Fraunhofer IKTS

FRAUNHOFER INSTITUTE FOR CERAMIC TECHNOLOGIES AND SYSTEMS IKTS

ANNUAL REPORT 2019 2020

ANNUAL REPORT 2019/2020

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Management System
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Dear friends and partners of IKTS,

Ceramics remains an exciting field with very dynamic growth. Fittingly, IKTS continued to grow in 2019 and now has a total budget of 64 million euros. It is particularly satisfying that we were able to increase our total rate of return relative to the operating budget by 5 % compared with the already successful previous year, to now more than 84 %. Approximately half of the income stems from industry, while the other half comes from public funds. This is the way it should be according to the Fraunhofer model. We have confirmed once again that we truly accomplish our mission – to transfer research to the industrial sector. This result has allowed us to undertake investments of nearly 5 million euros across all our departments focused on structural and functional ceramics.

We will continue to implement further development projects in the present year. At our site in Hermsdorf, we plan to open our new building at Technical Center 1 in 2020. The Free State of Thuringia and the Fraunhofer-Gesellschaft have contributed 5 million euros to this effort. The development serves to further our production capabilities for ceramic components, with a strong focus on electrolytes for $Na/NiCl_2$-batteries. Furthermore, we plan to build a technical center for the digitized production of lithium-ion batteries in Arnstadt, which is to cooperate closely with local industry and become an incubator for establishing a battery-focused supplier industry. We thank the Free State of Thuringia – specifically the Thuringian Ministry for the Economic Affairs, Sciences and Digital Society – for its significant financial support. This project adds to our established, long-standing activities on the subject of lithium-ion batteries across all sites. At our project center in Braunschweig (ZESS), operated in cooperation with the Fraunhofer Institutes IFAM and IST, we continue to focus on solid-state batteries. Everything from the electrochemical basics to the production technologies is developed further in Dresden, with Pleissa the site of our pilot line, which we operate in cooperation with thyssenkrupp. The development of special sensor systems and non-destructive testing equipment as well as quality assurance for production technology still takes place at our Dresden-Klotzsche site and obviously goes far beyond battery applications. We are particularly happy that we have been entrusted with coordinating a recently incorporated competence cluster on the subject of green batteries and recycling under the "Forschungsfabrik Batterie" umbrella concept of the German Federal Ministry of Education and Research (BMBF). With strong support from the Free State of Saxony, we will be building a test plant for battery recycling on what up to now has been the Fraunhofer Technical Center for Semiconductor Materials (THM). We will be working closely with our colleagues from the TU Bergakademie Freiberg for this purpose. We thank the Free State of Saxony – in particular the State Ministry of the Sciences, Culture and Tourism (SMWK) – for its support. We will also build on the topics of hydrogen and fuel cells, as

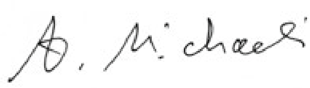
well as electrolytic systems. For these topics, larger projects are underway within the Fraunhofer-Gesellschaft, in which we will be taking part; they are currently being coordinated with the federal and regional governments. More details on that are to follow next year. All this shows that our activities in energy and environmental technology are evolving fast and are increasingly prescient for the current discourse on climate change and environmental protection. We are able and determined to contribute significantly to this debate, in line with our motto, “Fraunhofer for Future”.

I also would like to mention our institute’s new site in Forchheim, Upper Franconia. Headed by Prof. Dr. Silke Christiansen, it houses a new department, working on “Materials diagnostics and materials data”. We will create wholly new opportunities in the field of microscopy and analytics and strengthen our efforts in the area of digitization.

However, beside all these future topics, we will not lose sight of our core business and our other business divisions. On the contrary: We will invest heavily in developing our structural ceramics manufacturing capabilities, from shaping (not just additive manufacturing) and furnace technology to the final processing steps. Functional ceramics is a field that is undergoing very propitious changes, most prominently with regard to our pastes for sensor systems and electronics, and our tape casting technology. These too are areas in which we have made significant investments in order to be prepared for growing demand.

You can find more highlights and development trends from our business divisions in our report. I hope you will enjoy leafing through this edition. As always, you are welcome to take advantage of our outstanding equipment and our formidable IKTS team. We are looking forward to collaborating with you.

Yours,



Alexander Michaelis

April 2020

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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. Superbly equipped laboratories and technical facilities covering 30,000 m^2 of useable space have been set up for this purpose at the sites in Dresden and Hermsdorf. Based on comprehensive materials expertise in advanced ceramic materials, the institute's development work covers the entire value creation chain, all the way to prototype production. Fraunhofer IKTS forms a triad of materials, technology and systems expertise, which is enhanced by the highest level of extensive materials diagnostics for materials beyond ceramics. Chemists, physicists, materials scientists and engineers work together on an interdisciplinary basis at IKTS. All tasks are supported by highly skilled technicians.

The focus is placed on manufacturers and especially existing and potential users of ceramics as project partners and customers. Fraunhofer IKTS operates in nine market-oriented divisions in order to demonstrate and qualify ceramic technologies and components as well as non-destructive test methods for new industries, product ideas and markets outside the traditional areas of use.

The focus is on the challenges facing society as a whole in the area of new forms of mobility, sustainable concepts for energy and water technologies as well as efficient digital production for which Fraunhofer IKTS integrates tried-and-tested and new materials, technology and systems concepts. They are used in the business divisions Mechanical and Automotive Engineering, Electronics and Microsystems, Energy, Water, Environmental and Process Engineering, Bio- and Medical Technology as well as Non-Destructive Testing and Monitoring. In the cross-sectional divisions of Materials and Processes as well as Material and Process Analysis, established and new technologies are continuously being further developed as "enabling technologies" for all other fields.

Among our unique areas of expertise, we offer:

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

For any class of ceramic materials, Fraunhofer IKTS has access to all the standard processes of raw materials preparation, forming, heat treatment and finish processing. Where it makes sense, the institute can even conduct phase synthesis. In functional ceramics, IKTS holds a particular core competency in paste and tape technology. Multiple clean rooms and low-contamination production areas are kept at the ready, among other things, for multilayer ceramics and highly purified oxide ceramics lines of technology.

Multi-scale development

Fraunhofer IKTS can convert developments from the lab into the technical standard. There is industrially suited equipment and machinery of the latest designs available for all relevant lines of technology, in order for partners and customers to realize the prototypes and pilot-production series needed for market launch, to develop production processes, and to implement quality processes. Thus, residual cost risks and time to market can be minimized.

Competent analysis and quality assessment

High-performance analysis and quality control are a decisive factor for market acceptance of products, especially in ceramic production processes. The fundamental understanding of materials and ceramic manufacturing processes in conjunction with the design and integration of complex testing systems enables unique solutions to be found for key material issues in product development, manufacturing and quality assurance.

Synergies between materials, technologies and applications

The targeted combination of different technology platforms, of functional and structural ceramics for example, allows for multi-functional components and systems that intelligently exploit various ceramic properties. Innovative products with significant added value and lower costs can be directly tested, validated and optimized in several application centers.

Network creator

In ongoing projects Fraunhofer IKTS is currently associated with over 450 national and international partners. In addition, IKTS is active in numerous regional, national and international alliances and networks. Thus, the institute is well networked with the Fraunhofer Group for Materials and Components – MATERIALS – as well as with another 11 alliances within the Fraunhofer-Gesellschaft. By building up and actively working within various networks, Fraunhofer IKTS is able to identify and impart complementary competences at an early stage and integrate them for successful product development. In this way, solutions can be found in the interests of our partners far beyond the traditional materials development.

Cross-locational management for sustainable quality assurance

Quality, traceability, transparency and sustainability: to Fraunhofer IKTS, these are the most important tools to provide partners and customers with valid, reproducible and resource-saving research results. The IKTS therefore administers a standardized management system per DIN EN ISO 9001 as well as an environmental management system in accordance with DIN EN ISO 14001. Furthermore, each site of the institute is certified according to additional guidelines, including the German Medical Devices Act, and is regularly subjected to a variety of industrial audits.

CORE COMPETENCIES OF FRAUNHOFER IKTS

MATERIALS AND SEMI-FINISHED PARTS

STRUCTURAL CERAMICS

Oxide ceramics

Non-oxide ceramics

Hardmetals and cermets

Powders and suspensions

Polymer ceramics

Fiber composites

Composite materials

Ceramic foam

FUNCTIONAL CERAMICS

Non-conducting materials

Dielectrics

Semiconductors

Ion conductors

Magnets

Pastes and tapes

Solders, brazes and glass sealings

Precursor-based inks and nanoinks

Composites

ENVIRONMENTAL AND PROCESS ENGINEERING

Substrates
- Granules
- Plates
- Tubes
- Capillaries
- Hollow fibers
- Honeycombs
- Foams

Membranes and filters
- Oxides, Non-oxides
- Zeolites, carbon
- MOF, ZIF, composites
- Ion and mixed conductors

Catalysts
- Oxides
- Metals, CNT

RAW MATERIAL AND PROCESS ANALYSIS, MATERIALS DIAGNOSTICS, NON-DESTRUCTIVE EVALUATION

Analysis and evaluation of raw materials
- Analysis of particles, suspensions and granules
- Chemical analysis

In-line process characterization
- Ceramic-suitable data acquisition and instrumentation
- Process simulation and design
- Quality management

Characterized materials
- Steel, non-ferrous metals
- Ceramics, concrete
- Materials of semiconductor industry
- Plastics, composite materials (GFRP und CFRP)
- Biomaterials and tissues

Process design, process monitoring

TECHNOLOGY

Powder technology

Shaping

Heat treatment and sintering

Final machining

Precursor technology

Fiber technology

Additive manufacturing

Pilot production and upscaling

Coating technology

Joining technology

Thick-film technology

Multilayer
- HTCC, LTCC

Aerosol- and Inkjet-Printing

Thin-film technology

Electrochemical machining

Galvanics

Materials separation
- Filtration, pervaporation
- Vapor permeation
- Gas separation
- Membrane extraction
- Membrane distillation
- Electromembrane processes

Catalysis

Biomass technology
- Preparation
- Conversion

Photocatalysis

Chemical process engineering

COMPONENTS AND SYSTEMS

Component design

Prototype production

Wear-resistant components

Tools

Optical components

Heating systems

Medical device technology and implants

Filters

System definition and plant development

Modeling and simulation

Design and prototype production

Validation/CE marking

Test stand construction

Support in field tests

Samples and prototypes
- Membranes, filters
- Membrane modules
- Membrane plants

Filtration tests
- Laboratory, pilot, field
- Piloting

Modellierung und Simulation
- Materials transport
- Heat transport
- Reaction

Reactor development

Plant design

Materials and component characterization
- Microstructure and phases
- Mechanical and physical properties
- High-temperature properties
- Corrosion

Component and systems performance
- Damage analysis
- Failure mechanisms
- Measurement and simulation of component behavior
- Testing in accordance with certified and non-certified standards

Technologies
- Non-destructive and destructive test methods
- Micro- and nanoanalytics
- Ultrasound testing
- High-frequency eddy current
- Optical methods
- X-ray methods
- Acoustic diagnosis

Components, systems and services
- Sensors and sensor networks
- Testing heads and systems
- Structural health monitoring
- Data analysis and simulation
- Biomedical sensor systems
- Testing in accordance with certified and non-certified standards

Component performance, reliability analysis, lifetime and quality management, calibration

ORGANIZATIONAL CHART

Institute Director	Prof. Dr. habil. Alexander Michaelis
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

Materials

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

* certified according to DIN EN ISO 13485

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
- Zeolithe Membranes and Nano-Composites
- Carbon-Based 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

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

Sites of Fraunhofer IKTS
Headquarter Dresden-Gruna, Saxony
Site Dresden-Klotzsche, Saxony
Site Hermsdorf, Thuringia
Office Berlin
Project group BTU Cottbus-Senftenberg, Brandenburg
Site Forchheim, Bavaria

Application Center
Battery Technology, Pleißa, Saxony
Bioenergy, Pöhl, Saxony
Bio-Nanotechnology Application Lab BNAL, Leipzig, 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

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

- Chemical and Structural Analysis
- Hardmetals and Cermets
- NDT Test Lab*

Correlative Microscopy and Materials Data

Prof. Dr. Silke Christiansen

* accredited according to DIN EN ISO/IEC 17025

Energy Systems / Bio- and Medical Engineering

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

Bio- and Nanotechnology

Dr. Jörg Opitz

- Biological Materials Analysis
- Characterization Technologies
- Biodegradation and Nanofunctionalization

Energy Storage Systems and Electrochemistry

Dr. Mareike Wolter

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

Electronics and Microsystems Engineering

Smart Materials and Systems

Dr. Holger Neubert

- Multifunctional Materials and Components
- Applied Material Mechanics and Solid-State Transducers
- Systems for Condition Monitoring

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

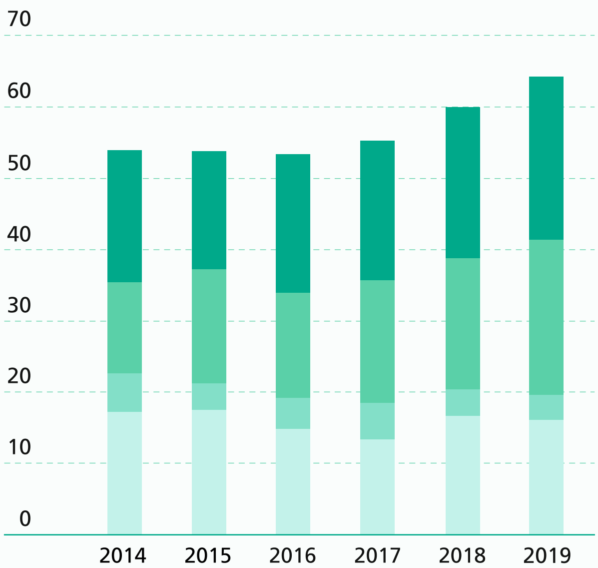
Microelectronic Materials and Nanoanalysis

Prof. Dr. habil. Ehrenfried Zschech

- Nanoscale Materials and Analysis
- Nanomechanics and Reliability for Microelectronics

FRAUNHOFER IKTS IN FIGURES

Revenue (in million euros) of Fraunhofer IKTS for the budget years 2014–2019

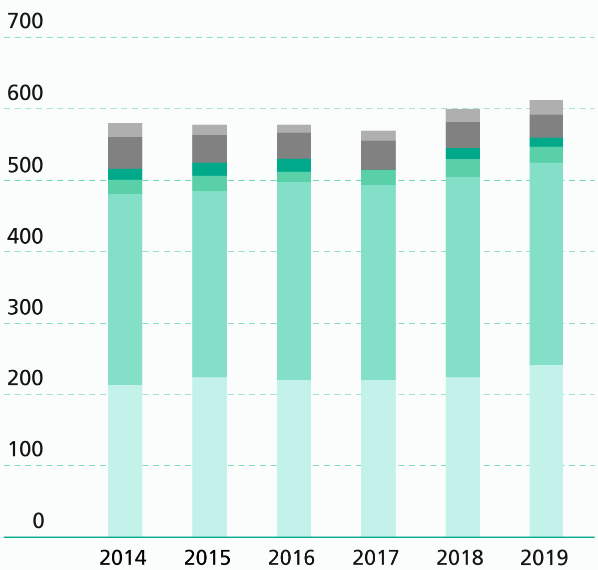


	2014	2015	2016	2017	2018	2019
Industrial revenue	18.6	16.3	19.6	19.6	21.2	22.9
Public-sector revenue	12.9	16.4	14.8	17.3	18.4	21.8
EU and other revenue	5.5	3.6	4.4	5.1	3.8	3.5
Institutional support	17.2	17.8	14.8	13.5	16.6	16.1
=	54.2	54.1	53.6	55.5	60.0	64.3

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

Personnel developments at Fraunhofer IKTS

Number of employees 2014–2019, full-time equivalents, personnel structure on December 31 of each year



	2014	2015	2016	2017	2018	2019
Apprentices	19	15	11	14	18	20
Student workers, trainees, undergraduate students	44	38	36	40	36	32
Part-time and contract workers	16	18	19	1	16	13
PhD candidates	20	21	15	21	25	22
Employees with university degrees and technicians	267	260	276	273	280	284
Scientists	214	223	220	220	224	241
=	580	575	577	569	599	612

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


1

Budget and income

With 64.3 million euros, the total budget exceeds the previous year's level by 4.2 million euros. Of that budget, 6.1 million euros was invested in equipment. All in all, 48.2 million euros of external income was obtained, of which 22.9 million came directly from the industry. With 3.7 million euros volume, the Saxon and Thuringia economy was particularly committed.

Industrial projects to the value of 6.4 million euros were commissioned from abroad. The main part of this in 2019 came from China, Austria and the US, which together make up half of the income from outside Germany. Currently, only 2 % of the income must be considered to be affected by Brexit. A positive development is that the funding of projects by the States has increased in Thuringia (0.8 million euros) as well as in Saxony (3.6 million euros). All in all, the various States support projects with a volume of 5.2 million euros. The share of the EU project volume was 1.6 million euros, somewhat below expectations. Acquisition efforts in this area will be stepped up in 2020. New constellations will arise in particular thanks to integrating the Forchheim site. Required administrative restructuring increases the pertaining organizational effort. The disparate costing approaches applied by the various funding bodies remain a challenge. These disparities lead to insecurity when determining billable costs and financial planning. Decentralizing administrative tasks combined with the Fraunhofer-wide introduction of the SAP ERP system will be very challenging in 2020. Thankfully, 2019 was spent preparing for these challenges.

Buildings and infrastructure were developed and expanded across all sites, with various construction projects supported extensively by the Free States of Saxony and Thuringia as well as the State of Lower Saxony.

Human resources development

A total of 754 staff members work at the three sites. The institute's family-friendly structure allows many young women and men to work part-time if they wish. For increased comparability, the different groups are represented as full-time equivalents in the illustration. The number of scientists has increased by 18 positions and is now at 241. 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.

We are happy to report that the number of apprentices has increased by another two positions and now stands at 20. For the first time, Fraunhofer IKTS also provides professional training for IT specialists. Planning the development of our staff is one major area of human resources work. Systematically developing our colleagues and creating the required plans and approaches to further education are a main objective for the institute's directors. We strive to consistently support personal career goals. Fraunhofer IKTS as an employer remains well positioned in the marketplace.

Expanding the infrastructure

Based on the significant growth in nearly all areas, more than one million euros has been invested so far into expanding at both sites in Dresden. In addition to extensive conversions to improve fire safety, the lab area was also expanded. At the Dresden-Klotzche site alone, the added surface amounts to 330 square meters. Another 220 square meters was leased to house the "Technical electrolysis and geothermic" workgroup.

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

Combining different additive manufacturing processes in Dresden will lead to a unique demonstration laboratory with various technologies. This will give manufacturers and users the option to have oxide and non-oxide ceramic prototypes made and tested with application-oriented methods. New process technology is due to be presented in autumn 2020.

The construction of the pilot center for powder synthesis and extrusion has started at the Hermsdorf site. It will be completed in the second half of 2020. The plants and machines in the pilot center will be equipped such that the digital production of ceramic components becomes possible. Among other things, machines for shaping will be equipped with the latest sensor technology, providing unprecedented insight into process details. Also, methods are being developed to combine various sensor data in real time to provide continuous quality monitoring and process control. The building provides tailored technical solutions for separating different materials, for gas and dust extraction as well as waste water treatment. Two cutting-edge labs, six technical centers as well as office spaces and storage areas will be housed on 583 square meters surface.

BOARD OF TRUSTEES

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

THE FRAUNHOFER-GESELLSCHAFT

Research for practical applications, that is the central task for the Fraunhofer-Gesellschaft. The research organization was founded in 1949 and conducts application-oriented research for the benefit of industry and the general public. Our contractual partners and clients are industrial and service companies as well as the public sector.

The Fraunhofer-Gesellschaft currently operates 72 institutes and research units. More than 26,600 employees, most of them qualified natural scientists and engineers, work with an annual research budget of 2.6 billion euros, of which 2.2 billion euros is generated from contract research.

Fraunhofer locations in Germany

The Fraunhofer-Gesellschaft derives approx. 70 % of the contract research revenue from contracts with industry and publicly funded research projects. Around 30 % is provided by the German federal and state governments as core funding, enabling the institutes to develop solutions for issues which will only become relevant to the industry and the public five or ten years later.

International cooperative projects with outstanding research partners and innovative companies around the world make for direct access to the most important scientific fields and economic areas of today and tomorrow. Thanks to its clear focus on applied research and key technologies that are relevant to the future, the Fraunhofer-Gesellschaft plays a central role in the process of innovation within Germany and Europe. The impact of applied research goes far beyond any direct benefit for clients, since the Fraunhofer Institutes research and development efforts contribute to making Germany's regions, the country itself, as well as Europe, more competitive. They promote innovation, strengthen technological capabilities and improve the acceptance of modern technology, in addition to educating and training the next generation of much-needed researchers and scientists. The Fraunhofer-Gesellschaft provides its staff with the chance for professional and personal development and the capability to reach high-ranking positions in their institutes, as well as in universities, companies and the society. Thanks to their practice-oriented education and the experience gained at Fraunhofer Institutes, our students find excellent entry positions and opportunities for development with corporate employers.

The Fraunhofer-Gesellschaft is recognized as a charitable institution. It was named after the scholar Joseph von Fraunhofer (1787–1826) from Munich. Fraunhofer found success in his life as a researcher, inventor and entrepreneur.

RETROSPECTIVE

Fraunhofer IKTS presented its work at 45 trade fairs in Germany and abroad this year, organized several science conferences and was present at many public events. The international network has also grown, while IKTS researchers received prestigious awards.

January 16 | February 20 | May 15, 2019 2

Promoting young researchers at IKTS

Eleven young researchers from the Fröbel Kindergarten center in Dresden's Darwinstrasse visited the IKTS site in Dresden-Klotzsche. The kids learned interesting facts about condition monitoring and heard about some of the ongoing projects. As part of the "Juniordoktor" program, interested third- and fifth-graders conducted experiments as part of workshops. After examining various metals for invisible defects using eddy currents, all participants were able to answer the "Juniordoktor" question. The juniors received their doctoral caps in a festive ceremony on September 14 at TU Dresden. Susanne Hillmann enthralled the young scientists with her presentation about researching at Fraunhofer.

February 12, 2019 1

MoU signed for joint venture for energy storage in India

As part of a delegation trip to India organized by the Ministry for Economic Affairs, Science and Digital Society of the Free State of Thuringia, Prof. Alexander Michaelis signed a memorandum of understanding with the Indian technology companies h2e Power Systems, Ltd. and R Cube Energy Storage System, Ltd. The aim of the MoU is to industrialize the current development activities in the field of hybrid energy systems based on ceramic high-temperature batteries and solid-oxide fuel cells and to find suitable production sites in Thuringia and India.

March 12–14, 2019

Energy Storage Europe | Ceramic battery

"Ceramic batteries – powering grid, industry and home" – was the motto under which IKTS organized a joint appearance and symposium with its corporate partners Alumina Systems GmbH, König Metall Group, NGK Insulators, Ltd. and R Cube Energy Storage System, Ltd. Visitors learned about the versatility of sodium-based ceramic batteries as stationary energy storage solutions.


1

2

March 12–14, 2019

JEC World | CFRP testing and CMC

At its booth at the leading international show for composite materials, IKTS presented EddyCus® MPECS mini, a system for non-destructive real-time testing, from individual fibers to complete CFRP assemblies. As another highlight, IKTS showed a new class of materials: fiber-reinforced ceramics are characterized by their high damage tolerance and quasi-ductility, suitable in particular for use in extreme temperature ranges under strong abrasive load, e.g. as heat shields for spacecraft.

March 14–21, 2019 1

Special Olympics World Games in Abu Dhabi

Conrad Kluge, IKTS employee and competitive cyclist, won silver and bronze medals in the 5 kilometer time trial and road races with outstanding performances. The goal of the Special Olympics is to help mentally handicapped people gain respect, self-confidence and a more prominent role in society through the medium of sport. Germany will be hosting the global inclusive sports event in 2023.

March 21, 2019

New Fraunhofer Portugal Center for Smart Agriculture and Water Management AWAM

Agriculture 4.0 is the motto which the new AWAM Center in Portugal focuses. Researchers at the Vila Real and Évora sites will develop new approaches to agricultural networks and water treatment. The construction of the new center is supported by the universities of Évora and Trás-os-Montes e Alto Douro (UTAD), with IKTS acting as a partner. The opening ceremony and festive presentation of the new center was attended by guests from industry and science, as well as the Portuguese Minister for Science, Prof. Manual Heitor.

March 28, 2019

Girls' Day

For almost 20 years, thousands of companies and institutions have invited female students on Girls' Day to provide them with insight into careers in technology and natural sciences. At the Hermsdorf site, the students from the region familiarized themselves with the work of material researchers and lab technicians. Microscopy work and experiments in the field of oxide ceramics were perfect opportunities to gain hands-on experience with the research conducted at IKTS.

April 6, 2019

Open Day at Fraunhofer IKTS Hermsdorf

"Experience research in high-performance ceramics!" said the invitation to Open Day in Hermsdorf. Hundreds of inquisitive minds heeded the call and familiarized themselves with the work of Fraunhofer researchers in talks and on guided tours through the labs and technical centers. Highly motivated, the staff organized the day, answered questions and explained to the visitors the versatile uses of ceramics, a "hidden champion".

April 8, 2019 2

Thuringia Research Award

For developing an affordable and environmentally friendly battery, IKTS researchers Prof. Michael Stelter, Dr. Roland Weidl, Dr. Matthias Schulz, Heidi Dohndorf, Lutz Kiesel, Martin Hofacker and Benjamin Schüssler received the Research Award of the Free State of Thuringia in the "Applied research" category. At the awards ceremony in the Imaginata science center in Jena, Thuringia's Minister of Economy, Wolfgang Tiefensee, praised the team's work. The complex development work, from preparing the powders for the solid-state electrolyte to integration in a battery module, is currently provided to the industry in a transfer project. The jurors of the Thuringia Research Award were swayed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by the battery's importance for the switch to renewable energies in Germany and its symbolic power beyond the Thuringian region.

April 15, 2019 3

Start of construction of new pilot center for powder synthesis and extrusion

Ceramic batteries and membranes for filtration and gas separation – these are the research topics on which the future "Pilot center for powder synthesis and extrusion" will be focusing. The pilot center, which will be supported by funds of the Free State of Thuringia as well as federal funds, has been tailored to the requirements of complex research topics and constitutes an important link for the future technology transfer. The groundbreaking ceremony was attended by Thuringia's Prime Minister, Bodo Ramelow, and the state's Minister of Economy, Wolfgang Tiefensee, as well as local policy makers and representatives of the Fraunhofer-Gesellschaft. The new wing will go into operation by autumn 2020.

April 16, 2019 4

autartec® | FreiLichtHaus near the F60 overburden conveyor bridge completed

For five years, a cross-disciplinary team from 15 companies, universities and non-university research institutions out of southern Brandenburg, Saxony and eastern Thuringia worked on constructing a floating, self-sufficient building, which was now officially inaugurated. The autartec® house on the Bergheide lake in Lichterfeld-Schaksdorf can produce electricity, heat and drinking water, all on its own. A waste water treatment system that works without chemical or biological agents was tested by IKTS and is an integral part of the project, which was funded by the German Federal Ministry of Education and Research (BMBF).

