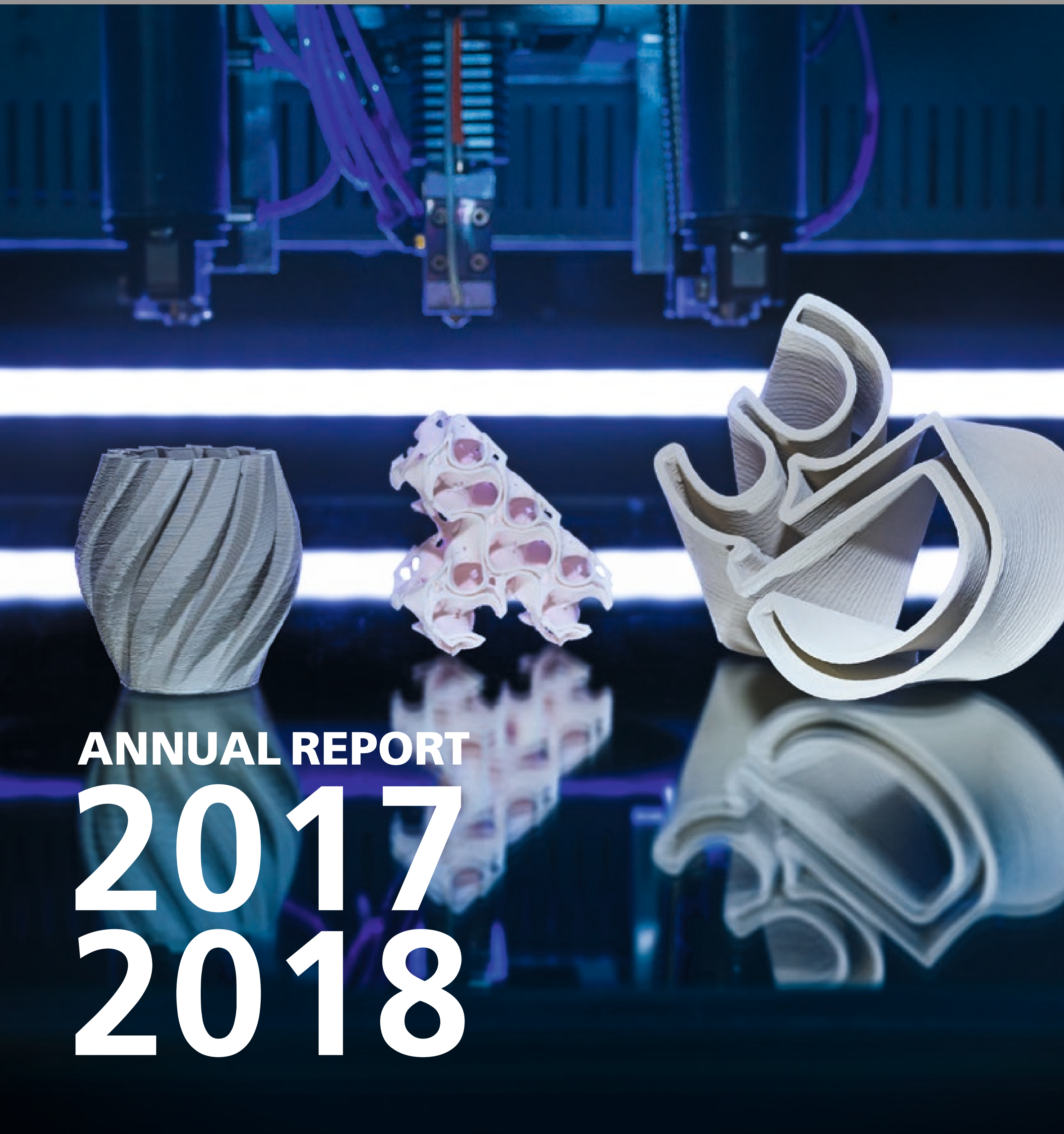
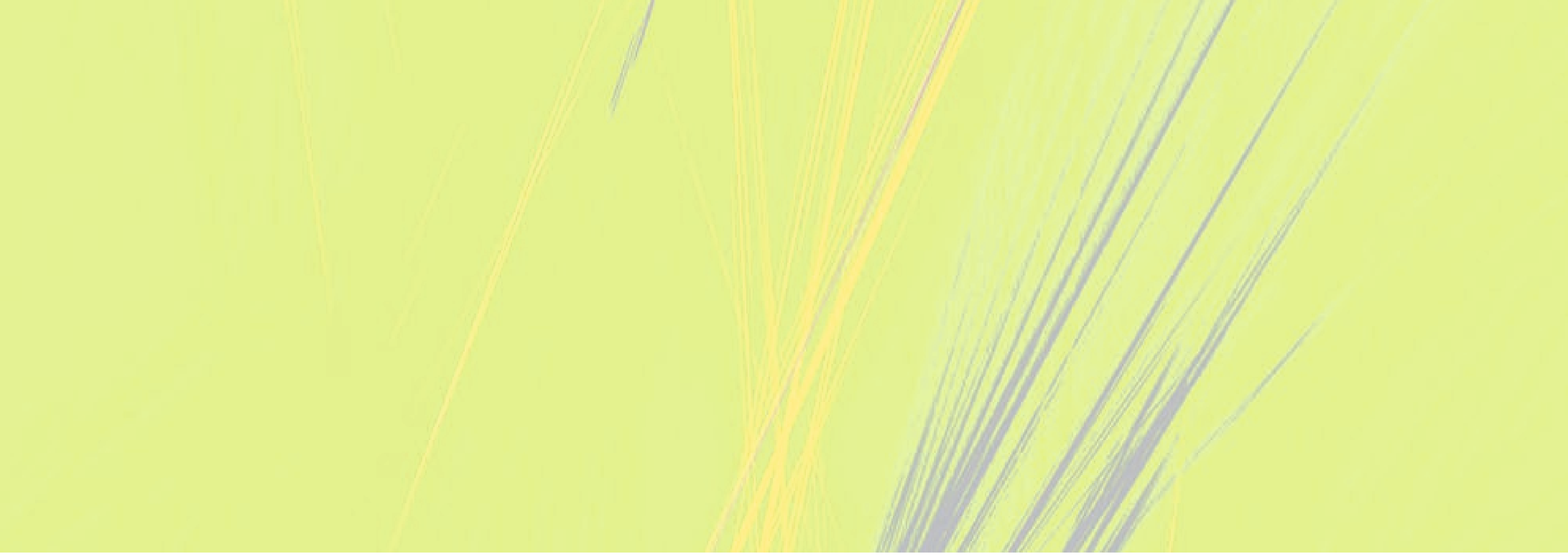
IKTS

FRAUNHOFER INSTITUTE FOR CERAMIC TECHNOLOGIES AND SYSTEMS IKTS



ANNUAL REPORT 2017 2018



ANNUAL REPORT 2017/2018

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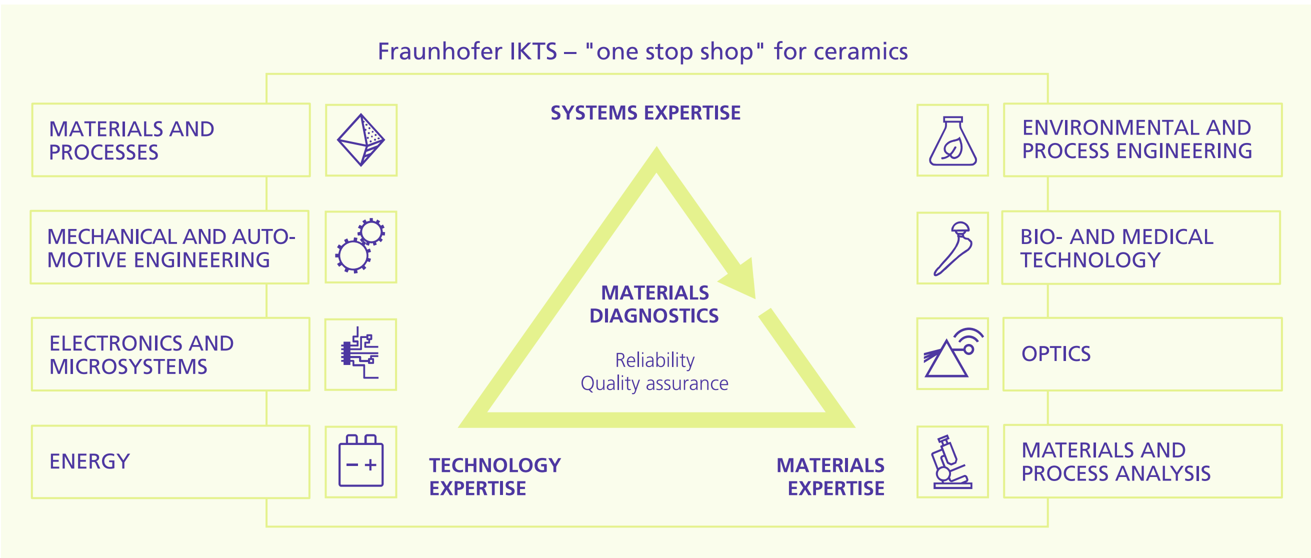
FOREWORD

ANNUAL REPORT 2017/18

Dear partners and friends of IKTS,

We are pleased to present our new annual report. 2017 has been another very successful year, and our economic figures bear this out: our number of staff has increased to now 680. Our total budget for 2017 has slightly exceeded the 55-million-euro mark. This includes 3 million euros for investment used to strengthen our infrastructure in the various areas of structural and functional ceramics. We have earned more than 42 million euros from industry-oriented third-party-funded projects, of which almost 50 % are directly from industry. This is confirmation that we are doing well in meeting our research goals, which are geared toward knowledge transfer, in line with Fraunhofer's mission. We are determined not to let up in these efforts and remain at your disposal at any time for future collaboration. I would like to say a big thank you to all our partners for their cooperation. We would also like to thank the states of Saxony and Thuringia, as well as the federal government, for their continued support.

We will continue to cover the field of applied ceramics research in all its breadth, as evidenced in the pages of this report. The areas of additive manufacturing, environmental process engineering and energy storage technologies have seen particularly dynamic development. For instance, we founded a battery research project center in Lower Saxony in 2017, in collaboration with our colleagues of Fraunhofer IFAM and Technische Universität Braunschweig. This center is to house research activities not just on Li-ion batteries for mobile-, but also on storage solutions for stationary applications. This includes electrochemical storage systems such as high-temperature $NaNiCl_2$ batteries as well as electrolytic processes such as SOEC for hydrogen technology. Since manufacturing processes are a big factor in this regard, we benefit in particular from our capabilities in non-destructive testing and process monitoring, which are available in our IKTS site in Dresden-Klotzsche.



We have also strengthened our position from an organizational perspective, thanks to our newly founded battery research department. We will continue to develop our numerous activities in environmental process engineering with the new core area "Closed-loop economy for smart agriculture". In addition to membrane technology, sensors and actuators also play an important part in this area. In this regard, we are now able to use our know-how on systems used in particularly harsh environments, won through our role in the Fraunhofer lighthouse project "eHarsh". This subject is also especially relevant for the area of security research, which we intend to develop further. It should also be mentioned that we have repositioned our center in the US to the field of environmental technology, and membrane technology in particular. Our impact in the region can be seen, for instance, in the work done by TRIDELTA CAMPUS HERMSDORF e. V., an association we have founded together with 23 companies from the region around Hermsdorf in Thuringia. As part of this initiative, we want to help to make the high-tech location of Hermsdorf more attractive and visible for clients, skilled workers and investors alike.

Finally, I would like to report that we celebrated the 25th anniversary of IKTS in the reporting period 2017. We may look back proudly on the very successful evolution of our institute. IKTS was founded in January 1992 with a staff of 80 and an operating budget of just under 8 million deutschmarks. Our founding director, Prof. Waldemar Hermel, was able to set the institute on a very promising path and assembled an outstanding team – achievements that have propelled us forward ever since.

It was that team that started the IKTS success story. We want to do everything we can to make this success go on. I thank the whole IKTS team for its efforts. In particular, I would like to express our gratitude to our founding director, Prof. Hermel, who incidentally had another reason to celebrate in January 2018 – his 80th birthday. Therefore, on behalf of all our staff at IKTS, I dedicate this year's issue of our annual report to Prof. Hermel.

Lastly, as always, I hereby repeat my offer to make use of our outstanding equipment and our formidable team here at IKTS. We are looking forward to our mutual cooperation.

Sincerely,

A. Michaelis

Alexander Michaelis

April 2018

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

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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 eight market-oriented divisions in order to demonstrate and qualify ceramic technologies and components for new industries, new product ideas, new 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, networked hard- and software components as well as innovative concepts for resource-saving energy and agriculture, for which Fraunhofer IKTS integrates tried-and-tested and new materials, technology and systems concepts. They are used in Mechanical and Automotive Engineering, Electronics and Microsystems, Energy, Environmental and Process Engineering, Bio- and Medical Technology as well as Optics. 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 "pacemaker technologies" for all other fields.

The institute is therefore available as a competent consulting partner and starting point for all ceramics-related issues: a real "one stop shop" for ceramics.

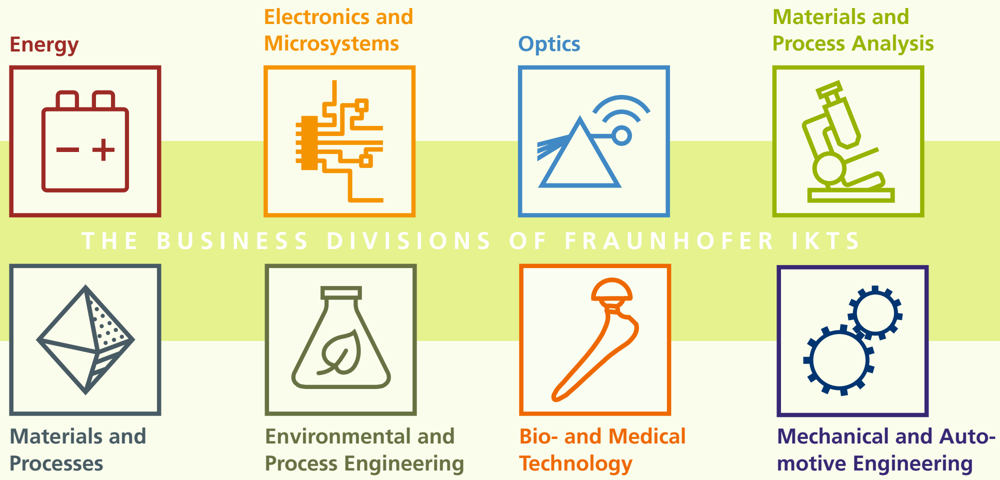
Among our unique areas of expertise, we offer:

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.



Synergies between materials, technologies and applications

The targeted combination of different technology platforms, of functional and structural ceramics for example, allows for multifunctional 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.

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.

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.

Furthermore, as founding member Fraunhofer IKTS serves as spokesperson for the Fraunhofer AdvanCer Alliance, which consists of four institutes that specialize specifically in ceramics. 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 foams

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 in ceramic technology
- Characterization
- 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

Modeling and 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
- Micro- and nanoanalytics
- Ultrasound testing
- High-frequency eddy current
- Optical methods
- X-ray methods

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

FRAUNHOFER IKTS IN FIGURES

Budget and revenues

With 55.5 million euros, the total budget 2017 exceeds the previous year's level by 2.1 million euros. Of that budget, 3.1 million euros were invested in reinforcing our equipment. Material expenditure increased by 1 million euros to 19.3 million euros in total. All in all, 42.3 million euros of external income was obtained, of which 19.6 million came directly from the industry. Projects to the value of 5.2 million euros were commissioned from abroad – mostly from India, China, Japan and the US, which together make up approximately half of the industry income from outside Germany. A positive development is that the funding of projects by federal states has increased in Thuringia (0.64 million euros) as well as in Saxony (3.3 million euros), translating into an increase of 28 % in total. The takeover of the buildings at Maria-Reiche-Strasse, Dresden by the Fraunhofer-Gesellschaft in 2017 was the basis for comprehensive extension works. The focus of the investment in buildings in 2018 will be on the renovation of fire protection infrastructure at that site. Various smaller construction projects at Winterbergstrasse, Dresden focused on extending lab areas for structural ceramics and functional ceramics research. In total, 2017 saw construction measures carried out at the three locations for 597,000 euros, in addition to the budget mentioned above. The share of EU project volumes increased by 350,000 euros. The successful efforts to extend the network of IKTS continue. Required administrational restructuring increases the pertaining organizational effort. The disparate costing approaches of the various funding bodies remains a challenge. The disparities lead to insecurity when it comes to determining billable costs and financial planning.

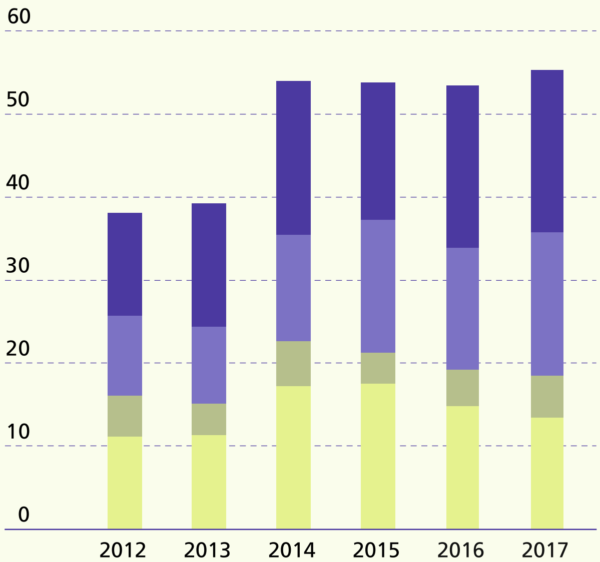
Personnel development

All in all, IKTS employs 680 staff members at three locations. The option of part-time work is particularly popular with our many young mothers and fathers. For increased comparability, the different groups are represented as full-time equivalents. 21 PhD students work on their specific research topics, side by side with the 220 scientist positions – six more than in the previous year. The number of apprentices has also increased by three positions and is now at 14. The support program for Syrian refugees has been in use since 2017. It represents our contribution to integrating refugees. We expect more promising applications from this group in the future. The lookout for 2018 is very good overall. Human resources development planning comes to the fore not just for our PhD students. Other areas will also offer the prospect of a specialist career with us. The aim is to support personal career goals while at the same time conducting an open and transparent HR strategy.

Expansion of the research basis

Within the classic field of activity of IKTS, the area of raw materials preparation was expanded as part of our strategy. With a particular view on cooperating with medium-sized companies, we have extended the capacity and technological basis for spray drying in order to be better able to process the various material groups. This will enable us to take on more projects in the field of oxide and non-oxide materials, and raw materials for cemented carbide. Supported by the federal state of Thuringia, the Hermsdorf site will be equipped with a synthesis plant, which will open up new possibilities of materials development – from structural ceramics to battery development. The sintering technology capacities in Dresden will also be expanded. In particular, the area of non-oxidic materials will boast new furnace systems from 2018, strengthening the technology chain from raw material to prototype. A TÜV-approved mobile test bench is available for exposition and electrochemical in-situ testing in deep geothermics. It also enables evaluating new materials for the oil and gas industries and use in deep-sea applications. At the Maria-Reiche-Strasse site in Dresden, investments were made in new camera systems for non-destructive materials testing. The area of battery and energy research will be extended as planned in 2018. The required evaluation of new buildings in the Braunschweig region was completed in 2017.

Revenue (in million euros) of Fraunhofer IKTS for the budget years 2012–2017

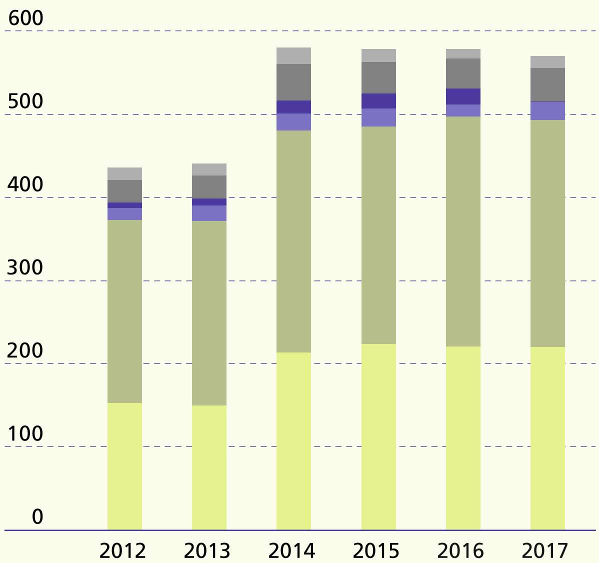


	2012	2013	2014	2015	2016	2017
Industrial revenue	12.6	14.4	18.6	16.3	19.6	19.6
Public-sector revenue	9.8	9.4	12.9	16.4	14.8	17.3
EU and other revenue	5.0	4.2	5.5	3.6	4.4	5.1
Institutional support	11.5	11.6	17.2	17.8	14.8	13.5
=	**38.9**	**39.6**	**54.2**	**54.1**	**53.6**	**55.5**

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

Personnel developments at Fraunhofer IKTS

Number of employees 2012–2017, full-time equivalents, personnel structure on December 31 of each year



	2012	2013	2014	2015	2016	2017
Apprentices	16	14	19	15	11	14
Student workers, trainees, undergraduate students	27	28	44	38	36	40
Part-time and contract workers	5	8	16	18	19	1
PhD candidates	15	19	20	21	15	21
Employees with university degrees and technicians	221	223	267	260	276	273
Scientists	154	150	214	223	220	220
=	**438**	**442**	**580**	**575**	**577**	**569**

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

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

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	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
- 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

Environmental and Process Engineering

Nanoporous Membranes
Dr. Hannes Richter
- Zeolithe Membranes and Nano-Composites
- Carbon-Based Membranes
- Membrane Prototypes

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 Water Technology
- Mixing Processes and Reactor Optimization
- 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
Project Group Berlin

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

Friedrich Schiller University Jena

Technical Environmental Chemistry — Prof. Dr. Michael Stelter

Iowa State University

Aerospace Engineering — Prof. Dr. habil. Norbert Meyendorf

- Powder and Suspension Characterization*
- Quality Assurance Laboratory* and Mechanics Laboratory
- Chemical and Structural Analysis
- Hardmetals and Cermets
- Accredited Test Lab*

* accredited according to DIN EN ISO/IEC 17025

Energy Systems / Bio- and Medical Technology

Materials and Components
Dr. Mihails Kusnezoff
- Joining Technology
- High-Temperature Electrochemistry and Catalysis
- Ceramic Energy Converters
- Materials MCFC

System Integration and Technology Transfer
Dr. Roland Weidl
- System Concepts
- Validation
- Functional Carrier Systems and Layers
- Stationary Energy Storage Systems
- Thin-Film Technologies
- Electrolytes and Samples

Bio- and Nanotechnology
Dr. Jörg Opitz
- Biological Materials Analysis
- Characterization Technologies
- Biodegradation and Nanofunctionalization

Energy Storage Systems and Electrochemistry
Dr.-Ing. 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 Photovoltaics
- 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

Microelectronic Materials and Nanoanalysis
Prof. Dr. habil. Ehrenfried Zschech
- Micro- and Nanoanalysis
- Materials and Reliability for Microelectronics

Project Group Berlin
Dipl.-Ing. Ralf Schallert

BOARD OF TRUSTEES

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

Dr. A. Beck
Saxon State Ministry for Science and the Arts, Dresden
Head of Department "Bund-Länder-Research Institutes"

Dipl.-Ing. R. Fetter
Thuringian Ministry for Economy, Science and the Digital Society, Erfurt
Department "Institutional Research"

Dr. habil. M. Gude
Thuringian Ministry for the Environment, Energy and Nature Conservation, Erfurt
Head of Department "Energy and Climate"

Dr. P. Heilmann
arXes Information Design Berlin GmbH, Berlin
Managing Director

A. Heller
Landrat of the Saale-Holzland-Region, Eisenberg

Dr. W. Köck
Plansee SE, Reutte
Executive Director

A. Krey
State Development Corporation of Thuringia (LEG), Erfurt
Manager

Dr. R. Lenk
CeramTec GmbH, Plochingen
Vice President R&D

Dr. C. Lesniak
3M Technical Ceramics, branch of 3M Deutschland GmbH, Kempten
Senior Laboratory Manager

Dr. H. H. Matthias
TRIDELTA GmbH, Hermsdorf
Managing Director

Dr. R. Metzler
Rauschert GmbH, Judenbach-Heinersdorf
Managing Director

P. G. Nothnagel
Saxony Economic Development Corporation, Dresden
Managing Director

M. Philipps
Endress + Hauser GmbH & Co. KG, Maulburg
Head of Business Division Sensor Technology

Dr.-Ing. W. Rossner
former Siemens AG, München

Dr. K.-H. Stegemann
X-FAB Dresden GmbH & Co. KG, Dresden
Manager Business Development

Dr. D. Stenkamp
TÜV Nord AG, Hannover
Board of Management

MR C. Zimmer-Conrad
State Minister for Economic Affairs, Labour and Transportation, Dresden
Head of Department "Innovation Policy, Technology Funding"

1 *Meeting of the Board of Trustees at Fraunhofer IKTS in 2017.*

THE FRAUNHOFER-GESELLSCHAFT

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

At present, the Fraunhofer-Gesellschaft maintains 72 institutes and research units. The majority of the more than 25,000 staff are qualified scientists and engineers, who work with an annual research budget of 2.3 billion euros. Of this sum, almost 2 billion euros is generated through contract research. Around 70 % of the Fraunhofer-Gesellschaft's contract research revenue is derived from contracts with industry and from publicly financed research projects. Around 30 % is contributed by the German federal and state governments in the form of base funding, enabling the institutes to work ahead on solutions to problems that will not become acutely relevant to industry and society until five or ten years from now.

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

With its clearly defined mission of application-oriented research and its focus on key technologies of relevance to the future, the Fraunhofer-Gesellschaft plays a prominent role in the German and European innovation process. Applied research has a knock-on effect that extends beyond the direct benefits perceived by the customer: Through their research and development work, the Fraunhofer Institutes help to reinforce the competitive strength of the economy in their local region, and throughout Germany and Europe. They do so by promoting innovation, strengthening the technological base, improving the acceptance of new technologies, and helping to train the urgently needed future generation of scientists and engineers. As an employer, the Fraunhofer-Gesellschaft offers its staff the opportunity to develop the professional and personal skills that will allow them to take up positions of responsibility within their institute, at universities, in industry and in society. Students who choose to work on projects at the Fraunhofer Institutes have excellent prospects of starting and developing a career in industry by virtue of the practical training and experience they have acquired.

The Fraunhofer-Gesellschaft is a recognized non-profit organization that takes its name from Joseph von Fraunhofer (1787–1826), the illustrious Munich researcher, inventor and entrepreneur.

Fraunhofer locations in Germany

RETROSPECTIVE


1


2

In 2017, Fraunhofer IKTS presented itself at 35 trade fairs in Germany and abroad as well as organizer of various scientific congresses and events for the general public. The year was also successful with regard to the further international networking of the institute. In addition, IKTS researchers were honored with prestigious awards.

January 17–18, 2017

Ceramics Vision | Dr. Bärbel Voigtsberger honored 1

At the 10th "Ceramics Vision" symposium, 110 participants met in Hermsdorf, Thuringia, to discuss new ceramics developments and application trends in energy and environmental technology, medical engineering, as well as micro- and nanotechnology. The application areas represented included energy generation and storage, industrial waste water conditioning, increasing the efficiency of combustion processes, sensor systems, and ceramic dental components. The potential of additive manufacturing and of ceramic fibers and composite materials for the development of novel high-tech products was also pointed out.

"Ceramics Vision 2017" was dedicated specially to Dr. Bärbel Voigtsberger and her visionary contributions to Fraunhofer IKTS, the ceramics location of Hermsdorf, and Deutsche Keramische Gesellschaft e. V. (DKG). Voigtsberger was awarded the Fraunhofer Medal for her life's work.

March 14–16, 2017

JEC World | Real-time composites testing

The institute used its presence at the leading trade fair for composite materials, "JEC World", to present the EddyCus® PolarLab eddy-current system, which measures and evaluates multiaxial carbon fiber structures and thus the mechanical strength of lightweight components in real-time. Materials made of carbon fiber composites are manufactured in complex processes. Therefore, effective non-destructive testing solutions are needed to detect manufacturing defects in resin-free or consolidated condition. The EddyCus® test series sets new standards in flexibility and precision.

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March 15 and November 20, 2017

Early-morning science with Fraunhofer | Media talk

Breaking news for breakfast... From ceramic bone replacement to sensor technologies for safe aviation – at the Fraunhofer media morning talks on March 15 and November 20, researchers from the Fraunhofer Institute Center Dresden introduced their latest research highlights to local and specialized journalists. The experts from Fraunhofer IKTS, FEP, IWS and IFAM briefly presented their developments and presented potential industrial applications. Furthermore, journalists had the opportunity to conduct one-to-one interviews and take a look into the laboratory. Interested stakeholders were invited to follow the event in a live stream via Periscope, Twitter or Facebook, and could ask questions. Further press events are planned for 2018.

March 22, 2017

Dresden kindergarten children visit IKTS 2

Unusual guests were expected in March at IKTS in Dresden-Klotzsche: The large group of preschoolers from "Pfiffikus" kindergarten visited the institute. In the application labs of the "Systems for Condition Monitoring" working group, the children gained insights into the work of a research institution and became acquainted with the professions of technician and scientist. The reactions of children and educators were enthusiastic, so the program will be continued in 2018.

April 2–5, 2017

EuroSimE | International microelectronics meeting 3

International electronics and microelectronics experts met for the 18th edition of the "International Conference on Thermal, Mechanical and Multi-Physics Simulation and Experiments in Microelectronics and Microsystems", organized by Fraunhofer IKTS. More than 160 participants from 21 countries followed the invitation to Dresden. Attendees discussed the latest results in fundamental research and industrial applications in these areas in about 80 lectures, some of which took place in parallel. Workshops, a poster session, a panel session and an industrial exhibition completed the program. The 19th EuroSimE will take place in Toulouse in 2019.

