FRAUNHOFER INSTITUTE FOR CERAMIC TECHNOLOGIES AND SYSTEMS IKTS

ANNUAL REPORT 2018 2019

70 YEARS OF FRAUNHOFER

70 YEARS OF FUTURE

#WHATSNEXT

ANNUAL REPORT 2018/2019

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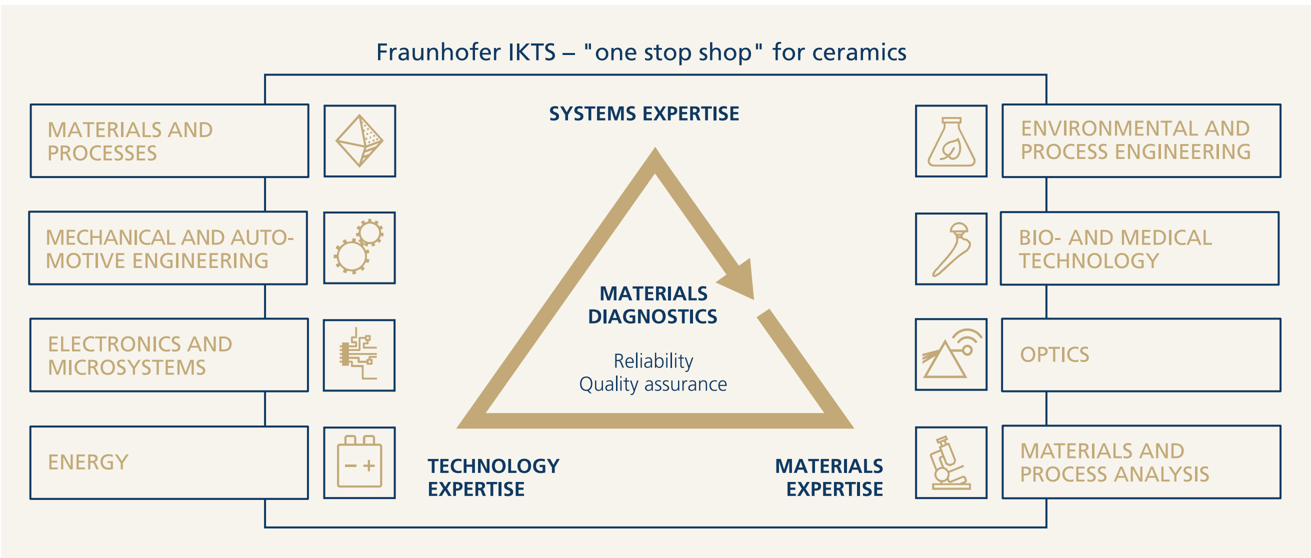
FOREWORD

ANNUAL REPORT 2018/19

Dear friends and partners of IKTS,

As we look back on another successful and eventful year, we are pleased to present our annual report. In the reporting year 2018 our total budget was, for the first time, slightly above 60 million euros. Compared with the previous year, this is an increase of approx. 5 million euros. While the number of staff has grown to now 700 at our three sites, a major share of the budget growth was invested to boost many of our areas in structural and functional ceramics. Chief among these are the continued development of our powder preparation facilities, new kiln equipment, shaping technology – specifically in the field of additive manufacturing – and a newly equipped technical center for solid-state battery development. Now as ever, we are ideally equipped to fulfill the mission of Fraunhofer and meet the challenges of applied research to support our partners from the public sector, but also – and especially – from the industry. We would like to thank the Free States of Saxony and Thuringia, as well as the federal government, for their continued support. Our team of scientists, engineers and lab technicians continues to be at your service to talk with you about ideas for projects and make them reality. I would like to take the opportunity to thank the entire IKTS team for their outstanding efforts.

As mentioned in our previous report, together with Fraunhofer IFAM we have founded a Project Center for Energy Storage and Systems ("ZESS" or "ProZESS") in Braunschweig, which now receives support from our colleagues at Fraunhofer IST and collaborates closely with Technische Universität Braunschweig. Thanks to this initiative, we are able to develop our know-how in electrochemistry and storage technologies for stationary and mobile applications. We are grateful to the State of Lower Saxony and the Fraunhofer-Gesellschaft for granting the considerable financial funds for this initiative. In addition to our materials know-how, our competence in materials and process diagnostics also plays a major role in this context: It allows us to offer our partners from the industry our

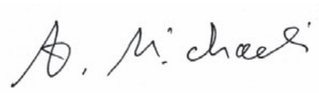


full support in planning novel, fully digitized production facilities. In the Free State of Thuringia in particular, further efforts to expand are being planned; they are currently being coordinated with the state's governing institutions. In this context, our new research group "Cognitive Material Diagnostics" in Cottbus cannot go unmentioned. It is part of the effort to further develop the IKTS competencies in the field of machine learning and data analysis, especially with regard to questions of material diagnostics and non-destructive testing. The research group works closely with the neighboring research cluster "Cognitive Systems" at the Brandenburg University of Technology Cottbus-Senftenberg. This cluster conducts research in technical systems that have the ability to sense, interpret, think and act; it integrates the work of various technical departments, such as information technology, electrical engineering, mathematics and media sciences.

All this means that the subject of digitization in ceramics is ever more important for IKTS: It is incorporated in all our business divisions. In this regard, we have found the business environment of IKTS at its Dresden-Klotzsche site to be very helpful. Another fine success was achieved in our Environmental Engineering business division, where together with other Fraunhofer partners we were able to acquire the new lighthouse project "Cognitive Agriculture" (Cognac). We plan to intensify our efforts in smart agriculture and water technologies – topics we want to develop into a business division of its own. For instance, we have already founded a Fraunhofer Center in Portugal which is dedicated to this area of research, and we are involved in various projects within the framework of the "SIMUL future initiative" hosted by the Environmental Ministry of Saxony.

You can find more highlights from our business divisions in our report. I hope you will enjoy leafing through this edition. As ever, our offer to make use of our outstanding equipment and our formidable team here at IKTS stands. We are looking forward to collaborative projects and are always open to your suggestions with new ideas and topics.

Yours,



Alexander Michaelis

April 2019

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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, innovative concepts for energy and water technologies as well as for 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.

Among our unique areas of expertise, we offer:

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

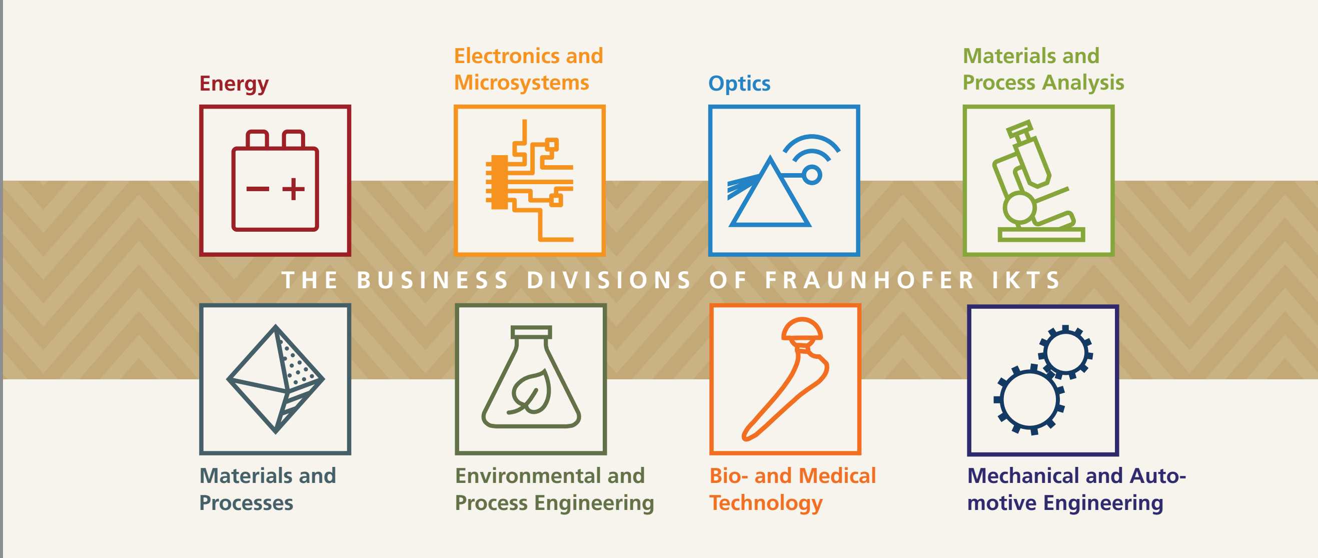
For any class of ceramic materials, Fraunhofer IKTS has access to all the standard processes of raw materials preparation, forming, heat treatment and finish processing. Where it makes sense, the institute can even conduct phase synthesis. In functional ceramics, IKTS holds a particular core competency 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 multi-functional components and systems that intelligently exploit various ceramic properties. Innovative products with significant



added value and lower costs can be directly tested, validated and optimized in several application centers.

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 12 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 foam

FUNCTIONAL CERAMICS

Non-conducting materials

Dielectrics

Semiconductors

Ion conductors

Magnets

Pastes and tapes

Solders, brazes and glass sealings

Precursor-based inks and nanoinks

Composites

ENVIRONMENTAL AND PROCESS ENGINEERING

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

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

Catalysts
- Oxides
- Metals, CNT

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

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

In-line process characterization 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

Modellierung und Simulation
- Materials transport
- Heat transport
- Reaction

Reactor development

Plant design

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

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

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

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

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

ORGANIZATIONAL CHART

Institute Director	Prof. Dr. habil. Alexander Michaelis
Deputy Institute Director / Head of Administration	Dr. Michael Zins
Deputy Institute Director / Marketing and Strategy	Prof. Dr. Michael Stelter
Deputy Institute Director	Prof. Dr. Ingolf Voigt
Deputy Institute Director	Dr. Christian Wunderlich

Materials

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

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

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

* certified according to DIN EN ISO 13485

Sintering and Characterization / Non-Destructive Testing
Dr. habil. Mathias Herrmann
- Thermal Analysis and Thermal Physics*
- Heat Treatment
- Ceramography and Phase Analysis

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
Office Berlin
Project group BTU Cottbus-Senftenberg

Application Center
Battery Technology, Pleißa, Saxony
Bioenergy, Pöhl, Saxony
Bio-Nanotechnology Application Lab BNAL, Leipzig, Saxony
Membrane Technology, Schmalkalden, Thuringia
Tape Casting Center, Hermsdorf, Thuringia

Technische Universität Dresden

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

Friedrich Schiller University Jena

Technical Environmental Chemistry	Prof. Dr. Michael Stelter

Ernst Abbe University of Applied Sciences

SciTec department – Materials Engineering	Prof. Dr. Ingolf Voigt

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

* accredited according to DIN EN ISO/IEC 17025

Energy systems / Bio- and Medical Engineering

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

System Integration and Technology Transfer
Dr. Roland Weidl
- System Concepts
- Validation
- 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. Mareike Wolter
- Electrochemistry
- Cell Concepts
- Electrode Development
- Electrochemical Energy Storage Systems and Converters

Electronics and Microsystems Engineering

Smart Materials and Systems
Dr. Holger Neubert
- Multifunctional Materials and Components
- Applied Material Mechanics and Solid-State Transducers
- Systems for Condition Monitoring

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

Testing of Electronics and Optical Methods
Dr. Mike Röllig
- Optical Test Methods and Nanosensors
- Speckle-Based Methods
- Reliability of Microsystems

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

Microelectronic Materials and Nanoanalysis
Prof. Dr. habil. Ehrenfried Zschech
- Nanoscale Materials and Analysis
- Nanomechanics and Reliability for Microelectronics

FRAUNHOFER IKTS IN FIGURES

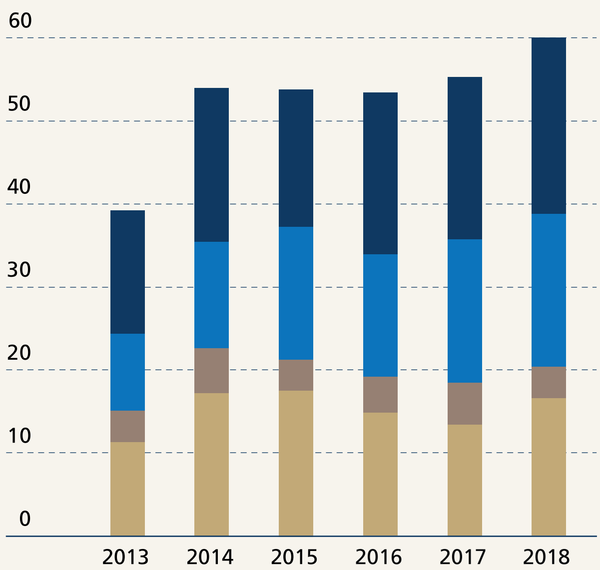
Budget and income

With 60 million euros, the total budget of 2018 exceeds the previous year's level by 5 million euros. 5.7 million euros were invested in reinforcing and modernizing our equipment; 3.9 million euros alone was used for strategic investments at the Dresden-Winterbergstrasse site. Material expenditure increased by only 0.2 million euros; it now stands at 19.5 million euros. By consistently optimizing the infrastructure, we were able to maintain costs for energy and water at their respective previous year's levels. Personnel expenditure increased by 3.3 million euros.

All in all, the external income increased to 43.4 million euros, of which 21.2 million euros stem directly from the private sector. Projects to the value of 8.7 million euros were commissioned from abroad; of these, 2.5 million euros are attributable to projects with EU funding. The bulk of the projects came from the US and the EU, with a share of close to 25 % each, while China and India also played a significant role.

In a very positive development, the funding of IKTS projects by German federal states has increased by 15 % all in all, with funds coming from the Free States of Thuringia and Saxony. In the meantime, maintenance work at the complex of buildings in Maria-Reiche-Strasse has commenced. A major share of investment in the buildings in 2018 focused on updating the fire safety infrastructure. In 2019, we will see further significant costs when implementing the site concept. Smaller construction projects at Winterbergstrasse in Dresden focused on extending lab areas for structural and functional ceramics research. In total, 2018 saw construction measures carried out at the three sites for 1 million euros, in addition to the budget mentioned above.

Revenue (in million euros) of Fraunhofer IKTS for the budget years 2013–2018



	2013	2014	2015	2016	2017	2018
■	14.4	18.6	16.3	19.6	19.6	21.2
■	9.4	12.9	16.4	14.8	17.3	18.4
■	4.2	5.5	3.6	4.4	5.1	3.8
■	11.6	17.2	17.8	14.8	13.5	16.6
=	**39.6**	**54.2**	**54.1**	**53.6**	**55.5**	**60.0**

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

The successful efforts to strengthen the network of IKTS continue. The Fraunhofer Project Center for Energy Storage and Systems in Braunschweig, the new research group in Cottbus, and our participation in the Fraunhofer Center in Portugal form the basis for intensifying our activities with regard to collaborative projects. Required administrative restructuring, however, increases the associated organizational expenses. New procurement directives (German regulation for awarding contracts below the EU threshold – UVgO) and the disparate cost accounting methods of the various funding bodies are a growing challenge. The disparities lead to insecurity when it comes to determining billable costs and financial planning. At the same time, reduced funding rates for Fraunhofer are an additional strain when it comes to developing strategic research topics.

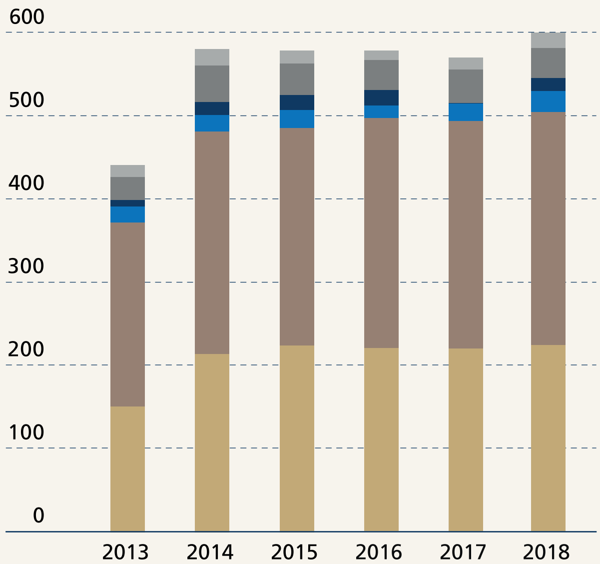
Human resources development

A total of 700 staff members work at the three sites. Owing largely to the strong growth of the Energy business division, we employ almost 30 more full-time equivalents than in 2017. The number of PhD students has increased again, this time by four. It now stands at 25. Nowadays many employees opt for part-time work to be able to put aside enough time for their families or other important matters. Therefore, for better comparability, the different groups are represented as full-time equivalents. Beside 224 scientists, 280 staff members have roles in technical areas. The share of female employees is

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

Personnel developments at Fraunhofer IKTS

Number of employees 2013–2018, full-time equivalents, personnel structure on December 31 of each year



	2013	2014	2015	2016	2017	2018
Apprentices	14	19	15	11	14	18
Student workers, trainees, undergraduate students	28	44	38	36	40	36
Part-time and contract workers	8	16	18	19	1	16
PhD candidates	19	20	21	15	21	25
Employees with university degrees and technicians	223	267	260	276	273	280
Scientists	150	214	223	220	220	224
=	**442**	**580**	**575**	**577**	**569**	**599**

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

38 %; or 27 % when looking just at the scientific positions. It is our declared goal to recruit and promote female management talents.

The number of apprentices has increased by four positions and is now at 18. Also, further training to become a trainer provides employees with attractive opportunities for personal development. In 2018, IKTS has made great strides in systematically planning career opportunities and periods of employment. Human resources development planning is coming to the fore – and not just for our PhD students. Prospects of a specialist career are created in other areas as well. Personal career goals are supported while an open and transparent HR strategy is pursued at the same time. Revised salary options and further training opportunities will be important tools to recruit staff over the coming years.

The support program for refugees was used with success to prepare for university education in Germany or find employment in the technical field. We are very pleased with the broad support the program has received.

The lookout for 2019 is very good overall. Dedicated resources have been allocated to the planned recruitment of new staff.

Extending the research base

Within the classic field of activity of IKTS, the area of additive manufacturing has been broadened as part of our strategy. However, many projects will not be completed before 2019. Special attention is given to new technologies while looking at the economic aspect and the ability of processes to accommodate the production of multiple components. New test methods are being integrated. This will enable us to take on more projects focused on oxide and non-oxide materials, and hardmetal materials. Supported by the Federal State of Thuringia, the Hermsdorf site will receive a synthesis plant for nanopowders, which will open up new possibilities in materials development – from structural ceramics to battery development. The construction of the Powder Synthesis and Extrusion Pilot Center, which will begin with a ground-breaking ceremony in April 2019, will provide ideal conditions for this focus at the Hermsdorf site. Sintering technology capacities in Dresden will be expanded. Unfortunately, current projects are delayed as suppliers are working to capacity. The area of maritime research will be further expanded. Efforts at the Dresden-Klotzsche site focus successfully on the development of novel sensor technology for the monitoring of wind energy converters. At the Dresden-Winterbergstrasse site, new technologies for the production of materials for deep-sea applications are implemented in conjunction with the required manufacturing processes. In Hermsdorf, a test facility for external pressure trials is currently under construction. The topic is being further developed in collaboration with our Fraunhofer sister institutes. The construction work in Braunschweig previously scheduled for 2018 has been postponed to 2019. Energy and environmental technology remains a key topic.

BOARD OF TRUSTEES

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

1 *Meeting of the Board of Trustees at Fraunhofer IKTS in 2018.*

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 26,600 staff are qualified scientists and engineers, who work with an annual research budget of more than 2.5 billion euros. Of this sum, more than 2.1 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.

Fraunhofer locations in Germany

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.

RETROSPECTIVE

Fraunhofer IKTS presented itself at 29 trade fairs in Germany and abroad as well as organized various scientific congresses. Further international networking was also successfully extended.

January 17 | February 12 | April 26 | May 30, 2018

Mini-researchers, junior PhDs and Girls' Day 1

IKTS once again opened its laboratories in 2018 to preschoolers from the "Pfiffikus" kindergarten in Dresden-Striesen and interested 3rd to 5th graders as part of the "Juniordoktor" program. The mini-researchers gained insights into condition monitoring of wind turbines and examined various materials with ultrasound. On Girls' Day, schoolgirls from Holzland High School learned about non-"typically female" apprenticeships at IKTS in Hermsdorf. They made their own ceramic dental prostheses in the lab – from raw material preparation to shaping.

February 15, 2018, Porto, Portugal

Kick-off for new Fraunhofer Center in Portugal

The Portuguese Fundação para a Ciência e a Tecnologia (FCT), the Fraunhofer-Gesellschaft and Fraunhofer Portugal signed a cooperation agreement to establish a Fraunhofer Center for Smart Agriculture and Water Management AWAM - with the active participation of IKTS.

March 13–15, 2018, Cologne

Filtech | Ceramic filtration and separation technology

Clean air, clean water – at Filtech, IKTS presented safe and sustainable solutions to achieve just that: When it comes to the treatment of produced water from oil and gas production, silicon carbide (SiC) membranes are significantly more efficient than conventional membrane filters. Since the manufacturing costs are below 170 €/m², the robust SiC filters are also an attractive solution for mass applications, such as closing the loop from grey water to drinking water.

April 10–13, 2018, Munich

Ceramitec | Technical ceramics for extreme conditions 2

With the ceramic technologies developed at IKTS, extremely robust components for highly stressed environments can be manufactured cost-efficiently: At the world's leading trade fair

1

2

for the ceramic and powder metallurgy sector, IKTS exhibited cast nozzles and bearings made of SiC-bonded diamond materials, which enable maintenance-free operation for more than 30 years. At the special show "Additive Manufacturing", IKTS presented its service portfolio to ceramic manufacturers and plant developers.

April 24–27, 2018, Stuttgart

Control | Non-destructive testing technology

At the world's leading trade fair for quality assurance, IKTS presented the devices of the PCUS® pro family. These ultrasonic systems are developed according to customer specifications for automated and, if required, robot-assisted materials testing in metal processing, railway and automotive construction, power plant and wind power technology.

June 5–7, 2018, Stuttgart

Surface Technology | From coating materials to surface testing

For the first time, IKTS presented its portfolio at the leading international trade fair for surface technology. One focus was on particle suspensions for thermal spraying, which can be used to produce extremely thin, smooth coatings on large-area metal and lightweight components without post-processing. The visitors also gained insight into our non-destructive test methods, which ensure a high surface quality during the coating process.

June 11–15, 2018, Frankfurt on the Main

ACHEMA | Green chemistry made by ceramic electrolysis

The German Energiewende, the effort to transition to renewable types of energy, makes it possible to generate electricity with significantly lower CO_2 emissions. With the aid of electrochemical processes, the electricity generated from renewable sources can be synthesized in basic chemicals. At the heart of these processes are high-temperature ceramic solid oxide fuel cells, developed at IKTS Dresden. Not only do they produce electricity and heat, they are also able to generate hydrogen and synthesis gas for the industry.

June 18–22, 2018, Dresden

International Conference on Inorganic Membranes 1

Innovative developments from the fields of membrane science, technology and application were the center of attention at the 15th International Conference on Inorganic Membranes (ICIM) in Dresden, which for the first time took place in Europe, at the invitation of Fraunhofer IKTS and Forschungszentrum Jülich. 300 international experts from 29 countries informed themselves about research trends and new products in more than 160 lectures and at the accompanying industrial and poster exhibition. At the laboratory workshop at IKTS in Hermsdorf, the participants got insights into the production, testing and application of ceramic membranes.

July 4, 2018

Max Buchner scholarship for young IKTS scientist

IKTS researcher Dr. Adrian Simon was one of 15 young German scientists to receive a Max Buchner fellowship of 10,000 euros. Each year, the DECHEMA Society for Chemical Engineering and Biotechnology awards this prize to research projects in process engineering, biotechnology or chemistry, in which new methods are developed. Simon is developing a process for the production of ultra-thin, highly selective palladium membranes for hydrogen separation. These membranes are also suitable for product preparation in power-to-X processes and for reaction in the production of high-purity fine chemicals.

July 6, 2018, Hermsdorf

Thuringian Minister of Economy Tiefensee visits IKTS 2

On his summer tour through "digital Thuringia" Wolfgang Tiefensee, the Thuringian Minister for Economy, Science and

Digital Society, visited the IKTS in Hermsdorf. During a lab tour, Tiefensee learned about the manufacturing of ceramic tapes. They are the basic material for sensors that supply data on production processes and quality parameters as part of Industry 4.0. In addition to tape casting technology, ceramic battery components, which integrate such sensors, are also being developed at the site. During his visit, the minister also met with representatives of the regional initiative TRIDELTA CAMPUS HERMSDORF e. V.

September 12, 2018, Dresden

Early Morning Science with Fraunhofer | Media talk

For the 5th time, Dresden's Fraunhofer scientists presented a wide range of application-oriented research at the "Early Morning Science with Fraunhofer": from filter systems for aquafarming to lasered and thus low-friction surfaces for the automotive industry, from environmentally friendly aluminum production to intelligent data glasses. Journalists on site – as well as interested persons connected via livestream – used the opportunity for individual interviews. Further press events are planned for 2019.

September 24, 2018, Dresden 3

Visions for future of NDT | Farewell to Prof. Meyendorf

The potentials of non-destructive testing (NDT) in the age of Industry 4.0 were the central topic of the symposium, which took place at IKTS in Dresden-Klotzsche. It was held as an honorary colloquium for Prof. Norbert Meyendorf, who retired on October 1, 2018. From 2004 to the end of 2013, he headed the Dresden branch of the Fraunhofer IZFP, which has been part of the Fraunhofer IKTS since 2014.

October 4, 2018, London, England

German Unity Day 4

On the occasion of the German Unity Day, the Saxon Prime Minister Michael Kretschmer and the German Ambassador in London Dr. Peter Wittig invited numerous guests from politics, culture, business and research to a joint reception in the embassy building. The Free State of Saxony presented itself with a large exhibition to promote Saxon ideas, initiatives and projects. The Saxon Fraunhofer Institutes also presented their latest research activities in London, together with the Saxon universities.

October 8–12, 2018, Berlin

Fraunhofer's tomorrows working worlds 5

In the interactive exhibition "tomorrows working worlds #futurework", the Fraunhofer-Gesellschaft staged working worlds of the future in Berlin. Eight exciting themed areas enabled visitors to experience at first hand visionary work scenarios in the fields of production and health. The leap motion application demonstrating the 3D printing of personalized ceramic bone implants from Fraunhofer IKTS attracted a great deal of attention.