May 7, 2019

Prof. Alexander Michaelis voted new DKG president

The general meeting of the German Ceramic Society (DKG) in Leoben (Austria) unanimously voted Prof. Alexander Michaelis president for an initial term of two years. Michaelis succeeds Joachim Heym of Schunk Ingenieurkeramik GmbH, who had exercised the function for four very successful years. For 100 years the DKG has been Europe's biggest ceramic society by members, in addition to being one of the oldest existing professional associations worldwide.

May 24, 2019 5

Science speed dating in the tram

Because of strong demand, Science Tram by DRESDENconcept (DDc) was underway once again – immediately following the global Fridays for Future demonstration in Dresden. On this special trip, four DDc researchers answered questions from students and Dresden residents on current research projects regarding climate change, the switch to renewable energies, and sustainability. Prof. Michael Stelter, deputy director of IKTS, presented new approaches in the areas of energy, water and waste water treatment, among other topics (e.g. how we use our raw material resources, and the issue of microplastics).

May 27, 2019

MICRO-FATE starts expedition in the Pacific Ocean

An international team of scientists from the MICRO-FATE project aims to find out where exactly in the ocean microplastics accumulate, how they affect the environment and how they can be eliminated. For this purpose, the SONNE research vessel embarked on a five-week expedition through the Pacific Ocean. The aim is to take and conserve samples for lab testing later on and to conduct some initial testing. IKTS was on board, examining the changing properties of plastic particles caused by weathering and fragmentation.

June 14, 2019 1

Dresden Science Night

The 17th Dresden Science Night took place under the motto "Science instead of pillow fight". With a total of 39,000 visitors, Dresden as a research location presented itself extremely varied and diverse with 699 events at 66 venues. At 16 stations in the Fraunhofer IKTS, about 2000 young and adult guests were able to experiment and find out about our projects. Starting with the production of a functioning battery from fruit and vegetables or personalized biocompatible bones from the 3D printer, an adventurous temperature trail and even an electric magic pen – there was a lot to discover.

June 25–29, 2019

GIFA | Ceramic foundry solutions

The foundry industry plays a key role in the development and manufacture of components for automotive construction and machine engineering, as well as many other industrial branches. The protective plates, filters and crucibles made from ceramic high-performance materials presented at GIFA are able to meet the ever more challenging requirements for the manufacture of cast parts regarding quality, pricing, reliability and diversity of shape.

June 26, 2019

German-Korean Technology Center opened

In the presence of the mayors of Dresden, Dirk Hilbert, and the South Korean city of Changwon, Huh Sung-moo, as well as the president of the Korea Institute of Material Science (KIMS), Dr. Junh Hwan Leer, a German-Korean Technology Center (DKTZ) was opened in Dresden. The DKTZ, with the participation of the IKTS, the Institute for Lightweight SEngineering and Polymes Technology of the TU Dresden and KIMS, is intended to facilitate the settlement of Korean companies in Dresden and to realize cross-border, accelerated developments.

July 5, 2019 2

ECerS | Dr. Mathias Herrmann receiving multiple honors

At the 16th Conference of the European Ceramic Society (ECerS) in Turin, Dr. Mathias Herrmann was honored on two occasions, receiving the JECS Trust Award for his scientific publications in addition to being named ECerS Fellow. The prize has been awarded every two years since 2013 to researchers for outstanding services in the field of ceramic research and teaching. The nomination as Fellow is for special commitment and achievements in ceramic science and technology.

September 14, 2019 3

Charity boat race | Rowing against cancer

For the third year running, IKTS employees teamed up with staff from the Dresden Red Cross blood donor service to row on the river Elbe for charity. The money raised goes to the Living with Cancer Foundation and will be used to support regional services supporting cancer therapy.

September 17, 2019 4

Media talk | Fraunhofer Early Morning Science – Women's power for Fraunhofer

For 70 years, Fraunhofer's motto has been "Research for the future". In the anniversary year 2019, four female Fraunhofer researchers reported, for the 6th time, on current application-oriented projects. High-performance heat shields for fuel-efficient engines in aerospace, infinite OLED light strips or the monitoring of foundation structures, and a 3D-printed turbine: The breadth of current research highlights inspired viewers of the live stream, as well as the journalists who had come to the event. The event series is set to continue in 2020.

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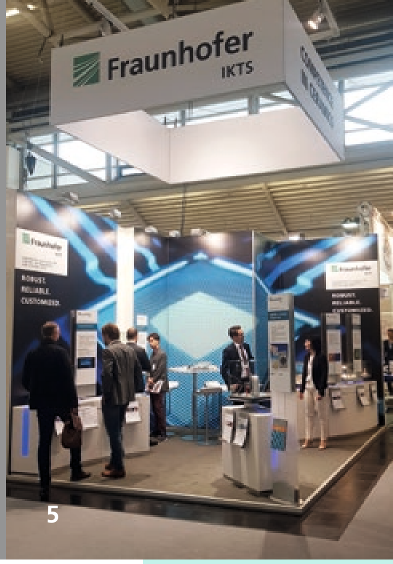

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September 23–25, 2019

Dresden Battery Days | Batteries for the future

Stationary energy storage systems are considered a key element of a modern and sustainable energy supply. At the 3rd Dresden Battery Days, almost 90 international experts discussed the current research and development trends for solid-state batteries, issues relating to production and their future prospects. In addition, manufacturers presented their latest developments in batteries and systems at an industrial exhibition. 2020 the experts will meet in Graz.

October 9–11, 2019

ISPA | International Symposium on Piezocomposite Applications

Piezoceramics combined with electronic, functional and structural materials are increasingly used in medical technology, mechanical and automotive engineering. 50 engineers, designers and experts from eight nations discussed current research results and market requirements for the optimal technology transfer of piezoceramic innovations. This year's symposium was opened with a thematic workshop by Meggitt A/S on the subject of "Piezoelectric materials and applications". The next ISPA will take place in 2021.

November 12–15, 2019 5

Productronica | Conductor lines with ultra-fine pattern definition

Miniaturization is the main development driver in electronics. For the first time, a new generation of thick-film pastes was presented at the trade fair. These pastes can be structured through photo-lithography via an extended screen printing route. This makes it possible to generate very fine structures of 20 micrometers or even finer, which are required for the next mobile network standard 5G.

November 13, 2019

First Fraunhofer Career Night Dresden

About 40 students took the chance to explore the Fraunhofer Institutes IKTS and IPMS at the 1st Fraunhofer Career Night Dresden. At the Campus Dresden-North the guests got to know different research areas and made first contacts with Fraunhofer researchers in many conversations. Besides a lecture program, there were guided tours through both institutes and as a highlight an escape game.

November 13, 2019

Franz Müller is Thuringia's best physics lab technician

The chamber of industry and commerce of eastern Thuringia declared Franz Müller to be one of 2019's best trainees. The physics lab technician started his apprenticeship at Fraunhofer IKTS in 2016 and was able to complete it with much success and ahead of schedule in 2019. He now works at IKTS as a technical assistant in the field of carbon membranes.

January 1, 2020

Prof. Alexander Michaelis appointed as member of the Energy Research Advisory Board

Prof. Alexander Michaelis, Institute Director of Fraunhofer IKTS, was appointed as member of the Energy Research Advisory Board Germany. The board advises the German Federal Ministry of Education and Research (BMBF) on questions of strategic research planning for electrochemical energy storage systems. More than 30 high-ranking representatives from industrial companies and research institutions are involved in the board.

HIGHLIGHTS FROM OUR BUSINESS DIVISIONS

ANNUAL REPORT 2019/20

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 24–28

The "Materials and Processes" business division provides a central point of contact for all matters related to development, manufacturing, and qualification of high-performance ceramics for a wide range of applications. A wealth of experience has been accumulated in all relevant materials and technologies, for which requirement-related functional solutions are developed. The scope of activities encompasses the entire process chain, making this division crucial to all other business divisions.

Mechanical and Automotive Engineering

page 29–31

High-performance ceramics are key components in mechanical and automotive engineering. Due to their outstanding properties, they are often the only available options. The "Mechanical and Automotive Engineering" business division offers high-performance ceramic, hardmetal, and cermet wear parts and tools as well as parts for specific loading conditions. A new core area comprising test systems for monitoring components and production facilities based on optical, elastodynamic, and magnetic effects has also been established.

Electronics and Microsystems

page 32–34

The "Electronics and Microsystems" business division offers manufacturers and users unique access to materials, technologies, and know-how to help them develop robust, high-performance electronic components. Focus is on sensors and sensor systems as well as power electronic components and "smart" multifunctional systems. With the help of innovative test methods and systems, Fraunhofer IKTS provides support along the entire value-added chain – from materials to integration of complex electronic systems.

Energy

page 35–42

Ceramic materials and technologies form the basis for improved and fundamentally new applications in energy technology. To that end, Fraunhofer IKTS develops, builds, and tests innovative components, modules, and complete systems, focusing mainly on ceramic solid-state ionic conductors. Applications range from electrochemical energy storage systems and fuel cells, solar cells, energy harvesting modules, and thermal energy systems to solutions for biofuels and chemical fuels.

Environmental and Process Engineering

page 43–46

Fraunhofer IKTS develops innovative materials, technologies, and systems for safe, efficient, environmentally, and climate-friendly conversion of energy and substances. Focus is on processes involving conventional and biological energy sources as well as strategies and processes for water and air purification and treatment, and for recovery of valuable raw materials from waste. New reactor designs for the chemical industry are made possible by ceramic membranes and catalysts.

Bio- and Medical Technology

page 47–50

Fraunhofer IKTS makes use of the outstanding properties of ceramic materials to develop dental and endoprosthetic implants and surgical instruments. In well-equipped, certified laboratories, the interactions between biological and synthetic materials are investigated and applied towards the development of improved materials, analytics, and diagnostics. In part unique optical, acoustic, and bioelectrical techniques are available for this purpose.

Water

page 51–55

The efficient use and purification of water is ecologically and economically of the highest priority. IKTS offers solutions for the chemistry- and biology-free treatment of waste waters – from multifunctional components to compact complete systems. Process combinations from filtration, adsorption or sono-electrochemical oxidation are far superior in contrast to established approaches. Furthermore, specific sensor systems are integrated in order to increase process efficiency and to reduce production costs.

Materials and Process Analysis

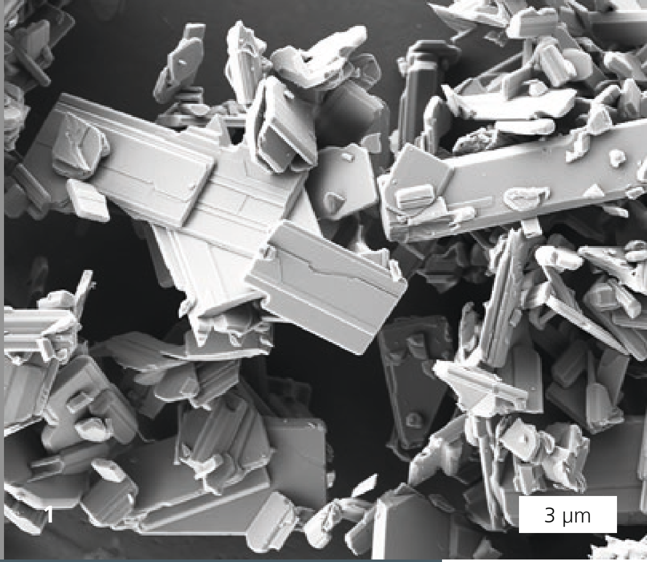
page 56–59

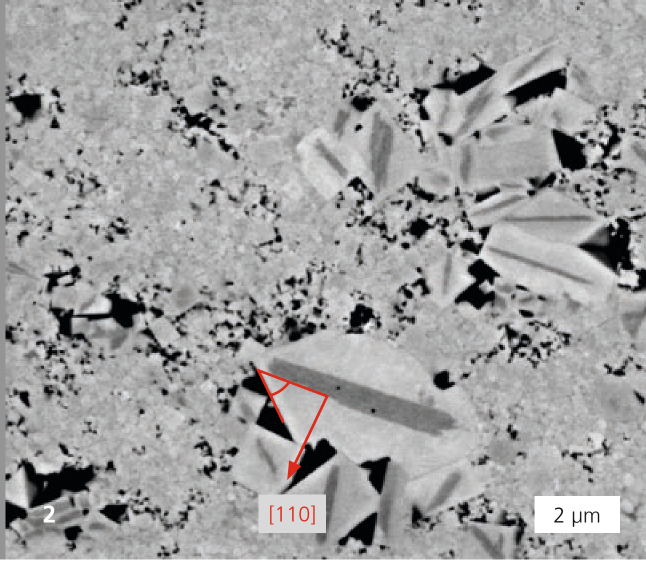
Fraunhofer IKTS offers a wide range of test, characterization, and analysis methods for materials properties and production processes. As a reliable, multiply accredited, and audited service provider, Fraunhofer IKTS assists in the investigation of fundamental aspects of materials science, application-specific issues, and measurement-related developments. Characteristic parameters are not only determined but also interpreted within the context of the respective application to uncover any potential for optimization.

Non-Destructive Testing and Monitoring

page 60–62

Quality, costs and time are crucial factors in order to convince the market with own products and services. Non-destructive test methods help to continuously improve these. IKTS combines its decades of experience in the testing of components and plants with novel measuring technologies, automation concepts and approaches for the interpretation of complex data volumes. These competences exceed the portfolio of traditional NDT providers by far.





LAYERED PEROVSKITES FOR TEXTURING OF LEAD-FREE PIEZOCERAMICS

M. Sc. Christoph Briegel, Dr. Mathias Herrmann, Dr. Sylvia Gebhardt, Dr. Holger Neubert

Piezotechnology has been very present for decades in the form of actuators, sensors, ultrasonic transducers or generators in various fields of applications. The most frequently used piezoceramic material is $Pb(Zr_{1-x}Ti_x)O_3$ (PZT), thanks to its excellent electromechanical properties. However, its highly toxic lead content of > 60 wt % has long been inducing researchers to look for lead-free alternatives, more recently as a result of legislative pressure (ROHS 2011/65/EU). $K_{1-x}Na_xNbO_3$ (KNN) has emerged as promising lead-free piezoceramics from this search, based on its strong piezoelectric properties and high Curie-temperature. However, KNN materials are far less efficient than commercially available PZT compounds. The doping of compounds to texture the microstructure or the use of special sintering techniques can also help to improve piezoelectric performance. Thus, electromechanical properties that are comparable to PZT can be achieved.

Texturing of lead-free piezoceramic materials

Templated grain growth is often the method of choice for texturing the microstructure. This process uses platelet-shaped single crystal templates which have been inserted and aligned in the green compound through tape casting. Epitaxial grain growth on the single crystal templates leads to oriented grain growth during the sintering process, resulting in a textured microstructure. $NaNbO_3$ (NN) templates are typically used for KNN ceramics. However, at present these can be synthesized by means of a cost-intensive and laborious molten salt synthesis process only, essentially preventing the industrial application of textured KNN.

Layered perovskites form platelet-shaped morphologies based on ordered defect structures in their crystaline composition and could therefore qualify as potential candidates for templates. They are easy to produce via a mixed oxide route. Another advantage is the large range of available layered perovskite compounds. This means that it is possible to introduce not only a [100] texture direction into the microstructure – as is the case with NN templates – but also [110] or [111].

At Fraunhofer IKTS, several layered perovskites have been developed and investigated as possible template systems for texturing KNN ceramics. Based on microstructural analyses, it was shown that KNN particles grow epitaxially on $NaCa_4Nb_5O_{17}$ templates and exhibit a [110] growth direction. It was thus possible to show for the first time that layered perovskites are suitable for texturing KNN materials. Further challenges on the path to finally achieving a textured KNN microstructure are template size and stability of the layered perovskites, quality of the green bodies as well as sintering conditions.

1 *FESEM image of $NaCa_4Nb_5O_{17}$ template powder.*
2 *FESEM image of epitaxially grown KNN on $NaCa_4Nb_5O_{17}$ templates with a [110] growth direction.*

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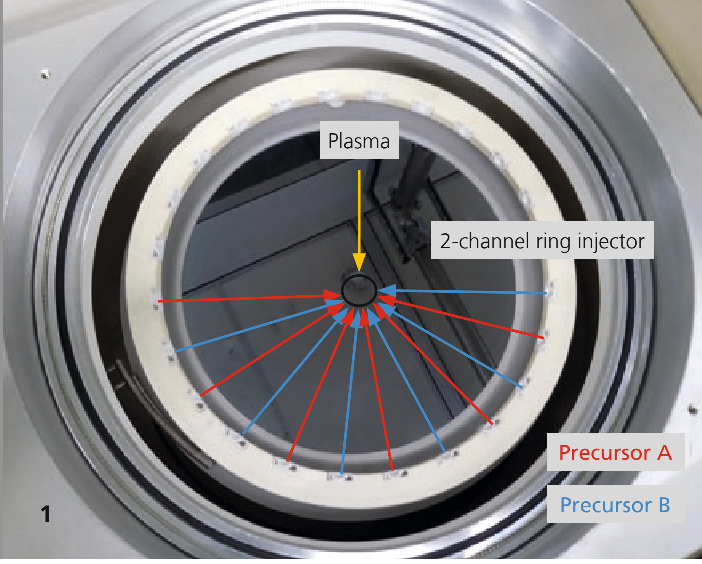

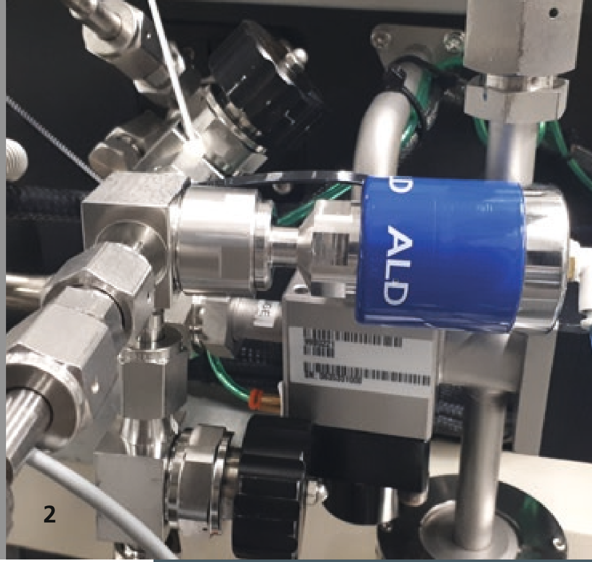

SUPERFAST PLASMA ALD WITH 3D-PRINTED CERAMIC ROCKET NOZZLES

Abhishekkumar Thakur, Dr. Jonas Sundqvist, Dipl.-Phys. Mario Krug, Dr. Roland Weidl

Atomic Layer Deposition (ALD) for self-aligned multiple patterning has been the key process to the continued scaling of nanotechnology and microchips. The process requires plasma ALD at low temperatures and a conformal deposition of spacers on photoresist features for the subsequent pitch splitting processes. However, ALD is limited by low throughput, which can be improved by increasing the growth per cycle (GPC), using new precursor, spatial ALD, shrinking the ALD cycle length or omitting purge steps. Today's highly productive platforms can realize very fast wafer transport in and out of the ALD chambers. Currently, 300 mm wafer ALD chambers for high volume manufacturing are used.

Fraunhofer IKTS, in collaboration with Plasway Technologies GmbH, has developed a new type of fast plasma ALD process. It uses a top-down showerhead gas flow to ignite a 60 MHz CCP plasma in a 300 mm chamber. The chamber gas system has been modified to realize precursor pulses of ≤ 10 ms with supersonic precursor gas injection. The supersonic gas speed is made possible by a 3D-printed ceramic rocket nozzle, named "Art de Laval", manufactured and patented by Plasway Technologies, which enables high-speed (> 300 m/s), all-round precursor injection across the wafer. Initial process qualification was made with the well-understood aluminum oxide plasma ALD process using the trimethylaluminum precursor. With the de Laval ring injector, the saturation started at a TMA pulse length of 10 ms, which is the tested switching limit of the electropneumatic ALD valve. The process linearity and the saturation curve demonstrated the ALD nature of the process. For 50 ms of TMA pulse, a wide ALD temperature window (30–120 °C) with constant 1.3 Å GPC was extracted. Even with very short pulses, we achieved a very good uniformity of the applied layers – from wafer center to the edge.

Additional ALD processes, as well as atomic layer etching (ALE), will be the focus of future development efforts by Fraunhofer IKTS and Plasway Technologies GmbH.

1 300 mm plasma ALD process chamber.

2 Ultrafast electropneumatic ALD valve for precursor pules below 10 ms.

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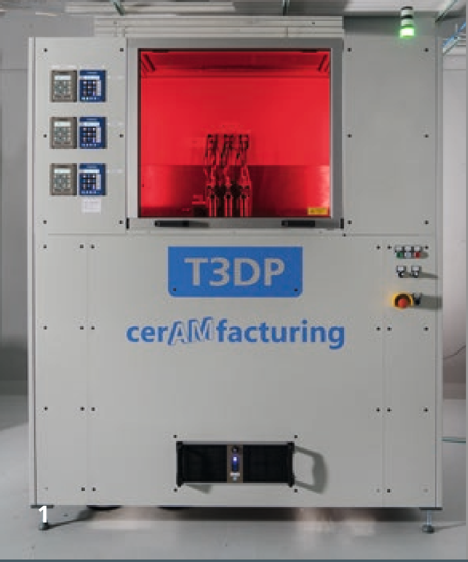

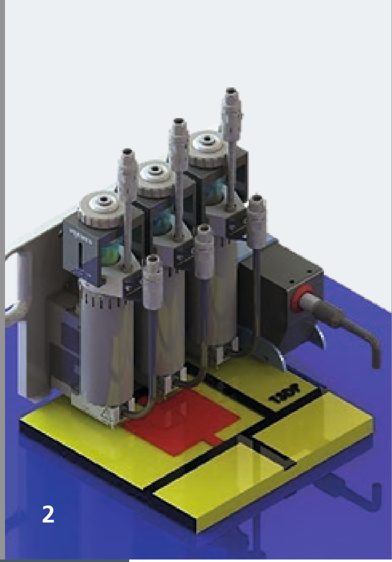
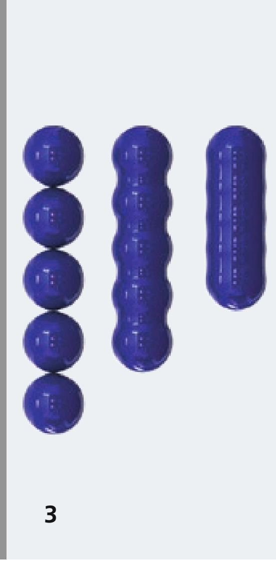
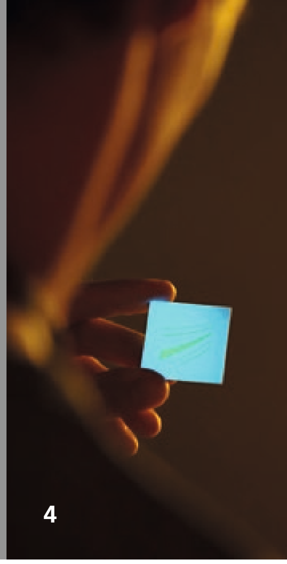

MATERIAL JETTING – THERMOPLASTIC 3D PRINTING FOR MULTIMATERIAL PARTS

Dipl.-Ing. Steven Weingarten, Dipl.-Ing. Uwe Scheithauer, Dipl.-Bio.-Inf. (FH) Oliver von Kopp, Dipl.-Ing. (FH) Jens Baade, Dipl.-Ing. (FH) Martin Stecker, Dr. Tassilo Moritz, Dr. Hagen Klemm

Components that are, for instance, thermally or electrically equally insulating and conductive or multicolored place high demands on production. The additive manufacturing technology of Thermoplastic 3D Printing CerAM T3DP holds a great deal of potential when it comes to such multi material parts.

Technology

CerAM T3DP is based on a unique technology and plant development of IKTS, which overcomes the limits of conventional methods. The technology is based on the drop-by-drop deposition of particle-filled thermoplastic feedstocks. Defined overlapping of single droplets enables producing dense green components. A special feature is the solidification mechanism based on cooling. This is virtually independent of the physical properties of the materials used. It allows metals, hardmetals as well as oxide, nitride and carbide ceramic materials to be processed. The shaping is followed by debinding and sintering. The use of high-precision microdispensing systems (MDS) allows droplet volumes to be generated on a nanoliter scale. Depending on the dynamic viscosity of the used feedstock, the parameterization of the dosing cycle allows to realize droplet diameters between 300 and 1000 µm and layer heights between 100 and 200 µm.

Device development

The CerAM T3DP device developed at Fraunhofer IKTS has a 200 x 200 x 180 mm^3 building platform that moves in x, y and z directions under up to four implemented MDS and a profile sensor. The maximum velocity of the building platform is 60 mm/s. The system is equipped with the latest hardware components, boasting a positioning accuracy of ≤ 20 µm and a repeatability of ≤ 5 µm. After successful validation, the technology is to be commercialized based on this device.

Multifunctional components

Since up to four different feedstocks can be used, it is possible to realize material or property gradients, generating graded physical (mechanical, electrical, optical, thermal) and chemical properties.

