is dependent on the dose of electron beam irradiation. Thus, the optical read-out of the luminescence decay time makes it possible to determine the inserted radiation dose in the range of 0.1 to 30 kGy.

As the ceramic phosphor is provided in powder form, various deposition techniques are possible: The µm-sized phosphors can be embedded into other materials, giving access to dose information inside the products, at each spatial position of a particle, along a line (e.g. depth dose profile) or within a cross-sectional area, respectively.

New fields of application

The possible preparation of dosimetrically active polymeric twin products (Figure 1) is particularly interesting. By retaining the radiation penetration properties of the original product, it is possible to conduct dosimetry of bulk dry goods, such as seeds. Another option is the chemical attachment of the phosphor particles to fibers. When these are interwoven to meshes for medical scaffolds, it becomes possible to monitor the sterilization process of the scaffolds. The phosphor powder can also be integrated into polymer matrices to formulate inks and lacquers, which allows the labeling of specific surface areas or coating of entire 3D product surfaces prior to radiation exposure (Figure 2) and thus, 2D or 3D dose maps are obtained thereafter (Figure 3).

The user obtains test product bodies equaling the original product's geometry and properties but equipped with dosimetric functionality. These test products then undergo the radiation exposure during installation qualification, process qualification or for routine process quality assessment. They provide automated in-line read-outs with an unprecedented spatial dose resolution.

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1 Embedded phosphor particles (right) in a polymeric twin almond (left).

2 Optical dose read-out of a phosphor-coated 3D surface.

3 Resulting 3D dose map.

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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«

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

Association of Electrochemical Research Institutes (AGEF)

Association of German Engineers (VDI)

Association for Manufacturing Technology and Development (GFE)

Association of Thermal Spraying (GTS)

Automotive Thuringia

BfR Commission for Risk Research and Risk Perception (RISKOM)

biosaxony

BTS Rail Saxony

Carbon Composites (CCeV)

CiS Forschungsinstitut für Mikrosensorik GmbH

CO_2 Value Europe AiSBL

Competence Center for Nano Evaluation nanoeva®

Competence Network on Optical Technologies (Optonet)

COMPOSITES UNITED

Cool Silicon

DECHEMA – Society for Chemical Engineering and Biotechnology

DeepSea Mining Alliance

Deutsche Glastechnische Gesellschaft (DGG)

Deutsche Keramische Gesellschaft (DKG/German Ceramic Society)

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

DKG/DGM Community Committee

DRESDEN-concept

Dresden Fraunhofer Cluster Nanoanalysis

Dresdner Gesprächskreis der Wirtschaft und der Wissenschaft

ECPE European Cluster for Power Electronics

EIT Health

Energy Saxony

European Powder Metallurgy Association (EPMA)

European Research Association for Sheet Metal Working (EFB)

European Society of Thin Films (EFDS)

Expert Group on Ceramic Injection Molding in the German Ceramic Society

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

Fördergemeinschaft für das Süddeutsche Kunststoff-Zentrum

Fördergesellschaft Erneuerbare Energien (FEE)

Fraunhofer Adaptronics Alliance

Fraunhofer Additive Manufacturing Alliance

Fraunhofer Battery Alliance

Fraunhofer Big Data Alliance

Fraunhofer Energy Alliance

Fraunhofer Group for Materials and Components – MATERIALS

Fraunhofer Lightweight Design Alliance

Fraunhofer Nanotechnology Alliance

Fraunhofer Numerical Simulation of Products and Processes Alliance

Fraunhofer Textile Alliance

Fraunhofer Water Systems Alliance (SysWasser)

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

German Association of University Professors and Lecturers (DHV)

German Biogas Association

German Chemical Society (GDCh)

German Electroplating and Surface Treatment Association (DGO)

German Energy Storage Association (BVES)

German Federation of Industrial Research Associations (AiF)

German Materials Society (DGM)

German Society for Crystallography (DGK)

German Society for Membrane Technology (DGMT)

German Society for Non-Destructive Testing (DGZfP)

German Phosphor Plattform

German Physical Society

German Platform NanoBioMedizin

Gesellschaft für Fertigungstechnik und Entwicklung (GFE)

German Thermoelectric Society (DTG)

HYPOS Hydrogen Power Storage & Solutions East Germany

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

InDeKo Innovationszentrum Deutschland Korea

InfectoGnostics Research Campus Jena

Initiative Erfurter Kreuz

Innovationszentrum Bahntechnik Europa

Institut für Energie- und Umwelttechnik (IUTA)