April 8, 2017

Open house at Fraunhofer IKTS in Hermsdorf, Germany

IKTS opened its doors in Hermsdorf on April 8 under the motto "Experience research on high-performance ceramics". 350 interested visitors from all over Thuringia informed themselves about ceramic filter membranes, possibilities of energy storage with ceramics, polymer- or bioceramics, tape casting and plasma spraying at 14 different stations. In addition, the building services department offered insights into the ventilation and refrigeration systems that are essential for the successful operation of the research institute. The event was part of the "Day of Thuringian Porcelain", which was supported by 18 other institutions such as manufactories, institutes and museums.

April 24–28, 2017

Hannover Messe | Ceramic solutions for industry 4

With three booths, IKTS was successfully represented at the world's largest industrial fair in 2017. For instance, IKTS showed in Hall 2 (Research & Technology) how electric energy can be used as raw material for the production of high-quality chemicals. At the same time, the institute presented a selection of ceramic products and systems, such as reliable stationary batteries, robust 3D-printed microreactors or porous ceramics, which serve as problem solvers in hazardous metal melting processes, in the Industrial Supply area in Hall 6. IKTS welcomed the Saxon Minister of State, Martin Dulig, at the booth. In Hall 27, the institute displayed its successful cooperation in the field of fuel cell systems, e.g. with CONVION Ltd. The C50 biogas system, which was put into operation in March and introduced at HMI, has a very high overall efficiency of 82 %. At the core of the system is the MK351 fuel cell stack developed by Fraunhofer IKTS and Plansee SE.

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RETROSPECTIVE

May 4, 2017

agra Innovation Award for recycling process

Together with Sachsenmilch Leppersdorf GmbH and wks Technik GmbH from Dresden, IKTS researcher André Wufka and his team have developed a process that allows to use almost all of the residual materials from milk processing in terms of materials and energy. Thus, this process chain enables closed material and energy cycles within the production process. In addition to the recovered water and the production of regenerative energy, the process also constitutes an important contribution to the recycling of valuable phosphor. This innovation was realized in three years of development work – funded by the German Federal Ministry of Food and Agriculture BMEL – and thus awarded on May 4 with the "agra-Preis der Innovation" in the food industry category.

May 29–31, 2017

IKTS awarded with Fraunhofer Research Prize 1

The 16 Fraunhofer Institutes of the Eastern Laender celebrated their 25th anniversary at the Fraunhofer Annual Conference in Dresden. An interactive science exhibition presented their important milestones and future projects. In the presence of the Federal Minister for Education and Research, Prof. Johanna Wanka, the Prime Minister of Saxony, Stanislaw Tillich, and the Fraunhofer President, Prof. Reimund Neugebauer, the IKTS researchers Dr. Hannes Richter, Petra Puhlfürß and Dr. Ingolf Voigt received the Fraunhofer Research Prize 2017 for the development of ceramic nanofiltration membranes for sustainable water treatment. The award ceremony with more than 500 invited guests took place on May 29 at the Dresden Congress Center. On the evening of May 30, visitors to Dresden's old town were able to experience how science is changing the world. Under the motto "#real_digital: experience research", light and laser projections transformed the historical facades into scenic surfaces in which actors presented historical backgrounds of the city of Dresden, relevant research topics and the Fraunhofer-Gesellschaft.

May 30–June 1, 2017

Sensor+Test | Mini sensor warns of explosion risks

It is smaller than a one euro coin, yet able to achieve great things: the robust, autonomous flame ionization detector presented at Sensor+Test is used for the continuous monitoring and recording of process data in harsh industrial environments. For example, it is ideal for explosion protection in sewerage systems, emission monitoring in combustion plants or process analysis in the chemical industry. The project was one of the nominees for the prestigious "AMA Innovationspreis 2017", which was awarded at the trade fair.

June 16, 2017

Dresden Long Night of Sciences 2

The "night creating knowledge" achieved new records: more than 38,000 visitors followed the invitation of the "Dresden – City of Science" network to experience research and try it out for themselves at Dresden's universities, research institutions and science-related companies. At Fraunhofer IKTS, around 2100 visitors learned about ceramic water filters, sensors, 3D-printed implants and light converters at 14 different stations. Guided tours through environmental technology laboratories provided insight into the bathroom of a floating house with a self-sufficient water/waste water loop. Children gold-plated cent coins, tried their hands at screen-printing and witnessed the manufacture of sugar-glass lollipops. 670 events took place that night at 151 venues throughout Dresden.

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June 26–29, 2017

Laser World of Photonics | Ceramics for long-life LEDs

Enormous light yield, longevity and low manufacturing costs – the light-converting ceramics developed at IKTS meet the high requirements for use as a chip and hermetically sealed packaging in high-power LEDs and laser systems. Yellowing or premature ageing, often the bane of conventionally used polymers, can be prevented when using the new white light-converting ceramic technology presented at Laser World of Photonics.

July 12, 2017

Prof. Michaelis appointed Fellow of ECerS

On June 12, Prof. Alexander Michaelis, Director of Fraunhofer IKTS, was appointed "Fellow of ECerS". Every two years, the European Ceramic Society ECerS honors personalities for outstanding services to ceramic sciences in Europe in the fields of science, education and industry. The award ceremony took place at the 15th ECerS conference in Budapest.

September 13–15, 2017

ISPA | Piezoceramic innovations – smartly done

Piezoceramics combined with electronic, functional and structural materials enable smart solutions for aerospace, ultrasound and sensor applications as well as energy and research services. At the seventh "International Symposium on Piezocomposite Applications ISPA" at IKTS in Dresden, 65 engineers, designers and managers from nine nations discussed research results, market requirements and framework conditions for the optimal technology transfer of piezoceramic innovations. Furthermore, results from the innovation cluster "smart^3 | materials – solutions – growth" were presented, which is funded by Germany's Federal Ministry of Education and Research (BMBF) as part of its Twenty20 program. The accompanying industrial exhibition encouraged the exchange of ideas on new products and services. The next ISPA will take place in 2019.

September 18–20, 2017

Dresden Battery Days | Storage systems for the future 3

Electrochemical storage technologies play a central role in energy transition. At the 2nd Dresden Battery Days, almost 100 international experts discussed current research and developments of solid-state batteries, production issues as well as aspects of the system integration of the future. Suppliers and manufacturers presented their new developments at an industrial exhibition. The symposium takes place every two years in Dresden. In 2018, the experts will meet in Graz, Austria.

September 20, 2017

IKTS intensifies cooperation with South Korea 4

The Korea-Germany Materials Center (KGMC) was founded on September 20 in Changwon, South Korea, in the presence of Dr. Eva-Maria Stange, Saxon Minister of State for Sciences and the Arts, and Dr. Robert Franke, Head of the Office for Economic Development of the City of Dresden. With this joint materials research center, Fraunhofer IKTS, the Institute for Lightweight Engineering and Polymers Technology ILK at Technische Universität Dresden, and the Korea Institute of Materials Science KIMS aim to develop new materials systems, manufacturing processes as well as test and validation methods for lightweight construction, and make them available to the industry. As a start-up project, IKTS and KIMS initially operate a test center together. In addition, both research institutes investigate further topics, such as the condition monitoring of wind turbines and the additive manufacturing of ceramics.

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September 24–26, 2017

ICBM 12 | Barkhausen effect in materials testing 1

Prof. Heinrich Barkhausen discovered the effect named after him one hundred years ago – a good occasion for holding the 12th "International Conference on Barkhausen Noise and Micromagnetic Testing" in Dresden, where Barkhausen worked successfully in research and teaching. 70 participants from 19 countries discussed industrial applications of the magnetic effect in non-destructive materials testing as well as new developments, potentials and challenges for the future.

October 9, 2017

Prof. Michaelis honored with ACerS Medal 2

Prof. Bill Lee, president of the American Ceramic Society ACerS awarded Prof. Alexander Michaelis the "Medal for Leadership in the Advancement of Ceramic Technology". With this award, ACerS recognizes individuals who have made significant contributions to the success of their organization and to the promotion of the ceramics industry through their visionary work. Two medals are awarded each year, one to an American and the other to an international prizewinner.

October 13–16, 2017

Compamed | 3D-printed ceramics for medical devices

Lower costs, shorter waiting times – all for bespoke products: Tool-free additive manufacturing is the key to personalized medicine. The combination of ceramic materials and additive processes opens up new possibilities for medical devices – from patient-specific physical dimensions to components designed and validated for specific applications. IKTS presented ceramic spine and knee implants, infrared heaters to accelerate healing processes and grippers for minimally invasive surgery at Compamed.

October 24, 2017

cerAMfacturing | First results from the EU project

Partners of the "cerAMfacturing" EU project as well as interested developers, manufacturers and users of additive processes met on October 24 at Fraunhofer IKTS to discuss the early results of the technology, device and component development for the suspension- and feedstock-based additive manufacturing of ceramic and multi-material components. A total of 50 guests followed the invitation to Dresden. In the second part of the workshop, various 3D printers were demonstrated in operation. The research project focuses on 3D-printed ceramics for personalized medicine and bespoke consumer goods.

November 8–9, 2017

DKG advanced training for tape casting processes

For the second time, the DKG workshop "Tape casting, slot die coating and aspects of tape post-processing" took place at Fraunhofer IKTS in Hermsdorf. The focus of the two-day training course was on the fundamentals of tape casting processes and the further processing of the tapes and layers produced with them into multilayer structures. The eleven participants worked hands-on with the various casting systems of the new IKTS Tape Casting Competence Center. Further lectures dealt with the production and processing of different slurries as well as methods for analytical quality control.

November 30–December 1, 2017

INSECT | Electrochemical machining 3

Electrochemical machining (ECM) is a suitable technology to machine high-strength or very brittle materials, resulting in high surface qualities. At the "International Symposium on Electro-Chemical Machining Technology INSECT", 55 experts from all over Europe discussed the latest findings on electrochemical

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basics, material properties, application trends as well as the future prospects of ECM. The accompanying industrial exhibition provided participants with an overview on the latest products, services and technical equipment on the market.

December 7, 2017

Fraunhofer promotes smart agriculture

On December 7, Fraunhofer-Gesellschaft and the Portuguese research funding organization FCT (Fundação para a Ciência e a Tecnologia) agreed, in a joint declaration of intent, to push ahead with the digitization of agriculture and forestry. Digital technologies are to be used to manage agricultural and forestry land in an even more targeted and sustainable manner. For this purpose, the partners are pooling their know-how in the fields of information and software technology, process and energy technologies, sensor technology as well as new materials. A joint task force in cooperation with Fraunhofer IKTS will therefore develop potential areas of application and suitable scenarios.

December 12, 2017

TRIDELTA CAMPUS HERMSDORF e. V. founded 4

23 local companies and Fraunhofer IKTS founded the local initiative "TRIDELTA CAMPUS HERMSDORF e. V." on December 12 in Hermsdorf, Thuringia. The initiative is to promote Hermsdorf as a high-tech location for technical ceramics and microelectronics/microtechnology to customers, specialists and investors and strengthen the site for the requirements of globalization. As a first step, the association is planning joint trade fair participations as well as a shared website.

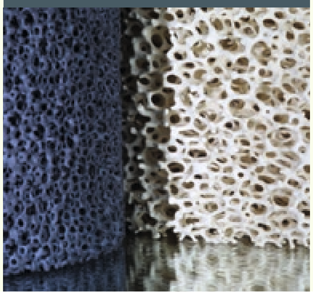
December 14, 2017

25 years of ceramics research in Hermsdorf

Within the scope of a scientific symposium, two events were celebrated on December 14 at the Stadthaus Hermsdorf: The 25th anniversary of the ceramic research institute in Hermsdorf – in various organizational forms over the years – and the founding of the "TRIDELTA CAMPUS HERMSDORF e. V." initiative, whose aim is to promote the site. 300 invited guests from industry, research and politics discussed current research and application trends, such as the potential of power-to-X technologies for a CO_2-neutral economy, ceramics for durable joint endoprostheses, and ceramic membrane technologies.

HIGHLIGHTS FROM OUR BUSINESS DIVISIONS

Materials and Processes

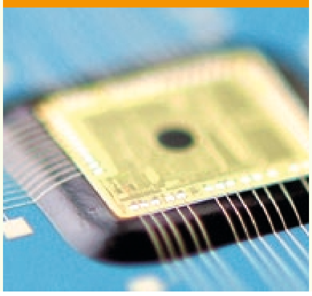


The "Materials and Processes" business division provides a central point of contact for all matters related to development, manufacturing, and qualification of high-performance ceramics for a wide range of applications. A wealth of experience has been accumulated in all relevant materials and technologies, 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

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, hard metal, 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.

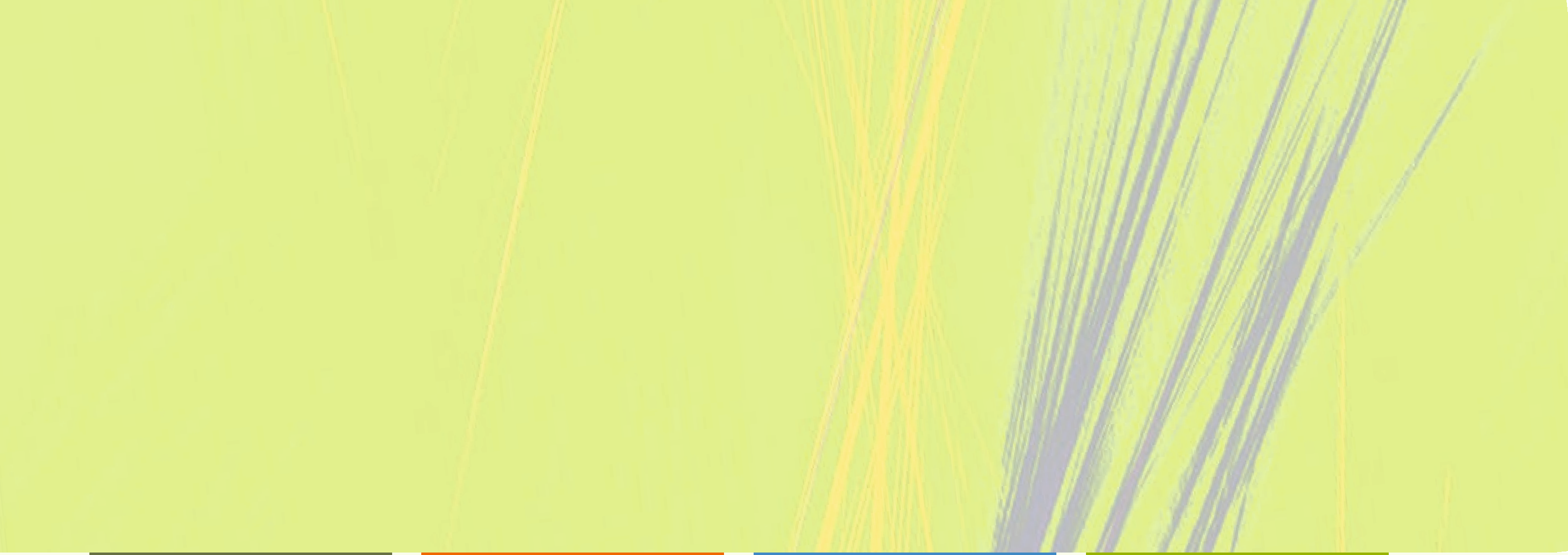
Electronics and Microsystems



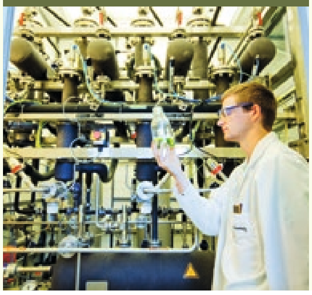
The "Electronics and Microsystems" business division offers manufacturers and users unique access to materials, technologies, and know-how to help them develop robust, high-performance electronic components. Focus is on sensors and sensor systems as well as power electronic components and "smart" multifunctional 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

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.

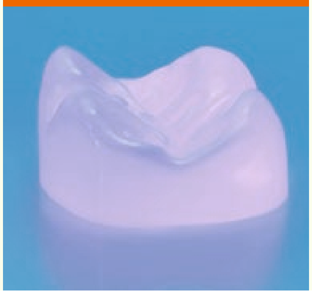


Environmental and Process Engineering



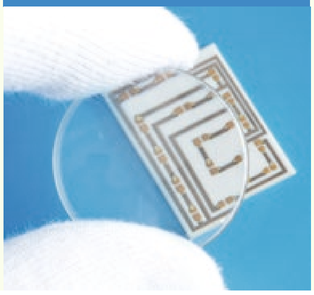
Fraunhofer IKTS develops innovative materials, technologies, and systems for safe, efficient, environmentally, and climate-friendly conversion of energy and substances. Focus is on processes involving conventional and biological energy sources as well as strategies and processes for water and air purification 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



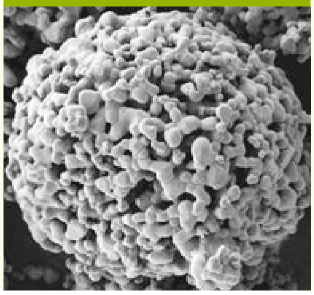
Fraunhofer IKTS makes use of the outstanding properties of ceramic materials to develop dental and endoprosthetic implants and surgical instruments. In well-equipped, certified laboratories, the interactions between biological and synthetic materials are investigated and applied towards the development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

Optics

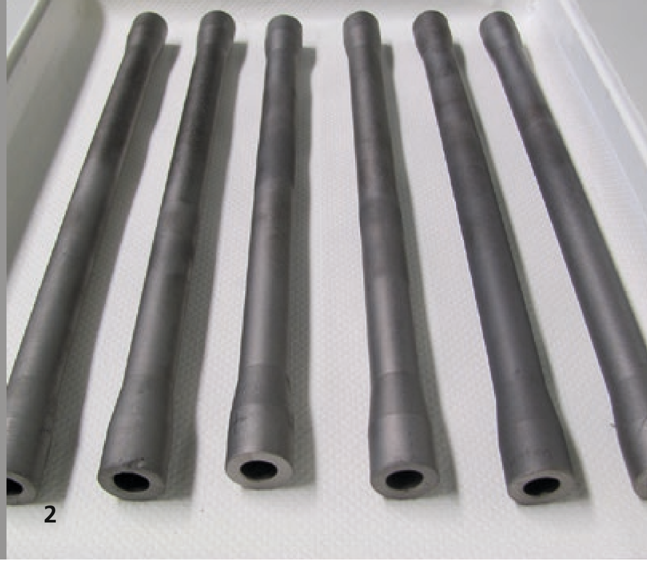


Fraunhofer IKTS develops ceramic materials and components for photonics, lighting applications, and ballistic protection. Phase synthesis combined with materials and technology expertise yields innovative luminescent materials, active optoceramics, optical and decorative elements, and transparent ceramics for defense applications. Optical technologies are also used in measurement and diagnostic systems in medicine, life sciences, and industry.

Materials and Process Analysis



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.



ZrC MATERIALS FOR ULTRA-HIGH-TEMPERATURE APPLICATIONS UP TO 2000 °C

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

Zirconium carbide (ZrC) belongs to the class of metal-like ceramics. It has – like only few other materials – a very high vacuum stability of 10–6 mbar up to 2000 °C und is extremely heat-resistant (Ts > 3500 °C). Thus, it can be utilized as a highly refractory, i. e. thermally insensitive material.

ZrC offers an outstanding protection against chemical and thermal corrosion of plant components under non-oxidizing atmospheres. Despite this, it has been rarely used so far due to the technically demanding manufacturing of massive and dense ZrC materials. As soon as there is a cost-effective and reliable manufacturing technology available, this material will be an attractive alternative to conventional refractory metals in every respect.

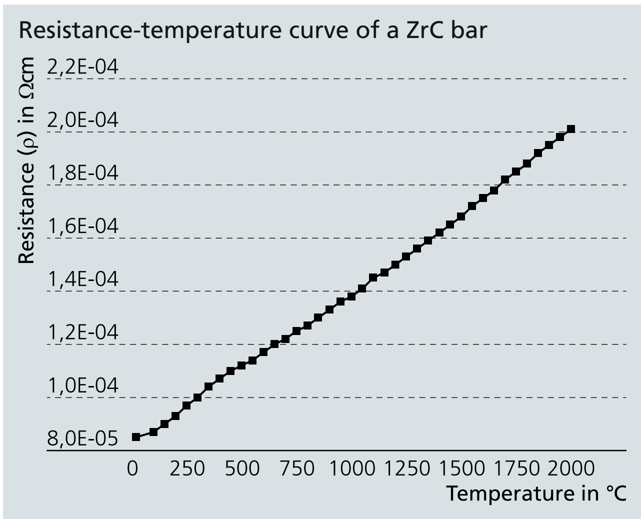
A technology developed at Fraunhofer IKTS now enables, for the first time, the cost-efficient manufacturing of dense ZrC materials in various geometries through pressureless sintering. When combined with an adapted powder processing route, this method even allows to manufacture large-scale components. The technology was registered with the German Patent Office (DE 10 2015 204 269).

Tubes with a length of > 250 mm are the first components realized, but the production of plates and bars is also possible. These components can be applied as electric heat conductors, thermal protection, fluid lines or construction elements for high-temperature applications.

Tests so far have confirmed that the components have a stable electrical resistance up to 2000 °C, high thermal stability, high mechanical strength, as well as the fracture toughness that is typical for ceramic materials. The vacuum stability up to 2000 °C is currently being investigated in a new test stand.

Services offered

- Development and manufacturing of ultra-high-temperature ceramics (UHTC)
- Characterization of UHTC up to 2000 °C



1 *Direct heating of a ZrC bar.*
2 *ZrC tubes with heat conductor geometry.*

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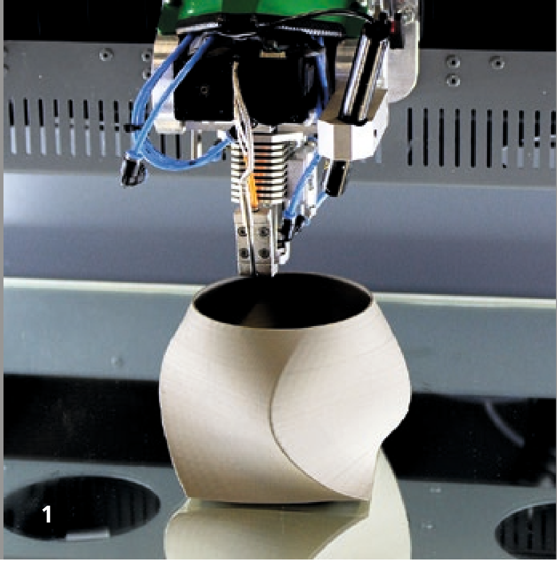

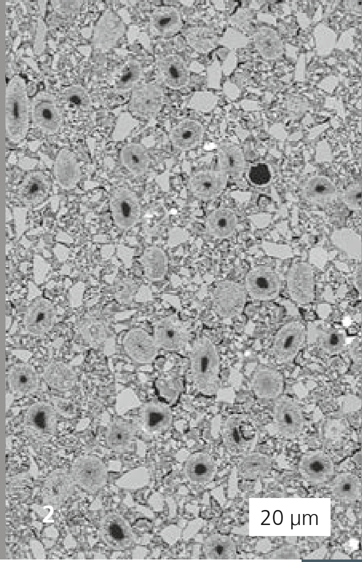

ADDITIVE MANUFACTURING OF CERAMIC PARTS THROUGH FUSED-FILAMENT-FABRICATION (FFF)

Dipl.-Ing. Johannes Abel, Dipl.-Ing. Uwe Scheithauer, Dr. Hagen Klemm, Dr. Tassilo Moritz

High-performance ceramics are already widely used in a number of applications in the areas of industry, research and consumer goods. At the same time, demand for complex geometries with a wide range of customization options and favorable manufacturing processes is increasing continuously.

The additive shaping process of fused-filament-fabrication (FFF) enables producing large and complex components quickly with high material efficiency. In FFF, a thermoplastic endless filament is melted and deposited under a heated nozzle. The print head movement is computer-controlled, building up the desired shape, layer by layer. FFF is the most widely used process within the field of commercial additive manufacturing of components. Devices are available from various manufacturers for as little as a few hundred US dollars. So far, however, this has only been true for the production of polymer components, such as PLA, ABS, PA, PET or PEEK, or for elastic components made from TPE or TPU.

Therefore, Fraunhofer IKTS works on adapting the process for the additive manufacturing of ceramic components. The green bodies are exclusively produced in an additive process, before being debindered and sintered, as in any conventional shaping process for ceramic components. Initially, filaments based on a feedstock of SiC powders were successfully produced and processed in the standard 140L printer from HAGE Sondermaschinenbau GmbH & Co. KG. As the next step of material development, the feedstock was reinforced with SiC short fibers. SiC materials with a SiC fiber content of up to 30 vol % were successfully realized and processed.

Through subsequent infiltration with ceramic precursors and pyrolysis, it was possible to further densify the components. A typical part and microstructure of a material produced with FFF is shown in Figures 1 and 2. These investigations helped to demonstrate the high potential of this new additive manufacturing method for ceramic fiber composite materials (CMC) in various applications, e.g. in the aerospace or energy engineering sectors. Further development stages looked at the production of components based on Al_2O_3, WC-Co and Si_3N_4. Final sintering resulted in materials with a relative density of > 99 %. Figure 3 shows an example of a sintered Al_2O_3 component.

The results for the production and processing of filaments on the basis of a wide variety of ceramics, as obtained in the current state of development, open up wholly new possibilities for further fields of application. Of particular interest is the simultaneous processing of several materials in order to combine properties such as electrically conductive and insulating, hard and ductile, or different colors within a complex component. In this way, components can be functionalized or provided for decorative purposes.

1 *SiC/SiC fiber-reinforced green body made by FFF.*

2 *Microstructure of a SiC/SiC green body.*

3 *Sintered Al_2O_3 component.*

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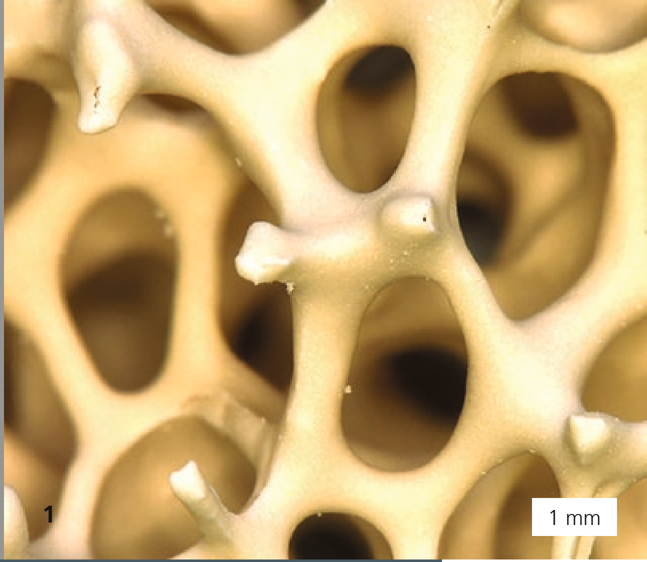

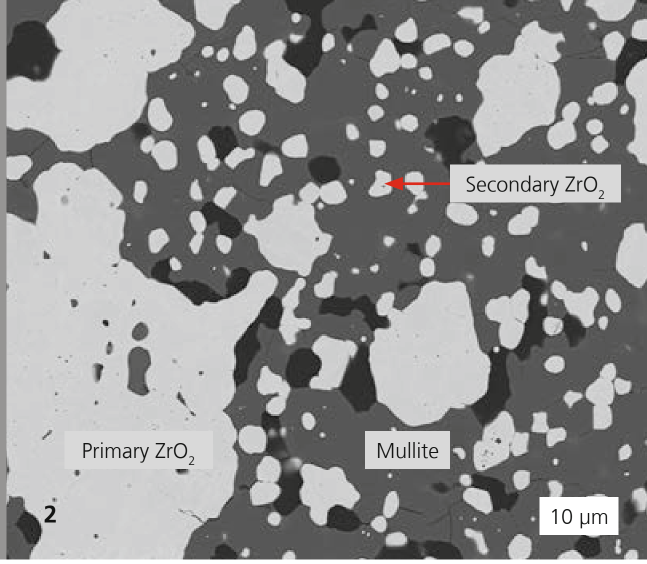

REACTION-BONDED ZrO_2 CERAMIC FOAMS – HIGH-STRENGTH, HEAT-STABLE, COST-EFFICIENT

Dipl.-Ing. Gisela Standke, Dipl.-Krist. Jörg Adler

Application of zirconia filters

High-temperature-resistant ceramic foams made of zirconia (ZrO_2) are used in foundries to clean steel melts from non-metal inclusions, such as slags, molding sand residues and deoxidation products. Nevertheless, on account of their relatively high raw material costs, they have been significantly more expensive than alumina or silicon carbide filters, which are used at lower casting temperatures and in other metal melts. Now, thanks to a new material concept, raw material costs can be lowered by about 40 %.

Material concept

The composition of the newly developed reaction-bonded (rb) foams was adjusted by replacing 65 % of the original zirconia powder with a stoichiometric mixture of alumina and zirconium silicate. During the thermal treatment of the filter, these raw materials react to produce fine-grained zirconia and mullite. After sintering, the microstructure consists of 37 % coarse zirconia (primary grain), 23 % newly produced zirconia (secondary grain) and 40 % mullite. In order to achieve a complete reaction and material properties equivalent to those of conventional zirconia filters, alumina powders with different particle sizes and specific surfaces were investigated. The particle size of zirconium silicate was kept constant at 2 µm. A complete conversion was reached with alumina powder at a d_{50} of 2 µm and a BET of 2.5 m²/g, at a sintering temperature of 1650 °C and with dwell of 3 hours.

Properties

In comparison to standard zirconia filters, the pore formation changes: the amount of total porosity decreases, as does the average pore size. Thus, reaction-bonded foam filters have a lower pure density and a higher strength.

Properties of new reaction-bonded filters compared with a standard zirconia filter

	rb filter	Standard
Pure density	4.3 g/cm³	5.6 g/cm³
Porosity of microstructure	20.5 %	24.4 %
Pore size	2.2 µm	4.7 µm
Fracture load	1500 N	900 N

For steel filters, we have developed particularly coarse-sized foams (ppi8). For this purpose, the coating suspension was adapted to the different particle sizes of the raw materials.