Dosable materials

Al_2O_3, ZrO_2, TiO_2, Si_3N_4, AlN, WC, WC-Co (6–12 % Co), 17-4PH, 316L, sinter glasses, LTCC and functional materials

Services offered

- Feedstock and component development, as well as technology transfer
- Development of hard- and software for process monitoring and automation

1 *CerAM T3DP production device.*
2 *Schematic representation of the MDS unit for monitoring.*
3 *Material deposition by fusion of individual droplets.*
4 *Functionalized sinter glass.*

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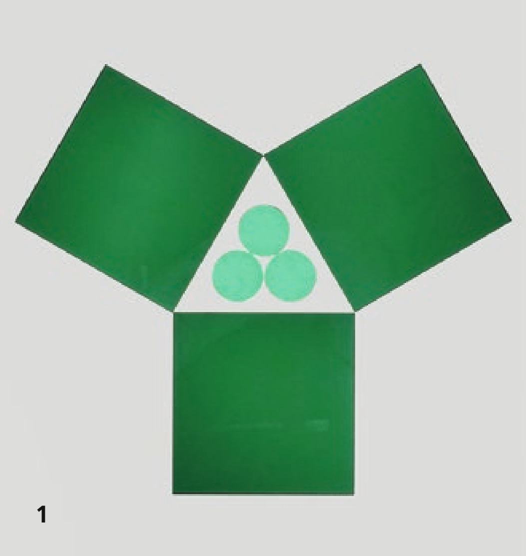
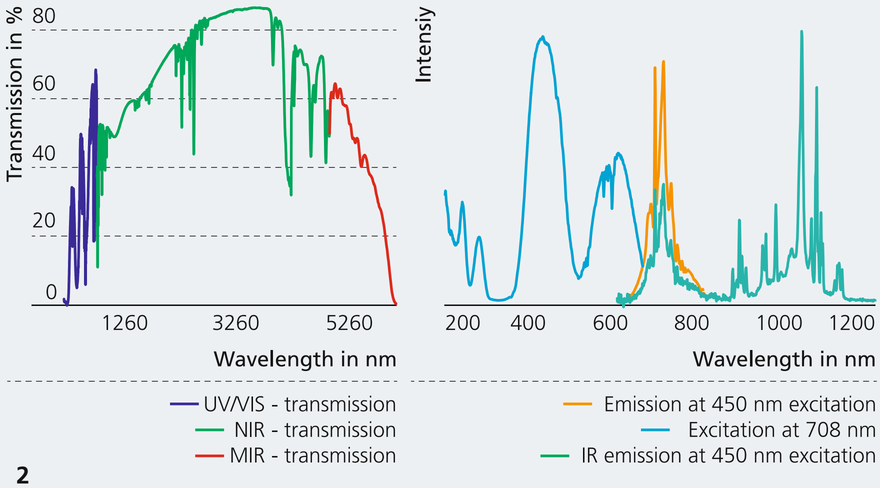




FUNCTIONALIZED TRANSPARENT YTTRIUM-ALUMINUM-GARNET CERAMICS (YAG)

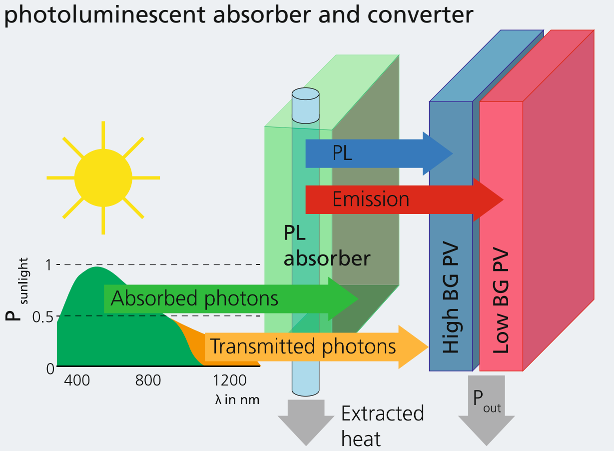
Dipl.-Ing. Thomas Hutzler, Dr. Stefanie Hildebrandt, PD Dr. Lutz-Michael Berger

Over several decades, doped YAG ceramics have established themselves as important components in light engineering, laser technology, optoelectronics and also as gemstones. Cerium-doped YAG in crystalline form, for instance, is used as fluorescent substance in LEDs for lighting. YAG single crystals doped with neodymium or ytterbium have enabled the development of high-energy solid-state lasers for material processing, medical applications and measurement technology. Additional doping with chromium makes it possible to use YAG ceramics as absorber/converter panels in solar technology, utilizing the broad light spectrum of the sun ("Concentrated Solar Power Concept") [1]. YAG single crystal growth using the Czochralski process is very expensive. The range of geometric dimensions and shapes of the parts is limited, as is the amount of dopants. Scientists at Fraunhofer IKTS have now managed to manufacture transparent doped YAG ceramics, adding to the manufacture of spinel $MgAl_2O_4$, cubic ZrO_2 and MgO. The defect-free shaping technologies used for this manufacture allow many variations in terms of shape, size and number of monolithic ceramic components. In addition, the type and concentration of doping elements can be selected as needed for the functionality of each application. In cooperation with Technion in Haifa (Israel), the researchers produced triple-doped (Cr, Yb and Nd) absorber/converter plates, 80 x 80 mm in size with a thickness of 3 mm (Figure 1). In a solar-power plant, the YAG ceramics are used to absorb sunlight and thermal radiation is transported away through a suitable medium (e.g. fused salt). Short-wave parts are converted to defined wavelengths, which can in turn be transformed into electricity by solar cells placed behind the absorbing ceramic plates (see working principle in graphic). Transparent CrNdYb:YAG ceramics enable precise and highly efficient conversion (Figure 2) in particular at high temperatures around 600 °C.

Literature

[1] S. Haviv u. a., OSA Technical Digest, Optical Society of America, 2019, paper jsiii_1_5].

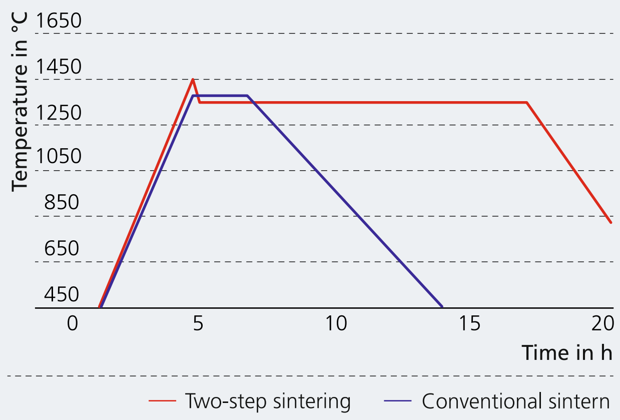
Basic design of solar-thermal element including a photoluminescent absorber and converter



PL – Photoluminescent, PV – Photovoltaics, BG – Band gaps

1 Shaped transparent CrNd-Yb:YAG ceramic panels for photoluminescence (PL) absorption and conversion.

2 Transmission and emission spectra of CrNdYb:YAG.



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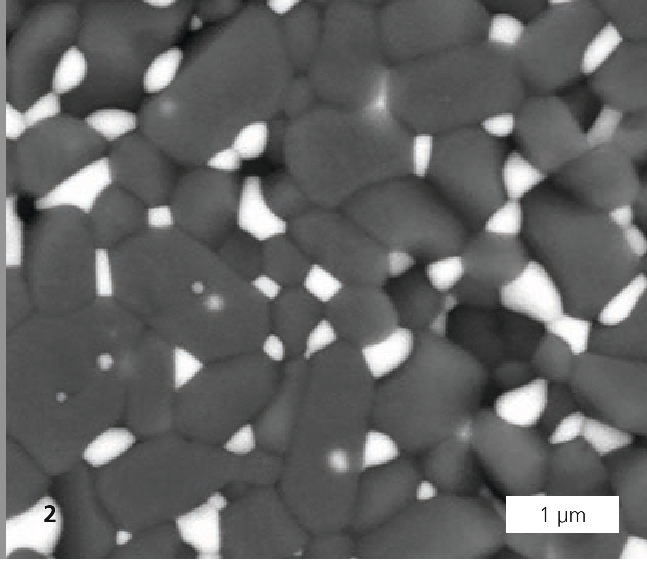

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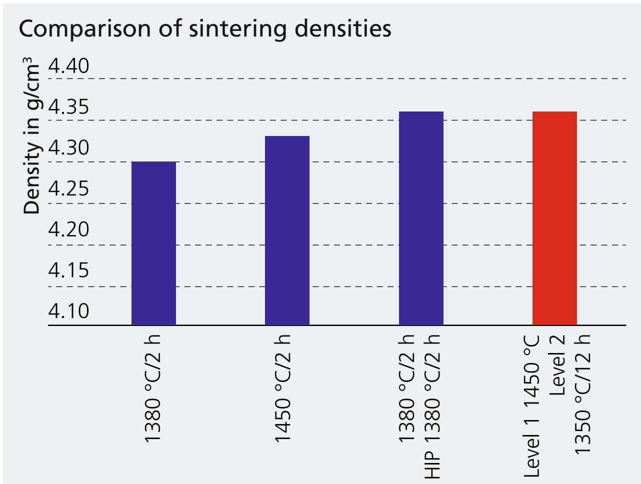
ENERGY-EFFICIENT TWO-STEP SINTERING OF ZTA-CERAMICS

M. Sc. Caroline Tschirpke, Dr. Uwe Reichel, M. Sc. Kerstin Simon, Dr. Sabine Begand

Zirconia (ZrO_2)-toughened alumina (Al_2O_3), known as ZTA ceramics, belongs to the mixed oxide ceramics and is more hydrothermally resistant and stronger than pure ZrO_2 or pure Al_2O_3. ZTA ceramics are therefore ideally suited for medical applications. The distribution of the individual phases is decisive for the improved properties of mixed oxide ceramics: A homogeneous phase distribution and high sintering density result in higher strength and hardness. ZTA ceramics are conventionally produced either through single-step sintering or through post-compaction via hot isostatic pressing (HIP) after sintering, which is energy- and cost-intensive. Fraunhofer IKTS has established a two-step sintering method, which achieves the same dense microstructure (with comparable grain size) as conventional methods but is considerably more resource- and energy-efficient.

The green bodies were initially produced by grinding the commercially available raw materials (75 wt % Al_2O_3 and 25 wt % ZrO_2 – stabilized with 3 mol% yttrium oxide) in a high-energy ball mill, followed by spray granulation and subsequent shaping using the dry pressing process. Green bodies with a density of > 56 % theoretical density were divided into three groups – the first was sintered conventionally in air, the second subsequently treated with HIP, while the third group was sintered in air in two steps. The sintering densities show that two-steps sintering compacts much better than single-stage sintering, with a complete compaction of > 99.9 % of theoretical density (corresponds to 4.36 g/cm³). In comparison with sintering and the subsequent cost-intensive HIP treatment, two-step sintering achieves equally good results in terms of sintering density and microstructure. Thus, two-stage sintering is a promising alternative sintering method to increase energy efficiency.



Services offered

- Material synthesis and development on the basis of commercially available raw materials
- Material-specific shaping and development of prototype components and pilot series
- Consulting on material-, construction- and application-specific issues

1 Thermal profile of two-step sintering.

2 Microstructure of ZTA ceramics after two-steps sintering.

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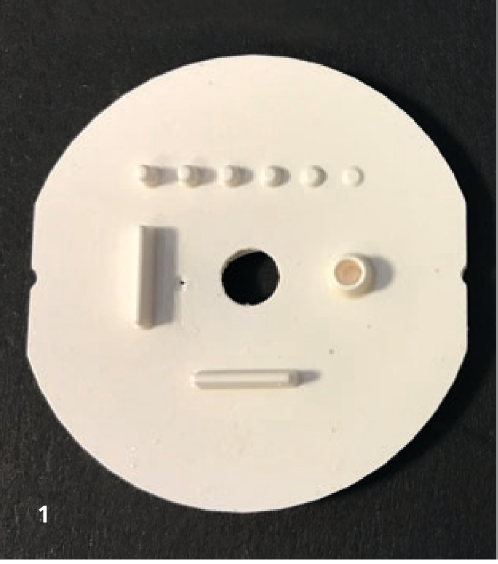
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CERAMIC MOLD INSERTS FOR INJECTION MOLDING

Dipl.-Chem. Ralph Schubert

Injection molding technology is widely established for the processing of plastic materials, since it is a resource- and time-saving way of manufacturing complex shaped parts. It is a basic technology implemented in many branches of industry. Due to its high tool costs, however, this technology becomes unprofitable as product designs change more frequently and lot sizes decrease. At Fraunhofer IKTS, an R&D project pursues the development of a novel approach to cost-efficient molding tools for the injection molding of small series up to 10,000 parts. The project shows that thin-walled, precise and wear-resistant mold inserts made of ceramics or ceramic-like composites are a cost-effective alternative to traditional metal designs.

The mold inserts joined with a supporting rear structure needed to be integrated into an existing mold base, together with other tooling components, such as ejector pins. Based on a three-level approach (basic design investigation – investigation of shape complexity – manufacturing of demonstrators) for the development and characterization of test parts, mold inserts were produced from different materials, such as alumina, ZTA, SiSiC and composites with a polysiloxane matrix. This process used various manufacturing techniques, including liquid ceramic manufacturing (LCM), ceramic slip casting, binder jetting and molding from a prototype. First investigations of injection molding with thermoplastics (e.g. with fiber filling, melt temperatures up to 320 °C, injection pressures up to 1200 bar), thermoset composites (tool temperature up to 200 °C) and ceramic feedstocks yielded series productions with up to 1000 parts. These production volumes can easily be expanded to up to 10,000 parts. After completion of the R&D project, the research should result in a decision matrix that enables manufacturers to select suitable fabrication processes and material systems for specific tasks and for the respective injection molding material.

In comparison: Injection molding tools with ceramic or composite mold inserts compared with conventional metal tools

	Design	Mold insert production	Tool integration
Metal mold	Design data ▶	Machining ▶	Complete construction
		Duration 4–5 weeks	Duration 3–4 weeks
Ceramic mold	Design data ▶	Primary shaping/sintering Image 1 ▶	Support manufacturing/tool integration
		Duration 1–2 weeks	Duration 1–2 Days
Composite mold	Prototype ▶	Warm pressing or pouring/cross-linking Image 2 ▶	Support manufacturing/tool integration Image 3
		Duration 1–2 days	Duration 1–2 days

1 *Mold insert with complex test structure (alumina, LCM).*
2 *Mold inserts made of Al_2O_3 (top), composite (center) and SiSiC (bottom) with substructure.*
3 *Mold insert (composite) with ejector pins mounted in base mold.*

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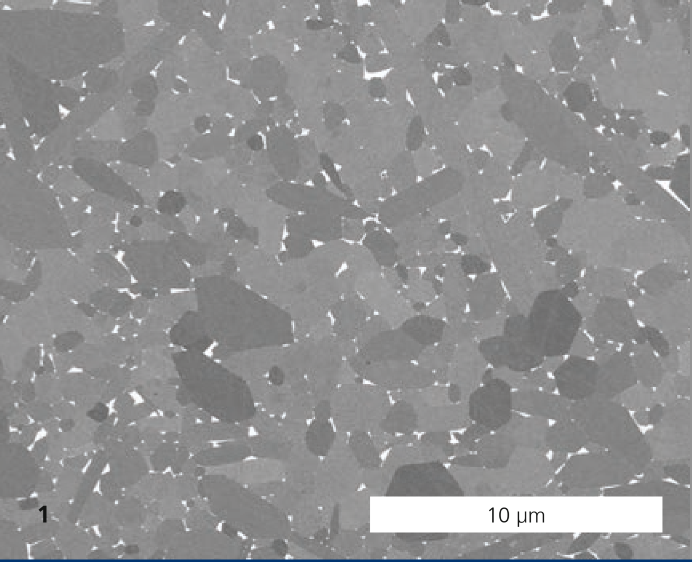


INTERCHANGEABLE CERAMIC HEADS FOR SINGLE-LIP DEEP DRILLING

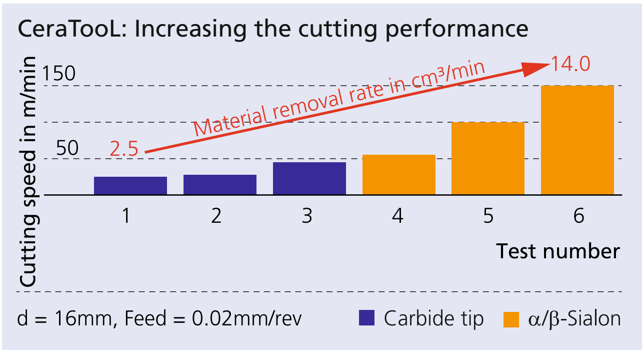
Dr. Eveline Zschippang, Dr. Mathias Herrmann, Dipl.-Ing. Jens Stockmann, Dipl.-Ing. Falko Oehme, Dipl.-Ing. Jan Räthel

The use of high-tempered or hardened steels, new high-strength, high-rigidity and high-temperature-resistant non-ferrous alloys and composite materials in mechanical and plant engineering puts higher demands on the machining of materials. Several partners collaborated in the joint project CeraTooL to develop the use of ceramic high-performance cutting materials combined with a replaceable head system for single-lip deep drilling. This specialized drilling technique produces bores with large length/diameter ratios.

Special α/ß-sialon ceramic were developed for this process at Fraunhofer IKTS (Figure1). It has a strength of > 850 MPa, a toughness of 6.5 MPa√m and a high-temperature hardness of HV10 > 1400 at 1000 °C, enabling very effective machining. In order to develop ceramic-compatible contours for the cutting area of the replaceable heads and to test the performance of the ceramics, trials were initially carried out on indexable inserts. In several steps, suitable cutting edge geometries for the inserts and replaceable heads were designed, samples were machined on the 5-axis ultrasonic machining center and process parameters were developed for wet and dry machining. The functionality and performance of the indexable inserts were tested thoroughly on the AUERBACH AX1-TL deep-hole drilling machine with different workpiece materials. Taking the example of quenched and tempered steel 1.2312 (hardened 45 HRC), a significant increase in cutting performance could be demonstrated by tripling the usual cutting speed (diagram). Combined with a minimum quantity of cooling lubrication in the machining process, considerable energy and oil savings are achieved. These promising results for the indexable inserts served as the basis for producing optimized cutting edges for ceramic interchangeable drill heads. With the production of new ceramic interchangeable heads with an optimized cutting area (Figure 2), more experiments are to follow – not only with Sialon but also with a newly mixed ceramic grade based on titanium carbonitride, corundum and zirconium oxide.

Services offered

- Research and development of ceramic cutting materials
- Development of structural ceramic components



1 *FESEM micrograph of the developed sialon ceramic.*

2 *Commercial single-lip drilling tool D = 16mm (top), Sialon drill head (center), drill head made of mixed ceramic with steel adapter (bottom).*

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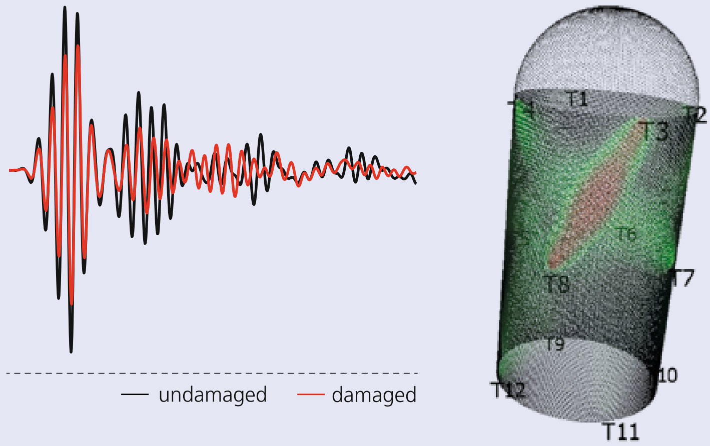

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SAFE STORAGE FOR HYDROGEN AND GAS IN PRESSURE VESSELS

Dr. Lars Schubert, Dr. Kilian Tschöke, Heiko Neunübel

Mobility for tomorrow

Various drive concepts exist for tomorrow's low-emission mobility. Among them are those using fuel cells, offering considerable advantages compared to battery-powered systems in terms of range and refueling times, which is why their development is currently being pursued by numerous automobile manufacturers. The necessary hydrogen can be produced under ecologically acceptable conditions by using renewable energy sources. The pressure vessel is the essential component for storing the liquid hydrogen in a vehicle (Figure 1).

Pressure vessels made of fiber composite material

Even in gas-powered vehicles, the standard steel tanks, which were widely used until recently, are currently being superseded by pressure tanks made of fiber-composite material (CFRP). They boast a lightweight construction as well as outstanding properties under cyclic load. The integrity of the pressure vessel must be ensured not only under cyclic loads when refueling or removing the hydrogen, but also in a damage event, e.g. in a rear-end collision. This can be assured through the permanent monitoring (termed "structural health monitoring") of the tank.

Services offered

At Fraunhofer IKTS, a monitoring and sensor system is available that can examine complex components made of fiber-reinforced composite material, such as wrapped pressure vessels, for structural changes. The monitoring system is designed and optimized on the basis of a simulation that models the measuring procedure. Extensive and complex laboratory testing can thus be simplified or even partly replaced by computer-aided investigations. Based on the results of optimization efforts, piezoelectric transducers are either integrated directly into the component during production or applied subsequently. For the measurement, actively excited ultrasound waves are applied on the component. These so-called guided waves are received passively by transducers, which are not active transmitting at that moment. These continuous or periodic pitch-catch measurements are performed on all paths between the transducers attached to the component.

In the case of a structural change, significant deviations of the measurement signals from undamaged conditions can be observed on several paths. Subsequent data analysis enables structural changes and damage to be detected, localized, classified and, finally, visualized (Figure 2).

1 *Instrumented pressure vessel made of wrapped fiber composite material, used in the automotive industry.*

2 *Recorded sensor signal of a monitoring system including visualization of a structural change.*

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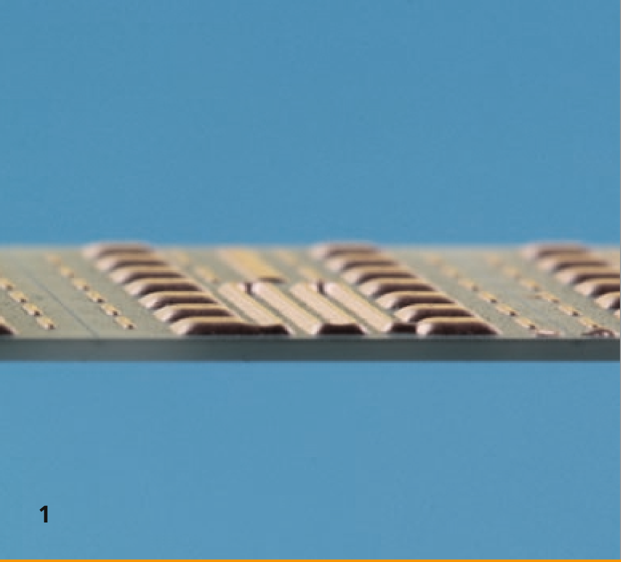

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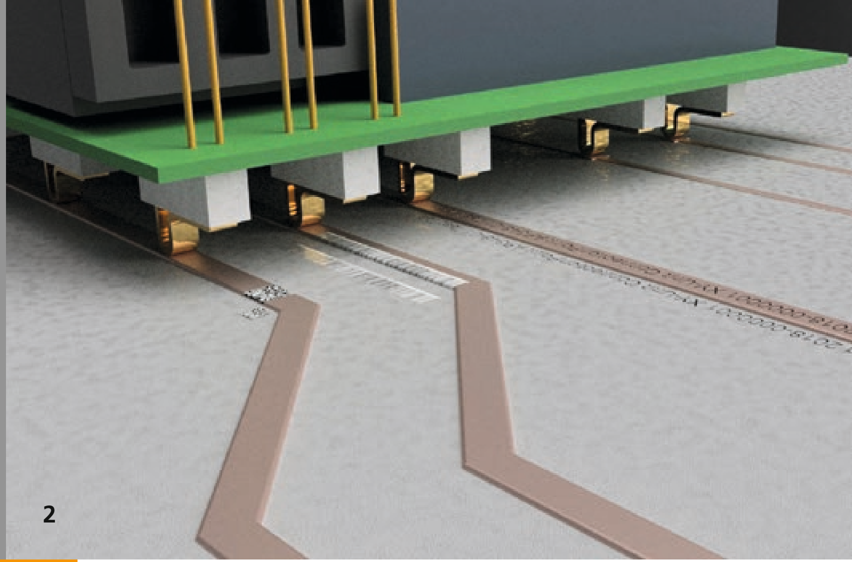

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THICK-PRINTED COPPER PASTES FOR POWER ELECTRONICS

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

Power electronic systems are the backbone of the supply infrastructure of renewable energies and electromobility. Modules in which power semiconductors and other components are integrated form the central components of such systems. However, the DCB (direct copper bond) substrate used in the majority of power modules limits the integration density of power modules. As a result, copper thick-film systems are currently being increasingly used in this field. Copper paste systems for substrate types, such as Al_2O_3 and AlN, have been successfully developed at Fraunhofer IKTS. Scientists have realized copper layers with up to 300 µm film thickness, which are deposited by screen or stencil printing (Figure 1). They allow finer structuring with a higher design flexibility than commercially available DCB substrates and show a higher degree of robustness under thermal cycling stresses. However, in order to achieve multilayer structures on ceramic substrates, the development of further paste systems, such as conductive and dielectric pastes, is needed. The development of such paste systems for the high-temperature (650 to 950 °C) and low-temperature (200 to 280 °C) ranges was also realized at IKTS. Above all, the challenge was to match the developed pastes to the copper ceramic substrate, in which the sintering under nitrogen atmosphere is a basic requirement. These novel IKTS developments will, in the future, make the production of power modules more compact, functional and cost-efficient. Over the past two years, these paste systems have been enhanced with respect to digital 3D printing technologies. In the BMBF-funded project "Agent elF" (additive manufacturing for the integration of electronic functionalities), a printed control panel was realized in cooperation with numerous project partners, such as Siemens. The manufacture of classic control panels involves the integration of wiring harnesses for the electrical connection between control systems and peripheral components. This process is currently associated with a high manual effort and low potential for innovation. The construction of printed conductor and insulation layers on a carrier plate (backplane) of the control panel and thus the realization of individual product backplanes eliminates the enormous manual effort and opens up a wide application potential when it comes to electrically connecting complex circuit systems. Part of the project inolved developing 3D-printable copper conductive and insulating pastes for dispensing technology. Figure 2 shows a section of a backplane with a power electronic component developed in the project for demonstration. The ground plate consists of a spinel-coated steel, which combines high-current and signal tracks with copper pastes to form a complex control cabinet module.

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INTEGRATION ELEKTRONISCHER FUNKTIONALITÄTEN
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SPONSORED BY THE Federal Ministry of Education and Research

1 *Copper layer on AlN – 300 µm film thickness.*

2 *Section of a demonstrator backplane of a copper-printed control panel.*

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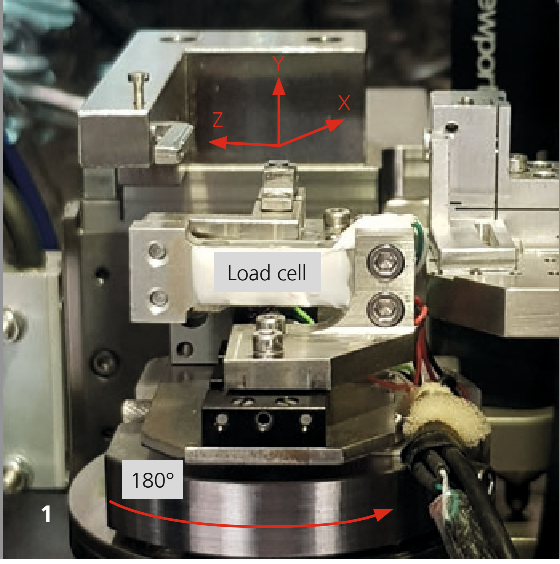

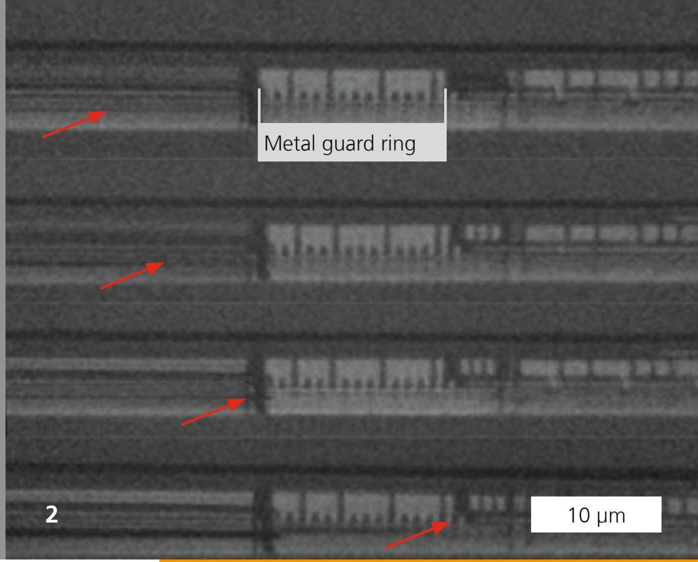

IN-SITU DETECTION OF CRACKS IN MICROCHIPS BY NANO-XCT

M. Sc. Kristina Kutukova, Dr. Jürgen Gluch, Dipl.-Ing. Christoph Sander, Prof. Dr. Ehrenfried Zschech

High-resolution transmission x-ray microscopy for in-situ investigation of 3D structures

Investigations of crack evolution in microchips currently fail due to the insufficient resolutions achieved by the methods employed. Therefore the Fraunhofer IKTS enhanced a laboratory-based Transmission X-ray Microscope (TXM) which is used for nano-X-Ray Computed Tomography (nano-XCT) with a novel miniaturized Double Cantilever Beam (micro-DCB) test system. This tool allows full tomographic access to the region of interest (ROI) under defined mechanical load, which enables insitu 3D imaging at resolutions of above 100 nm.