Institut für Mikroelektronik- und Mechatronik-Systeme gGmbH

International Microelectronics and Packaging Society, IMAPS Deutschland

International Zeolite Association

JenaVersum network

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

Materials Research Network Dresden (MFD)

medways

Meeting of Refractory Experts Freiberg (MORE)

Micro-Nanotechnology Thuringia (MNT)

Nachhaltigkeitsabkommen Thüringen

Organic Electronics Saxony

Ostthüringer Ausbildungsverbund Jena

ProcessNet – an initiative of DECHEMA and VDI-GVC

Research Association for Diesel Emission Control Technologies (FAD)

Research Association of the German Ceramic Society (FDKG)

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

Silicon Saxony

smart³

SmartTex Network

Society for Corrosion Protection (GfKORR)

Thueringer Erneuerbare Energien Netzwerk (ThEEN)

Traegerverein Institut für Holztechnologie Dresden

Treffpunkt Keramik (Ceramics Meeting Point)

TRIDELTA CAMPUS HERMSDORF

VDMA Medical technology

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

Verein für Regional- und Technikgeschichte Hermsdorf

Wachstumskern smood® smart neighborhood

Wind Energy Network Rostock

FRAUNHOFER GROUP FOR MATERIALS AND COMPONENTS – MATERIALS

Materials science and engineering at Fraunhofer covers the entire value chain, from developing new and improving 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. Where materials are concerned, Fraunhofer MATERIALS covers the full spectrum of metals, inorganic non-metals, polymers, and materials made from renewable resources, as well as semiconductor materials. The scientists deploy their expertise in the fields of mobility, healthcare, mechanical engineering/plant construction, building construction/living, microsystems technology, safety and energy, and environment. Digitization of materials along their entire value chain is considered as a key requirement for the lasting success of Industry 4.0. With the initiative Materials Data Space© (MDS) founded in 2015, the Group supports this development. Special attention is also given to the development of customized materials for additive manufacturing, e.g. for multi- material systems. Another key topic is hybrid lightweight construction. Climate change, scarcity of resources and an 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. Lightweight construction as a holistic challenge 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 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.

Objectives of the Group

- Supporting accelerated innovation in the markets
- Promoting the success of Industrie 4.0 through suitable material concepts (digital twins, Materials Data Space©)
- Increasing the success of additive manufacturing with expanded ranges of materials and technologies
- Supporting the energy transition with material efficiency and resource strategies
- Holistic lightweight solutions as a key to sustainability
- Increasing integration density and improving the usability properties of microelectronic devices and microsystems
- Improving the use of raw materials and the quality of the products manufactured from them, and the development of recycling concepts
- Enhancing safety and comfort and reducing resource consumption in the areas of transport, machine and plant construction, building/living
- Increasing the efficiency of systems in the generation, conversion, storage and distribution of energy
- Improving the biocompatibility and function of materials used in medical biotechnical devices, improving material systems for medical diagnosis, disease prevention and therapy
- Improved protection of people, buildings, infrastructure through high-performance materials in protection concepts