Services offered

- Materials and process development for open-celled ceramic foams
- Further development of, and new applications for, reaction-bonded zirconia

1 *Cellular structure of the new zirconia filter.*

2 *Microstructure showing the new reaction bonding.*

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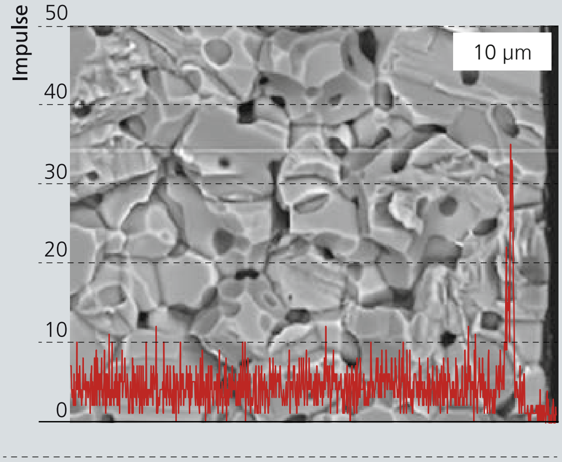

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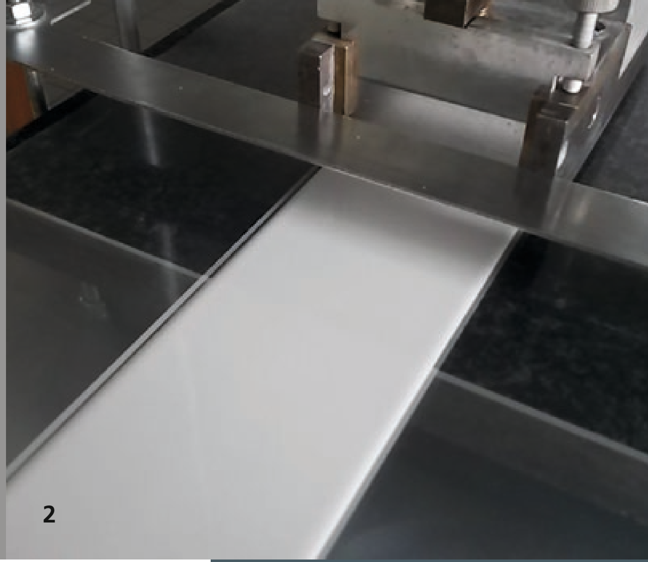

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HIGH-PURITY MgO TAPES AS SINTERING AID FOR MIEC CERAMIC FLAT MEMBRANES

Dr.-Ing. Uwe Reichel, Dipl.-Chem. Beate Capraro, Dipl.-Ing. (FH) Dirk Schabbel, Dipl.-Ing. (FH) Ute Pippardt

Thanks to its excellent chemical, electrical and thermal properties, high-purity dense magnesia ceramic is highly suitable for extremely stressed components, for example in analytics, electronics, high-temperature or (when using transparent materials) optical applications. Fraunhofer IKTS is currently investigating another type of application: suitable temperature- and reaction-resistant sintering aid is needed for the ion- and proton-conducting ceramic flat membranes developed at the institute on the basis of BSCF- (Ba-Sr-Co-Fe), CSFM- (Ca-Sr-Fe-Mn), La-Wolframat and Sr-Cereat materials. Such kiln furniture is not yet available with the quality required. The aim of the research project was therefore to develop the fundamental know-how for the material and technological basis of high-purity MgO ceramics for use as sintering aid.

Approach and results

The focus of the project was on specific preparation and shaping technologies for ceramic tapes of commercially available and highly pure (99,98 %) magnesia powders as well as PVB-based binder systems. The selection and characterization of these commercial highly pure and ultra-disperse magnesia powders with regard to their chemical purity, content of crystal phase and sintering behavior, as well as the analysis of dispersing power and castability, were key aspects. As a result, an MgO raw material with a purity > 99.98 % MgO, with pure periclase crystalline phase and a specific surface area (BET) of 7.9 m²/g was chosen for the magnesia development. Another fundamental aspect for the successful processing of thin-walled flat tapes was the development of suitable thermal processes for the debindering and sintering of these components. The aim was to achieve a crack-free homogeneous structure and distortion-free sintering. As a final step, the sintered MgO ceramic was characterized and its ability to serve as a reaction-stable sintering aid for ion-conducting ceramic flat membranes was reviewed. The diffusion of BSCF into the magnesia ceramic was shown to be very minor (Figure 1). Contact with the sintering aid did not lead to any changes in the composition of the BSCF ceramic. The examination of other materials systems for MIEC ceramic flat membranes has not concluded at the time of printing, but positive results may be expected.

Services offered

- Development of high-purity magnesia ceramic components for customer-specific applications
- Development of shaping technologies and thermal processes
- Characterization of materials and components
- Realization of small-batch series

1 *Line scan of (minimal) Co-diffusion in MgO ceramics.*

2 *Casting strip with MgO tape.*

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SHAPING OF MOFS THROUGH POWDER-TECHNOLGICAL PROCESSES

Dr. Hans-Jürgen Richter, Dr. Matthias Ahlhelm

Metal-organic frameworks – MOFs – are a new class of porous materials characterized by high specific surface areas and pore volumes and, thus, outstanding gas storage properties. The three-dimensional MOF networks consist of metal clusters and organic linker molecules. Other molecules can be "stored" in the intermediate spaces. Selecting appropriate raw materials provides a variety in composition and structure of MOFs, which allows for targeted properties tailored to specific applications.

The shaping of MOF powders to formed bodies plays a key role for opening up the excellent material properties of MOFs to a broad range of applications. Fraunhofer IKTS has succeeded in developing application-specific MOF bodies, such as pellets, granules or monolithic honeycomb and foam structures through various powder-technological shaping and granulation methods, such as extrusion, dry pressing, freeze-casting, freeze-granulation and freeze-foaming. These can be used, for instance, in gas storage systems, in heat pumps or as catalyst support. IKTS has been successfully contributing its expertise in the powder-technological shaping of MOFs in a number of projects (Fraunhofer-internal project "MOF2market", EU project "MATESA" – Grant Agreement 608534) since 2012. Current projects include "ProDIA" (Grant Agreement 685727) and "H-CCAT" (Grant Agreement 720996) – both funded by the EU – as well as "MOFSchutz", funded by the German Federal Ministry of Eduction and Research, BMBF (grant number 13N14194). These ongoing projects assess the influence of process parameters and binder components on the specific surface area and application-relevant performance (e.g. in terms of NH_3 adsorption, CH_4 storage, H_2O adsorption). The specific shaping processes are adapted and optimized accordingly.

Various MOF powders like e.g. HKUST-1, Fe- BTC, Al-Fumarate, UiO-66, CPO-27(Ni), CAU-10 or PCN-250, which had been synthesized by project partners, were processed to granules, pellets or monolithic parts. With regard to those MOF parts, next to obtaining mechanically stable components, the challenge was to retain as much of the initial properties of the MOF material as possible. The necessary usage of binder components and/or the shear forces occurring in shaping processes (e.g. extrusion, compression) can have negative effects on the porosity or the specific surface area and, thus, the application properties (e.g. storage capacity) of the MOF. Extruded HKUST-1 pellets yielded particularly good results, with surface areas between 83 % and 100 % the size of the raw material (1460 m²/g), depending on processing and binder. PCN-250 pellets reached between 72 % and 77 %. For other MOF bodies obtained through pressing, freeze-granulation, freeze-casting or freeze-foaming, these values are in the range between 55 % and 95 % compared with the raw material. Using the adapted shaping processes and shaped body compositions, it is possible to utilize MOFs with their excellent material properties for various applications.

1 *Extruded MOF honeycomb structures (Fe-BTC).*

2 *Extruded MOF pellets (HKUST-1).*

3 *Freeze-granulated MOF granules (Al fumarate).*

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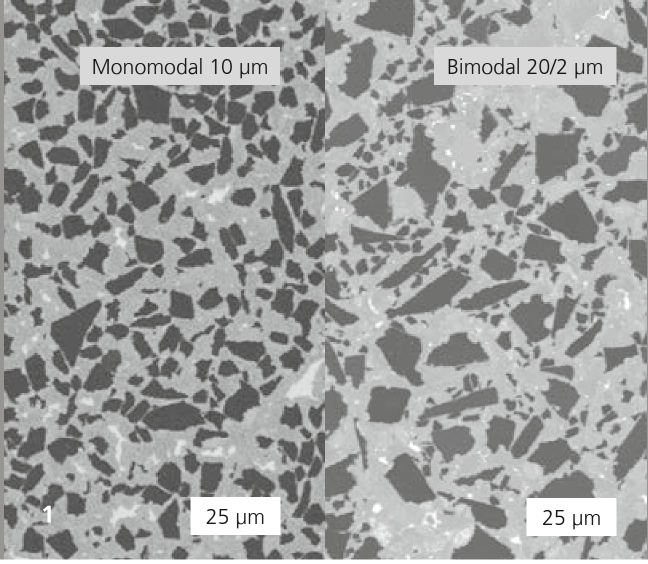

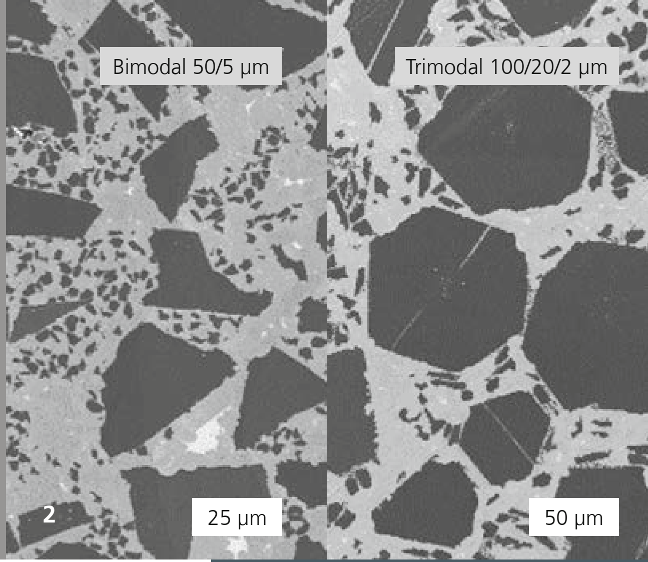

SILICON CARBIDE-BONDED DIAMOND MATERIALS WITH HIGHEST WEAR RESISTANCE

Dipl.-Ing. Björn Matthey, Dr. Steffen Kunze, Dr. Mathias Herrmann

In deep-sea mining down to 6000 m, as well as for oil and gas production at sea, the durability and freedom from maintenance of all materials and components over timespans of 10 to 30 years is essential. Achieving this is next to impossible with conventional materials – specifically, for example, with regard to wear components in pumps. For this field of application, Fraunhofer IKTS, in collaboration with its Fraunhofer AdvanCer Alliance partners, is developing superhard, wear-resistant SiC-bonded diamond materials with diamond contents of approx. 50 % by volume.

These materials can be prepared pressure-free as compact components through the silicon infiltration of diamond preforms. Moreover, SiC components with locally placed diamond-SiC composite in wear areas can also be realized. Even large-scale complex components, such as pipe segments, bearings or nozzles, are manufactured effectively. The microstructures of the materials can be adjusted across a wide range (Figure 1). This allows the production of components with customized properties.

The materials thus developed are characterized by a solid chemical integration of the diamonds into the three-dimensional SiC framework, which is formed by reaction of diamond with silicon during infiltration. As a result, the materials have a higher strength than silicon-infiltrated SiC material (SiSiC) (HK2 up to 48 GPa against more than 20 GPa, or a biaxial strength above 450 MPa against approx. 280 MPa, measured in ball-on-3-balls tests). The silicon content of less than 5 % by volume is considerably lower than in conventional SiSiC materials. As a result, in contrast to SiSiC materials, the materials show a high corrosion resistance in basic media and under hydrothermal conditions.

Tribological tests show that these materials have a wear behavior similar to that of superhard polycrystalline diamond (PCD): in contrast to PCD they can be produced in almost any dimensions and shapes. Moreover, their wear resistance is ten times higher than for commercial boron carbide material. Depending on the microstructure design, thermal conductivity can be increased to more than 500 W/mK, which offers potential e.g. for heat exchangers [1; 2].

The new SiC-bonded diamond materials open up new possibilities for cost-effective, wear-resistant components of different geometry and dimension for a vast variety of areas.

Services offered

- Technology development
- Development and testing of sample components
- Characterization of microstructures and properties of superhard materials

Literature

[1] B. Matthey, et al. J. of Materials Research, 32, (2017), 3362–3371.
[2] B. Matthey, et al. J. Eur. Ceram. Soc., 37, (2017), 1917–1928.

1 *SEM image of different microstructures of SiC-bonded diamond materials.*

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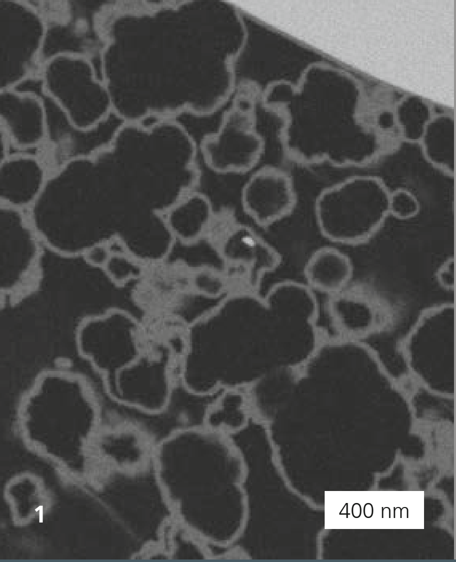

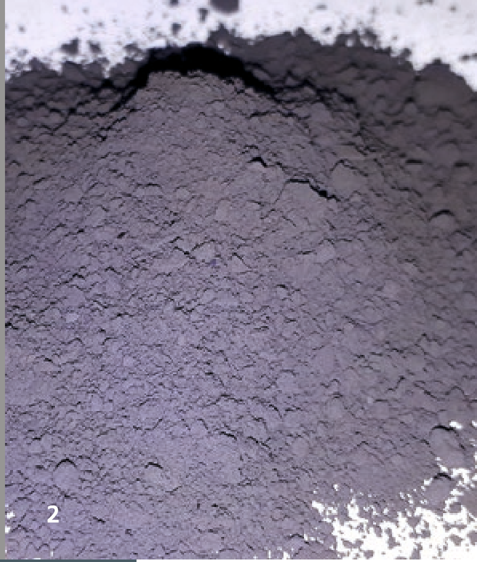

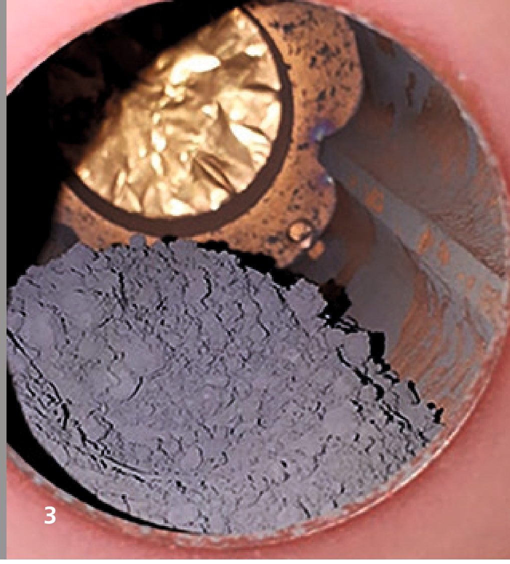

SURFACE-CONFORMAL POWDER COATING USING ALD AND CVD PROCESSES

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

The Thin-Film Technologies Group of Fraunhofer IKTS has extended its expertise and service portfolio into the field of thin-film deposition on particles and powders. Using the available equipment and deposition technology, powder quantities of up to 100 g can now be coated using conformal ALD and CVD processes.

The recent research and development has focused on conformal functional layers on powder materials for applications for Li-ion batteries (LMNO – $LiNi_{0,5}Mn_{1,5}O_4$ powder), as well as applications in hardmetal tool manufacturing. The group has developed novel ultrathin barrier layers and layer systems for LNMO powders and other hygroscopic and easily oxidizing materials, e.g. metal powders and hardmetal powders such as tungsten carbide (WC).

The first results for the coating of tungsten carbide powder with titanium nitride show that it is possible to produce coatings with excellent surface conformality using both ALD and CVD techniques (Figure 1). With a 10 to 50 nm thin TiN coating on tungsten carbide powder, new types of polycrystalline tungsten carbide based on polycrystalline WC particles can be produced for various applications in the tooling industry. As these hardmetals are being manufactured, a TiN barrier layer can prevent the molten cobalt from penetrating into the polycrystal and dissolving it. This results in extraordinarily high hardness and good fracture toughness. A broad range of TiN ALD- and CVD-coated powder is currently being investigated for their sintering processing behavior and material properties, such as hardness and rupture strength.

In a second project, LMNO powders for Li-ion batteries were coated with an extremely thin Al_2O_3 coating. This layer improves the interface with the electrolyte, which in combination with the high-voltage material LNMO prevents degradation of the electrolyte. The aim is to benefit both the battery cell's cycle stability and performance. The coated powders are currently being characterized and show promising results.

When coating powders with low density or low weight, the coating process was frequently marred by high powder losses. By optimizing the ALD pulse sequences and the reactor geometry, it is now possible to achieve a powder yield of more than 95 % for Al_2O_3 coatings in the layer thickness range of 1 to 20 nm. The agglomeration of the particles could also be avoided through rotation (Figure 3).

1 *Tungsten carbide powder coated conformally with TiN.*
2 *Al_2O_3-coated LMNO powder.*
3 *LNMO powder in the drum reactor. After processing, the powder character is retained without particle agglomeration.*

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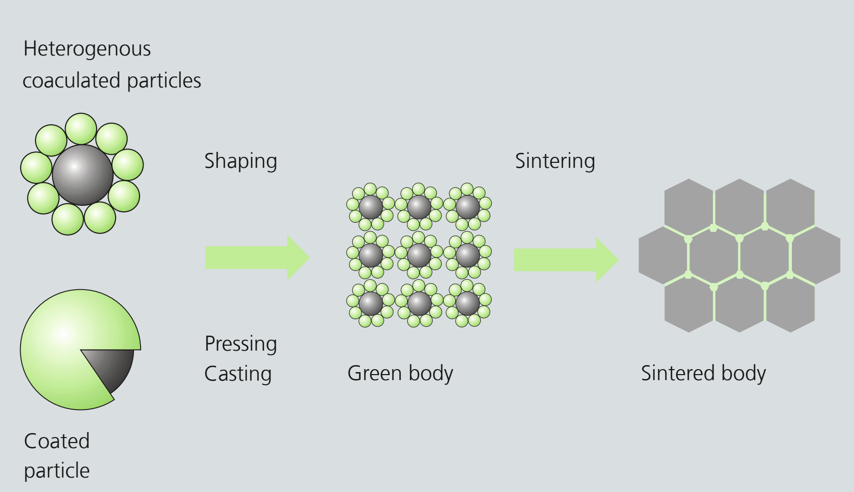

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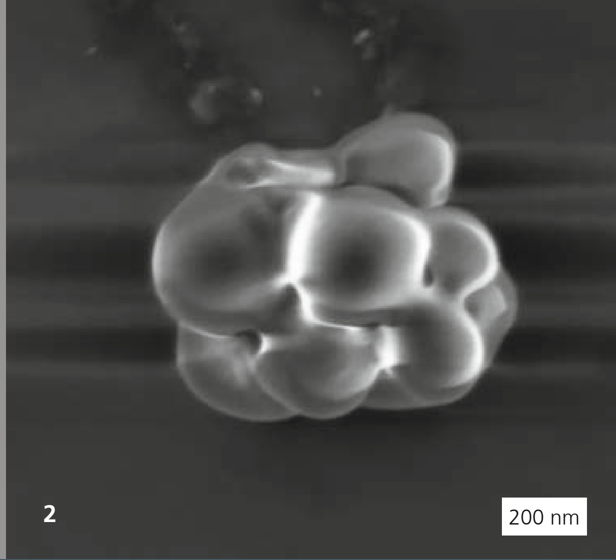

2

CORE-SHELL COATING FOR IMPROVED HARDNESS AND STRENGTH OF ZTA CERAMICS

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

Zirconium oxide-toughened alumina ceramics (ZTA) possess several remarkable properties. For example, they are less prone to hydrothermal degradation than pure zirconia ceramics, which makes them very suitable for medical applications. Furthermore, they are much tougher than unstrengthened alumina ceramics. Also, when compared with zirconia-based ceramics, ZTA ceramics are in many cases more cost-efficient. The homogenous distribution of the alumina and zirconia phases, however, has proven to be the most critical factor for the mechanical properties of a mixed-oxide ceramic. The efforts within the scope of the growth core "pades – Partikeldesign Thüringen" focused therefore on developing ZTA ceramics with a more homogeneous phase distribution (with comparable grain size and material density) in order to achieve the highest possible strength and hardness.

For wet-chemical coating of particles different methods are applied. One possibility is the heterogeneous coagulation of solid particles by variation of surface charges and another one is the coating of solid particles with a liquid second phase. Within the presented project the second approach was used. As a first step, the commercially available powdered raw material, alumina (Al_2O_3), was coated with the second phase, zirconium dioxide (ZrO_2), in a wet-chemical process. In addition to very small quantities (< 100 g) – produced in a rotary evaporator – larger quantities can also be produced in the rotary kiln. The particle coating (core shell) produced on an alumina powder already shows the uniform distribution of the second phase (Figure 2). Subsequently, the material was processed mainly by uniaxial pressing. The ceramics thus produced have up to 20 % smaller grain sizes after sintering compared with ceramics produced using conventional raw materials. The new technology for refining the microstructure of a composite ceramic is easy to use on an industrial scale and also relatively cost-efficient. Furthermore, the described method can be transferred onto other materials as well.

Services offered

- Materials synthesis and development based on commercially available raw materials and unique developments with the emphasis on dense, single-phase and multi-phase oxide ceramics based on sintered corundum (Al_2O_3), spinel ($MgO{\cdot}Al_2O_3$), zirconium oxide (ZrO_2) or other oxides (Y_2O_3, $Y_3Al_5O_{12}$, etc.), dispersion structures or composite materials
- Material-specific shaping and development of prototypical components and pilot series
- Accompanying characterization and analysis
- Consultation on material, design and application-specific questions

1 Schematic view of an ideal process chain including coated powder.

2 FESEM image of a ZrO_2-coated Al_2O_3 particle before calcination (image: Friedrich Schiller University Jena, OSIM, Chair of Material Science).

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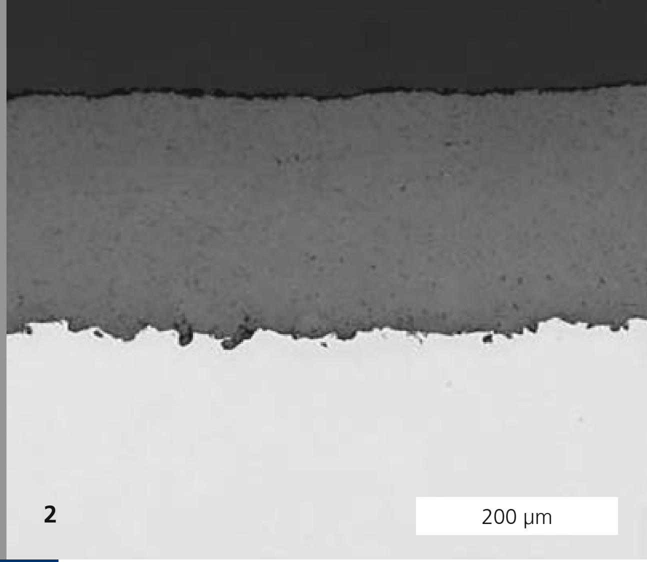

CERAMIC SUSPENSIONS FOR ABRASION AND CORROSION PROTECTION COATINGS

Dr. Annegret Potthoff

Applying ceramic protection coatings is one way of adapting the surface properties of components specifically to the respective application: Al_2O_3 coatings improve electrical insulation, while Cr_2O_3 coatings effectively protect metal components against corrosion, and hardmetal coatings are indispensable for wear protection.

Thermal powder spraying is an established process for surface coating. The use of suspensions instead of powders offers decisive advantages, as it allows to produce thin (< 100 µm) and dense coatings with very smooth surfaces. Besides the reduction of raw materials there are economic advantages, too. For example, the otherwise necessary finishing steps for coated surfaces can be either reduced or eliminated altogether. In addition to the process parameters for thermal spraying (suspension high velocity oxy-fuel spraying [S-HVOF], suspension plasma spraying [SPS]), the properties of the processed suspension also determine the coating results. In order to increase the efficiency of the spraying process, the solids concentration must be at least 25 wt %. At the same time, the applied suspension has to be homogeneous to ensure a stable spraying process. Furthermore, viscosity must be low in order to guarantee a good feeding capacity. Carefully chosen raw materials are key for developing high-quality spraying agents. Materials with homogeneous particle size distributions and high purity levels are particularly suited for the development of protection coatings.

Suspension properties are optimized and adjusted by means of electro-acoustic, rheological and sedimentation measurement technology.

In collaboration with the Fraunhofer Institute for Material and Beam Technology IWS, we developed the foundations for implementing the entire process chain on the industrial scale, from feedstock development to coatings with application-specific properties.

One example for the spraying of a suspension resulting in considerably advanced layer properties is Al_2O_3 layers with strongly increased electrical resistance in humid environments. Also, laser-structured Cr_2O_3 layers were obtained in very high resolution for paper industry applications. Other types of layers providing hydrophobic properties thanks to their structure and processed raw materials are used effectively as nonstick coating.

Services offered

- Selection, sampling and characterization of raw materials; development of aqueous and solvent-based suspensions for thermal spraying
- Feasibility studies and technology development for the thermal spraying of suspensions in collaboration with IWS

1 *Preparation of a suspension for thermal spraying.*
2 *SEM image of an Al_2O_3 coating.*

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PASTES FOR LASER-SINTERED FUNCTIONAL LAYERS ON 3D STEEL COMPONENTS

Dr. Uwe Partsch, Dipl.-Ing. Markus Pohl, Dr. Sylvia Gebhardt, Dr. Rena Gradmann, Dr. Markus Eberstein

Ceramic thick-film technology is typically used to produce functional layers, e.g. for ceramic circuit boards or sensors. The technology uses pastes and is based on the typical process sequence of screen printing, drying, and firing. Continuous furnaces are used for high-throughput firing. The deposition of the required functional pastes is currently limited to planar or tubular substrate bodies due to technological and plant-related reasons. For the first time, researchers at the Fraunhofer Institutes IKTS, ILT and IZM have now succeeded in printing sensor layers directly onto large steel components, thus functionalizing them locally. Due to their size and heat sensitivity they would melt if sintered in the furnace.

3D thick films without screens and sintering furnaces

The objective of the Fraunhofer "InFuroS – Integrated functionality on robust structural elements" research project was to overcome the restrictions of classic thick-film technology by using modern 3D printing technologies (dispensing, aerosol-jet printing). Instead of the usual furnace processes, we use fast laser treatments to sinter the required functional layers. The focus is on the development of adapted paste systems and laser processes for the deposition and sintering of insulation, conductor, resistor and piezoelectric layers on solid steel components (1.4016, 1.3035) to generate strain, temperature and body sound sensors.

For the development of laser-sinterable insulation pastes, we selected suitable thick-film glasses of different compositions which differed in terms of their glass transition temperatures. We optimized specific glass properties by adding different dispersing phases which affect, among other things, the absorption properties or glass viscosity during laser treatment. At Fraunhofer ILT, the glass composites were characterized in terms of their optical properties (absorption) and at IKTS in terms of shrinkage and other layer properties (adhesive strength, insulation resistance).

Over the course of the project, we developed more laser-sinterable pastes, such as conductor path pastes (Ag-based), resistance pastes (RuO_2-based) for temperature and strain sensors, as well as piezoelectric pastes based on lead zirconate titanate (PZT) for structure-borne sound sensors. Thanks to their significantly reduced interaction times in laser sintering, piezoelectric layers combined with steel, as well as insulation and electrode layers, showed particularly improved material properties compared with furnace-sintered structures.

To demonstrate the project results, sensors for measuring strain and structure-borne sound were printed and laser-sintered onto the shell of a roller bearing.

1 *Demonstrator assembly: sensors printed and laser-sintered onto roller bearing (source: Fraunhofer ILT).*

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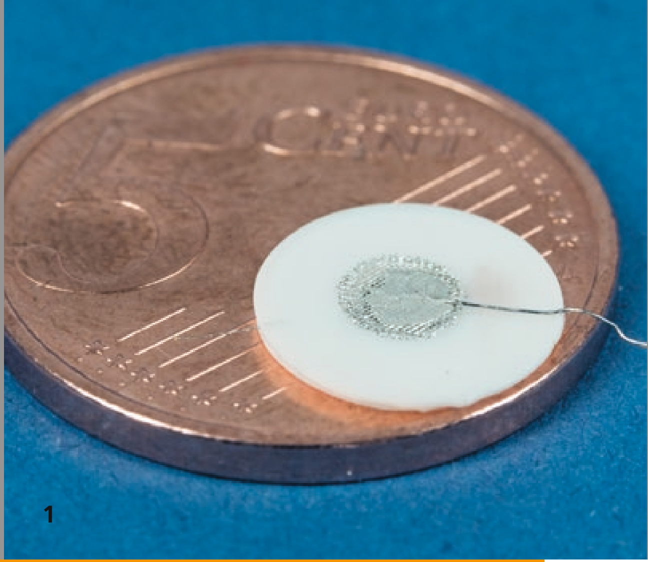

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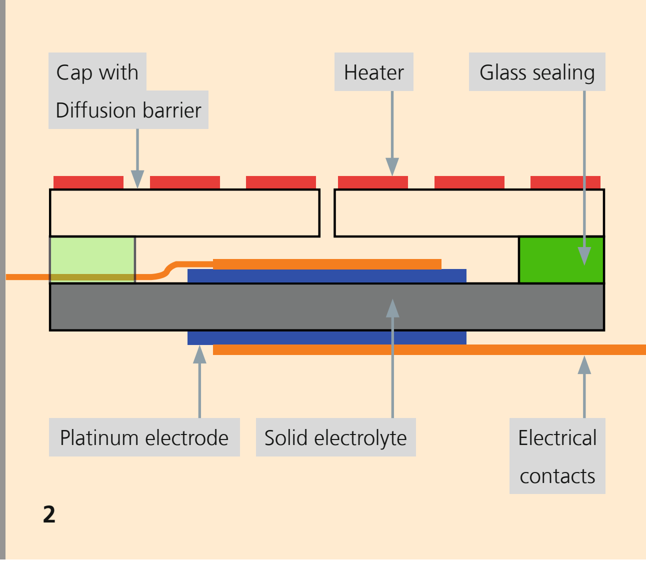


2

LIMITING CURRENT TYPE OXYGEN SENSOR FOR INDUSTRIAL APPLICATIONS

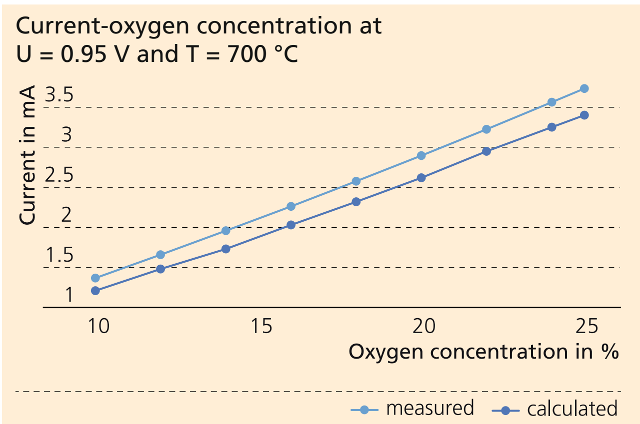
Dipl.-Phys. Stefan Dietrich, Christian Eckart, Dr. Mihails Kusnezoff

Sensors for the measurement of the oxygen content in gas mixtures are not only essential components of fuel drives, but also of medical systems for respiratory gas monitoring and various industrial processes. By choosing the appropriate measurement principle, sensor design and operating parameters the oxygen sensors can be adapted to various applications. Fraunhofer IKTS has now developed a limiting current type oxygen sensor based on a ceramic solid electrolyte (3YSZ).