For optimal imaging, the micro-DCB sample needs to be about 50–80 µm thick. The crack growth is driven by controlled piezo displacement with steps of 50 to 100 nm during continuous force measurement.

In-situ micro-DCB study of crack propagation in micro-chips

Crack propagation was localized and visualized in an in-situ study of the pathways of cracks in fully integrated multilevel interconnect structures during mechanical loading. Also, the delamination of the crack in weak dielectrics and along dielectric interfaces was determined. To prevent fracture and mechanical damage of the microchip, metal guard ring (GR) structures are integrated into the on-chip interconnect stack, with the aim of stopping the micro-crack propagation or redirecting cracks. The in-situ micro-DCB test allows a non-destructive study of the complex failure modes in real interconnect stacks. This opens the discussion of the impact of process-induced thermomechanical stress and Chip-Package-Interaction (CPI) on reliability. These studies provide the information needed to design guard ring structures for future advanced technology nodes and to guarantee the requested product lifetime.

Services offered

- In-situ visualization of cracks in materials with sub-100 nm resolution
- Determination of weakest components and interfaces in materials based on 3D data
- Quantitative determination of the fracture toughness of materials

The project was funded by SRC in accordance with the member-specific research agreement.

1 *Experimental setup of micro-DCB test in the nano-XCT.*

2 *Virtual cross-sections through the Cu interconnect stack at several stages of the micro-DCB test, based on nano-XCT data.*

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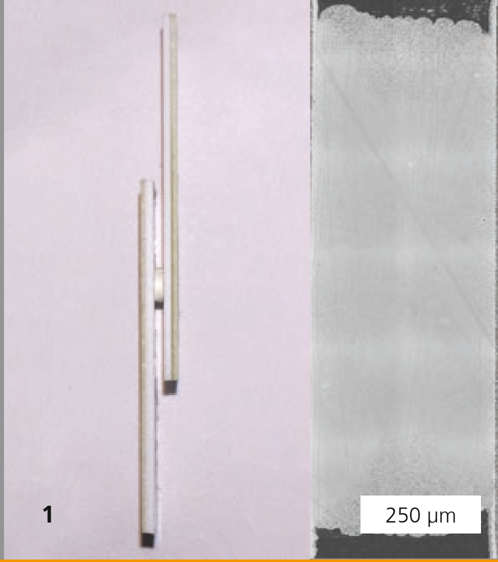

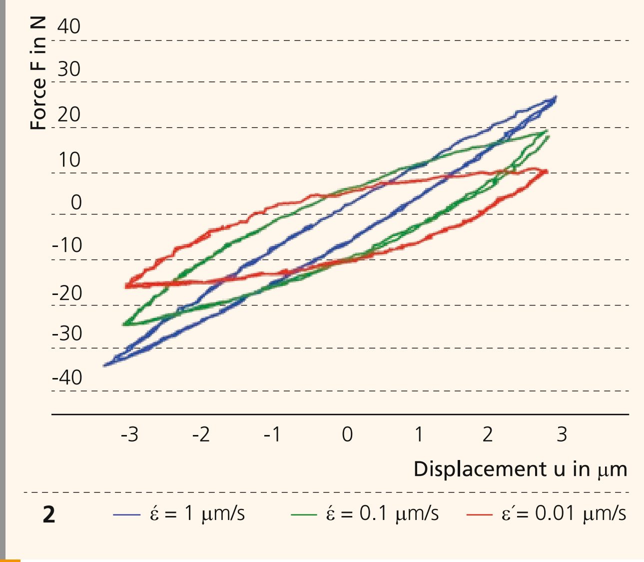

MICROMECHANICS OF SILVER-SINTERED INTERCONNECTS IN POWER ELECTRONICS

Dr. M. Röllig, Dipl.-Ing. R. Metasch, Dr. R. Schwerz

The power electronics market is growing continuously at a rate of 8 to 10 % per year. The reasons for this are the electrification of mobility, renewable energy technologies and the increasing transport of electrical energy. More and more electric and hybrid vehicles (electric vehicles/EV, hybrid electric vehicles/HEV) will be equipped with a new generation of increasingly temperature-resistant SiC chips. With barrier layer temperatures upward of 175 °C, new high-performance packaging solutions are required.

Silver sintering is a joining technology that promises highly reliable interconnections and may be able to replace current soft solder connections, which have a temperature limit of around 150 °C. Ag sinter connections are processed under pressure at 230 °C and are therefore melt-resistant at temperatures up to 900 °C. Silver sinter contacts generate a microporous structure during pressure- and temperature-based sintering. This porosity influences the mechanical properties of the contacts. Mechanical creep and relaxation behavior, as known from soft solder material, also occur in porous sinter contacts. Plastic deformation can be observed at temperatures above 120 °C, and this effect intensifies further above 230 °C. Fraunhofer IKTS scientists have now measured these expansion rate-dependent plastic deformations and discovered time- and temperature-dependent creep behavior.

The team at IKTS has developed a mechanical measurement system and method for the characterization of Ag sinter joints. The method includes the technological manufacturing process of silver sinter interconnections as lap shear specimens (Figure 1, left) under industrial process conditions. The micro lap shear specimen allows a very high degree of parallelism between connection pads, comes with an adjustable sintered area footprint and creates a homogeneous microstructure within the joint. As this technology is already mature, it is possible to reliably create specimens free of defects and voids (Figure 1, right). The contacts are characterized mechanically by determining the porosity of the sinter structure with high-resolution imaging analysis and quantitative determination of the porosities. Subsequent micromechanical measurements up to temperatures of 300 °C and the calculation of mechanical properties using the finite element method (FEM) form the basis for creating characteristic data sets. These are transferred into mechanical models suitable for FEM and thus allow dimensioning robust and long-term stable power electronics assembled with silver sinter contacts.

Future efforts will systematically investigate the correlation between microporosity, Ag sinter paste materials and mechanical creep properties. The characterization of sinter contacts is particularly relevant for low-pressure sintering, which is increasingly used for pastes. By adjusting porosity, it is possible to influence mechanical properties.

1 *Left: Lap shear specimen with Ag sinter joint (2.5 mm, h = 0.5 mm). Right: REM image of Ag joint.*

2 *Force-displacement measurement of Ag joint at different strain rates.*

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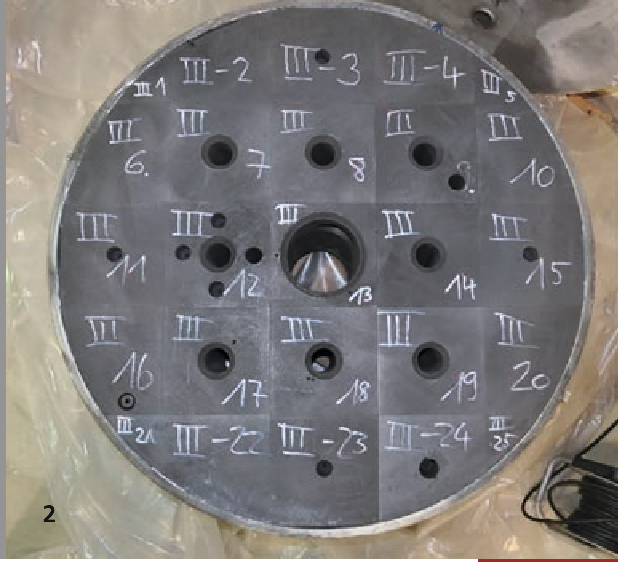

PROCESS DEVELOPMENT FOR THE DECOMMISSIONING OF NUCLEAR INSTALLATIONS

Dipl.-Chem. Hans-Jürgen Friedrich, Dr. Katrin Viehweger

The decommissioning of nuclear installations in Germany is in full swing. This means large volumes of problematic residual materials have to be processed and kept safe within a rather short period of time. At present, however, appropriate treatment methods are not available for all types of such radioactive materials. Scientists at IKTS have developed approaches to tackle this challenge as part of projects funded by the German Ministry of Education and Research (BMBF). Fraunhofer IKTS runs its own radionuclide laboratory, it holds the legal permissions and employs trained and experienced staff, familiar with the very specific requirements in this field. Three promising methods for the treatment of radioactive waste are currently being investigated in the lab:

- Electrochemical total oxidation of liquid C-14-wastes
- Investigations of new conditioning routes for irradiated graphite
- Decontamination of radioactive concrete from the nuclear sector

Liquid C-14-containing wastes from the nuclear industry, but also from pharmaceutical research, are not approved for final disposal. The current state of the art for their treatment is traditional incineration – to the extent that this is even possible at all. With its electrochemical cold incineration process, IKTS has developed and tested a new route for the conditioning of such wastes which allows to fixate the carbon-14 as disposable C-14-$CaCO_3$ and even opens up the possibility of C-14 recycling. The process has been tested for more than 2000 hours as part of bench-scale testing using a self-developed electrolyzer of the RODOSAN® type. Trials with real waste samples went off without complications and the treated solutions were completely decontaminated.

Thermal neutrons are able to cause nuclear fission of uranium. Reactor graphite is used in some reactors as a moderator for the deceleration of neurons. The irradiation near the reactor core leads to the formation of C-14 and other radionuclides in the graphite, making its disposal very difficult. That is why a solution to the "graphite problem" is essential with respect to creating final deposition capacities in Germany. Current research at Fraunhofer IKTS focuses on the separation of C-14 and other radionuclides from the graphite and their subsequent conditioning. To achieve this, electrochemical, thermal and biochemical approaches, as well as membrane processes (i.e. for isotope separation) are employed.

In case of radioactive concrete, the contamination is often bound only to the cement stone phase, which makes up only a small fraction of the total mass. Using a promising method, Fraunhofer IKTS is attempting to separate the non-contaminated aggregates by means of electrodynamic disintegration and subsequent water treatment.

1 *Pilot plant for C-14 total oxidation.*
2 *Segment of the thermal column of the former Rossendorf Reactor© (Source: VKTA.)*

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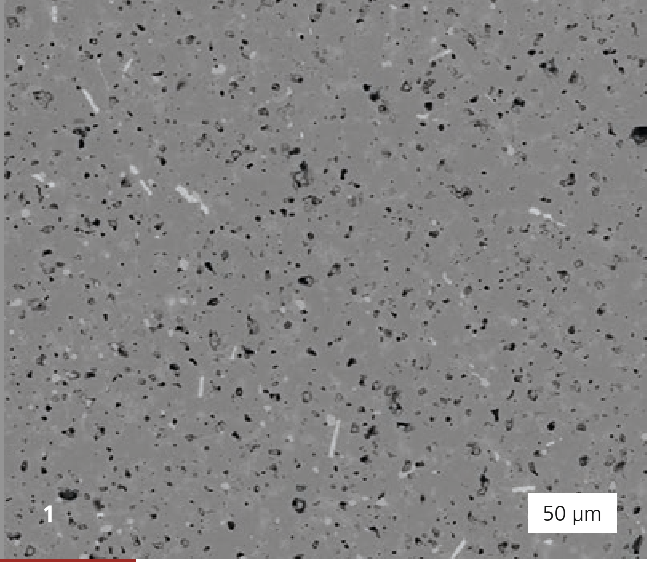
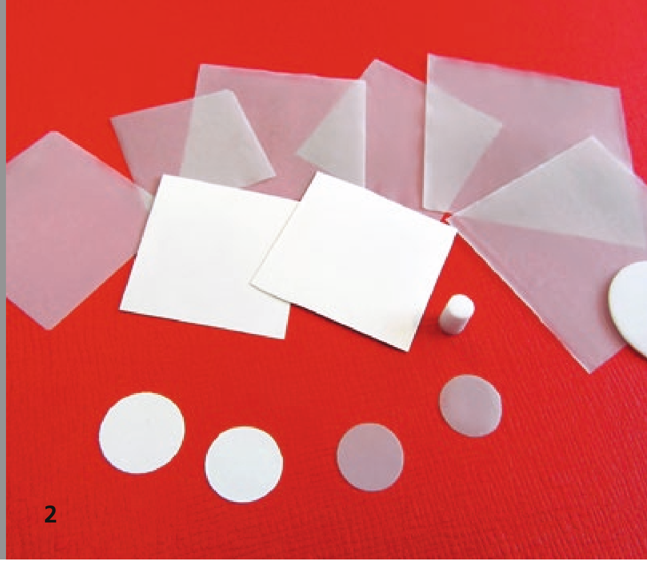




CERAMIC ELECTROLYTES FOR LITHIUM AND SODIUM SOLID-STATE BATTERIES

Dr. Mareike Wolter, Dr. Mihails Kusnezoff, Dr. Roland Weidl, Dr. Arno Görne

Motivation

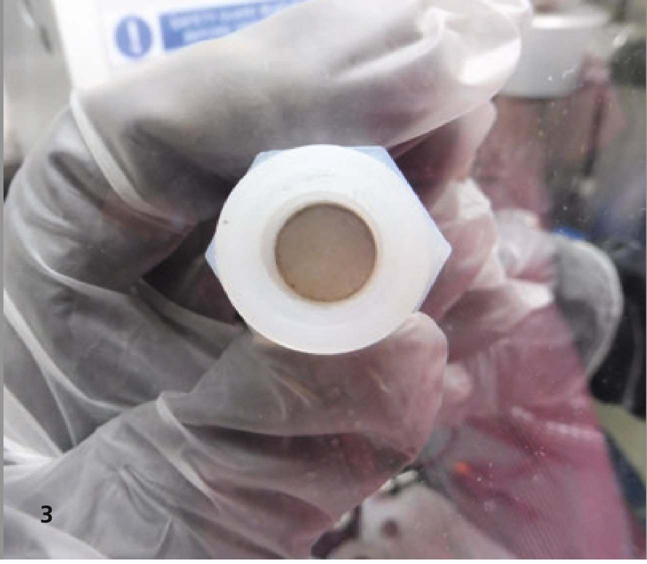
Solid-state batteries (SSB) are considered a promising candidate for the next generation of batteries for automotive, industrial and stationary applications. The main advantages of this technology are improved safety thanks to the avoidance of flammable and harmful liquid electrolytes, and increased energy density thanks to the application of metal lithium or sodium anodes. Currently, very different material classes of solid electrolytes for use in solid-state batteries are being investigated and described. Polymer electrolytes have the advantage of high mechanical flexibility and compatibility with conventional manufacturing processes. However, their thermal stability and conductivity at room temperature are limited. In contrast, ceramic materials have many beneficial properties, which form the basis for new battery concepts.

Ambient-temperature secondary lithium SSB

With regard to room-temperature lithium batteries, one focus of the R&D activities at IKTS is on ceramic electrolytes based on oxide and phosphate materials (LLZO, LATP), which have a high electrochemical and chemical stability and ionic conductivity in the range of 10^{-3} to 10^{-4} S/cm. However, ceramics are brittle, potentially placing limits on its handling and lifetime. A particular challenge of this material class is the high sintering temperature required for densification, as well as the chemical interaction with the individual components of the composite electrode (active material, ionically conductive and electronically conductive phase) during co-firing. To resolve this challenge, the researchers looked at various approaches to reduce the sintering temperature of solid electrolytes. At Fraunhofer IKTS, NASICON-based structures, such as LATP ($Li_{1+x}Ti_{2-x}Al_x(PO_4)_3$) are investigated to develop strategies that achieve a reduction of sintering temperatures from 1100 °C to around 800 °C by using precursors as starting materials. However, chemical interactions of the active materials were observed during cofiring, which need to be avoided. These interactions are evident between NMC ($Li(Ni,Mn,Co)O_2$) and LATP at well below 800 °C. Further approaches are in development to resolve this challenge. In addition, sulfide electrolytes showing an exceptionally high ionic conductivity but limited electrochemical and chemical stability are utilized for electrochemical cell manufacturing and tests. Current research efforts at Fraunhofer IKTS focus on optimizing boundary layers in order to overcome these limitations. Sulfides can also be processed with typical ceramic technologies, such as tape casting, but do not require a sintering step. With this regard, processes for coating active materials are of special interest.

Ambient-temperature secondary sodium SSB

Low-temperature sodium batteries have so far been in the shadow of Lithium battery development, as they have lower energy densities than common lithium batteries. Current trends in the development of solid-state batteries suggest the advantages of sodium-based batteries over lithium chemistry. Numerous active materials have already been developed which show energy densities comparable to those of lithium chemistry but are based on readily available and environmentally friendly raw materials. The ionic conductivity of inorganic solid electrolytes for sodium is similar to that of established materials for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lithium, but processability with other components of solid-state batteries is much easier. Moreover, the integration of metal sodium as anode can boost energy density. A special glass-ceramic material group based on Na_2O-Y_2O_3-P_2O_5-SiO_2 (NaYPSiO), developed at IKTS, shows excellent processability using ceramic shaping technologies and high ionic conductivity (5 mS/cm) at 25 °C. Tests with sodium anodes on NaYPSiO electrolytes have shown low polarization resistance values. The use of this high-performance material in the development of battery components for solid electrolytes and active materials on the cathode side is the next step in realizing sodium-based systems for solid-state batteries.

High-temperature sodium SSB

While the previously mentioned battery types are used in the field of E-mobility, sodium-nickel chloride (or ZEBRA) batteries find commercial use in stationary energy storage solutions. They are low-cost since only nickel and rock salt are applied as active materials. Furthermore, their energy density is similar to that of lithium batteries (125 Wh/kg) and they typically operate at 300 °C. Fraunhofer IKTS is actively developing the entire chain of battery technology: from components, such as solid electrolytes and cathode materials, to battery cells in different designs (tubular, flat), to battery modules with integrated temperature management. The material beta-alumina has one of the highest ion conductivity levels found in solid electrolytes (~300 mS/cm at 300 °C and ~5 mS/cm at room temperature). It can generally also be used in room-temperature secondary sodium solid-state batteries. Beta-alumina is classically applied in tubular sodium-nickel-chloride batteries and produced by isostatic pressing. Fraunhofer IKTS has established several techniques for the straightforward shaping of betalumina, including tape casting, extrusion, uniaxial pressing and slip casting.

Conclusion

Solid-state batteries are an essential contribution to the future development of a sustainable energy economy. Ceramic materials and technologies are the focus of extensive battery research activities at Fraunhofer IKTS, because they can contribute to solving key technological challenges.

ARTEMYS

1 *LLZO pellet manufactured from powder synthesized at IKTS.*

2 *Pressed and tape-casted LATP electrolytes.*

3 *Sulfide electrolyte separator inside a cell with Swagelok housing.*

4 *100 Ah sodium-nickel-chloride cell – developed at Fraunhofer IKTS.*

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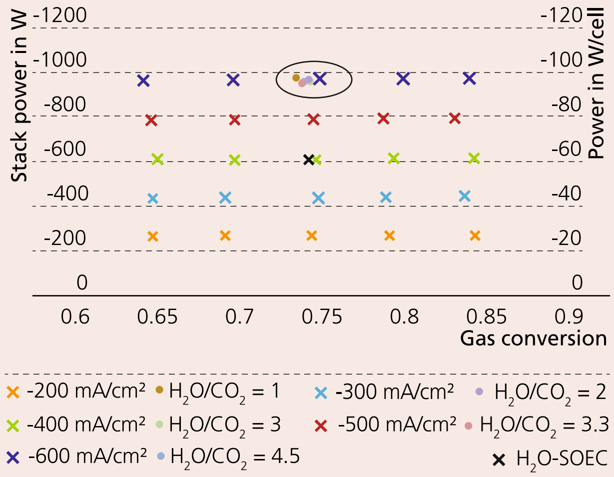

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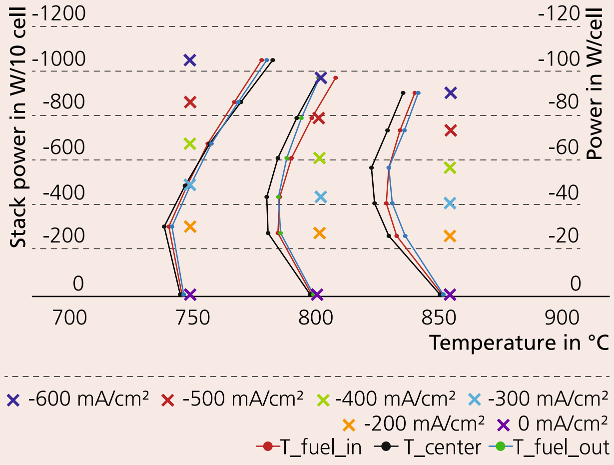

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SOLID-OXIDE CO-ELECTROLYSIS AS A KEY TECHNOLOGY FOR CO_2 UTILIZATION

Dr. Mihails Kusnezoff, Dr. Stefan Megel, PD Dr. Matthias Jahn, Dipl.-Ing. Sebastian Hielscher, Dr. Erik Reichelt, Dipl.-Ing. Gregor Herz, Paul Adam

SOE technology

The possibility of substituting crude oil with synthetic hydrocarbons produced from CO_2 and H_2O is of increasing interest worldwide as a way to decrease dependence on fossil resources and to limit CO_2 emissions. The coupling of solid-oxide electrolysis (SOE) technology and Fischer-Tropsch synthesis (FTS) is especially promising for the production of various types of hydrocarbons thanks to the possibility of integrating heat and utilizing by-products.

The reliable operation of solid-oxide cell (SOC) stacks in the co-electrolysis of H_2O and CO_2 is still considered a challenging technical task. Results on cathode-supported cells (CSC) reported in the literature show that operation in steam electrolysis and co-electrolysis modes below 800 °C brings with it considerable degradation rates. In contrast, electrolyte-supported cells (ESC) exhibit higher durability for electrolysis operation. Scientists at Fraunhofer IKTS have devised a CFY stack design that utilizes up to 40 high-power-density ESCs based on scandia-doped zirconia electrolytes. To prove their long-term stability, ten-cell stacks were tested in water electrolysis and co-electrolysis modes. A comparative analysis of the performance depending on operating temperature, feed composition and utilization was conducted for typical gas compositions for FTS (H_2O:CO_2 = 2) and methanation (H_2O:CO_2 = 3.3). The stack performance with a gas conversion rate up to 85 % at different temperatures in water and co-electrolysis modes at -600 mA/cm² is visualized in Figure 1. A comparison between water and co-electrolysis modes at similar operating conditions yields similar power consumption figures: at 830 °C and -600 mA/cm², 946 W_{el} are consumed in co-electrolysis mode and 943W_{el} in steam electrolysis mode. A higher Nernst potential of the $H_2O/H_2/CO_2/CO$-containing gas system was identified as the primary reason for the difference.

High-temperature electrolysis is an endothermal process, consuming not only electric energy but also heat. The heat can be provided internally by the cell resistance (i.e. ohmic and electrochemical losses) for thermally self-sustaining operation. The voltage needed for such an operation is called thermoneutral voltage (U_{TN}). In a system context, operating near U_{TN} is beneficial for practical applications. For this reason, the temperature distribution inside the stack in co-electrolysis at a gas conversion rate of 75 % was investigated. Figure 2 shows a performance map and the temperature distribution within the CFY stack. It is possible to conclude, based on the temperature distribution, that at low current densities most of the steam is converted at the stack inlet, acting as a heat sink. At current densities close to U_{TN}, the temperature profile inside the cell is homogenized.

Techno-economic assessment for SOE-based processes

Because of the advantages of SOE technology, such as high electric efficiency and direct formation of syngas from CO_2 and H_2O, the cells and stacks developed at IKTS are applied for system development. Process modeling tools are used to identify the optimal process design for a given production process. Additionally, the calculations allow for the identification of advantageous operating conditions for the SOE stacks in a system context. This feedback allows to deduce development


3


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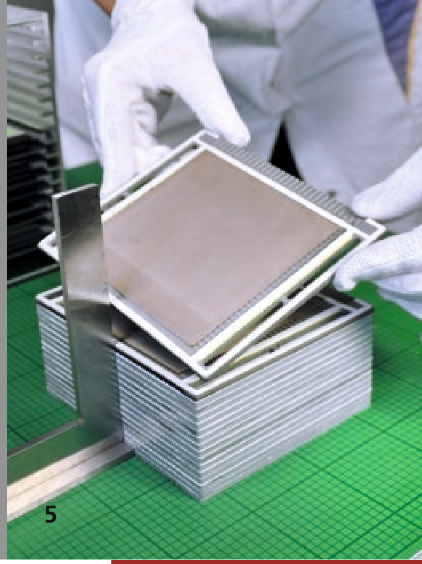
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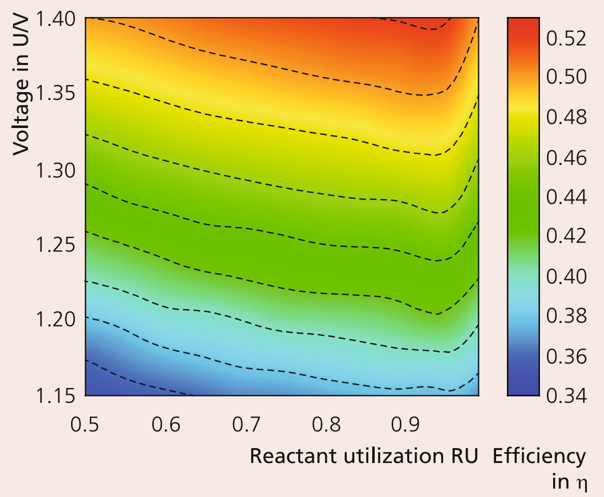
goals for the SOE components, creating a design loop that leads to technological improvements.

One of the processes studied is the coupling of SOE and Fischer-Tropsch synthesis. Not only was the achievable electric efficiency assessed for this process, its economic viability was also evaluated. Production costs for sustainable hydrocarbon products were calculated for different factors, such as costs for SOE production, electricity and CO_2. The results of this study showed that with increasing maturity of the SOE technology and with availability of renewable electric energy at reasonable costs, SOE-based processes look very promising with regard to the sustainable production of chemicals in the future.