October 14–18, Bilbao, Spain

EuroPM | Harder tools from the 3D printer

Fused filament fabrication is an additive manufacturing process in which complex 3D components are constructed from a melt-processable filament. IKTS develops the filaments individually for each application from ceramic or hardmetal powders and organic binders for use in standard printers. For the first time, IKTS presented at EuroPM, via lectures and the accompanying exhibition, extremely hard components with up to 1700 HV10, which can be printed additively.

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October 22, 2018, Hermsdorf

Thuringian Prime Minister Bodo Ramelow visits IKTS 1

Thuringia's Prime Minister Bodo Ramelow, visited the IKTS in Hermsdorf to learn about current projects in the field of battery development and hydrogen production. Prof. Ingolf Voigt and Prof. Michael Stelter presented the broad research portfolio of IKTS during an extensive lab tour, including Europe's most modern center for tape casting technology. Ramelow was particularly interested in the versatile contribution high-performance ceramics can make to the production of different types of batteries.

October 23–24, 2018, Dresden

Silicon Nitride – a material for top performance

Silicon nitride materials meet the highest reliability requirements even under extreme operating conditions – be it as cutting material, high-temperature component, insulator in microelectronics, medical device or machine component. At the Industry Day, around 50 researchers and industry representatives gathered information on current developments and application potentials of silicon nitride materials. The focus was on new manufacturing processes, component reliability, high-temperature and corrosion resistance, mechanical and tribological properties, optimization of thermal conductivity and electrically conductive composite materials. Seven companies presented their products in the accompanying exhibition.

October 24–26, 2018, Dresden

10th International Symposium on NDT in Aerospace

As first-time hosts of the established international conference series, IKTS invited more than 140 participants to Dresden to discuss current issues around non-destructive testing for aerospace applications. This year's program focused on topics, such as simulation, big data, robotics, and additive manufacturing. In addition to plenary speeches and workshop sessions, the accompanying exhibition was a highlight of the event. As is the tradition, the event ended with a tour of thematically relevant companies in the region, such as Elbe Flugzeugwerke GmbH, IMA Materialforschung und Anwendungstechnik GmbH, as well as Aircraft Maintenance and Engineering Service GmbH (AMTES) in Leipzig. The 11th International Symposium on NDT in Aerospace will take place in France in 2019.

November 14, 2018, Dresden

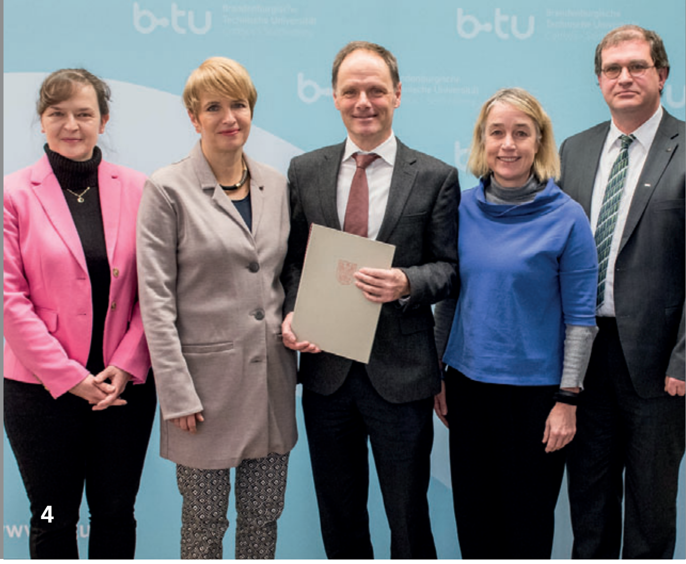
Prof. Michaelis appointed to "Energiebeirat Sachsen" 2

Saxony's Minister of Economic Affairs Martin Dulig has appointed Prof. Alexander Michaelis to the "Energiebeirat Sachsen" for another three years. This energy advisory board is an informal expert committee, whose honorary activity of the currently 22 members aims to advise the Saxon state government in questions of energy policy and to give recommendations.

November 14, 2018, Dresden

CIO-Campus | Innovative water purification technologies

Clean technologies offer opportunities and enable the establishment of new business fields for water purification and water management. On November 14, the CLEANTECH Initiative East Germany (CIO) invited Central German experts from SMEs and science institutions to the Fraunhofer IKTS in Dresden to discuss sustainable solutions for modern water management at the CIO Campus. The issues discussed included energy efficiency, drinking water treatment, waste water as an energy source, and the fourth purification stage. The newly founded CIO working group on water management began its work during the event. Fraunhofer IKTS is a founding member of this working group.



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November 29–30, 2018, Dresden

Hybrid materials and additive manufacturing processes

Around 50 experts from all over Europe came to Dresden in November at the invitation of the Fraunhofer Institutes IKTS and IWS to find out about new additive manufacturing processes for the production of metal, ceramic and hybrid components. In hands-on laboratory workshops, various production devices were demonstrated in operation. With the new processes, highly complex geometries can be produced, and different materials and functional properties (conductive/insulating; dense/porous, etc.) can be combined in one component. In addition, serially produced components can be functionalized (sensors, heaters) and individualized (product labeling) quickly and inexpensively.

December 5, 2018, Jena 3

Ingolf Voigt receives honorary professorship of EAH Jena

On December 5, Dr. Ingolf Voigt was appointed honorary professor of the Ernst Abbe University (EAH) Jena by its president, Prof. Steffen Teichert. The honorary professorship recognizes Voigt's many years of teaching at the university. Since 2010, he has held the lecture "Ceramic Technology" for master students of materials technology in the SciTec department. As site manager of IKTS Hermsdorf, he has supervised numerous students for their qualification work. Voigt is also a member of the EAH Jena University Council. The University of Applied Sciences and IKTS have been cooperating closely for many years – including the education and recruitment of young talents.

December 11, 2018, Munich

IKTS trainee among Fraunhofer's best

IKTS physics laboratory technician Robin Anton is one of the eight best Fraunhofer trainees in 2018. He completed his training with the grade "very good". Fraunhofer Human Resources Director Prof. Alexander Kurz personally honored the laureates at a ceremony on December 11 at the Fraunhofer headquarters in Munich.

January 3, 2019, Cottbus

IKTS research group "Cognitive Material Diagnostics" 4

Right at the beginning of the new year, Brandenburg's Minister of Science Dr. Martina Münch presented Dr. Christian Wunderlich with the grant decision for the new IKTS project group "Cognitive Material Diagnostics" in Cottbus. This Fraunhofer project group develops novel self- learning and intelligent systems for material diagnostics based on artificial intelligence and machine learning. The IKTS know-how on non-destructive testing and the expertise of the Brandenburg University of Technology Cottbus-Senftenberg on artificial intelligence will be combined for this purpose. The Federal State of Brandenburg is supporting the project with 2.6 million euros over a period of five years. The Fraunhofer-Gesellschaft is contributing 1 million euros to the project.

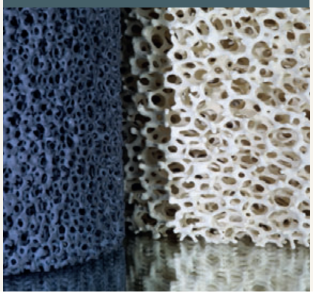
February 7, 2019, Braunschweig

Fraunhofer Project Center ZESS opened in Braunschweig 5

In the presence of Stephan Weil, Prime Minister of Lower Saxony, and Ulrich Markurth, Lord Mayor of the City of Braunschweig, the Fraunhofer Project Center for Energy Storage and Systems ZESS was launched at the Automotive Research Centre Niedersachsen on February 7. The event was followed by a press conference, streamed live to introduce journalists to the ZESS project and selected demonstrators. The Fraunhofer Institutes IKTS, IFAM and IST, in close cooperation with the Technische Universität Braunschweig, are the participating partners. The aim of the project center is to bring mobile and stationary energy storage systems to industrial maturity and demonstrate sustainable solutions with a focus on technology maturity levels four to six.

HIGHLIGHTS FROM OUR BUSINESS DIVISIONS

Materials and Processes

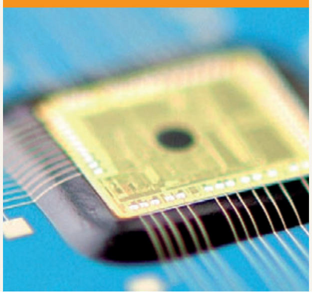


The "Materials and Processes" business division provides a central point of contact for all matters related to development, manufacturing, and qualification of high-performance ceramics for a wide range of applications. A wealth of experience has been accumulated in all relevant materials and technologies,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

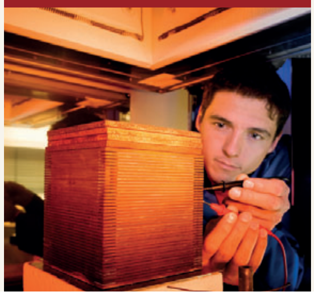
High-performance ceramics are key components in mechanical and automotive engineering. Due to their outstanding properties, they are often the only available options. The "Mechanical and Automotive Engineering" business division offers high-performance ceramic, hard metal, and cermet wear parts and tools 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.

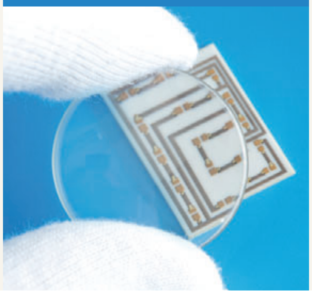
Environmental and Process Engineering

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

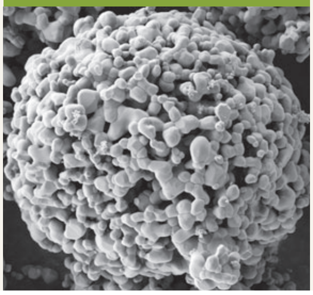
Fraunhofer IKTS makes use of the outstanding properties of ceramic materials to develop dental and endoprosthetic implants and surgical instruments. In well-equipped, certified laboratories, the interactions between biological and synthetic materials are investigated and applied towards the development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

Optics

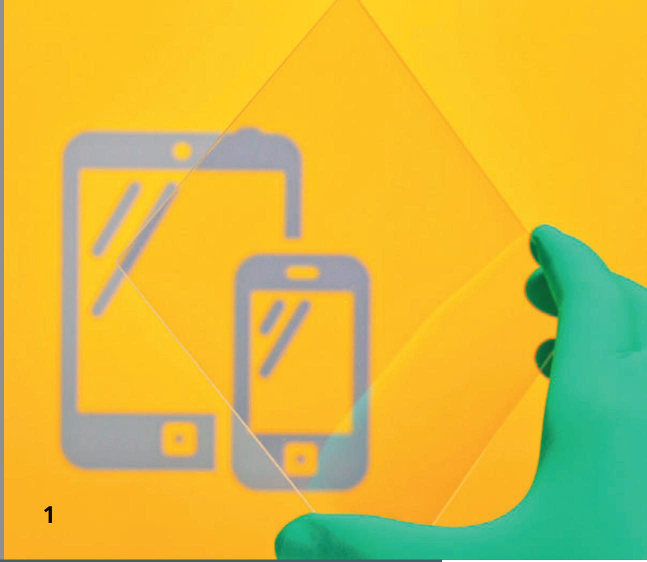


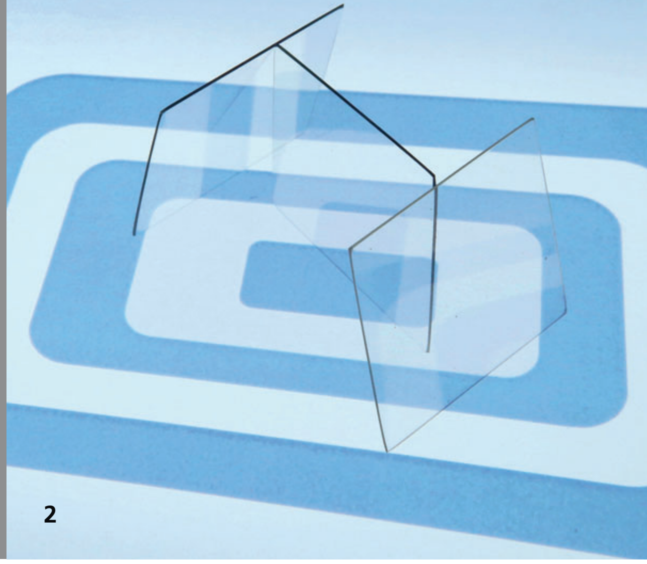
Fraunhofer IKTS develops ceramic materials and components for photonics, lighting applications, and ballistic protection. Phase synthesis combined with materials and technology expertise yields innovative luminescent materials, active optoceramics, optical and decorative elements, and transparent ceramics 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.





ULTRA-THIN TRANSPARENT CERAMICS FOR SCRATCH-RESISTANT DISPLAY COVERS

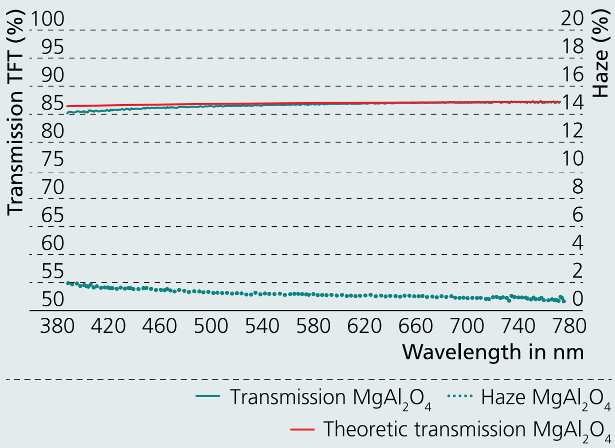
Dipl.-Ing. Thomas Hutzler, Dr. Stefanie Hildebrandt, PD Dr. Lutz-Michael Berger

Whether for industrial applications, medical technology devices, household equipment or in the leisure sector, modern communications technology relies on electronic display and contact elements. Built-in displays with touch-functionality are subject to great mechanical stress not only in industrial environments, but also in every-day consumer applications. Therefore, suitable cover materials should be not just particularly thin but also offer a combination of high optical transparency, scratch resistance and mechanical stability. Transparent spinel ceramics meet all these requirements in an outstanding manner.

The manufacturing of planar transparent spinel parts with thicknesses above 2 mm using uniaxial pressing is already well-established in industrial manufacturing. However, larger and thinner plates, which are near their finish thickness, geometrically accurate and very planar, could up to now be manufactured only in a time- and cost-consuming finishing post-sintering treatment.

Within an internal Fraunhofer project, MAVO CeGlaFlex, it was possible to adapt the technological steps of powder processing, shaping, and sintering so that planar green bodies with a maximum length of 160 mm in one direction and thicknesses below 1 mm can be prepared as early as during the primary forming process, using uniaxial and cold-isostatic pressing. A multi-step sintering procedure results in high-density transparent parts with a maximum length of 110 mm in one direction, and a thickness between 0.5 and 0.8 mm. A comparatively small effort is then required to get to the necessary final thickness of 0.1–0.4 mm for covers, e.g. for smartphones. Double-sided grinding, lapping and polishing provides these transparent plates with high optical transmission near the theoretical limit, and a low haze below 2 % (diagram).

Optical transmission und haze of a thin spinel ceramic plate with a thickness of 0.4 mm



Thanks to the fine-grained and defect-free microstructure, the transparent spinel ceramics have a hardness of HV10 = 14.5 GPa, exceptionally high scratch resistance and sufficiently high mechanical stability (bending strength of about 280 MPa) for use in display covers.

1 *Spinel ceramic plate with a thickness of 0.8 mm.*

2 *Spinel ceramic plate with a thickness of 0.4 mm.*

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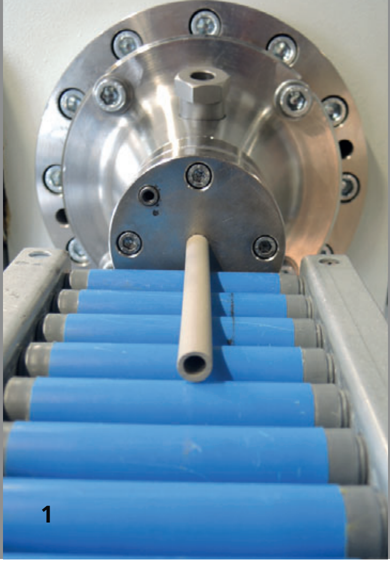

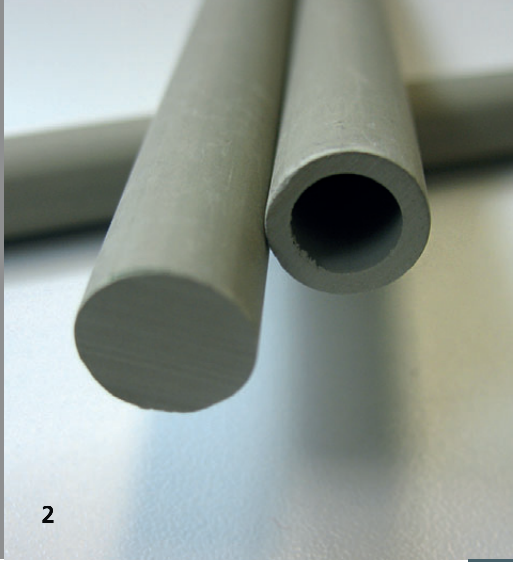

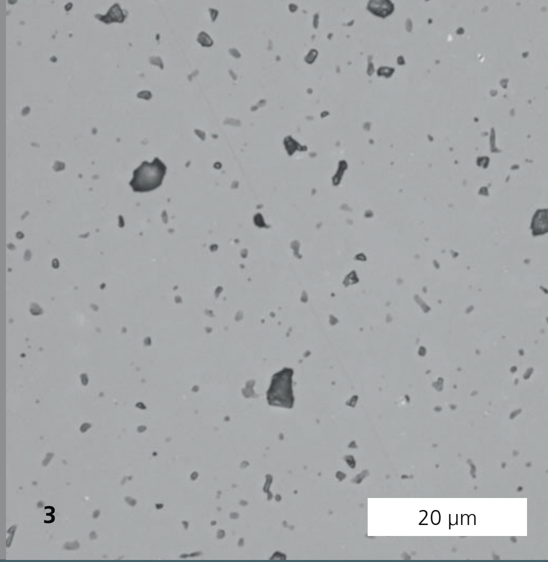

EXTRUDED COMPONENTS MADE OF HIGH-DENSITY SILICON CARBIDE (SSiC)

Dr. Alexander Füssel, Dr. Hans-Jürgen Richter, Dipl.-Ing. (FH) Kim Mazitschek, Dipl.-Krist. Jörg Adler

Silicon carbide sintered in a pressureless process (SSiC) can have sintered densities of up to 98 %. Due to its monophasic structure and purity, SSiC is characterized by a better high-temperature stability and corrosion resistance compared with more traditional SiC materials, such as RSiC, SiSiC, LPS-SiC and NSiC.

Up to now, SSiC components have been produced predominantly through uniaxial or isostatic pressing, which has its limitations regarding possible shapes. Long and filigree profiles with a constant cross section, such as rods, tubes and honeycombs, can only be realized by extrusion which, up to now, has not been available for SSiC, or has been possible only with significant quality losses regarding density and mechanical strength. Challenges in handling the ceramic extrusion compound are the primary reason for this situation. The compounds have to contain fine, submicron powders in combination with comparatively high amounts of binders and process aids, resulting in relatively low green densities in the extruded parts. In addition, the necessary sintering aids – boron and carbon – have to be dosed accurately and distributed homogeneously within the compound. Since established additives, such as black carbon or resins, impede the dispersion and, ultimately, the shaping, they are less suited for this kind of shaping. Furthermore, the crack-free drying and the pyrolysis and sintering processes prove to be very demanding, too. It is necessary to facilitate a linear sintering shrinkage of up to 20 % in order to prevent deformation or even the creation of defects.

As part of a feasibility study at Fraunhofer IKTS, a cold-plastic compound for the SSiC processing was developed. As a result, the extrusion of various geometries, such as rods, tubes and honeycombs, was successfully demonstrated. The SiC particle size and the inserted additives were chosen to attain good processability with low wear on the die and high green density in the extruded parts. The organic binders have been adapted in order to reach a high concentration of well-dispersed carbon after the pyrolysis.

Within the scope of this study, test parts with densities up to 96 % of theoretical density and a linear shrinkage of up to 17 %, were prepared through pressureless sintering. Based on the results achieved, even higher densification might be possible by further modifying the cold-plastic compound composition and adapting the process parameters.

Services offered

- Development and optimization of cold-plastic compounds for the production of SSiC extrudates
- Application-related design and development of extrudable SSiC components

1 *Extrusion of the cold-plastic compound.*
2 *Sintered SSiC components.*
3 *Microstructure of an extruded SSiC tube.*

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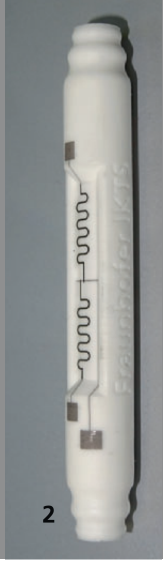

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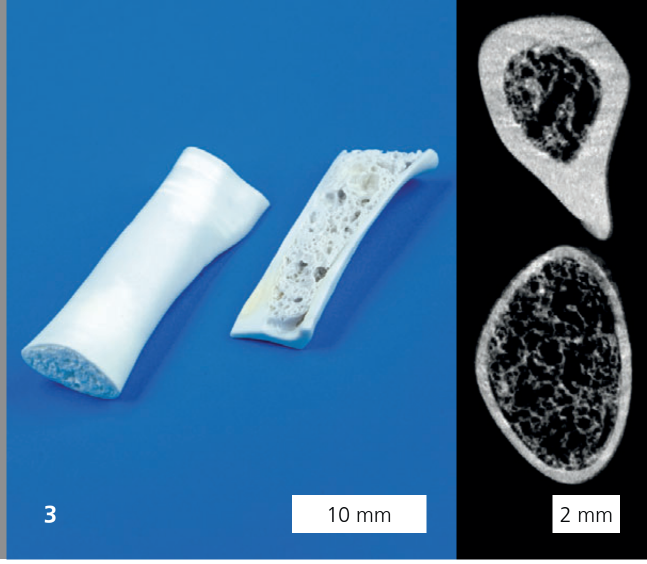

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HYBRID PROCESSES: TAKING ADVANTAGE FROM MANUFACTURING METHODS

Dipl.-Ing. Steven Weingarten, Dipl.-Ing. Johannes Abel, Dipl.-Ing. Uwe Scheithauer,
Dipl.-Ing. Eric Schwarzer, Dipl.-Ing. Axel Müller-Köhn, Dr. Matthias Ahlhelm, Dr. Tassilo Moritz

Few manufacturing methods have grown as fast in recent years as additive manufacturing. Fraunhofer IKTS develops additive manufacturing methods and adapts them to be suitable for the 3D printing of ceramic materials. Efforts currently focus on the production of multi-functionalized components.

The thermoplastic processes of CerAM-FFF (Fused Filament Fabrication) and CerAM-T3DP (Thermoplastic 3D Printing) were developed at IKTS. These methods allow to achieve highly complex geometries with varying structural properties, as well as co-manufacturing by combining different complementary materials within one layer. The materials are deposited only where they are required, meaning that no additional tools are needed and less material is required. In accordance with client requirements, material systems can also be characterized and developed for multi-component printing. By combining additive manufacturing with conventional and industrially well-established manufacturing processes, the advantages of each individual process are used to better effect. Functionalized and individualized components or component series can be created cost-efficiently.

As part of the CerAMfacturing (EU, GA 678503) and Addimat (ZIM, ZF 4076417EB6) projects, components produced using ceramic injection molding (HP-CIM and LP-CIM) were individualized afterwards by means of the additive manufacturing processes CerAM-FFF and CerAM-T3DP (Figure 1). A green body, produced by ceramic injection molding, was later supplemented by an individual structure using additive manufacturing. The hybrid component was then debinded and sintered. Thus, it is possible to retroactively modify bulky bodies produced by ceramic injection molding with a functionalized material or to individually mark these components. By combining different manufacturing methods, electrically conductive and insulating properties (Figure 2 – CerAM-VPP | aerosol-printing) can be realized within a component in a cost-effective and quick manner. Furthermore, dense-porous structural hybrids (Figure 3 – CerAM VPP | freeze foaming) can be manufactured as potential bone replacement materials. CerAM VPP technology (VAT photopolymerization) is suitable for producing such complex, highly structured and small ceramic components with very good surface properties. It is based on the hardening of light-sensitive suspensions by selective irradiation with light. The project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement No 678503.

Services offered

- Suspension, filament as well as feedstock development for multi-material applications
- Technology development and transfer based on additive manufacturing processes or process hybrids

Europäische Union

cerAMfacturing

1 *Base plate made with LP-CIM, individualized by CerAM VPP.*
2 *Additively manufactured flow sensor functionalized by aerosol printing.*
3 *Artificial hip implant made by CerAM VPP and freeze foaming.*

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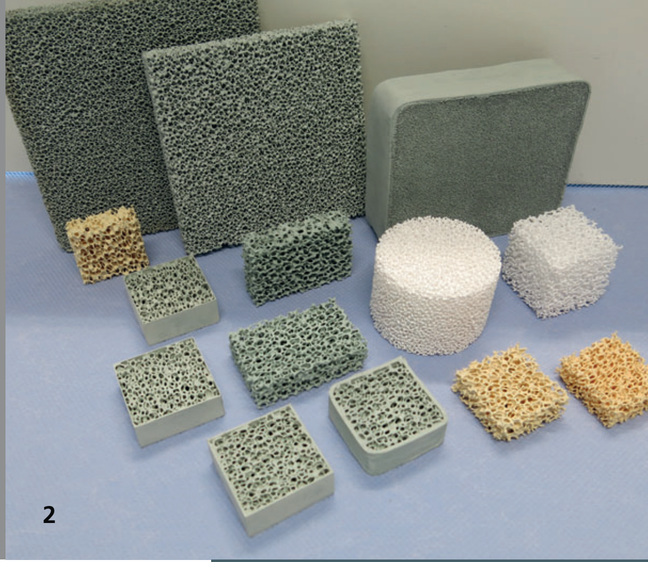


INDUSTRY-ORIENTED CONTINUOUS MANUFACTURING OF CERAMIC FOAM

Dipl.-Ing. Gisela Standke, Dr. Alexander Füssel, Dipl.-Krist. Jörg Adler

Ceramic foams are usually manufactured on continuously working rolling mills using Schwartzwalder replica technique. Testing changes in the recipes of ceramic suspensions in operation are very challenging due to the associated efforts (production stop, cleaning, change-over, rejects). At the same time, slurries and system parameters optimized in the laboratory can only be partly transferred to the real conditions of industrial rolling mills.