The sensor principle takes advantage of the high oxygen ion conductivity of 3YSZ at temperatures above 600 °C: a DC voltage applied between two electrodes deposited on the electrolyte will cause oxygen ions to flow and a resulting electronic current in the external circuit. To maintain the ion current, oxygen is extracted from the measuring gas at one electrode and released at the other – an electrochemical oxygen pump. By controlling gas access to the oxygen-deficient electrode using a diffusion barrier, the ionic current is limited and a corresponding limiting current can be measured in the electronic circuit. If suitable geometrical and operating parameters are selected, the limiting current is proportional to the oxygen concentration in the measuring gas.

Limiting current oxygen sensors offer several advantages over other oxygen sensor types. First of all, sensor operation does not require a reference gas. Theoretical limiting current density data can easily be calculated, allowing for simple sensor calibration. In contrast to the logarithmic signal dependence of potentiometric oxygen sensors, the linear response of limiting current sensors permits the use of a larger measuring range.

The sensor developed at IKTS features a disc of 10 mm in diameter and a power consumption of 6 W at 600 °C operating temperature. The chart below illustrates the linear sensor response of a prototype in the concentration range relevant for breath analysis. The data correlates well with theoretically calculated values. However, the measurement range can be adjusted between 0–100 vol % by modifying sensor parameters, so the sensor can easily be used for other applications as well. The sensors operate at temperatures of up to 700 °C and the robust materials used make them suitable for the use in harsh environment applications. A miniaturized version of the sensor is currently being developed to reduce power consumption.



1 *Sensor prototype.*

2 *Scheme of a sensor structure.*

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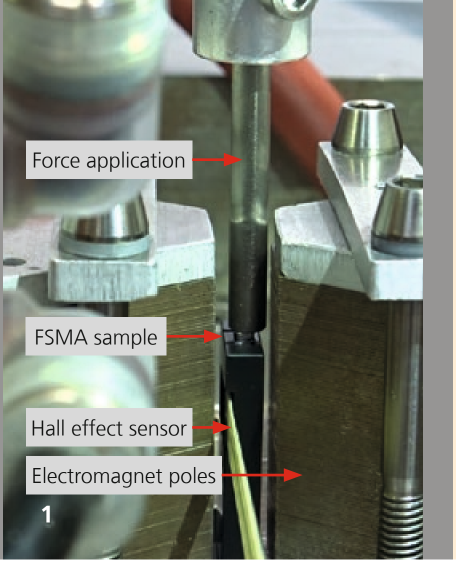

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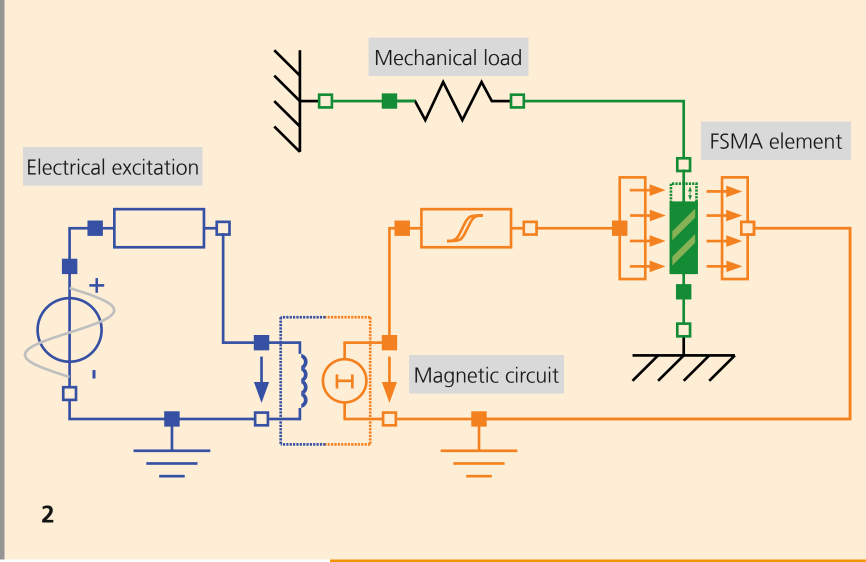


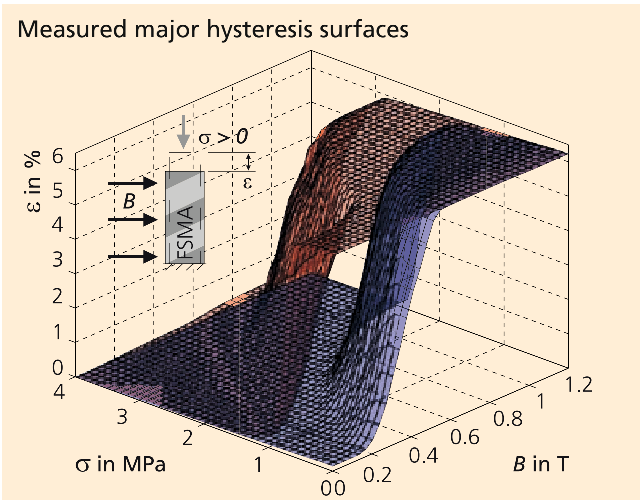
2

MODEL-BASED DESIGN OF FAST-SWITCHING SOLID-STATE ACTUATORS FOR VALVES

Dipl.-Ing. Fabian Ehle, Dr. Peter Neumeister, Dr. Holger Neubert

Numerous industrial applications require fast-switching pneumatic valves to control air flow within milliseconds. Some of the typical applications are pick-and-place, separation tasks or the pneumatic emergency stop of an entire production line. Commonly used valves based on solenoids are limited with regard to size, switching time and fatigue life. Within the grant project "SMS2.0", funded by the German Federal Ministry for Education and Research (BMBF), Fraunhofer IKTS is currently investigating the potential of ferromagnetic shape memory alloys (FSMA) for these and other applications. Alloys are metallic single crystals with a twinned lattice structure of reduced symmetry and high saturation magnetization. Extrinsically induced magnetization results in a strong magneto-mechanical coupling. The lattice structure aligns with the external field and the FSMA actuator changes its length. This process of twin boundary movement is very fast, leading to the potential application of FSMAs for fast switching actuators. Compared with conventional electromagnets, however, alloys behave in a fundamentally different way, characterized by strong non-linearity and distinct hysteresis. Therefore, models are necessary for the design of FSMA-based systems. At Fraunhofer IKTS, such models are currently being developed by characterizing crystals experimentally and deriving application-oriented models from that. FSMA crystals are characterized on a self-developed magneto-mechanical test bench (Figure 1). It allows to apply and measure any desired magnetic and mechanical trace. Within the project a scalar macroscopic modeling approach – currently a two-input Tellinen model – is used. Its main advantage is the possibility to parametrize directly from the major hysteresis surfaces (series of major hysteresis loops) measured, which limit the overall work range (Diagram).

The hysteresis models are implemented in Modelica, a modeling language for multiphysics modeled with lumped elements. In this way, interaction with other system elements, such as control electronics, the magnet system, and non-linear mechanical load, can be examined (Figure 2).



The method shown is currently being applied for the design of pneumatic valves with adapted magnetic excitation and valve mechanics, with switching times below 1 ms being attained.

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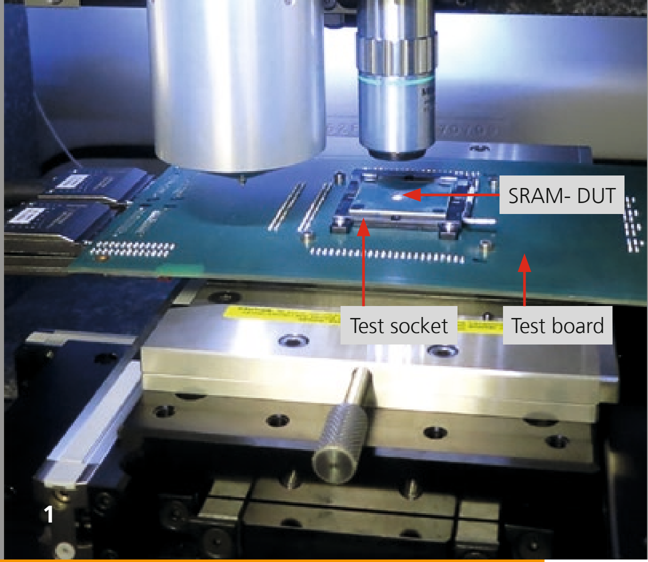
1 Magneto-mechanical test bench for FSMA samples (detail).

2 Simple model of a FSMA drive in Modelica containing an implemented material model.



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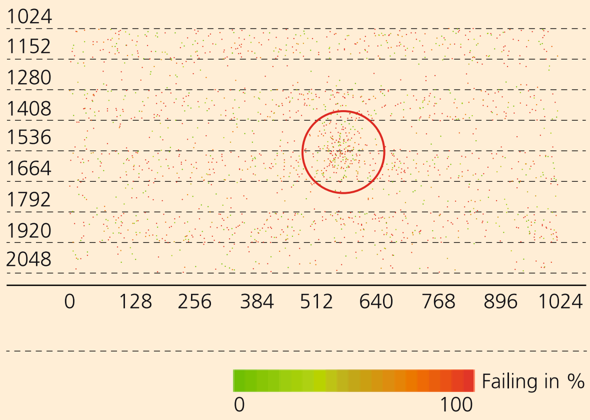

2

RELIABILITY ASSESSMENT OF 28-NM SRAM CELLS WITH APPLIED MECHANICAL LOAD

M. Sc. Simon Schlipf, Dr. André Clausner, Dr. Martin Gall, Prof. Dr. Ehrenfried Zschech

Microelectronic devices for automotive applications need a stringent reliability assessment due to a high-stress environment and expected long lifetimes. Additionally, they are becoming increasingly miniaturized thanks to advanced technologies.

Fraunhofer IKTS has investigated the reliability of leading-edge 28 nm high-k metal gate CMOS SRAM circuits (GLOBALFOUNDRIES Dresden) with applied mechanical loads. For detailed investigations, we developed a new three-in-one test method combining a mechanical process based on nanoindentation, an electrical test setup, and FEM simulations of mechanically induced stresses at the transistor level.

This approach makes it possible to examine chip-package-interaction (CPI) and chip-board-interaction (CBI) for novel SRAM devices in operation and to detect potential failures of the architecture. The chips were assembled on a flip chip substrate without a lid and the silicon was thinned down to a minimum of 16 µm at the back side. To enable electrical in-situ measurements, the chip was connected to a socket before, during, and after the indentation with forces of various magnitudes. The experimental setup with the used SRAM chips is shown in Figure 1.

The first step – the spherical, elastic nanoindentation – is performed on several spots at the backside of the chip. This is followed by the electrical measurement, which incorporates a read-fault procedure and a bit-cell-fault calibration procedure to determine eventual bit flips with applied load.

For the read-fault procedure, a chessboard pattern is written in, with the writing step taking place with an undervoltage at the bit flip threshold. The bit flips are detected in the subsequent reading step with target conditions. After 50 repetitions, the error frequency is correlated with the load. Figure 2 shows a bit cell fault matrix with additional background noise for an applied load of 1.3 N. Loading leads to a significant 40 % radial increase of the bit cell fault probability at the indentation area (red circle). The process is fully reversible, meaning that the fault disappears upon unloading. As a last step, the results thus obtained are compared with FEM simulations using the SRAM layout and the semiconductor stack parameters to predict optimal indentation points and stress/strain fields at the indented area. Furthermore, the described test approach is suitable for estimating mechanical stress on active transistor regions and can be used for design optimization on the chip, package and board levels. We plan to conduct further investigations of new leading-edge technologies.

This work was a collaboration of Volkswagen AG Wolfsburg, GLOBALFOUNDRIES Dresden, Fraunhofer IKTS, and Fraunhofer IIS-EAS.

1 *Experimental nanoindentation setup.*

2 *Bit-cell-fault matrix with background noise for an applied load of 1.3 N.*

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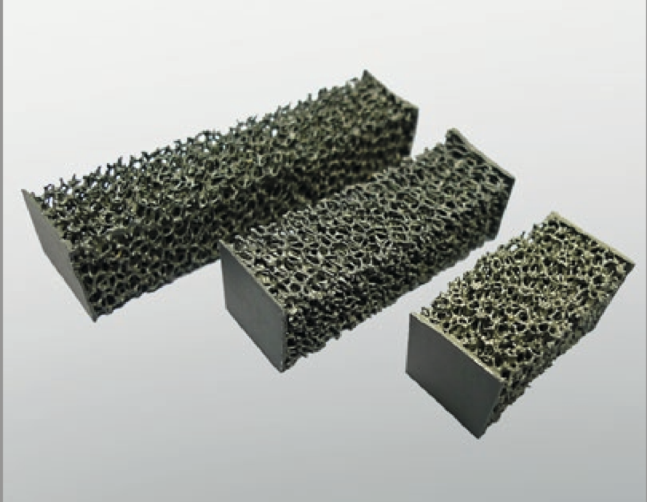

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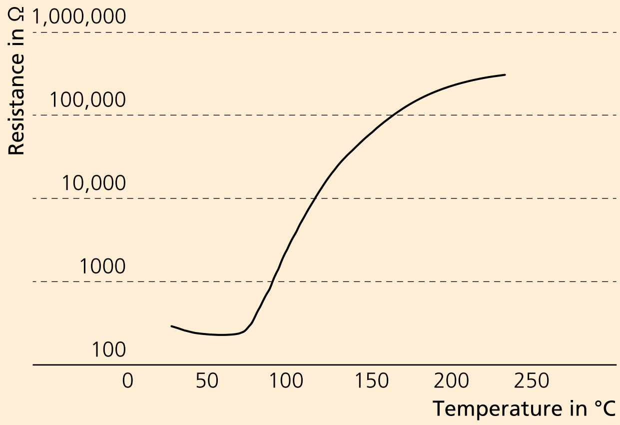

2

COMPACT PTC HEATERS MADE OF FOAM CERAMICS

Dr. Daniela Haase, Dipl.-Ing. Gisela Standke, Dr. Michael Arnold, Dipl.-Krist. Jörg Adler

PTC heating elements (positive temperature coefficient) are used in large quantities in automotive supply air heaters or as heaters for household appliances. They can be characterized by special resistance-temperature properties, which show a sharp increase of electrical resistance within a narrowly defined temperature range. Compared with NTC heaters (negative temperature coefficient), they offer the advantage of being self-regulating, which means that no additional temperature regulation and over-temperature protection equipment is needed. Due to their typical design (mostly pins, platelets, rings and honey combs), PTC elements provide a very poor thermal transfer to the medium that needs to be heated. To compensate for this, they have to be combined with metal heat exchangers.

Fraunhofer IKTS has developed ceramic foams based on leaded and unleaded barium titanate powders with transition temperatures of 45 °C, 100 °C and 120 °C. Their cellular structure provides large geometrical surfaces and, thus, strong heat transfer to the medium to be heated. The media – such as gases or liquids – can flow through the heater structure directly and in every direction, resulting in a particularly effective heat transfer as well as swift and precise temperature control. Thanks to this direct contact, additional heat exchangers are no longer needed, which enables especially compact heaters. The construction of the foam ceramics as a sandwich structure (Figure 1) allows for easy electrical contacting – simple and customizable in production and therefore profitable even in small series. The components developed by IKTS were examined with a standard testing method according to DIN EN 60738-1 (06/2010). The tests did not show any significant changes of electrical resistance after 1000 and 50,000 cycles of operation in cold atmosphere and at room temperature; the specimens showed the same good behavior in permanent operation (1000 h), with the highest operating temperature at 70 °C and under an operating voltage of 30 V. Furthermore, IKTS developed an after-coating process for the foam structure using epoxy resin. This makes the ceramic material inert when in contact with circulating media, avoiding the penetration of PTC material into the media in the event of mechanical damage done to the foam structure – an essential requirement for medical applications, such as intravenous drips.

Services offered

- Development and synthesis of doped leaded and unleaded barium titanate powders with different transition temperatures
- Development of foam ceramics with PTC and NTC behavior
- Evaluation of electrical properties and standard testing in accordance with DIN
- After-coating of foam structures with resins or active components (e.g. catalysts)
- Manufacturing and analysis of prototypes and small series

1 *Cellular PTC heater in sandwich construction for easy contacting.*

2 *Resistance-Temperature curve of a PTC ceramic foam with a nominal temperature of 100 °C.*

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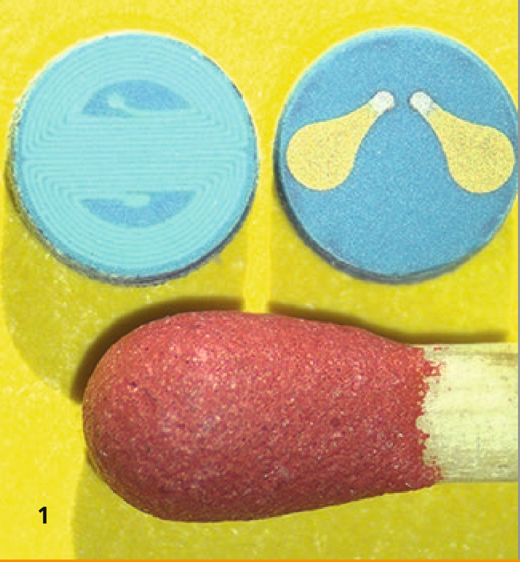

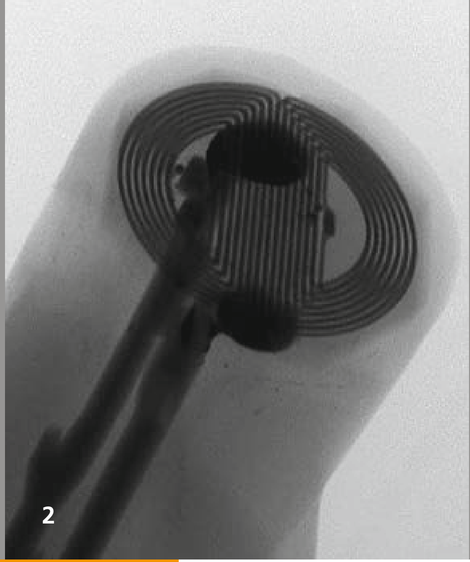

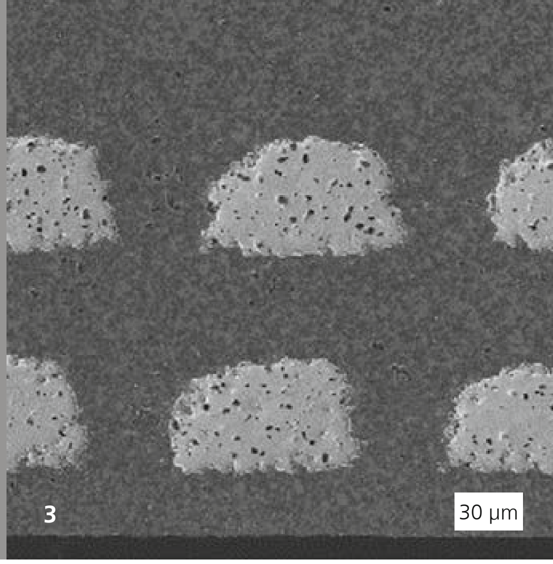

CERAMIC-INTEGRATED MINIATURIZED COILS FOR SPEED MEASUREMENT IN TURBOCHARGERS

Dipl.-Ing. Martin Ihle, Dr. Steffen Ziesche, Dr. Uwe Partsch

Eddy-current sensors enable the non-contact detection of path, distance, position, vibrations and speeds in electrically conductive materials. Ceramic multilayer technology (LTCC – low-temperature co-fired ceramics) offers a great platform for integrating bespoke eddy-current-sensing coils into very small assemblies. LTCC-printed and embedded measuring coils can be used in very rough environments at operation temperatures of up to 550 °C.

Together with the Jaquet Technology Group, Fraunhofer IKTS has developed an LTCC coil for measuring the rotational speed in the turbochargers of vehicle engines. Speed measurement is crucial for supplying the engine with the optimum air mass and thus minimizing fuel consumption.

Sensor element layout

A crucial element for its performance is the quality factor of the embedded coil. Thanks to new LTCC manufacturing processes developed at Fraunhofer IKTS, the lateral winding distance of the printed coils could be reduced to 30 µm, which improves the coil's conductivity. At the same time, the metallization thickness was enhanced, reducing the internal resistance. The result was a measuring signal with much less noise and loss. In addition to miniaturization with optimized quality, the integration of a bespoke coil design in LTCC was also a big driver of development. Coils of this type are typically produced as wound coils with a spiral-like shape.

The LTCC double D-coil developed at Fraunhofer IKTS delivers a narrow-band magnetic field thanks to the tailored design and thus a clearer measuring signal on turbocharger blades, for example on those made of aluminum or titanium. These innovative microcoils in the bespoke LTCC double D-design with optimized quality and an aspect ratio of > 1 (height to width ratio of printed conductor paths) stand out from the current state of the art.

Manufacturing

Because of its optimized sensor properties, the novel LTCC coil technology will be included in the product portfolio of the Jaquet Technology Group for the measurement of turbocharger speed on both passenger cars and trucks.

Services offered

- Development and construction of bespoke LTCC coils (sensors, transformers, etc.)
- Assembly and testing of pre-production series

1 *Sintered and separated LTCC double-D coil, size compared with matchstick.*
2 *CT scan image of LTCC double-D coil in the sensor head.*
3 *Complete turbocharger speed sensor from Jaquet Technology Group.*

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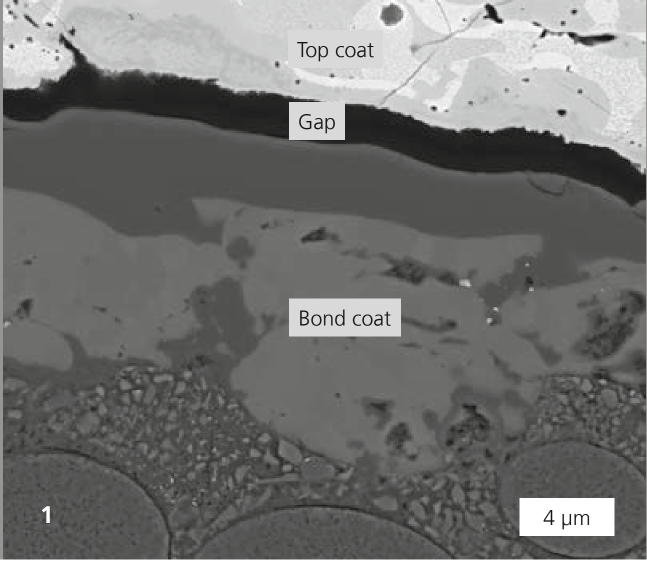

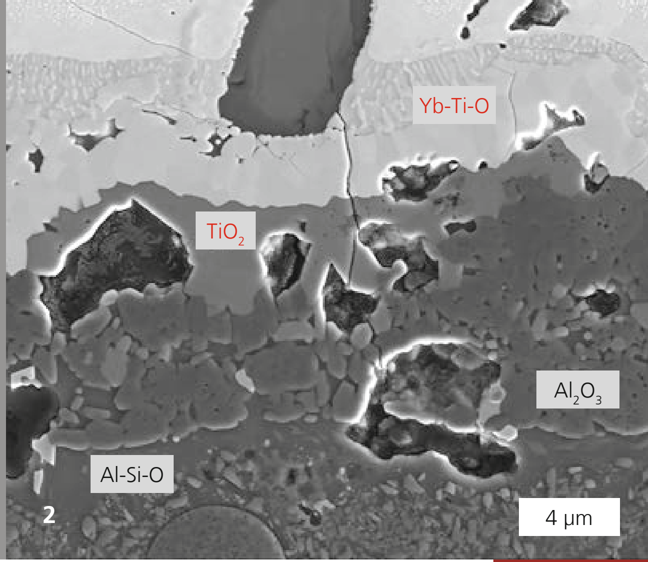

CORROSION PROTECTION COATINGS FOR CERAMIC FIBER COMPOSITE MATERIALS

Dr. Hagen Klemm, Willy Kunz, Dipl.-Ing. (FH) Bernd Gronde, Dipl.-Ing. Katrin Schönfeld

Intensive R&D activities in recent years have brought about several high-temperature-stable ceramic fiber composite materials (ceramic matrix composites, CMC), which offer a high potential for structural applications in advanced gas turbines. Besides high-level mechanical properties (strength, damage tolerance), they boast a high oxidation stability thanks to the formation of a protecting layer on the surface of the CMC. The hot gas path of gas turbines, however, involves corrosion processes which destroy the layer that is meant to act as an oxygen diffusion barrier. Consequently, oxidation processes were observed, caused by the free admission of O_2 and H_2O, leading to material degradation inside the CMC.

Environmental barrier coatings (EBC) may be helpful in slowing these processes down significantly. Typical current EBC systems with good functionality consist of a bond coat from silicon, and a corrosion-resistant topcoat, such as BSAS, rare-earth silicates, YAG or ZrO_2 and HfO_2 compounds. Si bond coats are particularly suitable since their thermal coefficient of expansion is comparable to that of the CMC. The Si layer additionally acts as an effective diffusion barrier against O_2 and H_2O penetrating into the ceramic fiber composite material. Nevertheless, the diffusion of O_2 and H_2O into the CMC down into the Si bond coat was found to be a major reason for failure in long-term application. As the result of this diffusion, oxidation processes were observed at the Si layer/topcoat interface. A SiO_2 layer was formed (thermal-grown oxide, TGO), which corroded in hot-gas environments. The associated material loss led to the formation of a gap, which resulted in the flaking of the EBC system with continued use. In order to prevent the formation of the TGO layer and thus improve the lifetime of the EBC system, modifications were made to the layer structure. An Al_2O_3 bond coat was used instead of a Si layer. The diffusion processes took place up to the CMC surface. Part of the SiO_2 formed by oxidation at the CMC/Al_2O_3 interface reacted with the Al_2O_3 in the volume of the bond coat, producing phases similar to mullite (Al_2O_3-SiO_2). As a result, this mullite-bound SiO_2 was no longer available for TGO formation. A complete shift of the oxidation process into the Al_2O_3 volume, and thus the suppression of the TGO formation, was achieved through the additional incorporation of non-oxidic particles into the bond coat layer. In the case of stored Si and SiC particles, however, corrosion processes were observed in the hot gas. An SiO_2 margin was formed through oxidation around the Si and SiC particles, which corroded in the hot gas and made the bond coat porous at these points. In contrast to this, TiCN particles and their oxidation products TiO_2 and SE titanates were found to be significantly more stable in hot gas. As a result of the layer modifications described above, it was possible to specifically influence the degradation processes taking place in the hot gas and thus to improve markedly the service life behavior of the entire EBC system.

We gratefully acknowledge the BMBF for funding the project "NewAccess" (funding reference 03EK3544C).

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1 *Typical damage mechanism of an EBC in a hot gas environment due to gap formation.*

2 *Layer composition of Al_2O_3 bond coat with TiCN particles after oxidation (1200 °C, 100 h).*

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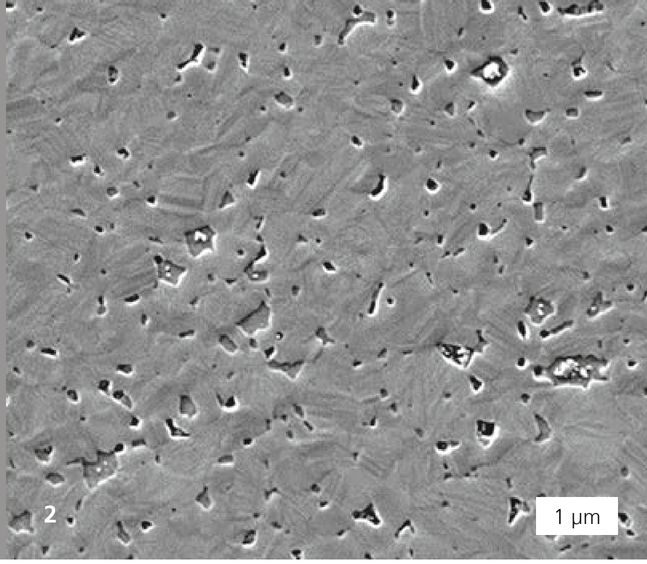

ENERGY

MATERIALS AND PROCESS DEVELOPMENT FOR LATP-BASED ALL-SOLID-STATE BATTERIES

Dr. Katja Wätzig, Dr. Kristian Nikolowski, Dr. Jochen Schilm, Dr. Christian Heubner, Dr. Mareike Wolter

Future battery concepts for applications concerning electromobility should, in particular, combine a high level of safety with a high energy density and quick-charging capabilities. Novel Li-ion solid-state batteries are promising candidates to match these requirements. One benefit of using inorganic solid electrolytes instead of the more commonly used liquid electrolytes is that in case of damage leakage and combustion are prevented, which allows using metallic Li-ion for the role of the anodic component, promising high energy densities. A key requirement for solid-state batteries is the development of highly conductive, cost-efficient and producible solid electrolytes that are compatible with active materials in electrodes.