Services offered

- Process development for SOE integration in chemical production processes
- Performance of techno-economic feasibility studies for electrolysis-based process concepts
- Design and testing of prototype units as proof of concept
- Design and testing of system components including SOE stacks and modules

Overall efficiency map of a system for wax production with MK352 stacks in SOE operation



STROM ALS ROHSTOFF

HydroMetha

FFG

1 *Stack performance as a function of gas utilization.*

2 *Relationship between power and temperature distribution in the stack.*

3 *Small-scale plant for demonstration of a coupled process for co-electrolysis and Fischer-Tropsch synthesis.*

4 *Liquid Fischer-Tropsch products.*

5 *Assembly of an MK352 stack from individual components.*

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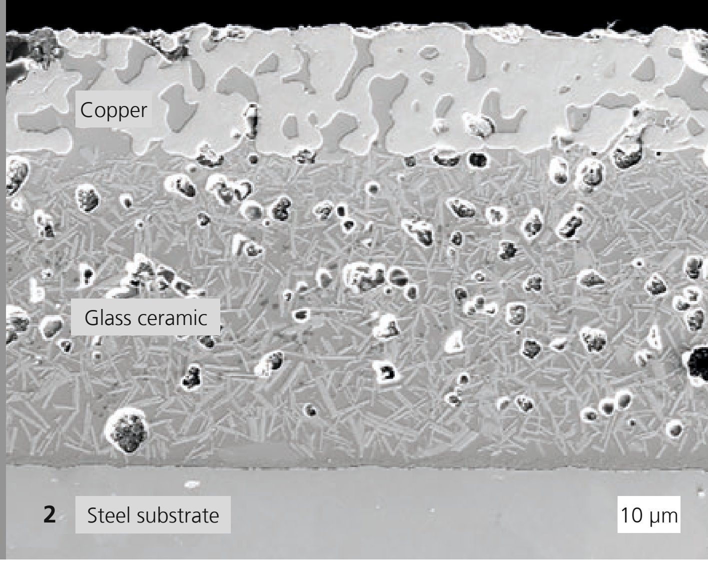


COST-EFFECTIVE HOT-SIDE INTERCONNECTS FOR THERMOELECTRIC GENERATORS

Dr. Axel Rost, Dr. Jochen Schilm, Dipl.-Ing. Mario Trache, Dr. Sindy Mosch, Dr. Kathrin Reinhardt, Dr. Stefan Dietrich, Dr. Tim Gestrich, Dipl.-Ing. Kerstin Sempf

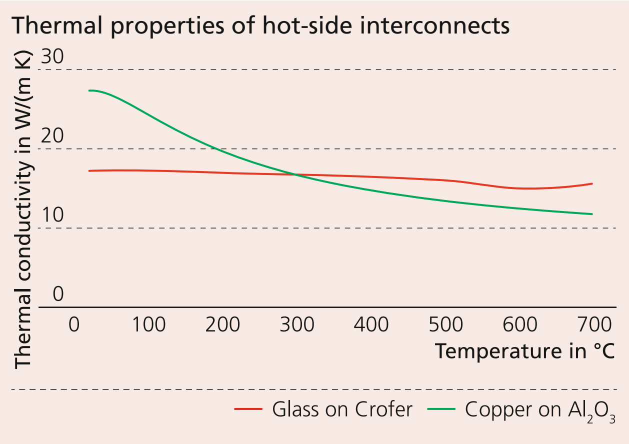
Using waste heat to generate power results in significant energy efficiency potentials. Thermoelectric generators (TEGs) offer the advantage of directly converting thermal energy into electricity without the use of high-maintenance moving components.

However, conventional TEGs use cost-intensive and toxic substances, such as bismuth or lead telluride, as active materials. These can be replaced by new, less expensive and more environmentally friendly materials, such as Half-Heusler alloys made of zirconium, titanium and tin. In addition, these materials allow operation at higher temperatures, which utilizes more waste heat. Due to the current layout of ceramic substrates with structured metallization, applied in multiple process steps, the production of these TEGs is currently still very cost-intensive.

As part of the EU INTEGRAL project, Fraunhofer IKTS has developed an interconnect technology using the more cost-effective ceramic screen printing technology. In this process, inexpensive steel substrates are provided with dielectric coatings based on structured glass ceramics. The developed glass ceramic materials, with a high coefficient of thermal expansion, are particularly suitable for use at temperatures up to 600 °C. They can be applied as pastes using screen printing technology in layer thicknesses of approx. 50 µm and serve as a dielectric insulation layer. Pastes based on copper and silver are applied in thicknesses of up to 200 µm. They serve as contact layers for the thermoelectrically active materials. The thermal conductivity of the developed hot-side interconnects equals that of metallized Al_2O_3 ceramics at high temperatures. Fraunhofer IKTS can thus offer the technology for cost-effective and environmentally friendly TEGs – even as multiple connectors with increased reliability. In addition, this approach enables the production of segmented and wireable hot-side contacts.

Services offered

- Interconnect technology for elevated temperatures
- High-temperature joining technology
- Development of ceramic and metal pastes for high-temperature applications



1 Hot-side interconnect elements for thermoelectric modules.

2 Cross-section of three layers: copper, glass ceramic, steel substrate.

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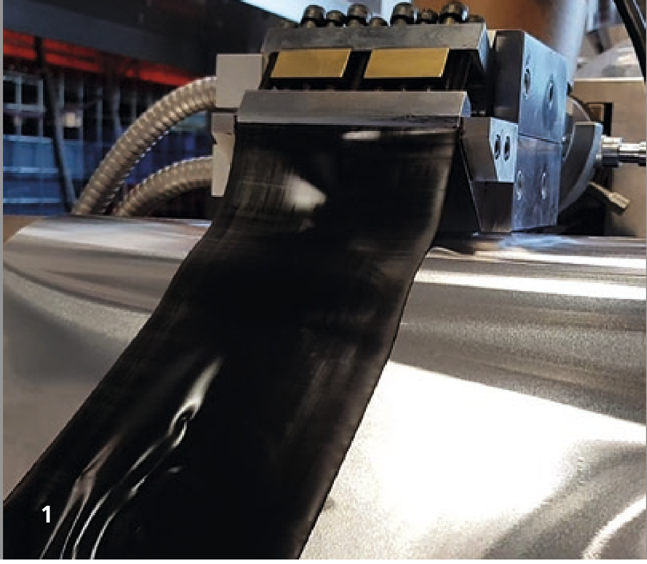

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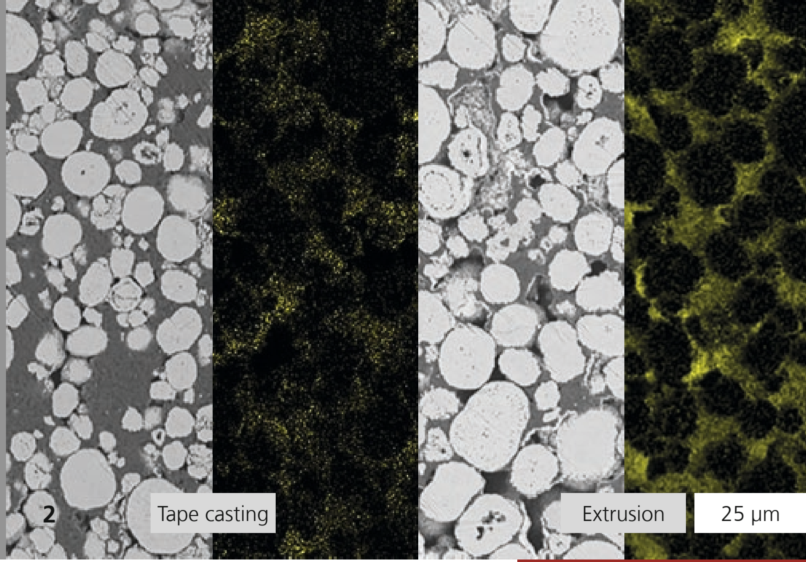

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EFFICIENT DESIGN TOOLS AND COATING PROCESSES FOR LITHIUM-ION BATTERY ELECTRODES

Dr. Sebastian Reuber, M. Sc. Jann Seeba, Dr. Christian Heubner, Dr. Axel Müller-Köhn, Dr. Michael Schneider, Dr. Tassilo Moritz, Dr. Mareike Wolter

User acceptance of electric vehicles is largely dependent on their driving range, fast-charging capabilities and acquisition costs. These criteria are directly related to energy and power density as well as the production costs of the Li-ion batteries employed. Electrodes with increased active material loading and thicknesses exceeding 100 µm are considered highly promising when it comes to increasing energy density and cost efficiency. However, the conventional casting processes for so-called high-load electrodes are severely limited regarding form stability and homogeneity, as well as their electrochemical performance. To tackle these issues, Fraunhofer IKTS develops innovative coating processes combined with model-based design tools.

Based on computer-aided numerical simulations of the electrode behavior and advanced electrochemical characterization techniques, Fraunhofer IKTS develops and validates application-oriented design tools, which can be directly implemented into manufacturing processes of Li-ion batteries. Important electrode parameters, such as layer thickness, microstructure and composition, are optimized for maximum energy and power density through the use of model-based processes. Additionally, predefined boundary conditions, such as assembly space or rate capability, are included and applied in practice to the electrode manufacturing process.

For the extrusion-based coating process developed at IKTS, a pre-mixture of active materials, additives and binder solution is dispersed well in a twin-screw extruder under high shear forces. The resulting pastes are extruded via a slot die, laminated onto a current collector tape and dried. By optimizing the geometry of the slot die and the rheological properties of the pastes, a continuous coating process is established (Figure 1). Compared to conventional casting processes, a distinctly higher solid content of up to 85 wt % is achieved. Accordingly, the required amount of solvents is lowered by 80 vol % and the corresponding drying time is significantly reduced. At the current level of development, the process enables manufacturing electrodes with high active material loads and coatings of up to 300 µm. At the same time, disadvantages of conventional casting processes, such as binder migration and adhesion problems for fast drying processes (Figure 2), do not occur in the developed high-viscosity pastes. The proper electrochemical function of the electrodes prepared this way has been successfully demonstrated for NCM-graphite full cells. Besides increased energy density on the cell level, the developed process yields substantial savings regarding materials and energy costs when compared to conventional casting processes. In a next step, the extrusion-based coating technology is transferred to a pilot process in the IKTS Battery Technology Application Center.

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ProZell HiLo

1 Continuous extrusion of high-load battery electrodes.

2 Comparative analysis of binder migration and homogeneity for casting- and extrusion-based electrodes subjected to a fast drying process.

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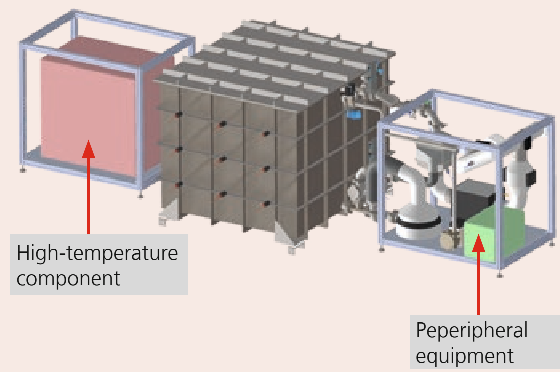

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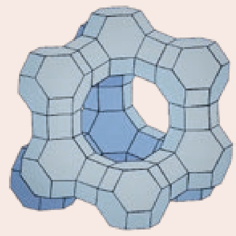

ZEOLITE Y (NaYBF)

Pore opening:	12-ring
Pore size:	0.75 nm
Si/Al:	2–5
Characteristics:	very hydrophilic
Water adsorbtion:	45 wt %

3

SEASONAL HEAT STORAGE SYSTEM WITH BODIES FORMED OUT OF ZEOLITES

Dr. Hannes Richter, M. Eng. Andy Vogel, Dipl.-Chem. Andreas Häusler

Hydrophilic zeolites have a high water adsorption capacity combined with a high adsorption enthalpy. For these reasons, zeolites are commercially used for short-term heat storage and for cooling. However, zeolite-based long-term heat storage solutions for using solar energy or waste energy from industrial processes have not yet reached the market. Fraunhofer IKTS researchers systematically investigated the adsorption properties of binder-free zeolite granules and zeolite honeycombs in order to determine under which conditions they can be used as seasonal heat accumulators. Binder-free zeolite granules, dried at various temperatures, were tested in a closed and in an open heat storage system. The released energy was determined by measuring the adsorption capacity, the heat and the local temperature curve. After drying at 300 °C and remoistening in a saturated steam atmosphere, a high adsorption capacity of 26 wt % H_2O was achieved for binder-free zeolite NaY granules. Temperatures of up to 80 °C were maintained for more than five hours. As expected, the adsorption capacity was lower at lower drying temperatures, which led to a shorter period of heat development. Nevertheless, the granules reached temperatures of 70 to 80 °C during water adsorption. Open and closed heat storage systems achieved the same results in heating and remoistening. But due to the low thermal conductivity and the very fast water adsorption in the granulate pile, large temperature differences were found at certain points, which can be reduced by constructive measures in the heat accumulator. Based on these results, a prototype zeolite heat storage system was designed and built. 900 liters of NaYBF zeolite granulate with a thermal capacity of 150 kWh were filled in between the closely spaced heat exchanger plates of the storage unit. In this closed system, energy could be thermochemically bound at an optimal temperature of 200 °C and in a 50 mbar vacuum. The temperature required for the activation of the zeolites can be provided in the summer by solar heat collectors or through electrical heating with solar power. In this way, the thermochemical energy can be stored seasonally in the zeolite structure.

Services offered

- Development of new zeolite structures
- Application-related design and development of binder-free zeolite bodies
- Configuration and design of heat storage systems

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autartec

1 Design of a prototype heat storage system.

2 Zeolite beads in heat storage device before closing.

3 Structure and properties of zeolite NaY.

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1

NUTRIENT RECYCLING FROM ORGANIC RESIDUE MATERIALS

Dipl.-Ing. Marc Lincke, Dr. Burkhardt Faßauer, Dipl.-Ing. Björn Schwarz

Organic residues such as slurry, manure, fermentation products, sewage sludge and biogenic production residues from the industry are generally a cost-effective and sustainable alternative to mineral fertilizers. They contain plant nutrients such as phosphorus, nitrogen and potassium as well as trace nutrients in different concentrations, but mostly water. Direct application is now severely restricted by law due to soil over-loading and partial contamination with pollutants, such as heavy metals, drug residues or microplastics. This is why in many places, especially in agriculture, major storage problems persist with regard to liquid manure and fermentation products from biogas plants. In addition, adjusting a fertilizer specifically for optimal effect on an individual crop is virtually impossible due to the often heterogenic composition of these substances. Under certain circumstances, this can lead to over-fertilization, undesirable input of substances such as nitrate into the groundwater or of climate-damaging nitrous oxide into the atmosphere.

The valuable components of these organic residual substances, i.e. nutrients and carbon, can and should nevertheless be used materially and energetically in the interest of sustainable regional economic cycles. To this end, the **abono**care® project was started in 2019 with the aim of developing technologies for complete nutrient recycling. A main focus is the processing of phosphorus- and nitrogen-containing substances into fertilizer products. Additionally, various technologies for the separation, processing and handling of organic waste products will be developed. Nine partners from the industry and six research institutions take part in **abono**care®, an initiative scientifically coordinated by Fraunhofer IKTS and funded with 10 million euros from the German Federal Ministry of Education and Research (BMBF).

Services offered by Fraunhofer IKTS as part of the abonocare® project:

- Development of ceramic membranes for phosphorus equilibrium shift during hydrothermal carbonization
- Development of filters and processes for hot-gas filtration for the separation of heavy metals directly in sewage sludge incineration
- Development of ceramic membranes for the direct extraction of ammonium from process waters stemming from biogas production as well as from vapors stemming from drying and stripping
- Development and testing of PAA-free flocculants based on starch for solid/liquid separation
- Development of analysis methods along the entire process chain

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1 *Fractionated digestate and end products, such as fertilizer granulate, liquid fertilizer and litter pellets.*

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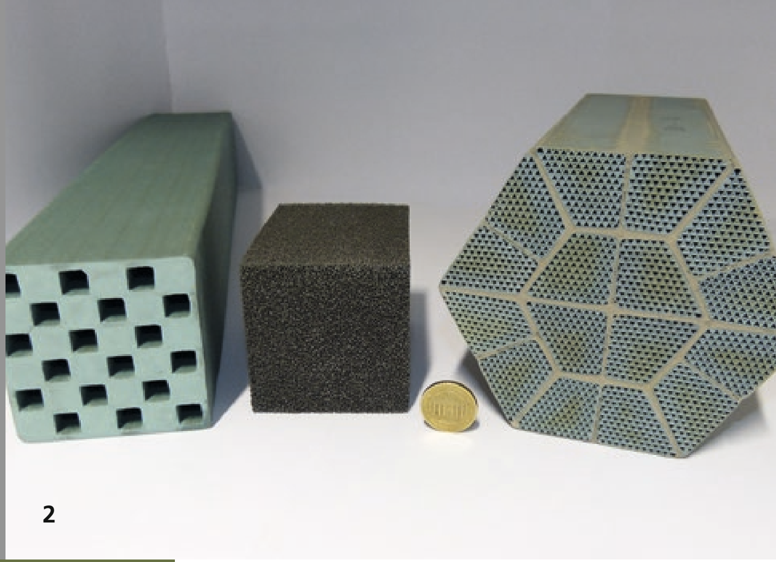


2

CERAMIC HOT GAS FILTERS FOR THE RECOVERY OF REUSABLE MATERIALS AND GAS CLEANING

Lasse Fabian Köhl, Dr. Uwe Petasch, Dipl.-Krist. Jörg Adler

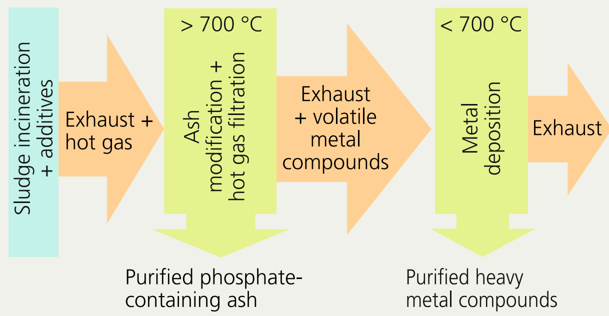
Ceramic filters capable of back-cleaning are used for the dedusting of hot gases and the recovery of recyclable materials from hot exhaust gases at operating temperatures of up to approx. 800 °C and sometimes above. For this application porous ceramic materials used because of their excellent temperature stability and chemical resistance, their mechanical strength and their superb filtration performance.

Fraunhofer IKTS develops and improve filter materials for hot gas filtration, technologies for the production of innovative filter geometries, as well as new hot gas filter applications. Current developments are concerned with the hot gas dedusting of exhaust gases from the steel and lime industry. Most recently, the separation and cleaning behavior of various dusts was investigated and the applicability of hot gas filtration was demonstrated with the aid of a special test rig set up for this purpose. By combining this with membrane-supported processes, it is also possible to extract CO_2 from hot and dust-enriched exhaust gases. A further process development at IKTS focuses on the environmentally relevant topic of phosphorus recovery from the mono-combustion of sewage sludge. By modifying the sewage sludge with special additives, the heavy metal load of the resulting ash fractions containing phosphate will be significantly reduced. The process is based on the targeted generation of volatile heavy metal compounds that pass into the gas phase at high temperatures and are separated from the combustion ash by hot gas filtration. The corrosive atmosphere in combination with temperatures of up to 1000 °C requires the use of ceramic filters that are particularly resistant to high temperature as well as chemicals attacks. In-situ modification makes it possible to reduce the specific energy consumption required for recovering valuable materials compared with processing the ash separately.

Services offered

- Development and testing of materials and filters for hot gas filtration and exhaust gas catalysis
- Development of manufacturing processes for the industrial production of complex ceramic filters
- Test rig investigations of the hot gas filtration behavior of industrial dusts

Process scheme for the selective separation of re-usable materials in the incineration of sewage sludge



1 Hot gas filtration test rig for honeycomb filters or filter candles.

2 Various ceramic filter elements.

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1

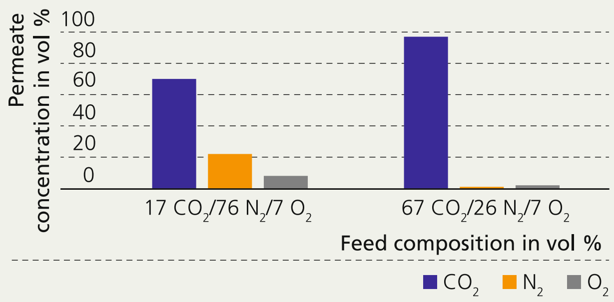
2

EFFICIENT CO_2 RECOVERY FROM INDUSTRIAL EMISSIONS THROUGH MEMBRANE SEPARATION

Dr. Norman Reger-Wagner, Dr. Hannes Richter, Dr. Marcus Weyd, M. Sc. Matthias Bernhardt, Dipl.-Ing (FH) Susanne Kämnitz, Stephanie Kaiser

In order to control CO_2 emissions at national and international levels, the acquisition of emission certificates has become mandatory. Particularly affected by this policy are industries which are inherently unable to eliminate the production of CO_2 for technological reasons, such as cement and chalk plants. In these cases, it is necessary to separate the generated CO_2. Ideally it can be converted afterwords locally into non-fossil fuels or chemicals. The separation of CO_2 from highly dusty exhaust gases requires a dedusting unit (see page 44) as well as an efficient gas separation unit based on membranes. The goal is to operate both cleaning processes at elevated temperatures, first to avoid expensive cooling and second to utilize hot CO_2 – ideally at its reaction temperature – for subsequent process steps, which is required for all CO_2 conversion reactions. At IKTS, all competencies are available for the development, manufacturing and testing of thermally stable ceramic membranes – from porous ceramic carrier structures to the final separating membrane layer. During multi-day on-site test runs with real exhaust gases at steel, chalk and dolomite plants, our improved carbon membranes generated a CO_2 flow with more than 70 % purity using a single-step separation setup (diagram, left bar). The application of a two-step separation led to CO_2 purities above 97 % (digram, right bar), which enables direct chemical conversion. A main commercial factor for membrane separation of CO_2 is the manufacturing cost of the membranes. This is being addressed in current activities by upscaling the manufacturing process as well as increasing the membrane area for each support.

CO_2 separation performance of carbon membranes for industrial exhaust gases with single (left) or double (right) membrane stage at 140 °C



Services offered

- Development of gas-separating, inorganic membranes, in particular for the treatment of exhaust and natural gas, biogas, and for the chemical industry
- Customer-specific gas separation tests
- Planning and construction of membrane plants for gas separation up to pilot scale
- Development of membrane reactors and their processes for increasing yield or selectivity in chemical reactions

DBI GUT Gas- und Umwelttechnik GmbH

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1 *Test facility for on-site assessment of improved carbon membranes.*

2 *Operation of the test plant for CO_2 separation in containers at the steel, chalk and dolomite plant.*

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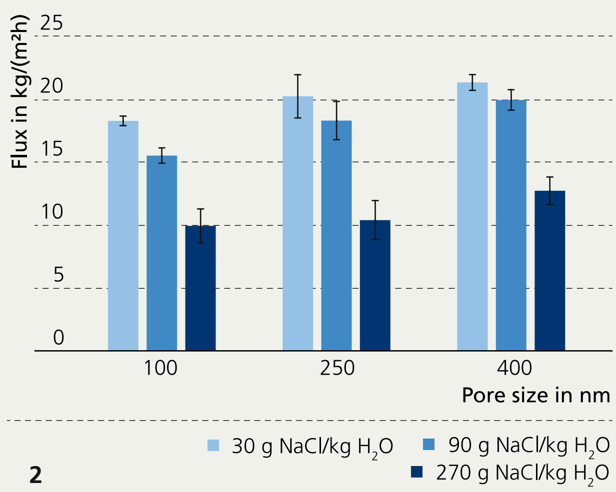


2

DESALINATION OF HIGH SALINITY SOLUTIONS WITH MEMBRANE DISTILLATION PROCESSES

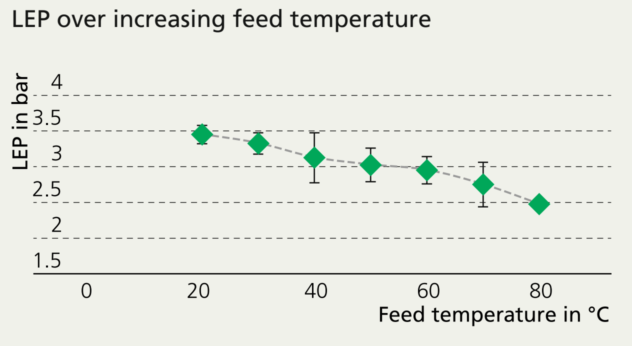
M. Sc. Johann Schnittger, Dr. Marcus Weyd

In order to meet the global fresh water demand and as a part of integrated environmental protection, desalination processes have become increasingly relevant. However, well-established conventional desalination technologies still have specific limitations: they are not viable for higher salinity levels, they are difficult to customize, require a lot of space and are prone to corrosion. As a hybrid process, membrane distillation (MD) combines the advantages of membrane-based and thermal processes: low sensitivity to high salinity levels, utilization of low-grade energy sources, modest space requirements, modular expandability and the ability to integrate with other technologies. Until now, MD has mainly used polymer membranes. The treatment of high-saline or aggressive aqueous solutions (e.g. abrasive properties, extreme pH, or the presence of solvents) as well as Zero-Liquid-Discharge applications could require the utilization of robust ceramic membrane systems. A potential field of application is for instance the treatment of drainage and waste waters from the petroleum and mining industries.

Functionalization of the membrane surface expands the range of applications of ceramic microfiltration membranes

Fraunhofer IKTS uses macroporous ceramic membranes (Al_2O_3, TiO_2, cordierite, mixed oxides) in MD. Their otherwise hydrophilic surface properties were functionalized at IKTS to produce a pronounced hydrophobicity. This ensures that the feed only passes through the membrane in vapor form, not as a liquid phase. The extent and stability of the hydrophobic characteristics are validated by contact angle measurements and liquid entry pressure (LEP) tests.

Single- and multichannel tubes were tested successfully in different MD configurations while varying relevant process parameters. For instance, when thin TiO_2 single-channel tubes were used, it was possible to determine permeate fluxes of more than 25 kg/(m²h) as well as permeate qualities below 2 µS/cm in a vacuum MD configuration. This makes these robust ceramic membrane systems ideal for separation tasks, for example in aggressive waters with a high salt content.