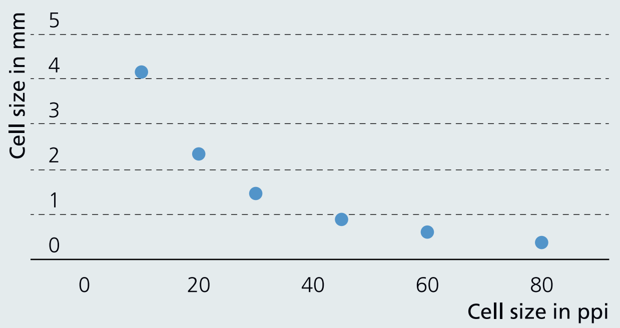
For this reason, Fraunhofer IKTS has developed and implemented a new continuously working coating line for foams in its technological center. It is designed for research purposes for the transfer from lab scale to mass production and has a high degree of freedom for adjustments. It consists of three freely combinable units:

- **Impregnation unit**: slurry impregnation of the foam via exchangeable rolls with structured or specially prepared surfaces
- **Homogenization unit**: squeezing out of surplus material and setting to open or closed side walls
- **Spray unit**: reinforcement of the external foam surface by spraying slurries onto coated green bodies or applying functional coatings after sintering

The coating plant in pilot scale is designed for lateral foam sizes of 200 x 200 mm² and variable height. The plant's high effectiveness is particularly noteworthy: Depending on the geometry, up to 60 specimens can be manufactured per hour.

Thanks to the excellent infrastructure of intensive mixers to support the new equipment, the significantly larger slurry amounts needed can be produced and provided with a very high standard of mixing and storage quality. Subsequently, slurry properties will be investigated intensively with scientific and application-oriented specifications in order to adapt production conditions and provide partners with characteristic parameters for production and quality assurance. This is based on the long years of experience of IKTS in the development and manufacturing of highly filled slurries for foam manufacturing, including new oxide and non-oxide ceramic materials. The production of ferrous and non-ferrous metal slurries, which can be manufactured by replica technique as well, is another capability provided.

Foam cell sizes and related ppi values



Services offered

- Development, optimization, testing of slurries for continuous foam coating
- Adaptation of coating technique to specific filter designs, i.e. lateral frames
- Consulting and support for the setup of foam coating plants

1 *Coating plant in operation.*
2 *Ceramic foam parts.*

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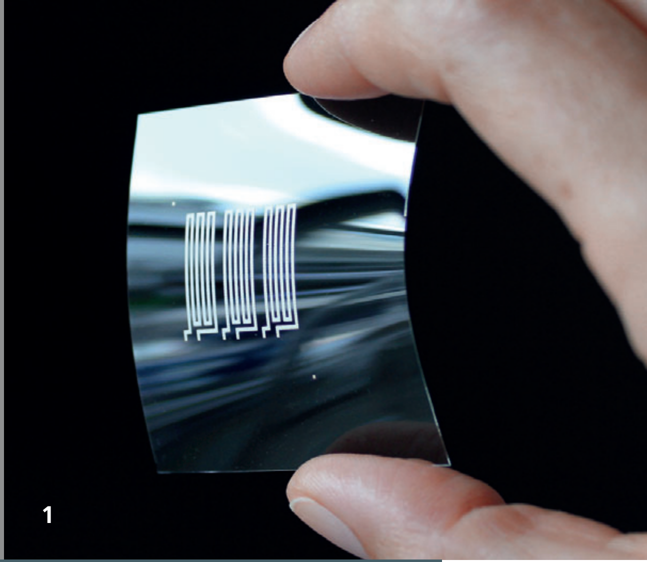

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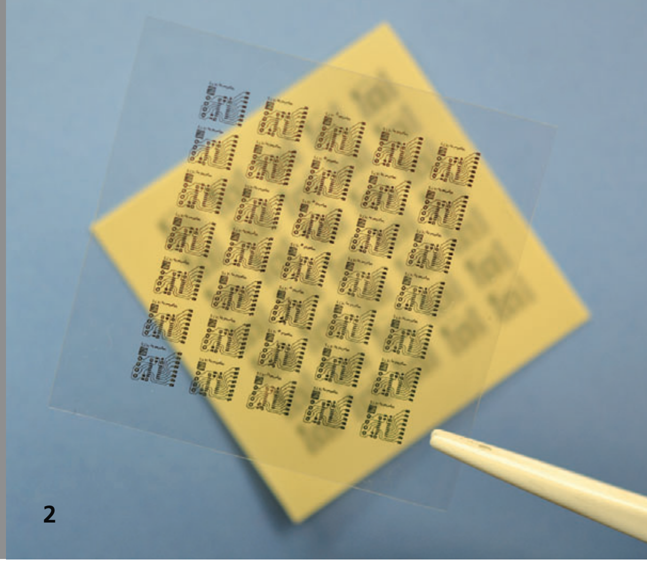


2

INKS AND PASTES FOR FUNCTIONAL LAYERS

Dr. Sindy Mosch, Dr. Stefan Körner

Functional layers are often printed on ceramic 2D substrates. Thin glass and polymer tapes or papers are increasingly used as carrier material as well. Examples of such applications are touch displays, RFID tags, strain gauges, chemical and physical sensors or measuring bridges. The printing methods – both digital and mask-based – now offer high resolution, which enables miniaturization of the functional layers not only on the 2D substrates but also on 3D structures.

Materials selection and preparation as basis

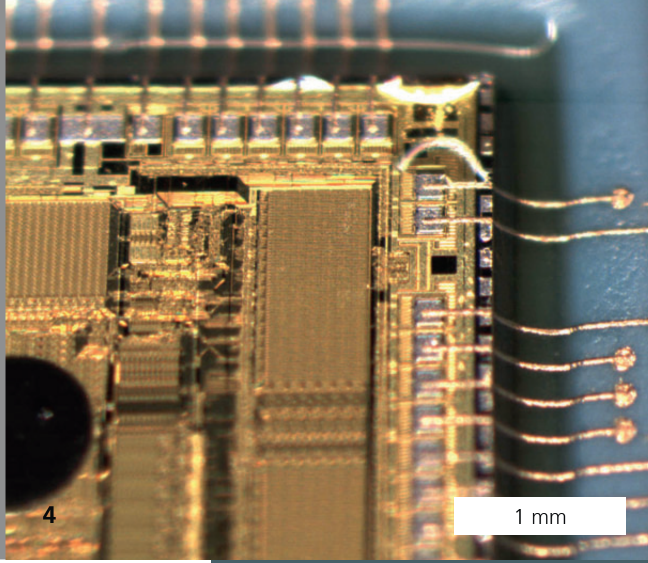
In order to optimally adapt functional layers to their application, Fraunhofer IKTS has decades of experience on inorganic powders and with regard to selecting the organic components (solvents, polymers, additives). The inorganic basic components of suspensions used for printing can consist of various materials classes, ranging from ceramic to metal oxides or even noble metal powders and types of glass. At Fraunhofer IKTS, different routes for adapting particles to their respective application are available. For functional inks, noble metal nanoparticles are synthesized directly at IKTS. For synthesis of gold, platinum, silver and others, the particles of these metals are influenced in a targeted way. Another approach consists in crushing powders to precise particle sizes through high-energy grinding, using disk mills or jaw crushers for coarse (up to the mm range), planetary ball mills for medium-range (up to 100 µm) and agitator bead mills for fine (up to 5 µm) powders. The achievable particle sizes of about 500 nm can be used in both functional inks for inkjet or aerosol-jet printing and pastes. In order to apply paste-like suspensions by screen or mask printing, (micro-)dispensing, jet-dispensing and roll coating, much coarser particles (up to 75 µm) are milled and processed.

Suitable organic composition

The organic components for the suspension are selected depending on substrate material, firing technology, final layer geometry and characteristics. Polymers are dissolved in various solvents in order to attain precisely the properties needed for the selected printing method. Thus, it is possible to adapt the viscosity from 1 to 100 000 Pa*s depending on the shear rate from 0.01 to 100.000 s^{-1}. The organic composition required for dispersion is chosen based on a comprehensive data matrix developed experimentally at IKTS. This matrix includes information on viscosity, evaporation rate and wetting behavior. For functional inks, the main aspects for polymer selection are wetting behavior and adhesion with a view to retaining good adhesive properties directly after drying. Polymers for pastes are selected according to the intended error-free printing image and geometric factors, for example high aspect ratios. Another aspect of the polymer composition concerns the firing conditions and subsequent use of the printed structure: If the firing is done under an inert atmosphere or at especially low temperatures, different polymers are selected than with applications where the polymers are supposed to remain in the printed layer (i.e. when electronics are printed onto flexible substrates). Furthermore, additives are used in the suspension to stabilize the particles and influence printability.

Preparation of the suspension

The main step of suspension preparation is the dispersion of the selected materials in the organic or water-based printing vehicle. In the process, the agglomerates existing in the powder



are broken up, the different inorganic components are homogenously mixed, solids are wetted with the organic printing stock and the final viscosity is adjusted with additives. Depending on the suspension content, application, solid content and application technique, Fraunhofer IKTS has different pieces of equipment at hand: dissolvers, bead mills, mortar grinder, three-roll mills, agitator bead mills and centrifugal mixers. The quality of a dispersed suspension becomes apparent in the long-term behavior with respect to the segregation of the inorganic components of the printing vehicle and their sedimentation.

Characterization through all process steps

At Fraunhofer IKTS, all process steps from the powder to the printed functional layer are extensively characterized, starting with the particle size distribution, form and specific surface of the materials used, and followed by the rheological properties, which are determined using suitable measuring instruments (conventional cone-plate rheometer, capillary rheometer, cylinder-cup setup for inks). The rheological measurements allow conclusions about both viscosity and shelf life, as well as levelling properties.

The wetting of the substrate surface and the dripping behavior of inks from the printing nozzle are characterized depending on the temperature. Additionally, printability is tested with special test structures. For functional inks, printing width and applied layer thickness are determined. For functional pastes, analysis is performed on specific test structures focusing on line-space ratio, aspect ratios of the printed layers, minimum line widths as well as the homogeneity of solid areas and levelling properties.

Finally, the applied functional layers are also comprehensively characterized. Various test methods are available for this purpose, ranging from the cross-cut or wire-peel test (layer adhesion), to the white light interferometer (layer geometry), scanning electron microscopy (layer composite) and electrical/electrochemical characterization.

360° service for the development of functional inks and pastes

With these competencies, Fraunhofer IKTS covers the entire range of development for functional inks and pastes for various applications: from the selection or synthesis of the basic materials through the adjustment of specific properties, the selection of the organic composition, to the preparation of the suspension, adapted to the suitable printing method. The characteristics of the individual components of ink and paste up to the finished functional layer are constantly monitored throughout this process.

1 *Functionalized thin glass for flexible electronics applications.*
2 *Inkjet-printed interdigital sensors on planar substrates.*
3 *Inkjet-printed contacting on textile.*
4 *3D chip bonding with gold ink.*

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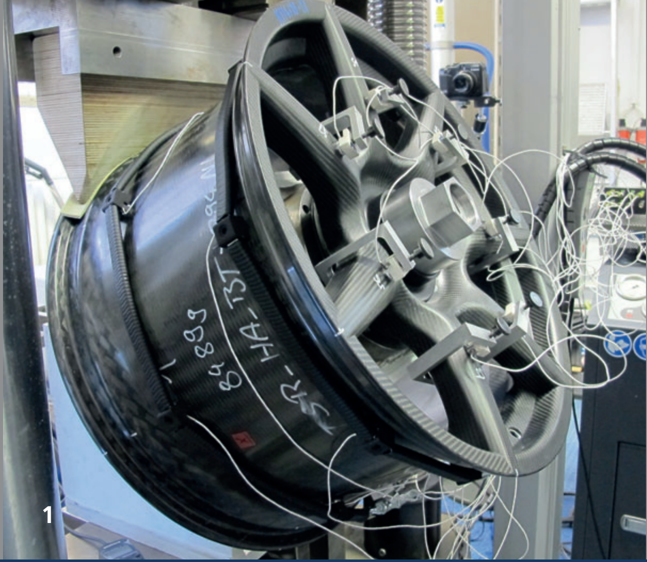

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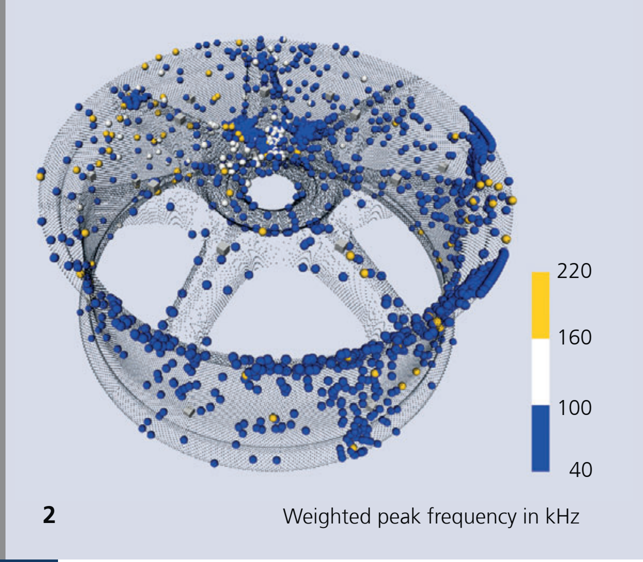

2

ACOUSTIC EMISSION TESTING ON COMPOSITE STRUCTURES FOR DAMAGE DETECTION

Dr. Lars Schubert

Fiber-reinforced plastics (FRP) have become an indispensable part of modern vehicle manufacturing. The reliability of these materials is paramount, especially when it comes to safety-relevant components. The service life of FRP components is affected by aging processes or improper use. Damages such as fissures in the matrix, delamination, or fiber breakage can lead to component failure.

Non-destructive testing using acoustic emissions

Acoustic emission testing (AT) is a non-destructive method for component testing. The principle is based on detecting acoustic signals at the surface of solids when energy is released under stress in the form of an elastic wave. Acoustic emission testing differs from conventional ultrasonic testing significantly since the acoustic emission is initiated by the actual damage within the material – the damage itself is the acoustic emission source.

The results of testing on the coupon level showed clusters in the parametric space from the weighted peak frequency (WPF) and the partial sound power in a specific frequency range. This allows for the determination of the acoustic emission parameter, which provides information on the type of damage, its progress and therefore also on the structural integrity of the tested material samples.

The attenuation effect needs to be taken into account when interpreting acoustic emission signals from the fatigue testing of complete components, in particular regarding to the frequency analysis. As the distance from the acoustic emission source to the acoustic sensor grows, the attenuation of high-frequency signal parts increases as well and therefore needs to be taken into account. For component testing, two different cluster areas of the WPF point to different mechanisms of damage: low-frequency acoustic events indicate matrix-dominated mechanisms of damage (events marked blue in Figure 2), while high-frequency burst signals point to fiber-dominated mechanisms of damage (events marked yellow in Figure 2).

Measurements at high ambient noise levels

The acoustic emission testing system developed at Fraunhofer IKTS allows for AT measurements using specially adapted measuring and analysis software – even under high ambient noise levels, e.g. in the case of dynamic fatigue testing. For instance, AT was able to successfully identify damages in a bending fatigue test.

1 *Lightweight wheel equipped with acoustic emission sensors during quasi-static fatigue test on a universal testing machine.*
2 *Carbon fiber lightweight wheel: 3D location plot of the acoustic emissions during bending fatigue test.*

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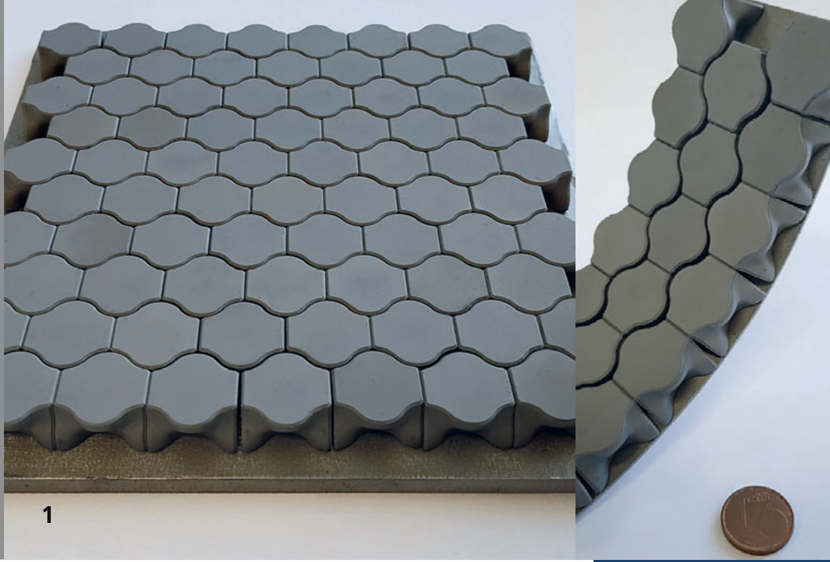

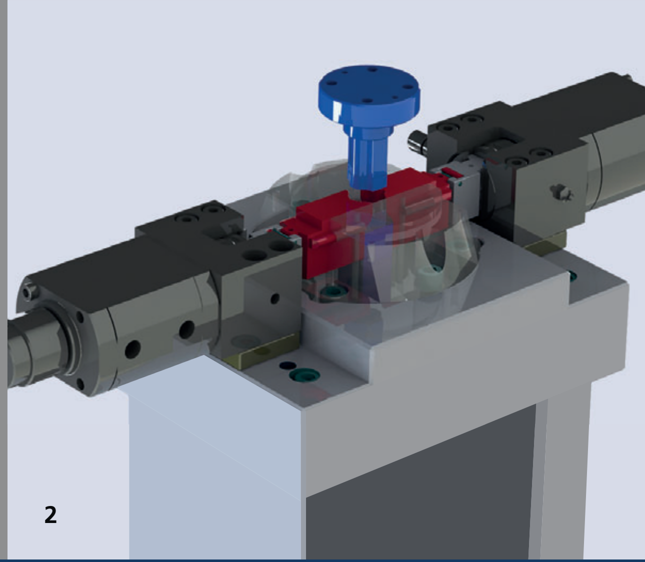

DUCTILE 3D CERAMIC ARMORING FOR NEW PROTECTION CONCEPTS – DuktAr

Dipl.-Krist. Jörg Adler, Dr. Steffen Kunze, Dipl.-Ing. Jens Stockmann, Dipl.-Ing. Sven Roszeitis, Dipl.-Ing. Gisela Standke

Today, protection methods for high dynamically stressed components in mechanical, plant and automotive engineering involve either high weight (metals) or limited formability (ceramics). Currently, no composite material exists which combines the excellent properties of both material groups, such as maximal strength with good ductility.

With the new ceramic components developed at Fraunhofer IKTS, in combination with cost-efficient brazing or bonding technologies, complex steel surfaces can be equipped now with ductile ceramic armoring (DuktAr), and thus innovative 3D protection methods can be realized. These methods can be implemented, for instance, in protective devices of centrifuges, rotors, recycling plants, or in high-speed cutting. With their unique geometry, the ceramic components are particularly advantageous, since they can be assembled to areas of variable sizes, very much like puzzle pieces, thus maximizing the freedom of design.

In addition to developing a suitable ceramic-compatible geometric design, IKTS has established a novel pressing technology, in which the DuktAr parts can be manufactured in one single step – cost-efficiently and without the need for subsequent mechanical machining. A new pressing die was developed for this purpose, which was integrated into an existing pressing device. Contrary to classic setups with vertical punches, the new tool includes two additional horizontal cross punches. They are positioned at an angle of 180° where their surfaces map the needed 3D contour. The cross punches operate hydraulically. During the manufacturing of the pressing parts, the punches are in the front position, forming a closed polygon course with the die. Then they move to the rear position to expose and remove the pieces. The automatic mode allows to produce 5–10 pieces per minute. So far, component series made of silicon carbide and alumina were pressed and sintered using this technology. The finished DuktAr pieces were then brazed or bonded on the metal sheet surface. Subsequently, their shear strength was measured to evaluate the composite quality. Soft solder joints reached values of 18 MPa, adhesive bonds even 40 MPa.

Services offered

- Development and manufacturing of 3D ceramic parts made of different ceramic materials for the reinforcement of metal surfaces as protective lining
- Development of joining technologies for metals and ceramics by brazing or bonding
- Manufacturing of prototype parts

The “DuktAr” project (funding number 601 039) was funded by an internal Fraunhofer program.

1 *Prototypes of armored metal sheets with “DuktAr” ceramic.*
2 *Schematic view of the newly designed pressing tool.*

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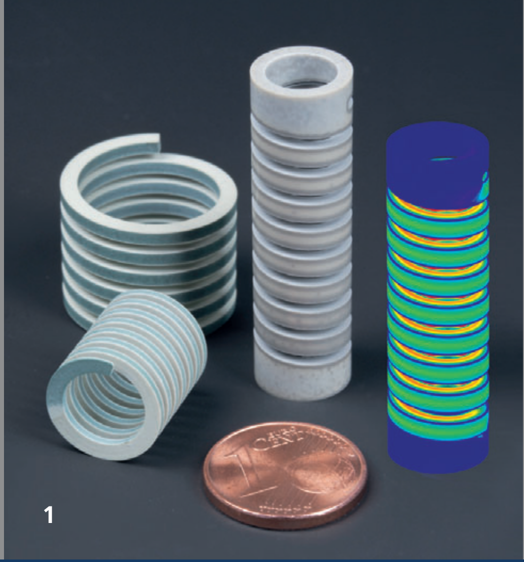

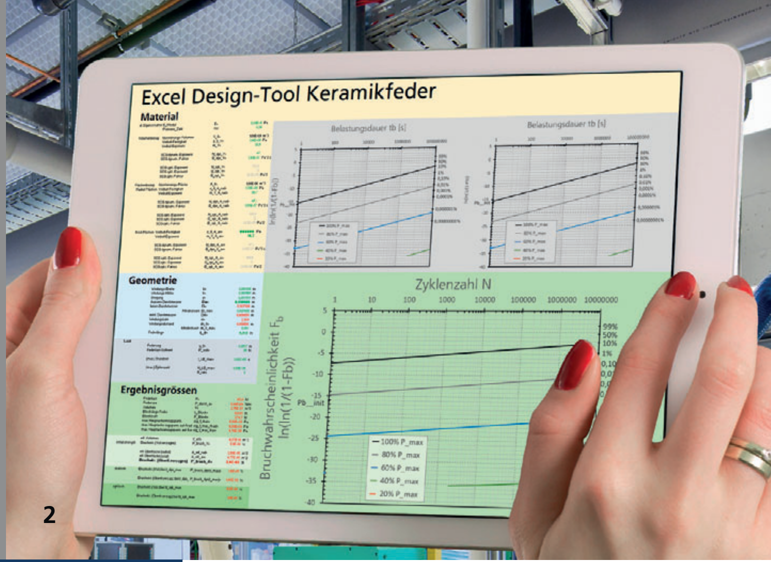

DESIGN, MANUFACTURE, AND RELIABILITY ASSESSMENT OF CERAMIC SPRINGS

Dr. Wieland Beckert, Dipl.-Ing. Jens Stockmann

Continuous progress in ceramic technology and materials provides opportunities for the manufacturing of ceramic spring elements, such as compression springs or disc springs. Compared to standard spring materials, excellent thermal, chemical, and tribological durability and the amagnetic characteristics of the ceramic material offer promising potential for specific high-load applications, such as in medical technologies, high-temperature plants, or in chemically aggressive media.

However, the current lack of experience in design, manufacturing, and use has so far effectively been a barrier for the more widespread use of ceramic spring elements. Due to manufacturing-related design adaptations (rectangular material cross section) and brittle material characteristics, standardized design procedures used for metallic springs cannot be adopted for ceramic compression springs. New design approaches need to be established, for instance for the load support at the spring ends.

As part of the AiF-funded project EndurSpring (IGF project no.: 19125 BG), extensive experimental and theoretical investigations on ceramic compression springs (Fraunhofer IKTS) and disc springs (Fraunhofer IWM) were carried out in cooperation with the Verband der Deutschen Federnindustrie e. V. (the Association of German Spring Industry). This work involved developing and verifying design tools, optimizing material and technology, devising methods for testing components and materials under operating conditions, and manufacturing prototypes.

A particular challenge with regard to the design of ceramic components is the requirement to apply statistical approaches (Weibull statistics) and consider defect evolution (subcritical crack growth, "SCG") in order to estimate failure probability and lifetime. An essential factor in the analysis is the experimental characterization of the needed Weibull- and SCG parameters, which have to be obtained from elaborate statistical experimental test campaigns under near-operational conditions.

At Fraunhofer IKTS, the favored spring material variants (Si_3N_4, ZrO_2) were experimentally characterized under stationary, dynamic, and cyclical loads, at room temperature and at 1000 °C and for a practical range of different machining quality levels of the ceramic material (green state milled, white processed and polished), using a four-point bending test. Based on the real data sets thus obtained, design tools were developed for the initial dimensioning (Excel-based) and fine dimensioning (FEM-based) of ceramic compression springs; these tools were verified according to the methodology of statistical reliability evaluation.

The experience and competence in statistical reliability validation enhanced through this specific work can also be used for the design of other ceramic components and therefore represent a valuable extension of the methodological portfolio of IKTS.

Forschungsnetzwerk Mittelstand

1 *Example of spring prototypes and FEM analysis.*

2 *Excel tool: Result sheet showing parameters of the life cycle analysis for an example spring under cyclic loading.*

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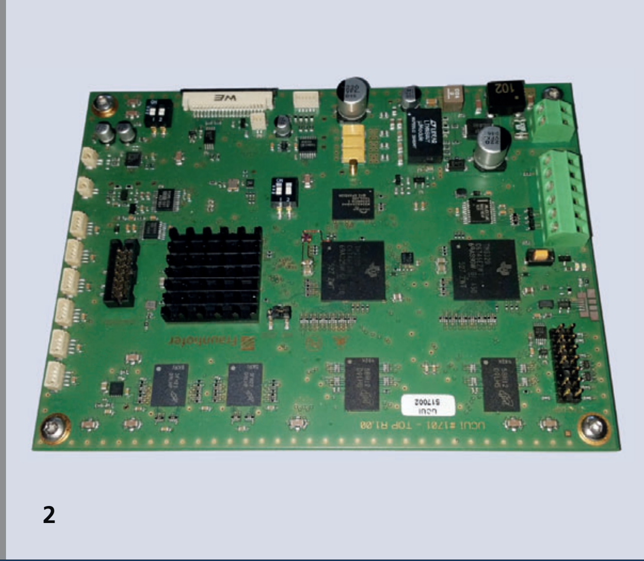

2

UNIVERSAL COGNITIVE USER INTERFACE FOR DEVICE CONTROL

Dr. Constanze Tschöpe, Dr. Frank Duckhorn, Dipl.-Ing. (FH) Christian Richter, Dipl.-Ing. (FH) Peter Blüthgen

The universal cognitive user interface (UCUI) enables intelligent and intuitive control of devices via various communication channels, such as speech, gestures or touch.