LATP as solid electrolyte

Recent studies investigate properties and performance of numerous inorganic solid electrolytes. Several material classes, such as halides or sulfides [1], show maximum Li-ion conductivities of up to 10^{-2} S/cm, but are very challenging to handle on a larger scale since they have to be processed under inert conditions due to their moisture sensitivity. By using oxidic and phosphatic solid electrolytes, conductivities in the range of 10^{-4} to 10^{-3} S/cm are achievable [1]. Their processing under typical conditions becomes feasible with conventional ceramic technologies, such as tape casting, screen printing and sintering. At Fraunhofer IKTS, we developd a phosphate-based, cost-effective ceramic solid electrolyte (LATP – $Li_{1.3}Al_{0.3}Ti_{1.7}(PO_4)_3$), which has an ionic conductivity of up to 10^{-3} S/cm at 25 °C as a sintered substrate, through materials optimization and adjustment of the production parameters. The synthesized electrolyte material can be used both as a solid electrolyte for the separation of anode and cathode, and as a replacement for the liquid electrolyte in the composite electrode.

Ceramic LATP composite electrodes

Composite electrodes in solid-state batteries contain – comparable to conventional battery technologies – the active material (cathode or anode material), an electron-conductive additive and, instead of the liquid electrolyte, a Li-ion-conducting solid electrolyte (e.g. LATP). IKTS develops composite electrodes that can be processed through scalable ceramic technologies beyond the laboratory scale. At the same time, work is being done to further increase energy density and safety by selecting and combining suitable materials. So far, a first concept for a composite anode based on LTO active material ($Li_4Ti_5O_{12}$) and LATP solid electrolyte has been investigated. Active materials, such as $LiCoO_2$ and $LiNi_xCo_yMn_zO_2$ in the sintered composite with LATP are currently in development for the cathode.

We gratefully acknowledge the BMBF for the funding of the "ARTEMYS" project (03XP0114I).

Literature

[1] Manthiram et al., NATURE Reviews Materials 2 (2017), 16103.

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1 Ceramic electrolyte contacted with Li-ion anode for test cell assembly.

2 Microstructure of a ceramic electrolyte.

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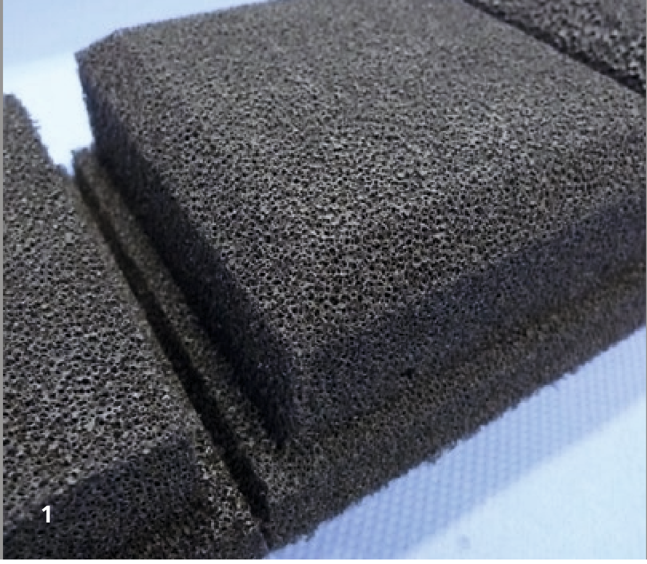
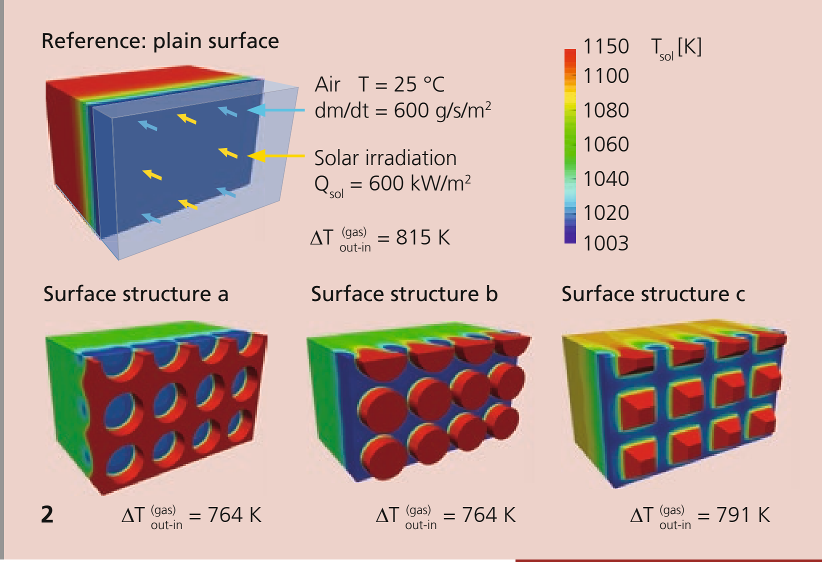




ENERGY

OPTIMIZED CERAMIC RECEIVERS FOR SOLAR-THERMAL POWER PLANTS

Dr. Wieland Beckert, Dr. Alexander Füssel

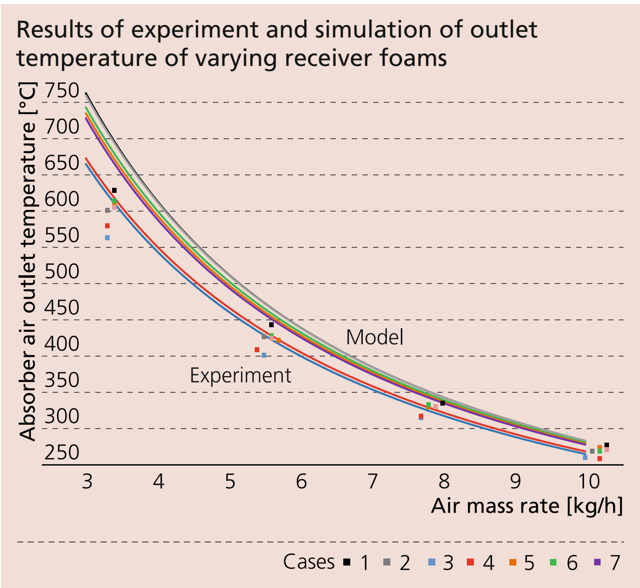
Open-celled ceramic foams can be used, among other applications, as receiver parts of concentrated solar power plants (CSP). Their main task is to collect the solar irradiation that is focused onto the receiver by a field of mirrors, and to transfer the irradiated heat energy to the air flowing across the receiver, all with as little loss as possible. For this purpose, Fraunhofer IKTS is developing silicon carbide (SiC) foams which are able to withstand the desired operation temperatures of above 1000 °C for long periods of time. Current research investigates the influence of the structural properties of foams, such as cell size and strut dimension, on the thermal receiver performance. Based upon these properties, numerical models have been developed and verified which allow to predict each absorber's thermal performance. Therefore, they can be used to identify the optimal design of the receiver foam elements.

Thermal absorber performance depends on the interaction between absorption and scattering of the solar and thermal radiation emitted by the foam, the heat transfer between solid and fluid domains, and the conductive (solid material) and convective (air) heat transport within the foam structure. All these processes are represented in a sophisticated homogenized continuum multiphysics model approach. In addition to analyzing general trends, the model was also used to examine the potential of multilayered absorbers and surface structuring for improving absorber performance. It was shown that simple, unstructured foams attain the best performance, and their production is more cost-efficient to boot. A cooperation with CENER institute (Spain) under the "CAPTure" EU project provided the opportunity to validate the model results with test data from an experimental absorber test set-up.

Services offered

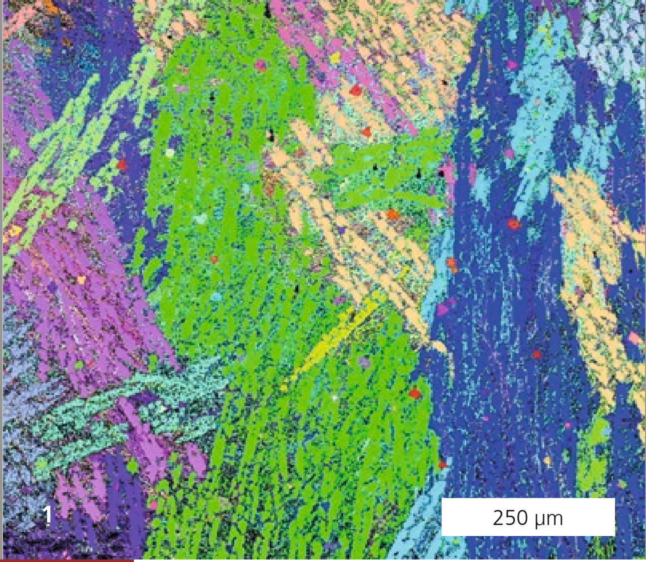
- Development of open-celled ceramic foams for high-temperature applications
- Manufacturing and analysis of test samples and small series
- Development and adjustment of models for the prediction of the properties of complex structure

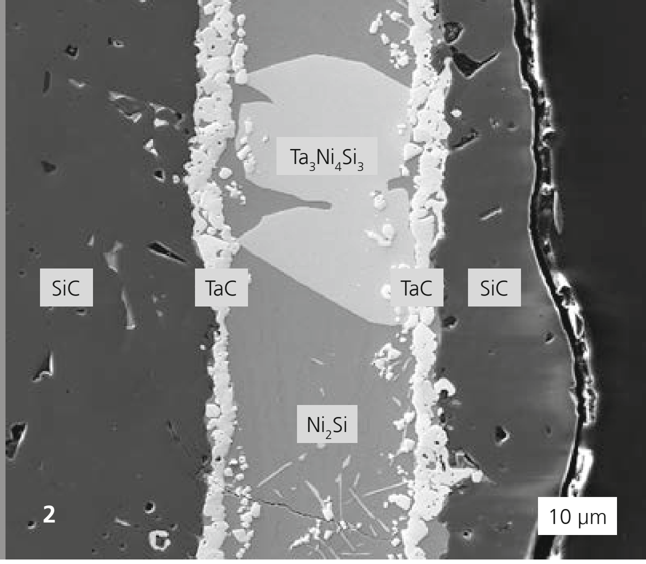
We gratefully acknowledge the EU for the funding of the project "CAPTure" (Framework: H2020-LCE-2014-1, No.: 640905).



1 Absorber component of foam ceramics.

2 Model results analyzing the effect of surface structuring.



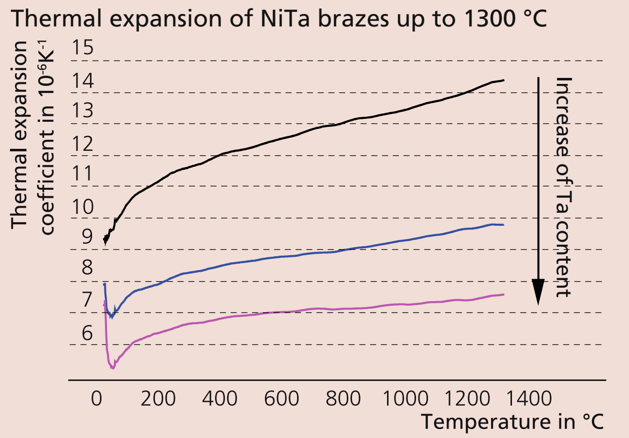


ENERGY

BRAZE DEVELOPMENT FOR HIGH-TEMPERATURE-STABLE CERAMIC COMPOSITES

Dipl.-Ing. Sven Roszeitis, Dr. Hans-Peter Martin

Thanks to their extremely high resistance, ceramic materials are suitable for use at very high temperatures and in chemically aggressive environments. Compared with other materials, significantly longer operating times are therefore possible. In addition, process-optimized ceramics can also increase the energy and material balance of an entire process, e.g. by achieving higher process temperatures or improved thermal insulation or heat conduction. The successful use of ceramic components almost always depends on their optimal integration into the overall system. This results in an increasing demand for ceramic-specific, reliable joints and thus the need to develop new processes and joining materials, such as brazing alloys, for very high application temperatures. At Fraunhofer IKTS, high-temperature stable soldering systems adapted to ceramic materials were manufactured and tested in various applications. Enhanced nickel tantalum solders (NiTa) exhibited relatively high strength even at high operating temperatures when compared to other metallic solders. Using these solders, SiC composites with a flexural strength of 275 MPa at 800 °C were achieved. Adjusting the coefficient of expansion (CTE) in the NiTa system optimized the material compound still further. The chart shows the wide range of expansion coefficients in the NiTa system from $12 \cdot 10^{-6}$ K^{-1} to $6 \cdot 10^{-6}$ K^{-1}. In addition, alumina, silicon carbide and zirconium oxide were joined using titanium-aluminum brazing alloys (TiAl) developed at IKTS. These low-cost high-temperature brazing alloys have an oxidation stability of up to 1000 °C, as well as the ductility of certain TiAl compositions, and are therefore suitable for ceramic-ceramic and ceramic-metal composites. Further work is currently underway to investigate whether a combined process of high-temperature brazing and 3D printing can significantly improve the efficiency of additive manufacturing methods for ceramic materials.



Services offered

- Development of high-temperature-stable composite materials based on NiTa and TiAl braze compositions
- Development of customer-specific metallic brazes and solders as well as related brazing processes
- Experimental manufacture of ceramic-ceramic and ceramic-metal test composites with metallic brazes

We acknowledge the financial support of the project "SuperHi" by EU, Free State of Saxony and SAB (grant no. 100231806).

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1 EBSD band contrast of a Ni-62Ta38 alloy.

2 FESEM of a SiC-Ni62Ta38-SiC joint.

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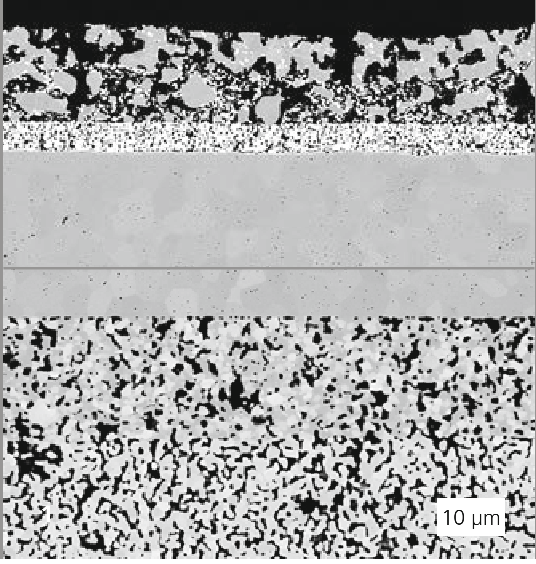

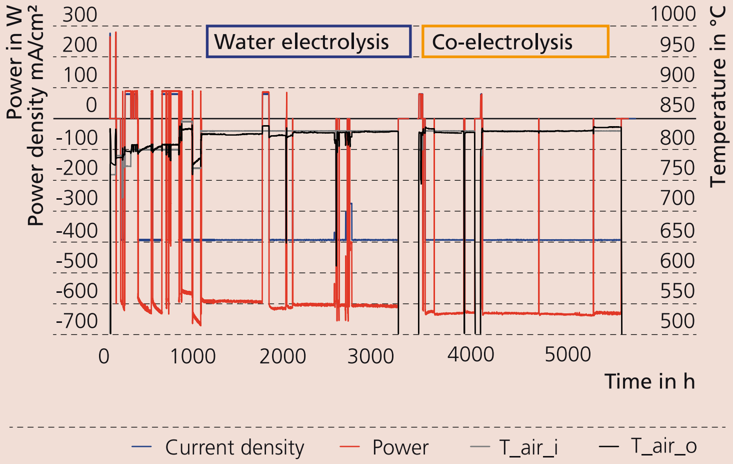

2

CELLS AND STACKS FOR THE PRODUCTION OF SYNGAS THROUGH CO-ELECTROLYSIS

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

The production of synthetic hydrocarbon fuels through the co-electrolysis of steam/CO_2 mixtures using renewable energy has been presented as a promising solution to reduce problems related to hydrocarbon consumption. The possibility to recycle CO_2 into chemicals and value-added fuels helps to reduce the accumulation of atmospheric CO_2 and realize the carbon-neutral cycling of fuels. The solid oxide cells have great potential within this field and can be used to convert steam/CO_2 mixtures into syngas at high temperatures above 750 °C, followed by a Fischer-Tropsch conversion using excessive electricity, allowing to produce any desired carbohydrates. However, as process efficiency decreases with CO and CO_2 present, it is important to select the right electrode materials and operating conditions. Fraunhofer IKTS has investigated the electrochemical performance of the electrolyte-supported cell with standard IKTSG3 electrodes for use as SOEC and SOFC over a wide range of operating conditions, varying the ratio of H_2O:H_2 and CO_2:CO, operating temperature (750–850 °C) and current. The ASR of IKTSG3 cells at 850 °C and 800 °C are 0.178 ± 0.010 Ωcm² and 0.286 ± 0.013 Ωcm², respectively. In the performance test above ~ 4.000 h the cell resistance increased only by ~ 5 mΩcm²/1000 h ($\Delta P/P_0 < 0.5$ %/1000 h). Based on the results of electrochemical and microstructural analysis, the electrodes were additionally optimized for co-electrolysis operation to avoid anomalous increases of the working voltage during the first 50 to 100 h of operation. The new cell (IKTSG5), with an additional layer between the substrate and the multilayer air electrode as well as an optimized microstructure of both electrodes, was successfully realized and tested. The calculated linear power degradation rate for co-electrolysis mode over the complete durability test was about $\Delta P/P_0 = 0.4$ %/1000 h. Subsequently, this new IKTSG5 cell generation was integrated into the robust MK352 CFY stack design of IKTS and tested in steam and co-electrolysis operation. Across a wide range of applications, the performance map of the stack shows only a tiny difference in electric power demand (less than 2 %) compared with water electrolysis. The stack durability (> 4000 h) was demonstrated successfully with the new cell generation. The next step will be to demonstrate the production of various hydrocarbons by coupling the SOC stack with a Fischer-Tropsch reactor, which will pave the way for storing excessive renewable energy and enable the CO_2-neutral production of high-value chemicals.

Services offered

- Cell development and technology transfer
- Test of stack components for SOFC/SOEC under real operating conditions
- Development of stack modules for utilization in SOC systems
- Sale of SOC stacks and modules

1 *FESEM images of fuel electrode (top) and air electrode (below) of IKTSG3 cell after durability test under co-electrolysis conditions.*

2 *Long-term test of 10-cell MK352-stack with IKTSG3 cells in water and co-electrolysis (H_2O:CO_2 = 2) at -50 A, conversion 75 %, 830 °C.*

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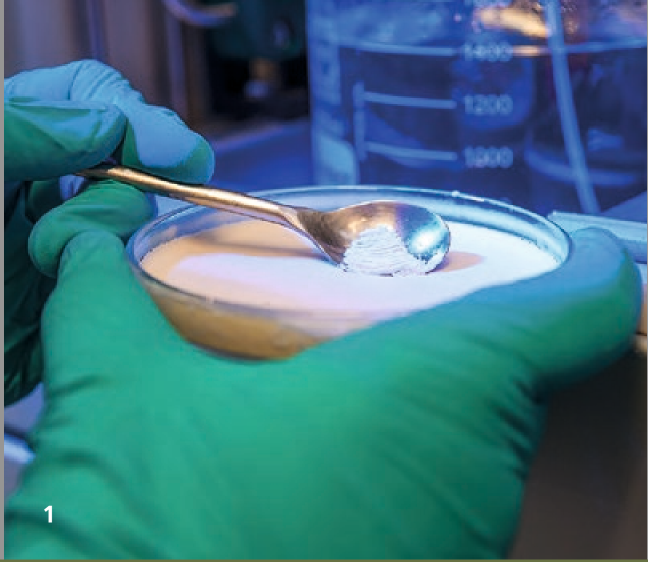
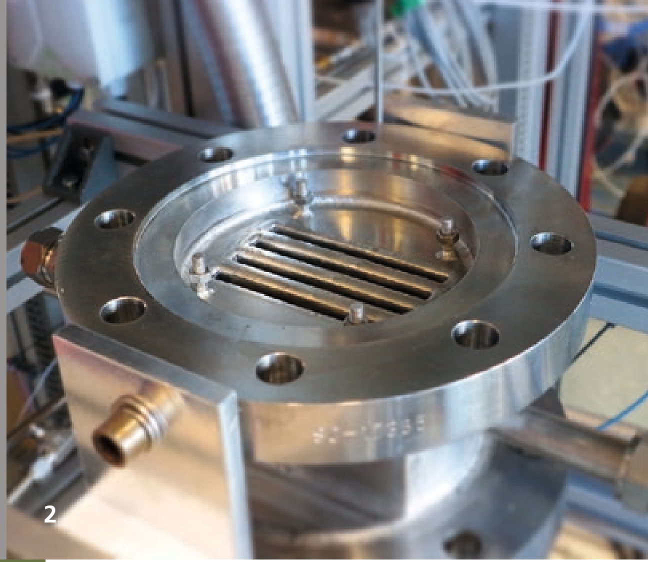




FISCHER-TROPSCH SYNTHESIS – DEVELOPMENT OF SELECTIVE CATALYSTS AND PROCESSES

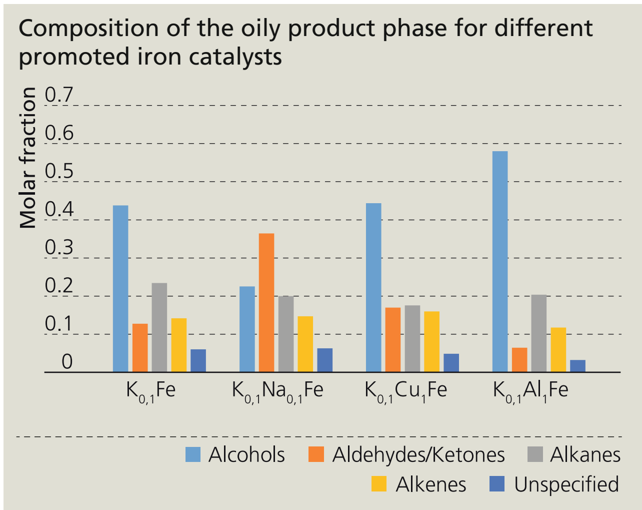
Dr. Erik Reichelt, Dipl.-Ing. Aniko Walther, M. Sc. Max Schaller, Dipl.-Ing. Gregor Herz, Dr. Matthias Jahn

In recent years, Fischer-Tropsch synthesis has undergone a renaissance against the background of the use of renewable resources. The possibility of producing several chemicals from different renewable carbon sources (biomass, CO_2) via the intermediate step of synthesis gas production explains the renewed interest in this nearly 100-year-old process. While research is in many cases focused solely on catalyst development, the focus of Fraunhofer IKTS is on the complete development chain – from catalyst to the overall process.

Our research in Fischer-Tropsch synthesis looks mainly at process paths leading to high-quality chemical products. Selectivity for obtaining the desired end products is optimized by developing specific iron- and cobalt-based catalysts. The higher alcohols and waxes thus produced are of particular interest for use in the cosmetics industry.

Utilizing sustainable carbon feedstocks means that small-scale decentralized plants are needed. Therefore, novel process and reactor concepts with low capital and operational expenditures have to be developed. Novel ceramic manufacturing technologies available at IKTS allow for the production of catalyst support structures with advantageous mass and heat transfer characteristics. In addition, adapted reactor concepts are in development which, among other things, will enable easy replacement of the catalyst structures at the end of their service life.

Under the coordination of IKTS, two innovative process concepts are currently being demonstrated in pilot plants. For the first time worldwide, the conversion of biogas into wax and the production of higher alcohols from CO_2 and H_2O via co-electrolysis and Fischer-Tropsch synthesis are realized in one single technical process. The results of both pilot studies not only allow for the validation of the developed process models but also for the evaluation of economic feasibility.



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1 *Wax produced through Fischer-Tropsch synthesis.*

2 *Fischer-Tropsch reactor.*

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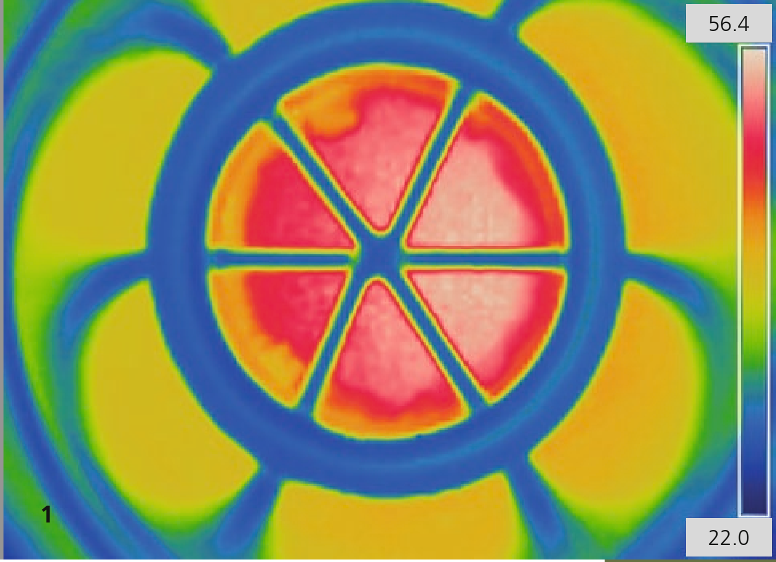

HIGHLY DYNAMIC MICROWAVE HEATING OF REACTORS

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

Thanks to their high geometric surface area and outstanding flow properties, structured catalysts offer several benefits for application in heterogeneously catalyzed reactions. The best-known example is the use of ceramic honeycomb catalysts for emission reduction in exhaust gases from engines and stationary sources. In contrast to honeycombs, open-celled foams have a network-like structure. This allows for additional radial mass and heat transport within the reactor.

Although catalyzed reactions require less activation energy, many catalytic processes still require increased temperatures in order to achieve adequate conversion rates. Accordingly, an optimized thermal reactor management is the prerequisite for efficient reaction control. Conventional methods of heating and cooling are typically based on the traditional techniques of heat transfer through convection, heat conduction and radiation. However, these processes are usually slow and thus difficult to control. Compared with this, the advantages of microwave heating consist in contactless and volumetric heat transfer as well as quick controllability of the heating process. This offers the possibility to respond much more efficiently than with conventional heating methods to discontinuous exhaust gas quantities, application-related fluctuations in the exhaust gas temperature, and dynamic reactions.

In cooperation with the Fraunhofer Institute for Chemical Technology ICT, Fraunhofer IKTS has investigated direct microwave reactor heating using specifically modified cellular catalyst carriers, tested in different applications of gas phase chemistry. Based on these results, a scalable system for microwave-heated reactors was developed. A homogeneous and deep penetration of the microwave energy is the prerequisite for the rapid and uniform heating of the reactor. In addition, a sufficient entry of the volumetric power dissipation is essential for using the catalyst structure as microwave susceptor.

Structured catalysts, which are able to meet the demands on microwave transparency and absorption of microwave energy, were developed by tuning the dielectric properties of silicon-carbide-based open-celled foams. For this purpose, both the cell structure and the material composition of the catalysts were modified. Validation tests of the reactor system demonstrated the specific advantages of the dynamic heating method in catalytic gas phase reactions, such as CO and HC oxidation and SCR-DeNOx reaction. Thanks to the very rapid heating rates, conversions greater than 90 % could be achieved for both reactions by heating-up the structured catalyst within less than ten seconds to the reaction temperature.

Services offered

- Development and characterization of structured ceramic catalysts with specifically adjusted microwave properties
- Test-bench experiments for the validation of the microwave behavior of catalysts in gas phase reactions

1 Temperature distribution in the microwave reactor (source: Fraunhofer ICT).
2 Tube reactor with open-celled ceramic foam as catalyst.