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1 *MD test rig in direct contact configuration.*

2 *Flux of TiO_2 single-channel tubes over pore size and feed salinity.*

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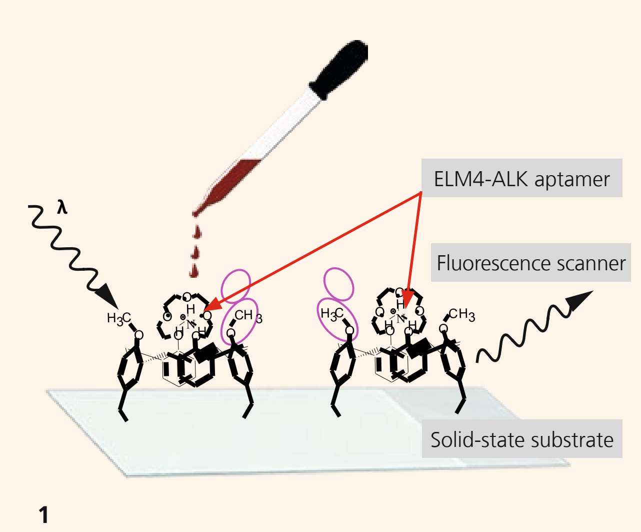

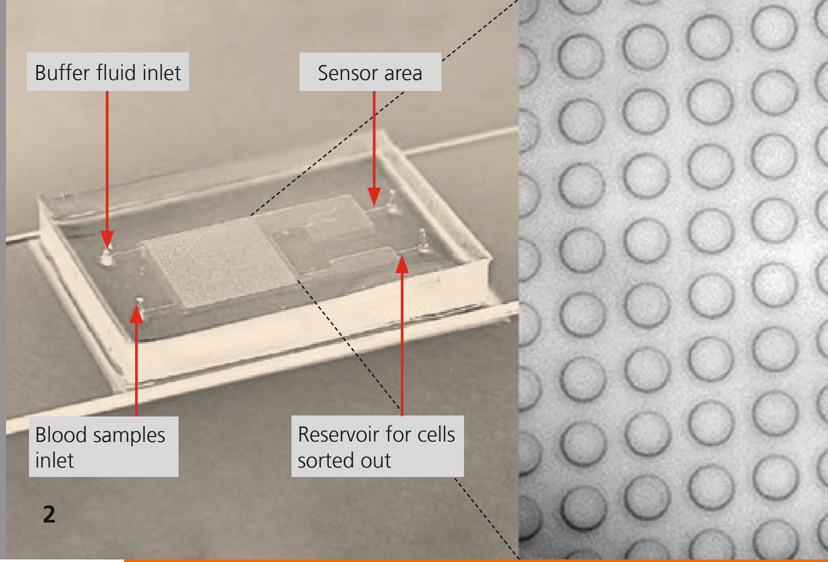

MICROFLUIDICS FOR APTAMER-BASED BIOSENSORS

Dr. Natalia Beshchasna, Ragul Sivakumar, Dr. Jörg Opitz

In an ageing society, the improvement of quality of life is one of the most important goals of global research efforts. The field of biosensors is one of the essential building blocks for preserving and improving the health status as it enables quick, precise and mobile analysis of biomarkers, pathogens or pollutants. As part of the Eureka joint project BIOSTAR17, IKTS is developing a novel diagnostic biosensor for the detection of the EML4-ALK fusion protein, a marker for non-small-cell lung cancer in the blood. The detection of this protein is based on its interaction with special highly sensitive receptors (aptamers), artificially manufactured antibodies made of self-folding single-stranded DNA chains or peptides. For this purpose, blood and aptamers are brought into contact on a microfluidic chip by firmly immobilizing the aptamers on a glass substrate and transporting the blood in channels to the aptamer. In order to develop a reliable packaging concept for the biosensor, the polydimethylsiloxane (PDMS)-based microfluidics and the relevant system technology were established at Fraunhofer IKTS. Lithographic technologies (laser, UV and soft lithography) were used for constructing microfluidic channels and assembling the PDMS package with the functionalized solid-state substrate. The compatibility of these technological steps with the sensitive aptamers was subsequently tested. Early analyses of fluorescent-microscopic images indicate that no disturbance of aptamer immobilization is observed. Using deterministic lateral displacement (DLD), the target molecules were separated from other blood components that can negatively influence the sensor measurements. Different sensor designs and sensor chips were developed and tested for this passive cell sorting method. Initial trials with test fluids confirm a dependency of the sorting function on the geometry of the microfluidic channels, as well as on particle size, flow rate and viscosity. The current work of the project consortium focuses on optimizing the sensor design and developing further the aptamers, as well as on sensor tests with patients' blood in cooperation with Asan Hospital in Seoul, South Korea. The developed biosensor concept will prospectively be transferred into a single-use diagnostic device for rapid detection of non-small-cell lung cancer.

Services offered

- Development of application-oriented sensor packaging designs including biocompatible sensors
- Development of electrochemical, ceramic-based sensors
- Assay development, biochemical functionalization, sensor measurements
- Sensor testing and evaluation under medium influence
- Development and fabrication of microfluidic structures

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1 Sensor principle of ELM4-ALK biosensor.

2 Sensor package based on PDMS.

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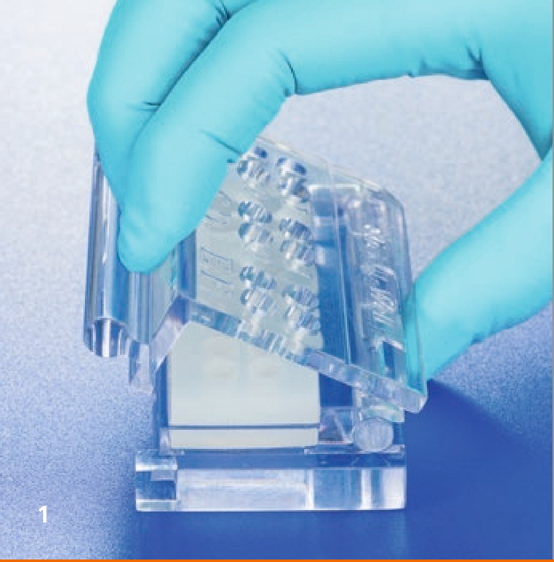
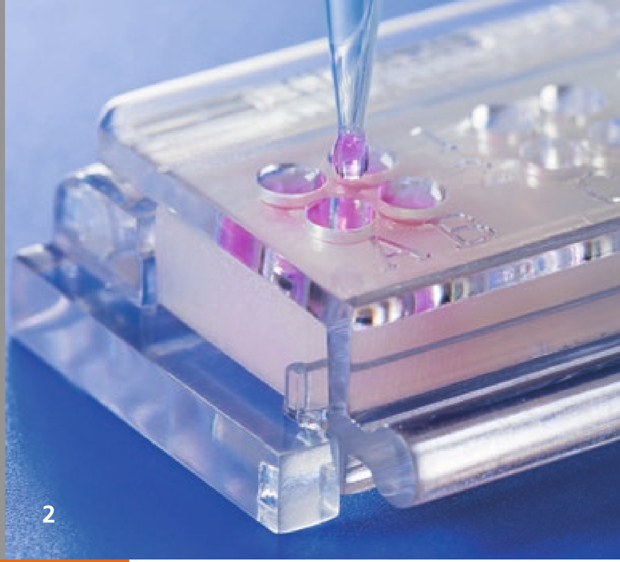


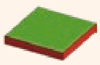
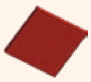
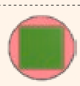
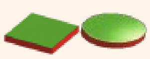


BIOMATERIAL TESTING 2.0 – STANDARDIZED, RESOURCE-EFFICIENT: ClicKit-Well

M.Sc. Constantin Ißleib, Dr. Susanne Kurz, Dipl.-Ing. Elisabeth Preuße, Dr. Juliane Spohn

The rapid development of patient-specific innovative implant materials requires reliable, standardized test procedures and systems. These are vital for a preventative evaluation of material safety and functionality. Currently, biological tests are carried out in plastic cell culture plates (gold standard). In this method, samples are placed into an indentation (well). However, this leads to a number of sources for errors (see table).

Analytical sources of error during material testing in the cell culture plate (gold standard) and elimination of those due to the specifically developed in-vitro test system

Sources of error (cell culture plate)		In-vitro test system
	Sides and edges	Only the treated side is investigated
	Bottom side (incl. ID tag)	Only the treated side is investigated
	Influence of environment is dependent of material dimension	Influence is identical on all material samples
	Differences in material dimensions	Standardization for different material sample dimensions

Novel in-vitro test system (ClicKit-Well)

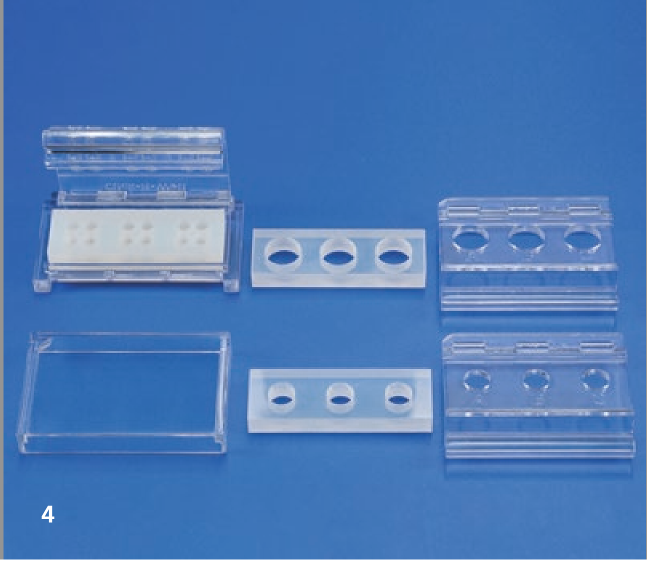
To reduce these errors, an in-vitro test system, "ClicKit-Well" (DE 10 2018 221 415.8, 12/18), was developed at Fraunhofer IKTS. The device creates standardized surface areas and wells (analog to common cell culture formats). This is achieved by attaching a deformable, perforated frame on top of the test material sample. Biological material can be introduced into the created wells and the interaction with the test material sample can be evaluated. The specific construction of the test system tolerates various surface characteristics (e.g. different roughnesses) and enables execution of multiple tests on a single material sample.

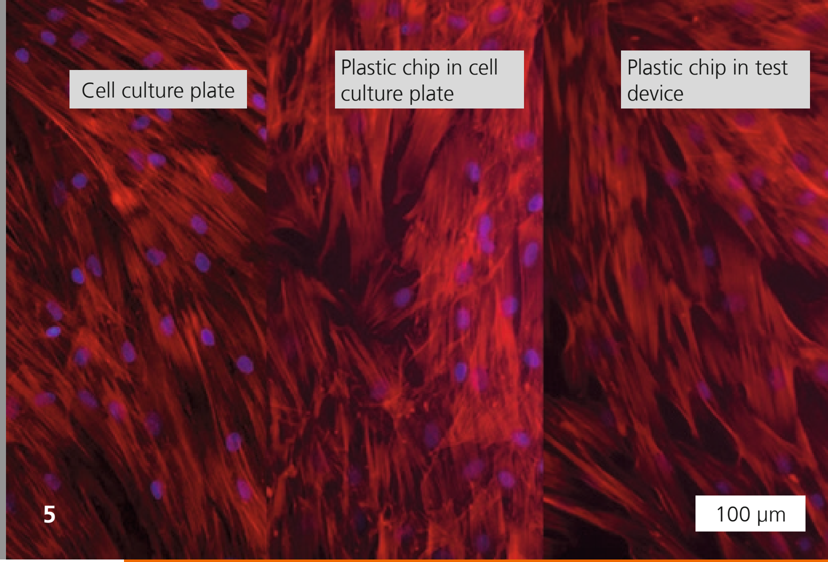
The in-vitro test system limits the contact of the biological material and the material sample to the surface that is to be tested. The specifically developed closing mechanism allows for a lasting, fluid-tight seal between frame and test material sample. The test system has a modular design and is constructed in the established 96-well, 48-well, and 24-well cell culture plate formats. The frame of the 96-well format version is designed so that up to four wells are generated at once on one test material sample. A covering lid that can be placed on the assembled test system makes sterile work possible.

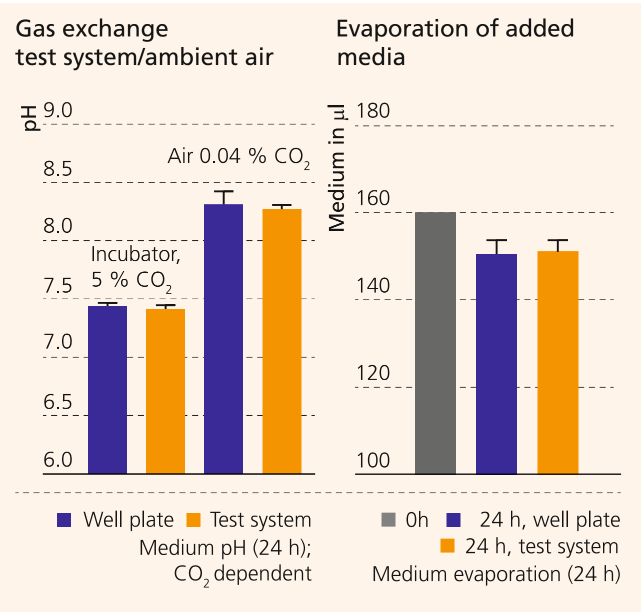
The new approach – creating standardized surface areas on test material samples – provides a consistent test scenario that is more independent from material dimensions and minimizes the current sources of error of in-vitro testing.

Feasibility study

The gas exchange between test system and ambient air as well as the evaporation rate of added medium compared to the standard cell culture plate were tested in feasibility studies. To achieve ideal growth conditions of cultivated cells, it is necessary to ensure the gas exchange with the ambient air. Using a bicarbonate media buffer system, the ambient air in the incubator contains 5 % CO_2 by default.







The proper gas exchange was tested by determining the pH value of the cell culture media after 24 hours of incubation in ambient air which contained 5 % CO_2 and 0.04 % CO_2 (Figure: Gas exchange). The incubation of the medium in ambient air containing 0.04 % CO_2 resulted in the same increase in pH value for both the in-vitro test system and the cell culture plate. As expected, the media is buffered around an ideal pH value of 7.4 when incubated in the test system and the cell culture plate in ambient air containing 5 % CO_2. Thus, the desired gas exchange with the ambient air and the test system could be demonstrated based on the dependence of the bicarbonate buffer system on the CO_2 content in the surrounding ambient air. Similar results were shown for the analysis of the evaporation rate of the media over the course of a 24-hour incubation at incubator conditions (37 °C, humid atmosphere) (Figure: Evaporation). In a comparative cell culture experiment, human bone marrow stem cells (MSCs) were seeded into a 96-well cell culture plate and on plastic material samples that were placed in a cell culture plate as well as in the in-vitro test system at a density of 2.5 x 10^3/cm^2/0.5 ml. Following a 24-hour incubation period, a nearly identical image of cell density and spread evolved in all three test scenarios.

The results show that the in-vitro test system is suitable for cell cultures. The next research phase will validate the qualification of the test system for broad use in the cell culture, e.g. for cell secretion and cell metabolism analysis. Technical requirements for market-relevant applications will be implemented and investigated.

Services offered

- Biological material assessment (safety and efficacy)
- Cell biological assays for direct application on material surfaces
- Miniaturization of biological in-vitro tests
- Development of standardized test scenarios
- Bio-interface studies: surface effects

1 *The in-vitro test system "ClicKit-Well" (DE 10 2018 221 415.8, 12/18) enables standardized testing directly on the material, with reproducible results.*
2 *Cell test in the 96-well format.*
3 *Examples for material samples.*
4 *Individual components of the test system.*
5 *Cell density and spread in various test scenarios.*

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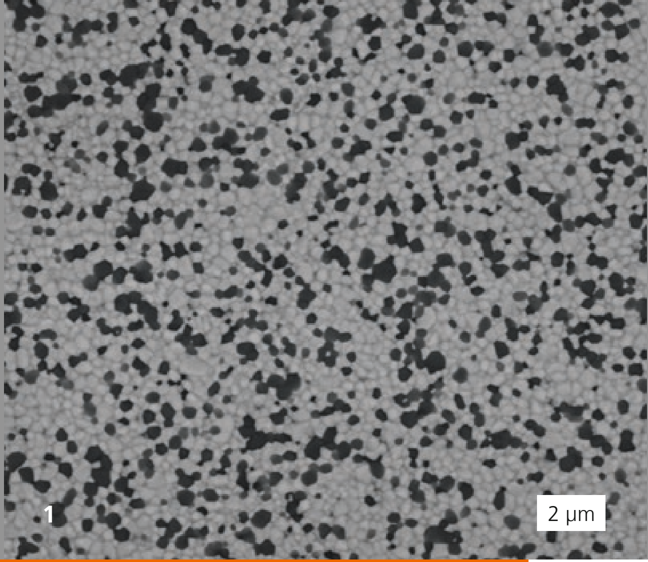


CERAMIC BONEPRESERVER – CERAMIC RESURFACING PROSTHESIS FOR THE HIP JOINT

Dipl.-Chem. Martina Johannes, Dipl.-Ing. Olaf Sandkuhl

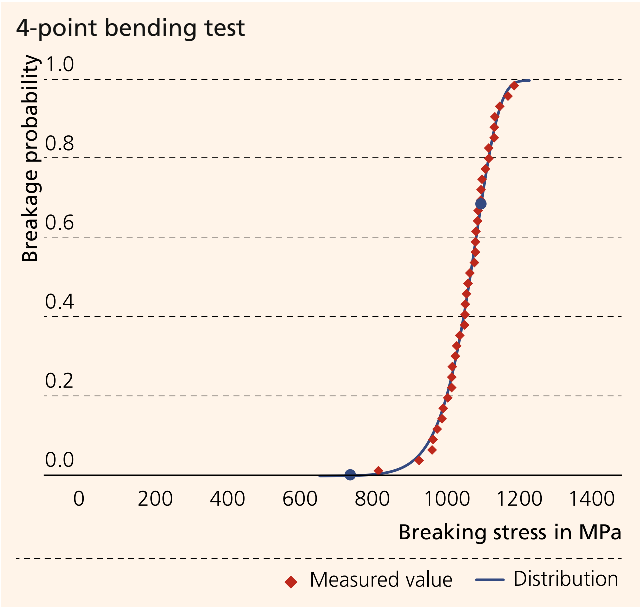
The only resurfacing prostheses available today are made of metal CoCrMo alloys. These cause metal abrasion, with particles and dissolved metal ions being detectable both in the surrounding tissue and in the blood. This may lead to metallosis disease, which causes irritation, infections, allergic reactions and pseudotumors. Fraunhofer IKTS is part of a collaborative research project, which aims to realize a metal-free ceramic surface replacement for the endoprosthetic reconstruction of the human hip joint. To that end, Fraunhofer IKTS has joined with medical technology manufacturer Mathys Orthopädie GmbH to develop constructive and manufacturing solutions for the fabrication of a femoral cap and a monolithic acetabulum made of ATZ dispersion ceramics (alumina-toughened zirconia).

Fraunhofer IKTS uses a slip casting process to achieve the shape of the acetabulum. The surface of the ceramic component is structured during the shaping process, so that it does not need to be subsequently processed with subtractive or additive methods. The first half shells with structured surfaces have been produced and the molded ceramic surfaces have been characterized. Various alumina- and yttrium-stabilized zirconia powders from different price segments have been processed as part of the project. Figure 1 shows the structure of such ATZ dispersion ceramics.

The mean grain size at a sintering and HIP temperature of 1450 °C for the light phase (TZ3Y) is at 350 nm and for the dark phase (alumina) at 300 nm. The four-point bending test (EN 843-1) determined that the Weibull parameters were promising: $\sigma 0$ = 1110 MPa and m = 18.5.

Strength distribution

In the further course of the project, investigations will be carried out to learn more about the component strengths of hip shell prototypes. As a result, surface replacement prostheses will be developed which offer a longer service life and are better tolerated by the patient.



1 FEREM of the structure of ATZ dispersion ceramics.

2 Half shells structured via slip casting process.

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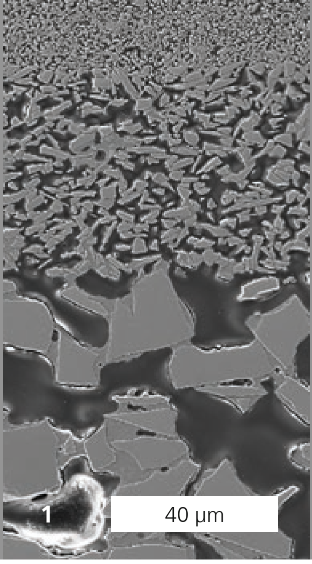
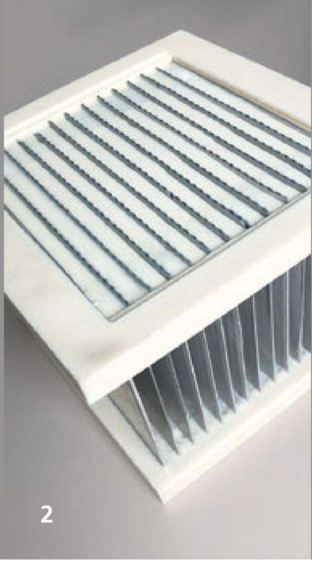
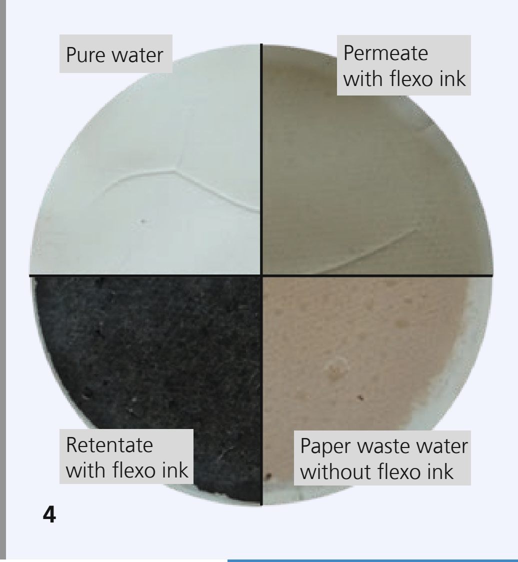






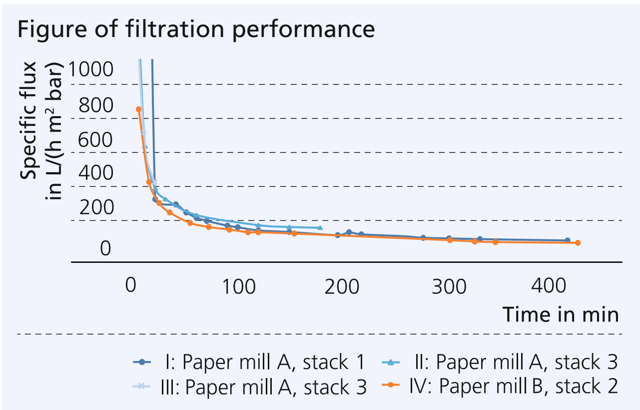
CIRCULATION WATER TREATMENT OF CRITICAL PRINTING COLORS WITH CERAMIC MEMBRANES

Dipl.-Ing. Franziska Saft, Dipl.-Ing. Anne Deutschmann, Dipl.-Ing. Heike Heymer, Dr. Hans-Jürgen Richter

As graphic papers are increasingly produced from waste paper, the removal of printing inks is an essential and indispensable part of the recycling process. Using cost-effective high-performance ceramic membranes, a complementary innovative deinking process was developed at Fraunhofer IKTS, which removes hard to deink or even non-deinkable ink residues in the water cycle of waste paper mills. The need results from a lack of treatment processes in the waste paper cycle and, at the same time, an increase in the amounts of such critical print products. An ongoing AiF project hosted by the pulp and paper industry in cooperation with the TU Dresden managed to determine a ceramic filter configuration for the removal of such colors and investigated it with model and real waters. Corrugated ceramic membranes of glass-bonded SiC are produced by ceramic tape casting, structuring and joining, which allows for subsequent co-firing of the multilayer composition. Finest commercial SiC powders with close grain distributions and D_{50} values between 0.3 to 1.2 µm were investigated for the dip-coated membrane layer. Evaluative filtration tests with flexo-colored model water found that the SiC powder with D_{50} = 1.2 µm and the resulting pore size distribution of D_{50} = 0.25 µm is able to remove flexo-color particles completely. The multichannel elements were used to develop filtration stacks for cross-flow filtration and for use as submerged membranes. Waters from two paper mills were filtered using the different stack variants. As a result, it was possible to achieve a reproducible filtration performance with different water qualities (diagram). In addition, it is possible to reliably produce filtration stacks (Figure 2) with which flexo-color particles can be almost completely retained. The quality of the permeate was also evaluated for turbidity (reduction by 99 %) and concentration of flexo-color particles on the basis of the brightness value "Y" of the test filter paper after permeate flow. The permeate has a Y of 74 compared with pure water, which has a Y of 97, while the recycled water of the paper mill has a Y of 56, compared with the retentate enriched with flexo-ink particles of 12 (Figure 4).

Services offered

- Material and technology development for ceramic membranes
- Filter module development and production
- Upscaling and commercialization



Forschungsnetzwerk Mittelstand

1 *Filter structure of SiC membrane.*

2 *Stack for cross-flow application.*

3 *Feed (l) and permeate (r).*

4 *Evaluation of water quality.*

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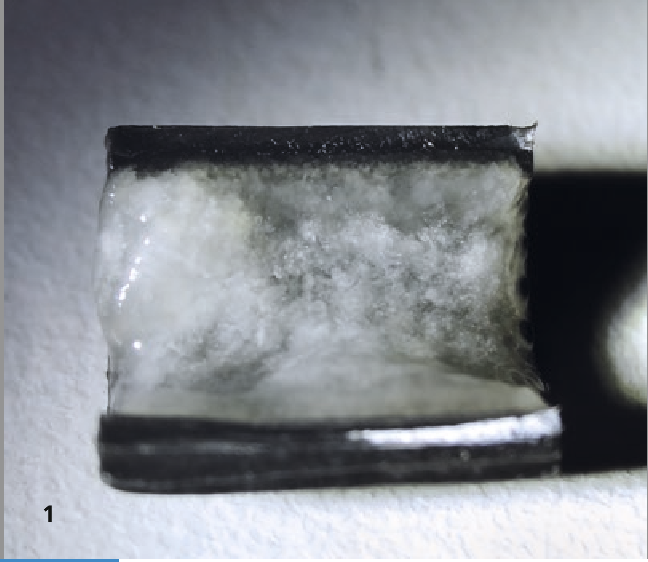

WATER

TREATMENT OF COMPLEX INDUSTRIAL PROCESS WATERS WITH HIGH SALT CONTENT

Dipl.-Ing. André Wufka, Dr. Burkhardt Faßauer

Challenges in treating saline waste and process waters

Water is not only a valuable food item but also an essential factor of production and a resource that sometimes limits growth. Attempts to extend production in the chemical, food, pharmaceutical and processing industries often fail because of insufficient water treatment capacities. Therefore, intelligent recycling and innovative waste water treatment technologies are becoming increasingly important. Particularly challenging are high-salt waste waters or process waters, which often also contain significant loads of organic matter. For repeated use of the water, these organisms must be eliminated. However, due to the damage and inhibition of the microorganisms associated with the high salt load, no cost-effective conventional biological aerobic or anaerobic process can be used. Thus, treatment is currently often complicated and expensive.

Technological approaches

Within the framework of several industrial projects, researchers at IKTS have developed and tested specific process combinations that enable the industry-specific process waters to be thoroughly cleaned despite the high salt concentrations, for example in waste water from pulp production (carboxymethylcellulose and methylcellulose), silicone chemistry, ion exchange and membrane production, as well as from the food industry. Each of these industry-specific waste waters has its own material composition. Therefore, IKTS offers a very broad range of technological approaches for economical and secure solutions for the customer. For example, in addition to conventional/traditional processes used for the anaerobic and/or aerobic reduction of organic pollution in submersed, fixed and suspended bed systems, newer methods also include physicochemical processes, such as ceramic-based membrane filtration, combined with chemical (precipitation, extraction) and thermal (evaporation, stripping) processes for the reduction of nutrients. In addition, special photo-, sono- and electro-oxidative processes, and electrodialysis based on special ceramic high-performance components are also part of the competence portfolio of IKTS.