Self-learning system fulfils highest requirements regarding data protection

The Fraunhofer IKTS system learns the individual user behavior and has the advantage that it requires neither an internet connection nor a wireless network to operate. Data are only stored on the device and are not transferred to external servers or a cloud of third-party providers, which guarantees absolute data security. A connection to other UCUI devices is possible only via an encrypted wireless network.

The implemented behavior control is based on feature-value relations and is, therefore, capable of handling the meanings of user input from different sources and in different ways, identifying missing information and computing queries to the user. This allows even utterances or inputs without direct meaning to be interpreted correctly.

Manifold potential applications for human-machine or human-computer interaction

The system is interesting for many applications: not only in industrial practice, but also in private environments (smart home) or for medical applications (for instance, voice control for operating devices during surgery).

It can be used to operate any device thanks to a standardized interface. Figure 1 shows an application for heating control systems. The system is able to adjust the heating with minimal effort, adapting perfectly to user requirements merely through user interaction and by learning user behavior.

Fraunhofer IKTS has developed the hardware (Figure 2) and algorithms for speech recognition and synthesis, which were implemented in digital signal processors (DSP) and field programmable gate arrays (FPGA).

We thank our project partners – the Chairs of Communications Engineering and Applied Media Studies of Brandenburg University of Technology (Cottbus-Senftenberg), Innotec21 GmbH, Javox Solutions GmbH, Agilion GmbH, and XGraphic Ingenieurgesellschaft mbH – for their collaboration, and the German Federal Ministry of Education and Research (BMBF) and VDI/VDE Innovation + Technik GmbH for their financial support (grant no. 16SV7305K).

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1 Example: Demonstrator for a heating control system.

2 Printed circuit board for the cognitive user interface.

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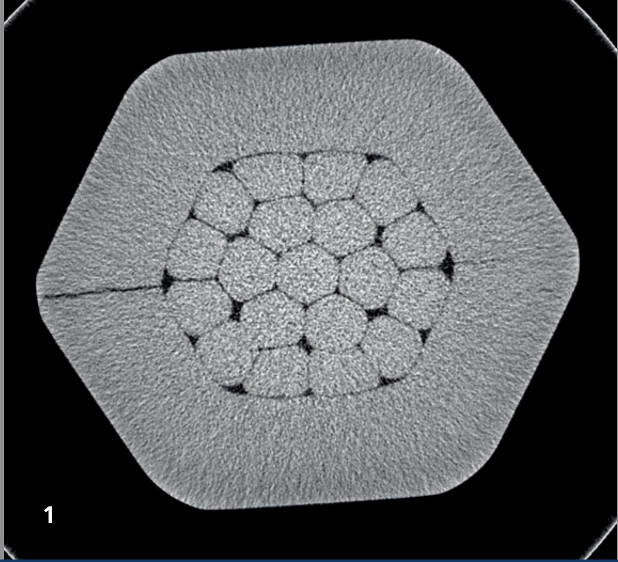


ULTRASOUND TEST SYSTEM OF TENSION-PROOF CRIMP CONNECTORS ON CATENARIES

Dr. Thomas Herzog, Dipl.-Ing. Susan Walter, M. Sc. Jürgen Michauk, Dipl.-Inf. (FH) Stephan Heilmann, Prof. Dr. Henning Heuer

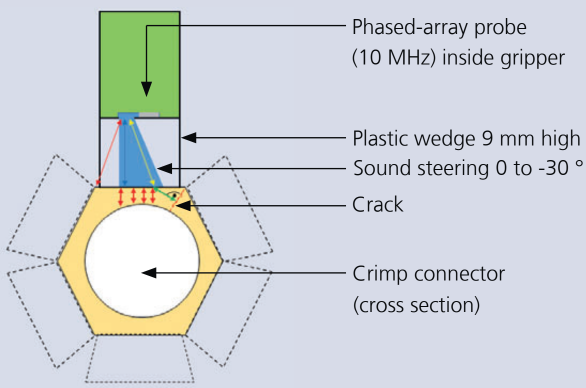
In electric railway technology, contact wires are mechanically and electrically connected to each other via tension-proof crimp connectors made of copper-containing alloys. The connectors must permanently sustain static tensile forces of up to 10.8 kN, withstand the dynamic vibration load caused by passing trains, and guarantee a service life of 30 years under the harsh, climatic conditions at the place of use.

In addition, the electric current needs to be guided safely and reliably without the connection heating up excessively. Consequently, after pressing the copper sleeve to a hexagonal cross section and mechanically fixing the cable ends inside, the electrical connection resistance must be as low as possible. This means that a very good electrical contact must be achieved when pressing the copper sleeves, which must not be allowed to increase excessively over time due to relaxation of the materials, cracking or chemical environmental reactions. The mechanical hold must not be endangered either.

Until recently, the only way to inspect these crimped connections has been visually, from the outside. Only where the crack has grown to the outside, through the cross section (Figure 1), can it be detected as a potential connector failure. Now, for the first time, a test system using ultrasound developed and successfully tested in the field by IKTS makes it possible to detect cracks as they form. By means of a test gripper (Figure 2), which is adapted to the hexagonal cross section of the crimp connector, an ultrasound probe is pressed onto the crimped surface. The ultrasound signals are controlled with the PCUS® pro Array ultrasonic electronic system developed at IKTS, and guided into the side of the press connector at 0 to 30 degrees to one side and 0 to -30 degrees to the other side. This directs the sound waves directly to the inner cracks and generates reflected echo signals. These echoes reach back to the test probe, indicating the presence of cracks. Crimp connectors found to be at risk of failure can now be detected in good time and replaced accordingly during the inspection.

The system has been successfully evaluated in the field as a prototype. In the future, it will be extended by integrating six ultrasonic probes in the gripper, making it possible to test complete crimp connectors without moving the gripper around.

Principle of measurement



1 *X-ray image of crimp connector (cross section).*

2 *Testing gripper and defect, removed connectors.*

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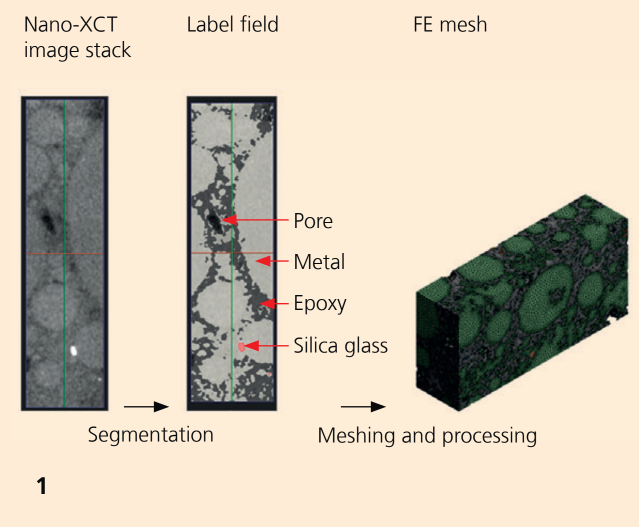

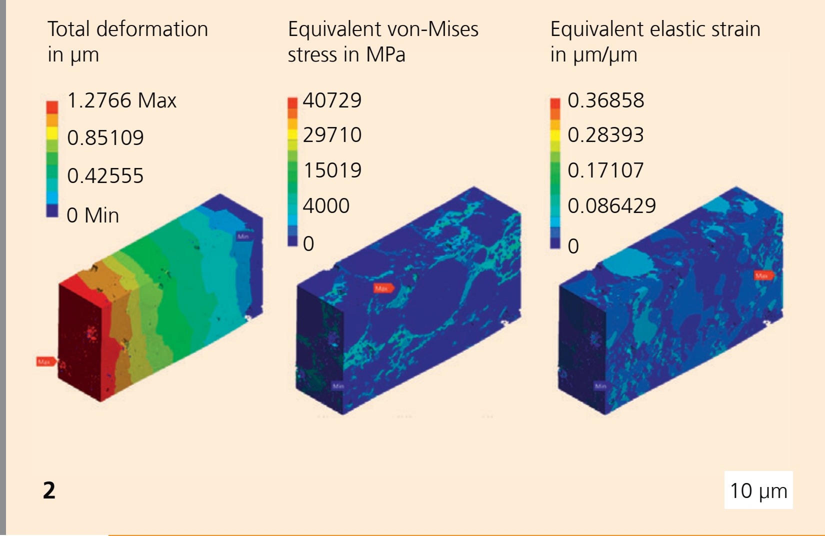

FINITE ELEMENT SIMULATION OF CHIP MOLDING COMPOUNDS BASED ON NANO-XCT DATA

M. Sc. Emre Topal (TU Dresden), Dr. André Clausner, Dr. Jürgen Gluch, Dr. Markus Löffler (TU Dresden), Prof. Dr. Ehrenfried Zschech

X-ray computed tomography (XCT) is a non-destructive method for the 3D characterization of the internal structures of an object, familiar in particular from diagnostic medicine. Over the last decade, high-resolution nano-XCT has been increasingly used in material science and engineering to image the internal structure of objects and the microstructure of materials in high resolution below 100 nm. Images taken from different perspectives are assembled to reconstruct the acquired 3D data. In the process, problems can occur, such as mechanical axis instabilities, misalignment, motion of samples, missing data, and physical artifacts. In order to reduce or eliminate these and gain artifact-free volume data, scientists of TU Dresden and Fraunhofer IKTS have jointly developed specific correction methods. The resulting software package employs machine learning for data recovery, computer vision for motion compensation, and statistical optimization methods for misalignment correction, in order to improve the reconstruction quality and accuracy of the acquired data. With these precise 3D data, it becomes possible to create computer models which consider the hierarchical microstructure of materials and morphological features, such as pores or reinforcement components. Simplified models, currently used to reduce the complexity of the material system in finite element simulations, can then be replaced by these more complex nano-XCT-based models, which allow to understand the local material response of the real material structure to an applied load.

Chip molding compounds are polymers used to encapsulate microelectronic products, such as processors and memory chips. Material simulations have become a critical part of the design process of these materials to ensure performance and reliability.

The 3D morphological data of the molding compounds obtained by using nano-XCT are used as input for the simulation model. First, a segmented surface geometry of a three-dimensional object is produced from the image stack (Figure 1). Then, the surface geometry is transformed into a volume geometry using ANSYS reverse-engineering tools. In the example shown above, a tetrahedral mesh with 1.2 million nodes and 4.6 million elements was generated in order to conduct compressive stress simulations. The resulting total deformation, equivalent von-Mises stress and equivalent elastic strain fields of the heterogeneous molding compound model are illustrated in Figure 2. The results show that the size and placement of the glass spheres included in the material considerably influences the mechanical properties of heterogeneous molding compounds.

The methodology is suitable for all kinds of material systems and allows to establish models based on real geometries by transforming 3D image data into a finite element model with accurate morphological features.

1 *Working steps for transforming the nano-XCT data of the chip molding compound into a finite element model.*

2 *Simulation results of mechanical compression of the heterogeneous molding compound.*

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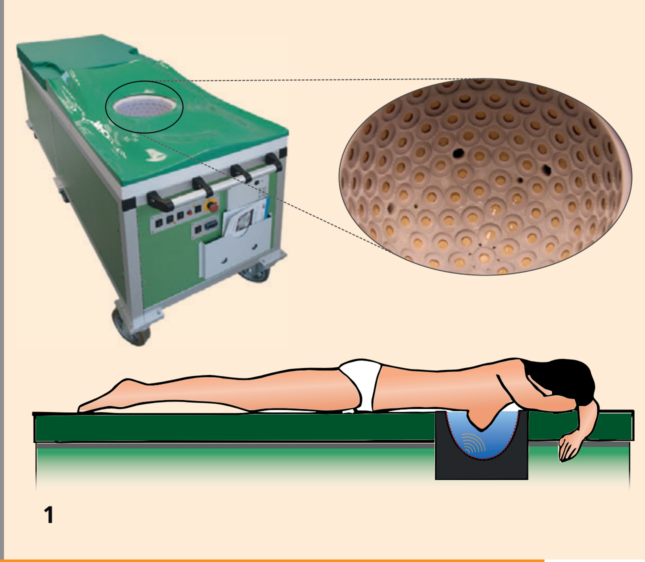

SINGLE-FIBER TRANSDUCERS FOR 3D-ULTRA-SOUND-COMPUTER TOMOGRAPHY (USCT)

Dr. Sylvia Gebhardt, Dr. Kai Hohlfeld, Dr. Holger Neubert

Imaging for breast cancer screening

3D-ultrasound-computer tomography (USCT) systems use ultrasound waves for creating multiple-plane cross-sectional images. They are especially interesting for the early detection of mamma carcinoma in breast cancer screening. Compared with X-ray mammography, conventional ultrasound, or magnetic resonance imaging (MRT), USCT is characterized by high sensitivity and specificity. Moreover, moderate equipment costs and the fact that the systems work without ionizing radiation support this technology for future imaging purposes. However, the configuration of USCT systems is complex. The system operates a large number of ultrasonic transducers in a semi-spherical aperture surrounding a region of interest (ROI) in repeated patterns. For the ROI to be scanned homogeneously, the transducers should exhibit large opening angles and high sensitivity and bandwidth while showing only little property variations among each other. Where such requirements have to be met, established ultrasonic transducer manufacturing technologies quickly reach their limit.

Ultrasonic transducers based on piezoceramic fibers

Fraunhofer IKTS has developed a purpose-built ultrasonic transducer technology which takes into account the specific requirements of 3D USCT systems. Ultrasonic transducers based on this technology were integrated and tested within a 3D USCT system of the Karlsruhe Institute of Technology (KIT). They are based on piezoceramic fibers with circular cross section. The fibers are made from a ceramic slurry by a spinning process in which the slurry is extruded continuously through a nozzle into a precipitation water bath. After spinning, the fibers are cut to length, dried and sintered before being arranged in a well-defined pattern and embedded in epoxy resin. The cured block is diced into discs of identical thickness. Each single piezoceramic fiber in the disc works as an individual addressable ultrasonic transducer, therefore called a single-fiber transducer. By preventing the periodic near-order arrangement of fibers, resulting images show an improved signal-to-noise ratio. The thickness of the piezocomposite discs is chosen according to the desired working frequency.

The single-fiber transducers thus manufactured had opening angles of 50° – an increase by the factor of close to 1.5 compared with conventional transducers manufactured by a dice-and-fill process. The transducers designed and manufactured for KIT's 3D USCT system work with a frequency of 2 MHz and use piezoceramic fibers of 460 µm diameter.

The described technology is scalable over a large geometrical and frequency range. For that reason, it is not limited to medical USCT applications but can also cover similar applications in which a large number of identical ultrasonic transducers have to be arranged in regular patterns.

1 *3D ultrasound tomography system for breast cancer screening (source: KIT).*

2 *Single-fiber transducers in a polymer matrix with sputtered electrodes.*

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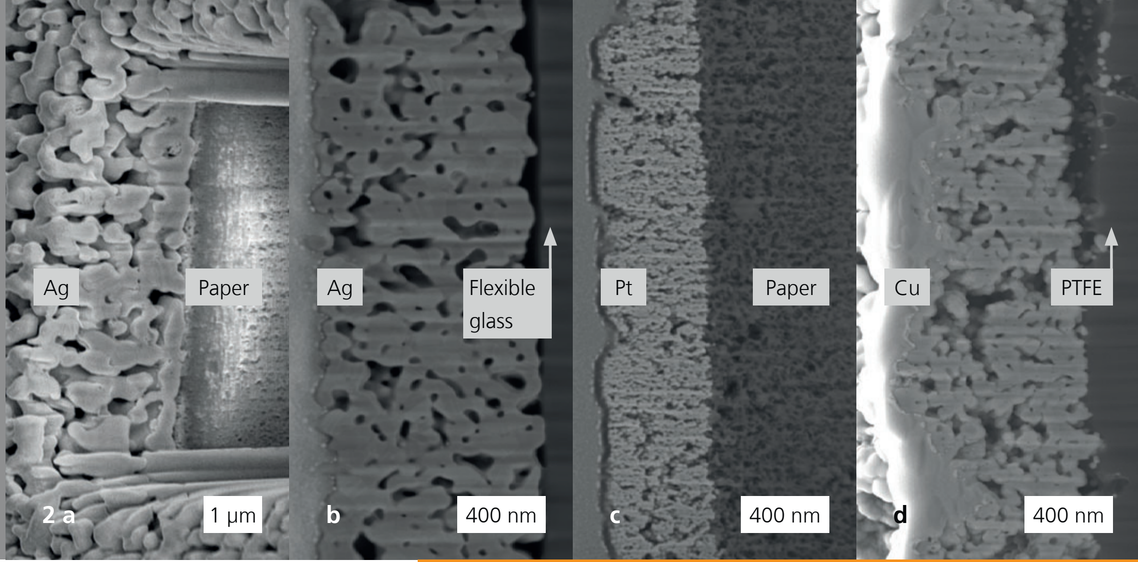

DIODE LASER ARRAY FOR THE POST-PROCESSING OF INKJET-PRINTED LAYERS

Dr. M. Vinnichenko, Dr. M. Fritsch, J. Xiao, Dr. V. Sauchuk, Dr. N. Trofimenko, Dr. M. Kusnezoff

Realizing high-quality inkjet-printed metal structures on large-area thin (100–200 µm) and ultrathin (< 10 µm) substrates enables a wide range of applications for flexible electronics. Thermal post-processing of inkjet-printed structures in a belt furnace for approx. 30–60 minutes at temperatures of at least 130 °C for silver, or more than 300 °C for copper and gold, is usually required to remove organic components, sinter the metal particles and enable electrical conductivity. This critical technological step is determined by the selection and properties of the printed materials and is very time-consuming. Furthermore, it requires high investment costs for furnace technology.

An alternative approach to post-processing, based on a micro-optically designed one-dimensional diode laser source (diode laser array) with a line-shaped beam profile and high energy input, opens up new possibilities in the field of printed electronics. Using this innovative approach, Fraunhofer IKTS was able to sinter a broad range of materials in an extremely short time. The substrate is moved forward continuously with a speed of 5–20 m/min (R2R compatible) during this process.

IKTS has a broad portfolio of specially developed water-based metal nanoinks (Ag, Cu, Au and Pt), which are used for laser sintering. To demonstrate the performance of the method, the metal conducting paths were inkjet-printed onto different thin (glass, 100 µm; PET, 120 µm; paper, 170 µm) and ultrathin (PET, < 10 µm) substrates. The printed structures of silver, gold and platinum showed moderate electrical conductivity already after drying. Subsequently, a few milliseconds of laser processing led to a drastic improvement of electrical conductivity, so that silver conducting paths showing an electrical resistivity three times that of the bulk silver were realized, even on ultrathin 2.5 µm PET substrates. This deviation from the bulk resistivity is due to the residual porosity (30–40 vol %) of the printed layers. In case of copper, gold and platinum structures, the new technique also yielded an improved resistivity, which was higher by the factor 10 compared to the values of the bulk material. In addition to the electrical conductivity, the mechanical bending ability of the structures was tested as well. The silver conducting paths printed on paper were successfully tested down to radii as small as 4 mm. The 100-cycle test with a bending radius of 10 mm resulted only in negligible changes (< 1 %) in the resistance values of the samples.

Thus, the laser-based ultrafast heat treatment can be used for post-processing even of materials which are high-melting and difficult to sinter. This key technology paves the way for the use of new classes of materials in printed electronics on thermally sensitive substrates.

This work was supported by the Fraunhofer Attract INNOVELLE project.

1 *Principle of diode laser array processing.*

2 *Microstructure of the inkjet-printed Ag-, Pt- and Cu-contacts after laser processing at energy densities of 2.8 (a), 4.8 (b), 0.8 (c), and 2.1 J/cm² (d).*

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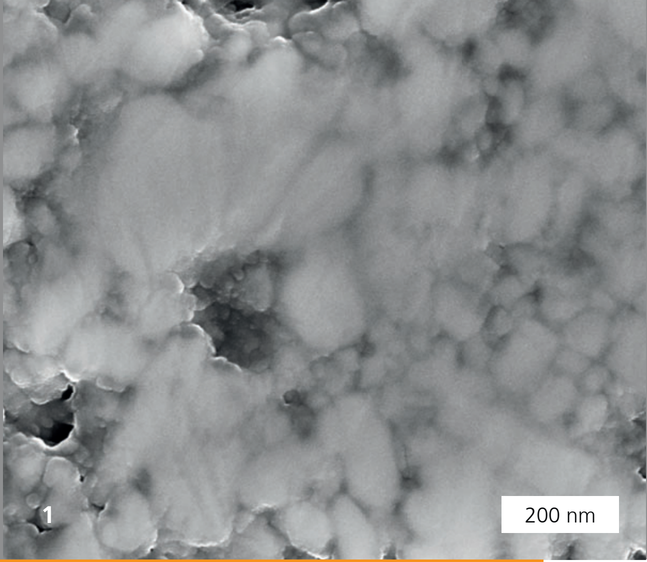
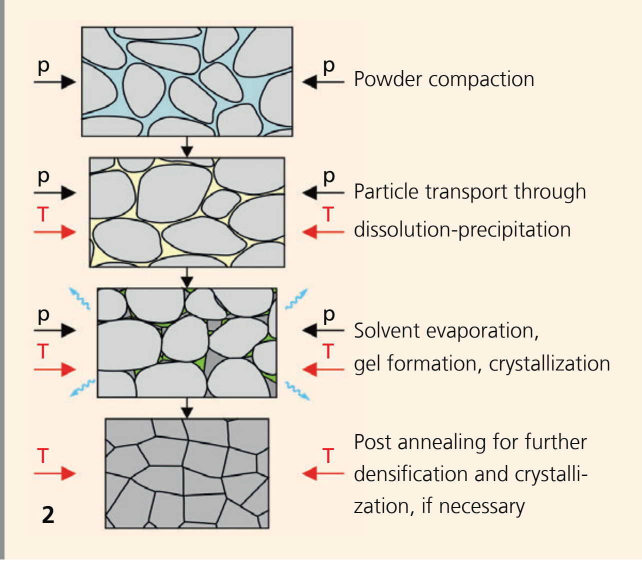




COLD SINTERING – NEW WAYS TO MANUFACTURE AND INTEGRATE FUNCTIONAL CERAMICS

Dipl.-Chem. Christian Molin, Dipl.-Phys. Michael Hofmann, Dr. Stefan Barth, Dr. Sylvia Gebhardt

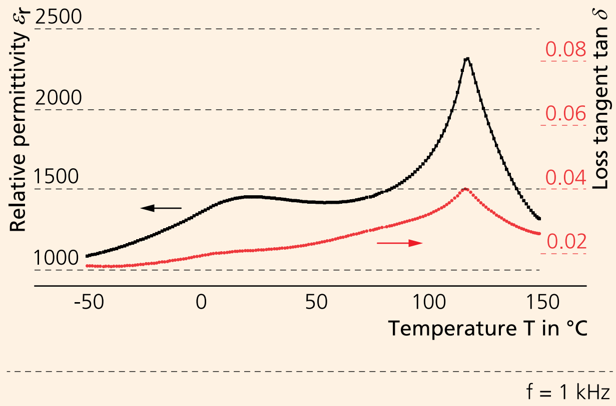
Cold sintering promises densification of ceramic materials at temperatures below 300 °C. The process uses transient solvents which aid densification through a mediated dissolution-precipitation process. The congruent solubility of a ceramic material in a suitable solvent (e.g. aqueous solution) is a prerequisite for this. With the aid of the liquid phase, the solid particles are rearranged under moderate temperatures and high pressures. The diffusive mass transport is followed by the precipitation process, where amorphous phases form at the grain boundaries. After the solvent has evaporated, these phases can either remain amorphous or recrystallize, depending on the material properties (Figure 2).

This paves the way for completely new material combinations, such as the monolithic integration of different ceramic materials (e.g. oxides and nitrides), the combination of different microstructures (e.g. nano and micro), and the preparation of ceramic-polymer composites in a single step. All this requires that suitable pressure and temperature environments are determined.

At Fraunhofer IKTS, research into different ceramic materials, such as $LiFePO_4$, $BaTiO_3$, $(K,Na)NbO_3$, ZrO_2 and TiO_2, has shown that ceramic materials vary in their suitability for cold sintering. Process parameters were determined which allow for the manufacturing of monolithic ceramic samples. $LiFePO_4$, for example, can be cold-sintered to 89 % relative density at 220 °C/150 bar (Figure 1). In contrast, $BaTiO_3$ requires additional thermal annealing. The phase transition temperatures determined for $BaTiO_3$ show a good agreement with samples manufactured under conventional thermal sintering conditions. However, standard material parameters have not yet been reached, which makes further research into cold sintering necessary.

The cold sintering process is therefore especially suited for materials with low lattice energies, reactive surface states, ionic bonding and reduced hydrolytic resistance.

Dielectric properties of cold-sintered $BaTiO_3$ after thermal annealing



1 *FESEM image of $LiFePO_4$ (prepared by a cold sintering process).*
2 *Schematic representation of the cold sintering process.*

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A WORLD'S FIRST: LARGEST EXISTING $NaNiCl_2$ CELLS IN cerenergy®-BATTERY MODULE

Dr. Roland Weidl, Dr.-Ing. Matthias Schulz, Prof. Dr. Michael Stelter

Stationary energy storage is one of the most promising growth markets in Germany, Europe, and globally. In connection with this trend, solutions beyond lithium-ion and lead-acid technologies are especially interesting, because they provide high security at low acquisition and operating costs. Sodium technology is set to make a comeback in a new form, ready to face the energy storage tasks of the future.

ZEBRA battery – an established technology, re-invented

The triumphant progress of the battery then called "ZEBRA – Zero Emission Battery Research Activities" began as early as in the 1980s. This type of battery is operated at around 300 °C and essentially uses the materials sodium chloride ($NaCl_2$) and nickel (Ni). However, towards the end of the 1990s research pivoted to the emerging lithium-ion batteries and the advance of the ZEBRA battery was stopped in its tracks. Nevertheless, these batteries never completely disappeared from production. The three largest batteries in the MWh range currently operated worldwide are high-temperature batteries – so-called sodium-sulfur batteries. They are based on the same technology and the same solid-state electrolyte: sodium beta aluminate.