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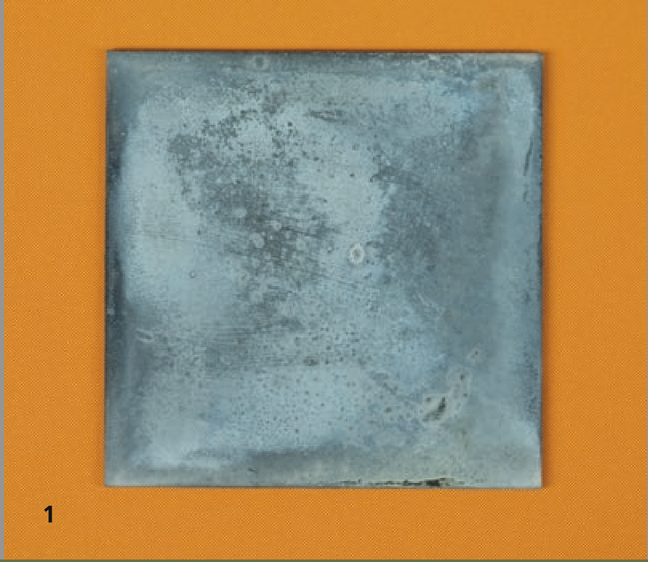
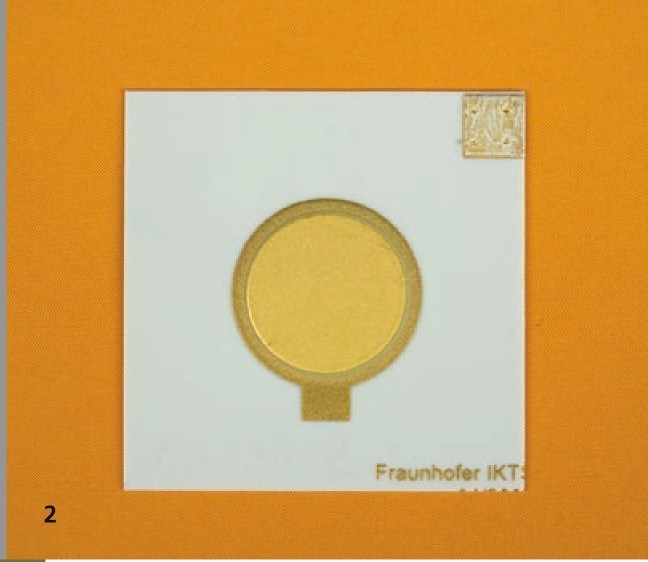
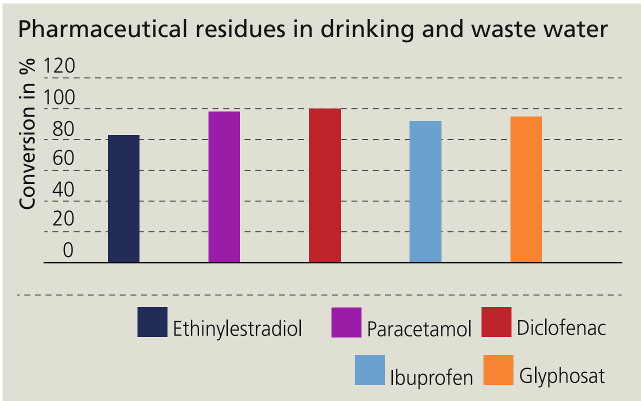




MATERIALS FOR ELECTROCHEMICAL DEGRADATION OF PHARMACEUTICAL RESIDUES IN WATER

Dipl.-Chem. Hans-Jürgen Friedrich, Dr. Katrin Viehweger, Dr. Lars Rebenklau, Dr. Peter Neumeister, Dr. Daniela Haase

Pharmaceutical residues in surface water and groundwater pose new challenges for the water treatment in many regions. Established methods are frequently found lacking when it comes to removing such substances, which continue to leak into water bodies, contributing to the propagation of antibiotic resistances and infertility. It is known from past projects that even stable substances, such as halogenated hydrocarbons or nitro-aromatic compounds, can be oxidized electrochemically to produce CO_2. Furthermore, the reductive transformation of these target agents to produce less environmentally toxic materials is possible for some substance classes. Such possibilities are currently being investigated under the BMBF funding initiatives "InnoEMat" and "MachWas" within the joint projects "SONEKTRO" and "KERAMESCH". "SONEKTRO" – a project in cooperation with CEEC Jena – is looking for alternatives for boron-doped diamond anodes (BDD), which represents the most powerful anode material for the electrochemical degradation of pharmaceutical residues to date. One great advantage of BDD is its high overvoltage for the anodic development of oxygen, enabling the complete destruction of organic compounds. However, BDD is very expensive, which has generated great practical interest for potential alternatives. With this in mind, IKTS researchers have synthesized and examined various semiconducting mixed-oxide phases – with and without noble metals – onto ceramic supports. The result was that SnO_2-based systems turned out to be particularly effective. Also, an array-shaped ultrasound source was integrated into the electrode structure in initial experiments, thanks to which near-surface transport processes close to the electrodes intensified and electrochemical activation was supported. The "KERAMESCH" project investigates a method for removing pharmaceutical and pesticide residues from sewage water through electrochemical conversion, resulting in less harmful substances. Fraunhofer IKTS develops and tests low-cost catalytically active iron alloys for this purpose. These alloys are deposited onto a ceramic foam support to realize fluidized-bed reactors for high water flow capacity. Early results show that diclofenac, for instance, was reduced electrochemically to a relatively high degree. Tests are currently being run for other compounds, such as ethynylestradiol (hormone) or erythromycin (antibiotic). For these analyses, C-14-labeled compounds are used as well, so that trace substances can be detected without elaborate concentration.



1 *SnO_2-mixed oxide anode on Al_2O support.*

2 *Anode with piezoelectric transducer.*

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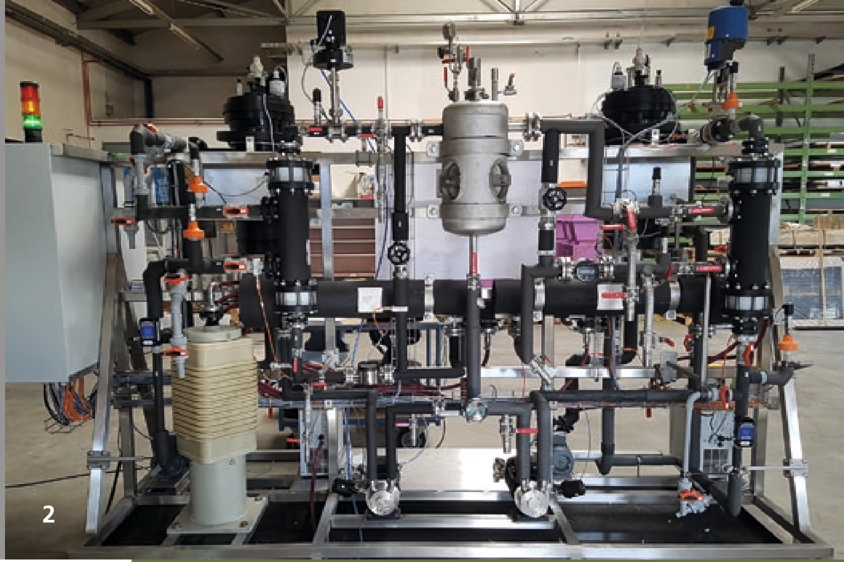


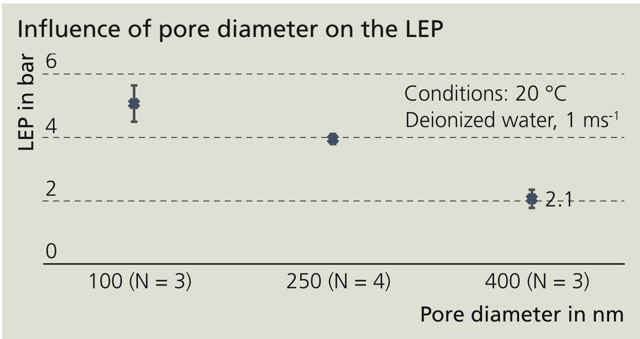
RECYCLING OF RARE METALS WITH CERAMIC MEMBRANES

Dipl.-Ing. André Wufka, Dipl.-Ing. Christian Pflieger, Dr. Marcus Weyd, Dr. Burkhardt Fassauer

The German high-tech industry's demand for rare metals such as Gallium and Indium is set to keep rising. However, the recycling rate of these elements in Europe remains low. For companies, the recovery of these raw materials from their own process waste water is usually not economically feasible due to their low concentration. Moreover, the recycling processes used today are complex and costly. For the recovery of metals from aqueous solutions, liquid-liquid extraction is often used. It involves disperging a metal-containing aqueous solution (aqueous phase) and an organic extractant (organic phase). The transition of the metal into the extractant takes place at the contact surface of the two phases.

Fraunhofer IKTS has developed a new membrane-supported liquid-liquid extraction process in which both phases are continuously brought into contact with each other via a porous ceramic membrane. The step of dispersing is omitted and both phases are contactable regardless of their volume ratio. The new process should make it possible to recover even very low concentrations of rare metals from process waste water. This process is centered around a ceramic membrane with a hydrophobic surface, for which different coatings (for instance with carbon, silanes or silicones) were tested on ceramic support membranes of different pore sizes. The hydrophobic properties of the membranes were demonstrated by contact angle measurements and by determining the liquid entry pressure (LEP). The LEP is known as the breakthrough pressure, at which the membrane is wetted by the liquid (Figure 1). Hydrophobic single-channel tubes with contact angles greater than 125 ° were produced. The LEP result – and thus process reliability at a later stage – depended strongly on the pore diameter of the supporting membrane.

The ceramic membranes allow a defined contact of both phases within the pores, which is where the mass transfer takes place. The organic phase wets the hydrophobic membrane completely. A slight overpressure on the side of the aqueous, non-wetting phase prevents the organic phase from breaking through the membrane. The phase boundary in the membrane pores is thus stabilized and the entire pore surface is active in the mass transfer of the metals from the aqueous to the organic phase.



Together with Andreas Junghans – Anlagenbau und Edelstahlbearbeitung GmbH & Co. KG, the IKTS team developed an extraction module equipped with ceramic single-channel tube membranes as well as a pilot plant for the selective extraction of different strategic metals. The process is currently being tested with real process waters at Nickelhütte Aue GmbH with the aim of demonstrating the performance of membrane-assisted liquid-liquid extraction.

Bundesministerium für Bildung und Forschung

1 *Breakthrough of the aqueous phase during LEP measurement.*

2 *Pilot plant for membrane-assisted liquid-liquid extraction.*

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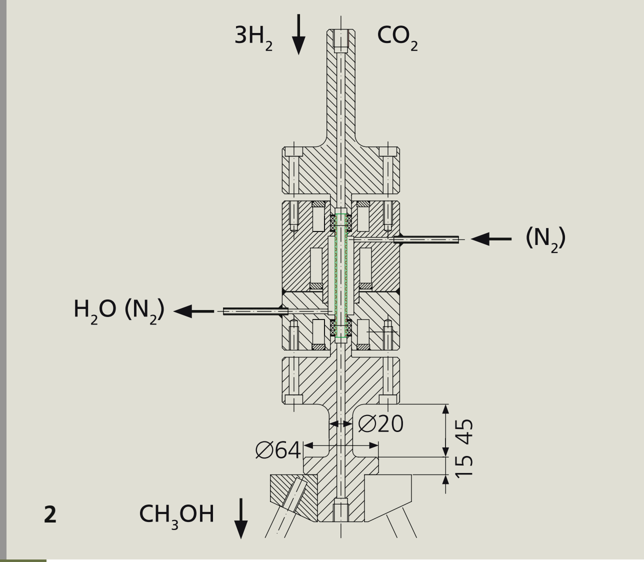
1



2

ENVIRONMENTAL AND PROCESS ENGINEERING

INCREASED PRODUCT YIELD THROUGH THE USE OF MEMBRANE REACTORS

Dr. Norman Reger-Wagner, Dr. Jörg Richter, Dr. Benjamin Jäger, PD Dr. Matthias Jahn

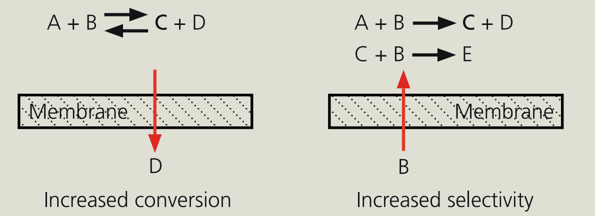
Initial situation and motivation

Many chemical processes are limited either by reaction kinetics or thermodynamics. In the latter case it is the chemical equilibrium that limits the conversion. The fact that by-product D is removed continuously means that the equilibrium is shifted towards product C. In the first case, educt B tends to react further with target product C. One example for this is a partial oxidation where complete oxidation needs to be avoided. The targeted dosing of one of the reactants – e.g. the oxidant – helps to suppress further reactions and increase the selectivity of the process. In both cases the process window can be extended by using a membrane reactor (Figure 1).

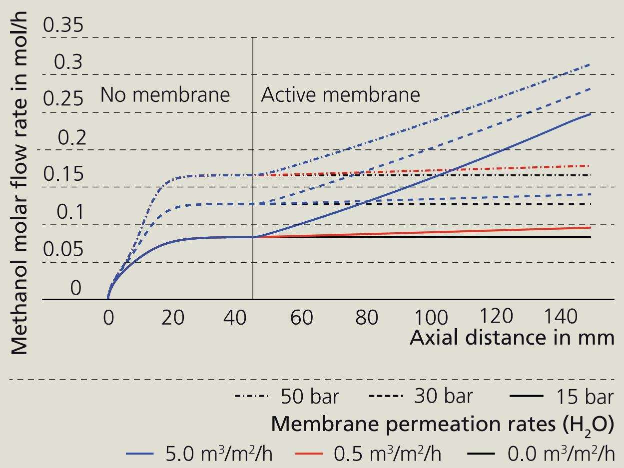
Current research at Fraunhofer IKTS

The successful development of processes with membrane reactors requires the combination of several skills (mastering catalysts, membranes, processes, process simulation and construction), which are all available at IKTS within the "Thüringer Forschergruppe Membranreaktoren". Membranes with according properties for use in different kinds of membrane reactors are being developed. Together with MUW Screentec GmbH we are working on a membrane reactor for methanol synthesis from hydrogen and carbon dioxide. Process simulations prove a significant increase in methanol yield (Figure 2). After proof on principle of the membrane reactor further work is centered around membrane performance and process development.

Process types of membrane reactors



Simulation of the reaction path of methanol synthesis along the membrane



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1 *Carbon-based membranes for membrane reactors.*

2 *Construction of a membrane reactor.*

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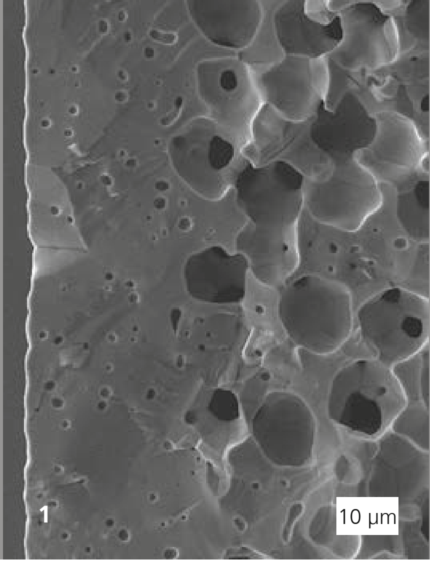
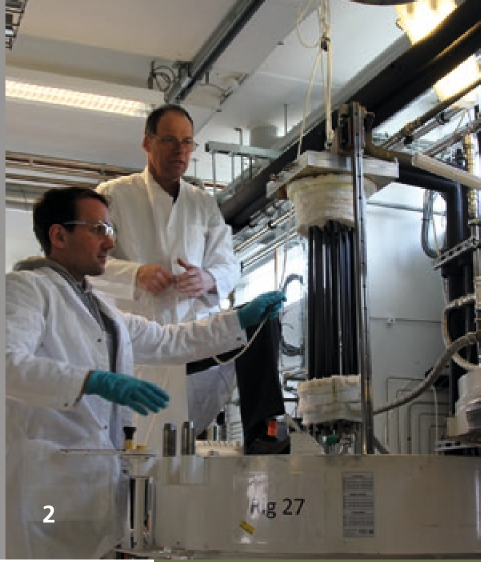
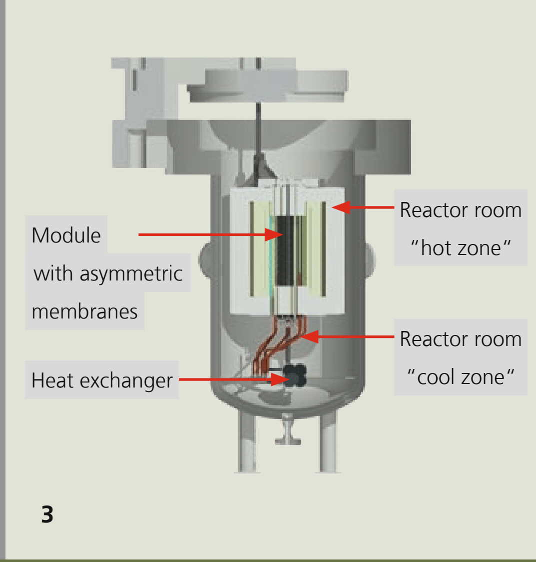


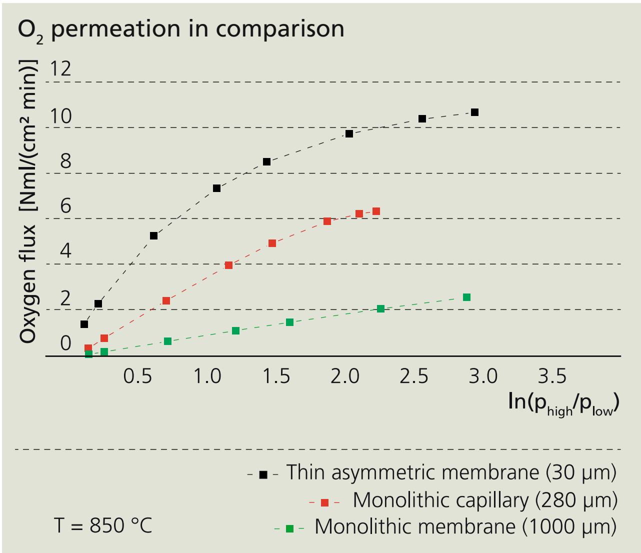




THIN SUPPORTED MEMBRANE LAYERS FOR OXYGEN GENERATORS

Dipl.-Ing. (FH) Ute Pippardt, Dr. Ralf Kriegel

Oxygen is one of the most frequently required industrial gases, with around 100 million metric tons consumed worldwide every year. Conventional production processes are very energy-intensive and the price of O_2 increases sharply for lower purchase quantities. The O_2 generators based on mixed conductive ceramic membranes (mixed ionic electronic conductor – MIEC) developed at Fraunhofer IKTS are an alternative. Gas separation is highly selective at approx. 850 °C via the coupled transport of oxide ions and electronic charge carriers. Up to now, membrane tubes or capillaries – so-called monolithic membranes – have been used in O_2 generators by IKTS. The relatively large wall thickness of these membranes (e.g. 280 µm for the capillaries) meant that large quantities (approx. 300 to 400 capillaries for 1 Nm^3 of O_2/h) were required. By contrast, lower membrane thicknesses lead to a considerable increase in O_2 permeation. In order to ensure the mechanical stability of membranes with thicknesses of 20 to 30 µm, these are applied onto an open-pored carrier ceramic (asymmetrical membranes). Manufacturing of such "asymmetric MIEC membranes" of BSCF ($Ba_{0,5}Sr_{0,5}Co_{0,8}Fe_{0,2}O_{3-x}$) was simplified and drastically optimized within the EU project "HETMOC" (Grant Agreement No. 268165). For the first time, membranes with a length of 750 mm were manufactured in a quantity sufficent for testing in a pilot plant. All in all, 3 modules, each of them equipped with 25 asymmetric membrane tubes, were tested successfully for several months at 5 bar air-side pressure by the project partner DTU of Denmark. The following chart compares the area-normalized O_2 permeation of an asymmetric membrane, a capillary, and a monolithic membrane tube. Since the asymmetric membrane's flow rate is multiple times that of a monolithic membrane, the required number of membranes produced decreases considerably. The purity of the O_2 produced by asymmetric membranes is reduced to approx. 96–98 vol % O_2 because of few pinholes inside the thin separation layer, which are hard to eliminate. Nevertheless, it was possibe to realize smaller and cheaper O_2 generators



by using the new asymmetric MIEC membranes. Accordingly, such membranes are presently used in the project "IBIS" (BMBF: 01LY1616A), which deals with the O_2 enrichment of combustion air in an industrial furnace. Fuel gas savings are expected.

1 *SEM image of an asymmetric BSCF membrane.*

2 *Pilot plant for overpressure operation (source: DTU, HETMOC).*

3 *Scheme of a pilot plant equipped with asymmetric membranes (source: DTU, "HETMOC").*

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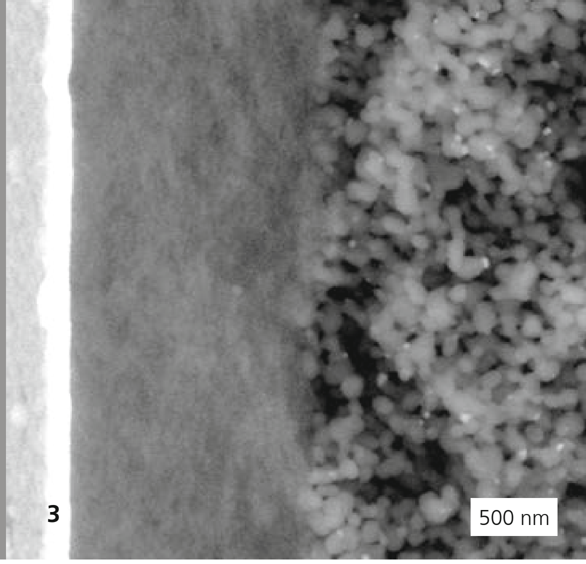


PALLADIUM MEMBRANES FOR H_2 SEPARATION FROM HOT AND HUMID GASES

Dr. Hannes Richter, Dr. Norman Reger-Wagner, Dr. Adrian Simon, Janine Hercher

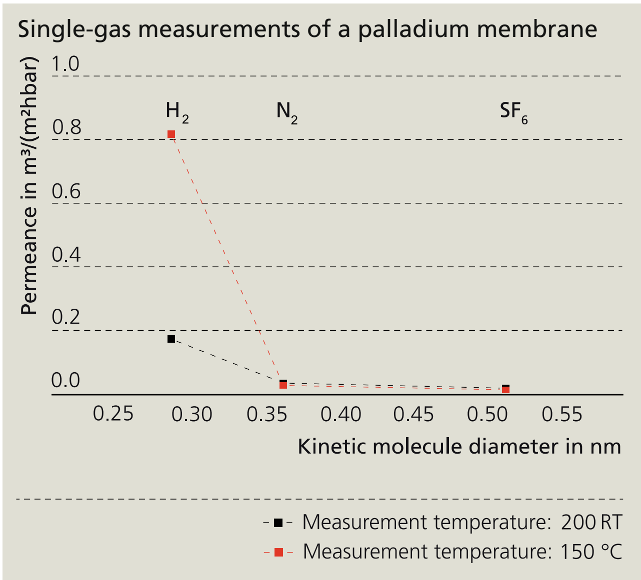
Motivation

Membranes are increasingly of interest for industrial processes because they enable energy-saving methods for separation. The separation of gas molecules is one possible field of such an application. The kinetic molecule diameter of gas molecules is significantly below 1 nm, which means there are specific requirements for the membrane: its layer should be free of defects and provide both high permeance and high permselectivity.

Current research at Fraunhofer IKTS

The choice of a specific membrane depends on the type of separation task. Fraunhofer IKTS has developed and characterized various membrane materials. Particularly, the separation of hydrogen from hot and humid gases puts high demands on the membrane material with regard to thermal and chemical stability. For such separation tasks, Palladium (Pd) membranes are candidates with high potential, since Pd is only permeable for hydrogen. Such membranes were prepared at IKTS using an innovative wet chemical method on porous, ceramic substrates. The synthesis method leads to very thin and dense membrane layers with high selectivities. Figure 1 represents a scanning electron microscopy image of the cross section of the membrane on a ceramic support. The Pd layer is approx. 200 nm thick. In the SEM image it appears as a white layer.

The characterization of the membrane was carried out through single-gas permeation measurements of different gases. The H_2/N_2 permselectivity level > 150 exhibited by the membrane is ideal. The very low SF_6 flow indicates that very few defects are included in the membrane layer, or even that their number is non-significant. Thanks to the low thickness of the Pd layer the permeance is very high. This allows for lower application temperatures and opens up new areas of application.



1 *Uncoated single-channel geometry (left) and coated inside of a substrate (right).*
2 *Automated test rig for gas permeation measurements.*
3 *SEM image of a Pd membrane (white) on ceramic substrate.*

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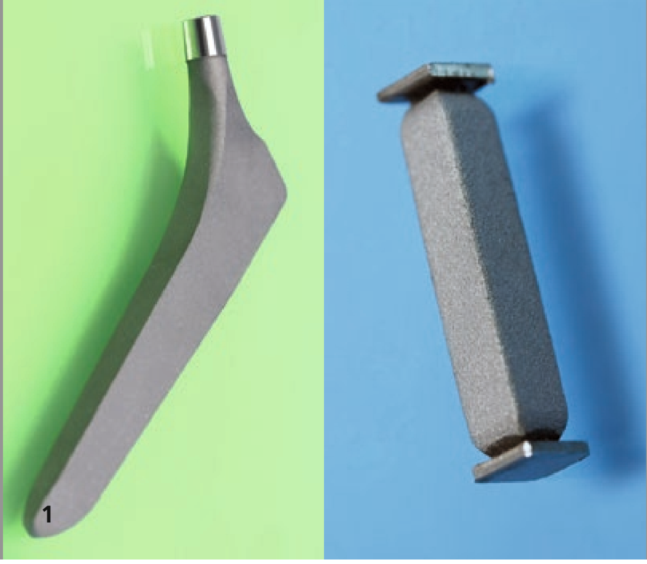


THERANOSTIC IMPLANTS – SMART FUNCTIONALIZATION AND MONITORING

Dr. Holger Lausch, Dipl.-Math. Michael Brand, Dr. Michael Arnold, Dipl.-Ing. (FH) Bernd Gronde

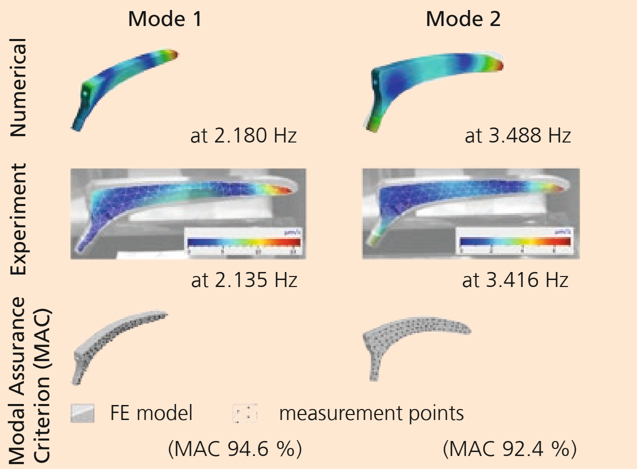
One of the biggest challenges within the leading project "Theranostic Implants" was the development (Fraunhofer IKTS), as well as the embedding within a hip implant (Fraunhofer IWU), of actuators and sensors for the detection of relaxation, the non-invasive activation of the reanchoring, stimulation of the healing process and timely detection of misloading and overloading by means of permanent monitoring.

The material- and form-fitting integration of temperature-sensitive actuators and sensors into metallic monolith bodies with complex shapes keeps posing a problem for which the available solutions are not fully satisfactory. On the one hand, these components require the optimal fit of form and material so that the gradients to be measured (force) are coupled with the sensor with as little loss as possible; the same applies to the integration of the gradients into the functional form body. On the other hand, the sensors and actuators have to be protected against any energy influx during the embedding process to achieve material- and form-fitting interfaces with the form body.

Such a strategy requires that the actuator be covered or coated by a thermally acting protective system consisting of multiple materials/layers, preferably made from ceramic and metallic material components. The integration interface between actuator-sensor system and form body is designed in such a way that the main flux of energy focuses topically on the interface and the energy is diverted away from the actuator-sensor system or distributed spatially, eventually resulting in a reduced energy influx into the zones of the temperature-sensitive components.

Using wireless energy transmission, it was possible to stimulate the implant acoustically. The resulting oscillations measured conformed well with the computer simulation. In addition to the active surface functionalization realized, energy self-sufficient operation in an inverse mode with the actuator as energy harvester is also possible. This enables an online/in-line structure health monitoring process as an early warning system, for safety and service beyond medical applications.

Comparison between numerical modal analysis and 3D laser scanning measurements



1 *Sensor production and embedding into an implant.*
2 *CAD and CT image of an implant with embedded IKTS sensor module (source: Fraunhofer IWU and Fraunhofer IKTS).*

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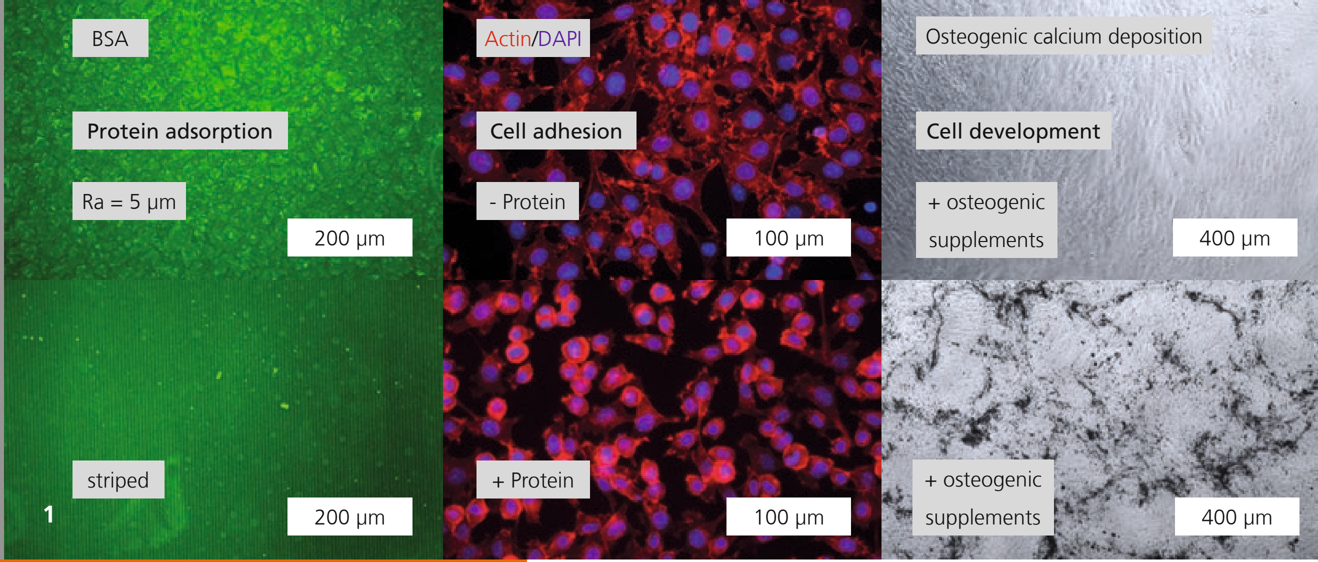
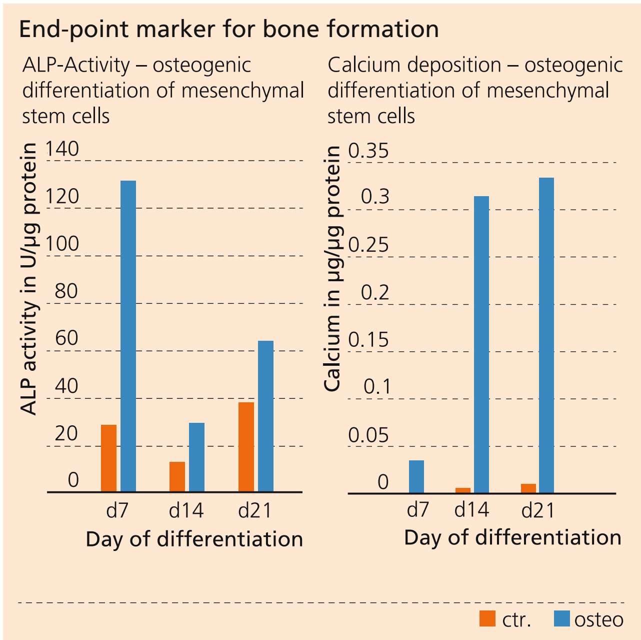


IN VITRO TEST METHODS FOR THE BIOLOGICAL EVALUATION OF CERAMIC MATERIALS

Dr. Juliane Spohn, Dr. Susanne Kurz, M. Sc. Vignesh Dhandapani, M. Sc. Timothy Esch, Carolin Preißler

To date, only a few standardized test methods exist for reliably assessing implant materials in the laboratory with regard to their compatibility within the biological system. As soon as an implant is introduced into the body, initial contact with blood causes a kind of preconditioning of the surface. Here it is important to understand what exactly happens on the surface. Fraunhofer IKTS is concerned with the following questions: How selective are material surfaces in terms of protein attachment? For how long are proteins stable or functional? How does the preconditioning of the surfaces control the interaction of the material with the surrounding tissue and immune cells?