Group chairman

Prof. Dr. Peter Gumbsch, Fraunhofer IWM
www.materials.fraunhofer.de

TREFFPUNKT KERAMIK – CERAMIC APPLICATIONS

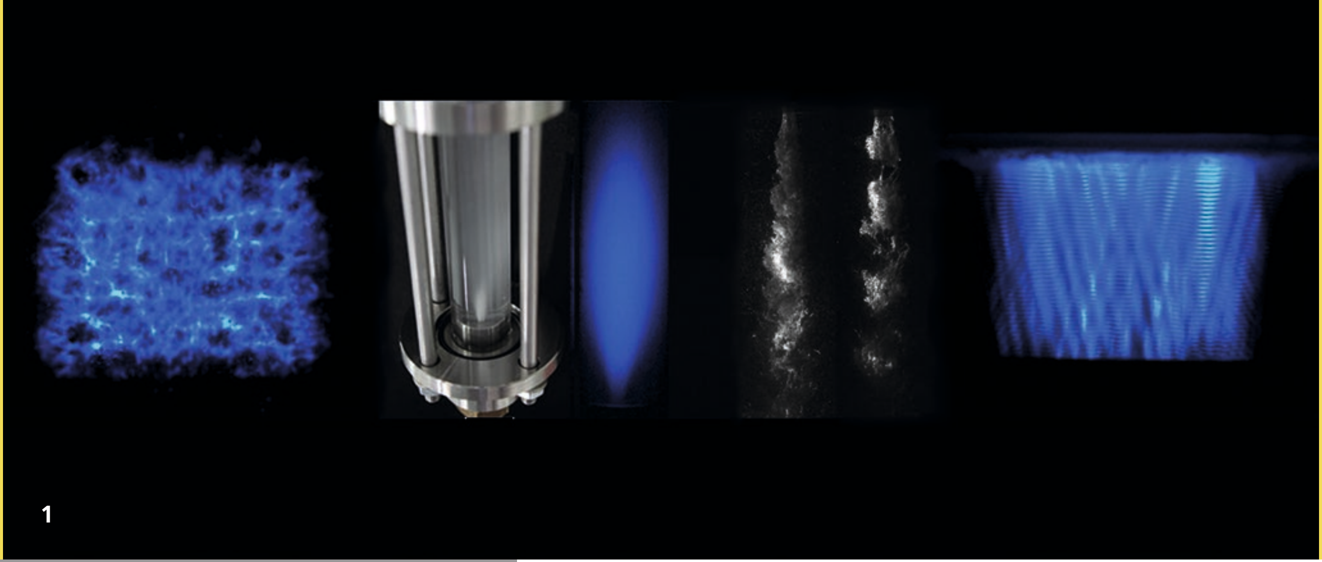
The Ceramics Meeting Point is an integral part of our institute's public relations activities. Due to reconstruction work, the exhibition was moved into the technical centers area. This move makes it possible to include the complete manufacturing chain, from powder to component, in every visitor's tour in a very effective way. In addition to learning about the research infrastructure, visitors can thus also gain insights into the market, with portfolios of more than 50 partner companies presenting real components weighing from a few milligrams to more than 100 kilograms.

Visitors can also observe current focal points of research while getting to know the manufacturers that commercially supply each product. 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.

The cooperation with more than 50 partners and members takes place under the label "Ceramic Application" of the publisher Göller Verlag.

Seminars organized by Fraunhofer IKTS, the German Ceramic Society (DKG), and the German Materials Society (DGM) present the state of technology in the industry and provide participants with the desired hands-on experience. With this approach, Fraunhofer IKTS continues to provide a project forum for small and medium-sized companies, facilitating contacts with project sponsors and research institutions.

1 *Ceramics Meeting Point at Fraunhofer IKTS in Dresden-Gruna.*



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CENTER FOR ENERGY AND ENVIRONMENTAL CHEMISTRY JENA (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

Contact

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

NAMES, DATES, EVENTS

Please find information on patents, publications and scientific engagement of IKTS employees in 2020 on the website
www.ikts.fraunhofer.de/en/dates2020

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 2021

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

Conferences and events

International Sodium Battery Symposium (virtual SBS2)
January 13–14, Virtual conference

NDT4INDUSTRY – A novel in-situ 4-point-bend system for stress impact analysis
February 3, Online seminar

Girls' Day
April 22, Online event

NDT4INDUSTRY – Numerical EFIT simulations for ultrasonic NDE applications
April 28, Online seminar

NDT4INDUSTRY – Series-capable hybrid component structures – new possibilities in manufacturing and quality assurance
May 26, Online seminar

2nd abonocare® conference "Technology developments for sustainable nutrient recycling from organic residues"
July 6, Virtual conference

NDT4INDUSTRY – Optical coherence tomography
September 29, Online seminar

Dresden Battery Days
October 5, Virtual conference

NDT4INDUSTRY – Cryo ultrasonics
November 24, Online seminar

Training seminars and workshops

DGM training seminar: Ceramic materials: properties and industrial applications (in German language)
June 16–17, Online seminar

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

Trade fairs

Hannover Messe
April 12–16, Digital edition

Sensor+Test
May 4–6, Digital edition

Woche der Umwelt
June 11–12, Berlin

ACHEMA Pulse
June 15–16, Digital edition

EAST
June 21–22, Erfurt

RapidTech
June 22–23, Digital edition

Karrierestart
July 2–4, Dresden

FAD Conference
September 15–16, Dresden

IDS
September 22–25, Cologne

Formnext
November 16–19, Dusseldorf

Productronica
November 16–19, Munich

Hagener Symposium
November 25–26, Hagen

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

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 Winterberg-straße 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 approximately 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 S-Bahn one stop to "Dresden-Grenzstraße", and after about 400 m turn right into "Maria-Reiche-Straße"
- Turn right into "Maria-Reiche-Straße" then

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 train

- 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

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Cover

Application and stacking machine for mass production of SOC components.