Because of the intrinsic safety of the $NaNiCl_2$ battery type and the fact that raw materials are locally available and non-strategic, development at IKTS over the past five years has focused on re-engineering this battery – with particular focus on manufacturing, layout, and size.

Technological challenges mastered

A cost-effective extrusion process was established for the production of the core element of the high-temperature battery, the solid electrolyte. In combination with a new cell layout, this has made upscaling possible. Numerous offset recipes and ceramic-metal bonding variants had to be tested and optimized during development. The seal turned out to be another technological challenge; it needs to show long-term stability under a sodium vapor atmosphere. As a result of the development work, 100 Ah cells could now be realized for the first time, instead of the 38 Ah cells typically available on the market. The world's largest $NaNiCl_2$ cell in terms of capacity has already been successfully tested in stationary battery modules.

Fraunhofer IKTS – a partner in battery development

The range of services at IKTS includes the development and manufacture of ceramic electrolyte prototypes, the electrochemical measurement of high-temperature cells, post-mortem analyses, and cell and module development, including energy system simulation for customer-specific applications.

1 100 Ah $NaNiCl_2$ battery cells.
2 cerenergy®-battery module in test stand.

Fraunhofer ZUKUNFTSSTIFTUNG

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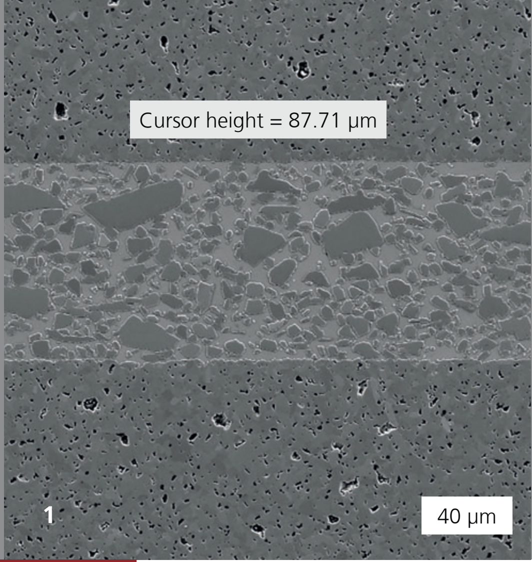

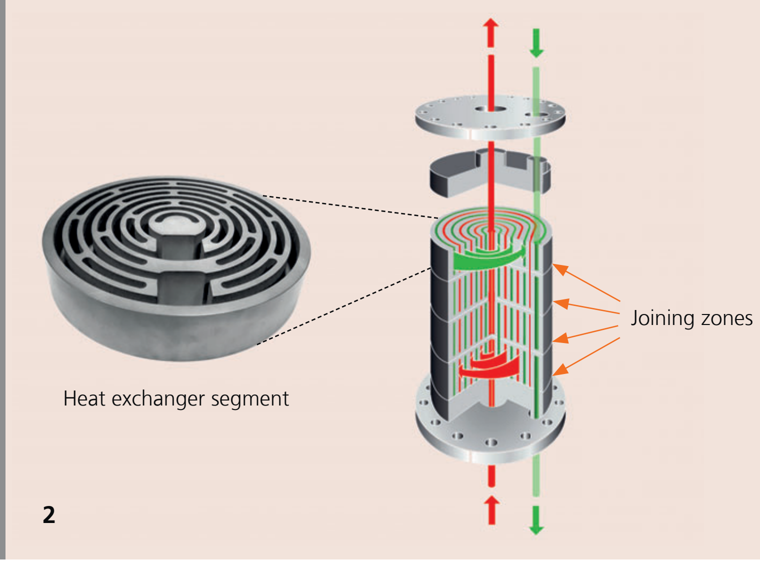

GAS-TIGHT JOINING OF CERAMIC HEAT EXCHANGERS MADE OF SILICON CARBIDE

Dr. Steffen Kunze, Dipl.-Krist. Jörg Adler

For the waste heat recovery from chemical reactions, modular recuperators made of sintered silicon carbide have become established in many industrial applications. However, the sealing and joining technologies of individual commercially available recuperator segments put restrictions on the chemical and thermal load capacity of heat transfer systems. To overcome these technological limitations, Fraunhofer IKTS and its industrial partner GAB Neumann GmbH have developed a process for the cohesive ceramic bonding of silicon carbide ceramics.

The joining process begins with a tape made of polymer-bound silicon carbide particles. By using a cutting laser, the tape can be tailored precisely to the dimensions of the component surfaces to be connected. This also enables the production of complex cutting patterns. The component surfaces to be connected can then be joined with the cut tape even at low temperatures of approx. 200 °C. Since thermoplastic binder is used, this can be done cost-efficiently, with only a minor effort in terms of instruments, under air and at low pressures starting at about 1 MPa. The tape can be draped easily and, in its plastic state, is able to optimally level out uneven areas. Therefore, it is also possible to join spherical or rough surfaces.

Subsequently, the thermoplastically connected parts are subjected to pyrolysis. During this working stage, the plastic binder in the joint transforms into glassy carbon. The resulting porous carbon zone, which contains silicon carbide, can be converted into a dense silicon-infiltrated silicon carbide (SiSiC) joining layer during a high-temperature step at about 1600 °C. For this purpose, silicon powder must be stored in reservoirs with direct contact to the joining zones. The reservoirs may be introduced in the form of grooves or blind holes in the material. When the melting temperature (1414 °C) is exceeded during the heat treatment, the silicon liquefies in the reservoirs and is drawn into the joining layer by the capillary forces, where it reacts with the present free glassy carbon to form secondary silicon carbide. The result is a gas-tight joint of silicon carbide with silicon-filled cavities.

The resulting ceramic joining layer is approximately 80–120 microns thick. It is suitable for high temperatures and very resistant to chemicals. The industrial partner GAB Neumann GmbH currently uses this newly developed joining technology for the first time in plate and annular groove heat exchangers.

Services offered

- Development of ceramic joining processes
- Application-related materials development
- Development of manufacturing processes for the industrial fabrication of complex ceramic components
- Recuperator design optimization using CFD simulations
- Development and optimization of adapted heat treatment processes

GAB neumann
Bundesministerium für Wirtschaft und Energie
ZIM Zentrales Innovationsprogramm Mittelstand

1 *Joining zone between two SSiC parts.*
2 *Annular groove heat exchanger segment to be joined.*

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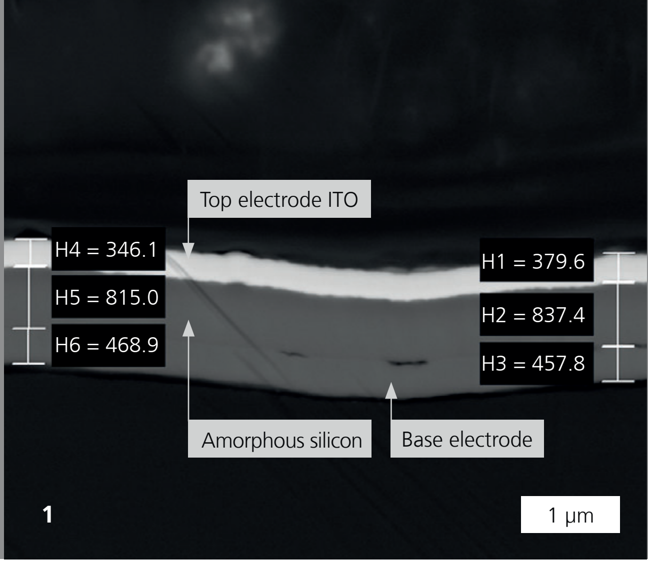

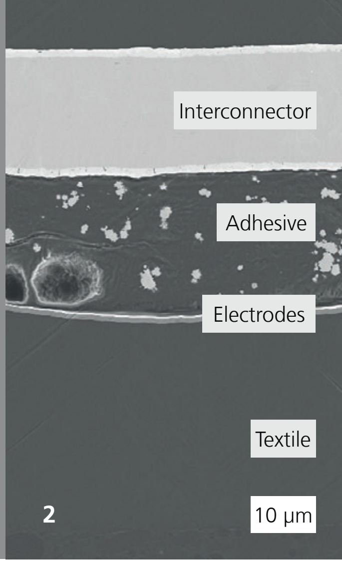

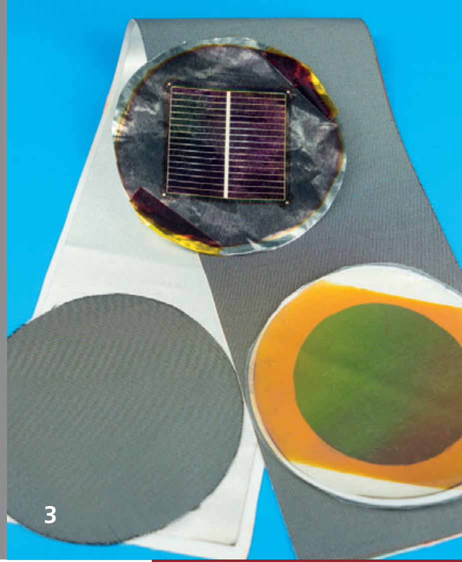

THIN-FILM PHOTOVOLTAICS ON TECHNICAL TEXTILES – PhotoTex

Dr. Lars Rebenklau, Mario Krug, Dr. Paul Gierth, Dr. Jonas Sundqvist

In the future, marquees, slats and sun sails may not only protect against the sun, but also generate solar power. This power can be used for the energy-autonomous control of the marquee, and for many other things. As part of the "PhotoTex" project, Fraunhofer IKTS is working with partners to equip, for the first time, flexible technical textiles with practical photovoltaic layers. This is done by combining thin- and thick-film technologies with textile technology. The goal is to develop and validate different photovoltaic coating systems, which are applied to textile substrates using different processes.

A prerequisite for the uniform application of thin-film solar cells on the rough textile surfaces, besides pretreating the substrate, is a base coating of the textiles. In a first step, textiles and compensating materials need to be found whose temperature behavior is compatible with thin-film technologies. To build up the layers, electrically conductive base electrodes made of aluminum and molybdenum were sputtered onto the leveling layers using DC magnetron sputtering. An electrode layer made of aluminum film laminations proved even more efficient. Photovoltaic active layers consisting of amorphous silicon layers were generated using PECVD. An indium tin oxide (ITO) layer generates the electrically conductive top electrode. Electrical conductive polymers were screen-printed on the ITO layer as interconnection areas. The latter are of particular importance as mounting levels for power tapping.

Soldering processes at low temperatures, conductive adhesives and connection solutions using rivets were investigated as interconnection technologies compatible with textile industry standards. Additionally, masking technology had to be developed to minimize shorts and shunts between the electrical conductive hybrid layers. Finally, hermetic sealing using a film lamination process facilitates a stable, long-term operation.

Trials and prototypes have shown that the production of technical textiles with photovoltaic active thin-film layers is possible. To assess efficiency and long-term stability, a small batch with active photovoltaic areas of up to 250 mm² per system was produced. All modules show an efficiency between 0.1 and 0.3 % under AM 1.5 sun spectrum. The project members believe that an efficiency increase of up to 2–5 % is realistic as the basic concept is developed further. This makes the economically viable use of solar-active sun protection-textiles a real possibility in the near future. We gratefully acknowledge the German Federal Ministry of Education and Research BMBF for funding the project "PhotoTex" (funding reference 03ZZ0614A).

Services offered

- Development and validation of functional layers on textiles
- Development and realization of packaging technologies
- Realization and characterization of small-batch production

1 *Photovoltaic thin-film layers on glass fiber fabrics.*

2 *Thin-film photovoltaic module on technical textile with conductive adhesive interconnection.*

3 *Prototype of a textile PV cell.*

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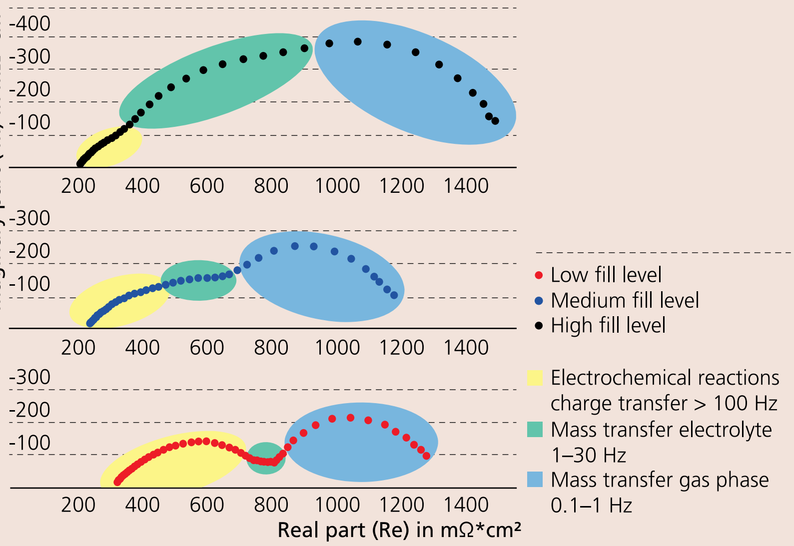

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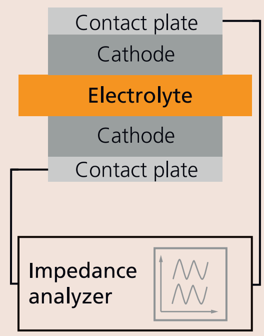

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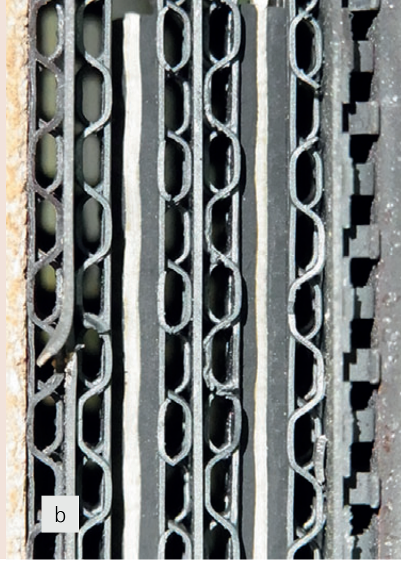

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IN-SITU CHARACTERIZATION OF MCFC CATHODES THROUGH IMPEDANCE SPECTROSCOPY

Dipl.-Ing. Christoph Baumgärtner, Dr. Mihails Kusnezoff, Dr. Mykola Vinnichenko

The molten carbonate fuel cell (MCFC) is at present one of the most mature and efficient fuel cell technologies in the field of stationary and decentralized power supply. Efficiency and service life are mainly determined by voltage losses at the electrochemically active electrodes. In comparison to the anode side reaction, the cathode side shows higher losses and has therefore a higher potential for optimization. The fundamental mechanism of the oxygen reduction in carbonate melts has been already extensively investigated. However in most cases, idealized experimental setups were used, which only insufficiently describe the processes at real porous cathode electrodes for short-term operation. The in-situ impedance characterization of cathodes under simulated operating conditions (600–700 °C; in O_2/CO_2/N_2/H_2O atmospheres) provides useful insight in the reaction mechanism and processes occurring at the cathode.

Fraunhofer IKTS has carried out impedance measurements of cathode half cells (CHC) using the same cathode material for working and counter electrodes. An advantage of this method compared with the characterization of a full single cell is the prevention of superimposed processes of the anode side reaction. The measurement in a wide frequency range from 10 mHz to 100 kHz enables the separation and evaluation of electrochemical processes with differing time constants, such as charge transfer at interfaces, and diffusion processes (mass transfer). This allows for investigating the impact of single operating parameters, such as temperature, gas concentration and lifetime, on the reaction steps, enabling the targeted optimization of the cathode. Three different processes can be identified for MCFC cathodes: electrochemical reactions at interfaces, mass transfer inside the electrolyte and mass transfer inside the gas phase.

In a Nyquist plot (Figure 1), individual electrochemical processes are represented schematically with half circles. Due to similar time constants of the single reaction processes, these half circles show a high degree of superposition at times. The investigations on cathodes with different fill levels of electrolyte inside the porous nickel-oxide structure have shown that the voltage loss by mass transfer can be decreased significantly by reducing the fill levels. However, such a reduction must be limited, since a high loss of electrolyte or super-low fill levels will increase electrode degradation. This in turn can lead to much higher voltage losses caused by the electrochemical reactions – which can be seen in the high frequency region of the impedance spectrum.

The trials have shown that impedance spectroscopy at CHC is an excellent tool to characterize complex electrochemical systems like MCFCs and to precisely optimize them in terms of special parameters. The process is suitable for the characterization of electrochemical processes at high temperatures and diverse operation conditions and can be transferred to other fields, such as high-temperature batteries.

1 *Impedance spectra (Nyquist plot) of cathode half cells with different electrolyte fill levels.*

2 *Schematic image of the impedance measuring setup (a), and setup of a half-cell stack, consisting of two half cells (b).*

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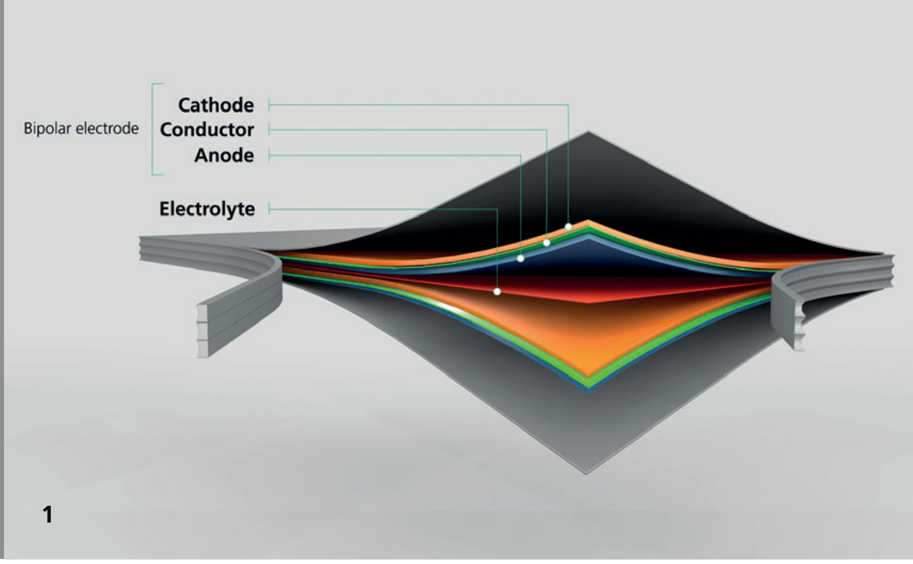

EMBATT – BIPOLAR LITHIUM-ION BATTERY FOR SAFE DRIVING WITH GREAT RANGE

Dr. Mareike Wolter, M.Sc. Matthias Coeler, Helmut Kotzur, Dipl.-Ing. Stefan Börner, Dr. Sebastian Reuber, Dr. Kristian Nikolowski

The concept behind the EMBATT battery

In addition to a reduction in product costs for vehicle batteries, an increase in energy density and range is seen as a prerequisite for electric vehicles to reach broad market penetration. When it comes to the established lithium cell technology, this issue is addressed by introducing active materials with increased energy density, and through optimized cell and system packaging.

The EMBATT bipolar battery is based on a design principle already established for fuel cells and transferred to Li-ion batteries (DE 10 2014 210 803 A1, WO 2015/185723 A1). The basis of the new battery structure consists of stacked large-area electrodes with a bipolar layer structure. The cells of the EMBATT bipolar battery in a stacked construction are stacked in such a way that the conductor of the negative electrode of one cell functions as the contact of the positive electrode of the next cell. Two electrochemical cells connected in series thus share the same conductor – one side of the bipolar electrode serves as the anode in one cell and the other side as the cathode in the next cell. The larger and thicker the electrodes, the higher the battery's capacity. The stacked structure of the EMBATT battery yields a high system voltage and excellent performance parameters by reducing the internal resistance.

In recent years, Fraunhofer IKTS and its partners have primarily developed processes for the production of bipolar electrodes on a pilot scale, thus creating the prerequisites for scaling EMBATT up to a size of 20 x 30 cm². Today, these cell stacks are filled with liquid electrolytes and then tested.

Increased safety thanks to polymer electrolytes

In a next development step, the flammable, highly volatile liquid electrolyte is to be substituted by polymer electrolyte materials. Suitable candidates are currently being investigated with regard to their suitability and processability. Specific properties, such as conductivity and, above all, chemical and electrochemical stability against potential anode and cathode materials, are being considered. When mixed into composites, active materials and polymer electrolytes form the basis for the composite electrodes of the future.

At IKTS, bipolar electrodes have already been infiltrated with PEO (polyethylene oxide), and thus composite cathodes have already been successfully produced on a pilot scale. PEO is cost-efficient and easy to process, and is therefore being investigated as a polymer electrolyte.

During the tests conducted in the pilot plant, the polymer was heated up to the softening point of 60 °C and infiltrated into the electrode before drying out the solvent at a temperature of 80 °C. This was followed by a final validation where the electrochemical function of PEO-LITFSI-infiltrated layers was confirmed in cycle tests with lithium as counter electrode.

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

1 The EMBATT setup.
2 Infiltration of polyethylene oxide in bipolar electrodes on pilot scale.

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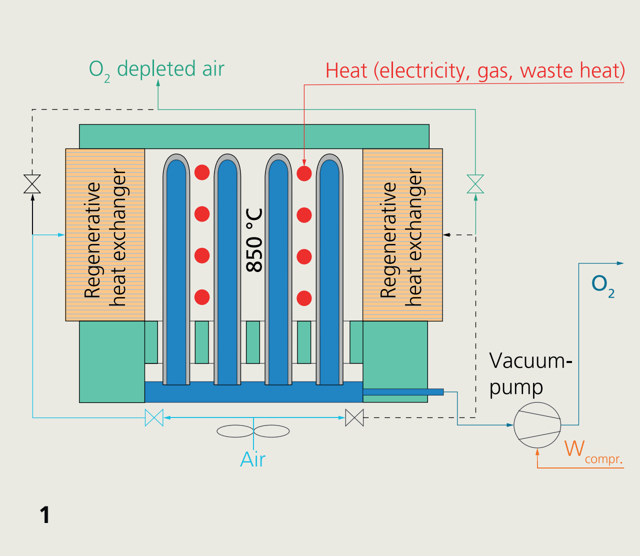

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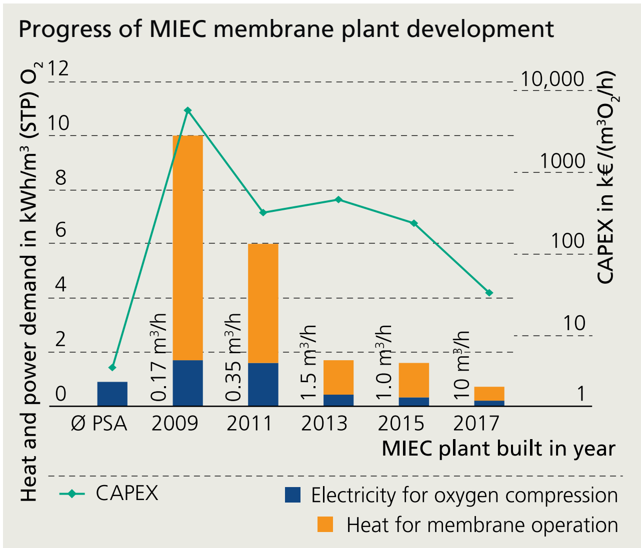
LARGEST MEMBRANE PLANT WORLDWIDE FOR HIGH-PURITY OXYGEN PRODUCTION

Dr. Ralf Kriegel, Dr. Robert Kircheisen

Oxygen is used in a wide variety of industrial applications, for example in the gasification of coal, in metallurgy (steel, copper, aluminum), and in the chemical industry. Additionally, combustion with pure O_2 enables highly efficient CO_2 capture and saves primary fuel. However, small heat treatment plants often cannot afford the supply of O_2, as the unit price is significantly higher for smaller order quantities. On-site production, using the pressure swing adsorption (PSA) method, delivers only 93 vol % O_2. This level of purity is frequently insufficient. Many industrial applications stand to benefit from the efficient and cost-effective on-site production of pure O_2. Fraunhofer IKTS develops ceramic MIEC (mixed ionic electronic conductor) membranes – at high temperatures, these are permeable only for pure O_2. Since 2009, several demonstration plants using these membranes have been realized. The diagram shows enhanced O_2 throughput and continuously reduced energy demand and investment costs. Since 2015, goal of the BMBF-funded project MedPROmM is to create a pilot plant that could remain below the specific energy demand of a large cryogenic air separation plant requiring at least 0.5 kWh/m³ (STP) O_2 (STP – standard pressure and temperature). In cooperation with industry partners, the patented concept for the plant (Figure 1) was implemented in a trial plant (Figure 2). During build-up, an enormous amount of modification and adaption of the CAD construction was required, since new technical solutions had to be implemented in many places. Due to thermal bridges at the plant housing, and because some regenerative heat exchangers recovered much less heat than anticipated, the real energy demand of 0.72 kWh/m³ (STP) O_2 was higher than the target value of 0.46 kWh/m³ (STP) O_2. However, the energy demand for O_2 compression of 0.2 kWh/m³ (STP) O_2 and O_2 throughput of 9.8 m³ (STP) O_2/h complied well with the target values. At 8000 hours of operation per year, a ten-year life-span, and electricity costs of 0.1 €/kWh_{el}, the calculated O_2 production costs amount to 0.43 €/m³ (STP). The alternative – supply with liquid O_2 – would be almost twice as expensive, with additional costs of around 29,000 € per year.