IKTS develops targeted methods and technologies to characterize protein adsorption as a function of surface properties. We examine whether the attachment of proteins can be influenced solely via the structure of the ceramic surface, or whether a targeted functionalization of the surfaces is essential for optimizing the material for biomedical applications. Researchers were able to demonstrate that proteins homogeneously attach themselves to the untreated ceramic (Figure top-left) and align themselves, for example, along a stripe pattern on doped silicon (Figure bottom-left). The protein-cell-material interaction, with a focus on protein-dependent cell adhesion, can be detected by fluorescence labeling of suitable cell structures (Figure center: nucleus blue, elements of the cytoskeleton – for example actin – red). For this, the ISO standard 10993 and the common fibroblast cell line L929 are used. In order to assess the osseointegration, i. e. the "ingrowth" of the material into the bone, differentiation tests on material surfaces are performed. In addition to using cell lines (MG-63, SAOS-2), which provide rapid – but not patient-specific – evidence, IKTS is currently working on human mesenchymal stem cells (bone marrow), which are isolated and grown at the institute, from healthy donors. Analytical end-points for the assessment of the osseo- integrative properties of material surfaces are defined: a suitable early marker is the activity of alkaline phosphatase, ALP (Diagram 1), followed at a later point by calcium incorporation (Figure right, Diagram 2).



1 *Immobilization of albumin (left); Proteins favor cell attachment (center); Calcium as an indicator of bone formation (right).*

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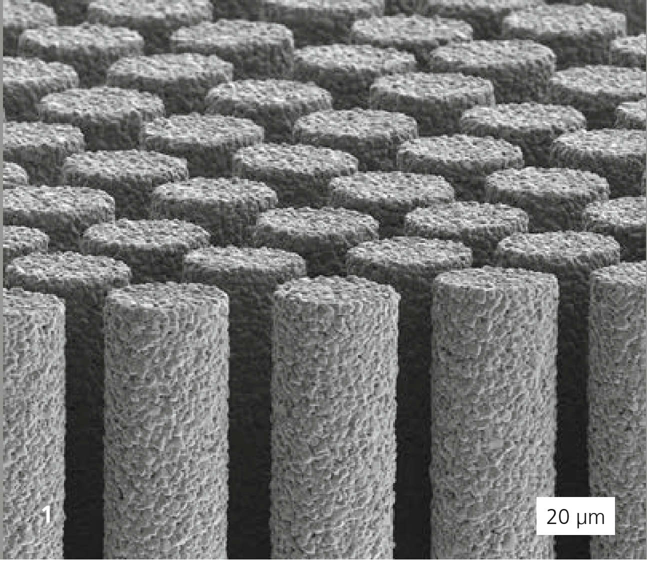
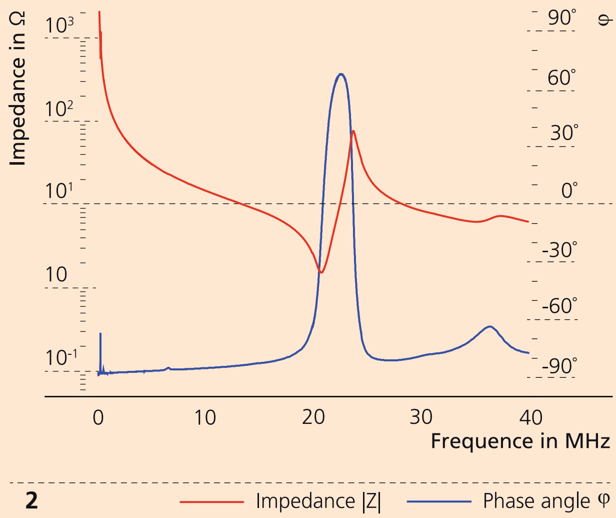




1-3 PIEZOCOMPOSITES FOR HIGH-FREQUENCY ULTRASONIC TRANSDUCERS

M.Eng. Paul Günther, Dr. Sylvia Gebhardt, Dr. Holger Neubert

Ultrasonic imaging plays an important role in medical diagnostics. The demand for more precise diagnosis requires higher resolution, which can only be obtained using high-frequency ultrasonic transducers with operating frequencies between 20 and 40 MHz. Since penetration depth decreases as the frequency increases, high-frequency ultrasonic transducers are suited in particular for near-surface or intracorporal imaging, for instance in the context of dermatological, ophthalmological or intravascular examinations.

1-3 Piezocomposites

1-3 piezocomposites of piezoelectric active ceramic rods embedded in a non-piezoelectric and elastic polymer matrix are advantageous when compared with single-phase materials because of their higher electromechanical coupling and thus higher sensitivity, bandwidth, as well as intermediate dielectric constant, lower acoustic impedance, and the ability to be formed into curved transducers. Moreover, phased-array transducers with acoustically separated elements can be manufactured easily by applying patterned electrodes.

Increasing operating frequencies means that the piezocomposite thickness needs to be reduced, while a smaller pillar geometry and pitch are necessary in order to shift spurious modes to uncritical frequencies. This results in great challenges for a reliable manufacturing process, which has to guarantee array structures with accuracies on the micrometer scale. To date, ultrasonic transducers with frequencies < 20 MHz are produced using the dice-and-fill method, which is too large-scale and thus insufficient for higher frequencies.

Soft mold process

The soft mold process developed at Fraunhofer IKTS enables the fabrication of markedly small-scale 1-3 piezocomposites via slip casting. Flexible intermediate molds made of silicone, into which a ceramic slurry is poured, are taken from an original mold produced through microstructuring. After drying, the green samples can be demolded and sintered. Advantages compared to dice-and-fill:

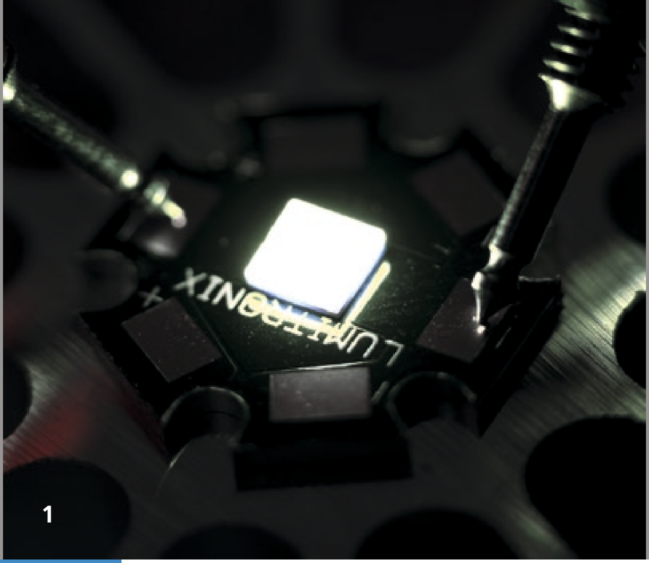
- Reusable master and soft molds
- High variety regarding pillar shape, size and arrangement
- Small pillar spacings
- Time- and effort-independent from array structure

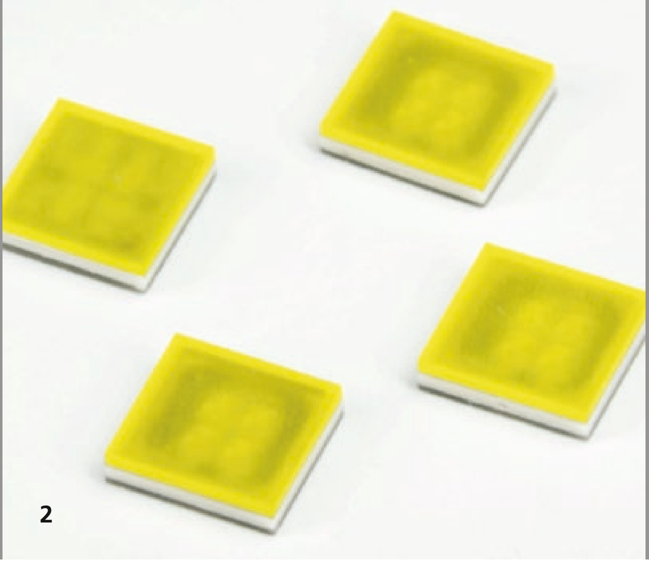
As a consequence, the soft mold process allows for the cost-effective fabrication of 1-3 piezocomposites for high-frequency ultrasonic transducers. Up to now, composites with round pillars in hexagonal arrangement enable ultrasonic transducers with operating frequencies of up to 30 MHz – compared with the 15 to 20 MHz realized with conventional methods. In the near future, even converters with > 40 MHz will probably be possible.

DFG

1 Sintered piezoceramic array.

2 Impedance spectrum of a 20 MHz ultrasonic transducer.





HERMETICALLY SEALED CERAMIC LED PACKAGE FOR LIGHTING IN HARSH ENVIRONMENTS

Dipl.-Ing. Martin Ihle, Dr. Paul Gierth, Dr. Uwe Partsch, Dr. Isabel Kinski

New potential market segments for LED lighting are associated with particularly humid atmospheres, such as those found in medical applications and biotechnology. Harsh industrial conditions with high concentrations of harmful gases also place special demands on LEDs. At present, such demands can only be met with completely encapsulated systems, which come with high manufacturing costs.

Under harsh conditions or in chemically aggressive or corrosive environments, housing with common polymers leads to rapid degradation of the emission properties of LEDs. Therefore, polymers are not suitable for this application. For this reason, the Fraunhofer "HeraKLED" project has developed an all-ceramic packaging technology for LEDs, with which the housing can be completely hermetically sealed. This enables operation in harsh environments with high color stability and constant light output.

Specification

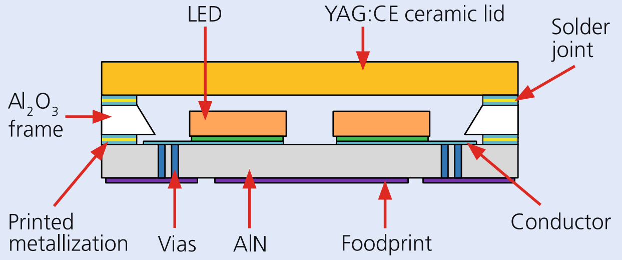
The individual components of the all-ceramic housing have been optimally adapted to each other with regard to their thermal expansion coefficients, so that the structure is able to accept a high thermal alternating load. The package was manufactured as a wafer-level version using cost-effective thick-film technology. The packages are made in SMD design, i.e. they are soldered directly to the PCB and have a size of 4.2 x 4.2 x 1.2 mm³ (electric power of 4 x 3 W) for a 4-LED configuration. To ensure maximum cooling for heat dissipation of the LEDs, the interposer is made of aluminum nitride, which offers good conductivity, and with vias. The ceramic light converter wafer made of Ce-doped YAG completes the module (WLF at 20 °C = 9.8 W/mK).

All steps for the manufacturing of the packages are carried out at Fraunhofer IKTS. Design and layout can be customized at any time.

Applications

These hermetically sealed all-ceramic LEDs can be used in humid environments such as swimming pools, greenhouses or in humid climates. But they can also be employed under harmful gases, such as in tunnels, farms and sewers.

Schematic structure of an all-ceramic package in sectional view



1 *All-ceramic LED package with YAG:CE phosphor in the field on heat sink.*

2 *Hermetic ceramic packaging with 4 x 3 W LEDs.*

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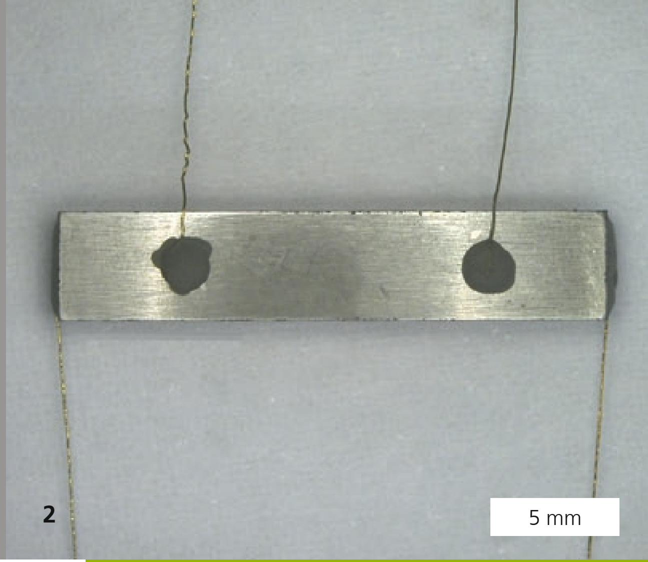


CHARACTERIZATION OF TEMPERATURE-DEPENDENT ELECTRICAL RESISTANCE UP TO 1400 °C

Dipl.-Ing. (FH) Mario Trache, Dr. Hans-Peter Martin

Electrically conductive ceramics can be used in numerous applications, e.g. as heating elements or thermoelectrically active materials. They are distinguished from conventional materials by high-temperature resistance and excellent chemical stability.

Detailed knowledge about the electrical behavior of these materials is a prerequisite before they can be adapted to their respective application. Additionally, measuring electrical resistance may also yield information about their oxidation behavior, phase conversion or crack formation in relation to their temperature, all with a high degree of precision and sensitivity.

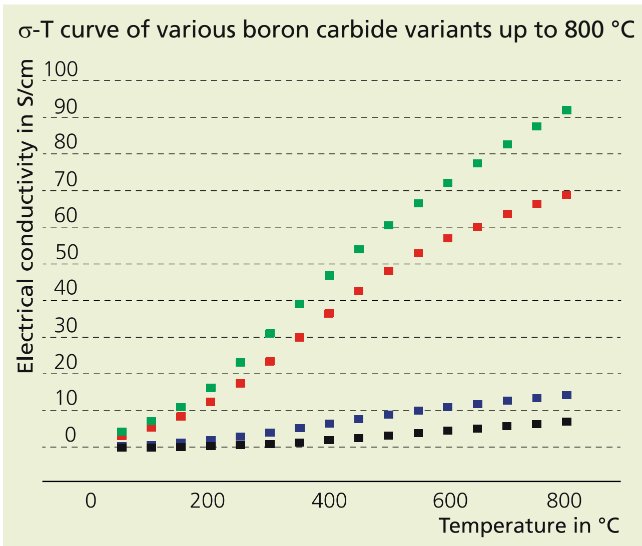
However, the precise measuring of the electrical resistance of ceramics is more of a challenge than is the case with metals. Depending on the type of ceramic material contact and wire resistance as well as thermoelectric voltages, for example, reach different levels.

Various equipment and contact concepts are applied depending on objectives and resistance level. In order to minimize errors due to contact and wire resistances when measuring small resistances, a measuring arrangement was used which combines a high-resistance nanovoltmeter with a current source in a four-wire measuring arrangement.

Fraunhofer IKTS has a number of test setups available for resistance measurements on air, forming gas and inert atmospheres at up to 1400 °C, as well as a cryostat vessel for temperatures down to -190 °C.

Services offered

- Precise measurement of electrical resistance in the range of 10^{-4} to 10^{6} Ω at temperatures from -190 to 1400 °C under argon-, nitrogen- or hydrogen-containing inert gases or in air
- Bespoke measurement set-ups (4-point or 2-point method, van der Pauw)
- Customer-specific solutions



1 *Resistance-temperature measurement up to 1400 °C.*

2 *Contacted sample related to 4-point method.*

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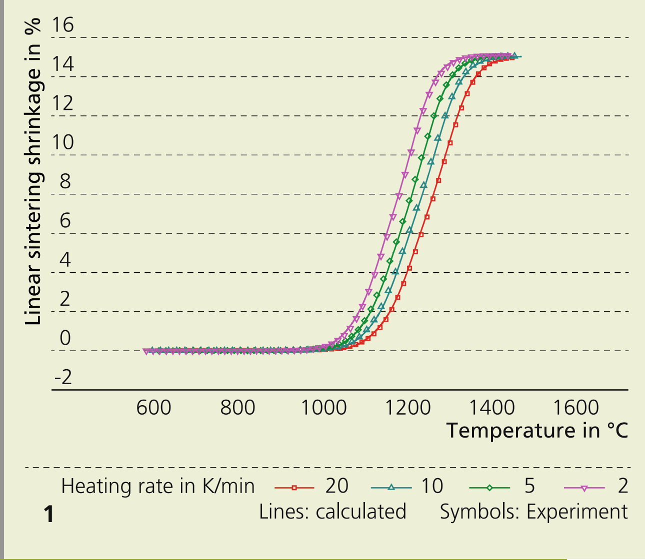
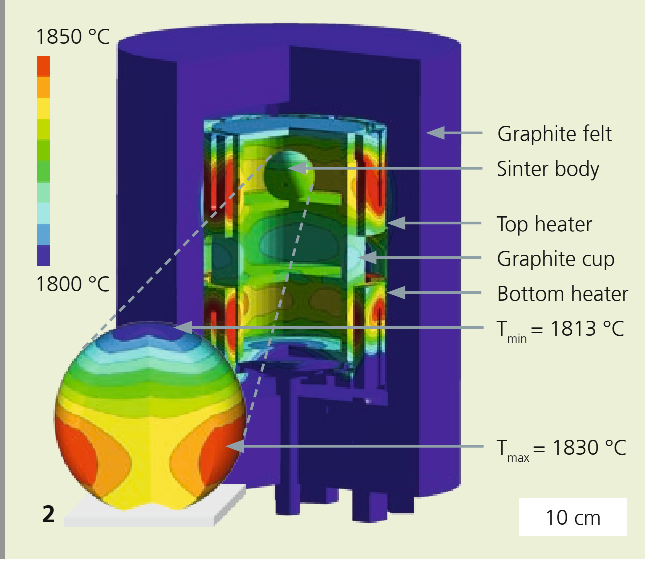




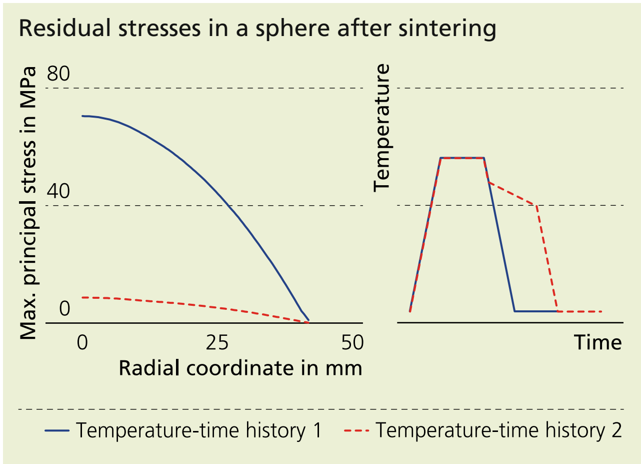
MODELING OF SINTERING PROCESSES

Dr. Sebastian Stark, Dipl.-Ing. (FH) Gregor Ganzer, Dr. Tim Gestrich, Dr. Peter Neumeister, Dr. Mathias Herrmann

The processing conditions during sintering of large and/or complex parts have significant influence on the reliability of the product and the efficiency of the manufacturing process. Consequently, it is desirable to optimize sintering processes. However, due to the variety of influencing factors, this is associated with significant effort if the approach pursued is purely experimental. It is expected that this effort can be reduced by computer simulations. Hence, suitable methods for the model-based optimization of sintering processes have been developed at Fraunhofer IKTS.

Before simulations can be performed, an experimental characterization of the relevant material properties is generally necessary. With regard to this aspect, a methodology has been established which allows for the collection of the required data with minimal effort. Essential to the experimental procedure is the measurement of material-specific shrinkage curves (Figure 1).

The actual simulations do not only cover the modeling of the sintering process of a component but also account for the impact of the sintering furnace, which generally cannot be neglected. Figure 2 exemplarily shows the calculated temperature field in a gas pressure sintering furnace including the sintering body. The temperature field exhibits inhomogeneity, resulting in inhomogeneous shrinkage and mechanical stresses. This aspect is incorporated by a thermodynamically and kinematically consistent constitutive model, which has been implemented into a standard simulation package. The following figure exemplarily demonstrates the predicted influence of the processing conditions on the residual stresses remaining in the body after sintering.



As can bee seen from the Figure, a modification of the temperature-time history during cooling, while keeping all other parameters of the process constant, can cause a dramatic reduction of residual stresses in the component.

The methodology described above allows for an efficient and economic optimization of sintering processes in regard to the reduction of residual stresses, with processing times being minimized. At the same time, the estimation of the sintering warpage becomes much more accurate.

1 *Experimentally determined and calculated shrinkage curves.*

2 *Temperature distribution in gas pressure sintering furnace and sintering body.*

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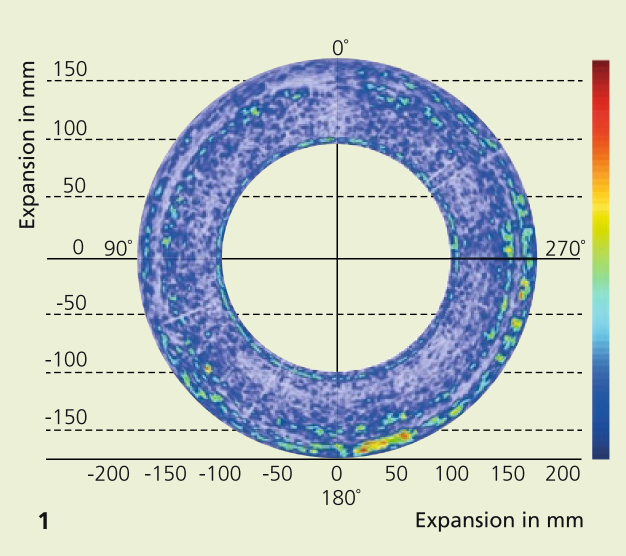

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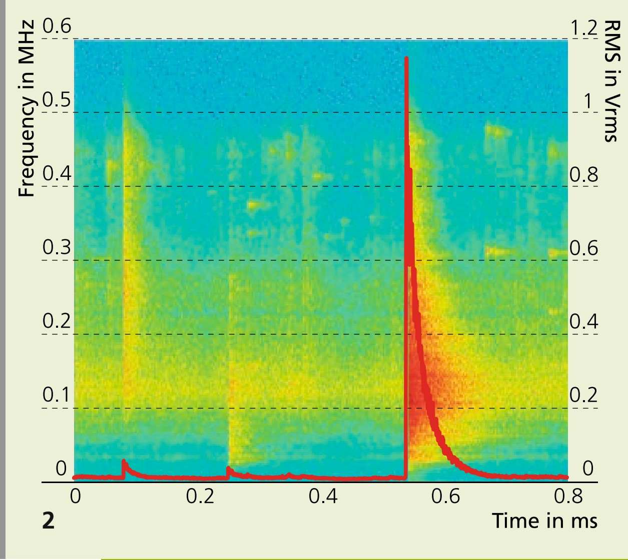

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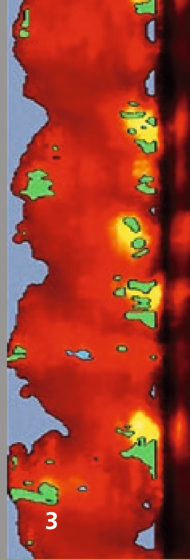

3

MONITORING OF LASER NARROW-GAP WELDINGS OF THICK-WALLED COMPONENTS

Dr. Frank Schubert, Dr. Beatrice Bendjus, Dr. Ulana Cikalova, Dipl.-Ing. Mareike Stephan, Dipl.-Ing. Raffael Hipp, Dipl.-Geophys. Eberhard Schulze

Components assembled from thick metal sheets are usually produced using conventional welding techniques. In recent times, laser multi-pass narrow-gap welding has increasingly been utilized for this purpose. Using this laser technique, metallic components with a large wall thickness of up to 100 mm can be welded efficiently. Due to economic reasons, a conventional NDT approach based on ultrasonic testing of fully welded components after the welding process is inefficient. If structurally relevant defects are found, a repair is no longer possible and the whole component has to be rejected. In order to allow for the identification of defects during the welding process, a temperature-resistant in-line monitoring approach would be necessary but is not yet available. In a collaboration project with the Fraunhofer Institutes IKTS, IWS (laser narrow-gap welding) and IWM (material analysis), funded by the Fraunhofer-Gesellschaft within the context of the WISA program, a multi-method approach based on three complementary testing procedures has now been developed and successfully verified.

Ultrasonic phased-array testing

Using a phased-array transducer consisting of a large number of single elements and the PCUS® *pro* Array electronics developed at IKTS, it is possible to efficiently steer and focus sound beams, thus capturing the entire depth of the narrow-gap weld and display defects. In addition, a high-temperature and in-line-compatible test concept was developed, for which special probe wedges with integrated coupling and coolant circuits are used.

Acoustic emission testing

A welding process continuously produces acoustic emissions (AE). These are detected by an AE sensor placed directly on the surface of the welded component. Following data reduction the in-line acoustic signatures in the frequency range between 50 and 600 kHz are compared with a database of reference signatures. This comparison allows to evaluate the welding process and identify defects and other imperfections and irregularities.

Laser speckle photometry (LSP)

LSP is a method of evaluating speckle patterns produced by laser illumination of the weld immediately behind the weld beam. A CMOS camera detects and evaluates these patterns and their temperature- and time-dependent behavior in-line. Correlations between speckle signals and surface-related defects on the one hand, and changes in process parameters on the other, have already been metallographically verified.

1 *Results of ultrasonic phased-array testing.*
2 *In-line defect detection by acoustic emissions.*
3 *In-line defects detection on the weld seam surface using laser speckle photometry.*

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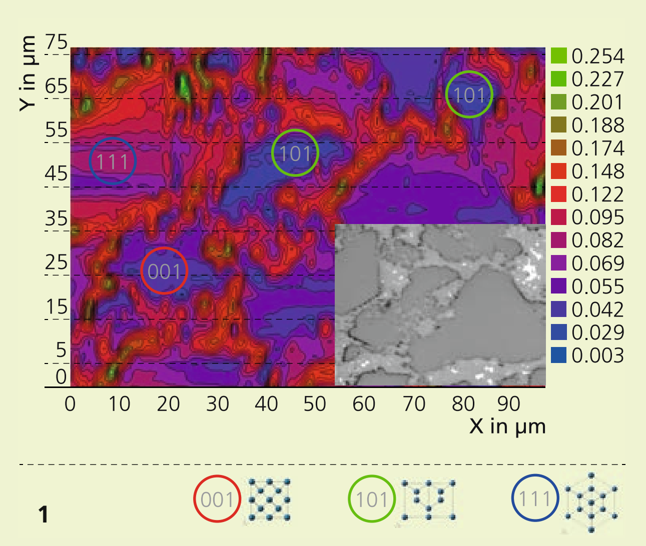

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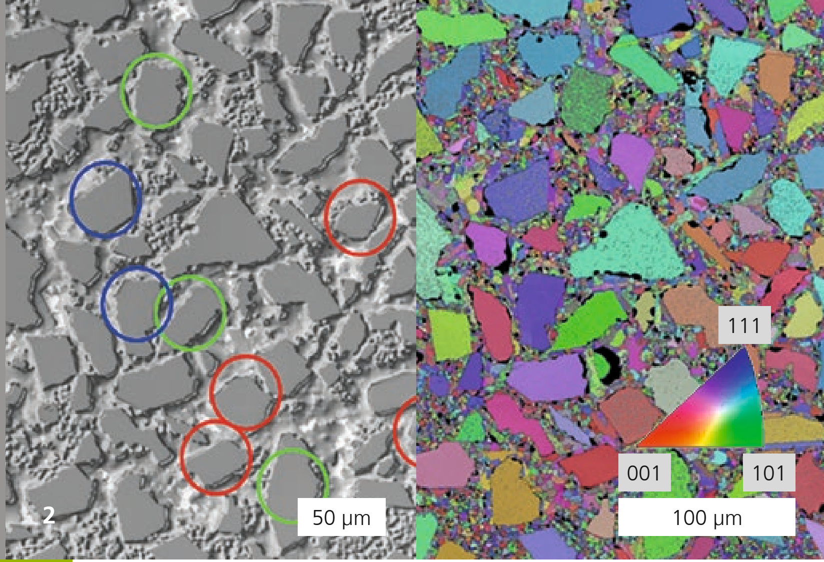

2

CORRELATION OF FRICTION COEFFICIENT AND CRYSTALLOGRAPHIC ORIENTATION

Dipl.-Ing. Björn Matthey, Dr. Mathias Herrmann

The tribological behavior of components often determines a system's lifetime. The most important influencing factors are the friction coefficient as well as several wear coefficients, which are characteristic for the respective material pairings under a specific load. Understanding the contact surface mechanisms can help to develop the systems further, thereby increasing the durability of machines and components and making industrial processes more effective and economical.

In particular, inorganic and ceramic materials are often used – thanks to their excellent mechanical properties – in applications (e.g. seals, bearings and valves) where high wear resistance is required. In addition, diamond-based materials, such as PCD, ceramic-bonded diamond materials and CVD diamond layers, are increasingly used, as diamond is the material with the lowest known friction coefficient. Since the physical properties are highly dependent on the crystal structure of the components and – in the case of anisotropic properties – on their crystal orientation, experiments were performed on diamond (bonded in a diamond-SiC composite) with a nanomechanical tester (ZHN, ASMEC Advanced Surface Mechanics GmbH) and then correlated with the results of electron backscatter diffraction (EBSD) in the scanning electron microscope. Thus, it was possible to measure the coefficient of friction as a function of the crystallographic orientation on several grains of a sample's surface. The nanomechanical test also allows two-dimensional (several 100 µm²) measurements of the frictional properties and the modulus of elasticity. The displacement resolution in the normal and lateral direction is around 1 nm and the resolution of the force is 3 to 10 µN at maximum forces of around 2 N, which allows contact pressures (between Brinell indenter and measuring surface) of up to 50 GPa.