Thus, IKTS has extensive, practical process know-how, many years of experience and the necessary material expertise to provide customer- and industry-specific solutions for the economic treatment of complex industrial process waters, even where conventional technologies fail due to high salt loads.

1 Plastic carrier with immobilized microorganisms for the purification of saline waste waters.
2 Fertilizer and water recovery from saline process waters.

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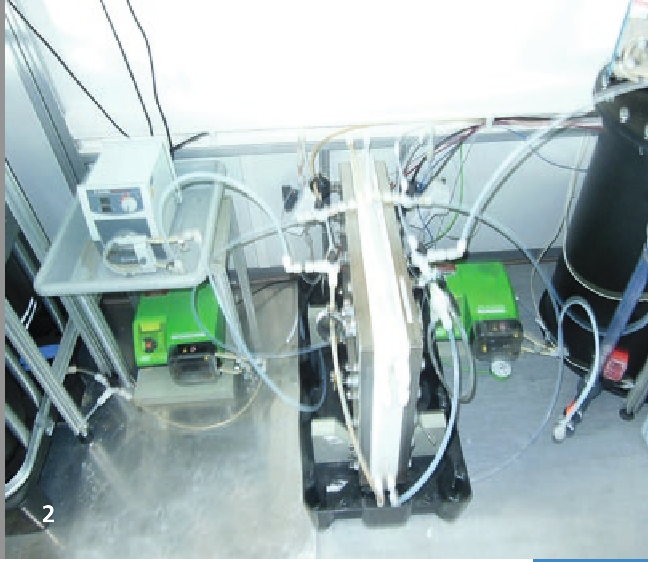

2

COMPARATIVE LONG-TERM INVESTIGATION OF PESTICIDE REMOVAL TECHNOLOGIES

Dipl.-Chem. Hans-Jürgen Friedrich

There has been increasing public concern in recent years about the ongoing contamination of fresh and ground water by pharmaceutical residues. In addition to medical deposits such as antibiotics, waste resulting from pesticides has become increasingly problematic. Pesticides are easily washed out, especially from sandy soils, to reach ground and surface waters. In the case under investigation here, the contamination of the ground water by the pollutant Bentazon, a broadband herbizide, lead to the closure of a drinking water well with a rated capacity of 20 m^3/h in a municipal waterworks.

Water purification processes in long-term trials

In order to prevent such drastic measures in the future, scientists at Fraunhofer IKTS examined and evaluated the efficacy of established technologies for the separation of Bentazon from well water: electrochemical incineration (EI), adsorption at activated carbon (AC) and reverse osmosis (RO). Oxidation by means of UV light, a method that had also been considered initially, proved to be unsuitable in preliminary tests. As part of this project, a pilot plant for the waterworks was specially planned and installed on site. Subsequently, all three methods were tested over a period of four months in continuous operation with a throughput of up to 80 l/h – partly as combined processes. All processes ran without failure. As the results (table) show, each of the methods is generally capable of separating the contaminant. Despite this, the real removal of Bentazon is only possible by electrochemical oxidation, which yields CO_2 as the main product. With 0.5 kWh/m^3, the energy consumption of the electrolysis is comparatively low.

Comparison of methods

Method	EI	AC	RO
Throughput (l/h)	36	12.5	80
Concentration at outlet (µg/l)	< 0.1	< 0.1	< 0.1
Elimination of Bentazon	yes	no	no

The adsorption at activated carbon is also effective but for large-scale applications an additional pretreatment of the pumped water is needed, creating additional disposal costs. Reverse osmosis also permitted an almost complete separation of Bentazon. However, the treated water is desalinated so that it is no longer drinking water and has to be remineralized. More importantly, RO requires elaborate and costly pretreatment, such as deironing and softening by ion exchange. In addition, large amounts of concentrates are generated, which amount to approximately 25 % of the feed water stream and have to be disposed of.

1 *Deep well of a waterworks.*

2 *Electrolysis apparatus for cleaning well water.*

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WATER

ONLINE MICROPOLLUTANT ANALYSIS SYSTEM FOR EFFICIENT WASTE WATER TREATMENT

Dr. Roland Wuchrer, Dipl.-Ing. Nadja Steinke, Dr. Christiane Schuster, Prof. Dr. Thomas Härtling

Anthropogenic micropollutants, such as drugs or pesticides, are increasingly found in the water cycle. These contaminants, which are invisible to the human eye, can only be removed incompletely with existing waste water treatment processes and pose new challenges for waste water treatment plant operators. A fourth treatment stage is intended to remedy this situation. However, the intended treatment with activated carbon or ozonation has not yet been tailored to demand and is thus not economical. This is mainly due to a lack of process monitoring. The available analytical methods for determining the concentration of trace substances, such as chromatography, are not suitable for on-site use, partly because they incur high laboratory preparation costs. In order to close this monitoring gap, the BMBF joint project "ANTHROPLAS" has developed on-site analysis for efficient waste water treatment.

The core element of the new pollutant analysis is an optical sensor chip (Figure 1) based on a nanostructured gold layer, developed by Fraunhofer IKTS. The nanostructuring makes it possible to excite surface plasmons (electron oscillations) in the gold layer with a LED. Complex optics are no longer needed, which results in a much more compact analyzer. In addition, the surface plasmons display a highly sensitive reaction to molecular bonds – a prerequisite for detecting micropollutants.

The greatest challenge in the detection of pollutants lies in the measurement of low concentrations in the µg/L range. For this reason, a protocol was developed which measures a directed reaction of antibodies (recognition structure) with the micropollutant in question. The gold surface is biochemically activated for this purpose. If a certain pollutant is present in the waste water, an immune reaction with antibodies is triggered. As a result, the optical properties of the gold nanostructure change, which ultimately provides information about the presence and concentration of the micropollutant that is being searched for.

The online-capable analyzer with automated measuring sequence (Figure 2) was set up by the industrial partners and tested successfully in the laboratory at Fraunhofer IKTS. As an example, the concentration of the pollutant diclofenac was determined in a range from 0.1 to 10 µg/L with a measuring cycle of 15 minutes. The sensor chip could be reused more than 100 times. In a last step, the analyzer was integrated in a waste water treatment plant.

In the future, the online micropollutant analysis system will be used to check compliance with limit values both directly at the waste water treatment plant and in water bodies. By adjusting the functionalization, it is possible to detect any micropollutant. In addition to the upcoming long-term tests under real conditions, standardizing the analysis process is aimed for.

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1 *Biosensor chip, e.g. for determining diclofenac concentration in waste water.*

2 *Online analyzer to be installed in the 4th treatment stage of waste water treatment plants.*

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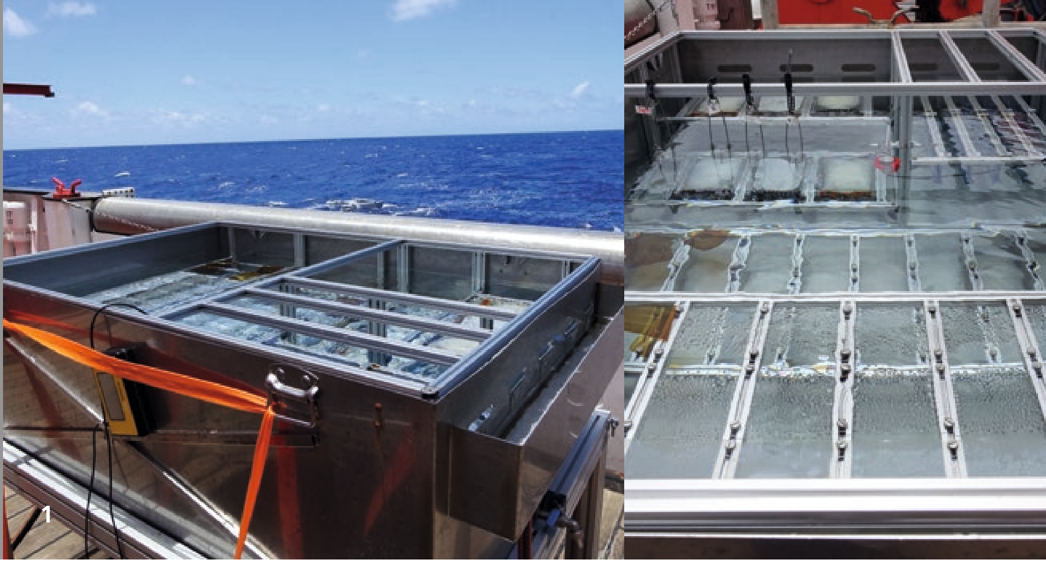

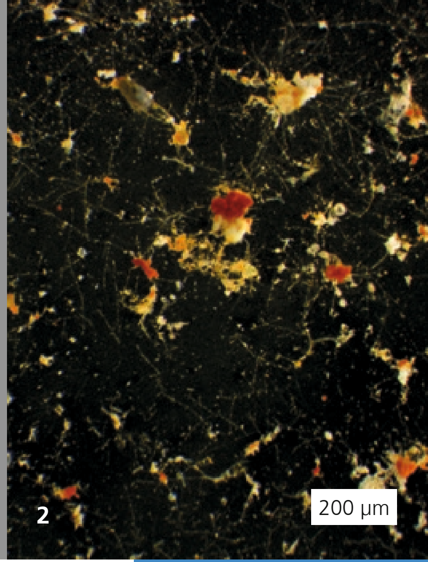

HOW DOES PLASTIC AGE? INVESTIGATIONS IN THE LAB AND THE PACIFIC OCEAN

Dr. Annegret Potthoff, Dipl.-Ing. Kathrin Oelschlägel, Markus Schneider, Dr. Annegret Benke

The public sees the increase in plastic waste in the sea as a major challenge. Scenarios that soon lead us to expect more plastic than fish in the oceans are both realistic and worrying. Important questions that need to be clarified in this context relate to polymer-type-specific risks resulting from the transport and fate of plastic as well as from its uptake and effect in organisms.

In order to understand this and to be able to develop prevention strategies in the future, a better understanding of how plastics weather and age is indispensable. Up to now, it has been possible to carry out test setups in the laboratory, e.g. for UV-induced weathering. The brittleness of materials increases; the wettability with water, quantified by contact angle measurements, changes and leads to differences in biofilm growth in quantity and quality.

In the real environment, weathering mechanisms are much more complex. Interactions between plastic surfaces and the contents of the surrounding water have to be considered, as does the fragmentation of the plastic debris into "microplastics" and possibly "nanoplastics".

In order to validate the findings gained in the laboratory, plastic aging was investigated under realistic conditions on the Pacific Ocean during an expedition on the research vessel SONNE. In specifically designed mesocosms (Figure 1), polymers of varying chemical compositions (LDPE, PS, PET) and geometries (granules, plates) were continuously flooded with seawater, whose composition was analyzed while taking time and location into account (Figure 1). Depending on the UV radiation, which was specifically varied by exposing the materials in different water depths, as well as on the aging period, different aging mechanisms became clear.

The considerable biofilm growth after 28 days of weathering (Figure 2) increases the density of the polystyrene to less than 1 g/cm^3 and thus contributes to the plastic particles moving towards the seabed. At the same time, the chemical composition (detection by FTIR analyses) and the specific surface roughness of the polymers change. The increase in brittleness is caused by structural changes and leads to an increase in the fragmentation and formation of microscale plastic particles.

The properties of the plastic aged under defined environmental conditions in the laboratory are compared to the samples taken from the Pacific Ocean, and thus a comparison of polymer types for risk assessment is possible. In the future, the standardized weathering conditions will be suitable for evaluating the degradation mechanisms of synthetic and biodegradable polymers.

Sponsored by the Federal Ministry of Education and Research

1 Mesocosms, applied at RV SONNE in the Pacific Ocean.

2 PS sheet with biofilm after 28 days of weathering (stereo microscope).

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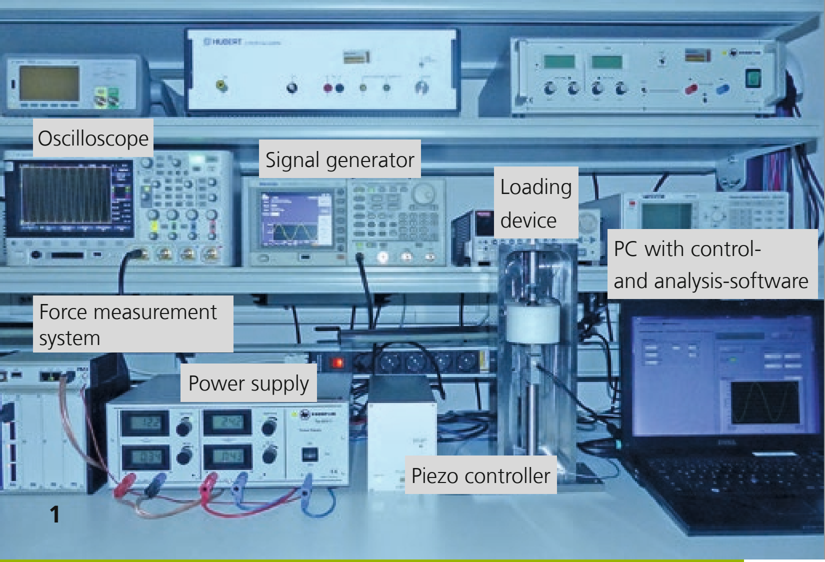

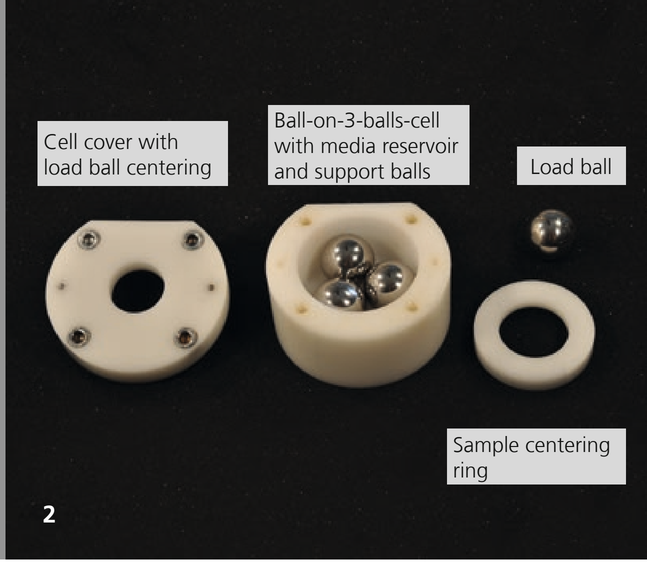

MEASURING DYNAMIC FATIGUE IN CORROSIVE MEDIA

Dipl.-Math. Michael Brand

Testing ceramics under operational conditions

Ceramic components are high-strength and functionalizable, which makes them ideal as construction elements in the industrial environment. This requires new methods for the investigation of their long-term stability under real operational conditions. The fatigue behavior under dynamic load as an essential aspect of material selection and component design is especially of interest. Depending on load frequency and ambient medium, ceramic materials show different tendencies for subcritical crack growth resulting in different fatigue behavior. Current test methods usually focus on low-frequency load scenarios up to 20 Hz. Thus, tests with a high number of load cycles above 10^8 become very costly and time-consuming. In addition, unlike many metals, ceramics are also used in corrosive media. Current dynamic tests, however, often do not allow any variation of the ambient medium and therefore do not sufficiently consider this aspect of real operational conditions.

Automatic load test

A new test stand developed at Fraunhofer IKTS now allows testing ceramic materials in corrosive media with dynamic loads and load frequencies up to 250 Hz and above. In conjunction with strength measurements and structural analyses, this enables a detailed and systematic investigation into the media- and frequency-dependent fatigue behavior of materials even at very high numbers of load cycles. The load scenario used is the established “Ball-on-3-balls” setup, which allows for sample testing without expensive and property-changing surface treatments. The setup is then immersed in a liquid medium. The modular design of the system facilitates the simple adaption of the setup to suit other standardized and customer-specific load scenarios. The entire test procedure is software-controlled on the basis of flexibly definable load parameters and termination criteria, so that the stand-alone continuous operation of the test stand including data acquisition is possible.

Independently controllable components for a static preload and a superimposed dynamic load can be defined as load parameters. In addition to an integrated logic for fracture detection of the sample and the maximum number of load cycles, definable corridors for static, dynamic and total load, as well as temperature measurement points are available as termination criteria. The functional verification of the system was carried out in endurance tests on SiC-bonded diamond materials in an aqueous medium. Investigations of the samples after 10^7 load cycles have shown the very high cyclic stability of the materials.

Services offered

- Testing of the fatigue behavior of ceramics
- Development of application-oriented test methods

1 *Dynamic load test stand.*

2 *Ball-on-3-balls cell for sample loading with media reservoir.*

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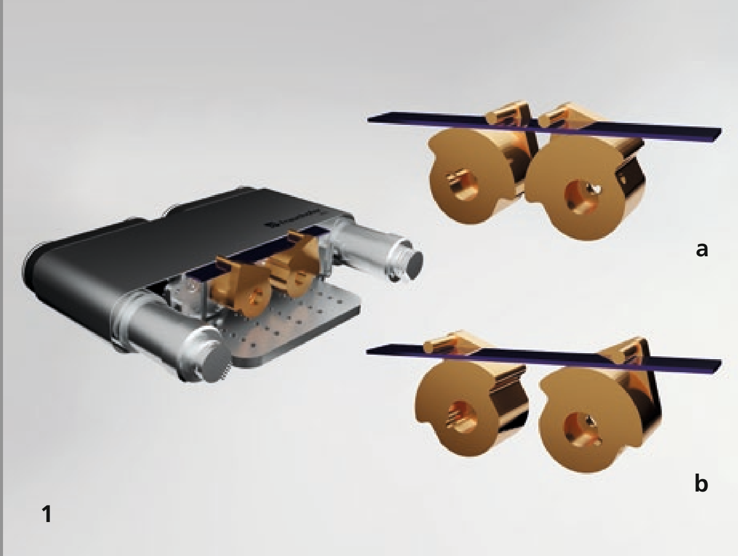

FLEXIBLE 4-POINT BENDING SYSTEM FOR TENSILE AND COMPRESSIVE LOADING

Dipl.-Ing. Christoph Sander, Dr. André Clausner, Dipl.-Ing. Frank Macher, Matthias Lehmann, Prof. Dr. Ehrenfried Zschech

Microprocessors and electronic devices are highly complex structures made of numerous materials with specific thermal and mechanical properties. Different thermal expansions during manufacturing and operation can lead to crack formation due to mechanical stresses and subsequently to the failing of the device. Therefore, it is necessary to characterize these materials and the influence of mechanical stress on the structures. A common method to apply stress is loading components and test structures with the 4-point bending (4PB) mode.

In-situ 4-point bending system

4-point bending is an often-used loading mode to bend beam-shaped specimens. The advantage of 4PB is the homogeneous bending moment between the inner support points. A novel 4PB device for in-situ scanning electron microscopy (SEM) was developed at Fraunhofer IKTS (Figure 1). One distinctive feature is the low height of the system, which enables use in closed and limited spaces, such as the vacuum chambers of SEM systems. Another unique feature is the ability to apply tensile and compressive stress on the specimen surface without changing the sample mounts. In contrast with standard 4PB devices, this is achieved by rotational sample mounts, which create the necessary relative linear displacement of the support points by eccentric rotation (Figures 1a and b). The mechanical stress on the sample surface can be determined at any point based on the knowledge of the sample geometry by measuring the actual torque on both sample clamps.

Flexible tool transfer

The tool can keep the bent state of a specimen due to the high 2 Nm holding moment even when powered off. This enables easy transfer to additional imaging or analytical tools. Hence, it is possible to conduct indentation experiments on a bent specimen, transfer the setup from the nanoindenter tool to an SEM, investigate the indents in the SEM and validate the applied mechanical stress with Raman spectroscopy.

Services offered

- Analytical measurements on clamped samples combined with SEM, nanoindentation (NI) or Raman spectroscopy analysis
- Correlated evaluation of the stress conditions of the sample with accompanying experimental techniques
- Customer-specific adaptation of the 4PB device on request

1 *Novel and extremely flat 4PB system. Sample clamps in the start position for the compressive (a) and tensile (b) loading configuration.*

2 *Silicon sample (thickness 300 µm) bent in tensile loading configuration.*

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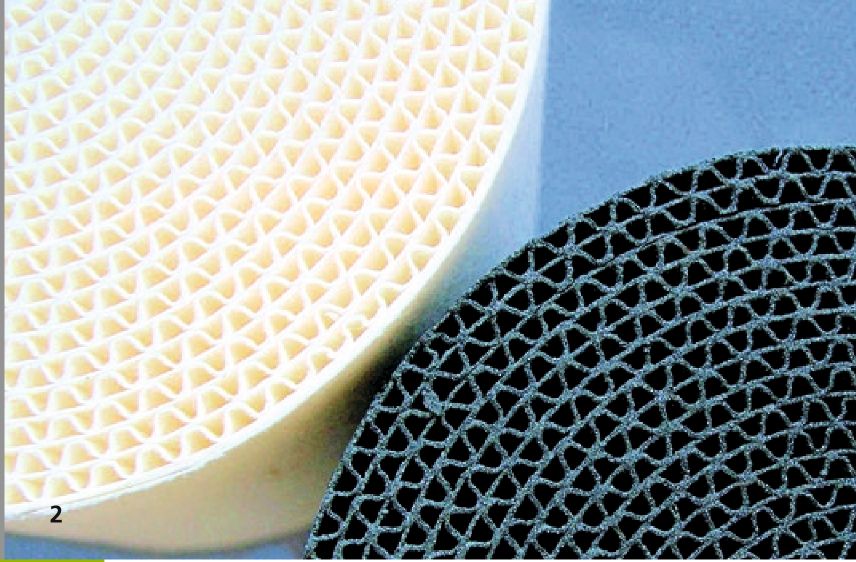
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DEFORMATION ANALYSES UNDER ISOSTATIC PRESSURE LOADING

Dr. Steffen Kunze, Dipl.-Ing. Heike Heymer, Dipl.-Krist. Jörg Adler

In many applications, components are subject to axial or allround compressive loads. Catalytic converters or particle filters, which are pressed into metal cannings in combination with high-temperature resistant sealing mats, are an example of this. Knowledge of the mechanical behavior of the complex and often filigree components under the compressive stresses is often essential for the design and layout of the overall systems. Determining reproducible and comparable mechanical characteristic values for these types of stress represents a major challenge for measurement technology.

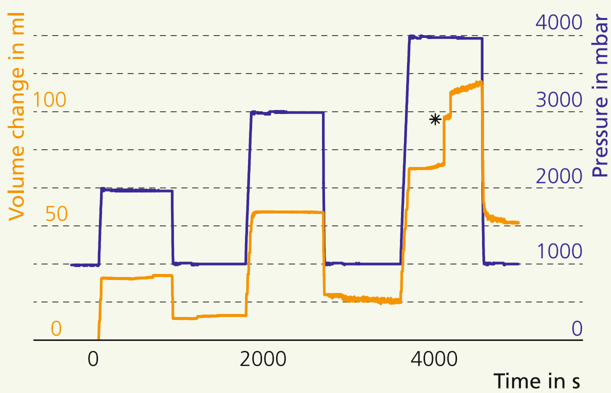
Fraunhofer IKTS has adapted an isostatic pressure test stand for such questions, with which the component compression can be measured in-line. The component, which is sealed and embedded in an incompressible fluid, is subjected to specific pressures and temperatures. The resulting deformation of the component leads to a reduction in the fluid level, which is measured capacitively during the test. The programming of pressure ramps and cycles enables implementing extensive test routines from which conclusions can be drawn about creep properties, elastic-plastic deformation behavior, and even the fracturing properties of the tested components (diagram).

The test bench can be used for a wide range of applications thanks to its advanced options for documenting real-time videos and carrying out vacuum tests. The applications range from classical pressure and tightness tests to the characterization of volume shrinkage during the consolidation of reactive resins.

Services offered

- Isostatic pressure testing of components, in particular filters and catalysts with following conditions:
  Component size up to: Ø = 360 mm; h = 270 mm
  Pressure: 0–10 bar
  Temperature: up to 250 °C
- Development of application-specific pressure ramps and cycles for the in-line measurement of volume changes to evaluate component elasticity, creeping and failure processes

Pressure-compression process of a component



⁕ Structural failure at 4000 mbar

1 *Isostatic pressure test stand.*
2 *Examples of ceramic honeycomb structures to be tested.*

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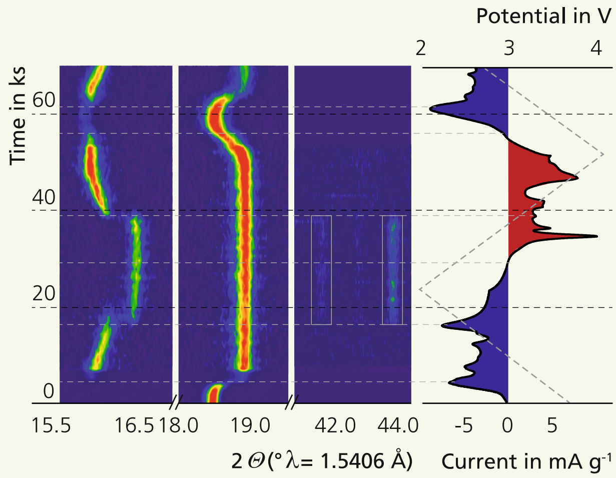

2

IN-SITU AND OPERANDO STRUCTURAL INVESTIGATIONS OF ELECTROCHEMICAL SYSTEMS

Dr. Björn Matthey, Dr. Christian Heubner, M. Sc. Christoph Lämmel, Dr. Michael Schneider, Dr. Mathias Herrmann

Electrochemical processes and systems are considered key technologies for sustainable production and energy sectors. This includes innovative coating processes as well as devices for electrochemical energy storage and conversion. Knowledge-based development and optimization of such systems requires a fundamental understanding of the ongoing reactions and potential degradation processes. In-situ and operando structural investigations by means of X-ray diffraction (XRD) allow a particularly detailed clarification of reaction mechanisms and resulting correlations between processes, structures and properties, based on complementary electrochemical and structural information. Fraunhofer IKTS develops customized electrochemical cell designs (Figure 1) for complementary in-situ and operando structural investigations (Figure 2).

Functional coatings

The most relevant properties of functional coatings are mainly determined by their microstructure. At Fraunhofer IKTS, in-situ XRD measurements are carried out to clarify the microstructural development during the fabrication of functional coatings. Corresponding results allow to determine and develop phase composition and microstructural parameters, such as crystallite size and microstrains, during deposition, depending on the electrochemical manufacturing conditions. Accordingly, process-structure-property correlations can be derived in order to optimize processes in a targeted way.