1 Schematic concept of the MIEC membrane plant.

2 Pilot plant for the production of 10 m³ (STP) O_2/h, 0.72 kWh/m³ (STP) O_2.

Bundesministerium für Bildung und Forschung

Maschinen- und Anlagenbau GmbH
TRIDELTA
KWH
PORZELLANFABRIK HERMSDORF GMBH

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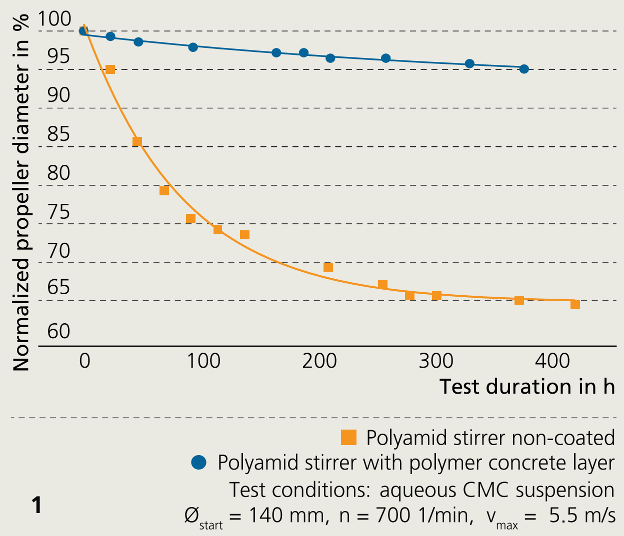

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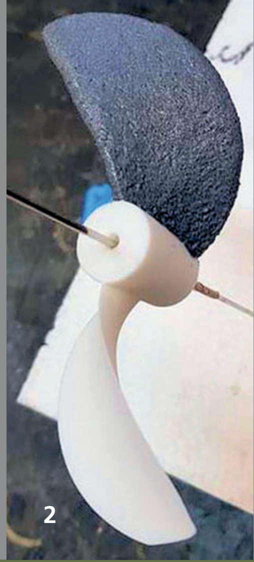

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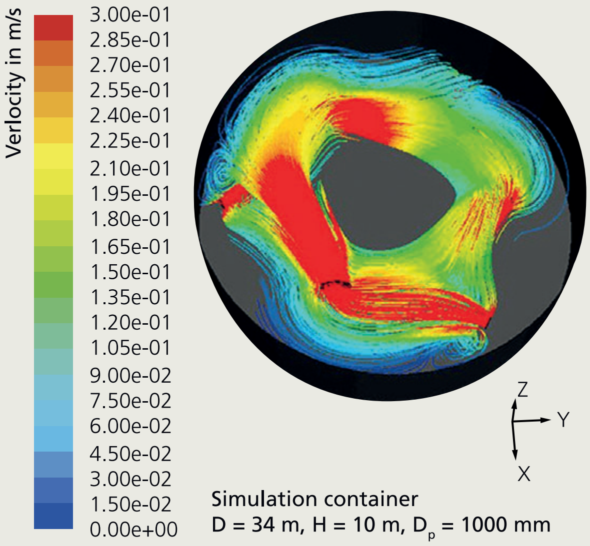
EFFICIENT AND WEAR-RESISTANT STIRRERS FOR BIOGAS PLANTS

Dr. Steffen Kunze, Dipl.-Ing. Anne Deutschmann

The main functions of stirring devices installed in biogas plants are to mix fresh substrate with the digestate, to reduce temperature gradients in order to achieve stable environmental conditions, and to avoid floating layers as a prerequisite for the free release of biogas from the suspension. Due to the high tribological and corrosive stresses caused by the aggressive digestate, the service life of stirrers currently in use is very short. Fraunhofer IKTS is working with the stirrer manufacturer RTO GmbH and the mineral casting specialist SiCcast GmbH to find better solutions. Changes in the design of the stirrer geometry and with regard to mineral coatings are being investigated, with the goal of developing a new stirrer generation with increased efficiency and wear resistance.

The researchers have developed a special stirrer design with improved mixing efficiency based on CFD simulations. The mixing performance achieved by the optimized stirrer geometries was validated through electrical resistance tomography (ERT) measurements. To extend service life, polymer concretes were used as wear protection layers in the tribologically stressed zones of the stirrer. Investigations at the wear test stand for stirrers of Fraunhofer IKTS showed that the silicon carbide coating developed leads to a significant reduction of wear compared with the standard material. The results of the tribological tests are shown next to the diagram (stirrer at bottom: initial state, center: after wear coated, top: after wear non-coated). The exposure to digestate confirmed the suitability of the polymer concrete coating for this field of application. A pilot test in a biogas plant with a newly developed and coated stirrer is planned for 2019.

CFD simulation of the fluid dynamics inside the digester (source: RTO GmbH)



Simulation container
D = 34 m, H = 10 m, D_p = 1000 mm

Services offered

- Characterization, development, optimization of stirring devices
- Application-oriented materials development
- Characterization of tribological and corrosive effects

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ptj Projektträger Jülich Forschungszentrum Jülich

1 *Comparison of wear between coated and non-coated scaled pilot stirrers.*

2 *Coating of a scaled pilot stirrer with polymer concrete (source: SiCcast GmbH).*

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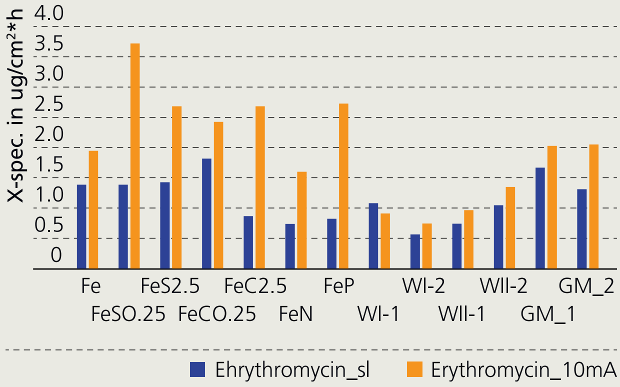

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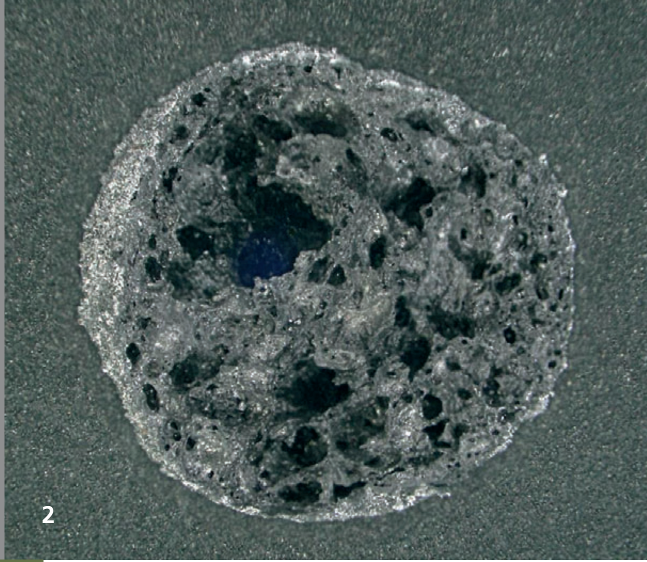

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FLOATABLE METAL-CERAMIC COMPOSITES REMOVE PHARMACEUTICALS FROM WATER

Dipl.-Chem. Hans-Jürgen Friedrich, Dr. Daniela Haase

A growing part of pharmaceuticals, pesticides or their residues can be found in ground and surface water, from which our drinking water is also made. This is especially true for urban agglomerations and areas with intensive agriculture. While these substances are only present in very small concentrations, they are nevertheless relatively stable and have undesirable biological effects. For example, antibiotic residues contribute to the development of multi-resistant germs or, as in the case of estrogens, they are considered to be partly responsible for the increase in fertility disorders. Unfortunately, current methods of municipal wastewater treatment – one of the major entry paths into the water cycle – have proven unfit for removing many of these substances.

Our approach: iron alloys on ceramic foam

Within the BMBF joint project KERAMESCH, Fraunhofer IKTS has developed materials with which pharmaceutical and pesticide residues can be removed from the water through the combined action of reduction and adsorption. This can be achieved, for example, with iron alloys with a special composition which are applied onto floatable ceramic foam beads.

Extensive investigations regarding the influence of the iron composition show that the sulfur content is the alloys' most important feature: a high content strongly promotes the removal of pollutants (example: erythromycin in Figure 1). The effect can usually be enhanced through the cathodic polarization of the iron. In the reductive transformation of the active substances, materials such as diclofenac are rendered harmless by cleaving off the chlorine atoms, or by attacking other functional groups. However, the reactivity of the iron decreases rapidly as a result of the formation of a corrosion layer, making it necessary to regenerate the iron surface constantly.

From material to floatable catalyst

The challenge was to develop a mechanically stable ceramic carrier material with a maximum density of 0.5 g/cm³ to make the iron-coated foam beads float. To achieve this, a clay suspension was foamed directly by introducing air while adding a surfactant. The resulting ceramic foam was filled into spherical molds, dried and sintered. The diameter of the beads was defined to be 20 mm so that they would float after being coated with a 500 µm thin layer of iron alloy. A stable suspension of the iron powder was developed for coating the clay foam beads. After drying, the iron layer was sintered at 1150 °C under inert gas.

In order to treat larger volumes of water in this way, the next step will be to test the novel catalysts in fluidized bed reactors. Such reactors also have the advantage that the reaction layer is renewed continuously as a result of natural abrasion.

Bundesministerium für Bildung und Forschung

MachWas
MATERIALIEN FÜR EINE NACHHALTIGE WASSERWIRTSCHAFT

1 *Influence of alloy composition on the removal of erythromycin.*

2 *Cross section of an iron-coated clay foam bead.*

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DEWATERING OF SUPERCRITICAL MIXTURES WITH CERAMIC MEMBRANES

Dr. Marcus Weyd, Dr. Hannes Richter, Dipl.-Ing. (FH) Susanne Kämnitz

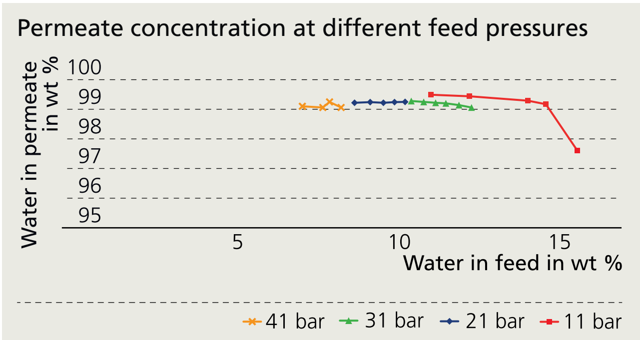
Increasing efficiency by in-line dewatering at supercritical conditions

Many industrial applications require new morphologies, for example for different polymers, temperature-sensitive biopolymers, or nano-composites. One way to create these materials is to dewater them under supercritical conditions, a method used in the Pressurized Gas Extended (PGX) Technology. This application uses a combination of carbon dioxide and ethanol at approximately 100 bar. This so-called supercritical mixture then absorbs water during a spray drying process.

In order for PGX to be efficient, the mixture of ethanol and carbon dioxide must constantly be recycled, i.e. relieved of water. Conventionally, the mixture is dewatered after it is expanded to normal pressure. A disadvantage of this technology is that the mixture must then be re-compressed. An in-line application capable of dewatering at supercritical conditions would greatly improve the efficiency of the entire process.

Membranes hold up under supercritical conditions

Fraunhofer IKTS has developed hydrophilic membranes which can be used for dewatering solvent-water mixtures by pervaporation or vapor permeation. However, dewatering at critical conditions places high demands on the chemical and mechanical stability of the membranes. In a German-Canadian research project, zeolite and carbon membranes were evaluated, further developed, and tested in the supercritical fluid application. Pore size and chemical stability of the active layer and the mechanical resistance of the extruded membrane layer had to be taken into account for this. In extensive lab trials, carbon membranes coated on membrane supports of increased mechanical stability demonstrated convincing separation properties and high selectivity at increased pressures. Even at pressures above 40 bar, almost pure water was extracted from a water/ethanol/carbon dioxide mixture. The membranes are currently being evaluated by the Canadian project partner CEAPRO in separation tests at supercritical conditions. Prevailing separation characteristics are very positive, making a future implementation in the industrial process most likely.



1 *Pervaporation plant for separation testing at up to 50 bar.*
2 *Carbon membranes on ceramic support for applications at increased pressures.*

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2

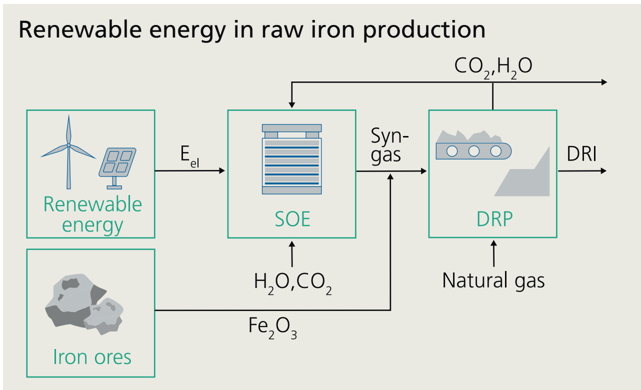
CO_2-REDUCED STEELMAKING VIA ELECTROLYSIS-BASED DIRECT REDUCTION

Nils Müller, Dipl.-Ing. Gregor Herz, Dr. Erik Reichelt, Dr. Matthias Jahn, Dipl.-Ing. Aniko Walther

In order to achieve a sustainable resource and energy system, the reduction of carbon dioxide (CO_2) emissions is essential in all branches of industry. Currently 5 % of all greenhouse gas emissions in the European Union are caused by the steel industry, which ranks amongst the largest overall emitters. In the production of steel – one of the most important raw materials of the 21st century – substantial amounts of CO_2 are emitted as by-product of the conventional iron ore reduction using the established blast furnace route. Therefore, at Fraunhofer IKTS a current area of research focuses on the reduction of CO_2 emissions associated with the production of raw iron, through electrolysis-based direct reduction using renewable energy sources.

Roughly 95 % of global raw iron is currently produced via the blast furnace route. In this process, coke is used as a reducing agent. During the reduction process, the oxygen content in the iron ore is bound to the carbon. The reaction produces raw iron and CO_2.

A commercially available alternative is the direct reduction process. Its product is direct reduced iron (DRI), which is characterized by its carbon content and a small amount of residual iron oxides. Existing commercial plants are predominantly fueled by natural gas. In a so-called reforming step, this feedstock is converted into hydrogen and carbon monoxide, which are both available as reducing agents for the reduction of iron ore. As a by-product besides CO_2, water is formed. The partial reduction with hydrogen results in a significant decrease in CO_2 emissions compared to the blast furnace route, because the oxygen is partially bound and emitted in the form of water. A potential pathway for a further reduction of emissions, and perhaps in future for the complete abandonment of fossil fuel sources, is the generation of the relevant reducing agents hydrogen and carbon monoxide via electrolysis from water and CO_2 – a process called solid oxide electrolysis (SOE). This makes the electrolyzer the link between renewable energy sources and steel production.



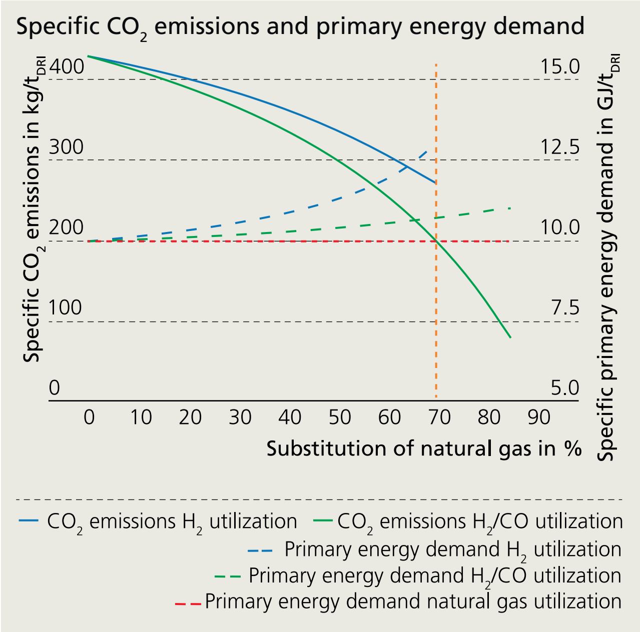
The simplest way to implement renewable energy into raw iron production would be a co-feed of sustainably produced hydrogen and natural gas, which would result in a significant decrease in CO_2 emissions without the need for any changes in the applied direct reduction shaft furnace. As the amount of hydrogen is increased, the CO_2 emissions decrease. However, beyond a certain threshold of hydrogen fraction reduction, the carbon content of the DRI also decreases. Such a decrease in carbon content within the DRI has an adverse effect on the subsequent process steps. Therefore the substitution of natural gas must be kept below 70 vol % to remain technically feasible.

This limitation is circumvented by a process concept proposed by IKTS, for which a patent is pending. The concept is based on the fact that SOEC stacks, also developed at IKTS, cannot only convert water, but also CO_2. During the direct reduction process, CO_2 that is already being separated can be recycled into the electrolysis together with water. This produces the reducing agents carbon monoxide and hydrogen. At the same level of substitution, the CO_2 recycle results in an even more significant decrease in emissions compared with simple hydrogen utilization. Additionally, the overall electricity demand required for the reduction of emissions decreases as well.

The boundary up to which the carbon content of the DRI is held stable is thus pushed from 70 vol % to 85 vol %, which means a significantly larger proportion of natural gas can be substituted – without negatively affecting the properties of the DRI. In the case of a 70 vol % substitution of natural gas with a syngas with a hydrogen-to-carbon monoxide ratio of 2:1, the CO_2 demand of the electrolysis is equal to the amount of CO_2 that is separated internally within the direct reduction process. Residual emissions are then caused only by the preheating of process gas through the combustion of a part of the H_2/CO mixture. The remaining carbon fed in via natural gas is bound in the produced raw iron. If renewable energy is also used for preheating, CO_2 emissions can be reduced to almost zero.

By further increasing the substitution beyond the 70 vol % threshold, the system of SOEC coupled with a direct reduction plant can even be operated as a CO_2 sink. This could allow for the sustainable production of raw iron and steel, without the demand for fossil carbon sources. Therefore, the proposed process concept offers enormous potential regarding the future goals of emission reduction.

We gratefully acknowledge the project funding of the Federal Ministry of Education and Research BMBF (funding reference 03EK3044A).



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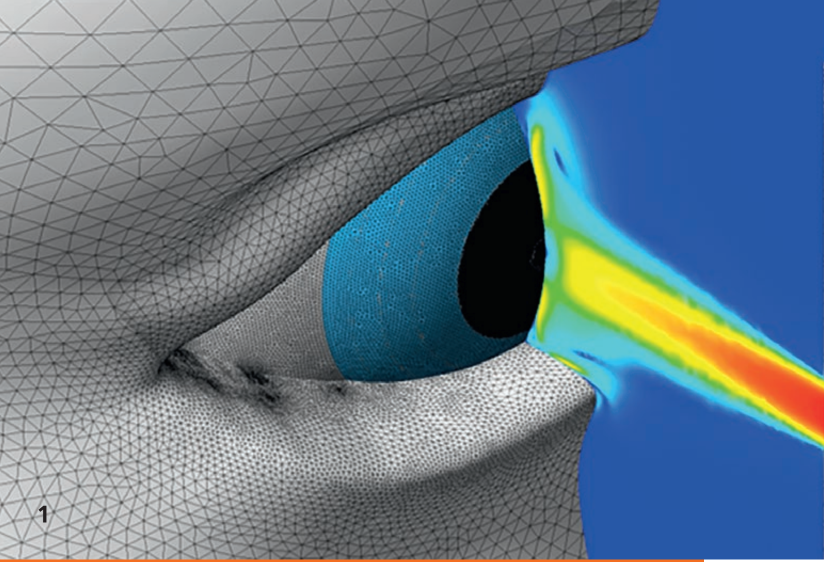
1 *Tapping of a blast furnace (Shutterstock, Oleksiy Mark).*

2 *Iron ores prior to reduction within the direct reduction process.*

3 *Quality assessment of the final product.*

4 *Raw iron bars (Shutterstock, Kaband).*

5 *Direct reduction plant (Shutterstock, M.Khebra).*



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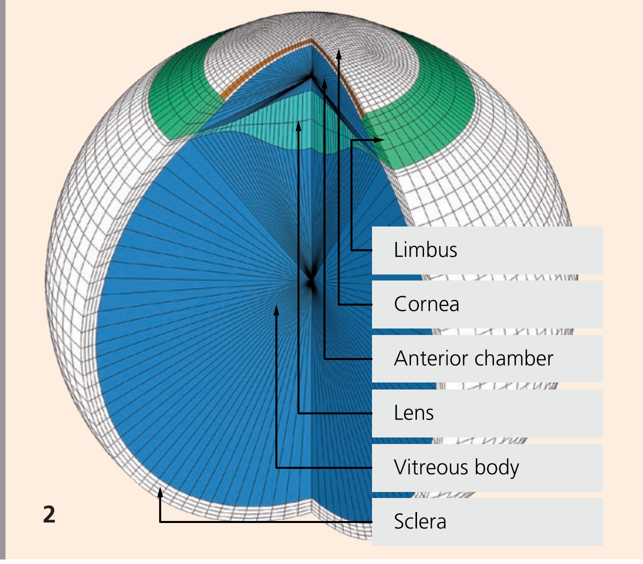

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NON-CONTACT DETERMINATION OF BIO-MECHANICS OF THE EYE THROUGH SIMULATIONS

Dipl.-Ing. Stefan Münch, Dr. Mike Röllig

The biomechanics of the human eye are of threefold importance in medicine. They reflect pathological processes through biochemical changes in the tissue structure and are therefore suitable for diagnosing diseases. Conversely, they also enable the investigation of healing processes after surgery. The biomechanics of the eye envelope also affect the imaging properties and thus visual acuity. To facilitate the non-contact identification of material properties of the human eye, IKTS is partnering with Technische Universität Dresden and Ruhr-Universität Bochum in a joint research project.

The research project is based on air pulse tonometry, which applies an air pulse to the eye and records the subsequent deformation of the eye with a camera system. If the deformation of the eye and the load required for the deformation is known, it is possible to draw conclusions about the material properties. This task is fulfilled by a numerical simulation based on the finite element method (FEM). It requires a realistic definition of the external loads, a detailed virtual model of the human eye and the use of a suitable material model.

The loads generated by the air pulse tonometer must be determined experimentally in their qualitative distribution and with regard to their quantitative values. For this purpose, a glass eye is placed in front of the air pulse tonometer and its movement caused by the air pulse is recorded with the laser triangulation method. In connection with a flow simulation (CFD) the pressure pulse can thus be characterized and the influence of eye deformation and the eyelids on load distribution investigated.

In order to accurately describe the complex structure of the eye envelope, which consists of cells, extracellular matrix and collagen fibers, a special material model was implemented in ANSYS with the UserMat routine. This model enables the modeling of incompressible and hyperelastic material behavior and also takes into account the position-dependent fiber orientation and statistical fiber scattering.

In summary, it can be said that the method allows to identify unique material properties based on optical deformation measurements. The function of the method has already been demonstrated with predefined test cases. In future work, the current computing time is to be reduced from approx. 24 hours to almost real time. This makes the method practicable for use in the respective examination equipment directly on the patient.

1 *Velocity profile of the air pulse at the eye.*

2 *Detailed FE model of the eye.*

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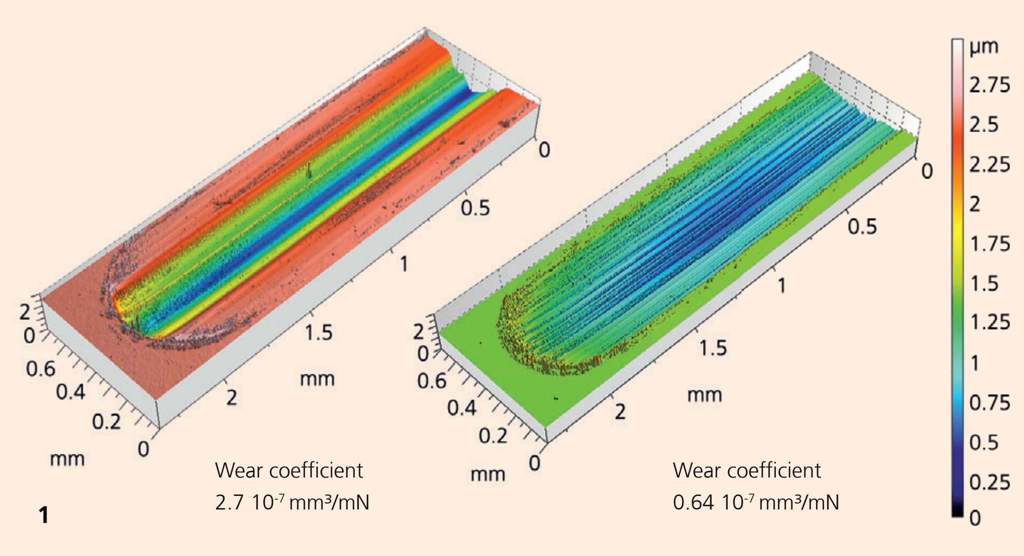


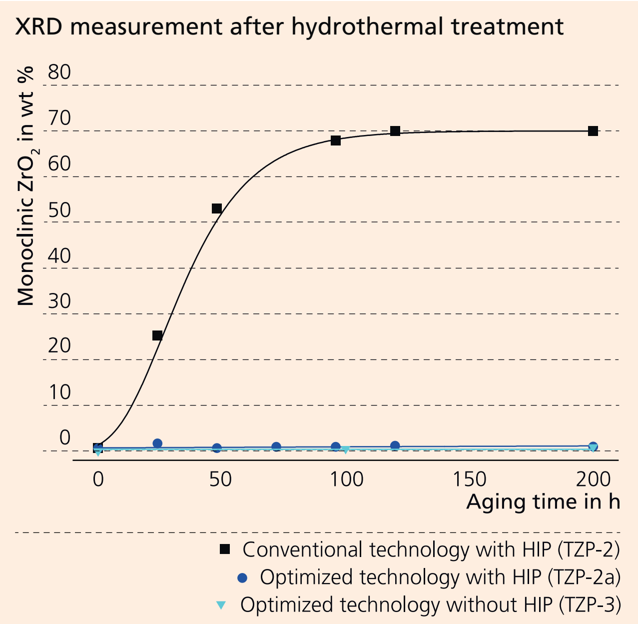
TRANSLUCENT CERAMICS – HYDROTHERMALLY STABLE AND WEAR-RESISTANT

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

At Fraunhofer IKTS, there is a wealth of experience in the area of raw material dispersion and shaping. Using cost-effective commercial submicron-powders, it was made possible to create a ceramic material which combines increased translucency (Figure 2), hydrothermal resistance (diagram), high hardness, and wear resistance (Figure 1): tetragonal yttria-stabilized zirconia (TZP). Such ceramics are ideal for dental implants, but also for industrial applications.