As a result of these investigations, the orientation dependence of the diamond friction coefficients could be demonstrated (Table 1). They provide a basis for further fundamental investigations of orientation-dependent or anisotropic properties. In addition to the grain orientation, the sliding direction, which can be determined via the EBSD measurement, also has a considerable effect.

Orientation-dependent friction coefficient of diamond

Grain orientation	Friction coefficient
001	0.07
101	0.03
111	0.06

Services offered

- Measurement of the grain orientation via EBSD
- Evaluation and correlation of local properties and crystal orientation

The nanomechanical tests were carried out by Dr. Chudoba (ASMEC Advanced Surface Mechanics GmbH) as part of the "EkoDiSc" project (03X3583H) funded by the German Federal Ministry of Education and Research (BMBF).

asmec ADVANCED SURFACE MECHANICS

Bundesministerium für Bildung und Forschung

1 *Mapping of the friction coefficient and allocation of grain orientations.*

2 *EBSD analysis of a diamond-SiC composite with labeling of pure (001)-, (101)- and (111)-orientations.*

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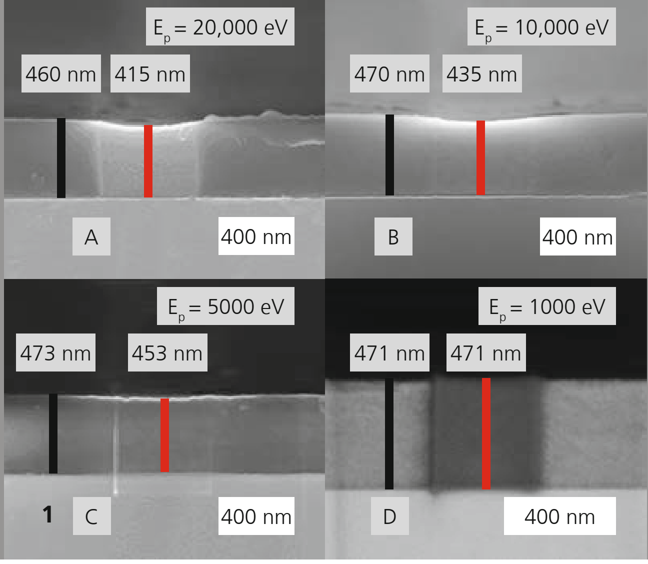

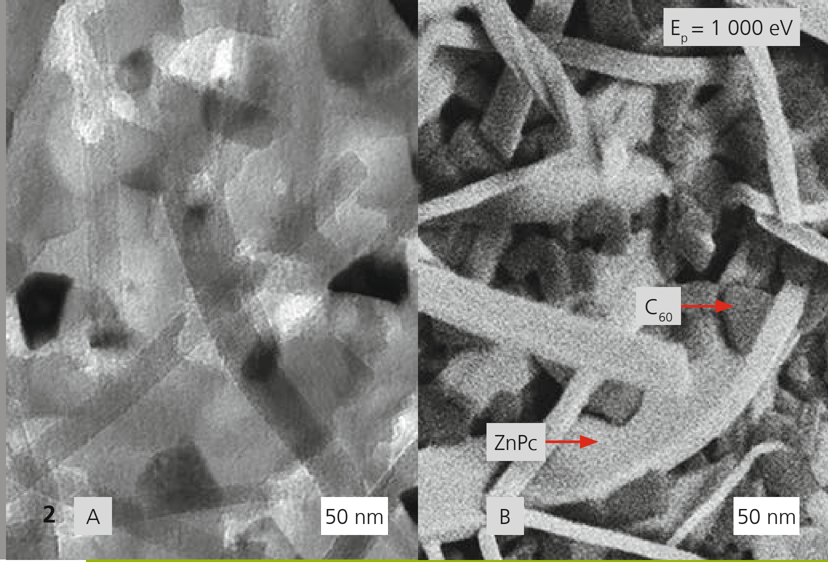

CHARACTERIZATION OF ORGANIC THIN FILMS AT THE NANOSCALE WITH LVSEM

M. Sc. Aránzazu Garitagoitia Cid, M. Sc. Mona Sedighi, Dr. André Clausner, Dr. Rüdiger Rosenkranz, Prof. Ehrenfried Zschech

Scanning electron microscopy (SEM) often shows a very low material contrast when examining materials that differ only slightly in their composition. In addition, radiation-sensitive samples can be damaged during observation. In order to significantly reduce the volume of interaction in the electron microscope and to obtain essential information from the surface area of the sample, it is possible to use low primary beam energies (E_p). Through advances in field emission source design, aberration-corrected optics and improved detector sensitivity, modern low-voltage SEMs (LVSEMs) are now able to provide additional analytical information. The combination of the signal of the backscattered electrons with low primary beam energy opens up new imaging possibilities for the characterization of radiation-sensitive materials. This reduction of radiation damage is essential in particular for thin films, organic samples and some hybrid materials.

Thin films of organosilicate glass (OSG) are used in modern microelectronic products as low-k dielectric between the metallic conductors. If the glass network of the OSG interacts with the electrical beam, it can become denser, which leads to a significant shrinkage of the material. By combining low primary beam energy (E_p = 1000 eV) with the use of the energy-selective backscattered (EsB) detector, however, the compositional contrast between the OSG thin film and the Si substrate is increased and the shrinkage phenomenon is significantly mitigated (Figure 1).

Characterizing the specimen morphology is a key step toward improving fundamental features of functional materials, such as the energy conversion efficiency of solar cells using organic photovoltaic thin films. With the EsB detector, only electrons with a certain energy (such as the backscattered electrons – BSE) can be used for SEM imaging. The low primary beam energy mitigates the charging effects for non-conducting specimens. Figure 2 shows an active zinc-phthalocyanine (ZNPC, donor) layer with embedded fullerene particles (C_{60}, acceptor) used in bulk heterojunction for OPV cells. In Figure 2A, the transmission electron microscope (TEM) image of the ZnPc-C_{60} (fullerene, acceptor) does show a mix of long rods and smaller (brighter and darker) domains, but the two compounds cannot be identified. In contrast to this, the BSE image (Figure 2B) allows to differentiate between the ZnPc (bright long rods) and the C_{60} (dark nanoparticles), providing optimized SEM working conditions.

1 *SEM images (A, B, C) of the shrinkage in OSG thin film on Si substrate after 3 min. Scanning with high magnification shows no shrinkage only in BSE image D (EsB grid voltage = 500 V).*

2 *Active zinc phthalocyanine layer with embedded fullerene particles. The two components are not visible in TEM image A; in contrast to BSE image B (EsB detector grid = 900 V).*

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COOPERATION IN GROUPS, ALLIANCES AND NETWORKS

ANNUAL REPORT 2017/18

Membership in Fraunhofer 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.

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 the Thuringian Economy

Association of Thermal Spraying (GTS)

biosaxony

Carbon Composites (CCeV)

Ceramics Meeting Point Dresden

Competence Center for Nano Evaluation nanoeva®

Competence Network on Optical Technologies (Optonet)

Cool Silicon

CO_2 Value Europe

DECHEMA – Society for Chemical Engineering and Biotechnology

Deutsche Glastechnische Gesellschaft (DGG)

DIN – German Institute for Standardization

Deutsche Keramische Gesellschaft (DKG/German Ceramic Society)

DKG/DGM Community Committee

DRESDEN concept

Dresden Fraunhofer Cluster Nanoanalysis

Dresdner Gesprächskreis der Wirtschaft und der Wissenschaft

Dual Career Network Central Germany

Energy Saxony

European Powder Metallurgy Association (EPMA)

European Rail Innovation Center

European Research Association for Sheet Metal Working (EFB)

European Society of Thin Films (EFDS)

Expert Group on Ceramic Injection Molding in the German Ceramic Society

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

Fraunhofer Adaptronics Alliance

Fraunhofer Additive Manufacturing Alliance

Fraunhofer AdvanCer Alliance

Fraunhofer Battery Alliance

Fraunhofer Cluster 3D Integration

Fraunhofer Energy Alliance

Fraunhofer Group for Materials and Components – MATERIALS

Fraunhofer Group for Microelectronics

Fraunhofer Lightweight Design Alliance

Fraunhofer Nanotechnology Alliance

Fraunhofer Numerical Simulation of Products and Processes Alliance

Fraunhofer Textile Alliance

Fraunhofer Water Systems Alliance (SysWasser)

German Acoustical Society (DEGA)

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

German Biogas Association

German Electroplating and Surface Treatment Association (DGO)

German Energy Storage Association (BVES)

German Engineering Association (VDMA)

German Society for Materials Research (DGM)

German Society for Non-Destructive Testing (DGZfP)

German Thermoelectric Society (DTG)

Hydrogen Power Storage & Solutions East Germany

International Energy Agency (IEA) Implementing Agreement on Advanced Fuel Cells

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)

NanoMat – Supraregional Network for Materials Used in Nanotechnology

Nanotechnology Center of Excellence for "Ultrathin Functional Layers"

ProcessNet – an Initiative of DECHEMA and VDI-GVC

Research Association for Diesel Emission Control Technologies (FAD)

Research Association for Measurement Technology, Sensors and Medical Technology Dresden (fms)

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

Silicon Saxony

smart³

SmartTex Network

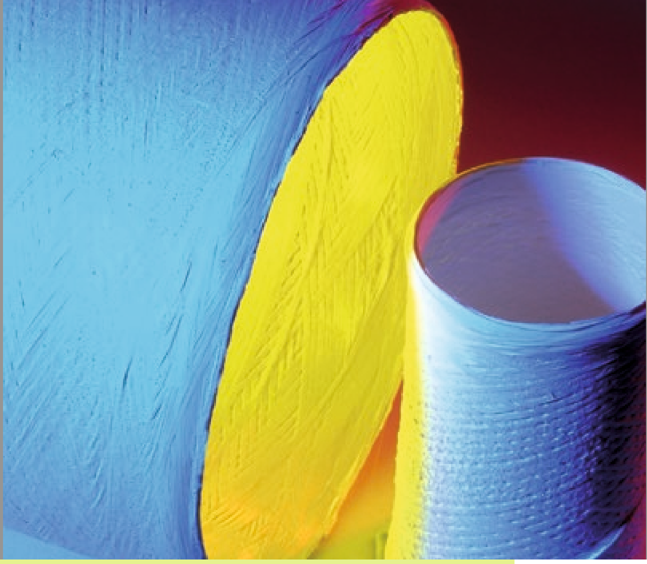
Society for Corrosion Protection (GfKORR)

TRIDELTA CAMPUS HERMSDORF e. V.

Thüringer Erneuerbare Energien Netzwerk (ThEEN)

Wasserwirtschaftliches Energiezentrum Dresden

WindEnergy Network Rostock



FRAUNHOFER GROUP FOR MATERIALS AND COMPONENTS – MATERIALS

Materials research and materials technology at Fraunhofer cover the entire value chain, from the development of new and the improvement of existing materials, through manufacturing technology on a quasi-industrial scale, up to the characterization of properties and assessment of service behavior. The same research scope applies to the components made from these materials and the way they function in systems. As far as materials are concerned, the 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. With strategic forecasts the Group supports 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 Industry 4.0 enabled materials. Digitalization of materials along their entire value creation chain is viewed by the Group as a key requirement for the lasting success of Industry 4.0.

Objectives of the Group:

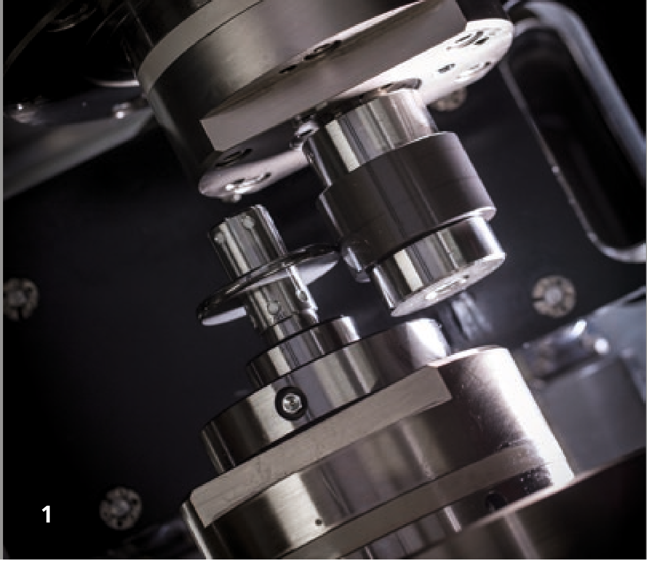
- Supporting accelerated innovation in the markets
- Promoting the success of Industry 4.0 through suitable material concepts (digital twins, Materials Data Space©)
- Increasing integration density and improving the usability properties of microelectronic devices and microsystems
- Improving the use of raw materials, quality of products manufactured from them, development of recycling concepts
- Enhancing safety and comfort as well as reducing resource consumption in the areas of transport, machine and plant construction, building & living
- Increasing the efficiency of systems in energy generation, energy conversion, energy storage and distribution
- Improving the biocompatibility and function of materials used in medical biotechnical devices, improving material systems for medical diagnosis, disease prevention and therapy
- Improving the protection of people, buildings, infrastructure through high-performance materials in tailored concepts

Members are the Fraunhofer Institutes for

- Applied Polymer Research IAP
- Building Physics IBP
- Structural Durability and System Reliability LBF
- Chemical Technology ICT
- Energy Economics and Energy System Technology IEE
- Manufacturing Technology and Advanced Materials IFAM
- Wood Research, Wilhelm-Klauditz-Institut, WKI
- Ceramic Technologies and Systems IKTS
- High-Speed Dynamics, Ernst-Mach-Institut, EMI
- Microengineering and Microsystems IMM
- Microstructure of Materials and Systems IMWS
- Silicate Research ISC
- Solar Energy Systems ISE
- Systems and Innovations Research ISI
- Nondestructive Testing IZFP
- Wind Energy Systems IWES
- Mechanics of Materials IWM
- Industrial Mathematics ITWM (assoc. institute)
- Interfacial Engineering and Biotechnology IGB (assoc. institute)
- Integrated Circuits IIS (assoc. institute)

Group chairman

Prof. Dr. Peter Elsner, Fraunhofer ICT
www.materials.fraunhofer.de



FRAUNHOFER ADVANCER ALLIANCE

Systems development with high-performance ceramics

The usage of high-performance 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. At present, AdvanCer is working in a joint project developing systems solutions and test methods for the oil and gas industry as well as for deep sea mining. It is the objective to develop new diamond-ceramic and hardmetal materials as well as the appropriate manufacturing technologies. So, components may be realized which allow for the maintenance-free operation in up to 6000 m depth in the sea.

Four Fraunhofer Institutes (IKTS, IPK, ISC/HTL and IWM) have joined together to form the Fraunhofer AdvanCer Alliance. It is the aim of AdvanCer to develop individual systems solutions with advanced ceramics for industry. The research activities of the Fraunhofer Alliance extend along the entire value-added chain from modeling and simulation through application-oriented materials development, production and machining of ceramic parts to component characterization, evaluation and non-destructive testing under application conditions. Development work is conducted and supported by modeling and simulation methods.

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

Fields of cooperation

- Materials development for structural and functional ceramics, fiber-reinforced ceramics, cermets and ceramic composites
- Component design and development of prototypes
- Systems integration and verification of batch-production capabilities
- Development of powder, fiber and coating technologies
- 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

Services offered

- Development, testing and evaluation of materials
- Prototype and small series production
- Technology development and technology transfer
- Process analysis and design
- Consulting, feasibility studies, training programs

Spokesperson of the Alliance

Dr. Michael Zins
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1 Test stand for the tribological testing of ceramic materials and components (Source: Dirk Mahler/Fraunhofer).

CERAMICS MEETING POINT – CERAMIC APPLICATIONS

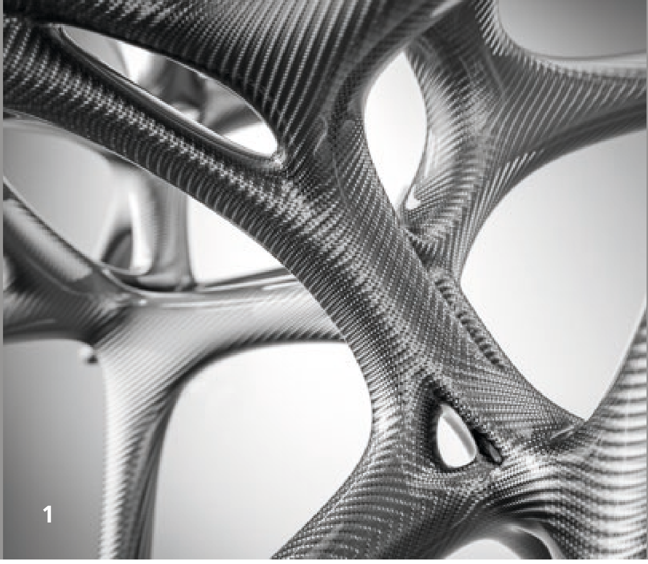
The Ceramics Meeting Point is an integral part of the public relations activities of Fraunhofer IKTS. The closed production chain from powder to component is displayed, not only from a scientific point of view but also as a mirror of technologies and capacities available in the industry. The visitor gets an impression of current focal points in research and is simultaneously informed about which manufacturers offer certain products commercially. With respective touchable models, the trust in the economic feasibility of new ideas is strengthened and the initiation of new projects facilitated.

Ceramic Applications of the Goeller Verlag embodies the new label of the cooperation with its currently 46 partners and members. The opportunity to see the latest research topics up to systems testing in one room and to get into contact with possible suppliers is thus available at all events at Fraunhofer IKTS. The members of the Fraunhofer AdvanCer Alliance also benefit from this infrastructure.

In the workshops and training courses of the Fraunhofer AdvanCer Alliance, the Deutsche Keramische Gesellschaft (DKG/German Ceramic Society) as well as the German Materials Society (DGM) the Ceramics Meeting Point is used to present the state of the art in industry and to show the practical relevance desired by the participants. Thus, a project forum particularly for small and medium-sized companies has developed, facilitating contacts to project initiators and research institutes.

The Ceramics Meeting Point was also an essential part of the DKG division 1 "Chemie-/Maschinen-/Anlagenbau" this year. The exhibition serves to present the results of the various projects funded.

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



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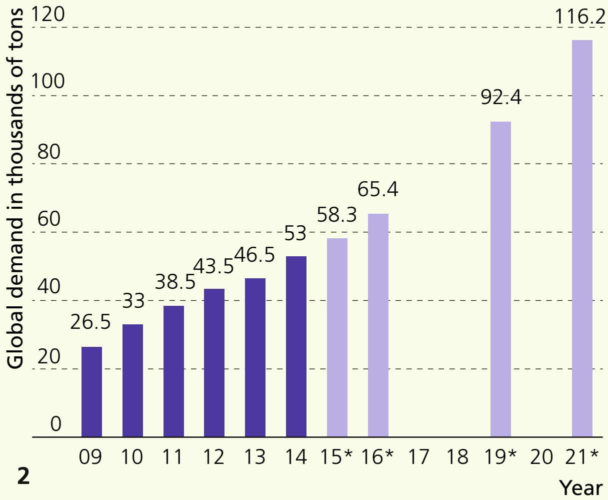

2

PROGNET – TESTING OF COMPOSITE MATERIALS

Project Group Berlin, located in Adlershof, was assigned the task of forming a cooperation network within the scope of the ZIM (Central Innovation Program for SMBs) by the Federal Ministry for Economic Affairs and Energy (BMWi).

Within the network, procedures and systems as well as simulation and monitoring tools are developed for ensuring the technical safety of highly reliable components manufactured with innovative materials.

Due to their outstanding properties, composite materials can be used for the efficient design of high-strength, lightweight components. For determining the structure-property relationships in these materials, methods and instruments that enable the characterization of the designed materials structure and behavior under load are called for. Both the aerospace industry and the automotive industry have identified a high demand for evaluation and testing of pure carbon fiber-reinforced composites (CFCs) and fiber-metal laminates (FMLs).

With the international trend in use of new materials that is beginning to emerge, it is safe to say that not only in Europe and the US but also in Asia in particular, a high demand for the products of the network will arise. Figure 2 depicts the predicted global need for carbon fibers. Demand is expected to rise until 2021. Similar trends are expected for other new materials. A corresponding increase in demand for tools and platforms for developing and testing components made of these materials is hence also anticipated.

The network provides its partners with funding options for a wide range of innovative technical projects. It aims to provide a sustainable improvement in the innovative and competitive capacity of partner companies and thus contribute to their growth as well as to the creation and preservation of jobs. The innovative capacity in the field of test technology generated through Prognet and the close relationships to standardization bodies for test regulations are sure to provide leverage to the solutions flowing into the network partners' various products.

Spokesperson of the cooperation network

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1 Carbon structures (Source: © mxd/Fotolia).

*2 Global demand for carbon fibers in thousands of metric tons for the period 2009–2021 (*estimates).*

Gefördert durch:
Bundesministerium für Wirtschaft und Energie
ZIM Zentrales Innovationsprogramm Mittelstand

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 12 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 Fraunhofer IKTS in Hermsdorf.

For IKTS, the CEEC represents a strategic cooperation platform with Friedrich-Schiller-Universität 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, Deputy Institute Director of Fraunhofer IKTS. The working group is dedicated to water treatment, water purification, and water analysis using novel, combined physical and electrochemical methods, such as ultrasound and hydrodynamic cavitation, electrochemistry, and ceramic membrane technology. The group thus functions as a bridge to the extensive work being performed at Fraunhofer IKTS in Hermsdorf and Dresden.

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

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

Contact

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1 *Button cell (Source: Jan-Peter Kasper/FSU Jena).*

NAMES, DATES, EVENTS

Please find information on patents, publications and scientific engagement of IKTS employees in 2017 on the website

www.ikts.fraunhofer.de/en/dates2017

Granted patents
Patent applications

Books and periodical contributions
Presentations and posters

Teaching activities
Participations in bodies/technical committees

Dissertations
Theses

EVENTS AND TRADE FAIRS – PROSPECTS

Conferences and events

Juniordoktor
February 12 and May 30, 2018, Dresden, Maria-Reiche-Strasse

Girls' Day
April 26, 2018, Hermsdorf, Michael-Faraday-Strasse

International Conference on Inorganic Membranes ICIM
June 18–22, 2018, Dresden, Westin Bellevue Hotel

Industry Day "Silicon nitride"
October 23–24, 2018, Dresden, Winterbergstrasse

NDT in Aerospace
October 24–26, 2018, Dresden, Steigenberger Hotel de Saxe

Workshop Additive Manufacturing Center Dresden
November 29–30, Dresden

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

Seminars and workshops

DGM training seminar
Ceramic materials: properties and industrial applications
June 26–27, 2018, Dresden, Winterbergstrasse

DKG training seminar
Spray drying: technology, statistical tests planning, product and process optimization
tba, Dresden, Winterbergstrasse

Trade fair participations

Clean India Show
January 18–20, 2018, Mumbai
Joint booth LEG Thüringen

nano tech
February 14–16, 2018, Tokyo
Joint booth Saxony Economic Development Corporation WFS

Thüringer Trinkwassertagung
February 21–22, 2018, Jena

JEC World
March 6–8, 2018, Paris
Joint booth Saxony Economic Development Corporation WFS

Energy Storage
March 13–15, 2018, Dusseldorf
Joint booth Fraunhofer Energy Alliance

Filtech
March 13–15, 2018, Cologne

Lope-C
March 14–15, 2018, Munich

ALD for Industry
March 22–23, 2018, Dresden

Ceramitec
April 10–13, 2018, Munich
Joint booth CERAMIC APPLICATIONS
Special show "Additive Manufacturing"

ILA
April 25–29, 2018, Berlin
Joint booth CleanSky

Hannover Messe
April 23–27, 2018, Hannover
Joint booth BMWi, Hall 2
Joint booth "Forschung für die Zukunft", Hall 2
Hall 5
Joint booth Energy Saxony, Hall 27

Control
April 24–27, 2018, Stuttgart
Joint booth Fraunhofer Vision Alliance

IFAT
May 14–18, 2018, Munich

RapidTech
June 5–7, 2018, Erfurt
Joint booth Fraunhofer Additive Manufacturing Alliance

Surface Technology
June 5–7, 2018, Stuttgart

PCIM
June 5–7, 2018, Nuremberg
Joint booth ECPE

ACHEMA
June 11–15, 2018, Frankfurt on the Main
Hall 4
Joint Fraunhofer booth, Hall 9.2

ECNDT
June 11–16, 2018, Göteborg

ACTUATOR
June 25–27, 2018, Bremen
Joint booth Fraunhofer Adaptronic Alliance

Sensor+Test
June 26–28, 2018, Nuremberg

ONS
August 27–30, 2018, Stavanger
Fraunhofer AdvanCer Alliance

GreenExpo
September 6–9, 2018, Mexiko City
Joint booth State Development Corporation Thuringia

EuroPM
October 14–18, 2018, Bilbao

FAD Conference
tba, Dresden

Compamed
November 12–15, 2018, Dusseldorf

Formnext
November 13–16, 2018, Frankfurt on the Main
Joint booth Fraunhofer Additive Manufacturing Alliance

Semicon
November 13–16, 2018, Munich
Joint booth VµE

Electronica
November 13–16, 2018, Munich

Hagener Symposium
tba, Hagen

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

HOW TO REACH US AT FRAUNHOFER IKTS

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

How to reach us in Dresden-Gruna

By car

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

By public transport

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

By plane

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

How to reach us in Dresden-Klotzsche

By car

- Highway A4: exit “Dresden-Flughafen” in direction Hoyerswerda along H.-Reichelt-Strasse to Grenzstrasse
- Maria-Reiche-Strasse is the first road to the right after Dörnichtweg

- From Dresden city: B97 in direction Hoyerswerda
- Grenzstrasse branches off to the left 400 m after the tram rails change from the middle of the street to the right side
- Maria-Reiche-Strasse branches off to the left after 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 to “Dresden-Grenzstraße“
- Reverse for ca. 400 m
- Maria-Reiche-Strasse branches off to the right

By plane

- After arriving at airport Dresden use either bus 80 to bus stop “Grenzstraße Mitte” at the beginning of Dörnichtweg and follow Grenzstrasse for 150 m
- Or take suburban train S2 to “Dresden-Grenzstraße” and walk about 400 m further along Grenzstrasse

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

EDITORIAL NOTES

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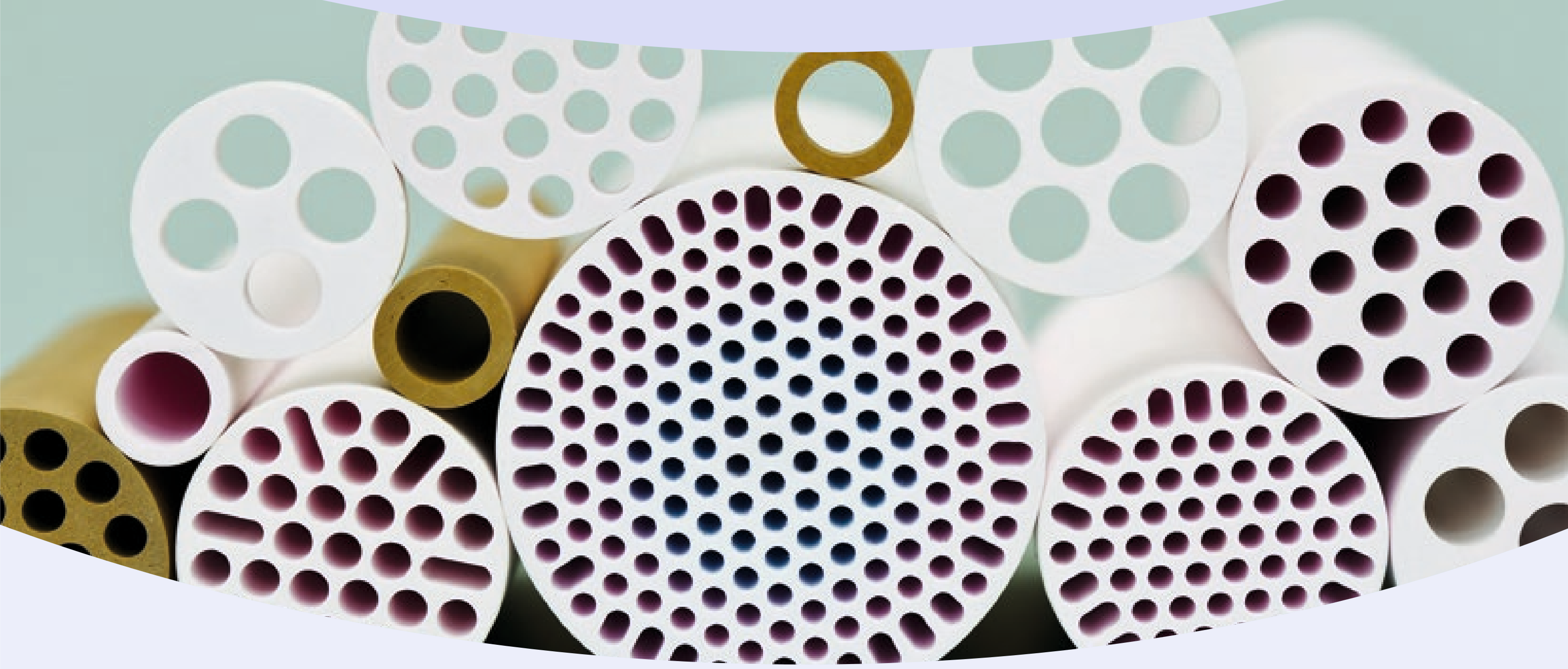
15 ICIM 2018

15th International Conference on Inorganic Membranes

Membranes: Efficient Separation

June 18—22, 2018
Dresden, Germany

www.icim2018.com



The 15th ICIM will provide an unique platform for scientists and engineers to present and discuss the latest research and development results in the field of **inorganic membrane science and technology**.

For the first time, the conference will additionally focus on **functional layers for batteries and fuel cells**.

Program

- Laboratory workshop on membrane preparation and characterization
- More than 160 international high-level lectures
- PhD-speech contest and award for the best PhD student lecture
- Poster party and awards for the three best posters
- Industrial exhibition
- Conference dinner and social program

Be part of the ICIM community and register now!
You are looking for attractive opportunities to promote your company?
Become sponsor or exhibitor at ICIM 2018.

Hosted by Fraunhofer IKTS, co-organized by FZ Jülich

Fraunhofer IKTS

JÜLICH FORSCHUNGSZENTRUM