Energy storage systems

The development of innovative systems for electrochemical energy storage and conversion is accompanied by complementary operando structural investigations by means of XRD and Raman spectroscopy. The measurements enable comprehensive insights into mechanisms and the reversibility of structural and compositional modifications during operation. Using knowledge gained, it is possible to develop novel lithium- and sodium-ion batteries as well as hybrid systems with a focus on enhanced power capability and improved long-term stability.

Services offered

- Development and validation of electrochemical cell designs for in-situ and operando structural investigations by means of XRD and Raman spectroscopy
- Phases and structural parameters
- Analysis of process-structure-property correlations

SPONSORED BY THE Federal Ministry of Education and Research

Europa fördert Sachsen. EFRE Europäischer Fonds für regionale Entwicklung Europäische Union

1 *Electrochemical operando XRD cell developed at Fraunhofer IKTS.*

2 *Phase analysis using X-ray diffraction (XRD) during electrochemical Li/Na substitution in $LiCoO_2$.*

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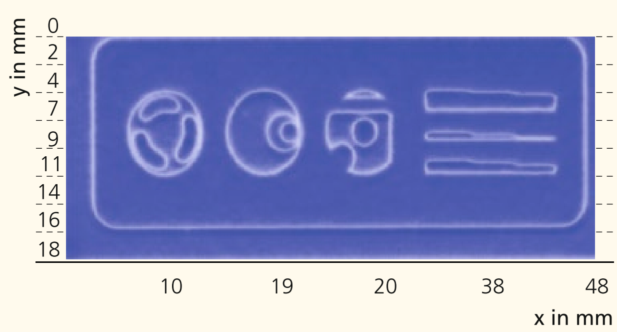

2

AUTOMATED ULTRASONIC TESTING OF THIN METAL SHEETS USING PCUS® PRO HF

Dipl.-Ing. (FH) Christian Richter, Dipl.-Ing. (FH) Hendrik Funke

Challenges of ultrasonic testing

Frontend devices of the "PCUS® pro" family are made for automated non-destructive ultrasonic testing. A usable frequency range of 500 kHz to 30 MHz enables conventional ultrasonic testing applications, such as the testing of welds and semi-finished products, or recurrent testing in the transportation sector. However, new materials and factory methods translate into new challenges for non-destructive testing. The growing demand for lightweight structures in the automotive industry has led to the use of very thin metal sheets with complex shapes, joined by small-sized laser or spot welding. Such small and mostly hard-to-access structures cannot be tested by conventional ultrasound techniques because they require higher measurement resolutions as well as higher signal frequencies. Until now, such test tasks have therefore been solved with destructive test methods or measurements with high-frequency ultrasound microscopes. As ultrasound microscopes are not inline-capable and cost-intensive, this technique is often applied to random samples only.

High signal frequencies for new test tasks

The frontend device "PCUS® pro HF", developed at IKTS, bridges the gap between classic ultrasonic testing and high-frequency ultrasound microscopy. The inline-capable frontend is suitable for signal frequencies in the range of 5 to 150 MHz. With its compact measurements of 170 x 120 x 30 mm³, it can be mounted in direct vicinity to the probe, e.g. directly onto mechanical scanners. Passive cooling combined with a low power consumption of only 7 watts allows for a wide range of industrial applications. It is connected to the host PC using a high-speed USB 3.0 data transfer bandwidth with the possibility for implementing fiber optics. The design offers very low-noise analog electronics, a widely adjustable transmitter and the implementation of as many features used in "classic" ultrasound test devices as possible.

Simple integration into existing plants

The "PCUS® pro HF" frontend device is compatible with all other members of the "PCUS® pro" family and can be controlled by a software development kit (SDK). This SDK enables the integration into customer-specific application software. For easy incorporation of the hardware into custom testing and production plants, the frontend device includes interfaces for incremental encoders, external triggers and digital inputs and outputs.

1 *"PCUS® pro HF" for ultrasonic testing with high frequencies.*

2 *C scan of an alumina test plate with structures of 100 µm size.*

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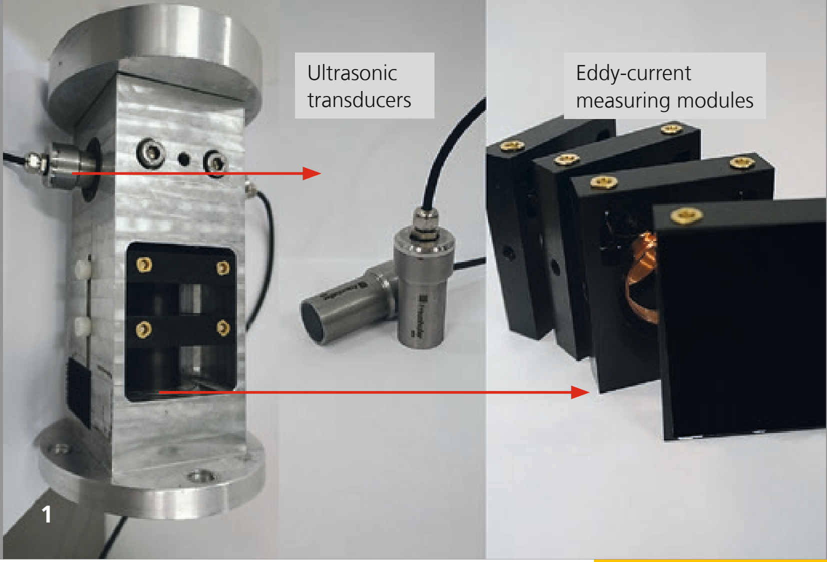

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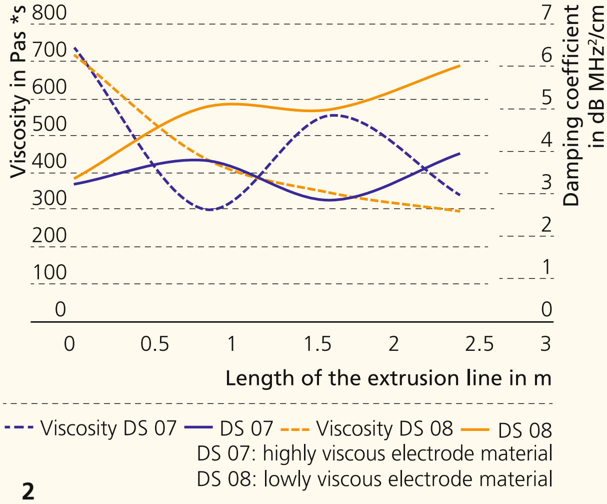


2

MONITORING OF THE EXTRUSION PROCESS IN THE PRODUCTION OF BATTERY TAPES

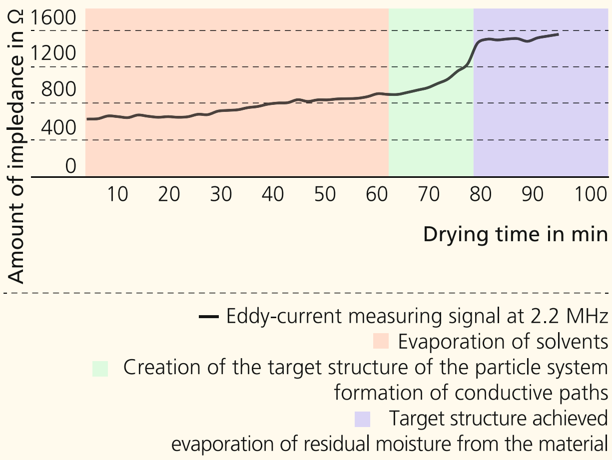
Dipl.-Ing. Marcel Wild, Prof. Dr. Henning Heuer, M. Sc. Martin Schulze, Dr. Thomas Herzog, Dr. Sebastian Reuber

Electromobility is becoming an essential market. Core elements of this market are the battery cells, whose production is at present not yet sufficiently economical. One approach to this problem is to increase production efficiency through lower reject rates and thus raising profitability. To achieve this, an inline monitoring system can be used, which non-destructively inspects during the electrode manufacture and detects defects or changes in the material composition as early as possible.

For this purpose, a multisensory mouthpiece was installed between the extruder outlet and the coating tool (Figure 1) of a twin-screw extruder for battery electrode manufacture. It uses the eddy-current and ultrasonic methods to monitor battery electrodes. The combination of both measuring methods makes it possible to record a wide range of material parameters.

The monitoring of acoustic material properties, such as density, viscosity or particle size, makes use of the parameters of sound velocity and sound attenuation, both stemming from the ultrasonic method. The eddy-current method makes it possible to monitor the electrical and dielectrical properties of materials using test frequencies from 1 to 10 MHz. In ultrasonic testing, the test frequencies for transmission measurements are between 1 and 5 MHz. Figure 2 shows that the viscosity changes as the extruder length increases. Such a change in viscosity leads to different damping coefficients in the ultrasonic method. This information can be used to adjust the process at an early stage, avoiding faults in production. In addition to viscosity, further correlations with the density of the active material component and the electrical and dielectric material properties could also be demonstrated. The monitoring of how battery tapes dry can be realized with a single or area sensor for eddy currents. Based on the definition of the drying state (diagram below), these measuring systems enable a higher production speed as well as reproducibility. This is possible e.g. by installing a shorter drying line.

Eddy-current drying monitoring of an anode material with LTO (lithium titanium oxide) active material at a measuring frequency of 2.2 MHz



1 *Multisensory mouthpiece for the monitoring of battery cell production.*

2 *Correlation between viscosity and ultrasonic signal during inline monitoring.*

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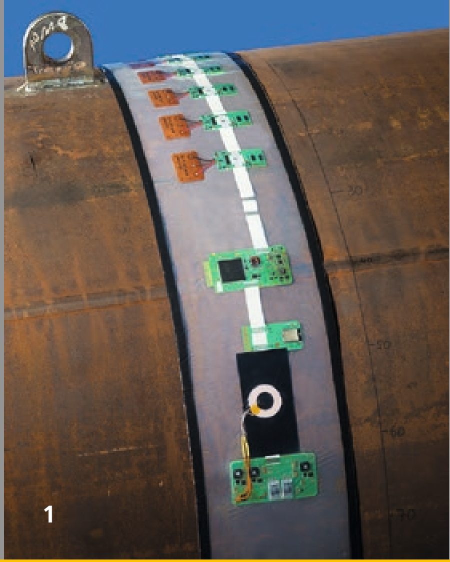

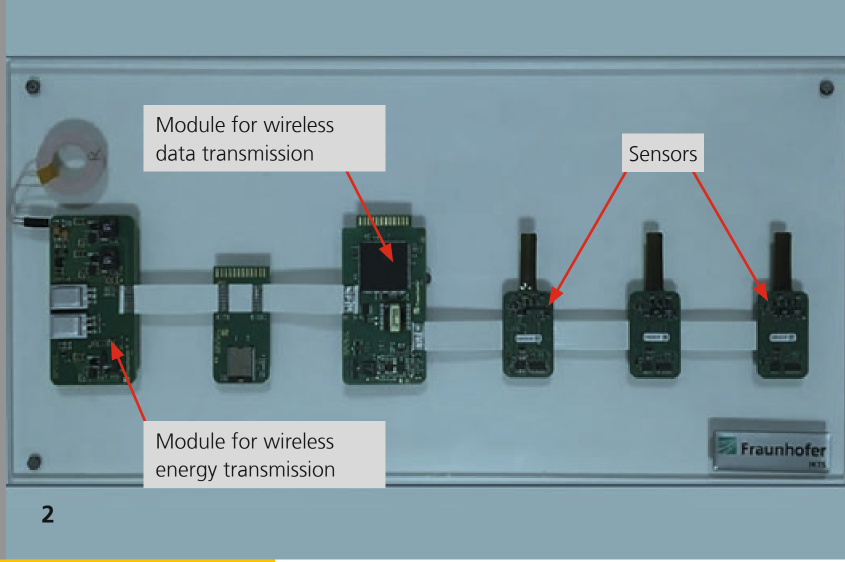

WIRELESS SENSOR SYSTEMS FOR SAFE OFFSHORE STRUCTURES – CoMoBelt

Dr. Bianca Weihnacht, Dipl.-Ing. Tobias Gaul, Dipl.-Ing. (FH) Thomas Klesse, Dipl.-Ing. Martin Oemus, M. Sc. Sebastian Sonntag, Dr. Lars Schubert

Wind turbines in offshore wind parks are an alternative to onshore wind power generation – but offshore energy generation is currently still significantly more expensive than onshore. This is due to higher maintenance costs, among other factors. Above all, testing the metal tube construction, known as foundation structures on the seabed, is time-consuming and dangerous. Technicians and material have to be brought to the plant with vessels to perform maintenance tasks. Transport and underwater operations require suitable weather conditions, which occur only on a few days per year. In addition, the costs for ship rental and diving are very high.

With its CoMoBelt sensor collar, IKTS has developed a measuring system that is installed permanently on the foundation structure of offshore wind turbines and can monitor their integrity. Continuously reducing the need for cost-intensive on-site operations, and thus cutting down on maintenance costs. Similar to a ring, the sensor collar is attached directly and permanently to heavily loaded areas of foundation structures, such as welded seams. This minimizes the effect of external biomaterial growth on the measurements and becomes void strenuous and time-consuming manual cleaning of the measuring points by divers.

Ultrasonic transducers are integrated in the CoMoBelt monitoring system and act alternately as sensors or actuators. As ultrasonic waves propagate in the object to be monitored, scattering and reflections occur as a result of material damage. These can be used to detect failures, such as weld seam cracks, by using integrated signal processing.

In addition to biomaterial, corrosive salt water and the enormous forces of the waves also pose a threat to sensory measuring systems. In order to be able to permanently measure under water, the sensor ring must withstand the harsh environmental conditions. For this reason, the sensors are sealed by lamination and thus reliably protected by the barrier layers against seawater penetration. This requires flat electronic components specially developed for this purpose.

Energy supply for the piezoceramic transducers and read-out of the data measured with the CoMoBelt is no longer done by divers, but by "Remote Operating Vehicles" (ROV) – underwater robots controlled remotely by cable. Using suitable wireless near-field communication, the data is transferred from the sensor collar to the diagnostic device on the robot and then via cable to the technicians on the ship. This new technology completely eliminates the need for plug connections on the measurement system, which contributes significantly to reliability offshore and allows the CoMoBelt system to be operated with a longer service life and less susceptibility to fail.

1 *CoMoBelt – monitoring system with wireless communication and energy transfer.*

2 *Components of the overall system for monitoring offshore structures.*

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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)

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

Association for Manufacturing Technology and Development (GFE)

Association of Electrochemical Research Institutes (AGEF)

Association of German Engineers (VDI)

Association of Thermal Spraying (GTS)

biosaxony

BTS Rail Saxony

Carbon Composites (CCeV)

Ceramics Meeting Point Dresden

CiS Forschungsinstitut für Mikrosensorik GmbH

CO_2 Value Europe

Competence Center for Nano Evaluation nanoeva®

Competence Network on Optical Technologies (Optonet)

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 Wisseschaft

ECPE European Cluster for Power Electronics

EIT Health

Energy Saxony

e.qua impuls – Wassewirtschaftliches Energiezentrum Dresden

European Society of Thin Films (EFDS)

European Network of Materials Research Centres (ENMAT)

European Powder Metallurgy Association (EPMA)

European Research Association for Sheet Metal Working (EFB)

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

Fördergesellschaft Erneuerbare Energien (FEE)

Fraunhofer Adaptronics Alliance

Fraunhofer Additive Manufacturing Alliance

Fraunhofer AdvanCer 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 Water Systems Alliance (SysWasser)

Fraunhofer Textile Alliance

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 Engineering Association (VDMA)

German Federation of Industrial Research Associations (AiF)

German Materials Society (DGM)

German Society for Membrane Technology (DGMT)

German Society for Non-Destructive Testing (DGZfP)

German Phosphorus-Platform DPP

German Physical Society

German Thermoelectric Society (DTG)

HYPOS Hydrogen Power Storage & Solutions East Germany

InDeKo Innovationszentrum Deutschland Korea

Innovationszentrum Bahntechnik Europa e. V.

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

International Microelectronics and Packaging Society

International Zeolite Association

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

NAFEMS – International Association for the Engineering Modelling, Analysis and Simulation Community

NanoMat – Supraregional Network for Materials Used in Nanotechnology

Organic Electronics Saxony

ProcessNet – an Initiative of DECHEMA and VDI-GVC

Research Association for Diesel Emission Control Technologies (FAD)

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

Silicon Saxony

smart³

SmartTex Network

Society for Corrosion Protection (GfKORR)

Trägerverein Institut für Holztechnologie Dresden e. V.

TRIDELTA CAMPUS HERMSDORF

Thüringer Erneuerbare Energien Netzwerk (ThEEN)

VDMA Medical technology

Verein für Regional- und Technikgeschichte e. V. Hermsdorf

WindEnergy 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. Equal importance is attached to experimental studies in laboratories, technical centers and pilot plants and to methods of numerical simulation and modeling; they are used across scales, from molecule and component, to complex system and process simulation. Where materials are concerned, the Fraunhofer MATERIALS group covers the full spectrum of metals, inorganic non-metals, polymers, and materials made from renewable resources, as well as semiconductor materials. Over the last few years, hybrid materials have gained significantly in importance. The Group uses strategic forecasting to support the development of future-oriented technologies and materials. With the initiative Materials Data Space© (MDS) founded in 2015, the Group is presenting a roadmap towards Industrie 4.0-enabled materials. It considers digitization of materials along their entire value chain as a key requirement for the lasting success of Industrie 4.0. Special attention is also given to the development of customized materials for additive manufacturing, from expanding the range of materials that can be used to developing multimaterial systems. Thus the Group is making a significant contribution to maximizing and economically exploiting this promising manufacturing technology.

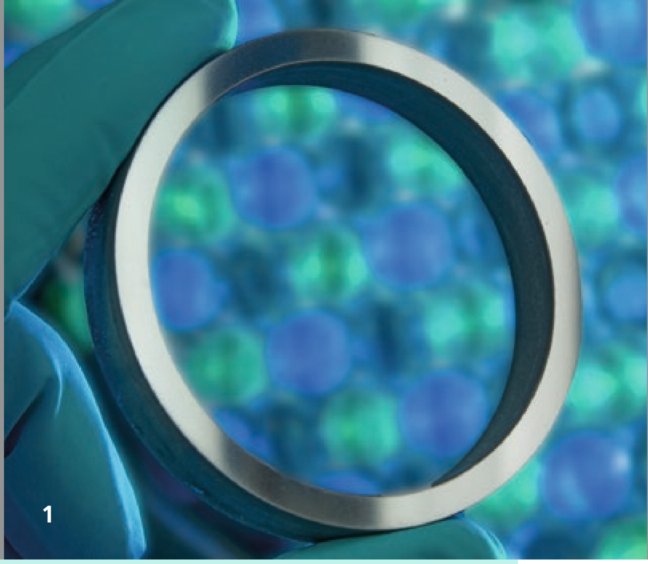
The importance of renewable energies is rapidly gaining momentum as the energy transition continues. A large number of materials, from copper, steel and concrete to rare earths will be used to generate, store, transport and convert energy, to a significantly greater extent compared with traditional energy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

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
- 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



FRAUNHOFER ADVANCER ALLIANCE

Systems development with advanced ceramics

The usage of advanced ceramics allows for new applications in energy engineering, mechanical and plant engineering, and medical technology. Well-known examples are highly efficient tools and coatings, new material and manufacturing technologies for medical-technical products as well as creative solutions for energy and resource saving industrial processes.

One research focus of the AdvanCer Alliance is on system solutions and test methods for the oil and gas industry and deep sea mining. This includes the development of new ceramic and hardmetal materials for wear and corrosion protection, process water treatment and optical applications. This enables component properties to be achieved that enable maintenance-free operation at depths of up to 6000 m. In addition, sensors and processes are being designed that allow non-destructive defect detection, real-time monitoring and associated condition-based maintenance or plant optimization even under harsh operating conditions.

In the Fraunhofer AdvanCer Alliance, the IKTS, IPK, ISC/HTL and IWM institutes participate along the entire value chain: from application-oriented materials development, production and machining of ceramic parts to component characterization, evaluation and non-destructive testing under application conditions. The development work is also accompanied and supported by methods of modeling and simulation.

Furthermore, AdvanCer has established a comprehensive range of training and consultancy services to support small- and medium-sized companies in solving complex tasks ranging from prototype development to technology transfer.

Services offered

- Development and evaluation of materials (structural and functional ceramics, fiber-reinforced ceramics, cermets, ceramic composites, hardmetals)
- Technology development and transfer
- Component design, prototype production, small series production
- Systems integration and verification of batch-production capabilities
- Materials, component and process simulation
- Materials and component testing
- Defect analysis, failure analysis, quality management
- Analysis of energy demand for thermal processes and to improve energy efficiency
- Increase of efficiency using ceramic components
- Consulting, feasibility studies, training programs

Spokesperson of the Alliance

Dr. Michael Zins
michael.zins@ikts.fraunhofer.de
www.advancer.fraunhofer.de

1 *Highly wear- and corrosion-resistant diamond ceramic seal ring for use in pumps.*

CERAMICS MEETING POINT – CERAMIC APPLICATIONS

The Ceramics Meeting Point is an integral part of our institute's public relations activities. Through the cooperation with the currently 51 partners and members under the label "Ceramic Applications" by the Göller-Verlag, the institute offers a unique overview of the technical ceramics market. It is possible to see the latest research topics up to systems testing in one room and at the same time to establish contact with potential suppliers. All events of the Fraunhofer IKTS thus become an ideal platform for users who are not yet familiar with the industry. Networking effects with Fraunhofer-Gesellschaft are enhanced further by including the Fraunhofer AdvanCer Alliance. This makes it possible to represent the complete service portfolio of all institutes.

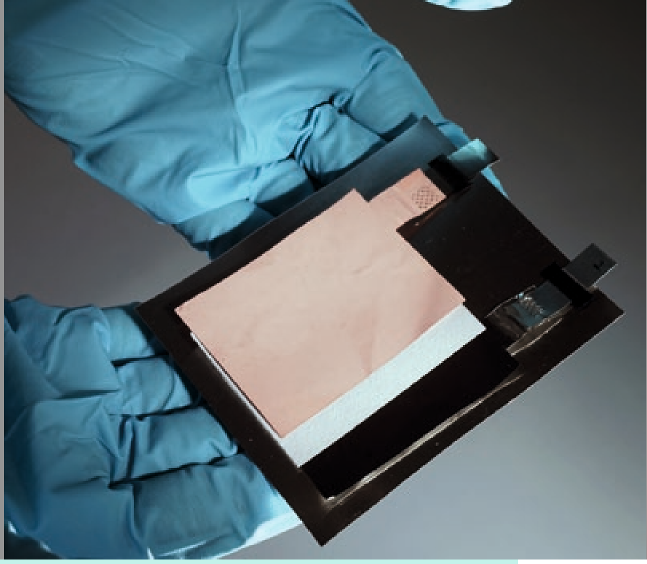
The seminars organized by the Fraunhofer AdvanCer Alliance, the German Ceramic Society (DKG), and the German Materials Society (DGM) present the state-of-technology in the industry and provide participants with the desired hands-on experience. With this approach, Fraunhofer IKTS provides a project forum,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

The entire production chain from powder to the component is shown. And that not only on the research side, but also as a mirror of the technologies and capacities available in the industry. Visitors gain insight into the current focal points of research while learning which manufacturer commercially supplies which product.

In 2019, the focus was on metal-ceramic joining technology and the latest additive manufacturing processes. The exhibition will remain integrated into the various events at the institute, thus ensuring that up to 2000 visitors per year will have quick access to the world of technical ceramics.

In 2019, the Ceramics Meeting Point was again an essential part of the work of the DKG's Department 1: Chemical/Mechanical and Plant Engineering. The networking of manufacturers, users and research institutes will make it easier to form the FDKG accompanying committees for projects funded by the AiF.

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



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 waste water treatment methods. There are currently 13 professorships from FSU and 5 departments from IKTS represented at the CEEC. 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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Chair Technical Environmental Chemistry
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www.ceec.uni-jena.de

1 *New battery electrodes from the CEEC (Source: Jan-Peter Kasper/FSU Jena).*

NAMES, DATES, EVENTS

Please find information on patents, publications and scientific engagement of IKTS employees in 2019 on the website www.ikts.fraunhofer.de/en/dates2019

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 2020

Conferences and events

Juniordoktor
February 12 and May 13, Dresden, Maria-Reiche-Strasse

Girls' Day
March 26, Hermsdorf, Michael-Faraday-Strasse

Symposium "20 Years Expert Board Ceramic Membranes"
May 12–13, Hermsdorf, Michael-Faraday-Strasse

Symposium Smart Production
May 25, Dresden, Winterbergstrasse

International Sodium Battery Symposium SBS 2
September 1–2, Dresden, Winterbergstrasse

AM Ceramics meets Ceramitec
September 16–17, Dresden, Winterbergstrasse

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

Seminars and workshops

DGM training seminar: Ceramic materials: properties and industrial applications
June 24–25, Dresden, Winterbergstrasse

Trade fair participations

Karrierestart
January 24–26, Dresden
Joint booth Fraunhofer Dresden

ICACC
January 26–31, Daytona

Battery Japan
February 26–28, Tokyo

Rad-Schiene
February 26–28, Dresden

Thüringer Werkstofftag
March 4, Jena

ZfP im Eisenbahnwesen
March 10–12, Erfurt

Energy Storage Europe
tba., Dusseldorf
Joint booth with Alumina Systems GmbH

LOPEC
March 25–26, Munich
Joint booth Organic Electronics Saxony e. V.

ALD for Industry
March 31–April 1, Freiburg

Analytica
March 31–April 3, Munich
Joint booth Fraunhofer-Gesellschaft

IFAT
May 4–8, Munich
Joint booth Fraunhofer Water Systems Alliance
Joint booth with Rauschert Distribution GmbH, Business area inopor

RapidTech
May 5–7, Erfurt
Joint booth Fraunhofer Additive Manufacturing Alliance

PCIM
May 5–7, Nuremberg
Joint booth ECPE

Control
May 5–8, Stuttgart
Joint booth Fraunhofer Vision Alliance

JEC World
May 12–14, Paris
Joint booth Saxony Economic Development Corporation WFS

WCNDT
June 8–12, Seoul
Joint booth with KIMS

Woche der Umwelt
June 9–10, Berlin

Sensor+Test
June 23–25, Nuremberg
IKTS booth
Special Forum "Sensor and Measuring Technology for Condition Monitoring"

ALD/ALE
June 28–July 1, Ghent

Hannover Messe
July 13–17, Hannover
Joint booth Ceramic Applications
Joint booth Energy Saxony e. V

ICC8
August 23–27, Bexco

Innotrans
September 22–25, Dresden
Joint booth Saxony Economic Development Corporation WFS

Chillventa
October 13–15, Nuremberg
Joint booth Fraunhofer-Gesellschaft

FAD Conference
November 4–5, Radebeul

Electronica
November 10–13, Munich

Formnext
November 10–13, Frankfurt on the Main,
Joint booth Fraunhofer Additive Manufacturing Alliance
Joint booth Fraunhofer-Gesellschaft

Compamed
November 16–19, Düsseldorf

Hagener Symposium
November 25–26, Hagen

Oceanology International
December 1–3, London
Joint booth Fraunhofer@Subsea

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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