Analysis has shown that translucency of TZP can be achieved by reducing the grain size of the microstructure and by reducing residual porosity and impurities. This is confirmed by measurements of the in-line transmission of TZP ceramics with different mean grain sizes in the microstructure (TZP-2: 340 ± 30 nm, TZP-2a: 150 ± 30 nm). These ceramics were post-densified by hot isostatic pressing (HIP). A reduction of the grain size by 55 % doubles the translucence. Even without HIP (TZP-3), there is a visible increase in translucence at an average particle size of 190 ± 10 nm. Furthermore, hydrothermal aging was simulated for 200 hours at 134 °C and 2 bar in the autoclave. The diagram shows the subsequent phase composition. While sample TZP-2 showed a rapid increase of the monoclinic phase, samples TZP-2a and TZP3 presented no increase of the monoclinic phase, are therefore hydrothermally stable.

Additionally, interference microscopic images of wear tests (Figure 1) showed that fine grained TZP-ceramics are four times as wear-resistant as coarse-grained probes.



Services offered

- Development of preparation and shaping technologies for oxide ceramic materials
- Development of prototypes
- Certification according to ISO 13485 (quality management for medical devices)

1 *Wear track TZP2, coarse grained (left), and wear track TZP2a, fine grained (right).*

2 *Translucency of TZP ceramics.*

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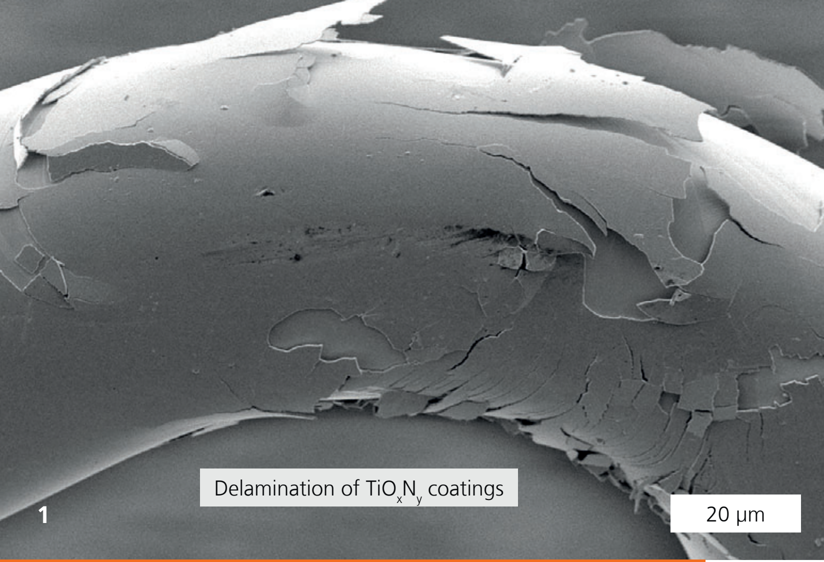
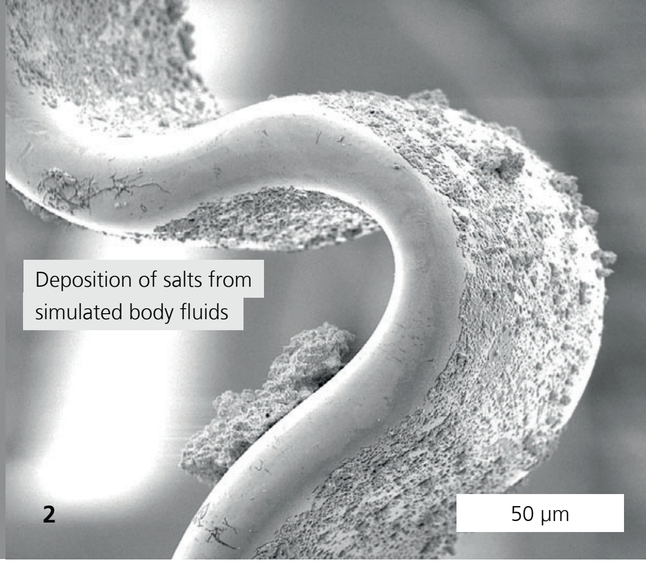




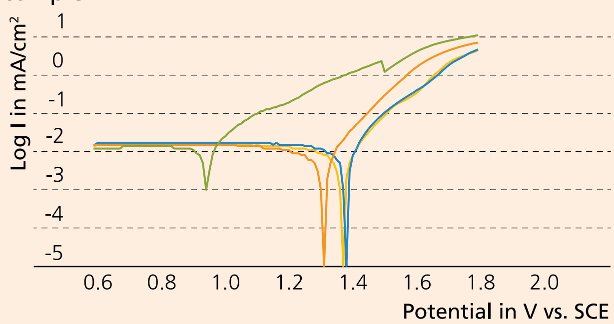
TITANIUM OXYNITRIDE STENT COATINGS WITH LONG-TERM BIOSTABILITY

Dr. Natalia Beshchasna, Dr. Jörg Opitz, M. Sc. Muhammad Saqib

Heart disease is the leading cause of death worldwide. Stenting of arteries is a common treatment to open up constricted or blocked blood vessels. Even though the risk of complications is low, restenosis (the re-narrowing of arteries) remains a clinical problem, and stents are coated to prevent it. One promising stent coating types is titanium oxynitride (TiO_xN_y), deposited by magnetron sputtering. Its biocompatibility improves with increasing thickness of the coating film. But by increasing the film thickness, its adhesion to the substrate deteriorates drastically, causing coating defects (Figure 1).

The research project "TiOxTechBio" (Funding code: 01DJ15023) led by Fraunhofer IKTS with partners from Poland, Romania, and Russia, has developed a new technology enabeling the manufacture of TiO_xN_y coatings for cardiovascular stents made of stainless steel (316L) with low thickness, high hardness, high corrosion, wear and oxidation resistance and sufficient biocompatibility. IKTS has contributed to the joint project by establishing an in-vitro method to investigate the long-term stability of different coated stent prototypes and by carrying out studies of physical-chemical surface properties and corrosion tests. Two determining factors for the TiO_xN_y coating microstructure were confirmed by the experiments: the nitrogen concentration in the gas atmosphere of the vacuum chamber and the supply of the negative bias to the substrate. We were able to determine an optimal O_2/N_2-ratio of 3/5 and an optimal coating thickness of 150 to 170 µm. An increase of the nitrogen concentration leads to a reduction of the grain size, increasing surface roughness and enhancing the coating tightness. The development of the deposition technology focused on improving coating quality, flexibility, and on achieving a good adhesion. These goals were reached by optimizing the deposition parameters in several steps by technological means, and through dynamic testing with simulated body fluids (Figure 2). Analysis of the test fluids after their interaction with stent surfaces of optimal design by means of mass spectroscopy with inductive coupled plasma showed no release of the coating elements, confirming the good stability of the surfaces. After successful in-vivo and clinical studies, the deposition technology developed so far can be transferred to industrial stent manufacturing.

Tafel curves of TiO_xN_y-coated stents and the reference sample



t = 37 °C $TiO_xN_y(O_2/N_2 = 27/10)$ $TiO_xN_y(O_2/N_2 = 13/10)$ $TiO_xN_y(O_2/N_2 = 6/10)$ Uncoated

1 TiO_xN_y-coated stainless steel stent with poor adhesion of the coating.

2 TiO_xN_y-coated stainless steel stent after dynamic contact with Hank's balanced salt solution.

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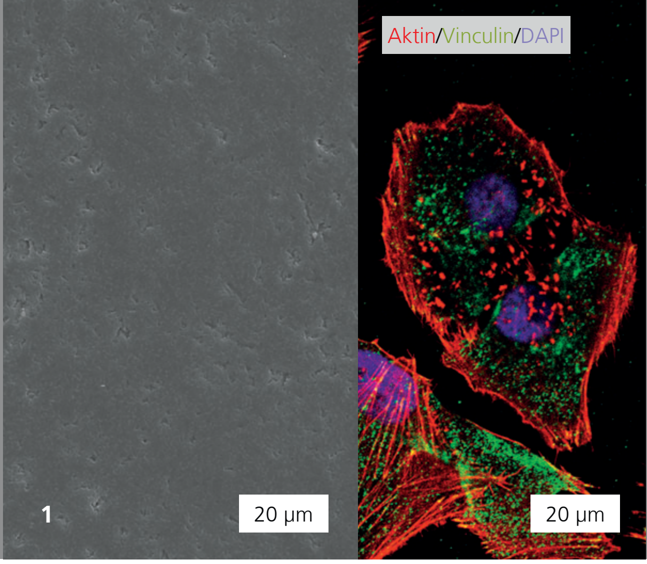
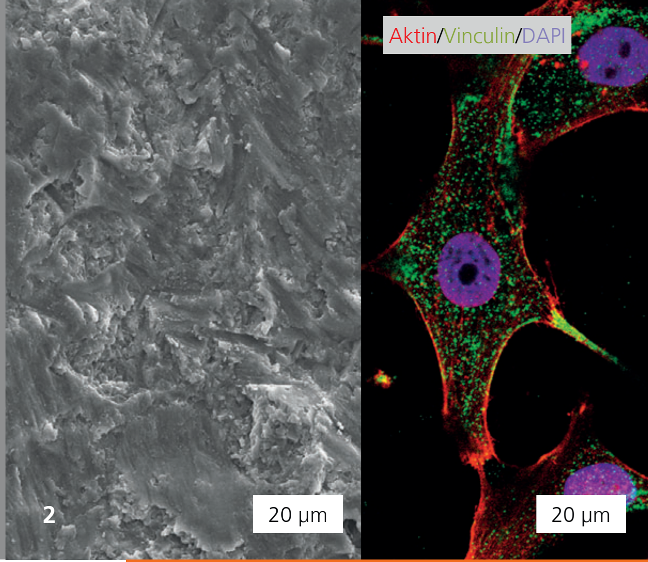




ANALYSIS OF CELL ATTACHMENT AND CELL SPREADING ON SILICON NITRIDE

Dr. Susanne Kurz, Dr. Juliane Spohn, Dr. Eveline Zschippang

Silicon nitride (Si_3N_4) is an advanced ceramic with a unique combination of material properties and is ideally suited as a material for implants. It is chemically stable and has a high stiffness, hardness, strength and fracture toughness. It is also extremely wear-resistant. Recent research has shown that not only is it biocompatible, it also displays antibacterial behavior. Designing the surface topography in a targeted way will significantly influence the cell adhesion and osteoconductivity. Therefore, Fraunhofer IKTS develops biocompatible Si_3N_4 and performs surface finishing processes to modify the surfaces.

Influence of surface on attachment and spread of osteoblasts

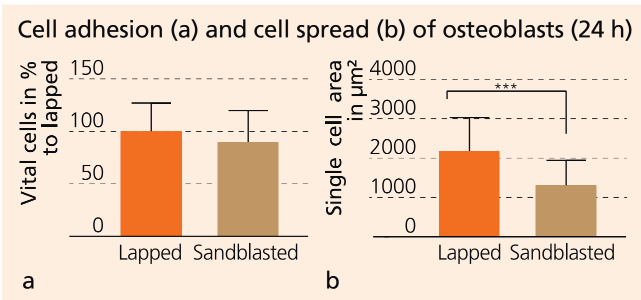
The connection between surface structure and osteoblastic cell behavior can be demonstrated by lapping and sandblasting, examples of surface finishing processes (MG63 cells). Lapping results in an average surface roughness of 0.03 µm, whereas sandblasting achieves an average roughness of 1.3 µm. There are also differences with regard to the wettability of the surfaces: The size of the contact angle is 41° for lapped surfaces, and 54° for sandblasted surfaces. Biological investigations of the cell adhesion and cell spreading behavior yield reduced spreading of the individual cells after 24 hours of cultivation on the rougher, less hydrophilic surface (sandblasted, Figure 2), compared with the smoother and more hydrophilic surface (lapped, Figure 1). The amount of vital cells adhering to the surface is not affected by the surface finishing processes used in this study. As a next step, effects of the altered cell spreading behavior on the osteoblastic functionality of the cells will be investigated.

Surface structuring and optimization

Sandblasting of Si_3N_4 is one possibility to alter the material surface and consequently influence the cell behavior. Other surface structuring methods, such as laser structuring, are available for producing textured surfaces optimized for biological concerns. Moreover, the chemistry, and thus the hydrophilicity of the Si_3N_4 surface, can be specially modified by thermal processes in an inert or oxygen-containing atmosphere to further optimize the surface for biological applications.

Services offered

- Research and development of silicon nitride materials, optimization of properties
- Osteo/immunological cell analysis on modified biomaterial surfaces



SEM (no cells) and fluorescence laser scan of osteoblastic cells
1 on lapped Si_3N_4
2 and on sandblasted Si_3N_4.

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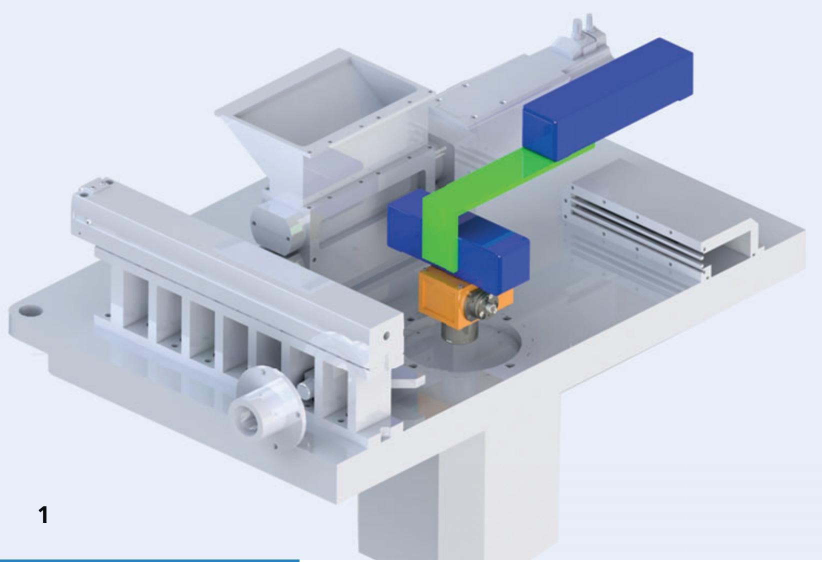

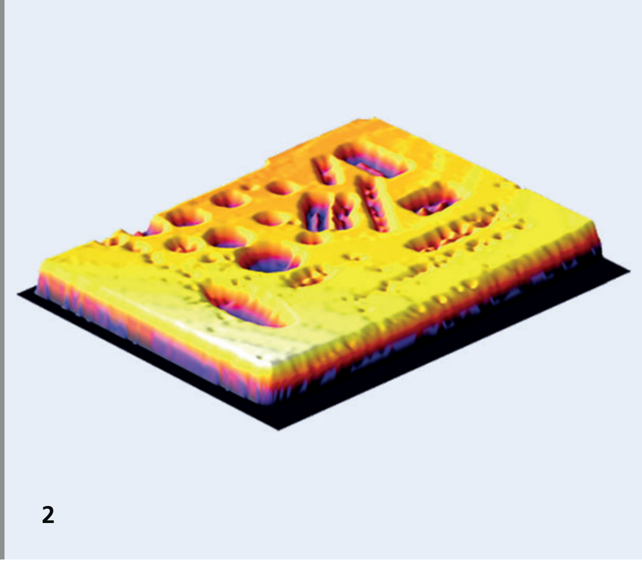

OPTICAL COHERENCE TOMOGRAPHY MONITORING OF SELECTIVE LASER MELTING

Dipl.-Ing. Andreas Lehmann, Thomas Schmalfuß, Dr. Jörg Opitz

Additive manufacturing (AM) of medical, automotive, and aerospace products is becoming increasingly important. This requires new lines of quality control. In contrast to conventional production, batch sizes in additive manufacturing are usually only a few parts, or even only one part, per production run. As a result, statistical test methods, such as random samples tested with laboratory equipment, cannot be used effectively. In addition, production errors should already be detected during the manufacturing process in order to intervene promptly and thus save valuable time and material. 100 % monitoring therefore requires not only adequate measurement technology, such as optical coherence tomography (OCT), but also a corresponding feedback loop.

For this purpose, in a project funded by the ZIM, optical coherence tomography was qualified for the monitoring of selective laser melting (SLM). The project partners are IMM electronics GmbH, Nanoval GmbH & Co KG, the Fraunhofer Institutes IKTS and IGCV, Yonsei University, as well as Sentrol Inc., who provide a self-designed SLM machine for the integration of OCT.

Currently, SLM processes are controlled using melt pool monitoring. OCT has advantages over this process because it supplies high-resolution 3D surface data of the finished parts. With the collected data it is possible, for the first time, to record errors during the process. In later projects, these can be the basis for machine-learning, which generates signals for a feedback loop from the OCT data.

The boundary conditions for the integration are very complex. Firstly, the installation space in the machine is very limited; furthermore, critical process conditions, like large temperature variations and contamination of the measurement system during operation, must be taken into account. In a first step, the measuring head of the OCT system is minimized and adapted. Another challenge lies in the large size of the measuring field, which is 10 cm in diameter. Toward the end of the project, an OCT tomogram of such a size will be measured for the first time. Surface data is obtained from the tomogram, which is then compared manually with the underlying construction (CAD) data. The required time for measurement and evaluation is not the primary focus during this project phase. It will be optimized in a follow-up project, with the introduction of a feedback loop.

In the future, the developed process monitoring concept will be adapted for other AM procedures. Particularly, the expansion to other materials, such as additively manufactured ceramics, biological materials or plastics is planned or already being carried out. For these materials, OCT offers further advantages, since deeper defects, such as delamination or inclusions between the layers, can be detected.

We thank the AiF for funding this project in the ZIM program.

1 CAD model of the OCT system in the SLM machine.
2 OCT image of a 3D-printed component.

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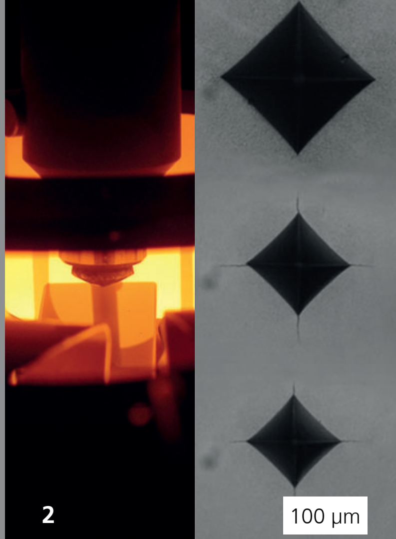

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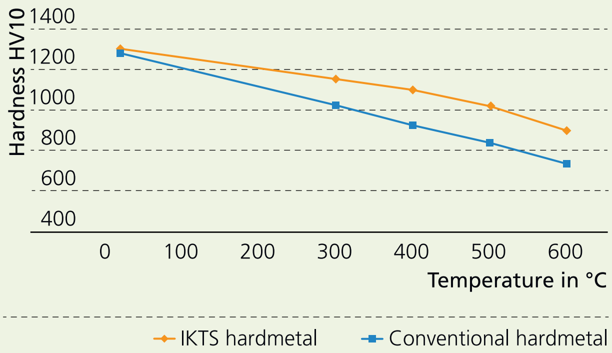

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HOT HARDNESS TESTING OF THERMALLY STRESSED HARDMETAL TOOLS

Dipl.-Ing. Clemens Steinborn, Dr. Johannes Pötschke

Fraunhofer IKTS develops innovative, wear-resistant hardmetals for cutting tools used in the machining of modern alloys and composite materials. The machining of titanium- and nickel-based alloys causes very high thermal loads on conventional hardmetal cutting tools. Despite active cooling, the cutting edge can reach temperatures of more than 500 °C, which greatly increases the wear on the tools and leads to higher machining costs. So far, solutions for wear-reduction have focused on tool geometry, inner cooling and CVD/PVD coatings.

The new IKTS approach consists in modifying hardmetals, especially the composition of binder metals and hard phases, to make them more resistant to higher cutting temperatures. In consequence, efficient machining and reduced tool wear are simultaneously possible and promote cost-efficient machining. An important instrument when it comes to quantifying wear resistance and comparing conventional and newly developed hardmetals is the measurement of the Vickers hardness in the temperature range between 300 °C and 900 °C. Compared with conventional hardmetals, which showed a significant decrease in hardness at temperatures above 400 °C, some IKTS hardmetals displayed a much better temperature resistance. Based on these findings, fundamental investigations were conducted as part of an SAB project (funding reference 100301902) to quantify the influence of the binder amount, the grain size of the tungsten carbide (WC) phase, the binder composition, and of additional hard phases. In a first step, model composites of adjusted WC grain size and binder composition were produced and tested. The newly developed hardmetals show a higher hot hardness in comparison with commercially available hardmetals with a medium WC grain size (Figure 2).

Further investigations to adhesion and oxidation resistance are being planned. In a next step, a first demonstration milling cutter with improved hot hardness will be tested.

Services offered

Development of hardmetals:

- With adjusted hardness to toughness ratio for a wide range of applications
- For high thermomechanical demands

Mechanical material characterization:

- Measurement of strength, hardness and fracture toughness from room temperature up to 1550 °C in air or in high vacuum
- Development of testing methods

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1 *Hot hardness test rig.*

2 *Hardness testing at 900 °C and Vickers indentations in WC-10 %CO at 20, 500 and 900 °C.*

3 *Comparison of hot hardness of hard metals.*

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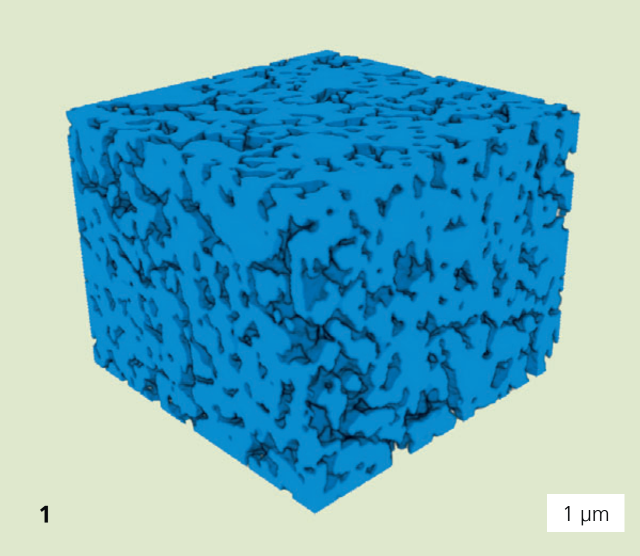

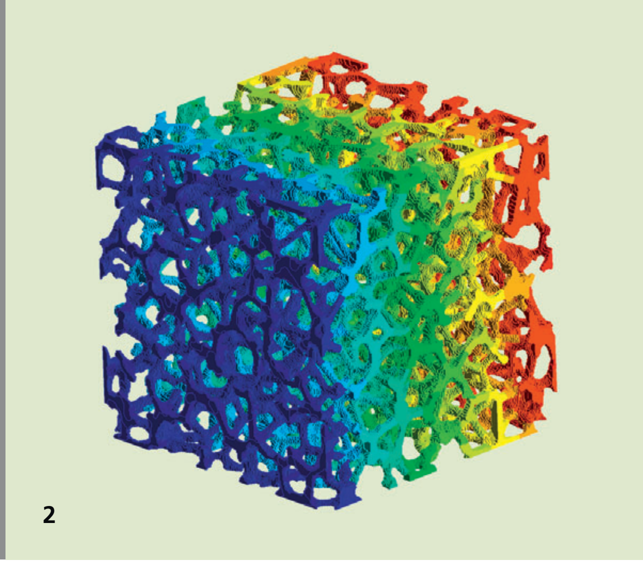

MODELING OF THE MATERIAL BEHAVIOR OF COMPONENTS BY 3D STRUCTURAL ANALYSIS

Dr. Wieland Beckert, Dr. Jürgen Gluch, Dr. Sören Höhn

3D structural analysis on the micro- and nanometer-scale

Porous or multi-phase materials can be analyzed using experimental data. This data allows not only for the determination of geometric parameters, but also for the direct creation of models for modeling. Two processes are used for this purpose: X-ray tomography methods (micro-CT and X-ray nanotomography) are suitable for larger volumes with moderate resolution, and for samples of several hundred micrometers in size with a high resolution of up to 50 nm. Serial section methods (FIB tomography) are used for the highest resolutions – up to several nanometers per voxel. In this second method, the scanning electron microscope with focused ion beam selectively removes material slice by slice (slice-and-view). The numerous imaging and analysis tools (EDS, EBSD) of the scanning electron microscope make high-contrast 3D microstructural data sets possible. Algorithms developed at Fraunhofer ITWM were used to assemble primary data of Fraunhofer IKTS into a 3D image. The quantifiable sample volumes are reconstructed from the several hundred two-dimensional sectional images (Figure 1).

Modeling of material behavior

Microstructure simulation on virtual test specimens represents an interesting option for determining structure-dependent material properties and for investigating the correlations between structural parameters and properties. Such simulation makes it possible to circumvent metrological limitations when determining properties, for example in the micro range. Furthermore, it is possible, through virtual analysis campaigns, to reduce the experimental effort involved in sample preparation and characterization. Mechanical properties as well as thermal and electrical conductivities of composite materials and cellular structures, flow and diffusion properties of porous structures can be represented. At first, geometric models are created from the 3D microstructure data sets or with the help of synthetic structure generators (e.g. GeoDict). The physical modeling for basic properties is then done directly in the software tools (GeoDict). For more complex analyses, it is possible to export the microstructure as CAD geometry models into powerful CFD and FEM tools (Fluent, COMSOL, ANSYS). All these options are available to clients at IKTS. The competences for this were developed through exemplary sample applications.

Services offered

- Analysis of ceramic 3D structures in the macro-, micro- and nano range
- Modeling of material behavior on the basis of 3D microstructure models

1 3D reconstruction of a nanoporous ZrO_2 membrane layer (voxel size 20 x 20 x 20 nm^3).
2 Microstructural analysis (temperature field → thermal conductivity) of synthetic foam structure (standard cell size 10 x 10 x 10 mm^3).

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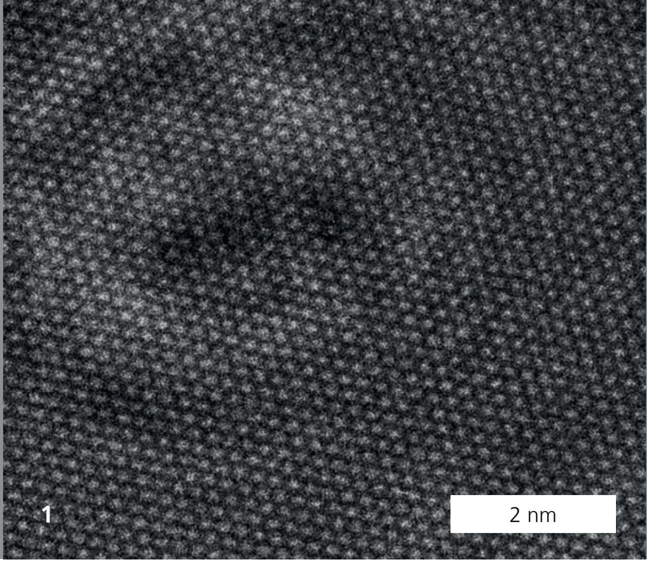

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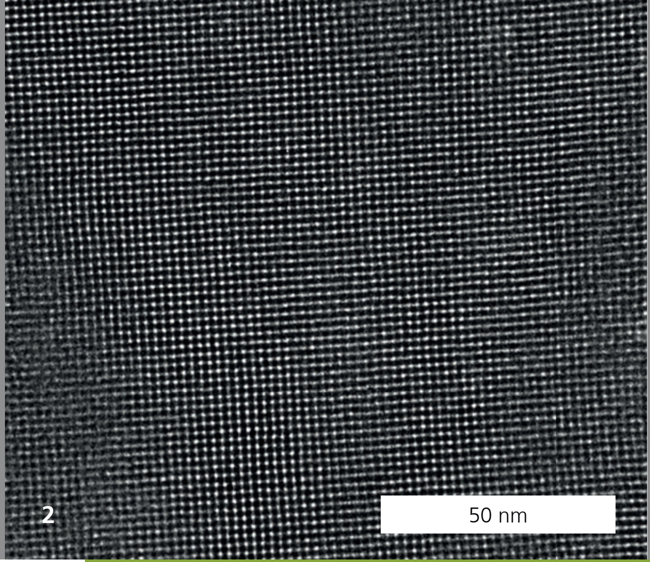

2

TEM – A VERSATILE TECHNIQUE FOR STUDYING EMERGING MATERIALS

Dr. Zhongquan Liao, Dr. Uwe Mühle, Dr. Jürgen Gluch, Prof. Dr. Ehrenfried Zschech

Transmission electron microscopy (TEM) uses the interaction between electrons and a material to characterize materials. The method provides insights into the microstructure, crystal structure, strain, defects, as well as composition (e.g. by energy-dispersive x-ray spectroscopy, EDS) and chemical bonding (electron energy loss spectroscopy, EELS) of the material. The resolution that can be attained by this method reaches down to the atomic level. TEM enables us to address many challenges in novel materials development, improving products properties and manufacturing processes, and supporting defect analysis and physical failure analysis.

High-resolution imaging and analysis of emerging 2D materials

Nanoelectronics, sensors and catalysts use beam-sensitive materials, e.g. graphene [1] and 2D polymers. Low-voltage TEM is used to characterize them. This means that the polymer molecules are not destroyed and can be measured directly in the high-resolution images. These images play a crucial role in guiding the synthesis process and understanding the electronic properties (e.g. electrical conductivity). TEM imaging combined with elemental analysis also provides structure information of electrocatalysts with fast water dissociation kinetics for energy storage [2]. The morphology and exact location of these nanoparticles, which were determined in the study, explain the fast water-splitting performance, which is comparable to platinum.

Stress and in-situ studies to support reliability engineering in the semiconductor industry

Electron diffraction has been used to quantitatively determine the residual stress in the transistor channel caused by advanced packaging. In addition, in-situ capabilities have been successfully developed for reliability engineering in emerging products for microelectronics [3] and for band-gap engineering in graphene nanoribbons [1]. This enabled to observe the degradation process of dielectrics in the back-end-of-line (BEoL) structures in microchips, and to provide directions for strain engineered bandgap in 2D materials for sensor applications.

Analytical services offered

- High-resolution imaging (TEM and STEM), tomography
- Analysis in TEM (EDS, EELS, electron diffraction)
- In-situ TEM experiments (electrical, mechanical, heating up to 445 °C)

Publications

[1] Z. Liao et al. Sci. Rep. 7, (2017), 211-1-7.
[2] J. Zhang et al. Nat. Commun. 8, (2017), 15437-1-8.
[3] Z. Liao et al. Microelectron. Eng. 137, (2015), 47-53.

1 *Graphene in TEM with atomic resolution.*

2 *2D crystal polymer in TEM, each bright spot represents a molecule.*

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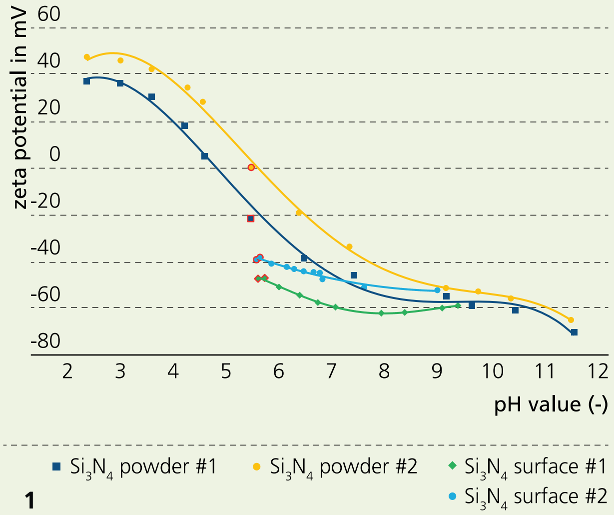

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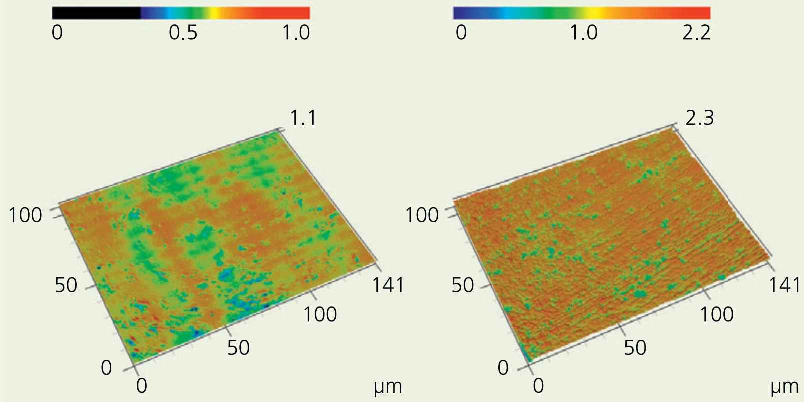

2

A BETTER UNDERSTANDING OF CERAMIC COMPONENT SURFACES

Dr. Annegret Potthoff

The behavior of components with ceramic surfaces is determined significantly by the structure and reactivity of the material. Such components are used in seals, bearings, fittings, as well as in medical and biological applications. A precise knowledge of material properties and behavior can help users analyze damage cases or further develop components in a targeted manner. Fraunhofer IKTS offers a wide range of methods for the surface characterization of ceramic components:

Using confocal laser scanning microscopes, it is possible to determine the topography of ceramic surfaces with high-resolution – even on samples with preferred orientation (Figure 1). Additionally, atomic force microscopy (AFM) and nanoindenter methods are able to determine local elastic, electrical, dielectric and thermal properties. The chemical or phase composition of the component surface is analyzed using elemental or phase analysis.

In order to understand tribological and biological processes, it is important to have knowledge of the interaction between surfaces and their surrounding media. Surface characterization by contact angle measurements is suitable for the quantification of the wettability of surfaces (i.e. hydrophilic/hydrophobic behavior). The surface charge can be determined by current potential measurements, giving insight into the chemical composition, especially the oxide formation, of whole component areas, for example of Si_3N_4- or SiC-components. The thicker the oxide layer in particle and component surfaces, the more the isoelectric point shifts to low pH ranges (Figure 2). Locally, oxide layer thicknesses on metals or non-oxides (thickness from a few nm to 100 nm) can be determined non-destructively using a thin-film tool in a scanning electron microscope.

Likewise, the kinetics of the adsorption of organic materials, such as proteins on ceramic component surfaces or plastics, can be detected at IKTS by means of flow potential measurements. This analytical procedure provides valuable insights into the use of ceramics in medical technology, e.g. as bone substitute material. This analytical technique may also be applied in technical applications (e.g. electro-corrosion). The effect of chemical, thermal or mechanical functionalization or modifications on the properties of the surfaces can thus be reproducibly quantified.

Services offered

Analytical assessment of component surfaces intended for applications in

- Machinery and vehicle construction
- Medical technology
- Power engineering

1 *Roughness of Si_3N_4 layers after lapping or sandblasting.*

2 *Zeta potential determination on particles and surfaces according to pretreatment.*

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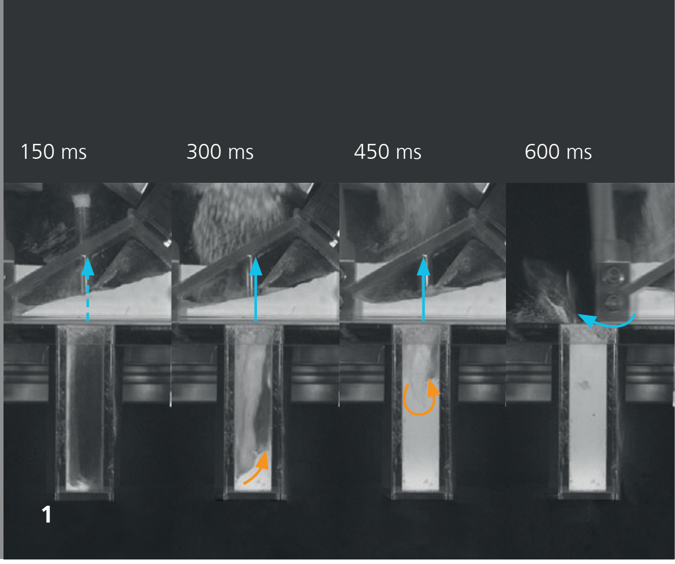

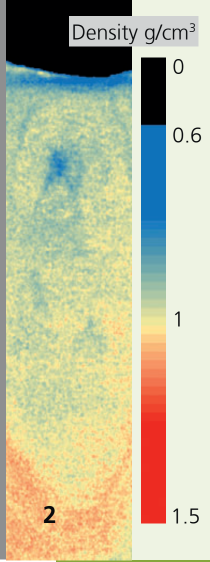

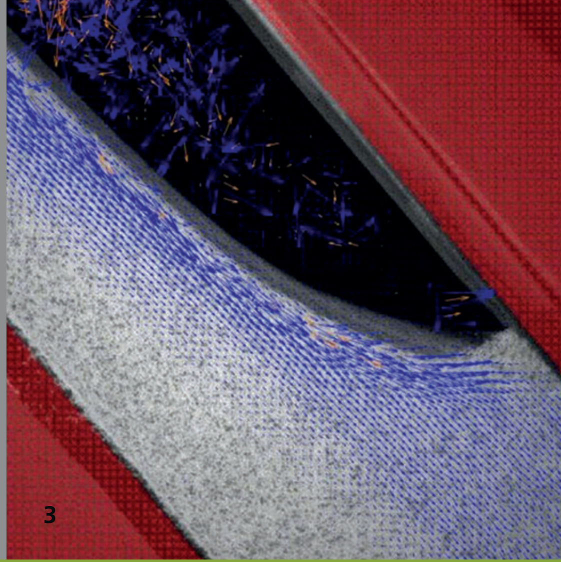

BULK BEHAVIOR – PROCESS ANALYSIS AND COMPLEX CHARACTERIZATION

Dipl.-Ing. Bianca Glöß, Dr. Manfred Fries

Finely dispersed powders and granules are stored, transported and processed as raw material, as intermediate or final product in almost all branches of industry. Bulk and flow behavior of these materials substantially affect the efficiency of the manufacturing process, as well as the resulting product quality. Comprehensive process analysis and adjusted methods for characterizing flow properties, ideally under process conditions, are the foundation for the development and optimization of tailor-made finely dispersed materials and their associated processing methods.

Process analysis and characterization (example)

Process analysis	→ Identification of state of bulk material	→ Selection of experiment
Die filling in dry compaction shaping operation	Influence of air, static, dynamic	Laboratory methods (fluidized bed + bulk density + Hall flow) Proces-oriented methods (FlowD + CT)

Research and development projects at Fraunhofer IKTS identify the state of bulk materials through process analyzes and create specific characterization concepts. A variety of standardized laboratory methods and self-developed process-oriented methods are available for this analysis. These methods allow for bulk characterization under real process conditions and enable the analysis of basic mechanisms of bulk behavior. In particular, ceramic granules for dry compaction shaping operations can be evaluated comprehensively and in a process-oriented way. In addition, the developed methods are available for the analysis of powders for additive manufacturing, e.g. for 3D powder printing or the evaluation of functional powders. If necessary, methods will be qualified and adapted to meet specific needs of the client. The following specific, process-oriented methods were developed for the analysis of the state of bulk material along the transport route of an uniaxial press:

- Visualization of **macroscopic flow behavior** during the filling process (Figure 1), as well as in the filling shoe, using high-speed video recordings with subsequent qualitative and quantitative assessment
- Qualitative and quantitative analysis of the density distribution of the bulk material in the die (Figure 2) and in the filling shoe by means of non-invasive computer tomography delivers information on the **bulk structure**.
- Within a planar transport route, a high-speed camera captures the **microscopic flow behavior**. Direction of motion and velocity of the particles can be quantified using "particle image velocimetry" analysis (PIV, Figure 3), down to 40 µm particle size and at a maximum flow rate of 0.3 m/s.
- Assessment of **local and temporal segregation** of bulk material by space-resolved sampling and particle-size measurement.

The complex process-oriented characterization of powders and granulates enables the continuously improvement of the quality of products and manufacturing processes. We thank the German Federal Ministry for Economic Affairs and Energy BMWi and the IGF for their financial support.

Bundesministerium für Wirtschaft und Energie

Industrielle Gemeinschaftsforschung iGF

1 Macroscopic flow behavior during die filling – FlowD.

2 Density distribution of the bulk in the die – CT.

3 Microscopic flow behavior – analysis of particle motion via PIV.

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COOPERATION IN GROUPS, ALLIANCES AND NETWORKS

ANNUAL REPORT 2018/19

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

Membership in Fraunhofer Groups, Alliances and Networks

AGENT-3D

AMA Association for Sensors and Measurement

American Ceramic Society (ACerS)

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

Association for Manufacturing Technology and Development (GFE)

Association of Electrochemical Research Institutes (AGEF)

Association of German Engineers (VDI)

Association of Thermal Spraying (GTS)

biosaxony

BTS Rail Saxony

Carbon Composites (CCeV)

Ceramics Meeting Point Dresden

CiS Forschungsinstitut für Mikrosensorik GmbH

CO_2 Value Europe

Competence Center for Nano Evaluation nanoeva®

Competence Network on Optical Technologies (Optonet)

Cool Silicon

DECHEMA – Society for Chemical Engineering and Biotechnology

DeepSea Mining Alliance

Deutsche Glastechnische Gesellschaft (DGG)

Deutsche Keramische Gesellschaft (DKG/German Ceramic Society)

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

DKG/DGM Community Committee

DRESDEN-concept

Dresden Fraunhofer Cluster Nanoanalysis

Dresdner Gesprächskreis der Wirtschaft und der Wissenschaft

ECPE European Cluster for Power Electronics

EIT Health

Energy Saxony

e.qua impuls – Wasserwirtschaftliches Energiezentrum Dresden

European Society of Thin Films (EFDS)

European Network of Materials Research Centres (ENMAT)

European Powder Metallurgy Association (EPMA)

European Research Association for Sheet Metal Working (EFB)

Expert Group on Ceramic Injection Molding in the German Ceramic Society

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

Fördergesellschaft Erneuerbare Energien (FEE)

Fraunhofer Adaptronics Alliance

Fraunhofer Additive Manufacturing Alliance

Fraunhofer AdvanCer Alliance

Fraunhofer Battery Alliance

Fraunhofer Big Data Alliance

Fraunhofer Energy Alliance

Fraunhofer Group for Materials and Components – MATERIALS

Fraunhofer Lightweight Design Alliance

Fraunhofer Nanotechnology Alliance

Fraunhofer Numerical Simulation of Products and Processes Alliance

Fraunhofer Water Systems Alliance (SysWasser)

Fraunhofer Textile Alliance

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

German Association of University Professors and Lecturers (DHV)

German Biogas Association

German Chemical Society (GDCh)

German Electroplating and Surface Treatment Association (DGO)

German Energy Storage Association (BVES)

German Engineering Association (VDMA)

German Federation of Industrial Research Associations (AiF)

German Materials Society (DGM)

German Society for Membrane Technology (DGMT)

German Society for Non-Destructive Testing (DGZfP)

German Phosphorus-Platform DPP

German Physical Society

German Thermoelectric Society (DTG)

HYPOS Hydrogen Power Storage & Solutions East Germany

InDeKo Innovationszentrum Deutschland Korea

Innovationszentrum Bahntechnik Europa e. V.

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

International Microelectronics and Packaging Society

International Zeolite Association

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

Materials Research Network Dresden (MFD)

medways

Meeting of Refractory Experts Freiberg (MORE)

Micro-Nanotechnology Thuringia (MNT)

Nachhaltigkeitsabkommen Thüringen

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

NanoMat – Supraregional Network for Materials Used in Nanotechnology

Organic Electronics Saxony

ProcessNet – an Initiative of DECHEMA and VDI-GVC

Research Association for Diesel Emission Control Technologies (FAD)

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

Silicon Saxony

smart³

SmartTex Network

Society for Corrosion Protection (GfKORR)

Trägerverein Institut für Holztechnologie Dresden e. V.

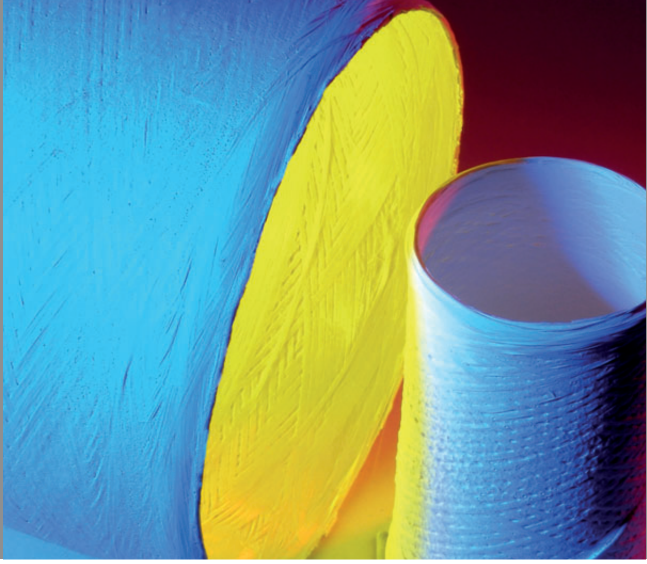
TRIDELTA CAMPUS HERMSDORF

Thüringer Erneuerbare Energien Netzwerk (ThEEN)

VDMA Medical technology

Verein für Regional- und Technikgeschichte e. V. Hermsdorf

WindEnergy Network Rostock



FRAUNHOFER GROUP FOR MATERIALS AND COMPONENTS – MATERIALS

Materials research and technology at Fraunhofer covers the entire value chain, from developing new and improving existing materials to manufacturing technology on a quasi-industrial scale, in addition to characterizing properties and assessing service behavior. This also applies to the components and products made from these materials and their system behavior in relevant applications. Where materials are concerned, the Fraunhofer MATERIALS group covers the full spectrum of metals, inorganic non-metals, polymers, and materials made from renewable resources, as well as semiconductor materials. Over the last few years, hybrid materials have gained significantly in importance. The Group uses strategic forecasting to support the development of future-oriented technologies and materials.

With the initiative Materials Data Space© (MDS) founded in 2015, the Group is presenting a roadmap towards Industry 4.0-enabled materials. It considers digitalization of materials along their entire value creation chain as a key requirement for the lasting success of Industry 4.0.

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

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

Objectives of the Group

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

Group chairman

Prof. Dr. Ralf B. Wehrspohn, Fraunhofer IMWS
www.materials.fraunhofer.de/en

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 medium-sized 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
michael.zins@ikts.fraunhofer.de
www.advancer.fraunhofer.de

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

CERAMICS MEETING POINT – CERAMIC APPLICATIONS

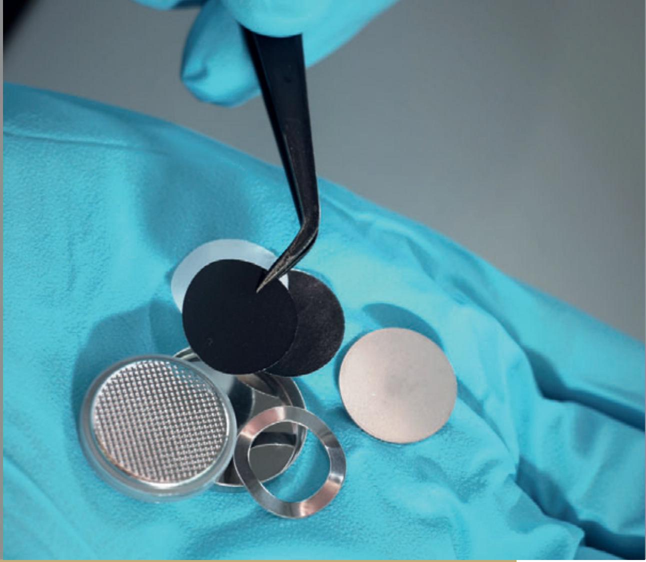
The Ceramics Meeting Point is an integral part of our institute's public relations activities. With this showroom, the institute provides a unique overview of the ceramic engineering market, drawing on its cooperation with the 51 partners and members joined under the label "Ceramic Applications" of the Göller Verlag publishing company. It is a place to take a closer look at the most current research topics, including systems testing. It also offers the opportunity to establish contacts with potential suppliers. This means that users who do not yet have extensive knowledge of the industry can use all Fraunhofer IKTS events as their ideal platform. Networking effects with Fraunhofer-Gesellschaft are enhanced further by including the Fraunhofer AdvanCer Alliance. This makes it possible to represent the complete service portfolio of all institutes.

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

The complete manufacturing chain is shown – from the powder to the finished part – and not just from the research perspective, but also as a reflection of the technologies and capacities available in the industry. Visitors gain insight into the current focal points of research while learning which manufacturer commercially supplies which product. In 2018, major topics included applications for the oil and gas industries, and the development of materials for deep-sea applications. Additionally, extremely large-scale machinery components, provided by our partners, expanded the scope of the exhibition – among them as one of the highlights a grinding cylinder manufactured by FCT Ingenieurkeramik GmbH, which weighs close to 400 kg.

In 2018, the Ceramics Meeting Point was a major focal point for the work of special field 1: Chemistry/Plant engineering and construction of the DKG. The exhibition showcases the results emerging from various funding projects.

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



CENTER FOR ENERGY AND ENVIRONMENTAL CHEMISTRY JENA (CEEC)

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

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

One focus of the collaboration is the "Technical Environmental Chemistry" chair, which is held by Prof. Michael Stelter, deputy 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 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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Chair Technical Environmental Chemistry
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www.ceec.uni-jena.de

1 *Parts of a button cell (Source: Jan-Peter Kasper/FSU Jena).*

NAMES, DATES, EVENTS

Please find information on patents, publications and scientific engagement of IKTS employees in 2018 on the website www.ikts.fraunhofer.de/en/dates2018

Granted patents
Patent applications

Books and periodical contributions
Presentations and posters

Teaching activities
Participations in bodies/technical committees

Dissertations
Theses

EVENTS AND TRADE FAIRS IN 2019

Conferences and events

Juniordoktor
February 20 and May 15, Dresden, Maria-Reiche-Strasse

Girls' Day
March 28, Hermsdorf, Michael-Faraday-Strasse

Open house at IKTS in Hermsdorf
April 6, Hermsdorf, Michael-Faraday-Strasse

Dresden Researchers' Night
June 14, Dresden, Winterbergstrasse

Dresden Battery Days
September 23–25, Dresden, Winterbergstrasse

International Symposium on Piezocomposite Applications
October 9–11, Dresden, Winterbergstrasse

Symposium "Anodizing – a never-ending story"
November 28–29, Dresden, Winterbergstrasse

Workshop "Hybrid materials and additive manufacturing processes"
December 11–12, Dresden, Winterbergstrasse

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

Seminars and workshops

DGM training seminar
Ceramic materials: properties and industrial applications
June 25–26, Dresden, Winterbergstrasse

DKG training seminar
Tape casting and slot die processes as well as aspects of further tape processing
November 5–6, Hermsdorf, Michael-Faraday-Strasse

Trade fair participations

nano tech
January 31–February 1, Tokyo
Joint booth Saxony Economic Development Corporation WFS

Clean India Show
February 20–22, Mumbai
Joint booth LEG Thuringia

Battery Japan
February 27–March 1, Tokyo

IDS
March 12–16, Cologne

Energy Storage
March 12–14, Dusseldorf
Joint booth Fraunhofer Energy Alliance
Joint booth with industry partners

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

ALD for Industry
March 19–20, Berlin

Hannover Messe
April 1–5, Hannover
Hall 3
Joint booth Energy Saxony e. V., Hall 27

POWTECH
April 9–11, Nuremberg

Printed Electronics
April 10–11, Berlin

agra
April 25–28, Leipzig

SMTconnect
May 7–9, Nuremberg
Joint booth EMS Park

Control
May 7–10, Stuttgart
Joint booth Fraunhofer Vision Alliance

Innovationstag Mittelstand
May 9, Berlin

4smarts
May 22–23, Darmstadt

DGZfP-DACH-Jahrestagung
May 27–29, Friedrichshafen

Global Petroleum Show
June 11–13, Calgary
Joint booth VDMA

DWA-Innovationsforum
June 19–20, Leipzig

Sensor+Test
June 25–27, Nuremberg

Rapid.Tech
June 25–27, Erfurt
Joint booth Fraunhofer Additive Manufacturing Alliance

Werkstoffwoche
September 18–20, Dresden
Joint booth Materials Research Network Dresden (MFD)

V2019 – Vakuum & Plasma
October 8–10, Dresden

EuroPM
October 13–17, Maastricht

Filtech
October 22–24, Cologne

Productronica
November 12–15, Munich

Compamed
November 18–21, Dusseldorf

Formnext
November 19–22, Frankfurt on the Main
Joint booth Fraunhofer Additive Manufacturing Alliance

Hagener Symposium
November 27–29, Hagen

FAD Conference
TBA, Dresden

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

HOW TO REACH US AT FRAUNHOFER IKTS

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

How to reach us in Dresden-Gruna

By car

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

By public transport

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

By plane

- From Airport Dresden-Klotzsche take a taxi to 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”

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How to reach us in Hermsdorf

By car

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

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

By train

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

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